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National Food Security: Towards a New Sustainable Food System (FS) in Burkina Faso

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Abstract

While the 2002 food crisis in Southern Africa is often used to highlight issues of chronic food insecurity, the concept of food security emerged after a long process of discussions and debates. These discussions within international institutions have focused on the definition of food security as a state of satiation of food in terms of quantity and quality. Unfortunately, they have neglected to emphasize that this state of satiation is influenced by several factors within and outside the food system (FS), which fall into three domains: environmental, social, and economic. Therefore, this article attempts to analyze the interactions that may exist between the food sector and the other sectors, and to study whether a food security objective is compatible with the improvement of many SDGs and sectors. We are using system dynamics, which has already proved its effectiveness in simulating the impact of public policies in several countries, and which has very powerful tools to enable us to make this diagnosis. The model built uses historical data from Burkina Faso for the period 2000 to 2020, and the flexibility of system dynamics method used allow us to simulate up to 2030 or beyond the results, with the aim of guiding policymakers in the implementation of public policies over the long term. The reproduction of the historical trend for food and nutrition indicators shows some significant results meaning that the FS model is useful to improve the performance of the SDG 2 by 2030 and other SDGs indicators linked to the SDG2 through the implementation of synergistical and strategic public policy.

Keywords

Causal Loop Diagram, Stock and Flow Diagram, Burkina Faso, Food Security, Sustainability

1. Introduction

While the 2002 food crisis in Southern Africa is often used to highlight issues of chronic food insecurity, the concept of food security emerged after a long process of discussions and debates. The first definition of food security emerged in the middle of the 1970s (Maxwell, 1996; Maxwell & Smith, 1992), as a process of negotiation leading to the World Food Conference of 1974. Food security was defined as *"availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices"* (UN, 1975). At that conference, the different members accepted to co-ordinate their action on three important fronts: *"(a) to increase food production especially in the developing countries, (b) to improve consumption and distribution of food, and (c) to build a system of food security"* (UN, 1975: p. 63).

In 1983, FAO expanded the concept to vulnerable people (low-income food-deficit countries), implying the balance between demand and supply at the global level (Clay, 2002). The production must ensure adequate food supplies to maximize stability in the flow of supplies, secure access to available supplies (FAO, 1983: p. 6). Three years later, the World Bank report on *Poverty and Hunger* outlines the nature and extent of food security problems in developing countries such as investment in human capital, inadequacy of food supplies, lack of purchasing power of households, agricultural policy, problem of poverty …, explores the policy options available to these countries in addressing these problems, and indicates what international institutions such as the World Bank can and should do to help countries solve their food security problems (Reutlinger & Others, 1986: p. 6).

By the middle of 1990s, food security was recognized as a significant challenge, from the local to the global level (Drèze & Sen, 1989; Maxwell, 1990). UNDP (1994), FAO (1996), World Food Summit (1996) proposed a more complex definition. Food security is a human right, the fruit of decisions inspired by an ethic of solidarity and a central subject to sustainable development. Food Security has three basic components (availability of food, stability of food supply and access to food) and takes the form of a plan of action. By insisting on the fact that food security was a state of food and nutritious satiety, FAO considered that the Food System (FS) should guarantee the entire population access to food, both in quantity and quality. In the following reports (most of them in the 2000s), four notions will qualify food security: availability, access, use and stability (CEDEAO et FAO, 2020). Unfortunately, the definition of food security does not show clearly that the local producers, the place where food is produced, soil, land availability, social and environmental laws play a key role in the FS. The FS concerns all elements (inflows, stocks, and outflows) and activities that relate to the food chain (Willett et al., 2019). The different stages of the chain comprise *"the production, trading, processing, marketing, consumption of goods that originate from agriculture, forestry or fisheries"* (FAO et al., 2021).

From these definitions, we may conclude that FS must take into account the five stages of the food chain (producing), handling and storage, processing and packaging, distribution, retail and wholesale, consumption and the coordination's process between many actors. At the first stage of the food chain, the different actors produce goods and services through their activities. From the economic, social and environmental problems that the planet is facing today and the contribution of agriculture activities (pollution, soil degradation, deforestation, biodiversity loss, ...) to the occurrence of these problems. FS may *"help to maintain ecosystems, strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality according to the UN SDGs programme"* (UN, 2015). This induces the transformation of actual Food Security System (FSS) into Sustainable Food System (SFS) to produce food in sufficient quantity and quality to feed the world's population and allow future generations to satisfy their needs in food and nutrition without destroying the environmental balance and human health (Nguyen, 2018).

The international crises, the incertitudes, climate hazards and the loss of populations' livelihoods prove that the term food security advocated by globalization is outdated today. The COVID-19 crisis and Ukraine war have shown that developing countries' FSs particularly Sub-Saharan African (SSA) are vulnerable to the global supply chain that not able to guarantee food supply everywhere in the world, especially with transport and logistic problems explaining the increasing in food prices increasing (especially wheat) (Balineau et al., 2021). Also, climate hazards with temperature changes, the scarcity of rain, the shortening of the rainy seasons and degradation of grazing and biodiversity in favor of desert negatively impact farmer livelihoods and further for the populations in general.

To add, the FS particularly in developing countries is unwell organized due to the lack of coordination between actors, the government's implication is less due to resources (human and financial) lack. So, the FS is not able to guarantee a better life and sufficient food for the overall population giving "food sovereignty" to people. The term "food sovereignty" refers to the rights of peasants, populations, local communities, and each country to take ownership of their FS, to adapt it locally (environment, and economic potentialities), culturally and their habit needs in terms of quantity and quality. Indeed, food sovereignty is a participative process that includes local population (consumers, traders, and producers, policymakers, ...), local agriculture practices and knowledge, and food needs for the purpose of building resilient FSS for sustainability. This means giving the power and the capacity to the local communities to adapt the food system to their environment in order to build sustainable local FSs which are resilient to stochastic and international shocks (Ibrahim & Yanti, 2019). The state of food security and nutrition in 2022 shows that hunger does not go down but jumps due to the increase of the number of undernourished people since the beginning of Covid-19 pandemic. Indeed, the prevalence of undernourishment has increased from 8 percent to 9.8 percent from 2019 to 2021. It is estimated that 702 to 828 million people in the world were affected by hunger in 2021.

In Africa, hunger affected 278 million people in 2021 or 20.2 percent of the population, compared to 17.4 percent in 2019. The projections in 2030 of these results do not give hope for the achievement of the UN's agenda for SDG 2 of

Zero Hunger. About 8 percent (670 million people) of the world's population will be facing hunger in 2030 showing a decrease in the number of undernourished people which corresponds to the situation of hunger in the world in 2015. However, in Africa, the scenarios predict a complicated situation because the undernourished people will grow from 280 to 310 million people (18% of Africa population) in 2030 (FAO et al., 2022). This situation implies the implementation of urgent and strong policies to reverse this trend by 2030 by supporting family agriculture with credit, fertilizers, seeds, information, market access, investments in education, health, and public infrastructure. This means a sustainable transformation of national and local FSS which are able to face some challenges such as "*jobs creation and poverty fighting, the reinforcement of solidarity between communities and generations, the insurance of food security and nutrition, the conciliation of production and environment, sustainable territories planning, sanitary risks affecting crops and livestocks, climate change adaptation and mitigation and end, the insurance of energy transition*" (Hébert et al., 2014). This transformation is very important for local FSS in Africa, which supplies urban areas, through the surplus food production sold by local farmers. In addition, it is necessary to build a FSS in which food chain stages are well interconnected and interacting from food production to food consumption (Kopainsky et al., 2017). That facilitates policy interventions in the food system and ensures better functioning. In addition, it helps to create synergy between actors towards a common goal (food security and nutrition achievement). The food system is composed of subsystems according to FAO and these subsystems interact with some non-food systems (Nguyen, 2018). These interactions can lead to a short term or structural change in the FS if a change has occurred in the FS (David-Benz et al., 2022). However, many drivers shape the food system such as demography, economic and social conditions, technology, climate conditions, natural resources, political stability, and governance. These drivers and factors affect the food system structure and its performance to ensure food security and nutrition.

So, the purpose of this paper is to analyze the state of food security and nutrition in Burkina Faso in order to model a food security module. We will use Systems Dynamics' method, especially Causal Loops Diagrams (CLD) and Stocks and Flows Diagrams (SFD) to map the qualitative structure of the food system and to quantify the model to design long term simulations. We will identify some leverage points which can guide Burkina Faso policymakers to implement consistent and synergistic policies. These leverage points are susceptible to improving food security and nutrition and contribute further to reaching the goal 2 of the UN 2030 Agenda.

We will answer the following questions: How Systems Dynamics Modelling may help to challenge food security and nutrition in Burkina Faso? What are the resistance factors which negatively impact food security? What are the leverage points for policy actions in the system?

Systems Dynamics may be helpful when we try to understand if a food security objective is compatible with the improvement of a large number of sustainable development objectives (SDGs). It is well known that SDG2 is interconnected to several SDGs, for example SDG1 (poverty eradication) and SDG3 (good health), SDG8 (decent work and economic growth), SDG10 (reduce inequalities), SDG11 (sustainable cities and communities), SDG12 (responsible consumption and production), SDG13, 14 and 15 referring to natural resources and climate change (Balineau et al., 2021). The building of the food module helps us to analyze the interactions between SDGs and SDG2 through the use of different indicators, but that work will be investigated in our future research.

This paper completes the literature on food modeling, especially agricultural models. It proposes a new way of conceiving food security as a whole by taking into account the different stages which interact with external systems. In addition, the paper recommends taking into account the effects of public policies implemented on all sectors and not only on the target sector in which the policy is implemented. The different sectors are interconnected and interacting, the consideration of long-term impacts of policies is necessary to prevent future problems because today's effects can be in the long run future causes. This analysis requests a transdisciplinary and interdisciplinary model which provides an understanding of the relations between economic, social and environmental domains. We know that understanding food security issues recommends the exploration of all disciplines which are critical such as policy science, anthropology, climatology, … So, we hope that this initial work will be improved with some discussions and surveys with all food actors in the future.

This paper also contributes to the use of System Dynamics tools to model the complexity of systems and to address development issues especially in developing countries like Burkina Faso. The structure of the paper is splitted in five parts. Firstly, we define the food security and nutrition state in Burkina Faso by highlighting the different factors that worsen it, identifying the challenges and opportunities within the different stages of the FS. Secondly, we provide a brief literature review on SD models' use in the agriculture sector and pay attention to the level of application across the different stages of the FS. We identify some key variables that will help us to build some CLDs and SFDs giving an understanding of the interaction in the FS. Thirdly, we present the results of the simulation. We use statistics such as R-Squared, Root Mean Square Percent Error, and Theil Statistics for error decomposition for the model validation. These statistics validate the ability of the model to reproduce the long-term trend of the FS Key Performance Indicators. Fourthly, we discuss the results' relevance and propose some leverage points and agriculture policies scenarios that can be implemented to improve the performance of Burkina's FS. The conclusion tackles the different limits of the model calibration and proposes some ways to overcome these limits for the model's robustness.

2. State of Food Security and Nutrition in Burkina Faso (Challenges and Opportunities)

The actual context of Burkina negatively impacts the FS. It is characterized by a rapid growing population (more than 21 million and 3.1 percent of population growth per year), a high level of poverty (36.2 percent of population is under poverty line) and irregular economic growth (3.92 percent in 2015, 5.69 percent in 2019, 1.93 percent in 2020) (INSD, 2021). The main constraints of development are persistent social inequalities, a failure of the productive system, an unqualified labor force and bad governance due to the weakness of the central administration. The country also faces climate change impacts, environment degradation (Ouedraogo et al., 2010), low productivity of the agriculture sector, a low modernization of the rural sector and a small domestic market. Nowadays, insecurity due to terrorism is more than worrisome because it disrupts the activities of the population and leads to population displacement, particularly those in rural areas who live from agriculture and livestock (Bildirici et al., 2022). The impact of mining activities on agriculture is unprecedented, they attract the young in the detriment of agriculture activities and the occupation of agricultural land (Ouoba, 2018). These factors weigh on the FS which lead to extreme levels of food insecurity and malnutrition that contribute to bad health of the populations and juvenile mortality. Burkina economy is highly based on agriculture, livestock, forestry and fishing activities. Gold and cotton are the main export products, but their benefit is impacted negatively by the international market prices that are volatile. Following the beginning of Covid-19, the exports of gold and cotton have reduced respectively −10% and −16% leading to revenue losses. The agriculture, forestry and fishing sector is responsible for 56.2% of jobs and its contribution to GDP (less than 30%) has been decreasing in recent years according to World Bank statistics due to low productivity and labor force movements. The prevalence of food insecurity and nutrition was decreasing in the 2 decades but, since the advent of the terrorism in 2015, the number of people undernourished started to increase to reach 3.8 million (18 percent of total population) in 2021 according to the INSD and FAO statistics. Among them, 2.7 million (6 percent) are in a severe food insecurity state, 26.7 percent of children under five are chronically malnourished (stunted or low height for age) and 8.4% are acutely malnourished (wasting or low weight for height). About 53 percent of women of childbearing age are anemic and 7.4 percent of adult men have diabetes. In addition, 5.6 percent of the adult population is overweight, although this percentage is increasing. This situation is caused by the limited food access and availability throughout the country (El Bilali, 2021).

This bad context of food insecurity is related to an unbalanced distribution of food availability and food value added between rural and urban and between cultures (Hébert et al., 2014). The disproportional government support to the cash crops to the detriment of food crops (FAO, 2021) while more than 80 percent of rural families' food production is based on cereals. The limited application of the new rural land standards leads to land grabbing and the competition on production spaces that is exacerbated by a poorly controlled agricultural migration (Dedewanou & Kpekou Tossou, 2022). Food processing infrastructures are concentrated around big cities and agropoles and this contributes to the unequal distribution of added value between rural (having the low added value) and urban areas. The same phenomenon is observed between territories: the unbalanced roads development policy slows down trading exchanges and increases price due to transport cost in particular Sahel and North regions. Beyond the environmental, climatic and social problems, credit access remains a key challenge for the agriculture sector (FAO, 2021). There are few financial institutions especially dedicated to the agriculture sector and the most part of government financing goes to the cotton sector. Some of the rest farmers benefit from fundings of traditional banks, associations and Non-Government Organizations but these financings are granted in the short term (maximum 2 years) with high interest rate of repayment (7.75% - 15%). The problem that limits the development and the modernization of the food system is the requirement of physical and financial guarantees by the banks; and also, there is a mismatch between the repayment schedule of the loans and the income cycles of the familial farmers (Marshall et al., 2021).

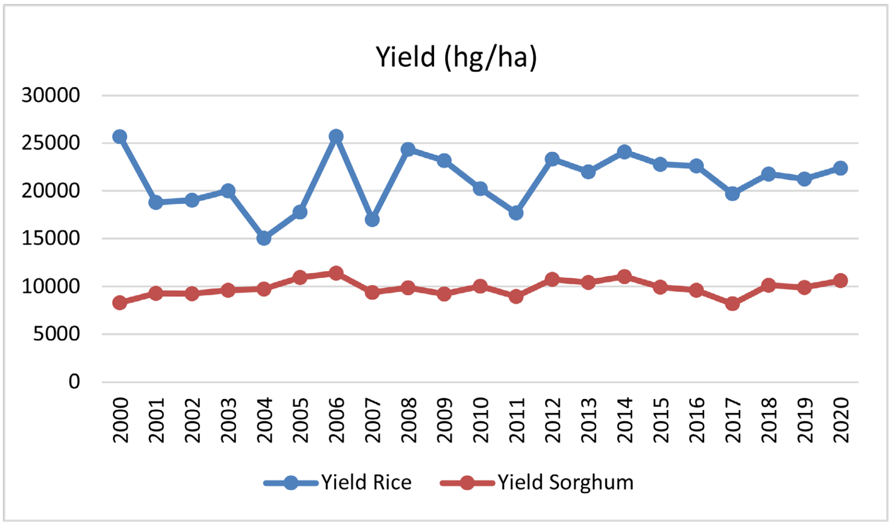
2.1. Production

Burkina has a Sudano Sahelian climate with a long period of dry season. It is facing high temperature and rainfall variations (Villiers, 1963). The main cultures are cereals, fruits and legumes. The global food balance sheet of Burkina is positive, but it varies from one region to another. The western zones of the Sudano Guinean agro-climatic zone have structural surplus, while the central, Sahelian and North zones in the Sudano-Sahelian zones have deficits leading to domestic trade. The western regions that are important areas for cotton and cereals (rice particularly) production benefit a large amount of equipment, inputs and training of the government while the North regions are important areas for livestock while benefit less support of government (Amadou et al., 2012).

The advent of climate change affects water availability, drought duration and rain intensity (desertification, droughts and floods) which can accentuate the low productivity of agriculture that is already low and crops loss. The breeding system is extensive and is practiced by mobile breeders and is oriented to local meat and milk production (Ouédraogo et al., 2020). It is a means for households to have revenue, adapt to climate change and livestock trading constitutes a revenue for the local economy through taxes. However, breeding is more and more threatened nowadays by agriculture land expansion, population growth and resource trading that reduce grazing spaces. In addition, terrorism has led to the loss of livestock for some pastoralists, especially in the north and in the Sahel, while others can no longer access grazing areas and livestock markets. This has led to a decline in the production of cattle, goats and sheep. Nowadays, there is growing land insecurity in Burkina due to the non-respect of land law by actors leading to conflicts. Land ownership and the right to use are determined by a complex mix of formal regulations and customary practices. The vagueness of the law leads to land revendications and tensions between farmers and breeders, local elites and some largess enterprises that acquire rural land for speculation.

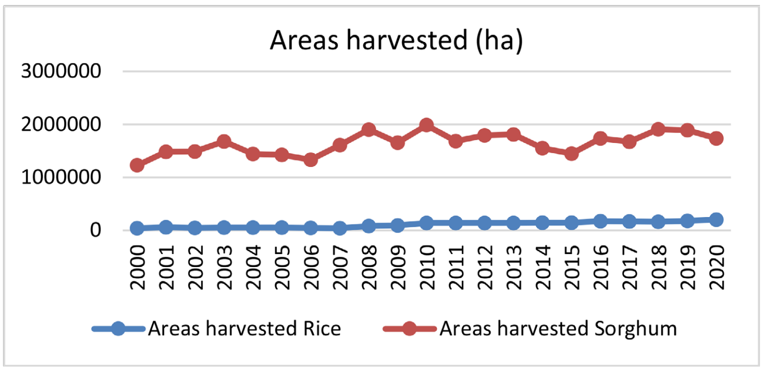
Burkina is a landlocked country and is not naturally endowed with surface water. Its origin hydrographic network is constituted by waterways, most of which are intermittent. In addition, some small reservoirs of water are constructed by the government for counter season crops and to support food production (Cecchi et al., 2008). The halieutic and aquacultural production comes from 1208 reservoirs of water and rivers (Mouhoun, Nakambé, Nazinon, Bougouriba, Comoé, Sirba, Pendjari, Léraba, Tapoa) and their tributaries, lakes, ponds and floodplains with an estimated area to 122,000 ha. In 2016, the national production of fish was 22,540 tons and the contribution of the growing aquaculture sector to this quantity is only 500 tons.

Despite the efforts of the government to increase food production and productivity to respond to food demand and ensure food security and nutrition, beyond land and water problems, the high intrants cost (Zahonogo, 2011), the low level of literacy of farmers, the bad organization of actors and insecurity are some other factors which impact negatively food production (Maré et al., 2022). However, many studies have shown that Burkina has a large economic and social potential agriculture sector particularly in its West regions (Centre-East, Hauts-Bassins, Cascades and Boucle du Mouhoun). This potential can contribute to reducing poverty with revenue provided to fisher and farmers, to create jobs for the young and to respond to the high demand of food products. And for this reason, the sector of food production must maximize rice and aquaculture production (D'Alessandro & Tondel, 2021) that have a higher productivity than sorghum and they have the capacity to attract private investments. Both sectors are complementary, and it is important for the government to explore some solutions such as the integrated "rizi-pisciculture" that is beneficial for water management, to fight against climate change and environmental degradation. The choice of these value chains is also based on their capacity of contribution to improve socioeconomic conditions of farmers and fishers. The national production covers only 44% of national demand and the challenges for the government is to increase rice productivity, the technical level of processing and to convert the unions of steamers into real processing industries for the goal to reduce rice production cost and to satisfy the national rice demand (**Figure 1**). Concerning the aquaculture sector, the national production covers only 5% of the national needs of fish and the rest of the demand is imported with the rest of the world especially in China (44 000 tons/year). The challenges are to address the low capacities of supply in inputs and the distribution of fish products to allow the local producers to concur with the imports of fish coming from China that the price is very low than local production. To reach this goal, it is necessary to maximize the diversification of production, the productivity of existent fishing, to promote intensive and the integration of aquaculture and agriculture, the training of actors for a participative management of resource and the quality of fishing products and end, to reinforce the research by using ecosystemic approach, the selection of efficient strains for aquaculture and the development of efficient feeds from local products (Zougmore et al., 2018).



Source: FAOSTAT (April 11, FAO, 2024).

Figure 1. Comparison of rice and sorghum yields (hg/ha) in Burkina.

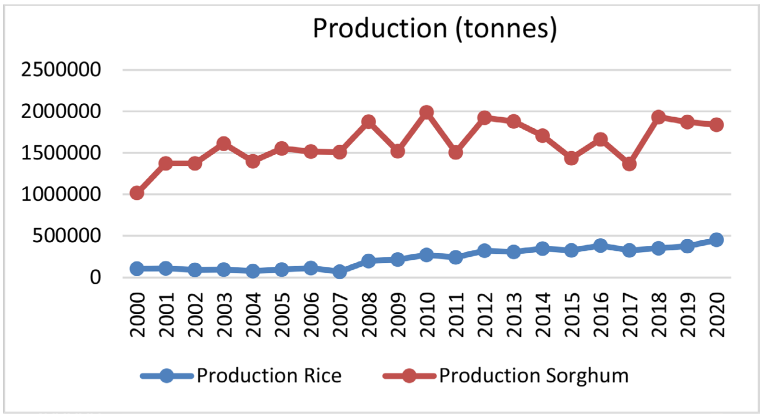


Source: FAOSTAT (April 11, 2024).

Figure 2. Areas harvested (ha) by rice and sorghum.

2.2. Storage

One of Burkina Faso FS problems is the food storage by actors (Gross et al., 2020). The capacity of producers to store food after harvest is very low although some producers are making efforts. They do not have the necessary infrastructure to keep food for a long period of time that would allow them to face lean periods and in case of a drop in their production. In recent years, their food stocks have been decreasing, passing from 349,000 tons in 2016 to 215,000 tons in 2020 (**Figure 2** and **Figure 3**). And the deterioration in farmers' storage capacity is not improving, due to climatic conditions and the lack of storage and preservation facilities. This problem can be resolved with the creation of the "Société Nationale de Gestion du Stock de Sécurité alimentaire (SONAGESS)" in 1994. The SONAGESS is an instrument of cereal and food security policy of the Burkina Faso government. Its roles are to ensure food security and carry out service provision missions through the constitution and management of food stocks, especially cereals. The stocks are composed of local production and the



Source: FAOSTAT (April 11, 2024).

Figure 3. Production quantity of rice and sorghum.

food aid that the State receives from its partners (D'Alessandro & Tondel, 2021). The SONAGESS capacity of storage is about 45,000 - 75,000 tons which enables it to realize some resilience operations for vulnerable populations through its 250 food stores.

2.3. Transformation

Burkina Faso faces the low modernization of the rural sector. The industrial sector is less developed, which means that processing industries are in the informal sector (75 percent of jobbers are working in the informal sector), with the exception of a few large companies around the major cities (FAO, 2021). According to the UNIDO, the processing of local products and the transformation of the agribusiness sector are essential for developing countries to achieve the "Sustainable Development Goals, including Goal 1 on no poverty, Goal 2 on zero hunger, and Goal 8 on decent work and economic growth" (Tezera et al., 2022). In Burkina Faso, less than 20% of local products of agriculture are processed and the products that are most processed are sorghum and maize. The traditional processing is done by women who essentially process these products to traditional beer and a few quantities are supplied to informal restaurants, industrial processing plants (BRAKINA) and scholar cafeterias. The most part of the food industries focus on consumable oil production through cotton grain processing. The meat processing is concentrated around two refrigerated slaughterhouses in Ouagadougou and Bobo-Dioulasso (Montcho et al., 2018). Some slaughterhouses exist in other localities but do not meet health standards and do not have the capacity to process the meat. Other products that are most processed are rice and aquaculture. More than 55% of the national capacity of rice processing is localized in the West of Burkina where most processing units are steamers. There are few industrial and semi-industrial plants around Bobo Dioulasso, but they have a small capacity of storage and transformation. The steaming of rice is mainly done by women (16,000 women formed in Unions) who treat about 52% of national rice production. Unfortunately, rice processing is limited by the lack of equipment, the low technical level of processing (Hauer & Nielsen, 2020). Aquaculture was not a priority and was marginalized during a long period that explains the low development of the sector. But since 1970, several measures have been implemented by the government in this sector to intensify and maximize fish production with the goal to achieve food self-sufficiency and improve the revenue of fishers. In general, the processing sector faces a high cost of energy, inappropriate taxation and low profit margins, poor processing techniques and the quality of the labor force. Even though this sector is embryonic and informal, the agri-food processing sector has a non-negligible contribution to economic growth. According to the International Food Policy Research Institute (IFPRI), its contribution to the GDP is 7.6% and 5.8% to employment in 2019 (Pauw et al., 2023).

2.4. Distribution (Marketing and Logistic)

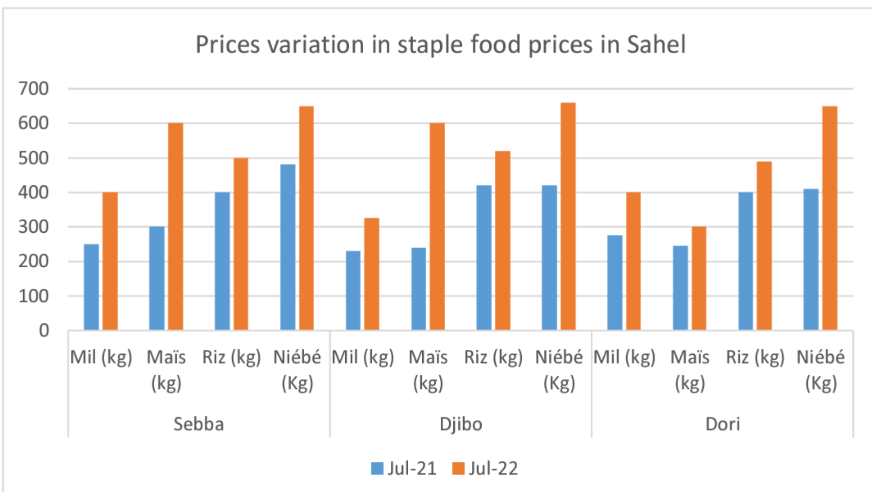
The food economy is dominated by informal trade networks linking rural areas and small towns (D'Alessandro & Tondel, 2021). These networks of small traders buy surplus food from local producers who then transport this food to the mass markets or resell it with SONAGESS (Pauw et al., 2023). They are responsible for most of the food trade except cotton and some institutionalized cereals and constitute a source of jobs creation. Unfortunately, the sector of food distribution suffers from organization problems because the farmers are little integrated in the formal food supply chain and the food traders operate in the informal market. The modern market for distribution is monopolized by a small group of large companies who have the financial means to access the international market. Another problem that weakens the FS of Burkina is the lack of infrastructures of food supply and distribution. These infrastructures are physical (roads, TIC, storage warehouses) and institutional (markets, supermarkets, transport, information on food prices) that permit linking producers and consumers, food demand and supply. Infrastructures are essential to transport food from the area of production toward the markets of consumption. They facilitate the transactional contracts between actors and the storage of food on wholesale and retail markets, rural and urban markets (Ruijs et al., 2004). They play a key role in the FS by allowing exchanges, influencing food prices, the space structuration of productive activities and market access to producers and consumers as well as territorial disparities through food balance sheet, conditioning food quality through the storage, the logistic and reducing food losses (Balineau et al., 2021). Unfortunately, Burkina Faso road network is unequally distributed across the country. The total road network is 15304.4 km, of which 3437.8 km are paved. The data show a wide regional disparity in infrastructure. There are 332 km of roads in the central region, 2084 km of roads in the Boucle du Mouhoun region, 691 km in the south-central region, and 1132 km of roads in the northern region. These infrastructural disparities, combined with the poor quality of the roads, which are impassable, especially in winter season, limit food trade between regions and contribute to the unequal distribution of the food balance sheet and food price between regions. One of the opportunities for the food value chain is that Burkina has a strategic position in terms of cross-border trade because it is at the crossroads of the central basin countries. Its geographic position allows it to export livestock surplus toward Mali, Ivory Coast, Togo and Ghana (Amikuzuno, 2011). To take full advantage of this benefit, the government must intervene to improve the informal economy regarding its role in food supply and jobs creation, to support women participation in food distribution to allow them to work in the formal market, to reinforce the system of market surveillance and improve the quality and the amount of food supply chain infrastructures in order to reduce the territorial disparities. In addition to private actors, SONAGESS is an important actor in the distribution of food through its model stores, especially in times of food insecurity. It is the regulatory instrument of the government on the food market. It provides vulnerable populations with food that is cheaper than the market price. Through its Food Market Information System (SIM), it collects, processes, and disseminates information on food markets, especially food prices, collection operations for stock replenishment (restoration) and in-depth studies on price formation and trade flows.

2.5. Consumption

With over 21 million people, food production of Burkina has grown at the same rate as the population growth (3% per year) in recent decades. The diversification of crops (cultures) is too low because the large part of production is based on cereals (millet, sorghum, rice, beans and maize), some legumes and vegetable fat. The consumption of meat and fish is very low among the population because their production is very low and unequal across the country and prices are high (Lykke et al., 2002). Only rich people in urban areas can include in their diet modern foods such as chicken, eggs, cheese and pasta. The weak diversification of cultures makes a large part of nutrient needs and health uncovered by local production leading to the government to increase the imports of some products to respond to the nutrients needs of the demand (D'Alessandro & Tondel, 2021). It's true that dietary diversity is largely linked to the diversity of crops (more than 80% of calorie production) produced by farmers (Nikiéma et al., 2010) and the agricultural incomes of rural households, but this can be nuanced from region to region. In northern Burkina Faso, for example, food diversity is much more closely linked to income from mining activities, due to the influence of mining activities on agricultural activities (Sanou et al., 2018). In terms of food availability and access which differ one region to another are related to the noted inequalities in regional production, the unequal repartition of infrastructure to facilitate food transport and exchange, the price disparities between regions, the instability (insecurity), the weakness of public administration and institutions. In addition, poverty through the low revenue of the population impacts food access. The SMIG (minimum wage) has barely increased since 2006 and stands at 30,684 FCFA/month (47 euros/month). The poverty line is 164,955 FCFA/month (251 euros/month) in 2018 with a poverty incidence of 36.2 percent. The share of food in total household expenditure is approximately 50% of income, meaning that food occupies an important place in a household's budget.

However, even if efforts have been made by the government in terms of production to ensure a positive cereal balance, it must be recognized that this is not sustained over time because Burkina has experienced negative cereal balances over the past ten years, particularly in 2011 (−154,000 tons), 2015 (−35,000 tons) and recently in 2017 with −477,000 tons. Food availability linked to national food production covers the food needs of the population because food availability is estimated at 4.135 million tons in 2016 and 4.586 million tons in 2020, while food needs are estimated at 4.042 million tons in 2016 and 4.476 million tons in 2020. This allows an average of an apparent food availability of 240 kg/person/year between 2016-2020 if we add the net cereal imports while knowing that the norm of consumption is about 190 kg/person/year. The price of a kg of white sorghum in December 2020 was 224 CFA francs in Ouagadougou, 169 CFA francs in Manga, 99 CFA francs in Solenzo, 150 CFA francs in Léo. This shows the price disparities which penalized food access in a few regions. The Figure 4 shows price variations of cereals in three localities of Sahel region of July 2021 and 2022. These variations are related to food availability problems due to the blockade of these towns by the unidentified armed groups (Food Security Cluster, 2022b).

In terms of nutrition, the cluster (includes NGOs, the Red Cross and Red Crescent Movement, UN organizations, Governments and Donors) reports that food insecurity is expected to increase in 2022 compared to 2021 due to declining food production, market disruptions (declining purchasing power, rising food prices, problems with market food supplies), insecurity which that has threatened economic and agricultural activities, food stocks availability, household size (Nikiéma et al., 2010), and water shortages due to climate and the drying up of water points in the Sahel regions. "*Water supply for domestic needs*



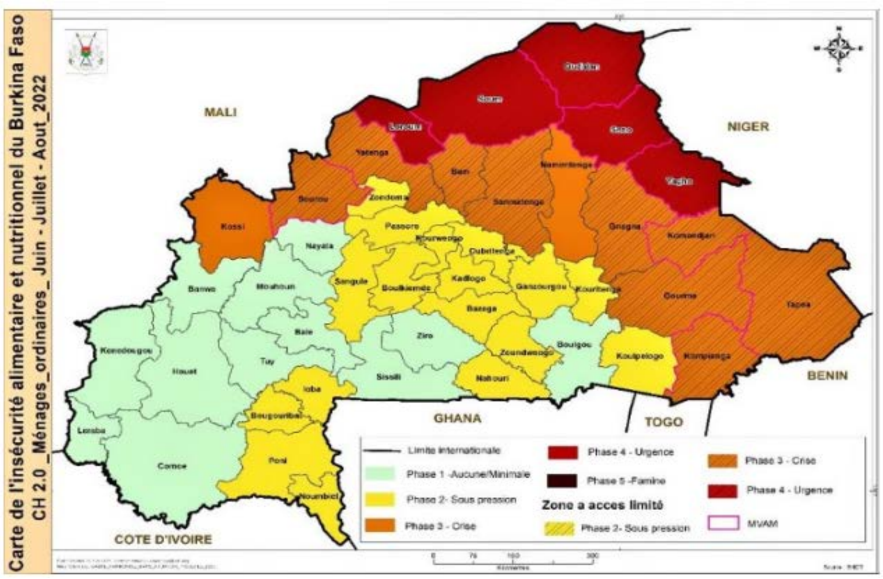
Source: Food Security Cluster/Sector.

Figure 4. Prices variation in staple food price in sahel.

and animal watering is done around the same traditional wells and boreholes. An estimated 21 *million head of livestock without access to the minimum required water per day*" (Food Security Cluster, 2022a). This situation negatively impacts food access and nutrition because the rate of water access decreases from 63% before the insecurity crisis to 44% in 2022, 2.5 million people don't have access to the required minimum of 20 liters per day. Over 20% of agricultural households have a limited food consumption score and 6% of them have a poor food consumption score. **Figure 5** presents the state of degraded food security and nutrition across the country. The regions of Sahel, East and North have a bad situation because they have more terrorist attacks than other regions, resulting in population displacement and food supply constraints (Onuabuchi et al., 2022). The roads in these regions are mined with explosives and ambushes are very frequent. So, the major challenges for the government are to fight against insecurity, to develop an urgent humanitarian response for the benefit of IDPs and populations who are impacted by terrorist activities because they can no longer carry out their agricultural and livestock activities in complete peace of mind, to build infrastructure that will facilitate the exchange of food between regions.

2.6. Food Sector Actors and Institutions

The characteristics and the development of the FS are shaped by the institutions which intervene in the system through the implementation of policy, law and actions taken (Le Cotty, 2021). In Burkina, rural agriculture development is based on the strategy of rural development which aims to ensure that agricultural interventions contribute to a durable food and nutritional security, economic growth, the improvement of households' livelihoods and the reduction of population



Source: Food Security Cluster.

Figure 5. Food insecurity map for Burkina Faso.

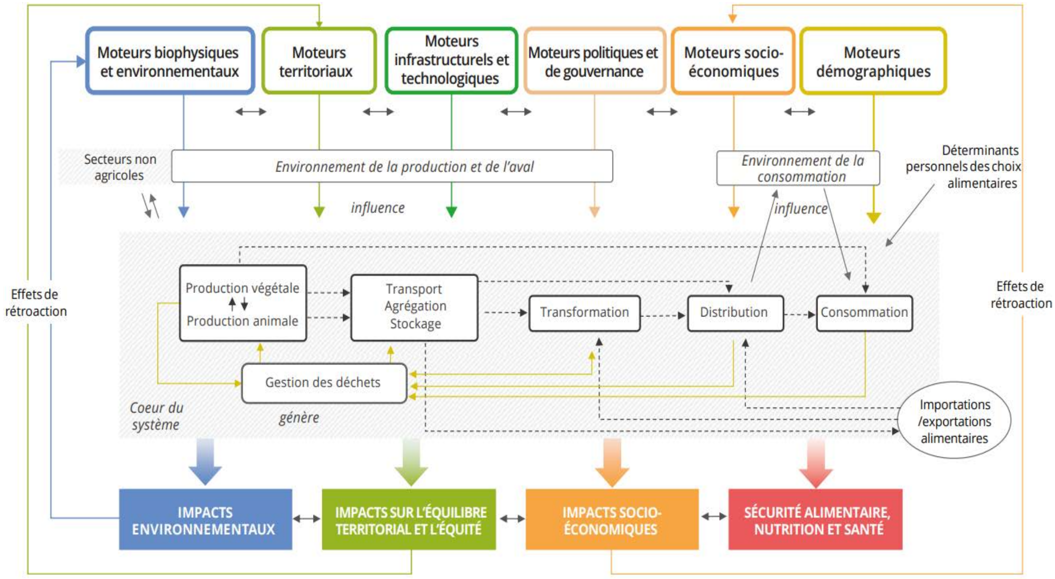
vulnerabilities to climate hazards. It is developed by the Ministry of Agriculture, Animal Resources and Fisheries (MAAH) which formulated the 2nd National Rural Sector Programme (PNSR II, 2016-2020) to prioritize investment toward sustainable production systems, processing units, market and irrigation infrastructure. Also, the National Food Security and Nutritional Policy (PNSAN) is the only reference framework to orient every action in agriculture, livestock and halieutic, forestry and wildlife products, nutrition, water and sanitation and social protection domains to promote and reach food and nutrition security by 2025. The government implements policies through its decentralized institutions that are responsible for supervising the actions implemented on the ground. They work closely with farmers who are organized in Unions or associations. We have for examples the National Union of Fishermen of Burkina (UNPB) with 32000 fishermen, the National Union of Fish Processors (UNTP) with 8000 actors, the interprofessional committee (producers, processors, distributors, traders) of rice of Burkina (CIR-B), the National Union of Seed Producers of Burkina (UNPSB), the National Association of Seed Companies of Burkina Faso (ANES-BF), the National Union of Rice Processors of Burkina, the Consumers' League of Burkina (LCB). These Unions are opportunities to pool efforts and benefit from funding. Unfortunately, they are not well organized and lack the support to increase their efficiency. They benefit from funding through the programs of several NGOs and international institutions such as the World Bank via its Agro-Sylvo Pastoral Sector Support Project (PAFASP) which is the main donor for food development. There is also The International Fund for Agricultural Development (IFAD) of the FAO, the United States Agency for International Development (USAID) and other NGOs which support FS actors through development projects and funds. Beyond policies taken at the national level, Burkina is part of Economic Community of West African States (ECOWAS) and West African Economic and Monetary Union (WAEMU), which have sectoral policies that influence Burkina's economic environment, particularly for agri-food markets. These policies are based on the ECOWAS Trade Liberalization Scheme (ETLS) that is the main operational tool for promoting free trade in West Africa. There is also the African Continental Free Trade Area (ACFTA) adopted in 2019 which aims to achieve greater economic integration by removing trade barriers and tariffs on 90% of basic products. The ACFTA is an answer to the reluctance of companies to invest in small, fragmented and uncompetitive African domestic markets, however its application by all countries is problematic. However, the development of the private sector and entrepreneurship of agricultural activities are crucial to develop the agriculture sector and to improve agriculture actors' conditions (Van Dijk & Sandee, 2002). So, the government must create the necessary and attractive conditions for business and promising value chains. These measures are the creation of growth poles (e.g. Bagré pole, Sourou valley,…), security, infrastructure, non-binding legal frameworks, strengthen the capacities of institutions, especially decentralized ones, develop a banking sector with investment funds dedicated to agriculture with long-term loans, increase irrigated areas with high-performance equipment, facilitate access to agricultural land for those who want to invest, formalize the Burkinabe economy. Other problems which limit the performance of the agriculture sector are the lack of infrastructure for research and agriculture technology and the weak link between research and vulgarization. There are some national scientific and technical research organizations whose capacities are not negligible such as the Institute of Environment and Agricultural Research of Burkina Faso (INERA) and International Center for Research and Development on Livestock in Sub-humid Zones (CIRDES) which are responsible for the formulation, execution and coordination of environmental, agricultural and livestock research in Burkina. Unfortunately, these institutions depend heavily on donors and development agency funding. The regional and international research institutions (IFPRI, CGIAR, CORAF,...) are engaged to support climate change actions but few fundings are put in agricultural policy analysis, actors training and the overall analysis of the food system performance.

3. Designing Food Security Module with System Dynamics

3.1. State of Literature on Food Security Modelling with SD

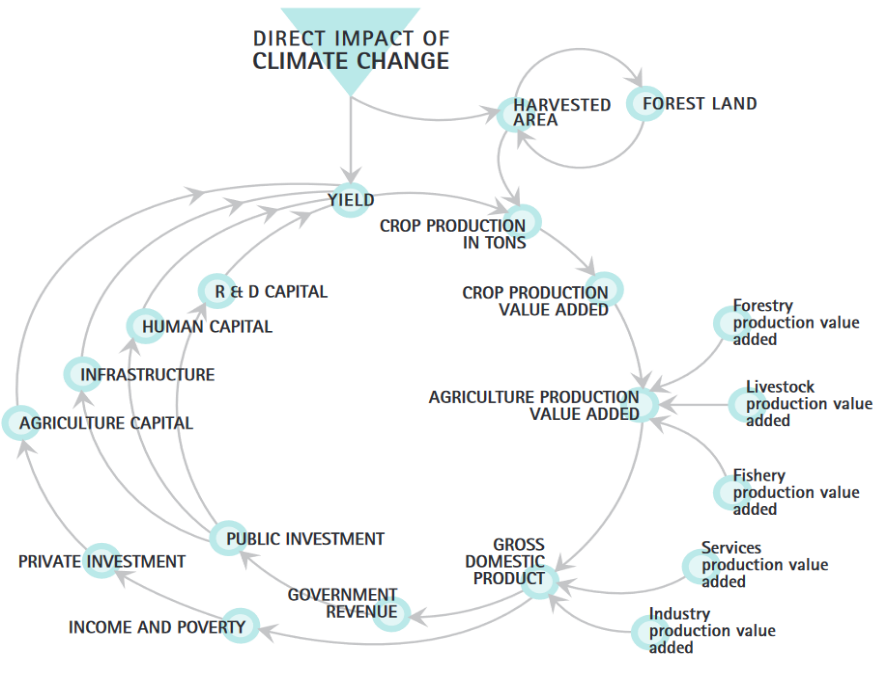
Nowadays, the state of research on food system (FS) modeling by using system dynamics (SD) methods is quite developed. But most studies are focused on the steps of food production, imports and consumption. Throughout the food chain, there are many challenges that threaten food security and nutrition in developing countries (Ibrahim & Yanti, 2019). So, it is crucial to consider the complexity of FS. SD method use is a key for understanding this complexity (Suryani et al., 2014). According to FAO, the FS is composed of different stages which are interconnected and interact dynamically (David-Benz et al., 2022). The overall set of stages constitutes a system that is affected by FS drivers. Indeed, it has developed a dynamic framework which helps to drive studies and research which try to apprehend FS of countries. The core of FS is composed of all actors and their interdependent activities of production, storage, processing, treatment, distribution, consumption, and waste management. These steps are interconnected by financial, information and physical flows. The core of the system is influenced by the external social, political, economic and environmental drivers through feedback loops. It is also impacted by internal drivers such as food actors' innovations, practices and dynamics (Béné et al., 2019). All these drivers shape FS structure and influence its results for food security and nutrition, environment, food added value and livelihoods (Suryani et al., 2014). **Figure 6** shows how a FS structure can be represented by FAO.

The FS is becoming more and more complex with climate change events, population growth associated with rural poverty accentuation and natural resources degradation (PNUE, 2014). These factors threaten food security and nutrition in developing countries and make them vulnerable. Food productivity as well as harvested land are crucial in food production meaning that they are the main elements on which governments must rely on to increase the quantity of food produced (Aprillya et al., 2019; Suryani et al., 2014). Unfortunately, climate change with irregular rainfall and very hot temperatures reduces the yield of agricultural production factors as shown (**Figure 7**) in the model below developed by FAO (Pedercini et al., 2012).



Source: David-Benz et al., 2022.

Figure 6. Conceptual architecture of the food system.



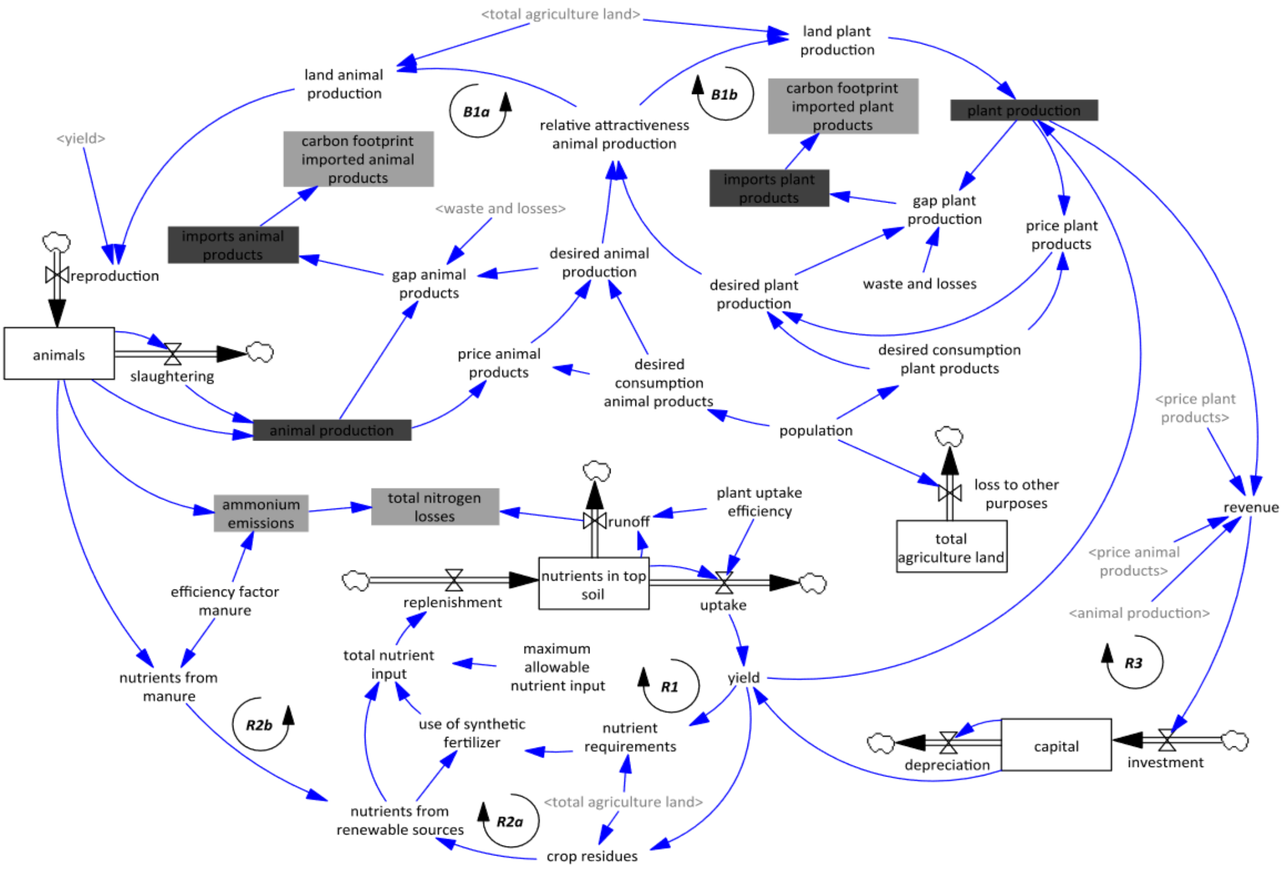
Source: Pedercini et al., 2012.

Figure 7. Climate change impact on agriculture.

So, to face this problem, governments encourage and subsidize fertilizer and pesticide use and farmers convert forest land to agriculture land. These solutions applied produce positive effects but in the short time (**Figure 8**).

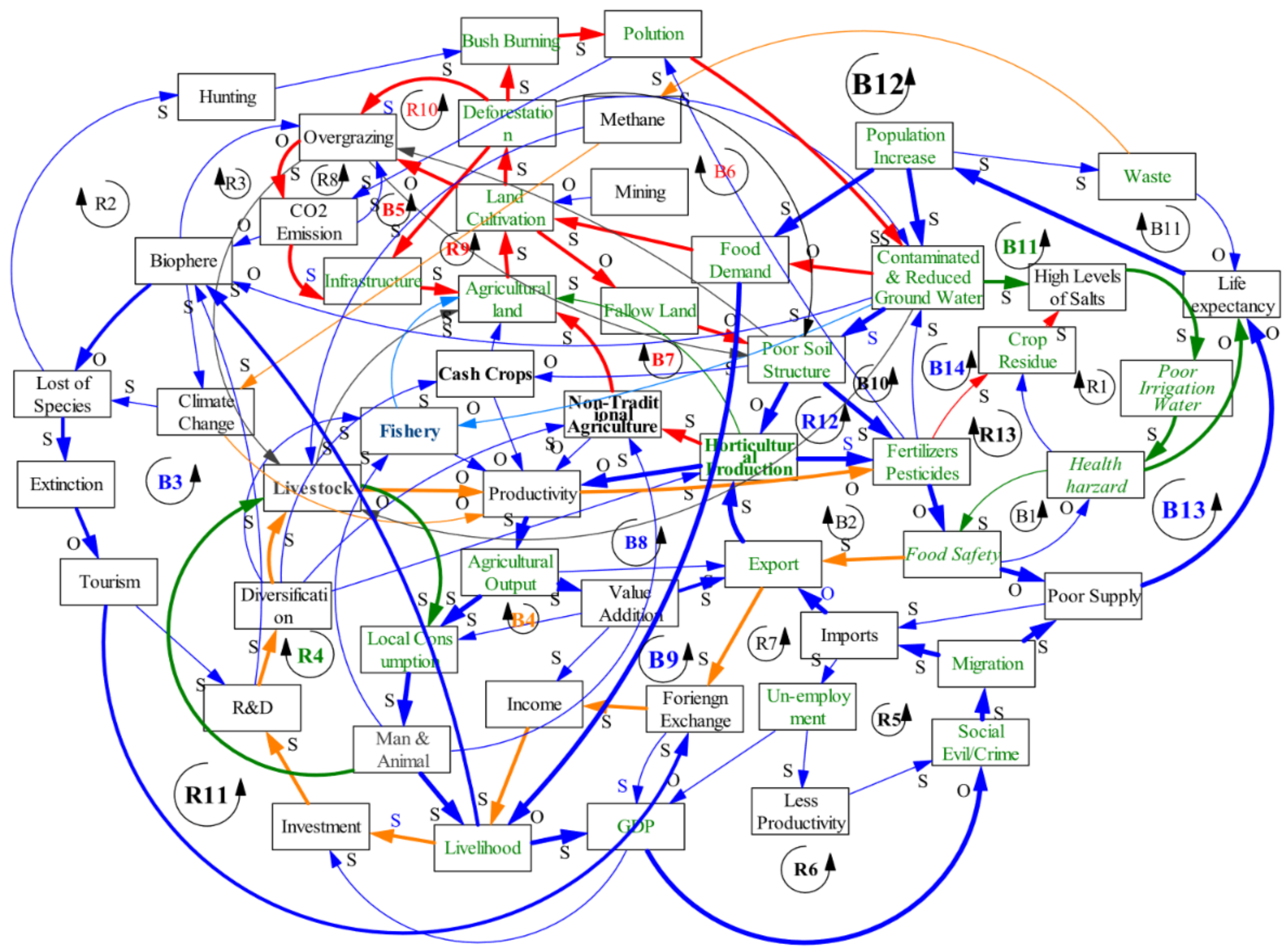
In the medium and long term, the application of fertilizer and pesticides will negatively impact food security, nutrition and livelihoods through low land productivity, underground and freshwater bodies pollution, land degradation, ecosystem extinction and climate change hazards (Banson et al., 2016).

Figure 9 shows the overview of complexity and interconnectedness of different elements which compose the agriculture systems. It shows how SD can be used to build an understanding of FS for the purpose of facilitating interventions, to manage complexity and to address challenges holistically. In the model, the population is the main driver. Population growth leads to an increase in food demand, waste production, pollution and climate change, eco-systems extinction and water contamination. To respond to food demand, farmers are obliged to increase food demand by harvesting more forest area to new agricultural land and using fertilizer and pesticide to revitalize land and increase yield. However, fertilizer and pesticide practices negatively impact food safety, water contamination and contribute to environment pollution and soil degradation. These factors



Source: Kopainsky et al., 2015.

Figure 8. Main feedback loops linking the different food system activities with their corresponding social-ecological systems subsystems and determining food system outcomes.



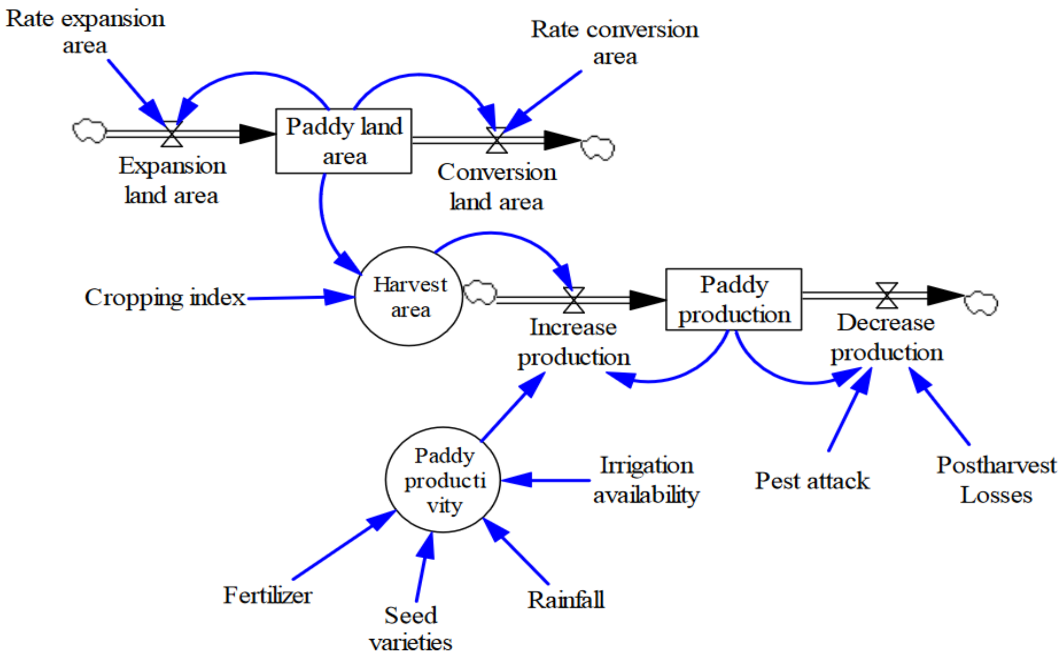
Source: Banson et al., 2016.

Figure 9. The agricultural system web of Africa.

together negatively impact return agriculture productivity, livelihoods, life expectancy and further GDP in the long term (Banson et al., 2016). Other problems (**Figure 10**) that limit food availability in particular in developing countries are food postharvest losses due to the use of bad techniques and the lack of infrastructure (mechanization) to harvest and store food and insect pests (Aprillya et al., 2019).

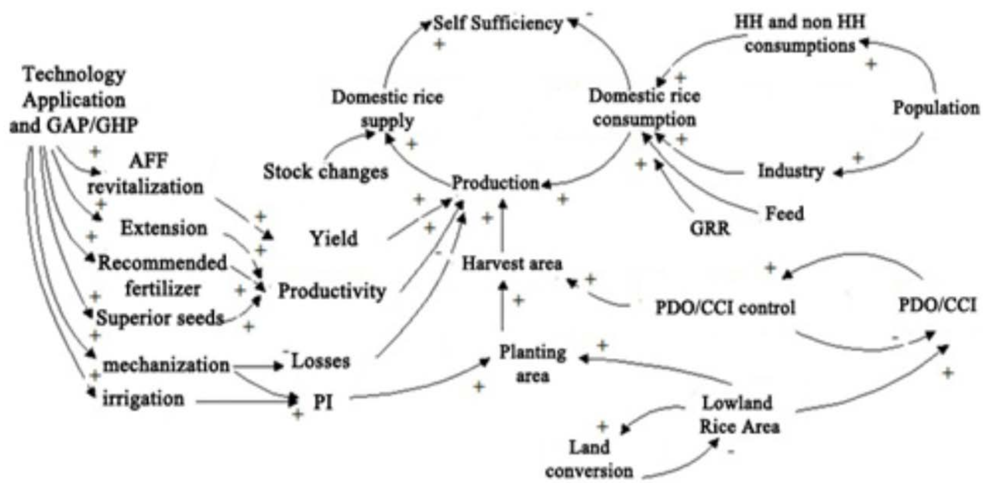
So, faced with the low capacity of national and local food systems to ensure food availability and self-sufficiency, the governments of developing countries are obliged to import food from the rest of the world to increase food accessibility. The mental model below (**Figure 11**) shows how food security can be captured through self-sufficiency. It results from the confrontation between domestic food supply and domestic food consumption. In the case where the domestic food supply is less than domestic food demand the system is in a food insecurity state. In that case, it is necessary to increase imports to fill the food shortage in order to satisfy consumer demand.

As mentioned above, the food system is very complex and it is therefore difficult to find convergent solutions to all FS challenges. Indeed, the use of system



Source: Aprillya et al., 2019.

Figure 10. Flow diagram of paddy production.



Source: Fristovana et al., 2020.

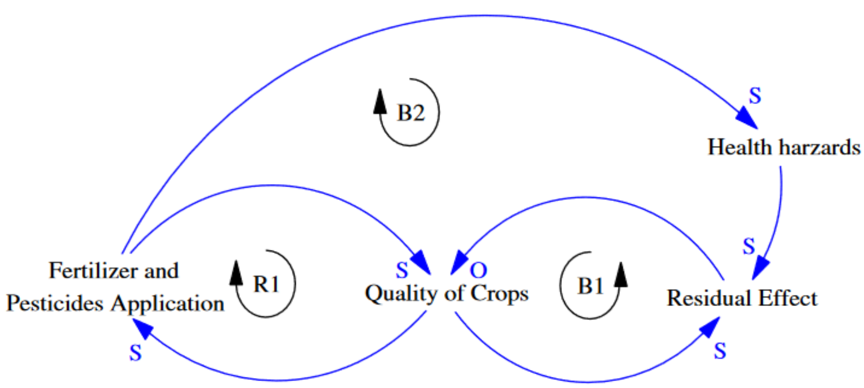
Figure 11. Rice self-sufficiency causal loop diagram.

archetypes also called "system traps" by Meadows are some tools that can help to anticipate potential problems and problem symptoms in the agricultural domain. They are opportunities for policymakers because they are *"responsible for some of the most intransigent and potentially dangerous problems, also can be transformed, with a little systems understanding, to produce much more desirable behaviors"* (Meadows, 2008). The system archetypes can help to describe the interactions of FS factors and contribute to finding adaptation and mitigation levers towards sustainable agriculture. The use of the System Dynamics approach shows that complex problems and challenges that face developing countries cannot be solved individually and with linear models. By using archetypes models (shifting the burden, limits to growth, success to the successful, escalation, accidental adversaries, tragedy of the commons and success to damage systems archetype), Banson et al. (2016) described the spiral problems of Ghana FS for the purpose to produce an understanding and to propose some leverage strategies which can be useful to address agricultural problems in the Horticulture, livestock and fishery domains. For example, to treat the negative effects of chemical products used by farmers to improve crop quality, they demonstrated that fertilizer and pesticides application leads in the short time to the improvement of quality of crops and increasing export success (**Figure 12**). But over time, this success is offset (balanced) by the accumulation of residual effects of fertilizer and pesticide application such as water contamination, poor irrigation water and health hazards. So, to solve this problem, the use of organic fertilizer and agroecology practices are beneficial to avoid land and health degradation and to help farmers to adapt to climate change that threatens crops productivity. The following figure shows the limits to growth concept with Ghana FS case.

In sum, there are many drivers that impact the performance of FS through the behavior and actions of indirect actors (banks, institutions, organizations, markets, …) of the food value chains. The interactions between these actors with FS actors (farmers and consumers) determine the quantity, the quality, the availability, accessibility, the use, the stability and food price. And according to FAO, the FS must: ensure the food security and nutrition and health of the population, create decent works to all food system actors and contribute to inclusive economic growth, contribute to territorial balance (equitable territorial development) in terms of capacities and resources (political power) between food actors and end permit the preservation, management and the regeneration of biodiversity, natural resources and to limit climate change effects (David-Benz et al., 2022).

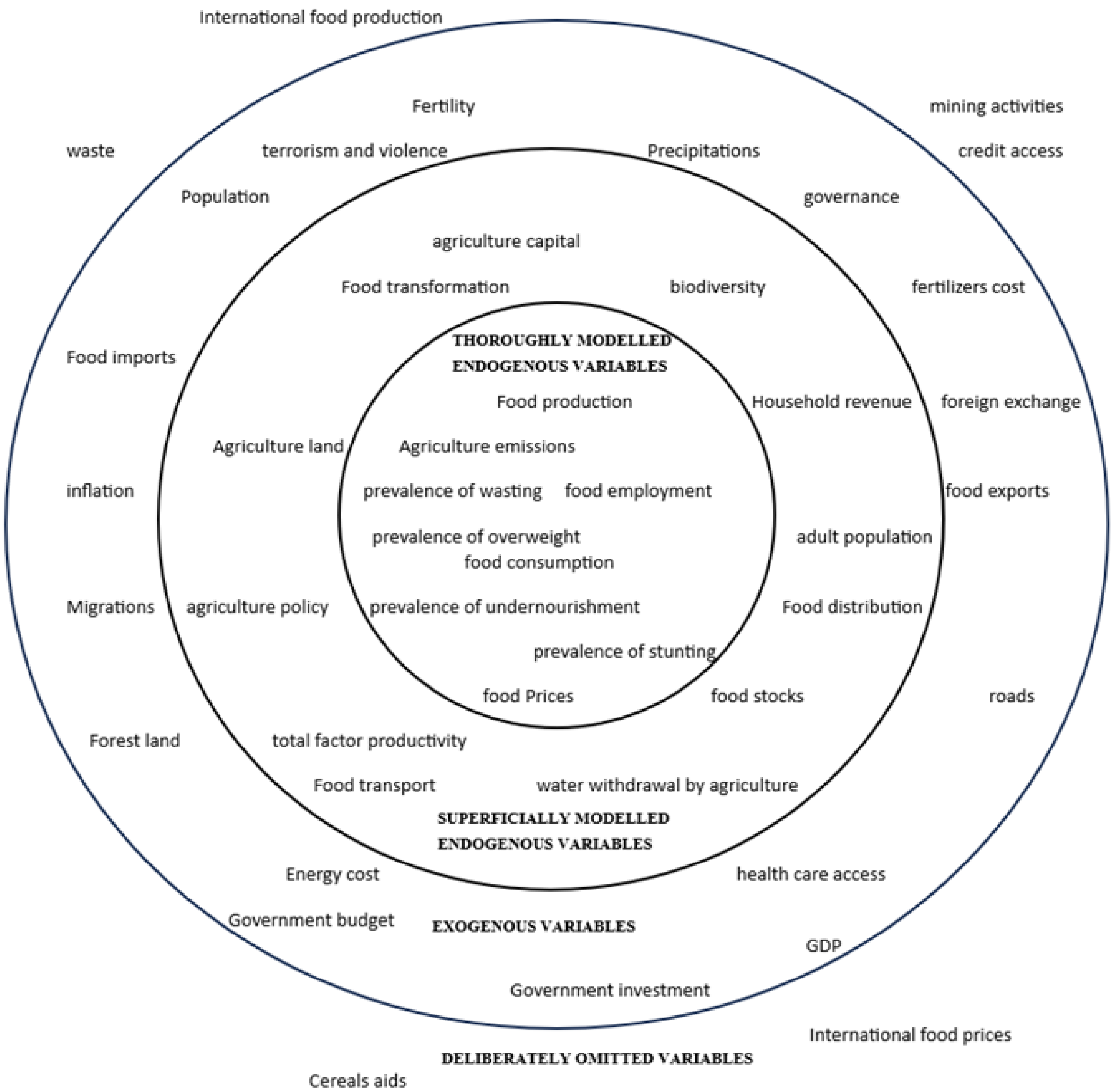
3.2. Some CLD and SFD Tracking Burkina Faso FS

The following Bull's eyes Diagram (**Figure 13**) provides an overview of the variables used in the modeling process through the endogenous variables to the



Source: Banson et al., 2016.

Figure 12. Limits to growth system archetype.



Source: authors.

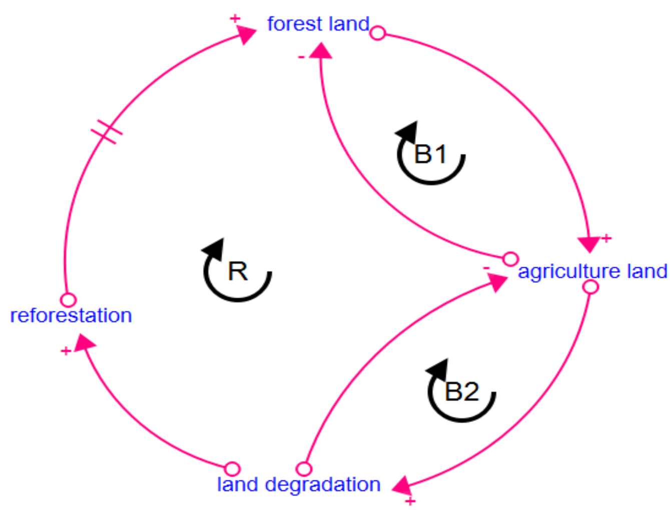
Figure 13. Bull's eyes diagram of Burkina food system.

deliberately omitted variables (PRUYT, 1982; Pruyt, 2013). It can be helpful in decision making through the prioritization of the system elements. The thoroughly modeled endogenous variables (the innermost circle) are the target variables of the model and some key variables of the FS core (highest-priority elements). The superficially modeled exogenous variables (middle circle) contain medium-priority elements. However, we have decided to include food transport, food distribution, food transformation and food stocks among the superficial modeled exogenous variables because of data lack and the fact that they have less impact on the model behavior. The largest circle contains the lowest-priority variables which are the exogenous variables. These variables are social, environmental and economic drivers which act in the system. And end, the deliberately omitted variables concern whose we don't include in the system but can have some impacts on the food system performances.

Figure 14 illustrates a simplification of the interrelations of some elements of the food system and the SFDs are used to show how they interact quantitatively with each other.

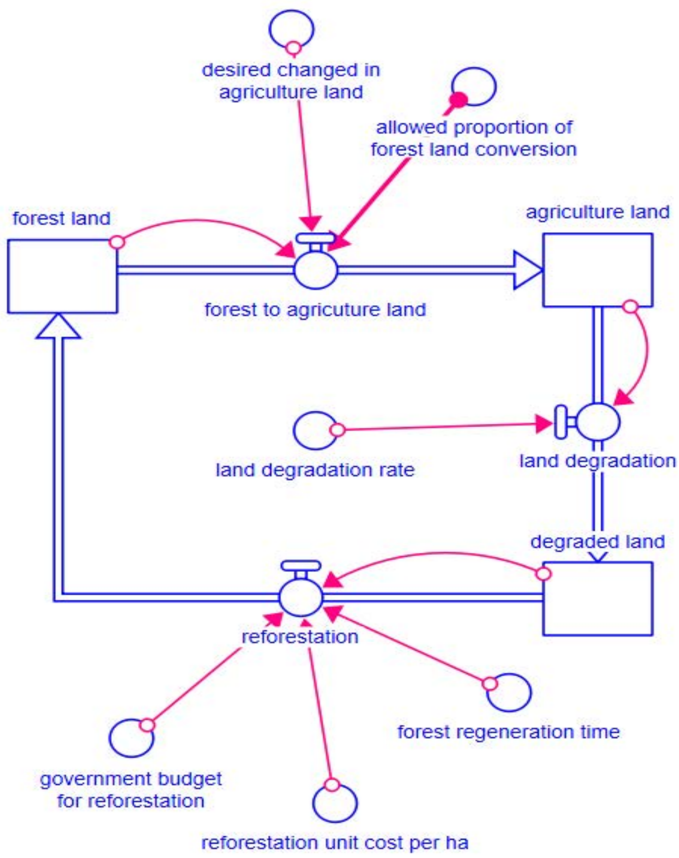
The land Causal Loop Diagram (CLD) describes the interaction between agricultural land (arable and permanent land and pasture land). The more forest land is available, the more we can convert it to agricultural land and that is going to decrease our forest land (B1). With time, we are going to lose agricultural land due to bad agriculture practices and climate change effects (B2). But degraded land could either be converted into housing or reforested (naturally or through government reforestation programmes). However, we're focusing on reforestation because of the leverage it can bring to natural resource management in Burkina Faso in the face of advancing desertification and climate change (R). This scenario (Figure 15) can be apprehended through the Stock and Flow Diagram (SFD).

The CLD above (Figure 16) characterizes factors of production demand (land, labor, capital) used in the step of food production. The more we use food production factors, the more we increase the food supply to cover food consumption needs. Also, food consumption increasingly leads producers to increase the demand of production factors (labor, capital and land) to meet the needs of food production. An increase in food production also contributes to an increase in farm income, part of which is invested in the acquisition of more capital for agricultural production and food purchasing. The model takes into account Burkina Faso insecurity (terrorism) context. The worsening security context since 2015 has strongly contributed to the decline in food production.



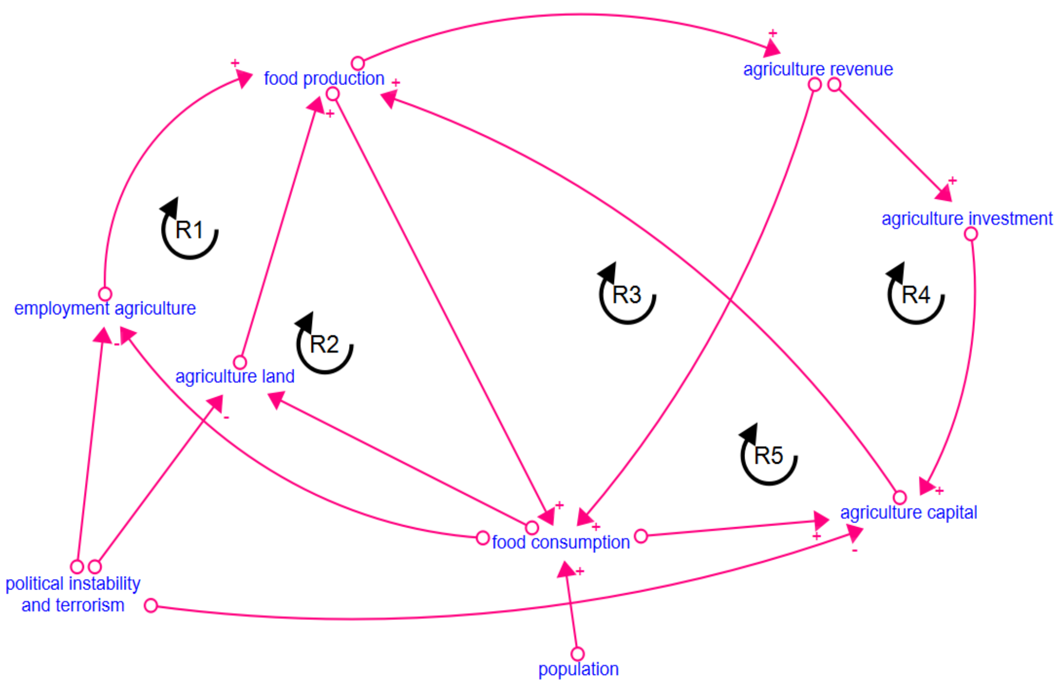
Source: authors.

Figure 14. Agriculture land system.



Source: authors.

Figure 15. Stock and flow diagram of land use.

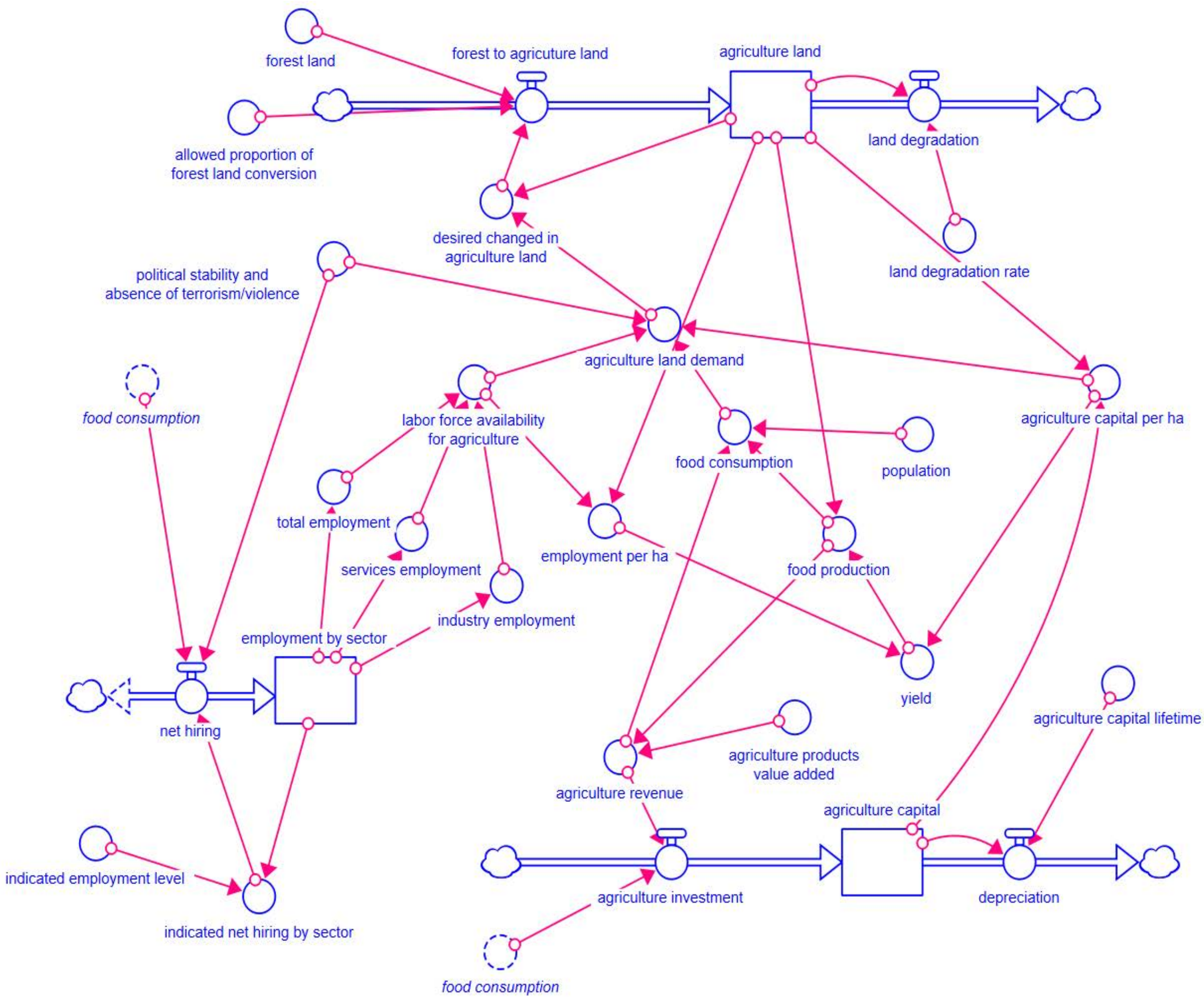


Source: authors.

Figure 16. Food consumption and factors of production demand.

These attacks, which target the civilian population lead them to abandon farmland and labor migration to the cities. The result is a reduction in key production factors such as agricultural labor, agricultural investment and cultivated land. This reduction in the main factors of production inevitably has a negative impact on agriculture production. At the same time, the ever-increasing population makes the food security context more difficult. The following SFD (**Figure 17**) is a simplified illustration of this situation:

Here, the model describes how food access can be facilitated by food transportation and the improvement of household revenue in Burkina Faso. The analysis of the food balance sheet at the national level shows a surplus to meet the national food needs of the population contrary to local (by region) food balance sheet analysis. Some regions have a deficit of cereal products, especially the North and Sahel regions of Burkina, while these regions have a surplus of animal products. Contrary to the West Regions of Burkina Faso, which have a surplus of

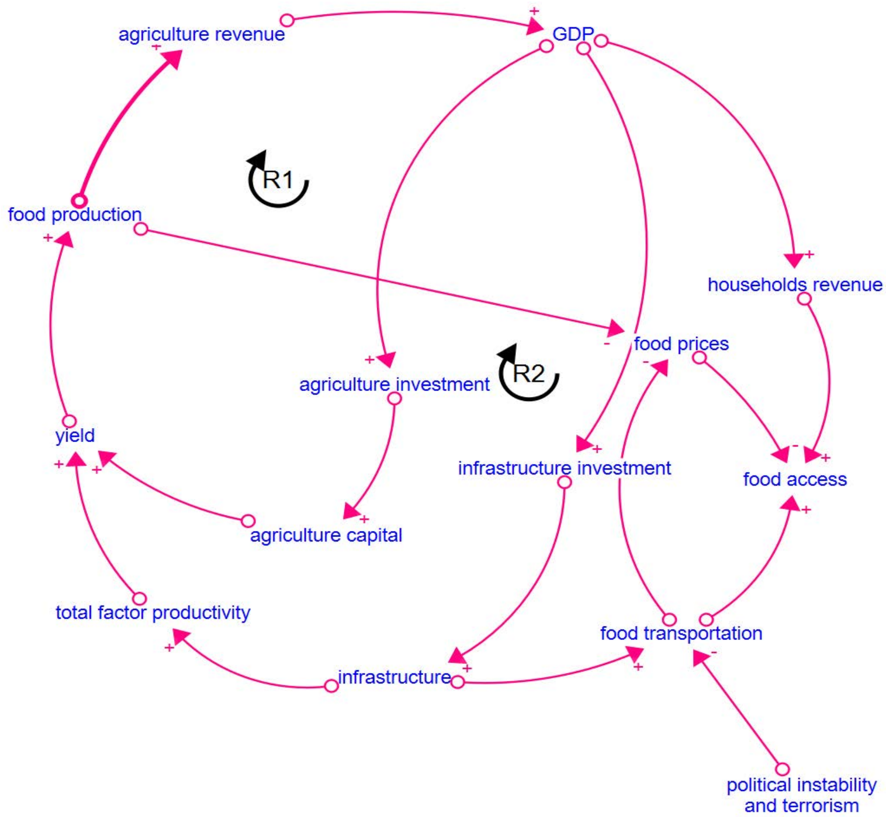


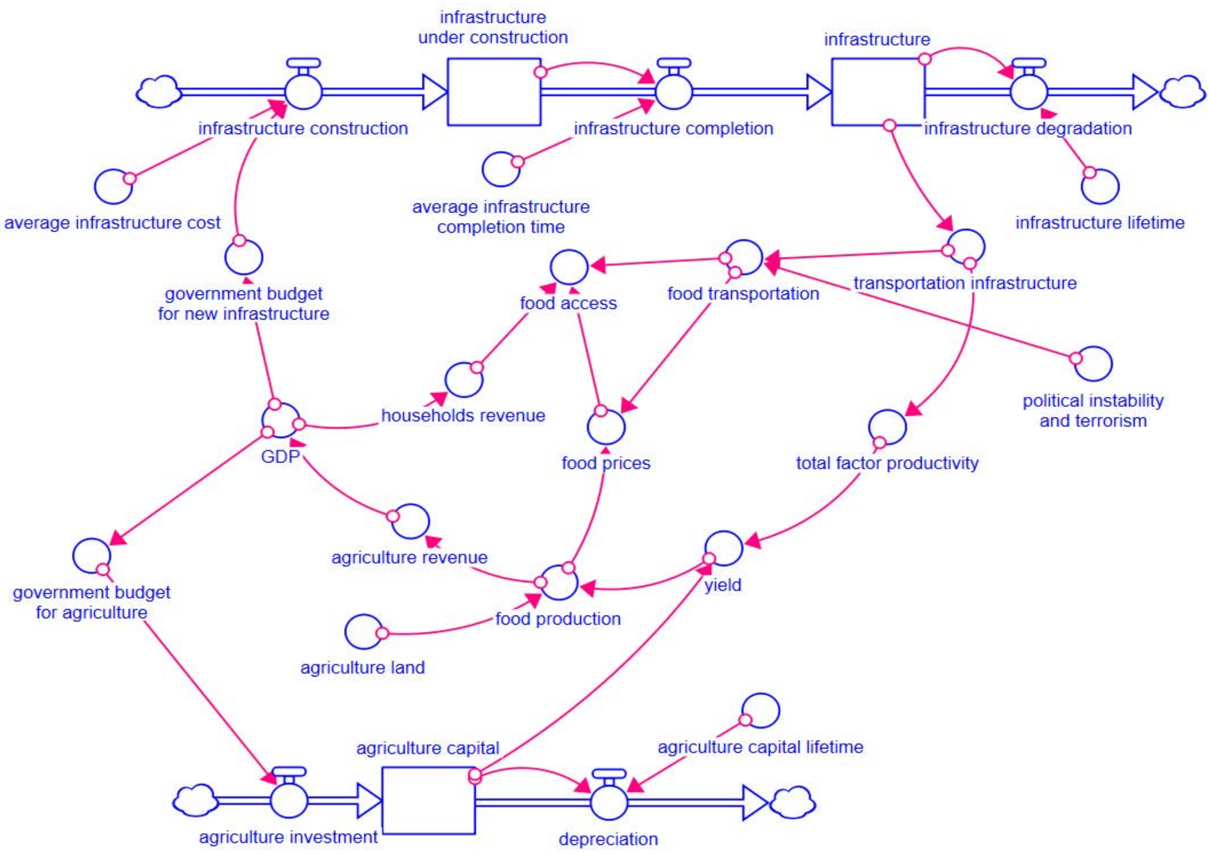
Source: the authors.

Figure 17. Stock and flow diagram of agriculture sector.

cereal products and a deficit of animal products. Normally, a fluid transport system should allow internal food exchanges to compensate for these imbalances. Unfortunately, internal trade is limited by a lack of road infrastructure, and even the roads that do exist are in poor condition, making access to remote areas very difficult. The advent of terrorism dealt a heavy blow to the trade that had previously existed, certain areas are controlled by unidentified armed men (HANI) who confiscate the goods of traders. Some roads have been mined, making it difficult for traders to use them to buy or supply food. Another factor limiting people's access to food is Burkina's low-income level. Food prices are constantly rising due to geopolitical tensions around the world, which increase the cost of food imports by knowing that the country is highly dependent on food imports. Let's not forget that farmers earn their income from agricultural production, as part of their harvest is consumed by themselves, and the other part is sold to generate income. Although agricultural productivity is low due to low levels of farm mechanization and human capital, agricultural production is average, allowing them to earn substantial incomes. In addition, central government subsidies are low and the price of agricultural inputs, especially fertilizer, is very high. All these factors have an impact on agricultural production, farmers' incomes and, consequently, access to food (**Figure 18**). Terrorism has also contributed significantly to rising food prices in the red zones, where food production and supplies are low.

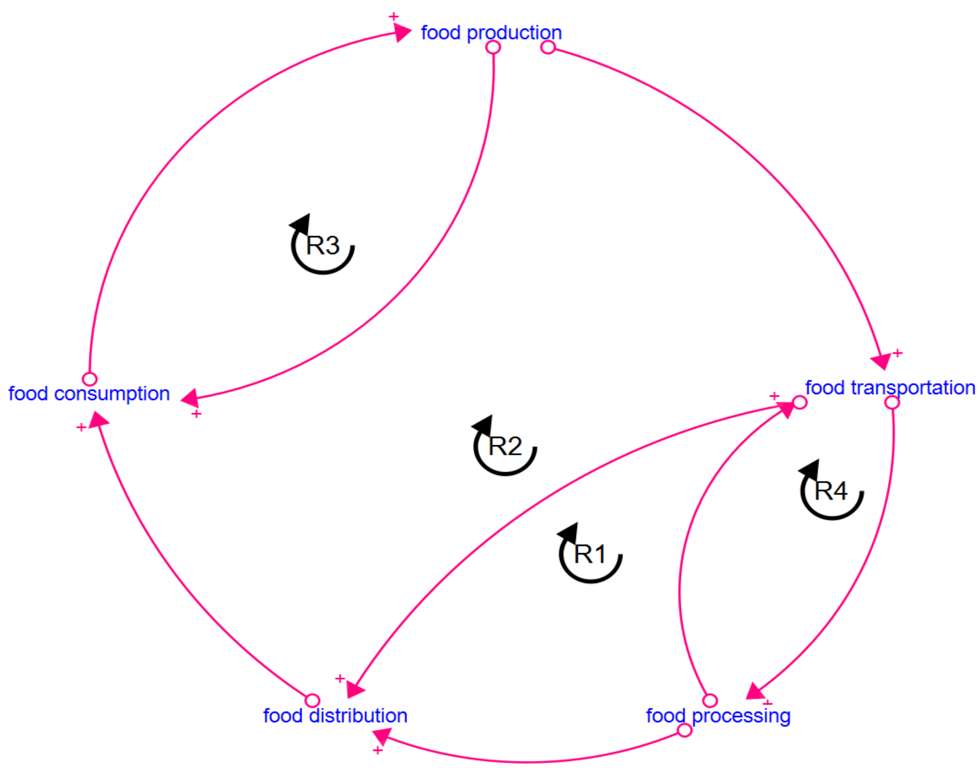
This CLD (**Figure 19**) captures the links between the main stages of the food

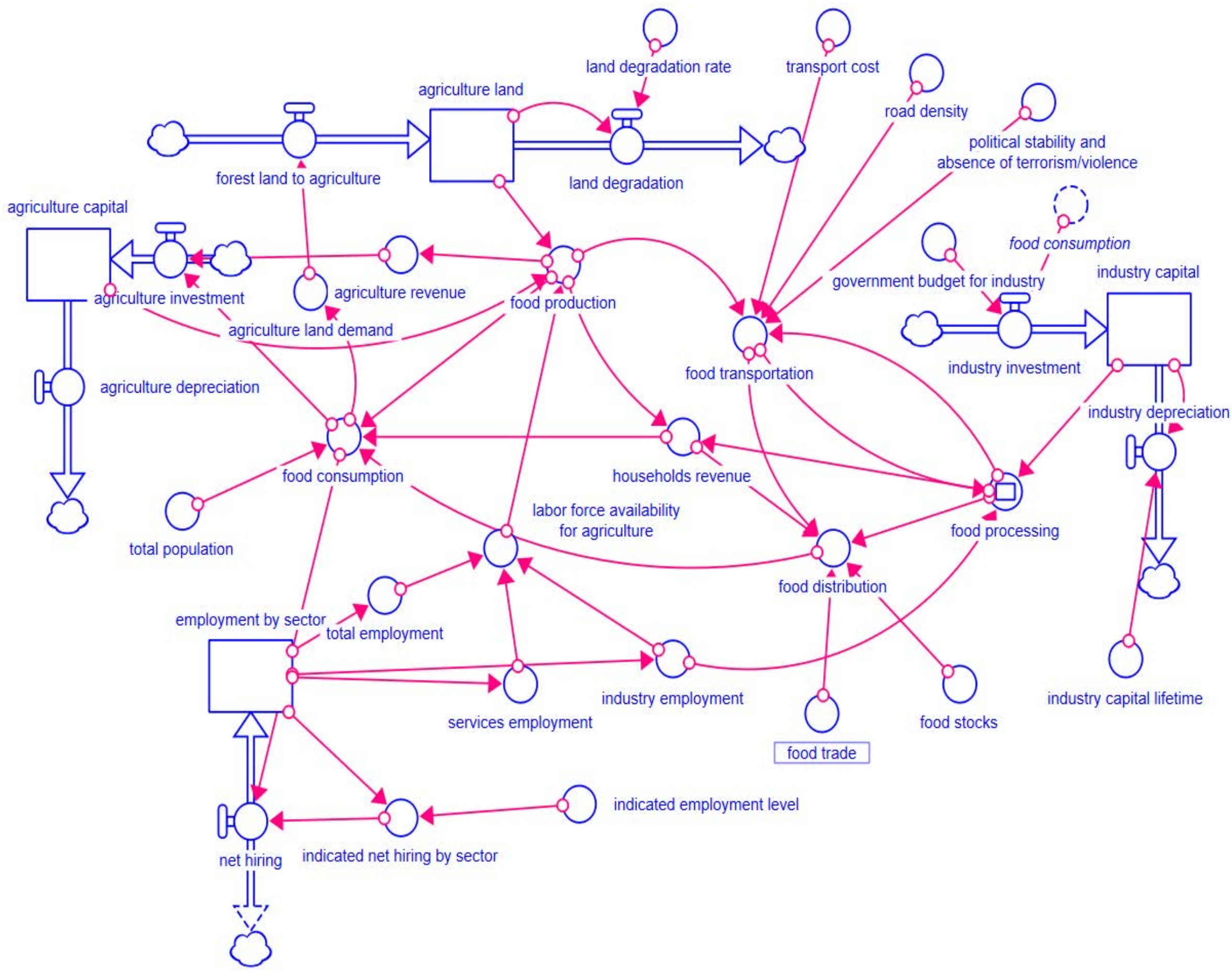




Source: authors.

Figure 18. Infrastructure, households' revenue, and food access.



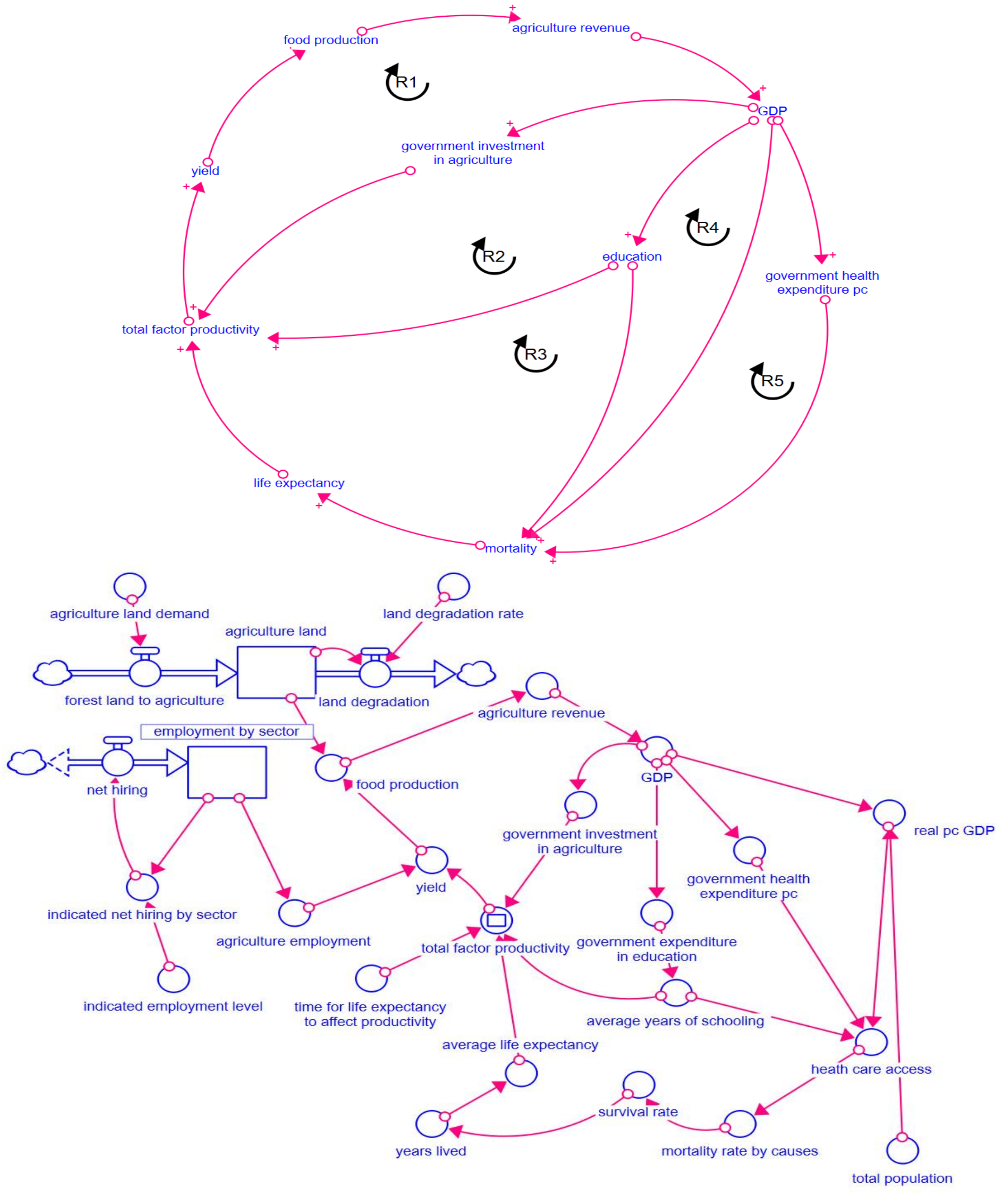


Source: authors.

Figure 19. Food distribution, transportation, processing and consumption.

system. It shows that one part of the food produced is consumed directly by the farmers themselves, while the rest enters within the food market through the transport of food consumption areas. Some of the food transported is then sold directly to consumers on the market, while the rest is delivered to food processing plants, which then resell their products on national and international markets. And we know that industrial and agricultural processing activities are sources of income for households, which will stimulate food consumption.

We may focus the attention on the importance of factor productivity and the level of agricultural production and income (**Figure 20**). The higher the level of factor productivity, the higher the level of agricultural production, and therefore the higher the income for farmers and the government. To achieve high levels of factor productivity, we need to invest in a certain number of domains such as education, farmers training, health care access, technology, and agricultural capital. A healthy, well-educated population is a source of growth for development sectors. If this advantage is used wisely and complemented by a high level of



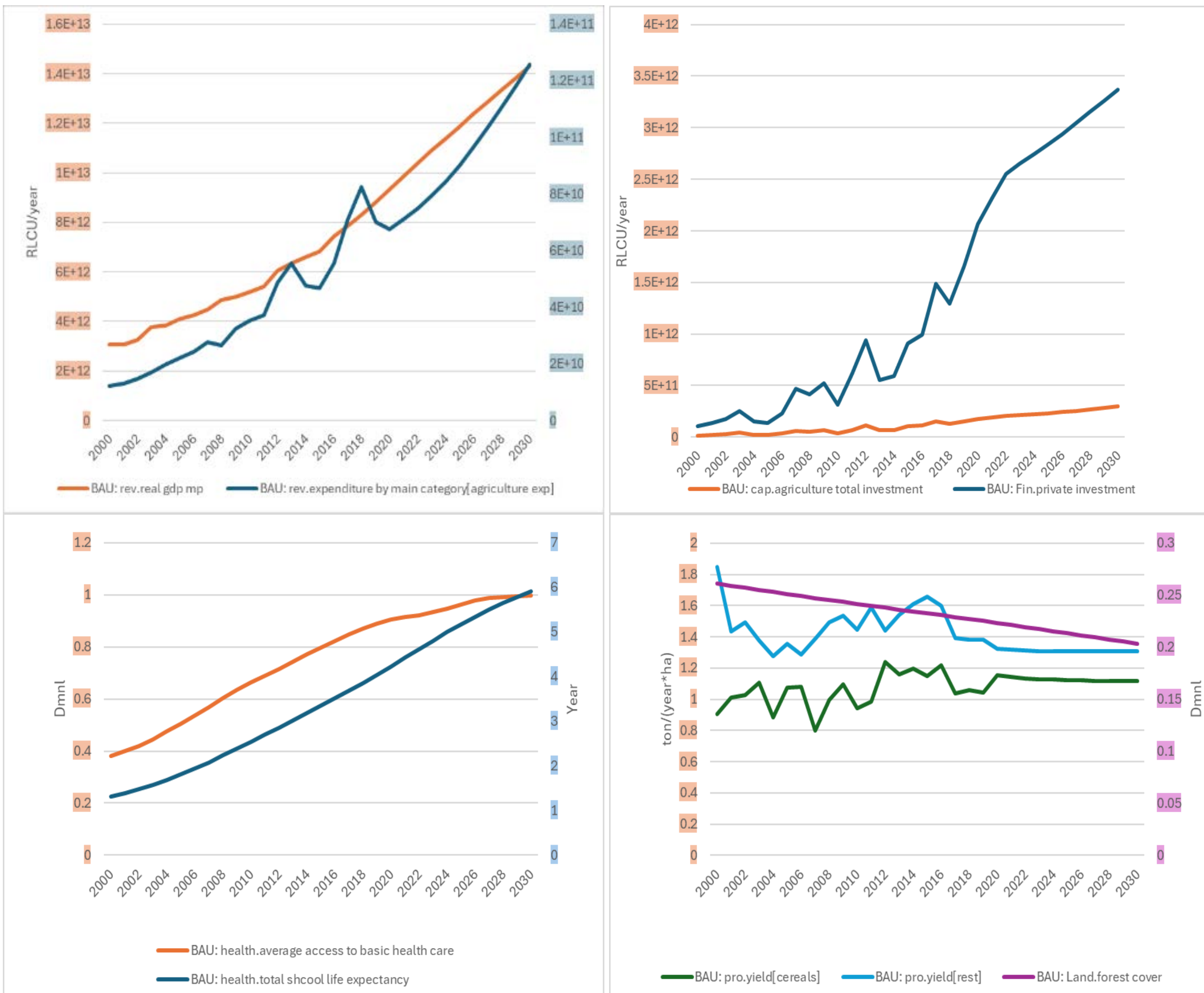
Source: authors.

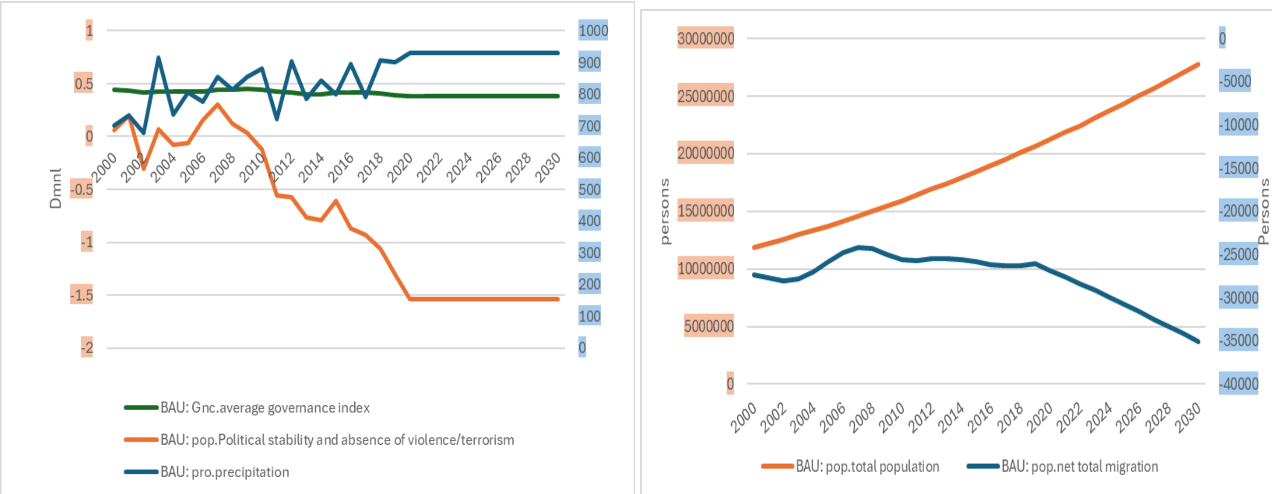
Figure 20. Total factor productivity, production and agriculture revenue.

technology and mechanization in the agricultural sector, it could boost the agricultural sector's performance (CLD, SFD).

3.3. Behavior over Time of Some Key Agriculture Variables for the BAU Scenario

This section presents the different steps of the FS modelized by considering the different interactions between the FS and other main sectors. These interconnections and interactions shape the FS and condition its performance to produce good results in terms of food security and nutrition. These interactions come from social, economic, and environmental factors. Among these factors, we have the infrastructure, forest land and agriculture land, environment (forest cover), household revenue, GDP, governance, government expenditure, agriculture capital, political stability and absence of terrorism, climate change, education, health, … They impact food production through the factors productivity and yield, food transportation and distribution through road density, food processing through investment and industrialization of the agriculture sector. And end food consumption through food prices, household revenue and credit access. The Figure 21 shows the behavior of some key drivers from 2000 to 2020 and their trend until 2030 in the BAU scenario.





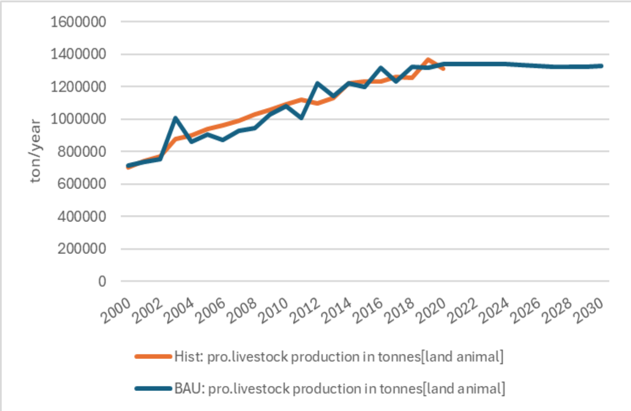
Source: authors.

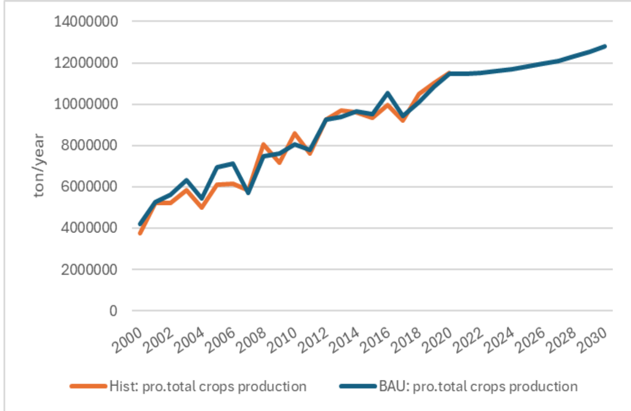
Figure 21. Interactions between food system and other systems.

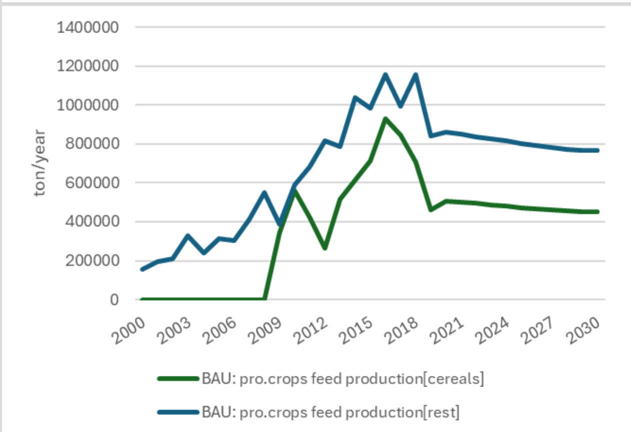
The reproduction of the historical trend of these elements illustrates the rapid growth of the population, more than half of which is young. Forest cover is decreasing at the same rate as forest area, due to the increase in arable land and drought. However, since 2014, the rate of increase in arable land has stagnated due to terrorism, internal migration of young people, and the impact of mining activities on agriculture. Government spending, which has been increasing since 2020, has been decreasing since 2020 due to the redirection of spending to the fight against terrorism and organized crime. Agricultural yields increase, but at a very low rate, allowing food production to increase significantly. Among the factors that enable the transportation, distribution and accessibility of food, we see that the road density of transportation infrastructure is very low (less than 0.06 km per 1 km^2), with rising food prices leading to an increase in household food expenditures.

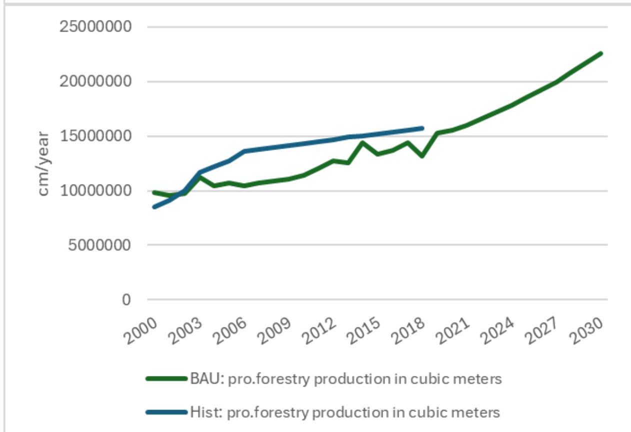
4. Results of the Simulation

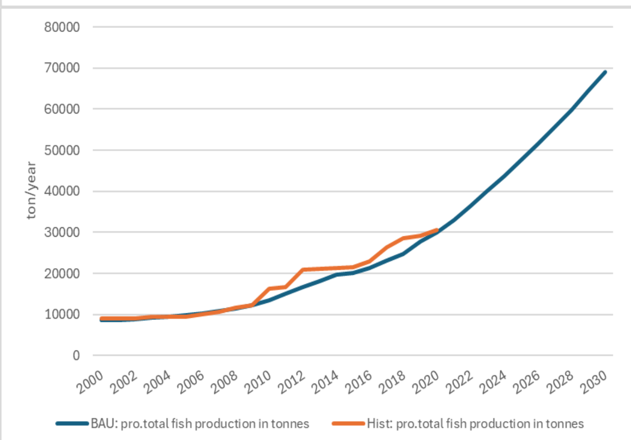
Here, the purpose is to analyze the ability of the model to replicate the historical and long-term trend of some key variables of food security and nutrition (Figure 22). The use of the SD method enables us to calibrate the model for the purpose to fit as well as possible the simulation results to the historical data by searching the acceptable boundaries in order to parameterize the model to the context of Burkina. The historical data has been collected during the modeling process from the "Institut National de la Statistique et de la Démographie (INSD)" and the missing data has been completed by international databases. The model takes into account nineteen (19) sectors (employment, biodiversity, land, water, agriculture emissions, agriculture production, food consumption, food processing, food trade, food transportation, food distribution, food stocks, revenue, poverty, health, infrastructures, capital, fertility and population). These sectors are interacting and that allows us to measure the performance of every sector by considering its key

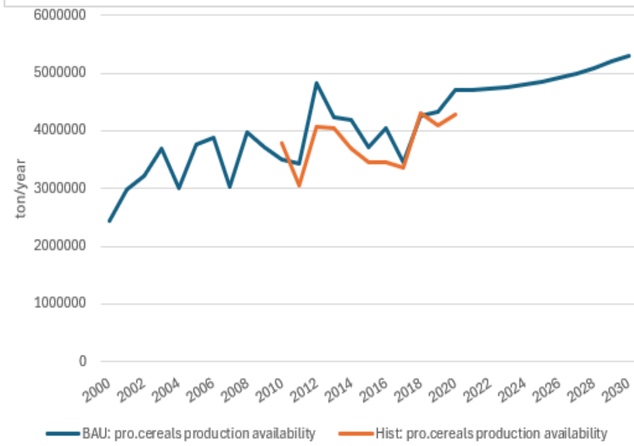

ton/year
Hist: pro.livestock production in tonnes[land animal]
BAU: pro.livestock production in tonnes[land animal]

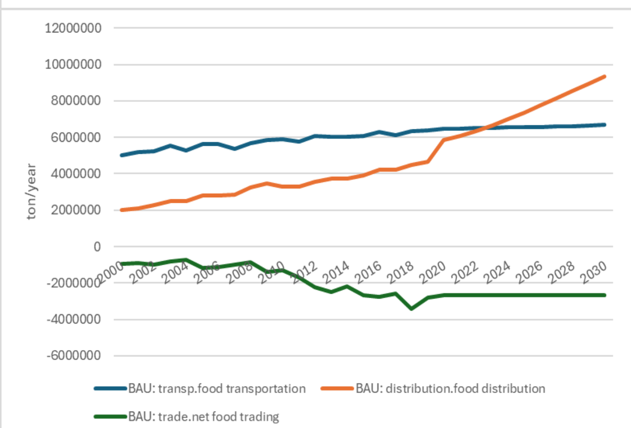

ton/year
Hist: pro.total crops production
BAU: pro.total crops production

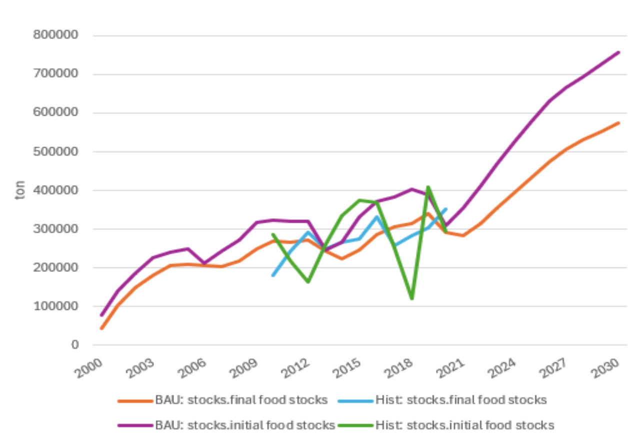

ton/year
BAU: pro.crops feed production[cereals]
BAU: pro.crops feed production[rest]

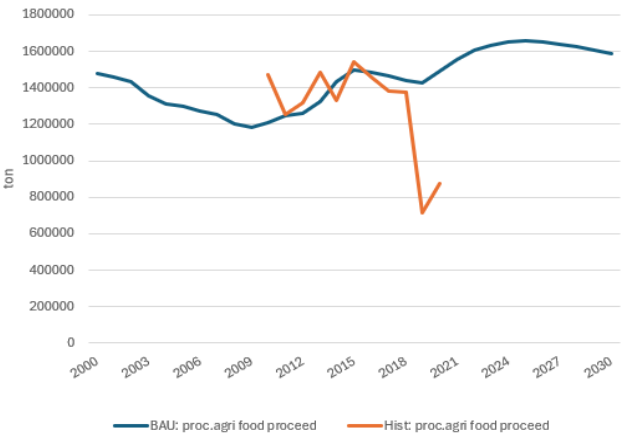

cm/year
BAU: pro.forestry production in cubic meters
Hist: pro.forestry production in cubic meters

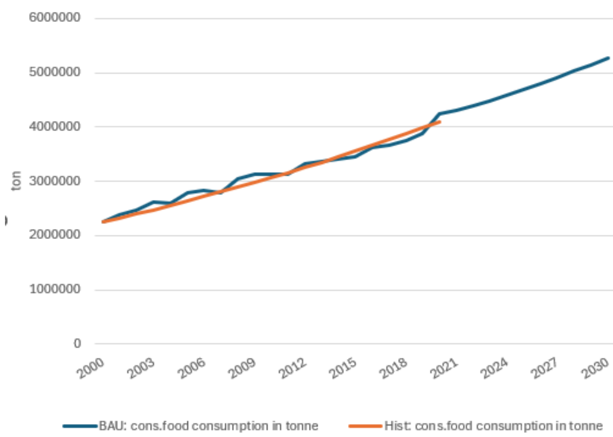

ton/year
BAU: pro.total fish production in tonnes
Hist: pro.total fish production in tonnes

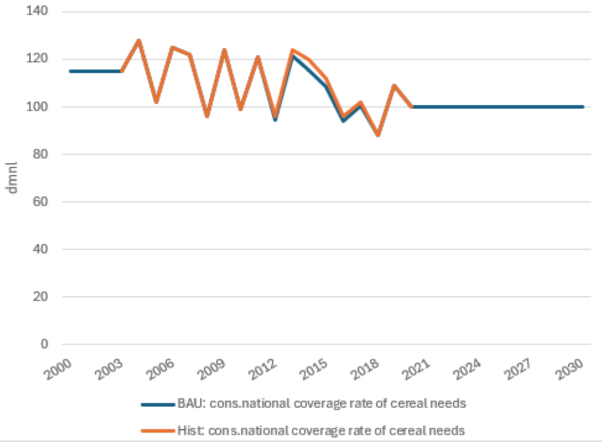

ton/year
BAU: pro.cereals production availability
Hist: pro.cereals production availability

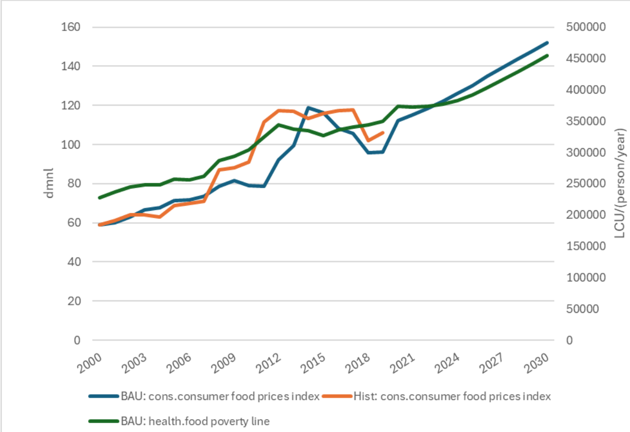

ton/year
BAU: transp.food transportation
BAU: distribution.food distribution
BAU: trade.net food trading

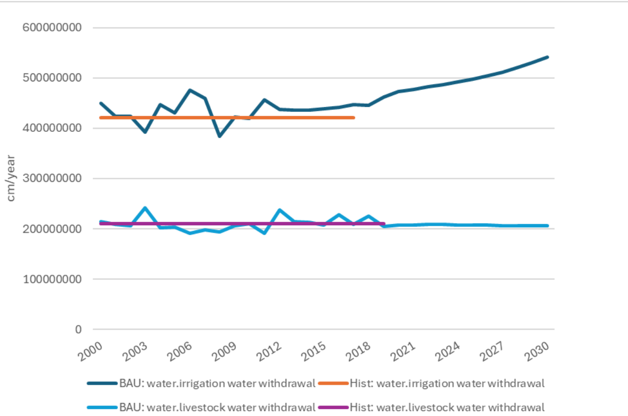

ton
BAU: stocks.final food stocks
Hist: stocks.final food stocks
BAU: stocks.initial food stocks
Hist: stocks.initial food stocks

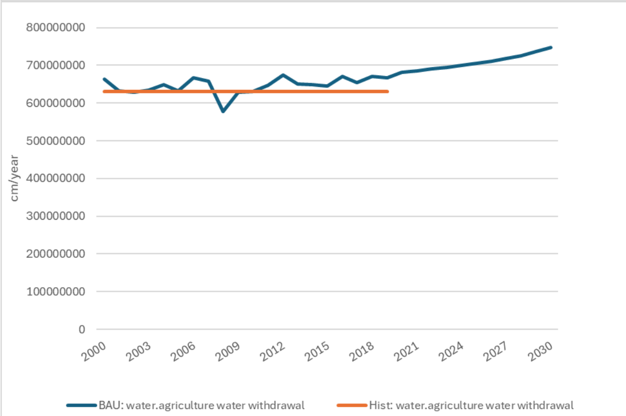

ton
BAU: proc.agri food proceed
Hist: proc.agri food proceed

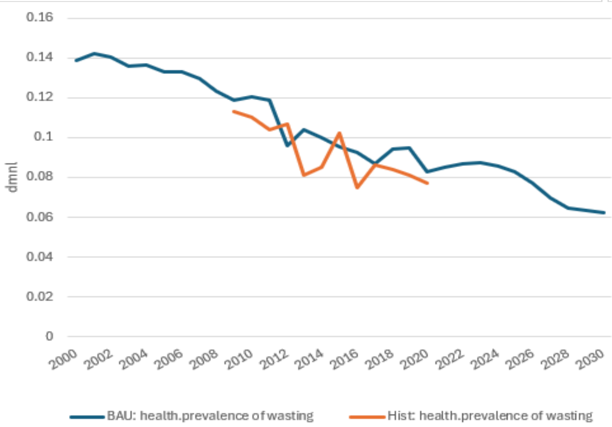

ton
BAU: cons.food consumption in tonne
Hist: cons.food consumption in tonne

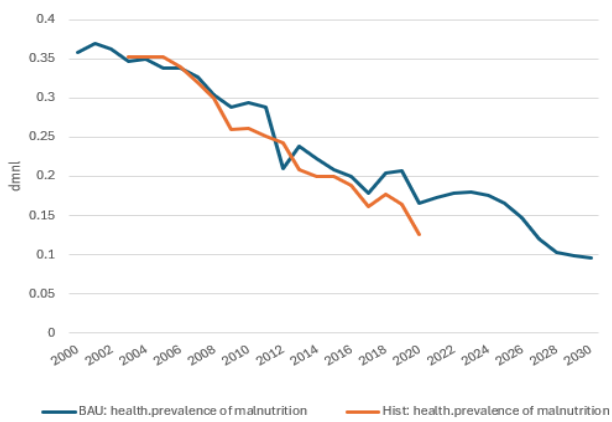

dmnl
BAU: cons.national coverage rate of cereal needs
Hist: cons.national coverage rate of cereal needs

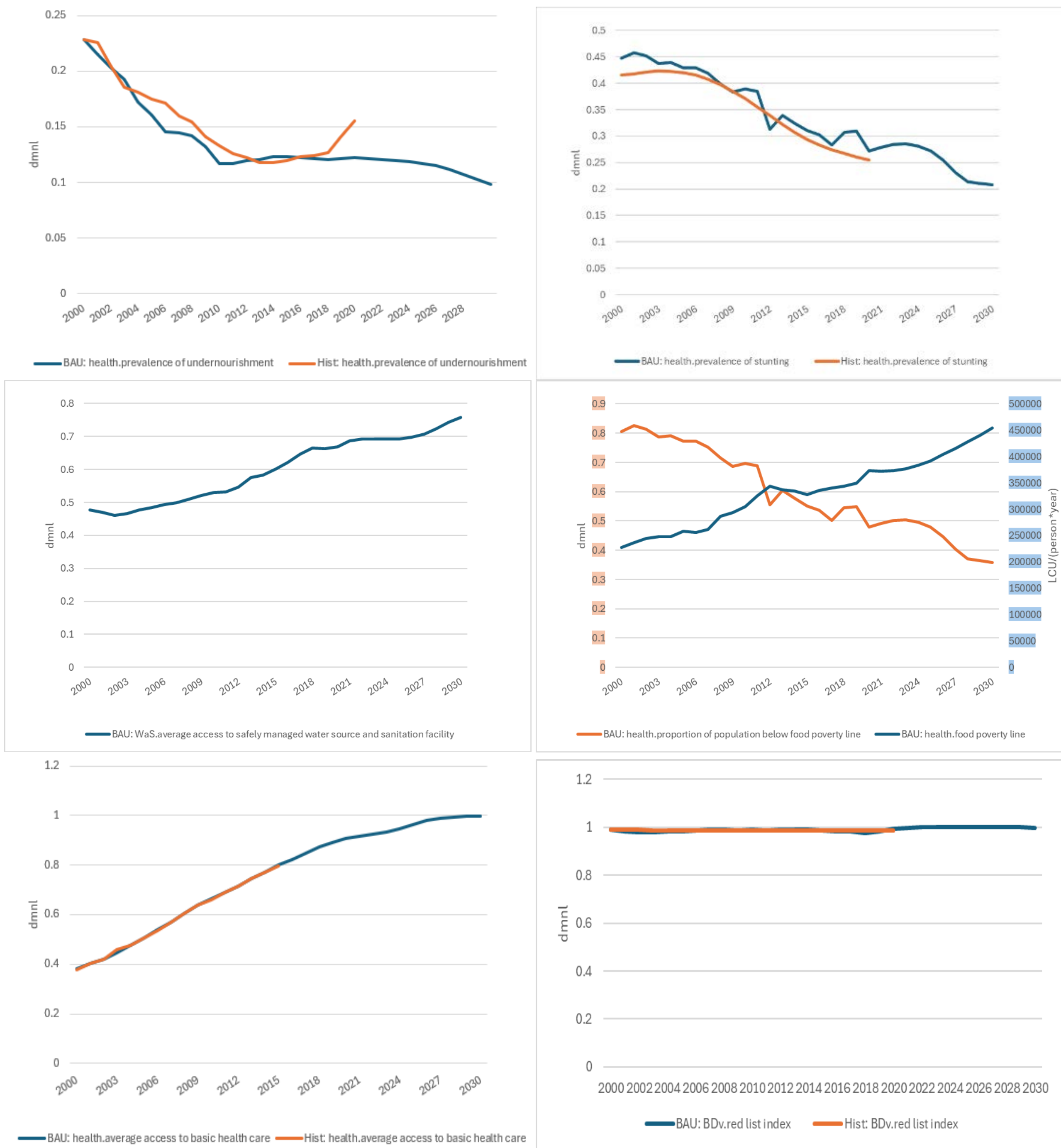

dmnl
LCU/(person/year)
BAU: cons.consumer food prices index
Hist: cons.consumer food prices index
BAU: health.food poverty line


cm/year
BAU: water.irrigation water withdrawal
Hist: water.irrigation water withdrawal
BAU: water.livestock water withdrawal
Hist: water.livestock water withdrawal


cm/year
BAU: water.agriculture water withdrawal
Hist: water.agriculture water withdrawal


dmnl
BAU: health.prevalence of wasting
Hist: health.prevalence of wasting


dmnl
BAU: health.prevalence of malnutrition
Hist: health.prevalence of malnutrition



Source: authors.

Figure 22. Historical and long-term trend for some variables of food security and nutrition.

performance indicators (KPI).

The model fit to historical data is validated by using the variable time series (historical data and simulations data) to calculate some five summary statistics to indicate calibration performance. They are R-Squared, Root Mean Square Percent Error, and the Theil Statistics for error decomposition that are used to measure goodness-of-fit of the model to historical behavior (Oliva, 2003). R-Squared

(R^2) or the coefficient of determination, in this case, compares the correlation between the simulated series and the historical series. It is measured between 0 and 1 and explains how much of the change in the dependent variable (historical) is explained by the independent variable (simulation). The RMSPE builds on the previous statistic, in that it indicates the percentage error between the historical and simulated values. In most cases, these statistics share an inverse relationship; the lower the RMPSE, then the higher the R^2. The error decomposition through the fraction of the mean-square-error (MSE) due to bias (U^M), unequal variance (U^S), and unequal covariance (U^C) shows the sources of error in the case where the model fails to fit the historical behavior (Sterman, 1984). Theil statistics are between 0 to 1 representing the percentage of residual error due to each source and when combined should sum to 1. In particular, UM describes the average difference between the simulation and history. If the error is large and most of the error lies in bias, it can indicate a systematic error to the model. U^S indicates the difference of variation around the mean of the time series and indicates how effectively the model tracks cycles in the data. While error in U^C measures how well the simulation matches trends point-by-point. Generally, if total error is low and observed error is concentrated in U^S and U^C, then the model tracks long term trends effectively, assuming a low U^M.

Statistics for the model validation

For the majority of variables, the RMSPE is below 0.2, except the agrifood processing in tonnes and the prevalence of overweight, that illustrates the model goodness of fit to the historical data or behavior. Concerning the agrifood processing in tonnes, the error is most related to unequal covariance between historical and simulated data (50%), so the model fails to match the simulation data to the historical data on a point-by-point basis. But the model tracks the long term trend of the variable ant that is attested by the fact the bias (Tbiais) is very low (7%). In the historical data, food proceed data is available between 2010-2020 and is in question because it fluctuates wildly around the simulated data. For the goodness of fit of the prevalence of overweight, the RMSPE is so high (0.393) meaning a systematic error of the model to fit the historical data as shown in the picture below. The error decomposition shows most of the error is due to the bias (68%) and the picture presents a rapid and sustained increase of the prevalence of overweight during the period 2000 to 2016.Then, the model fails to capture the fast growth of the variable and this problem is due to the fact that in the iSDG model, the reference overweight to income is set to a constant value. That setting cannot consider the dynamic of all factors which impact income in the Burkina Faso case (**Table 1**).

However, we have some non-available (NA) values of statistics for pasture land, irrigated water and livestocks withdrawal and fish resources availability share. For the variables pasture land, irrigated water and livestocks withdrawal, the R^2 is NA because the difference between the mean of these variables and their historical value is very close to zero meaning that they are seemingly constant during the period of study. Concerning fish resources availability share, its

Table 1. Statistics of fit.

Variables	N	R^2	RMSPE	Bias (U^M)	Variation (U^S)	Covariation (U^C)
Population by gender (male)	21	1.000	0.012	0.763	0.217	0.020
Population by gender (female)	21	1.000	0.020	0.581	0.404	0.015
Employment by sector (crops)	21	0.912	0.103	0.863	0.019	0.118
Employment by sector (livestocks)	21	0.023	0.089	0.000	0.288	0.712
Employment by sector (capture)	21	0.899	0.045	0.656	0.023	0.321
Employment by sector (aquaculture)	21	0.943	0.101	0.160	0.573	0.267
Employment by sector (forest)	21	0.808	0.082	0.336	0.494	0.169
Yield (cereals)	21	0.339	0.095	0.019	0.013	0.968
Yield (rest of cereals)	21	0.792	0.059	0.564	0.036	0.400
Crops production in tonnes (cereals)	21	0.654	0.132	0.004	0.005	0.990
Crops production in tonnes (rest of cereals)	21	0.957	0.098	0.447	0.248	0.305
Livestocks production in tonnes	21	0.952	0.057	0.468	0.003	0.530
Fish production in tonnes (capture)	21	0.956	0.103	0.405	0.113	0.482
Fish production in tonnes (aquaculture)	21	0.996	0.032	0.116	0.603	0.281
Forest production in cubic meters	21	0.990	0.021	0.000	0.101	0.899
Agriculture production in RLCU (crops)	21	0.832	0.103	0.009	0.015	0.977
Agriculture production in RLCU (livestocks)	21	0.902	0.057	0.438	0.036	0.526
Agriculture production in RLCU (capture)	21	0.765	0.098	0.415	0.028	0.556
Agriculture production in RLCU (aquaculture)	21	0.909	0.070	0.001	0.217	0.782
Agriculture production in RLCU (forest)	21	0.972	0.069	0.158	0.065	0.777
Agrifood food processing in tonnes	11	0.000	0.334	0.070	0.441	0.490
Food consumption in tonnes	21	0.972	0.036	0.255	0.014	0.731
Consumer food prices index	21	0.888	0.074	0.004	0.059	0.938
Gross national income	21	0.997	0.021	0.156	0.005	0.839
Real fc GDP	21	0.997	0.021	0.146	0.003	0.851
Forest land	21	0.999	0.002	0.000	0.560	0.440
Pasture land	21	NA	0.025	0.705	0.295	0.000
Arable land and permanent crops	21	0.719	0.076	0.024	0.053	0.922
Irrigated water withdrawal	21	NA	0.024	0.076	0.924	0.000
Livestocks water withdrawal	21	NA	0.056	0.165	0.835	0.000
Non energy agriculture emissions	21	0.960	0.049	0.540	0.000	0.460
Red list index	21	0.053	0.006	0.349	0.420	0.231
Fish resources availability share	21	NA	0.000	NA	NA	NA
Prevalence of undernourishment	21	0.948	0.069	0.497	0.003	0.500
Prevalence of stunting	21	0.715	0.106	0.073	0.007	0.920
Prevalence of wasting	12	0.021	0.161	0.027	0.241	0.732
Prevalence of overweight	17	0.474	0.393	0.678	0.304	0.018

Source: authors.

historical data is 1 during 2000-2020 and the simulation results returned also 1 to this period of simulation, thus the statistics of fit cannot be calculated.

5. Discussion

The simulation shows some interesting results of calibration for the mains steps of the FS such as food production variables, food consumption, consumer food prices index, national coverage rate of cereals, water withdrawal by irrigation and livestock and the total agriculture water withdrawal. Concerning food transport and food distribution, there is no available data that can guide and help us to validate the results of the simulation. It is for this reason that we have decided to classify these variables among the superficially modeled endogenous variables. However, the lack of data for a certain period in our database for food stocks and food processing made it difficult for the model to perfectly reproduce the historical trend of these variables. The lack of data constitutes some limits of the model, but this can be resolved through a deep and wide discussion with agricultural policymakers and other players who have a thorough understanding of the workings of Burkina's agricultural sector. This discussion would give us an idea of the food flows that are transported from production sites to distribution centers. This would help to readjust the parameters used to estimate the quantities of food flows transported and distributed. In terms of nutrition performances, the historical data show a decrease of the prevalence of undernourishment, stunting, wasting contrary to the prevalence of overweight of the total population that is increasing during the simulation period. But, between 2017-2019 there is a little divergence between the historical data trend and the simulation results that increase during this time before to degrowth after 2019 concerning the prevalence of nutrition, stunting and wasting. During the modeling and the calibration process, we have remarked that the robustness of the calibration and the model parameters estimation are linked to the historical data availability. So, the ability of the model could be performed with more data availability and the collection of more opinions with the agriculture policy makers about the FS elements where there is no available data. In terms of public policy implementation and action suggestions to improve food security and nutrition, the simulation results have shown that the increase in armed insurgencies by terrorists is a significant slowdown in the economic and social sectors particularly agriculture and livestock sectors. Next, the effect of climate change on crops yield is high and that is a reality in the fact that rainy seasons have become very short, increasing periods of drought, and temperatures are rising, leading to the disappearance of terrestrial resources. Also, the total factors productivity is very low in the food sector and that is counterproductive because more than 80% of the population is living through agricultural activities. So, the achievement of food security and a fair nutrition state require the transformation of the actual FS to a new sustainable food system that interconnects the different actors belong the food value chains, a good management of production factors and which the production of information and actions taking are focused on a shared and common goal of food security and sovereignty. Then, in the following table we list some leverage points (Meadows, 1999) on which the government can base and act. The more important things that we think it is important to maximize are farmers training and the supply of enhanced seeds to the farmers are a good way to face climate change hazards and to improve food productivity. After that, food production showed that the FS has the capacity to provide sufficient cereals and meat to cover national food needs. The food access problem is linked to a poor food distribution and exchange between Burkina Faso regions, and the fact that livestock production is geared towards sales on external markets, particularly cattle and not for self-consumption. That situation shows a less development of internal trade between regions and a poor infrastructure available to facilitate trade. In that case, the government must work to build a transportation network to encourage and simplify internal trade. Other limits of the FS are the difficulties of credit access by the food actors (from production to consumption) and the support of subsistence crops by the government is less in favor of cash crops. In that case we suggest connecting the financial system to the agriculture system for the purpose of shifting more private investment toward agriculture sectors by facilitating credit access and the guarantee of investment. Finally, nutrition problems are linked to insufficient energy intake of the dietary and the low diversity of cultures. By referring to the food poverty line estimated by the model, we see that the revenue per capita from the agriculture sector is lower than the food poverty line meaning that the agricultural population who doesn't have other sources of income has some difficulties to acquire food in quantity and quality, especially nutrient-rich meat and processed foods that are expensive. Here, food diversification is important to address this problem through many actions like government expenditure to support family farming, the development of agrifood transformation and the cultures diversification toward vegetables and fruits.

Through the leverage points in **Table 2**, we have built a policy strategy or scenario that is setting on the future value of some agriculture sector policy variables such as reforestation, food actors training, fertilizers subsidies, irrigation water efficiency, general transfers into the agriculture sector to improve total factors productivity and social transfers to reduce inequalities and improve food access. Also, we judge that the infrastructure sector such as paved and unpaved roads is important to improve the performance of total factors productivity in agriculture, food distribution and transport contributing to enhance food access and production. So, the policy intervention simulation period starts from 2020 to 2030 to cover the UN Agenda of SDGs time and we compare this scenario of policy to the Business As Usual (BAU). In the BAU scenario, it is assumed that there will be no agricultural policy changes after 2020 and the previously existing policies will continue until 2030. The alternative scenario provides an assessment of policy measures that might perform agriculture indicators and other related sectors.

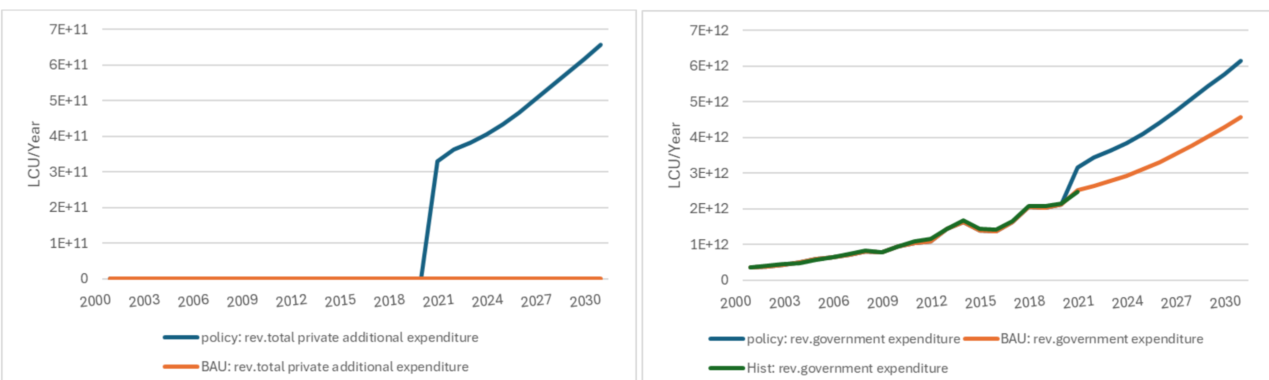
Table 2. Leverage points for food system.

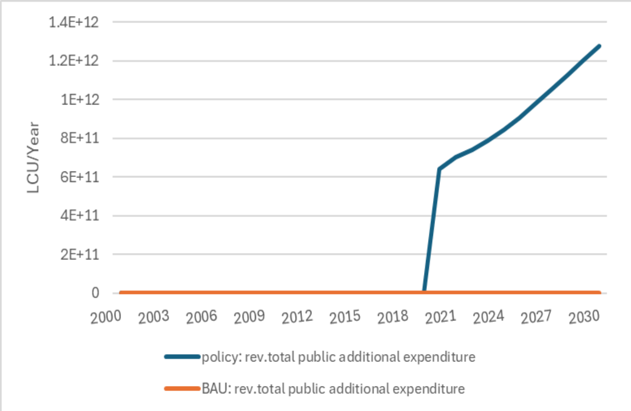
Constants, parameters, numbers	The sizes of buffers and other stabilizing stocks	The structure of material stocks and flows	The lengths of delays	The strength of negative feedback loops	The gain around driving positive feedback loops	The structure of information flows	The rules of the system	The power to add, change, evolve, or self organize system structure	The goals of the system	The mindset or paradigm	The power to transcend paradigms
- increase public spending share in agriculture sector - agriculture investment to increase agriculture capital and reduce capital depreciation - farmer training through participatory learning and knowledge management strategies concerning resources uses and agriculture practices - female labor valorization and participation in the food value chains - increase irrigated land to cope with long-term rainfall decline - subsidy intrants production particularly	- national poverty reduction - reduction of population growth - reduction of rural young migration to cities and traditional gold mining - material and infrastructure to reduce food losses during the harvest, transport and storage - development of agri-food sector to increase agrifood production - reforestation programmes for degraded land restoration	- land use to reduce agriculture land lossing - food storage network to cover all the country - reduce territorial inequality through the valorization of local potential and investments - the configuration or restructuring of a road network enabling and facilitating exchanges between the country's different regions to reduce regional disparities and increase markets access for farmers	- reduce crops growth time to face with short rainy periods through the production of improved seeds - increase water retention period of dams for off-season crops and irrigation - reduce administrative procedures for agribusiness creatives and agricultural policy implementa-	- reduce pesticides and fertilizers use to avoid soil depletion and water pollution in the long term by reducing chemical fertilizers and pesticides imports and subsidies - reduce the impact of agriculture land degradation on forest land through a sustainable use of land	- improve organic fertilizers use - raising awareness about the effects of good nutrition on health - TFP increase to boost food and agri-food production in the long term and to reduce harvested land expansion - agriculture labor force sustainable management to avoid rural migration	- climate change, and sustainable agriculture practices information availability for food actors (food prices, temperatures, precipitation,...) - review government support for regional agricultural policies and between crops to avoid regional disparities and the disappearance of family farming - set up producer-buyer-exporter relationship programmes to oblige the seller and exporter to participate in the process of food production, product quality assurance, training and technical support for the farmer, management of land, inputs, etc., and purchase of	- landlord to avoid speculation - food trade rules oriented towards local goods consumption and production - set up and strengthen agricultural and environmental regulations, and adapt them to counter gold-panning, land occupation (farmers and breeders), industrial pollution, poor-quality pesticides and conflicts. It can help to avoid the tragedy of the commons particularly pasture land. - in Burkina, the impact of mining activities on agricultural activities and water resources is remarkable, through the occupation of land and the use of chemicals such as cyanide to extract gold. This contributes to soil impoverishment and the	- connect banking system to FS to improve credit access - Build a strong interconnection between FS steps - collaboration and strong interactions between farmers and policymakers to adapt agriculture policy to the FS reality - most government technical support towards food systems organizations (producer, transformer, training, distributors, …) for a good understanding and implementation of food policy - more connection of international and regional food system to increase markets access to national food actors and to stabilize food prices with food importations and exportations - connect the FS to education system with strengthening research and	- self sufficiency food towards food security and further food sovereignty	- shifting from subsistence agriculture in which agriculture revenue is low towards a modern sustainable food system by reducing informal activities in the food value chains - diversifying livelihoods of rural population outside primary production with processing activities, storage and distribution capacities - short-term laboring work programmes and counter season cultures to face lean	- revolution of agriculture practices towards agroecology practices (cultures diversification and combination for example rice and fish farming to optimize water), short-circuits to give a power to local producers, preserve natural resources and preserve food prices increasing - adopting an geographical and territorial integrated approach to valorize regional potentialities - actors participation in agriculture poli-

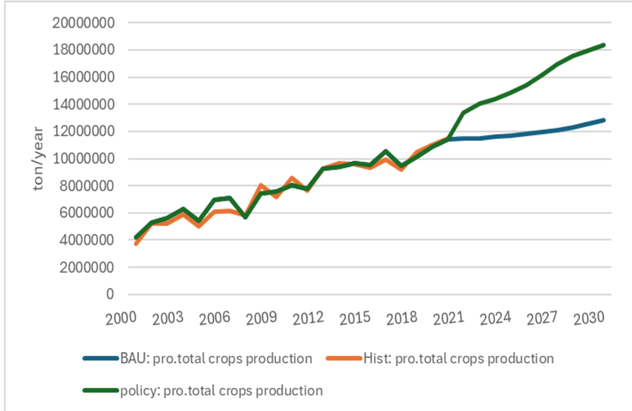
organic fertilizers, livestocks food and drinking water - increase SONAGESS food stores and school canteen - reduce taxes on food activities - reduce interest rates for agriculture credits	tion	the product at a predefined price interval. The farmer also undertakes to respect the delivery schedule, the product quality and the set price. This reduces market access risks and losses for all parties involved, and contributes to job protection and the development of local communities.	reduction of agricultural land, which in turn reduces soil fertility. This leads farmers to use more chemical fertilizers to increase their production. A strategy of sanctions and rules therefore needs to be found to counter the expansion of traditional gold panning and also to prevent the use of cyanide.	innovation focused on local value chains and the dissemination of knowledge - decoupling the crop sector from the cash crop sector so that funding does not depend on the profitability performance of each sector in the government budget. - connect the FS to the energy system to reduce biomass use through gas and solar cooking strategies	season for rural population	cy elaboration and implementation

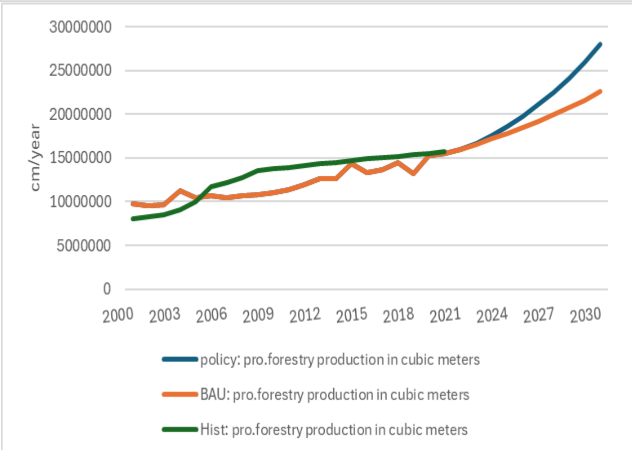
Source: authors.

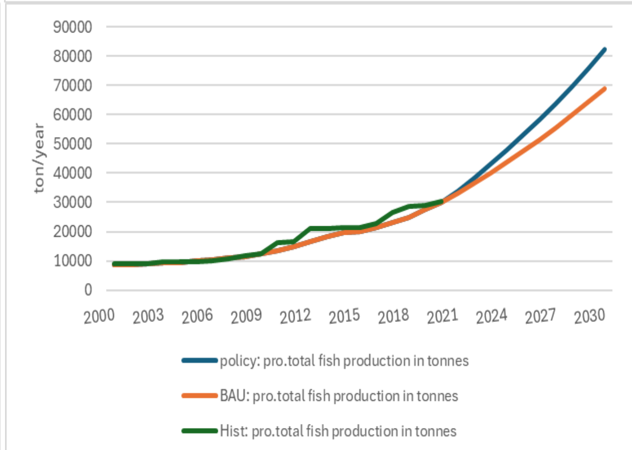
To assess these policies' impacts we made some assumptions. Given the importance of the agriculture, land, and the infrastructure and poverty sectors to influence the FS performances, we assume a further increase in spending as a percentage of GDP to 4.5%, 0.5%, 2% and 3% respectively. Nowadays, the participation of private investment is very low in the agriculture sector and roads construction. In that case, we assume a substantial engagement of the private sector to reduce the government expenditure from 100% to 50% in the agriculture and roads expenditures. The alternative scenario of policy interventions supposes changes in expenditures level on future development and can be helpful to simulate a SDGs or other objectives of development cost policies scenario which uses some policy variable settings. The following graphics (Figure 23)

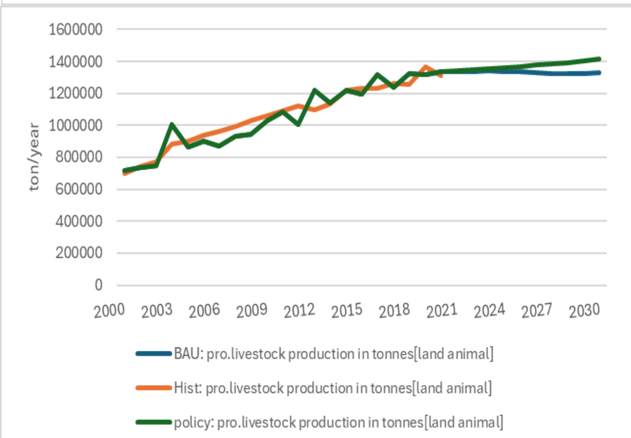


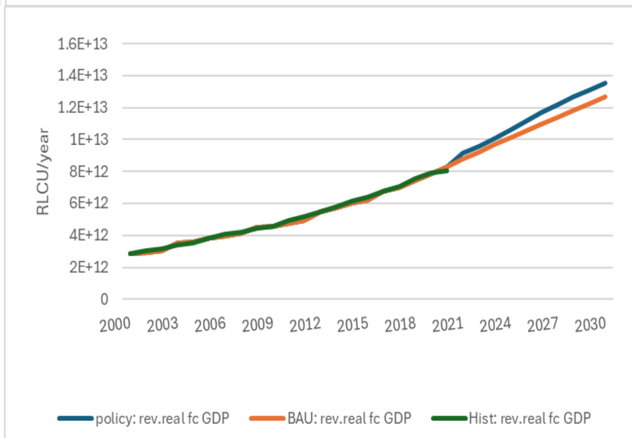

LCU/Year
1.4E+12
1.2E+12
1E+12
8E+11
6E+11
4E+11
2E+11
0
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
policy: rev.total public additional expenditure
BAU: rev.total public additional expenditure

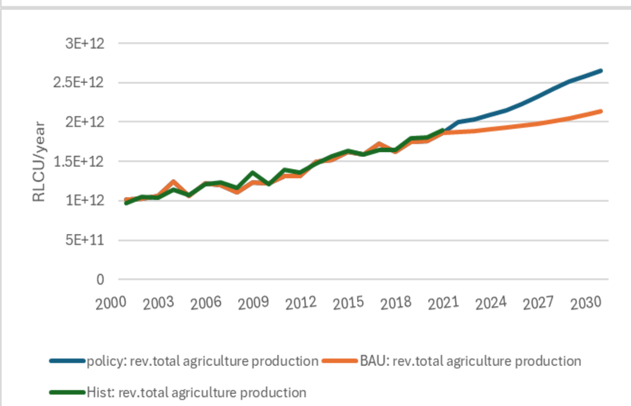

ton/year
20000000
18000000
16000000
14000000
12000000
10000000
8000000
6000000
4000000
2000000
0
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
BAU: pro.total crops production
Hist: pro.total crops production
policy: pro.total crops production

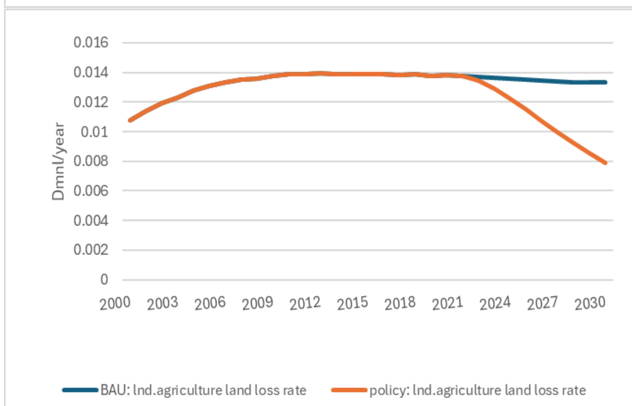

cm/year
30000000
25000000
20000000
15000000
10000000
5000000
0
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
policy: pro.forestry production in cubic meters
BAU: pro.forestry production in cubic meters
Hist: pro.forestry production in cubic meters

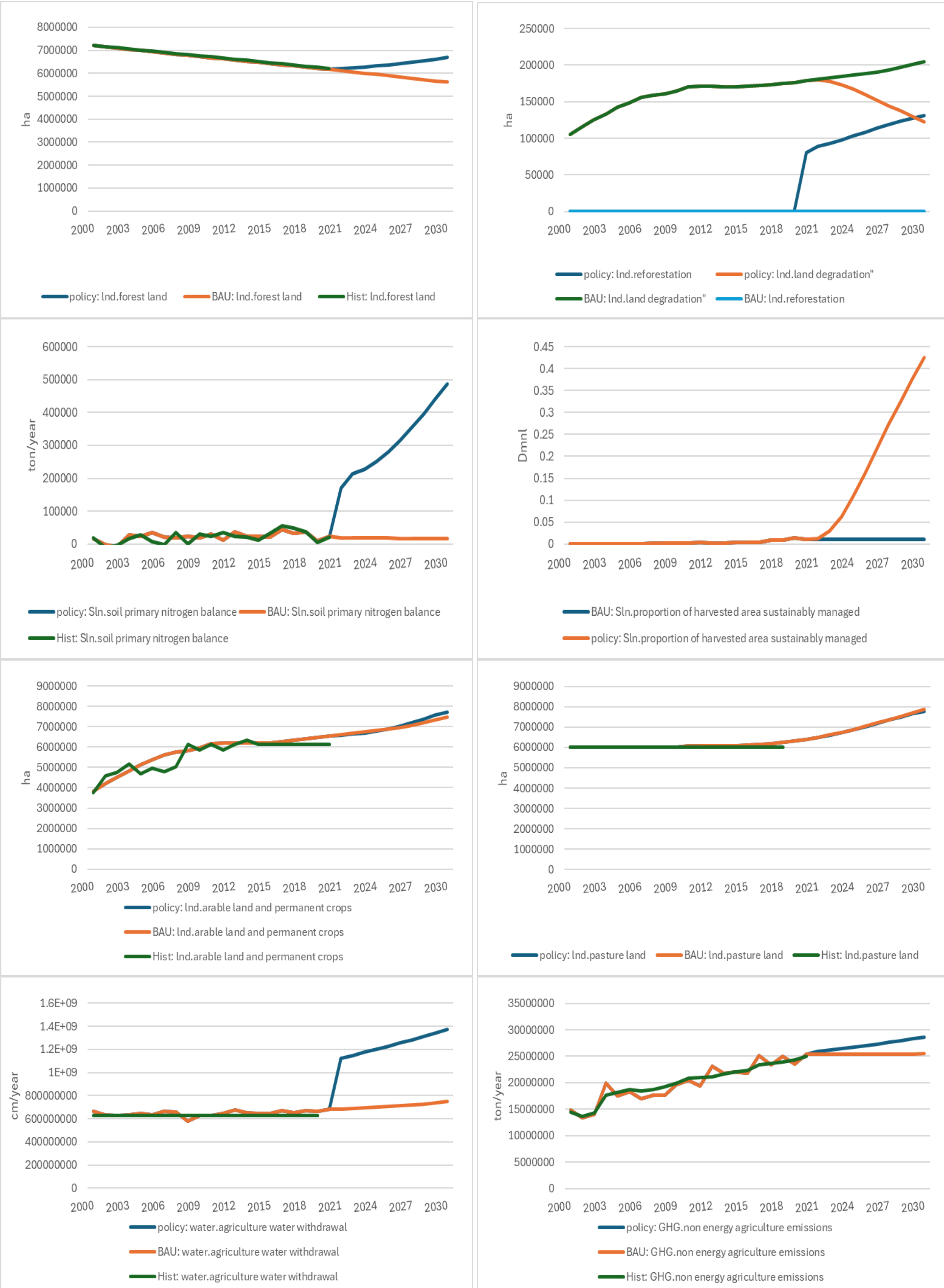

ton/year
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
policy: pro.total fish production in tonnes
BAU: pro.total fish production in tonnes
Hist: pro.total fish production in tonnes

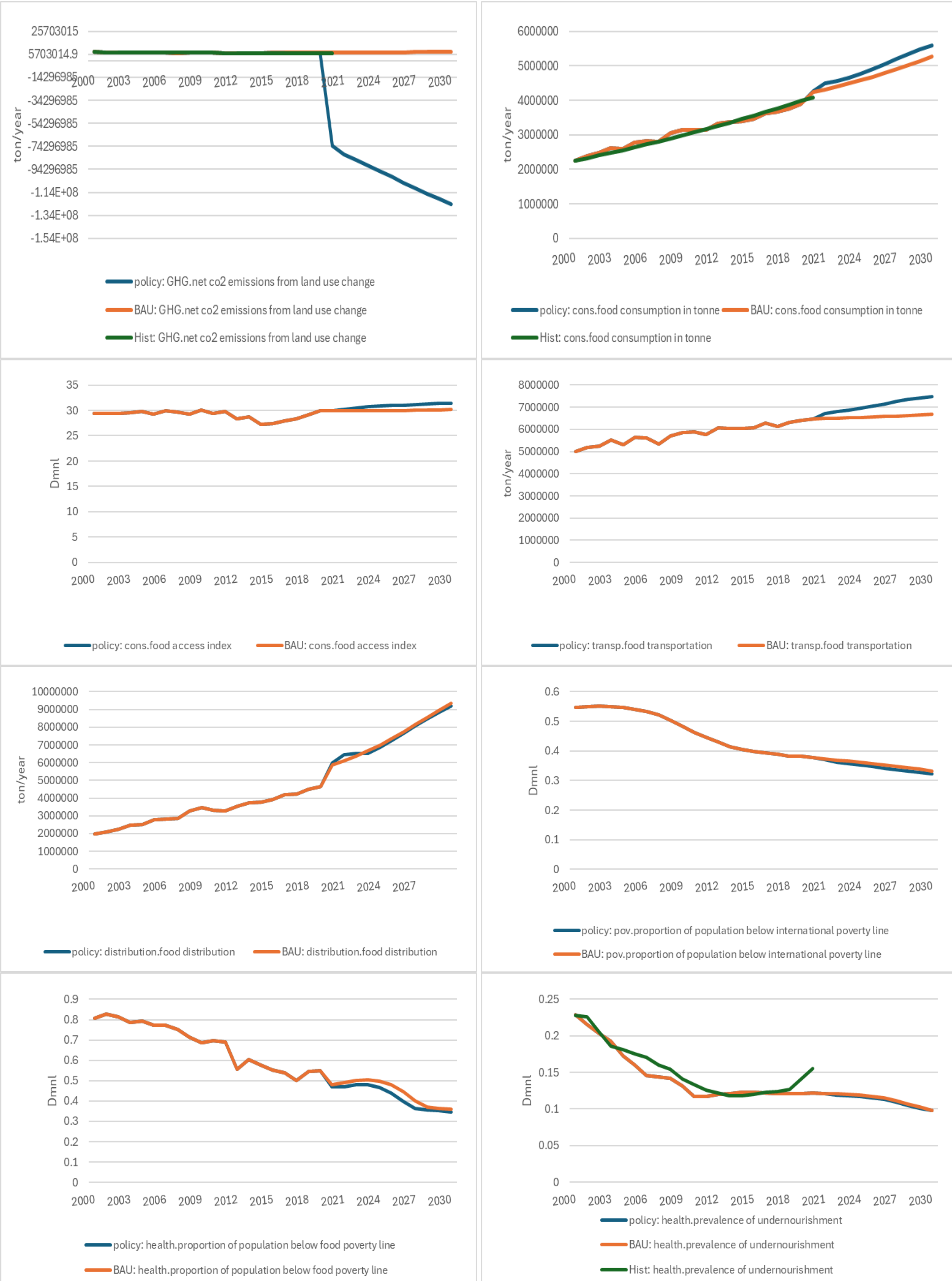

ton/year
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
BAU: pro.livestock production in tonnes[land animal]
Hist: pro.livestock production in tonnes[land animal]
policy: pro.livestock production in tonnes[land animal]

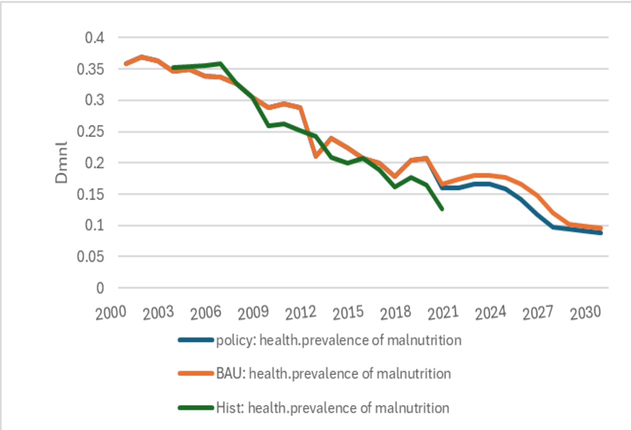

RLCU/year
1.6E+13
1.4E+13
1.2E+13
1E+13
8E+12
6E+12
4E+12
2E+12
0
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
policy: rev.real fc GDP
BAU: rev.real fc GDP
Hist: rev.real fc GDP

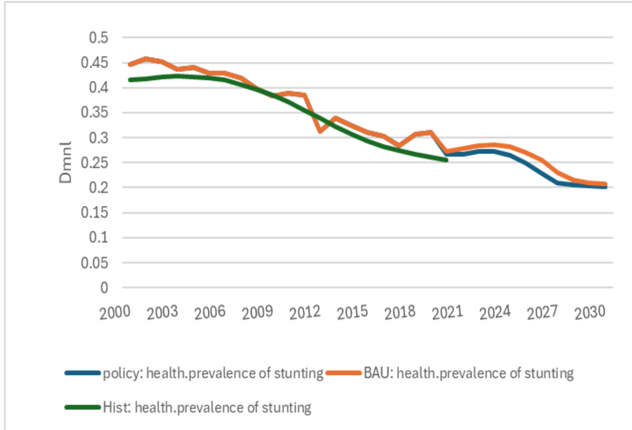

RLCU/year
3E+12
2.5E+12
2E+12
1.5E+12
1E+12
5E+11
0
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
policy: rev.total agriculture production
BAU: rev.total agriculture production
Hist: rev.total agriculture production

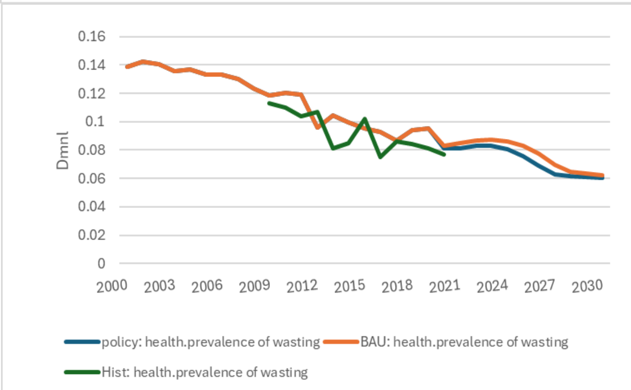

Dmnl/year
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
BAU: lnd.agriculture land loss rate
policy: lnd.agriculture land loss rate

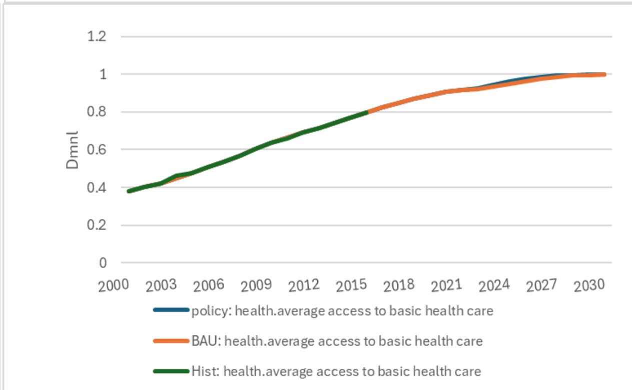

ha
policy: lnd.forest land
BAU: lnd.forest land
Hist: lnd.forest land
ha
policy: lnd.reforestation
policy: lnd.land degradation"
BAU: lnd.land degradation"
BAU: lnd.reforestation
ton/year
policy: Sln.soil primary nitrogen balance
BAU: Sln.soil primary nitrogen balance
Hist: Sln.soil primary nitrogen balance
Dmnl
BAU: Sln.proportion of harvested area sustainably managed
policy: Sln.proportion of harvested area sustainably managed
ha
policy: lnd.arable land and permanent crops
BAU: lnd.arable land and permanent crops
Hist: lnd.arable land and permanent crops
ha
policy: lnd.pasture land
BAU: lnd.pasture land
Hist: lnd.pasture land
cm/year
policy: water.agriculture water withdrawal
BAU: water.agriculture water withdrawal
Hist: water.agriculture water withdrawal
ton/year
policy: GHG.non energy agriculture emissions
BAU: GHG.non energy agriculture emissions
Hist: GHG.non energy agriculture emissions

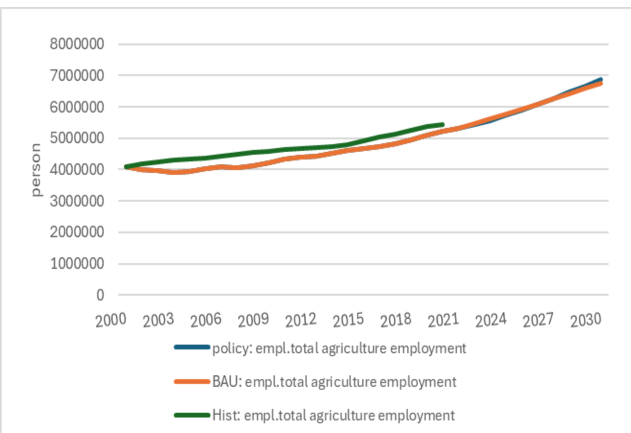

ton/year
policy: GHG.net co2 emissions from land use change
BAU: GHG.net co2 emissions from land use change
Hist: GHG.net co2 emissions from land use change
ton/year
policy: cons.food consumption in tonne
BAU: cons.food consumption in tonne
Hist: cons.food consumption in tonne
Dmnl
policy: cons.food access index
BAU: cons.food access index
ton/year
policy: transp.food transportation
BAU: transp.food transportation
ton/year
policy: distribution.food distribution
BAU: distribution.food distribution
Dmnl
policy: pov.proportion of population below international poverty line
BAU: pov.proportion of population below international poverty line
Dmnl
policy: health.proportion of population below food poverty line
BAU: health.proportion of population below food poverty line
Dmnl
policy: health.prevalence of undernourishment
BAU: health.prevalence of undernourishment
Hist: health.prevalence of undernourishment


Dmnl
policy: health.prevalence of malnutrition
BAU: health.prevalence of malnutrition
Hist: health.prevalence of malnutrition

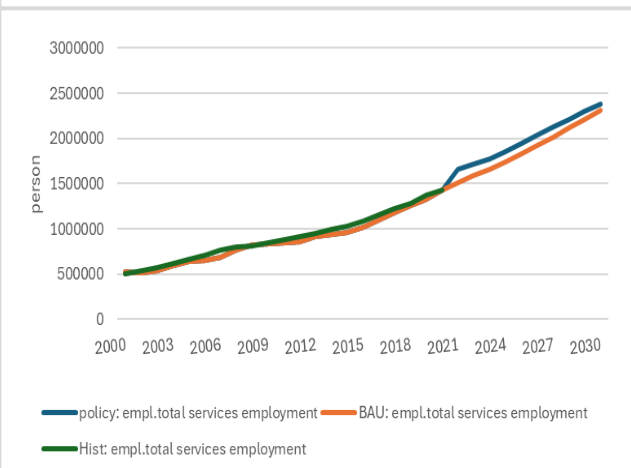

Dmnl
policy: health.prevalence of stunting
BAU: health.prevalence of stunting
Hist: health.prevalence of stunting

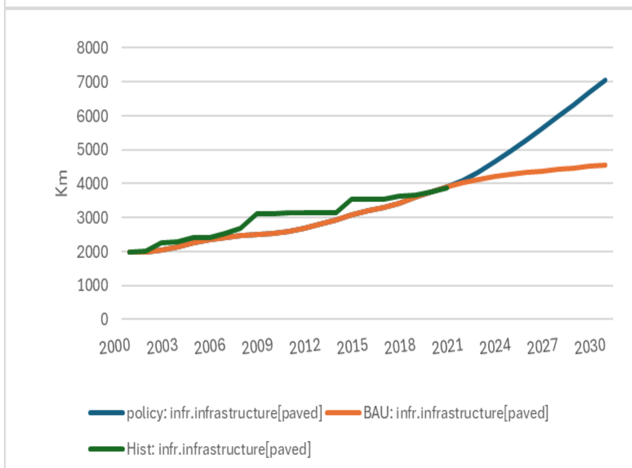

Dmnl
policy: health.prevalence of wasting
BAU: health.prevalence of wasting
Hist: health.prevalence of wasting

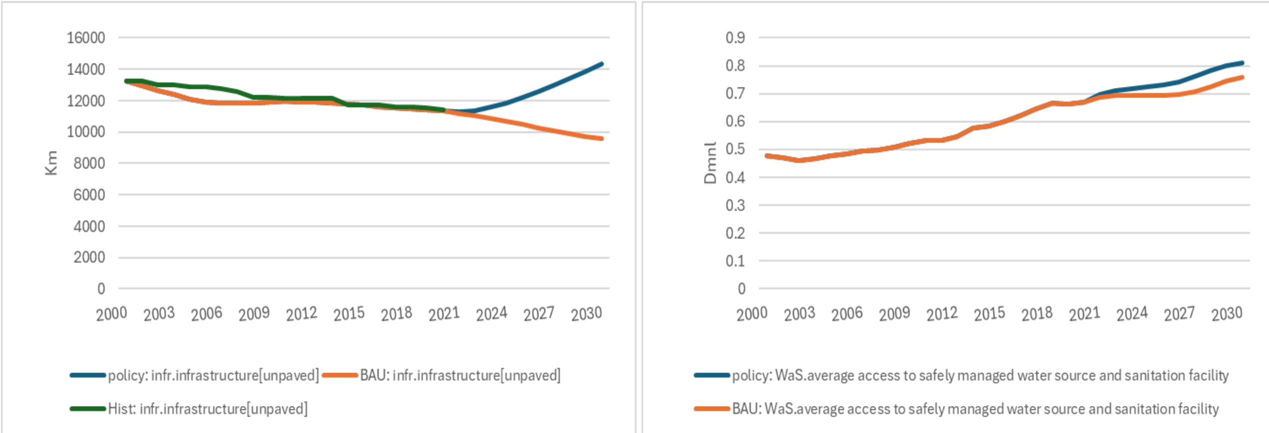

Dmnl
policy: health.average access to basic health care
BAU: health.average access to basic health care
Hist: health.average access to basic health care


person
policy: empl.total agriculture employment
BAU: empl.total agriculture employment
Hist: empl.total agriculture employment


person
policy: empl.total industry employment
BAU: empl.total industry employment
Hist: empl.total industry employment


person
policy: empl.total services employment
BAU: empl.total services employment
Hist: empl.total services employment


Km
policy: infr.infrastructure[paved]
BAU: infr.infrastructure[paved]
Hist: infr.infrastructure[paved]



Source: authors.

Figure 23. Simulations results for scenarios.

show the simulation results of the BAU scenario compared to those of the alternative scenarios for some main variables. The alternative scenario named agri_policy_scenario shows some interesting and hopeful results than the BAU simulation results following the strategic policy intervention.

6. Conclusion

In this paper, we have studied and built a FS simulation tool based on the Burkina Faso FS through the conceptual framework developed by FAO (David-Benz et al., 2022) and the iSDG model of the MI. The FAO model details the different elements that compose the FS notably the drivers and the different stages of the FS. By using the iSDG model we have completed the agriculture sector that concerned only the food production step by developing the other steps of food transportation, processing, distribution, stocks and consumption. By using System dynamics, which is a medium and long-term method, we have simulated the historical trend of some food like food production, consumption, stocks, … Also, some nutrition indicators such as the prevalence of undernourishment, malnutrition, stunting, wasting, ... and finally, some drivers that influence the food system such as land, GDP, agriculture investment and expenditures, agriculture capital, biodiversity, agriculture water withdrawal or availability (Nyamekye et al., 2018), infrastructure, employment, ... for the period 2000 to 2020. The modeling results show that there are strong interactions in and out the FS meaning that the intervention of one actor has some impacts on the actions of other actors. So, public policy implementation in the agricultural or nonagricultural sector influences the food system's performance. It means that the SDG 2 is interconnected to many other SDGs and the improvement or the deterioration of one or many other SDGs has some impact on its performance. These interconnections can be more explored and discussed in our upcoming research. In terms of calibration, the model manages to reproduce the trend of some food variables like the quantity of food produced in tonnes in Real Local Currency Unit

(RLCU), GDP, agriculture sector added value, nutrition indicators also some driver's trend. We used the statistics of fit such as R-Squared, Root Mean Square Percent Error, and the Theil Statistics for error decomposition to measure the ability of the model to reproduce the long-term trend of the Key Performance Indicators of the food system. Regarding the goodness-of-fit statistics, the model performs well overall and shows a strong and close relationship between the simulated and historical time series. In terms of policy intervention, the model is able to assess well public policy impacts on various sectors through the interrelated variables. The results of the alternative scenario we have developed prove the model's ability to do this and can be used to develop synergistic policies to achieve effective results and reduce public expenditure. Regarding the complexity of the methodology, the application of the paper recommendations necessitates some discussions with the government in the way to simplify the use of the model and to give background in SD modeling to some policymakers in the model using. However, the model has limits due to some data consistency issues causing outliers in the error levels and the unavailability of data for certain variables makes it difficult to make the model more robust. Firstly, for the variables that data do not exist such as food transported and distribution, we cannot validate the results of the simulation. Secondly, some variables like agrifood processing, food stocks have available data during a limited time and don't cover the entire period 2000-2020, and in that case also the model has difficulties in properly adjusting the historical trends of these variables. To overcome these limitations, a discussion is recommended between stakeholders in Burkina Faso's agricultural sector to determine if the results could reflect as well as possible such variable trends. Otherwise, the discussion could allow us to properly recalibrate the model through the optimization of the parameters or to review the structure and some goals of the whole model. Another limit is the fact that the time frame of our historical data is limited to 2020. This means that we do not compare the model's projections with the real post-covid-19 impacts as well as those of terrorism and global geopolitics. But in implementing the model with political decision-makers we intend to take these impacts into account and judge the capacity of the model to be able to evaluate these impacts.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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