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iSDG model For Burkina Faso

From National Food security to local food community

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Abstract

In the context of a profound transformation of the world, marked by the crossing of planetary boundaries and the scarcity of financial resources, achieving the United Nations Agenda 2030 requires massive investments in most sectors for developing countries. In particular, the desire for a sustainable food sector capable of contributing to the fight against climate change, unemployment, poverty, hunger, etc. is a necessity for these countries. In this quest for sustainable systems, the implementation of effective and synergistic public policies is now of paramount importance for governments that have to meet the expectations of their populations. This thesis examines the models used by certain international institutions to assess the impact of public policies in developing countries. We then propose a dynamic model to help these countries build sustainable food systems.

Chapter 1 introduces the basics of systems dynamics, recalling the work of Forrester and Meadows with the Industrial Dynamics and Limits to Growth reports of the 1960s and 1970s. It also describes the Millennium Institute's iSDG model, which uses system dynamics. The results show that the iSDG model is an effective tool for assessing the impact of public policies in multiple scenarios on achieving the SDGs, estimating the budget for each scenario, and guiding policymakers towards concrete, achievable targets.

Chapter 2 presents a benchmarking analysis of the Millennium Institute's iSDG model, which is based on system dynamics, with certain dynamic models, such as the dynamic stochastic

general equilibrium model, the World Bank's long-term growth model, and the AFD's stock-flow consistent prototype growth model. The aim is to analyse the structure of each model in terms of the SDG indicators consideration, as well as the place of GDP in each model. The study shows that the DSGE, LTGM and SFCP-GM are predictive models that try to identify the transmission channels of economic shocks. However, they do not take into account interactions between variables, except the AFD's SFCP-GM, which is based on an accounting balance sheet of economic agents' assets. Secondly, unlike the iSDG model, these three models do not take into account the sustainability of economic systems.

Chapter 3 takes a prospective approach to the analysis of the SDGs, translating them into planetary limits using the iSDG model through strong and weak interactions of their indicators. The scarcity of financial and natural resources, and the environmental scourges facing the planet today, limit the possibility or not of achieving these goals by 2030. This illustration teaches us that humanity must reduce its environmental footprint and that any public policy aimed at improving well-being must take into account the limits imposed on humanity by nature. Hence the importance of strategic planning for sustainable development.

Chapter 4 presents the modeling of a food system using Burkina Faso as an example. The study shows that this system interacts with several others in the governance, economic, social and environmental spheres, whether at local, national or regional level. The simulation results for Burkina Faso show that the country's food and nutrition situation is deteriorating and that urgent public policies are needed to reverse the trend. These include tackling insecurity, developing road and irrigation infrastructure, training farmers and increasing women's participation in the labour market.

Keywords: *iSDG, Systems Thinking, Systems Dynamics, T21, Sustainable Development Goals assessment tools, GDP, Public Policy modeling in developing countries, Causal Loop Diagram, Stock and Flow Diagram, Burkina Faso, Food Security, Sustainability.*

Résumé

Dans un contexte de transformation profonde du monde marqué par la transgression des limites planétaires et la rareté des financements, alors que l'atteinte de l'Agenda 2030 des Nations Unies requiert des investissements massifs dans la plupart des secteurs pour les pays en développement. En particulier, le souhait d'un secteur alimentaire durable, capable de contribuer à la lutte contre le changement climatique, au chômage, à la pauvreté, à la faim, etc., est une nécessité pour ces pays. Dans cette quête de systèmes durables, la mise en place de politiques publiques efficaces et synergiques est aujourd'hui d'une importance capitale pour les gouvernements, qui doivent répondre aux attentes de leurs populations. Cette thèse étudie les modèles utilisés par certaines institutions internationales pour évaluer les impacts des politiques publiques dans les pays en développement. Nous proposons ensuite un modèle dynamique qui permettrait d'aider ces pays à bâtir des systèmes alimentaires durables.

Le chapitre 1 présente les fondements de la dynamique des systèmes, en évoquant les travaux de Forrester et Meadows avec les rapports Industrial Dynamics et Limits to Growth des années 60 et 70. Il décrit également le modèle iSDG du Millennium Institute, qui utilise la dynamique des systèmes. Les résultats montrent que le modèle iSDG est un outil efficace pour évaluer l'impact des politiques publiques dans de multiples scénarios sur la réalisation des ODD, estimer le budget pour chaque scénario et guider les décideurs politiques vers des objectifs concrets et réalisables.

Le chapitre 2 présente une analyse comparative du modèle iSDG du Millennium Institute basé sur la dynamique des systèmes, avec certains modèles dynamiques tels que le modèle d'équilibre général dynamique et stochastique, le modèle de croissance à long terme de la Banque Mondiale, le modèle Stock-Flow consistent Prototype Growth Model de l'AFD. L'objectif est d'analyser la structure de chaque modèle à considérer les indicateurs des ODD ainsi que la place du PIB dans chacun d'entre eux. L'étude montre que le DSGE, le LTGM et le SFCP-GM sont des modèles prédictifs cherchant à déterminer les canaux de transmission des chocs économiques. Cependant, ils ne prennent pas en compte les interactions entre les variables, à l'exception du SFCP-GM de l'AFD, qui est basé sur un bilan comptable des patrimoines des agents économiques. Ensuite, ces trois modèles ne s'intéressent pas à la durabilité des systèmes économiques, contrairement au modèle iSDG.

Le chapitre 3 adopte une approche prospective de l'analyse des ODD en les traduisant en limites planétaires avec le modèle iSDG à travers des interactions fortes et faibles de leurs indicateurs. La rareté des ressources financières et naturelles et les fléaux environnementaux auxquels la planète est confrontée aujourd'hui limitent la possibilité d'atteindre ou non ces objectifs d'ici à 2030. Cette représentation nous apprend que l'humanité doit réduire son empreinte environnementale, et que toute politique publique visant à améliorer le bien-être doit prendre en compte les limites imposées à l'humanité par la nature. D'où l'importance de la planification stratégique du développement durable.

Le chapitre 4 présente la modélisation d'un système alimentaire, à travers l'exemple du Burkina Faso. L'étude montre que ce système interagit avec plusieurs autres des domaines de la

gouvernance, de l'économie, du social et de l'environnement, que ce soit au niveau local, national ou régional. Les résultats des simulations pour le cas du Burkina Faso montrent que la situation alimentaire et nutritionnelle du pays se détériore et qu'il est donc nécessaire de mettre en place des politiques publiques urgentes pour inverser la tendance. Cela passe notamment par la lutte contre l'insécurité, le développement des infrastructures routières et d'irrigation, la formation des agriculteurs et l'augmentation de la participation des femmes au marché du travail.

Mots clés : *iSDG, pensée systémique, dynamique des systèmes, T21, outils d'évaluation des objectifs de développement durable, PIB, modélisation des politiques publiques dans les pays en développement, diagramme en boucle causale, diagramme des stocks et des flux, Burkina Faso, sécurité alimentaire, durabilité.*

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General Introduction

In a paper prepared for the INET Annual Plenary Conference in Berlin (2012) and entitled *Towards an Ecological Macroeconomics*, Peter Victor and Tim Jackson considered that three major crises are confronting the world. The first is the increasing and uneven burden of humans on the biosphere (illustrated by the concept of planet boundaries, (Rockström et al., 2009)). The second is the astonishingly uneven distribution of economic inputs (illustrated by the rise of inequalities in the world, (Cohen et al., 2002), the economics of rising inequalities). The third is the instability of the global financial system (illustrated by the subprime crisis in 2007-2008, (Mishkin, 2011). These three major crises (ecological, social, and economic) are complex and interrelated, they have consequences on population migration, biodiversity degradation, political instability, increasing poverty, food insecurity, … across the world.

From the Covid-19 health crisis in 2020 to the current war in Ukraine, we have seen that today's economies are highly interconnected. These crises showed not only that countries' economies are interconnected and influence each other. But also, between countries' economies and the natural resources and society. Meaning that countries' wealth (financial capital) is obtained from the transformation of natural resources (natural capital) using labour (social capital). So, this proves that the three domains of environment, social, and economy are interrelated, and human actions and shock occurrences are determinants of the environment quality, natural resources extraction, social and cultural balance, wealth creation and sharing between populations, and the flows of trade between countries. The two crises mentioned above have had some impacts on all countries but developing countries have heavily supported the burden in terms of economics, social and environmental consequences the fact they are strongly dependent on the international market and financial stability (Balineau et al., 2021). Also, it is recognized by international institutions such as the UN, UNDP, FAO, … that the three domains of sustainable development on which the 17 SDGs are based are interconnected and some authors go so far as to say that certain SDGs are indivisible (McCollum et al., 2018). The degree of SDGs integration means that they are interdependent, so an improvement or deterioration in the performance of one SDG has positive or negative consequences for the performance of other SDGs. Furthermore, the policies adopted to improve the achievement of this SDG reinforce the performance or lead to counter-performance of the interrelated SDGs.

The persistence of problems shows that the solution seems to be out of the hands of policymakers to reduce poverty, food insecurity, inequality, unemployment, bad quality of environment,... Sometime, policies adopted and implemented have short impacts and create in the long run the same or other problems of more complex form ("shifting the burden") and the policies become more and more inefficient ("drift to low performance") (D. H. Meadows, Meadows, & Randers, 1972).

So, it seems so important to change a paradigm in problem analysis and policy implementation to address these problems. It is in this line that many institutions and authors recommend a systemic analysis to apprehend problems, to situate the responsibilities of every actor and what kind of actions they can take to overcome social, economic and environmental problems and to build a better future. Analyzing things or sectors with a systemic view means looking at how they are interconnected, what manner they interact, and what purpose or function they respond to. Changing a paradigm is seeing problems as the results or behaviors of a single or several systems. So, the persistence of certain problems such as food insecurity and environmental degradation are intimately linked to systems that are interconnected, and if we don't think this way, we could make a mistake, which would lead to the ineffectiveness of policies.

Corresponding to (D. H. Meadows, 2008a), a system is "an interconnected set of elements that is coherently organized in a way that achieves something". It shows that a system is made of elements or things, interconnections that present the structure of the system, and a function or purpose as a result of the system's operation. Every system must have interconnections and a function which is to create resilience, security, or efficiency (optimization). Then, systemic analysis helps to build an understanding of systems functioning, to identify their traps that are at the same time opportunities to change and restructure the system's behaviors for the purpose of reaching a desirable goal.

So, it makes sense for policymakers to get a good understanding of the interconnections of SDGs and how the different sectors interact with each other over time before taking action. Otherwise, achieving the UN's 2030 Agenda will be a difficult task for developing countries particularly, which have limited resources and unstable institutions to implement the policies recommended to achieve all the SDGs. To this end, it is necessary to prioritize investments and public actions and to be aware of the cross-cutting impacts of these expenditures across the socio-economic and environmental domains (PNUE & MI, 2014). These investments and actions must go in the catalyst sectors that have a positive and significant impact on a large number of sectors that are able to improve SDGs achievement (Millennium Institute, 2021). For this end, it is wise to use planning models that are able to model the linkages between sectors and measure the interactions that exist between them. Such models must be able to analyze the synergies and dissynergies (antagonisms) between sectors in terms of policy implementation in order to advise policymakers on the policies effectiveness to achieve tangible goals (Pedercini et al., 2019). For the fact of sector's integration, a political action or stochastic shock in one sector has repercussions on the other sectors. So, examining the evolution of these relationships over a prolonged period is important to avoid or anticipate the occurrence of some problems because the development process is a lengthy one. Hence, Systems Dynamics (SD) stands out as one of the most suitable methods for examining the links and interactions among various sectors. The integrated Sustainable Development Goal (iSDG)[1] developed by the Millennium Institute (MI) which uses the SD method is a powerful tool that transcripts the 17 SDGs indicators into realizable targets for countries.

Figure I. 1: SDGs performance overview and interventions

Source: Millennium Institute (MI)

Through this overview, we can track the evolution of countries' SDG performance levels over time, and see which SDGs are struggling to make progress. The model's purpose is to support national development planning for the medium and long terms (Pedercini et al., 2007).

The SDGs are subscribed within a bubble of planetary limits so that economic activities take place in the space of a society

[1] https://www.millennium-institute.org/isdg-simulator

whose social resources are used to create value. These two spheres, economic and social, interact with the environment, which is a source of natural resources. The natural resources are extracted to fuel the production of goods and services to meet society's needs, and in return waste is discharged into nature or water.

So, the accumulation process of socio-economic resources and the use of environmental resources over time lead to the development, which in turn generates other socio-economic resources that drive the development process forward. Indeed, the three spheres cover the economic, social and environmental sectors, which in turn are home to the various indicators of the 17 SDGs developed by the United Nations to analyze countries' progress towards sustainable development. According to the (UN, 2018), a “transition towards sustainable and resilient societies hinges on responsible management of finite natural resources". That shows the strong relationships between SDGs indicators and the implementation of policy to improve the performance of one SDG or sector affects others (Millennium Institute, 2021). For example, the food, fresh water and raw materials that fuels economic growth are obtained by exploiting the ecosystems of land, water, biodiversity and forest. As a result, agricultural intensification, population growth and increasing industrialization are having a considerable impact on the availability and quality of these ecosystems, and climate balance. Also, the level of education of the population, which is an output of the education sector, influences the level of productivity in production sectors such as agriculture, industry and so on, which then determines the availability of public resources, which in turn governs the level of reinvestment in the education sector, which then determines future developments in the level of education of the population. Then, improving the performance of one of the SDGs means contributing to the improvement of other SDGs, or on the contrary, contributing to the reduction of the performance of these SDGs. In short, it means creating synergy or dissynergy with certain SDGs (Pedercini et al., 2019).

01. A long-term model for national policy planning: system dynamics method

a. National policy planning

Developing countries like Burkina Faso are faced with several problems such as poverty, food insecurity, inequalities, exploding demography, unemployment, drought, climate warming, the lack of clean water, power shortage, natural resource degradation, bad governance, corruption, low public services especially in rural area, insecurity and violence, … Some have worsened and become more complex. Unfortunately, developing countries have to face them with few financial and human resources. For this reason, using an integrated tool that is able to interconnect a large number of sectors is important to understand the level of interconnections of these challenges (Anderson & Johnson, 1997) and to solve them individually or collectively. Focusing on sectors individually means that we ignore a large part of potential factors in the other sectors that can have an impact on the problem of the focused sector and the feedback impact of the focused sector on the other sectors' drivers. So, we have to develop a global and transdisciplinary thinking about the interdependencies of sectors and problems during the planning process. It enables us to take into account the dynamics effects of the interdependencies (Collste et al., 2017) for good public policy planning.

Indeed, four things are important in national policy implementation : firstly, taking into account sector interconnections is crucial to get the possible effects of the policy across sectors like agriculture sector and food system drivers and their impacts for food security and nutrition (Suryani et al., 2014); secondly, analyzing the feedback impacts between sectors is beneficial to get their synergies and dissynergies for better results in terms of policy implementation (Pedercini et al., 2018). The third important thing in policy planning is the vision. Policymakers must have long term goals by implementing policies. It means to have tangible goals to achieve in the future by analyzing the short, medium and long term impacts of policies implemented with countries' budgets (Millennium Institute, 2021). And the last, is the coordination of actors. We must give clear and sufficient information to all actors, the potential effects of their actions and their duty if we are to be successful in the achievement of our goals. These actors are concerned at the local and national level, institutions and NGO and they have to work in perfect symbiosis, aware that what they are doing in one sector affects other sectors development (David-Benz, 2022).

b. System Dynamics modeling and policy planning

There are few methods nowadays that are able to take into account our recommendations of the efficient implementation of public policy that we describe above. The majority of existing methods are correlative methods and haven't the ability to analyze the feedback interactions between several sectors for a long period. The structure of these models doesn't allow a long-term analysis of policy effects by focusing on the direct causal links between sectors and taking into account the feedback effects between sectors.

So, System Dynamics (SD) and System Thinking (ST) reasoning are some of the best approaches which give a good understanding of these four things that we describe above through the use of Causal Loop Diagrams (CLD) and Stock and Flow Diagrams (SFD). Both tools help us to describe problems, get a common comprehension and to address them by determining some leverage points (Richmond, 1994). The CLDs show the direct causal connections between sectors and variables and the SFDs help to quantify these relationships with data.

Source : Diemer, (2004); Sterman, (2000) System dynamics is “a method for describing a model, simulating and analyzing dynamically complex problems and/or processes in terms of systems, information, strategies and organizational boundaries” (Pruyt, 2013). It provides a set of tools, notably CLDs and SFDs, that allow us to reconstruct an understanding of systems with their feedback (Haraldsson, 2004). According to Forrester, 1961, this involves creating models to explain the past and predict the future of complex systems (sectors), and these models are called mental models - a simplified representation of our understanding of real-world entities. And we base our decisions most of the time on these models. These models allow us to understand the dynamics and structure of complex systems (Goodman, 1997), run simulations to solve problems, and implement effective policies through many scenarios analysis. And today, policymakers demand these types of models to gain a clear understanding of their actions over time and in their own and other areas of expertise. And only dynamics methods can help to see the complexity of the world through the designing of the interrelations between environment, social and economic domains, the interconnexions between SDGs and also between sectors. So, there are differences in resolving problems with the SD approach and the Linear approach. Linear approach is a single and simple representation of what we see between elements while SD digs deep to analyze the smallest relationships that may exist between elements, sectors, actors, policies, disciplines, thanks to its principle of cause-and-effect relationships, its consideration of delays and long-term analysis. So, SD is a participative, inter and trans-disciplinary model for understanding the complexity of systems, identifying their root causes of problems, and developing new opportunities or ways of development (D. H. Meadows, Meadows, & Randers, 1972) for countries and populations.

In this case, a systems analysis provides the opportunity and knowledge to find the places where we can take action to change things positively and efficiently in the way that countries need. It is called “leverage points” in system thinking and they are places where policymakers can make a small change to get a large outcome of many sectors’ development. They are “points of power” according to Meadows. “Finding a leverage point in the system is an invitation to think broadly about the ways we can use it to get systems changing” (D. H. Meadows, 2008a). Twelve (12) leverage points, ranging from minor to more profound changes to the system are developed by Meadows that can lead policymakers in public policy implementation.

These leverage points can refer to parameters or new variables, introduce new feedback loops, propose a different system structure, change the system’s goal or its paradigms on which the system is based (Abson et al., 2017). Sectors are highly interconnected, and today's interconnections are very complex for human beings to understand and perceive, making it difficult for public policy to be effective in tackling problems. This necessitates policymakers to construct a relevant understanding of the elements that comprise every sector, the type (positive or negative) and the delay of different interactions between these elements, the structure and the boundaries of sectors. We know that every sector also has specific goals to achieve, so policymakers must assess the sector performance by considering its key indicators. Then an understanding of these interconnections, feedback effects, sector structure and how it behaves, gives the power of policymakers to intervene to change sector performances. The following picture is the list of the twelve leverage points developed by Meadows that policymakers can use to create sector performance changes.

Table I. 1: leverage points for system change

Constants, parameters, numbers (such as subsidies, taxes, standards)
The sizes of buffers and other stabilizing stocks, relative to their flows.
The structure of material stocks and flows (such as transport networks, population age structures)
The lengths of delays relative to the rate of system change
The strength of negative feedback loops, relative to the impacts they are trying to correct against
The gain around driving positive feedback loops
The structure of information flows (who does and does not have access to what kinds of information)
The rules of the system (such as incentives, punishments, constraints)
The power to add, change, evolve, or self-organize system structure
The goals of the system
The mindset or paradigm out of which the system—its goals, structure, rules, delays, parameters—arises
The power to transcend paradigms

Source : Meadows, (2008)

However, the interaction's knowledge is built through an iterative process to tie the direct link between sector elements through Causal Loop Diagrams (CLD) which is a theoretical analysis. The CLD allows us to visualize reality through the representation of cause-and-effect feedback of sector variables with loops. The loops show the sense of variation of the destination variable when the first one is varied. It takes into account the delay in the variation because sometimes, the effects are not systemic, they can take a long range of time to manifest. When we finish describing the mental model with the CLD, the next step is to transcribe this theoretical model to a quantitative model with a Stock and Flow Diagram (SFD). The goal of the SFD analysis is to measure the flux and the accumulation of variables over time; it gives a statistical understanding of sector evolutions. This step consists of replicating sector historical behaviour for any actions by policymakers. It necessitates data collection for variables during the period of study and the calibration process to fit the simulation results to the historical data. The calibration process is the search for parameter inputs to parameterize the model to the sector reality in the BAU scenario. Finally, when the model is calibrated and works so well, an analysis of every sector's performance is made to guide policymakers to take action by identifying the sectors in which there are some leverage points to implement policy. Let's not forget that the aim here is for public decision-makers to set tangible goals, and to see to what extent public policies can be implemented to achieve these predetermined goals. An integrated approach enables them to identify the sectors in which action needs to be taken, the sectors to prioritize and the targets to achieve.

02. Necessary of a new Sustainable Food System (SFS) for Burkina Faso

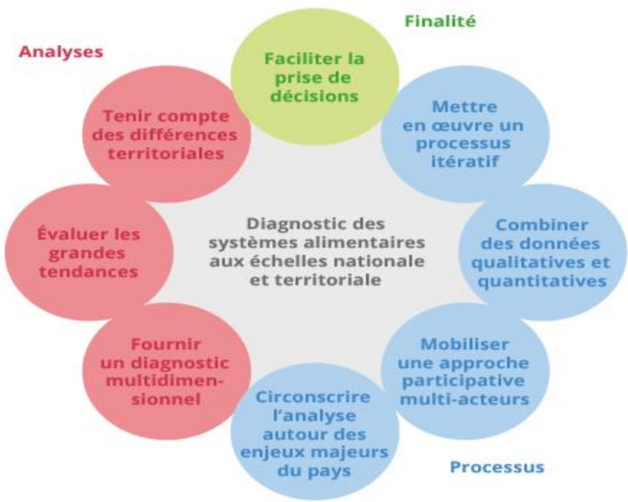
With a complex economic, social, governance, and environmental context, Burkina Faso has for several years been faced with growing insecurity with the phenomenon of terrorism, making development very difficult according to the WB report on climate and development in the old G5 Sahel countries (World Bank Group, 2022). This situation in Burkina is characterized by the displacement of populations from their places of residence, the abandonment of land and property, and the inaccessibility of certain areas to public authorities. Nevertheless, the agricultural system of Burkina Faso recognizes that it is the countryside that supplies the cities with food, thanks to the surplus agricultural production of the peasants. The agri-food sector is less developed so its contribution to food processing is low to meet the population's demand for processed products that leads the country to import food products from abroad.

In addition, the total factors productivity is low like every country in Sub-Saharan Africa (Oyo & Kalema, 2016), to compensate for this problem, farmers use chemical fertilizers and increase agriculture land from forest land, resulting in forest land reduction and soil degradation. We can also mention climate change, with its short rainy seasons and high temperatures which lead to the reduction in agricultural productivity and water stress. The agricultural sector is also affected by the migration of young people to the cities and gold mining, which occupies farmland and reduces the agricultural workforce (FAO, 2021a). All these factors weigh on Burkina Faso's food system and reduce its performance to meet the population's needs in terms of food quantity and quality, to improve living conditions, and to be a catalyst sector for other sectors. Therefore, it is crucial to reverse this context of climate change and insecurity, to exploit the country's opportunities, for example, its young labour force to develop the agri-food industry sector, a good use of mineral revenue, the valorization of water resources, the exploitation of renewable energy resources like solar energy and hydroelectric, an extensive soil regeneration, and the promotion of fair governance in all sector, ... To this end, we have judged that it is important for us to develop a dynamic model to support the agriculture national policy implementation with the purpose to allow policymakers to analyze the dynamics of the food system over time. That will be done in alignment with the objective of the iSDG model, adapting it to the country's socioeconomic and environmental context (Arquitt, 2020).

The purpose is to help policymakers and planners make sense of the dynamic complexity they face in their policy area and to help them design integrated policies for a certain number of SDGs, in particular for the SDG2 improvement.

The work consists of identifying the factors holding the agriculture system back and identifying the leverage points on which we can build to improve its performance. Carry out a more detailed analysis of the interactions between the driving sectors and the agricultural sector, to understand the transmission belts and dynamics specific to Burkina Faso. To this end, we have used two models to develop the dynamic food model for Burkina Faso. The first is the FAO model, which is a conceptual framework for analyzing the FS by taking into account the different activities and actors involved in the food chain, the territorial and environmental aspects that influence it, and the different interactions that take place between actors and the FS steps. It helped us to understand the food system to carry out a complete diagnosis of the system's components. The FAO study has elaborated a guide of preceding to diagnose an FS with many recommendations.

Figure I. 2: principles of process and food system analysis



Source: FAO with (David-Benz et al., 2022)

The diagnosis involves identifying the major issues facing the territory of analysis, identifying global trends in current and future factors influencing system performance, defining the major challenges at all levels (local and national), by considering territorial heterogeneities. Next, we need to use data (quantitative and qualitative) where they exist to provide statistical and visual information to better inform stakeholders about the current state of the system. We need to involve local stakeholders in the diagnosis of the system, as they are the main actors with a good knowledge of the food system and will help to produce more knowledge. Finally, we need to follow an iterative process through interviews to verify the data and information gathered, to reach consensus on the diagnosis made, and to agree on the simplifications to be made to the diagnosis to facilitate decision making by policy makers. Analyzing problems in that approach is called Participatory System Dynamics Modeling (Stave, 2010) on which we will give more explanation in the general conclusion.

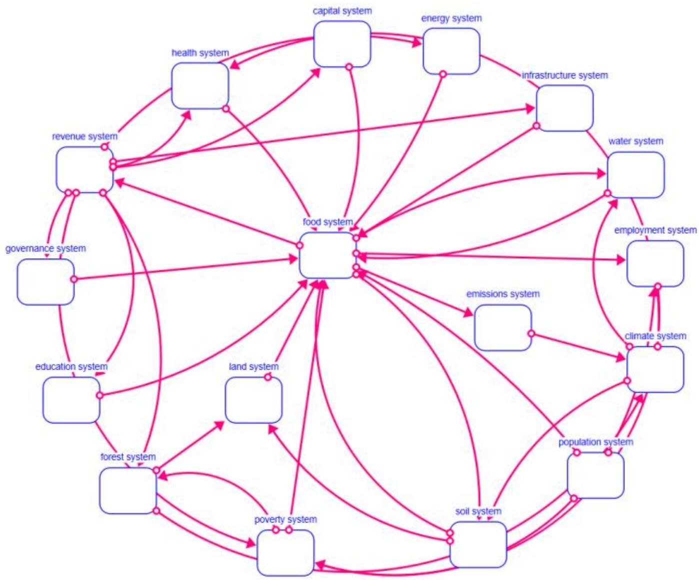
The second model is the iSDG model of the MI, which uses SD to analyze the interconnections between more than 30 sectors of economy, social and environment domains (Millennium Institute, 2021). The model helps us to make the links between the food sector and other sectors such as land, biodiversity, infrastructure, employment, revenue, health, ... By emphasizing the various factors that weigh on the food sector performances and, more importantly the achievement of the SDG2. By building a web of complex causal linkages between sectors, we want to analyze if achieving food security necessitates the implementation of public policy only in the agriculture sector or if the authorities of Burkina Faso need to implement complementary policy in the other sectors. It consists of creating synergistical policies in one sector or several sectors that have high impacts to perform the FS and lead to reduce poverty and improve the food security situation in Burkina Faso by 2030 or more. The model takes into account the different steps of the FS, the environment, social and territorial drivers and public policies that shape it in the modelling process. The model operates through the interactions between variables and sectors, and that must help us to identify the weaknesses of it and propose entry points (leverage points) on which policymakers can use to implement relevant agricultural or non-agricultural policies.

03. Interconnection of food system and other systems (food system as a driver of Burkina Faso development)

The food system (FS) is the foundation of all process of development. Its performance is linked to several challenges such as peasants' living conditions improvement (revenue, employment, education, health, housing), natural resources conservation and consumption or use (land, forest, biodiversity, water, waste), and climate change equilibrium (GHG emissions). Indeed, the FS is an important entry point for addressing issues of sustainability, resilience and inclusiveness according to FAO. Its challenge is not only to provide sufficient and quality food for the population, but to create jobs, revenue and favourable industry and economic environment, to preserve natural resources and biodiversity (David-Benz et al., 2022). Also, all actors at the national and local level, private, public and civil society in different domains intervene in the FS and interact between them through the different steps. In that case, we cannot talk about the sustainable development of Burkina Faso without taking an interest in the FS, how it works, the agricultural policies implemented, the actors involved, its drivers... and so on. It is therefore necessary to find synergistic policies between the driver sectors and food sectors, to find political compromises between actors that can positively increase the performance of the agricultural sector and reduce poverty.

By considering the complete definition given by FAO: “Food systems encompass all actors and their activities involved in the production, collection, transport, processing, distribution and consumption of food from agriculture, forestry or fisheries. They include the inputs used and the management of wastes generated by each of these activities. The main actors and activities in food systems are closely linked to non-food agricultural production systems” (David-Benz et al., 2022). Through this definition, it is seen that the FS is influenced by social, political, cultural, technological, economic and environmental factors which are interconnected with feedback impacts. For the food system organization and the well-functioning between the food steps necessitate also an interaction and collaboration between actors and adding a good governance of agricultural policy.

Figure I. 3: interconnections of food system and some systems



Source: the authors

So, with this qualitative and simple model, we see that from food production to food consumption many factors are used. Farmers must convert forest land to agricultural land (crops and livestocks land), and water withdrawal, soil, energy, labour, and capital, (human capital and material capital) infrastructures are used as inputs to increase food production, yield, and food processing. All of these factors don't come from the food sector but interact with the food system steps to guarantee food availability and quality. Also, some of these factors participate in food transport, distribution, retailing, and market access for food access. The different activities in the food system generate jobs and revenue which reduce the unemployment rate and allow the government and farmers to get revenue to invest in return in education, infrastructure, health, energy, forest land protection, and capital systems to increase their positive impacts on the food system and poverty reduction in the future. In that way, a food system where farmers are trained in the sustainable management of land, forest, soil, biodiversity, and water ecosystems and sustainable farming practices like agroecology, can be a driving force to put Burkina Faso on the road to sustainable development. Also, strengthening and supporting familial agriculture through investment and diversification on which 80% of Burkina Faso's population depends on is an important driver to reduce poverty, malnutrition, and migration. The idea is to industrialize the agricultural sector by moving away from subsistence agriculture, with massive investments that will drive the development of the secondary and tertiary sectors. It is possible with good and fair governance, accompanied by a reduction in the risks of capital investment in the agricultural sector, and good planning of agricultural policies. All of these, combined with a well-developed mining sector to support investment, would be an important lever for boosting development.

04. Contribution of the thesis

At the beginning of my thesis, I was wondering why SD is unknown by the majority of the scientific community although the model has been developed since 1960 with the first models and papers in SD (Forrester, 1961; D. H. Meadows, Meadows, & Randers, 1972). We are talking about that because at the academic level, SD method is not taught to the student, and in the economic literature, few academic papers are interested in using SD method in public policy analysis, particularly in the French community. So, the first papers of the thesis are written to complete this lack of knowledge by the presentation of SD method, the different sectors of applications of this model, and how it can be used to address social, economic, and environmental issues.

In political interest, we see that it has been used to guide policymakers in their decisions in many countries throughout the world. This is in line with the purpose and the utility of the method which is to help highlight countries' political decisions toward sustainable development.

Also, the purpose of the PhD is to develop a system dynamic food model that will stand agriculture policy implementation, monitoring food and nutrition indicators, and better use of financial and human resources for Burkina Faso and other countries that are interested in the model.

Finally, during the thesis work, we built a database from 2000 to 2020 of more than 1200 variables by using the National Institute of Statistics and Demography (INSD) which collects data at the national level, and we completed missing data by using the databases of international institutions. Also, we have developed some qualitative (CLD) and quantitative (SFD) tools that explain the functioning of the food system, the drivers that can influence it, and the feedback effects that can be found between the food system and its drivers. These tools can be used by institutions, researchers, and policymakers for policy implementation and research.

05. Outlines of the thesis

In summary, this thesis aims to disseminate in French literature a long-unknown research method in system dynamics. Developed in the 60s, it uses a non-linear approach to analyze direct interactions between variables, contrary to econometric methods. Secondly, it demonstrates that system dynamics can be used to simulate economic, social, and environmental policies, individually or collectively, thanks to these highly practical working tools. It is thanks to this possibility that we have developed the Food System model adapted to Burkina which can be replicated in any country.

So, the first chapter of the thesis presents the foundation of system dynamics with Forrester and the Limits to Growth report in the 60s and 70s, his reasoning and these analytical tools. This introductory chapter outlines the structure of the Millennium Institute's Integrated SDG Model (iSDG model), which uses system dynamics to simulate long-term SDG performance in several developing countries. The results of this paper show that the iSDG model can be used to evaluate the effects of several policy scenarios (a Business As Usual scenario, and alternative scenarios of supplementary or complementary policies) relating to the SDGs, to estimate the budget for each scenario, and to guide policy-makers towards tangible, achievable targets. The difference between the achieved levels of the SDGs in the alternative scenarios and their levels in the reference scenario (by 2030 or 2050) constitutes a kind of performance indicator for each SDG because of the new policies.

The second chapter is a comparative analysis (a benchmarking) of the Millennium Institute's (MI) iSDG model based on system dynamics, with some dynamics models used by some development institutions such as the Agence Française de Développement (AFD), the International Monetary Fund (IMF), and the World Bank. The goal is to analyze the ability of each model to model the sustainability of the SDGs indicators and GDP consideration in the modeling process for each model. By studying the methods used by the Dynamic Stochastic General Equilibrium (DSGE) model of the IMF, the World Bank's long-term growth model (LTGM), the AFD's Stock-Flow Consistent Prototype Growth Model (SFCP-GM), and the Millennium Institute's (MI) integrated Sustainable Development Goals Model (iSDG); In examining each model, we have seen that the three models commonly used by the IMF, the World Bank and the Agence Française de Développement are predictive models, seeking to determine only the channels through which shocks affect the economy. They do not consider interactions between variables, except for the AFD's consistent stock-flow model. Secondly, these three models are not interested in the sustainability of economic systems (they do not take into account the environmental and social spheres), as they are limited to short-term analyses, unlike the iSDG model, which takes all these elements of sustainability into account.

Then, the third paper gives an analysis of the SDGs in a prospective approach by translating them into an analysis of planetary limits. Whether they can be achieved by 2030, or their performance, is limited by the financial resources available to countries, especially developing countries, the scarcity of natural resources, and the environmental scourges facing the planet today. In this paper, we present the SDGs in a scheme of planetary limits through the iSDG model, which provides an analysis of the strong and weak interactions between the SDGs through the feedback loops between them. This representation teaches us that mankind must reduce its environmental footprint and that every public policy in pursuit of well-being must take account of the limits imposed on man by nature. Hence the importance of strategic planning for sustainable development is made possible by the iSDG model.

And end, chapter 4 constitutes the modeling of Burkina Faso Food System-Model (BFS-M). It tracks the evolution of definitions of the notion of food security used by United Nations institutions (FAO, UNDP), emphasizing the notions used to qualify a state of food security and nutritional satiety. It demonstrates that food security is linked to all stocks, flows in and out of the food system, and that the state of food security is influenced by the interactions between the different steps and actors involved in the food system. Through this, we demonstrate that a sustainable food system takes into account the interactions between the three spheres of sustainable development, the interactions between sectors and actors, hence the need to transform current food systems to improve food systems that take into account the sustainability of systems at local, national and global levels. To this end, we are using dynamic tools such as CLD and SFD to analyze the state of food security in Burkina, to determine the factors influencing it through the interactions between the food system steps and the other development sectors. And finally, to identify some leverage points that are likely to improve its performance in terms of food security and nutrition, natural and social capital preservation, farmers' living conditions improvement, and public resource management.

Table of publication of thesis's papers:

Title of the paper	Authors	Journal name	Year of publication
The iSDG model: systems dynamics for sustainable development policy planning in developing countries	Arnaud DIEMER, Henri Joël SOURGOU, Derek CHAN, Matteo PEDERCINI	Revue Francophone du Développement Durable	2022
Modeling Economics and Sustainability: GDP as a goal vs GDP as a driver	Henri Joël SOURGOU, Arnaud DIEMER	iBusiness Journal	2024
Modeling the SDGs with a forward-looking approach: the iSDG model	Arnaud DIEMER, Henri Joël SOURGOU, Matteo PEDERCINI	Current Science	2023
National food security: towards a New Sustainable Food System (FS) in Burkina Faso	Henri Joël SOURGOU, Arnaud DIEMER	Modern Economy	2024

1. The iSDG model: systems dynamics for sustainable development policy planning in developing countries

Abstract:[2] The advent of the Sustainable Development Goals (SDGs) has not only challenged the hegemony of economic growth and its indicator, gross domestic product (GDP), it has also triggered the emergence of new forward-looking models, better adapted to the context of developing countries and more likely to inform political decision-makers about the consequences of their actions. The iSDG model, associated with the IAM (Integrated Assessment Models) family, stands out for its use of system dynamics, popularized by Forrester and the publication of the Limits to Growth Report (1972). Behind this model lies a powerful simulation tool capable of responding to major societal challenges. These issues include demographic trends, food and energy consumption, mobility, education and health, land use, urbanization and agricultural production... all state variables that can be used to initiate a genuine dynamic of change and scenario possible trajectories.

Keywords: iSDG, Models, Systems Thinking, Systems Dynamics, T21

[2] This chapter was written with Arnaud DIEMER, Derek CHAN, Matteo PEDERCINI, and a French version is published in the Revue Francophone du Développement Durable.

1.1. Introduction

In 2015, the United Nations General Assembly adopted the 2030 Agenda for Sustainable Development, made up of the 17 Sustainable Development Goals (SDGs) and related targets (A/RES/70/1). The SDGs take the form of a call to action for all countries (poor and rich) to promote prosperity while protecting the planet (Khushik & Diemer, 2020). The aim is to put an end to poverty and inequality while combating climate change, preserving the environment, and meeting a range of social needs (education, health, social protection, jobs). The resolution stresses that "the interlinkages and integrated nature of the SDGs are of crucial importance" and that "the challenges and commitments identified... are interdependent and call for integrated solutions". To meet the need for planning tools, the Millennium Institute has developed the iSDG (Integrated Sustainable Development Goals) model for medium- and long-term national planning towards the SDGs. The iSDG model is the latest in the line of T21 models, based on system dynamics and developed by the Millennium Institute (Millennium Institute, 2017a). System dynamics, initiated by Forrester in the 1960s, is based on a non-linear approach to the relationships between many variables in a system and is particularly well suited to studying complex socioeconomic environments (J. Sterman, 2000).
In what follows, we will seek to show that beyond a simple modeling exercise, the iSDG model offers a new perspective on

sustainable development policies, and in particular the implementation of the SDGs in Southern countries. To this end, we will first present the structure and characteristics of the iSDG model. More specifically, we will return to the T21 models. Secondly, we will describe the method used by these models, system dynamics, which represents a radical departure from the general equilibrium and optimization models long prescribed by international institutions such as the IMF and the World Bank. Finally, we will look back at a few iSDG models applied to different countries in the South, to highlight the contributions and the criticisms that can be levelled at these models.

1.2. The structural framework of the iSDG model

The iSDG model is the latest in a series of models called T21 (Threshold 21), developed by the Millennium Institute[3] (Millennium Institute, 2003) on a US scale (A. M. Bassi, 2006, 2009, 2011; A. M. Bassi & Shilling, 2010; A. Bassi & Pedercini, 2007; Cimren et al., 2010), then in a large number of countries in Africa (Benin, Cape Verde, Egypt, Ghana, Malawi, Mali, Mozambique, Somalia, Tunisia), Asia (Bangladesh, Bhutan, Cambodia, China, Indonesia, Taiwan) or Europe (Italy, Lithuania). The T21 models integrate sustainability issues into a logic of medium- and long-term national development

[3] Herren, 2013 - President of the Millennium Institute (MI) - recalls that MI was founded in 1983 as a non-profit organization to promote holistic, long-term strategic planning using system dynamics models at local, national, regional and global levels.

planning, taking into account social, economic, and environmental factors, all within a coherent, integrated framework (A. Diemer, 2004, 2012). These models have several distinctive features: (i) they are based on a detailed review of the literature on modeling and scientific theory, from sources such as the World Bank, the IMF, the FAO, the IPCC, and the US Department of Energy; (ii) they are based on a method - system dynamics - and simulation tools (Vensim and Stella software) capable of solving complex problems and producing quantitative results (graphs) over horizons ranging from 5 to 100 years; (iii) the simulations make it possible to visualize time trajectories for any variable or series of variables over a given time horizon. This makes it possible to specify the impacts of public policies or structural changes, as well as to generate dialogue on the options chosen with the various ministries of a government, partner expert agencies, or civil society.

The T21 models are part of this long line of models that emerged in the 70s and 80s following the computer revolution and computer-aided simulations (Barney & Wilkins, 1986; Garrett, 1990). (Barney et al., 1991) have brought together this vast literature in a book entitled “Managing a Nation: The Microcomputer Software Catalog”. This book presents itself as “a collection of reviews of microcomputer programs of special relevance to those people around the world who are responsible for the management of the current and future affairs and business of their countries” (1991, p. 3). The book is divided into three parts.

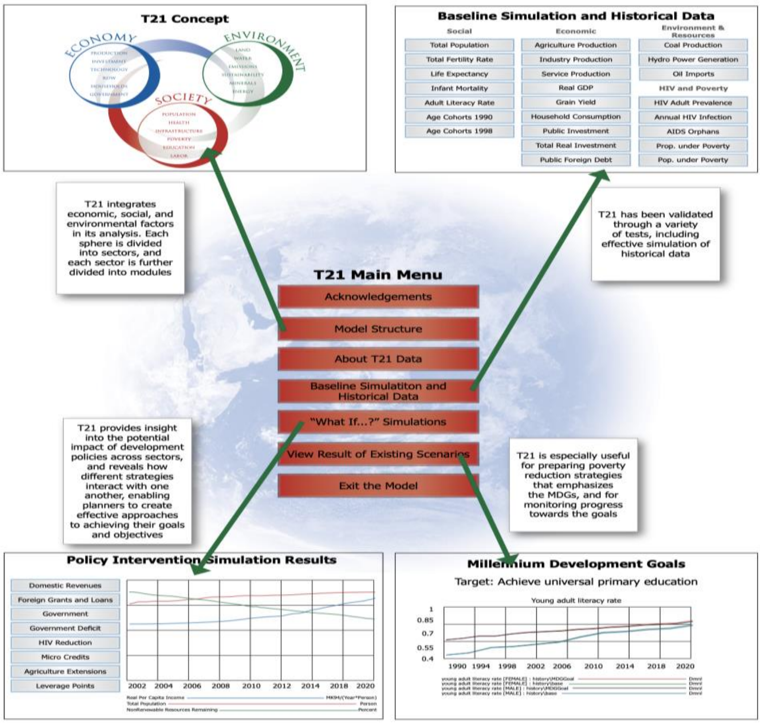
The first part lists sectoral models, the sectors here referring to various themes: agriculture, economy and industry, energy, environment and ecology, natural resources, politics, demography, health and education, rural and urban development, national security, transport and communication. For example, the DSBMT (Dynamic Synthesis of Basic Macroeconomic Theory) model provides a simple dynamic synthesis of the most important macroeconomic models used by economists. These include Samuelson's multiplier-accelerator principle (1939), Hicks' IS-LM model (1937) and Dornbush and Fisher aggregate supply and demand model (1978). There's also the System Dynamics National Model (SDNM), a computer simulation model of social and economic change in the USA (Forrester, 1976). The model has been designed for public policy analysis, and contains a deep policy structure ranging from government, fiscal and monetary policy to corporate accounting, pricing and the ordering of factors of production. The model addresses the interrelated issues of inflation, unemployment, recession, balance of payments, energy and the environment. In the case of energy, we can cite the LEAP (Long Range Energy Alternatives Planning System) model developed by the Stockholm Environment Institute (SEI). LEAP provides a computerized framework for evaluating energy policy and planning options in developing countries. LEAP was conceived as a flexible and accessible tool enabling planners and decision-makers to identify and quantify the long-term implications of energy policy alternatives (P. D. Raskin, 1985). When designing and implementing an effective energy plan, the planner needs to consider a wide range of issues: fuel sources and prices, rural energy strategies, environmental and land-use trade-offs, energy demand management and conservation, and changing economic and demographic patterns. LEAP has three main functions: "(1) an information bank and guide to data development in establishing national energy accounts; (2) an instrument for long-term projections of supply/demand configurations under alternative development scenarios; and (3) a vehicle for identifying and evaluating policy and technology options with respect to near and long-term supply/demand balance, capital requirements, costs and benefits and foreign exchange impacts" (P. Raskin, 1986).

The second part introduces national multi-sector and global models. National multi-sector models synthesize many of the individual areas discussed in Part One. This integration is very important, as virtually all important public policy issues cross departmental boundaries (Barney et al., 1991). Global models provide an overview of interactions between nations. These models are becoming increasingly important, not only because of international trade and relations, but also because of transnational environmental impacts and international migration. A case in point is the STRATEGEM (1) model created at the International Institute for Applied Systems Analysis (IIASA) by Dennis Meadows during the 1983-1984 period. STRATAGEM (1) followed on from the World 3 model (D. H. Meadows, Meadows, & Randers, 1972). Simpler than its predecessor, STRATAGEM (1) featured five sectors, representing the interconnections between population, energy production and use, agricultural production and environmental protection, production of goods and services, and international trade and foreign debt (D. L. Meadows, 2001; J. D. Sterman & Meadows, 1985). Players interact with the model through ten decision-making cycles: each cycle representing five years in the development of their game region. STRATEGEM (1) was designed to simulate the management of a nation, integrating the effects of political decisions on population, energy, nutrition, debt, material consumption, and the environment (D. Meadows, 2007). Subsequently, a STRATEGEM (2) version incorporating the question of long Kondratieff cycles was developed by Dennis Meadows and John Sterman (1985). WORLD 3 is the global model associated with the Limits to Growth report (D. H. Meadows, Meadows, & Randers, 1972). It involved simulating, over 100 years or more, the dynamic global interactions of population, arable land, agricultural and industrial capital, capital services, non-renewable resources, and pollution. The detailed structure of the model was presented in The Dynamics of Growth in a Finite World (D. L. Meadows et al., 1974) and reconceptualized in Toward Global Equilibrium (D. L. Meadows, 1973).

The third part helps the reader to take advantage of the benefits of computer models and simulations by questioning the purpose of the model, its assumptions, the use of data, and the origin of data sources. This chapter, written by John Sterman, introduces the difference between optimization and simulation models: “The distinction between optimization and simulation models is particularly important since these types of models are suited for fundamentally different purposes” (J. D. Sterman, 1991).

It was this review of the literature that initiated the Millennium Institute's initial work and the development of the T21 models. These models are based on a generic structure representing development mechanisms that can be found in most developing and industrialized countries. This structure covers a wide range of issues facing countries worldwide: from poverty to environmental degradation, from education to health, from economic growth to demographic expansions. In other words, T21 models are designed to cover the most common long-term problems that countries encounter in the development process.

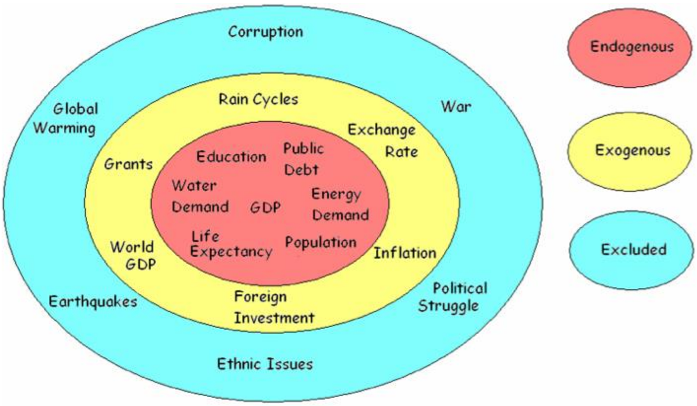
Figure 1. 1: T21 framework



Source: MILLENNIUM INSTITUTE, (2007b, P. 2)

In its original form, the T21 model incorporates both conceptual (endogenous, exogenous, and excluded variables) and spatio-temporal limitations (Zapata & Gauthier, 2003). Endogenous variables are an integral part of development mechanisms and include GDP, population, education, public debt, and energy demand. Exogenous variables have an important influence on the problems posed but are only weakly influenced by them (for example, the exchange rate, rainfall cycles, or the level of subsidies). Finally, there are variables that have no quantifiable effect and are not explicitly represented in the model. These include temperature, ethnic criteria, and corruption).

Figure 1. 2: inclusion and exclusion diagram for variables



Source: MILLENNIUM INSTITUTE, (2007a, p. 5)

The T21 model is relatively large because of the number of issues it covers. It contains over a thousand equations, nearly 60 stock variables and several thousand feedback loops. T21 consists of 37 modules grouped into 18 sectors (6 social, 6 economic and 6 environmental). The three spheres of sustainability (social, economic and environmental) are represented here.

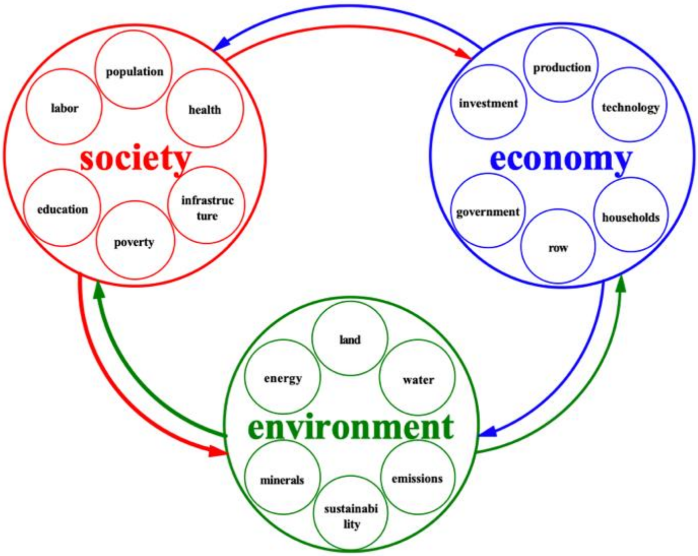
Table 1. 1: T21 modules, sectors, and spheres

COMPANY	ECONOMY	ENVIRONMENT
Population sector 1. Population 2. Fertility 3. Mortality	Production sector 14. Domestic production and revenues 15. Agriculture 16. Livestock, fisheries, forestry 17. Industries 18. Services	Land sector 30. The land
Education sector 4. Primary education 5. Secondary education	Technology sector 19. Technology	Water sector 31. Water demand 32. Water supply
Health sector 6. Access to essential health care 7. HIV/AIDS 8. HIV Children 9. Nutrition	Household sector 20. Household account	Energy sector 33. Energy demand 34. Energy supply
Infrastructure sector 10. Routes	State sector 21. Government revenues 22. State expenditure 23. Public investment and consumption 24. The public balance and its financing 25. Public debt	Minerals sector 35. Fossil fuel production
Work sector 11. Employment 12. Available work and cost	International sector 26. Balance of trade 27. Balance of payments	Emissions sector 36. Fossil fuels and GHG emissions
Poverty sector 13. Income distribution	Investment sector 28. Relative prices 29. Investment	Sustainability Sector 37. Ecological footprint

Source: MILLENNIUM INSTITUTE, (2007b, P. 8)

The main feature of T21, however, is the way in which the different modules are linked together to form a complex network of feedback loops. Figure 3 provides a conceptual view of the three spheres (society, economy and environment) and the links between them. Each sphere influences and is influenced by the other two.

Figure 1. 3: spheres, sectors, and cross-links



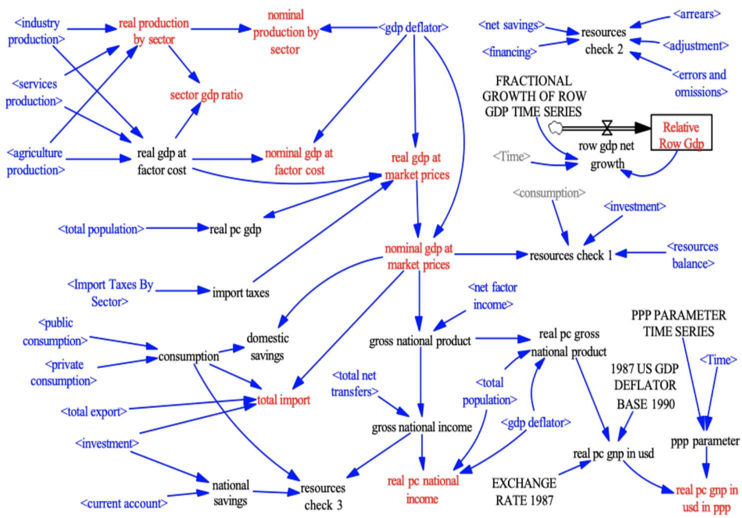
Source: MILLENNIUM INSTITUTE, (2007b, P. 10)

The blue arrow running from the economic to the social sphere indicates that at least one economic sector affects a social sector, e.g., production may affect population. Each sector consists of endogenous and exogenous variables, parameters, stocks and flows.

Let's take sector 14 National production and income. The module is based on accounting identities and key macroeconomic indicators, inspired by Dornbusch and Fischer's Macroeconomics (1978). This is the case for a given level of output, obtained by summing consumption, investment and exports, minus imports:

$$Y = C + I + X - M.$$

Figure 1. 4: domestic production and revenues

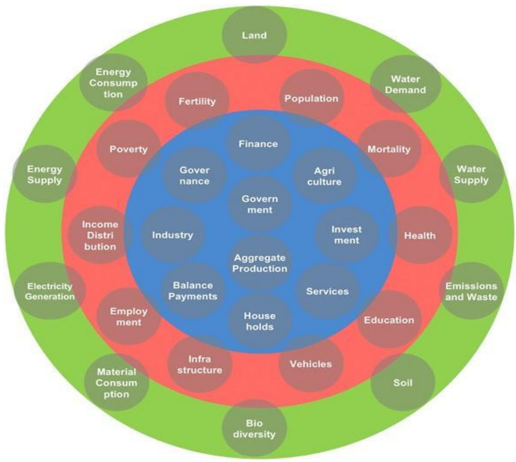


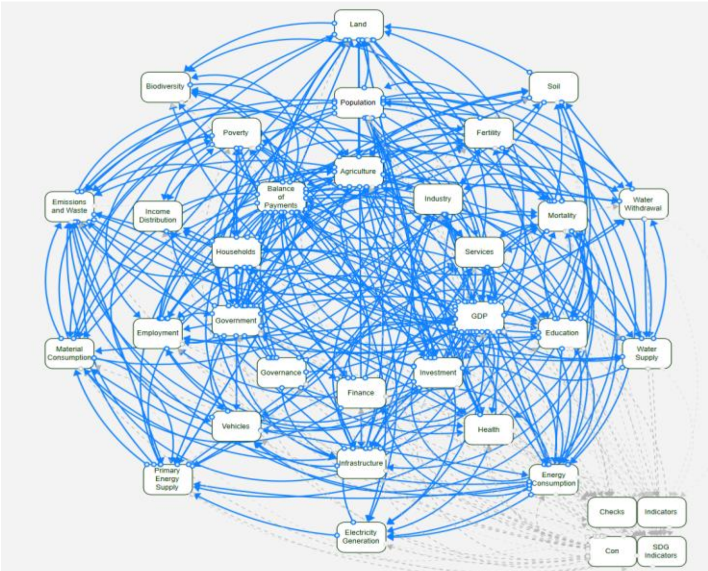
Source: MILLENNIUM INSTITUTE, (2007b, P. 65)

Over time, the T21 has evolved, incorporating additional structures as needed and verified by academics and practitioners in the field through the construction of group models and practical applications of the model. The iSDG model is the latest version of the T21 model.

(i) It's an integrated dynamic system model covering all the Sustainable Development Goals (SDGs) with a battery of over 80 indicators. The integration mainly concerns three domains (economic, social and environmental). Each area comprises sectors (30 in total) that interact with each other and with the sectors in the other areas.

Figure 1. 5: the structure of the iSDG model



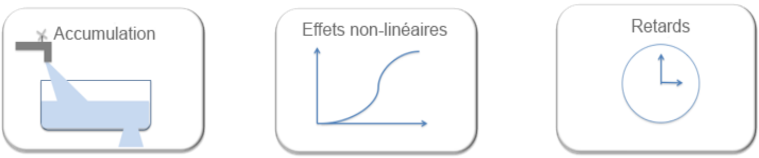


Source: Millennium Institute

The economy domain (blue) contains the main production sectors (agriculture, industry, services), which are characterized by Cobb-Douglas production functions with inputs of resources, labor, capital and technology. Demand is based on population and per capita income and is distributed across the subsectors. The social domain (red) includes detailed population dynamics by gender and age cohort, health and education challenges and programmes, basic infrastructure, employment, poverty levels and income distribution. The environmental domain (green) tracks pollution from production processes and its impact on health. It also estimates the consumption of natural resources (renewable and non-renewable) and the impact of resource depletion on production and other factors (Millennium Institute, 2017a).

(ii) It represents the important elements of complexity we find in system dynamics (flow-stock feedback relationships, non-linearity, lags).

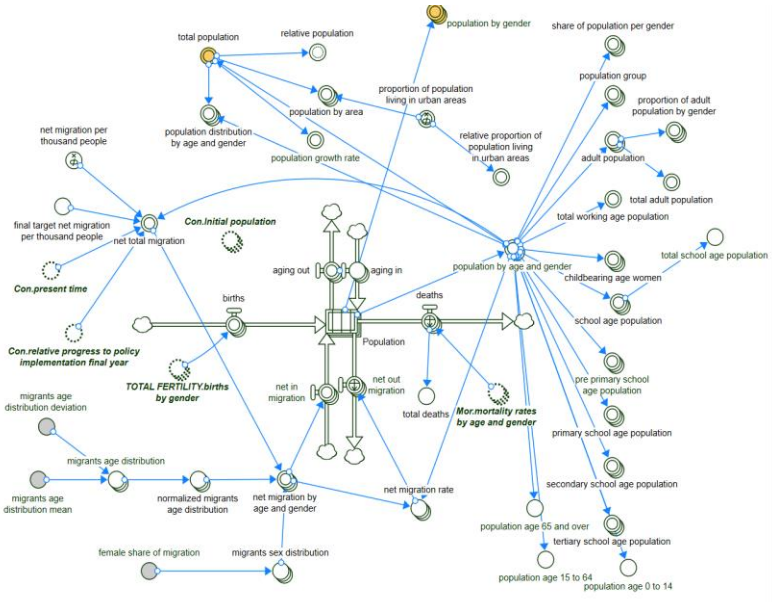
Figure 1. 6: elements of system dynamics



Source: Diemer, (2004)

Let's take the example of the population sector, which is part of the social domain. Its modelling, using the STELLA software, shows the inflows (births; migrations: net in-migrations) and outflows (deaths; migrations: net out-migrations) that modify the population stock. The fertility rate affects births, while the mortality rate affects deaths. The population is used to determine the school-age population and the age group attending primary or secondary school. The population also makes it possible to take account of gender, the proportion of the population living in urban areas, and the proportion living in rural areas.

Figure 1. 7: Population sector in the iSDG model (Stella)



Source: Millennium Institute

(iii) It is transparent in its structure (assumptions, equations, data requirements) to serve as a participatory tool (Van den Belt, 2004; Vennix, 1996) in consensus building and policy discussions (Collste, 2016).

(iv) It is flexible enough to be adapted to specific countries by training users based on country-specific conditions (Bangladesh for health, nutrition and education in 1994; Tunisia for water and fertility revisited in 1996; Cambodia for the effects of war in 1997; China for relative prices, transport and the Chinese interface in 1999; Guyana for structural adjustment in the sugar and bauxite industries in 2001; Mozambique for microcredit, agricultural extension, new roads and the Millennium Development Goals in 2003; Mali for cotton production and gold mining in 2005; Jamaica for crime, natural disasters, sugar cane production in 2006; ECOWAS and the design of regional integration models in 2010; Burkina-Faso for its exploratory report on the green economy in 2014; Senegal as a tool for the quantitative assessment of scenarios for 2035 in 2014; Côte d'Ivoire for the economic, social and environmental impacts of the transition to a green economy in 2017; Senegal as a tool for the projection of SDG indicators in 2017). The calibration of the model is based on a country database.

(v) It simulates the short- and long-term consequences of alternative policies (2030 - 2050).

(vi) It enables comparison with reference scenarios and supports advanced analytical methods such as sensitivity analysis and optimization.

1.3. iSDG Method

The iSDG model stands out in the landscape of Integrated Assessment Models (G. Diemer et al., 2019) for its use of system dynamics, which was developed by Forrester at MIT in the 1960s. His first book, Industrial Dynamics (Forrester, 1961), contained the seeds of a methodology that would find success in the 1970s, particularly through two books, World Dynamics

(Forrester, 1972) and Limits to Growth (D. H. Meadows, Meadows, & Randers, 1972).

For Jay Forrester, (1961), industrial dynamics was a way of studying the behavior of industrial systems to show how policies, decisions, structure, and lags interacted to affect the growth and stability of a system (A. Diemer, 2018). To speak of systems “implies a structure of interacting functions. Both the individual functions and the interrelationships defined by the structure contribute to the behavior of the system” (Forrester, 1976, p. 1). To describe a system, we need to describe not only the separate functions but also how they interact: "As used here, a system means a grouping of parts working together for a common purpose" (Forrester, 1968a, p. 1). Thus, in order to identify the structure of a particular system, we need to understand the fundamental nature of the structure that is common to all dynamic systems. In Industrial Dynamics, Forrester integrated the different functional areas of management, marketing, investment, research, personnel, production and accounting (Forrester, 1968b). Each of these functions is reduced to a common base by recognizing that all economic or business activity consists of flows of money, orders, materials, personnel, and capital goods. These five flows are integrated into an information network. As a result, industrial dynamics "recognises the critical importance of this information network in giving the system its own dynamic characteristics" (Forrester, 1961, p. 7).

According to Forrester, industrial dynamics was made possible by four major advances: (1) information feedback control theory, (2) decision process analysis, (3) experimental approaches to systems analysis, and (4) digital computers.

(1) An information feedback system exists "whenever the environment leads to a decision that results in an action that affects the environment and thus influences future decisions" (Forrester, 1961, p. 14). The study of feedback systems focuses on how information is used for control purposes. It enables us to understand how the quantity of corrective actions and delays in interrelated components can lead to unstable fluctuations. For Forrester, information feedback systems have three characteristics: structure (which tells us how the parts of the system relate to each other), delays (which are always present in the availability of information, in making decisions based on information, and in acting on decisions), and amplification (which occurs when an action is more energetic than the information inputs to the governing decisions might initially suggest).

(2) Decision making processes were realized in the 1950s. Military tactical operations were automated. At Forrester, fire control prediction decisions during the Second World War were made automatically by machines. A few years later, these automatic decisions were accepted and put into practice. It was therefore necessary to interpret the tactical judgment and experience of military decisions into formal rules and procedures: "It has been amply demonstrated that carefully

selected formal rules can lead to short-term tactical decisions superior to those made by human judgment under the pressure of time, with men of insufficient experience and practice, or in the rigidity of large organizations" (Forrester, 1961, p. 17).

(3) The experimental approach reminds us that mathematical analysis is not powerful enough to provide general analytical solutions to situations as complex as those encountered in business. Simulation is often used to conduct experiments on a model (for example, the design of an air defense system or an engineering process): "The use of simulation methods does not require great mathematical skills. Of course, the details of setting up a model must be followed by experts, as there are special skills required and pitfalls to be avoided" (Forrester, 1961, p. 18).

(4) Digital electronic computers became available between 1950 and 1960. Computing machines (with increased memory, speed and capacity) made it possible to handle more complex systems.

These four new fields, combined with business modeling, provided the breeding ground for the development of systems dynamics: "Chance intervened again when I found myself talking to people from General Electric. They were puzzled as to why their household appliance plants sometimes worked three or four shifts and then, a few years later, had to lay half their staff. It is easy to say that business cycles cause fluctuating demand, but not entirely convincing. After finding out how the corporation made hiring and inventory decisions, I started to do some simulations, using a pencil and a page in a notebook. At the top, I put columns for inventories, employees, and orders. Given these conditions and the policies being pursued, one could predict how many people would be hired the following week. This produced a new set of conditions for inventories, employment, and production. It became clear that there was the potential for an oscillatory or unstable system that was entirely internally determined. Even if incoming orders remained constant, employment instability could still arise as a consequence of common decision-making policies. This first pencil and paper inventory control system was the beginning of system dynamics" (Forrester, 1995).

In industrial dynamics, system dynamics can be presented as a form of computer simulation modeling that uses the concepts of feedback and state variables to model social systems and explore the link between system structure and evolutionary behavior over time (Forrester, 1968a). To model the dynamic behavior of a system, we need to introduce two new publications by Forrester, Principles of systems (1968) and Urban Dynamics (1969). In these books, Forrester proposed a detailed description of the system dynamics approach and recognized four hierarchies of structure: a closed boundary around the system; feedback loops as basic structural elements within the boundary; level (state) variables representing accumulations within the feedback loops; rate (flow) variables representing activity within the feedback loops.

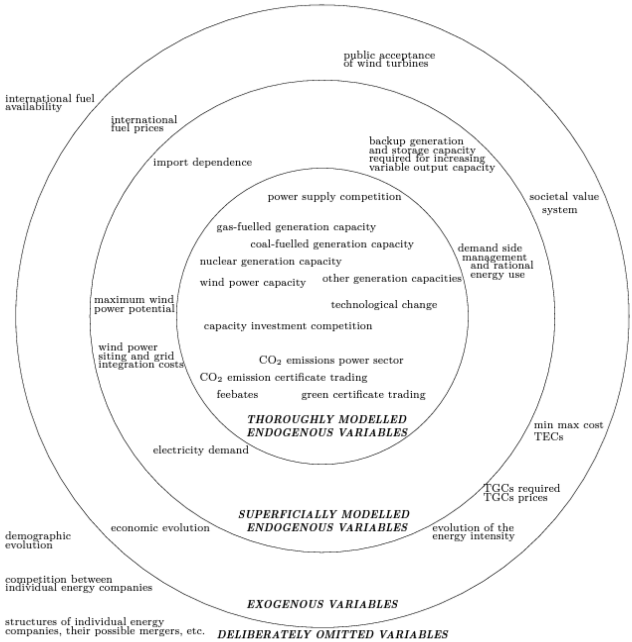
Table 1. 2: four stages in system theory structure

A Closed boundary		
1 Feedback loops		
	a Levels b Rates	
		(1) Goal (2) Observed condition (3) Discrepancy (4) Desired action

Source: Forrester, (1968a, p. 2)

Closed system boundary: To apprehend a system, we need to establish the boundary within which the interactions that give the system and its characteristic behavior occur. Forrester states that "the closed boundary does not mean that the system is unaffected by external events. But it does mean that these external events can be regarded as random events which affect the system and do not in themselves give it its intrinsic characteristics of growth and stability" (Forrester, 1961). The extended limit of a system explains what to include and what to exclude (endogenous and exogenous variables). The intensive limit defines the depth or level of detail at which the elements included in the model are represented. The model is based primarily on endogenous explanatory variables - drivers that drive the system's dynamics. These drivers introduce endogenous variables of second rank, third rank..., then exogenous variables... There are also endogenous variables that have not been taken into account, and whose non-inclusion must be explained (A. Diemer, 2004).

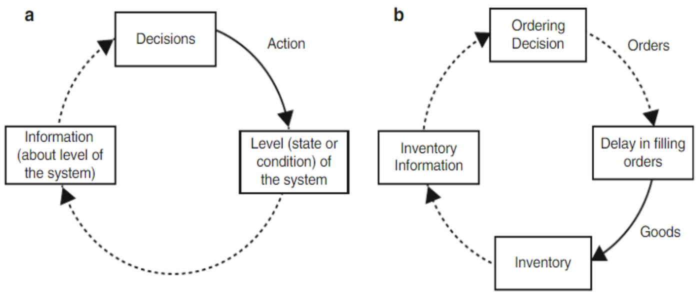
Figure 1. 8: system limits



Source: Pruyt, (1982)

Feedback loop structure: The dynamic behavior of systems is generated within feedback loops (Roberts, 1975). A feedback loop is composed of two types of variables, called rate and level variables (A. Diemer & Nedelciu, 2020). A feedback loop is a structure in which a decision point - the rate equation - controls a flow or action. The action is integrated to generate a level of system behavior. The level information is the basis on which the flow is controlled.

Figure 1. 9: feedback loop configuration



Source : A. Diemer & Nedelciu, (2020)

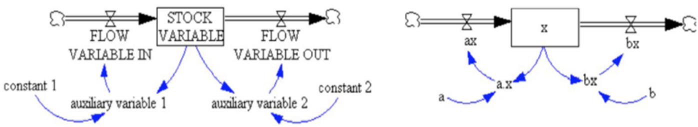
The figure on the left is the simplest form of a feedback system; there may be additional delays and distortions appearing sequentially in the loop. There may be many interconnected loops. The figure on the right describes the circular cause-and-effect structure of the feedback loop when a company orders goods to maintain an initial stock.

A feedback loop is based on the distinction between flows and stocks. A stock is an accumulation of matter, energy, people or things over a period of time. This accumulation varies according to incoming and outgoing flows. Mathematically, this is an integral calculation.

$$\text{Stock}(t) = \int_{t_0}^{t} [\text{Inflow}(s) - \text{Outflow}(s)]ds + \text{Stock}(t_0)$$

Flow is the rate of change of a stock. It represents materials or information flowing into and out of a stock over a given period. Mathematically, flow equations include variables, parameters and constants.

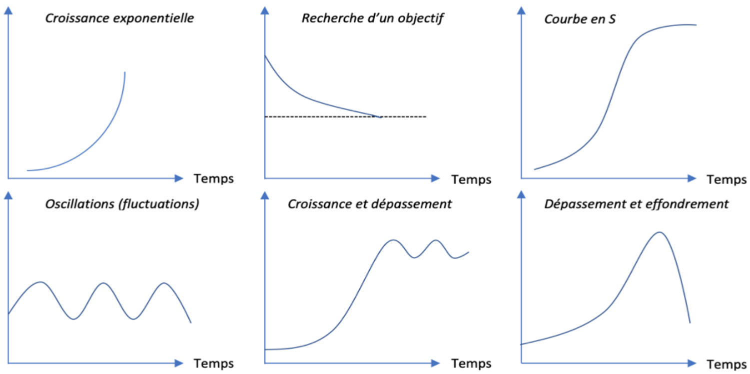
$$x = x_0 + \int_{t_0}^{t} (+ax - bx)\, dt$$



General representations of a model's variables and feedback structure are conveyed using causal loop diagrams (CLD). Stock-flow diagrams (SFD), on the other hand, are more detailed and distinguish between state and flow variables.

In a system dynamics model, the polarity of each feedback loop is crucial to understanding the model's behavior.

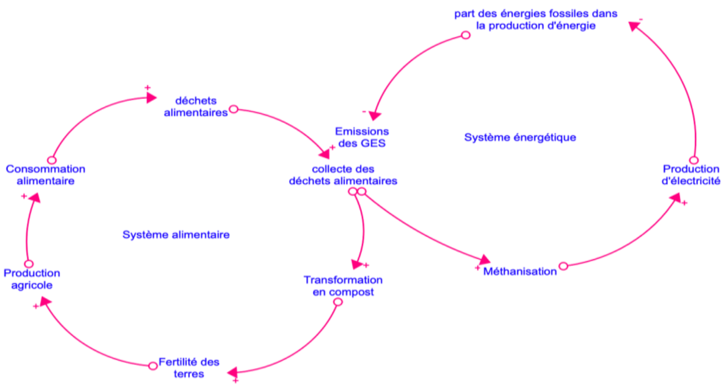
Figure 1. 10: different behavior models



Source: the authors

There are essentially two types of loops: reinforcing loops and balancing loops. Reinforcing loops (R) have a positive polarity (+) and generate exponential growth and collapse, which continue at an ever-increasing pace. Balancing loops (B) generate a force of resistance (which can limit growth). Balancing loops have a negative polarity (-) and find themselves in situations that are self-correcting and self-regulating.

Figure 1. 11: example of loops integrating the food and energy system

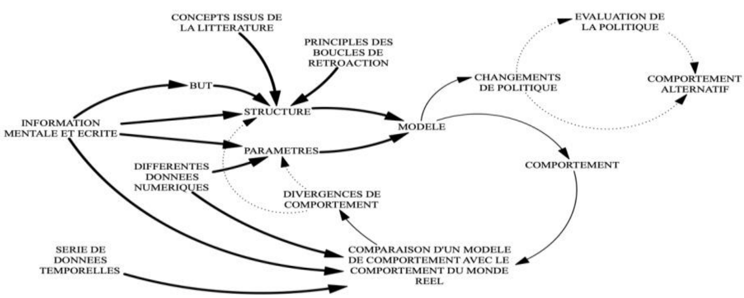


Source: the authors

In figure 1.11, the loop on the left suggests that food consumption generates ever more waste, which can be collected sorted, and transformed into compost, increasing soil fertility and hence agricultural production. It is then possible to respond to increases in a population's food consumption (we have a reinforcing loop). The loop on the right assumes that food waste will be fed into a methanizer, producing electricity, reducing the use of fossil fuels, and cutting GHG emissions (regulation loop).

The aim of system dynamics modelling is to explain behavior by providing a causal theory (Lane & Sterman, 2011), and then to use this theory as a basis for designing policies to intervene in the structure of the system (J. Sterman, 2007), which then enables attempts to modify subsequent behavior and improve performance (Lane, 2008). Every study of system dynamics begins with a problem situation and a set of assumptions used to describe that problem situation (Goodman, 1997). These assumptions are stored in a mental model of system dynamics (MMDS). Figure 1.12 describes the mental process (Arnold & Wade, 2015; Senge, 1990) associated with an objective (goal), which amounts to defining the structure of the model (set of variables linked by casualties via feedback loops) and identifying parameters (we speak of a structural model). It is this model that will generate a type of behavior (to be more precise, it should be emphasized that each variable in a model follows a type of behavior identified by Figure 1.12). The structural model is not simplified; system dynamics take into account all the complex relationships between variables. Data and time series allow us to compare the behavioral model with real-world behavior.

Figure 1. 12: creating a system dynamics model



Source: A. Diemer, (2004)

It should be noted that system dynamics plays an important role:

- The role of simulation: the interaction of these complex relationships almost always exceeds the deductive capacity of the human mind - mental simulation being deficient. Computer simulation is therefore rigorously necessary to deduce the consequences of these relationships, and to reveal the
- Diagramming methods: two diagramming methods are dominant in the system dynamics research community (Lane, 2008). General representations of a model's variables and feedback structure are conveyed using causal loop diagrams (CLD). Stock-flow diagrams (SFD), on the other hand, are more detailed and distinguish between state and flow variables.

At this point in the discussion, it is important to emphasize three four important points relating to the use of system dynamics:

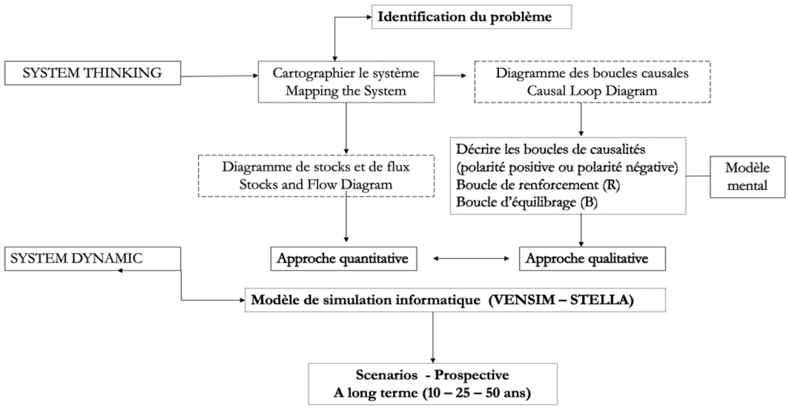
(i) If Industrial Dynamics (1961) and Urban Dynamics (1969) presented system dynamics as a computer simulation model of how sales or a city develop, stagnate or deteriorate, this is because Forrester's main effort was to develop a tool for use by urban managers and policymakers. But system dynamics is first and foremost a method “for dealing with questions about the dynamic tendencies of complex systems, that is, the behavioral patterns they generate over time” (Meadows, 1976, p. 31). System dynamics allows us “to learn about dynamic complexity, to understand the sources of policy resistance and to design more effective policies" (J. Sterman, 2000). As a method rooted in interdisciplinarity, system dynamics has its roots in the theory of nonlinear dynamics and feedback control developed in mathematics, physics and engineering (Milsum, 1968; Wolstenholme, 1985; Wolstenholme & Coyle, 1983). Because we apply it to understand the behavior of human systems as well as physical and technical systems, system dynamics has been used in the social sciences and economics (Morecroft, 1982, 1985). For the latter, it would seem that system dynamics has generated a "paradigm conflict" (A. Diemer, 2004, 2012), with another method, econometrics (Tinbergen, 1954), developed by economists (Irving Fisher, Ragnar Frisch) in the 1930s. As Donella Meadows suggests, "a closer examination of the two modeling paradigms reveals a deeper divide, not easily bridged" (D. H. Meadows, 1976, p. 47). Key words such as predictability vs. unpredictability, linearity vs. non-linearity, quantitative vs. qualitative, open structure vs. closed structure are symbols of the fierce opposition between the two approaches.

(ii) System dynamics focuses on general dynamic trends, "whether the system as a whole is stable or unstable, oscillating, growing, declining or in equilibrium" (D. H. Meadows, 1976, p. 31). Thus, system dynamics as a method, seems to be a very interesting way of improving the theoretical underpinnings and descriptive analysis of long waves (as well as the business cycle). This point is developed by (Forrester, 1977) in his article "Growth Cycles". Considering that most of the literature on business cycles falls into two categories, either statistical analysis of past time series or descriptive speculation on how different aspects of the socio-economic system interact to produce cyclical behavior, Forrester argues that "computer simulation models of system dynamics can be used to retain the strength of the descriptive method while overcoming its main weakness" (1977, p. 525) and to provide a powerful new basis for testing theories of how structure and policy interact to produce fluctuations and growth in a socio-economic system.

(iii) To explore the dynamic tendencies of systems, it is necessary to include in the models' concepts from many disciplines or fields of thought, including those from the physical and biophysical sciences, the social sciences and economics, and to update the theories in the light of our knowledge of the structure of systems. In Industrial Dynamics (Forrester, 1961), introduced models as "a basis for experimental investigation". Models have been widely accepted as a means of studying complex phenomena. A classification of models used certain keywords such as abstract - physical, static - dynamic, linear - non-linear, unstable - stable or steady state - transient.

(iv) System dynamics (Forrester, 1961, 1969) - via causal loop diagrams (CLD) and stock flow diagrams (SFD) - is the study of dynamic feedback systems with the aid of computer simulation (using VENSIM, STELLA or POWERSIM software). It applies to dynamic problems arising in complex social, managerial, economic or ecological systems - literally any dynamic system is characterized by interdependence, mutual interaction, feedback and circular causality. Causal loop diagrams lead us to consider causality as a “continuous process”, rather than a one-off event. The language of systems thinking is therefore that of “links” and “loops”. From any element of a situation (variable), it is possible to draw arrows (links) representing its influence on another element. These links can reveal cycles that repeat themselves over and over again. Links never exist in isolation, they always form a causal circle - a feedback loop (called reinforcement or regulation) in which each element is both cause and consequence. What's more, these loops often introduce delays. Delays can have far-reaching consequences in a system, often specifying the impact of other forces. Loops and delays are part of the Causal Loop Diagram (CLD). CLDs enable us to visualize the structure and behavior of a system, and to analyze the system qualitatively. This is an important point, as it reminds us that a model is first and foremost qualitative (it must be based on hypotheses that need to be tested, i.e., the structural model), then quantitative (the latter, in particular, enabling simulations to be carried out according to different scenarios).

Figure 1. 13: Systems Thinking, Systems Dynamic, Models and Simulation



Source: A. Diemer, (2004)

In addition, CLDs enable us to identify points of intervention in the system and to approximate the effectiveness of a certain policy intervention on the overall system (D. Meadows, 1999).

Table 1. 3: Donella Meadows' leverage points, where to intervene in a System?

12. Constants, parameters, figures (such as subsidies, taxes, standards)	6. Information flow structure (who has and who doesn't have access to which types of information)
11. Sizes of stabilizing stocks in relation to their flows.	5. System rules (such as incentives, punishments, constraints)
10. structure of material stocks and flows (such as transport networks, age structures of the population)	4. The power to add to, modify, evolve or self-organize the structure of the system.
9. Duration of delays, in relation to the rate of system change.	3. System objectives
8. The strength of negative feedback loops, relative to the impacts they attempt to correct.	2. The mindset or paradigm from which the system - its objectives, structure, rules, deadlines, parameters - emerges.
7. The benefits of activating positive feedback loops	1. The power to transcend paradigms

Source: D. Meadows, (1999)

1.4. Results and Discussion

The iSDG model is a simulation interface that interconnects the 17 SDGs and their development indicators proposed by the United Nations. Using system dynamics, it is one of the models that makes it possible to analyze the interactions between the SDGs, measure their performance and implement synergies between different policies to reach the targets set by the SDGs more quickly (Pedercini et al., 2019). Table 1.4 shows the results of applying the iSDG model in a number of developing countries.

Table 1. 4: table of iSDG models in some developing countries

iSDG model user country	**Subject**	**SDGs targeted by the iSDG model**	**Types of policies or programs evaluated**	**Number of scenarios analyzed**	**Results of the different scenarios analyzed**	**Model calibration limits for each study**	**Study recommendations**
Uganda (2020)	Dynamics analysis of Sustainable Development Goals: Achieving the SDGs with	The iSDG-Uganda model simulates the evolution of the 17 SDGs over the period 1995-2030 and for a 2040 vision of the SDGs, in order to identify leverag	The model examines the potential impact of 9 intervention categories the third National Development Plan (NPD 3 covering the period 2020-2025) for the period 1995-2030. These interventi	Three scenarios analyzed: - a Business As Usual (BAU) scenario, which assumes that the current level (2019 investment level) of investment will remain unchanged and that there are no policy	Under the BAU scenario, the average level of achievement for all SDGs is 32% in 2030, compared with 25.1% in 2020, 35.2% in the moderate scenario and 35.9% in 2030 in the optimistic scenario. SDGs 10, 12, 15 and 17 have appreciable levels of achievement (over 50%) in all scenarios, unlike SDGs 2, 5, 11 and 14, which have the lowest levels of	The iSDG model comprises several sectors and several indicators, so having data in all sectors is not obvious. In this report, the lack of data in certain sectors	To test the validity of the results, the technical team suggested comparing historical data with that simulated by the 2019-2030 model. This compar

	Uganda's Third National Development Plan	e points for improving their performance.	ons concern the financing of agro-industrialization, industry, services, infrastructure, water and sanitation, health and education, the environment and governance.	changes after 2020 (no NPD 3). - A moderate scenario with an average additional investment equal to half the budget planned for the period 20201/21 -2024/25 in NPD 3 is maintained after 2024/2025. - An optimistic scenario where after 2024/25 the average level of additional investment planned in NDP 3 for the period	achievement. The performance of each scenario is around 7%, 10.1% and 10.8% respectively. These performances are driven in particular by SDG 9 through investments in roads, railways and infrastructure, which have snowball effects on the other SDGs, and SDG 6 with the improvement in conditions of access to water and sanitation. SDG 12, on the other hand, generates a (very weak) counter-performance with the increase in consumption of natural resources, which has negative effects on the performance of the other MDGs due to the lack of environmental	led the technical committee to develop hypotheses to fill the data gaps. In addition, other existing data do not represent reality or are not consistent, so a readjustment was made through assumptions.	ison validated the results of the analysis, which appear to represent reality. Finally, the poor performance of the SDGs led the authors to propose important leverage points, such as improving governance indicators, environmental investments

				2020/21-2024/25 continues as a percentage of GDP.	interventions provided for in NDP 3.		and investments in industry. And above all, the collective implementation of these interventions, which have beneficial synergistic effects for all the SDGs.
Senegal (2017)	Senegal to 2030: Analysis of scenarios for progres	The T21-iSDG-Senegal modelanalyzes the performance of the 17 SDGs to achieve	The model evaluates the Plan Sénégal Emergent (PSE), the reference framework for Senegal's economic and social developm	Three scenarios: - A BAU scenario that tracks the pace of change in all socio-economic sectors whose current developm	The level of achievement of all the SDGs is 29% in 2030, driven by SDGs 3, 6, 12 and 14 under the BAU scenario. This poor performance is due to low economic growth (4.7%), low inclusion,	Problems of reliability of the data used and the influence of exogenous factors outside the	Model behavior test: compare model results with historical data from 1990-2015. To

	s towards the SDGs for the period 1990-2030	the target goals of the UN Agenda 2030 adopted in 2015	ent for the period 2015-2030. Major interventions include investing in climate change adaptation, increasing fiscal pressure to finance the MDGs, accompanied by the introduction of a taxation system favorable to the poorest, then combining agricultural, livestock, fisheries and aquaculture and agri-food policies, and	ent policies remain unchanged after 2015. - A medium scenario focused on the pursuit of unbridled growth without regard for the social fabric and the environment. This scenario seeks only economic growth, to the detriment of solidarity between and within generations. - This optimistic scenario, which is the quest for	very low levels of investment and unsustainable management of natural resource stocks. Under the medium scenario, the performance of all the SDGs is 41.6%, driven by SDGs 3, 6, 12, 14 and 17, which have achievement levels exceeding the 50% threshold. This level of 41.6% was made possible by an average annual economic growth rate of 5% and the allocation of more resources to building infrastructure and improving basic social sectors. Under the optimistic scenario, the level of SDG achievement is 61.3%, with economic	country that the model cannot take into account in the simulation.	achieve the agenda 2030, the study recommends taking into account all the dimensions of sustainable development, notably economic, social and environmental.

			finally, improving good governance.	emergence in all development sectors, aims for "*an emerging Senegal in 2035, with a society based on solidarity and the rule of law*" with the Plan Sénégal Emergent (PSE).	growth estimated at 7.3% over the 2015-2030 period. The optimistic scenario shows progress towards economically, socially and environmentally sustainable development by 2030, even if further policies remain to be put in place. The performance of this scenario is influenced by increased public investment, the involvement of the diaspora in development through foreign direct investment, and improved good governance. Hence the high performance of SDGs 2, 6, 8, 13, 15, 16 and 17.		
Ivory Coast (201	Toward achievi	The T21-iSDG-Côte-d'Ivoire	The model assesses the impact of	Three scenarios are simulated :	Under the BAU scenario, the level of achievement of all the SDGs is	The model is based on simulat	Replication of historical behavi

6)	ng Sustainable Development Goals in Ivory Coast: Simulating pathways to sustainable development	model integrates economic, social and environmental policies to achieve the 17 SDGs by 2030.	implementing the National Perspective Study (NPS) program on the performance of the 17 SDGs for the period 1990-2030 and a 2040 perspective.	- a BAU scenario that simulates the performance of the 17 SDGs by 2030 with current policies and without the implementation of the NPS. - an NPS scenario that evaluates the impacts of the policies included in the NPS with funding of 4.5% of GDP - an SDG scenario that assesses the effects of policies included in the	estimated at 21% out of a target of 100% achievement by 2030. This rather weak performance is due to a poor population living in famine with poor access to health infrastructures and a low level of education. However, under the NPS scenario, the level of SDG achievement is 50%, due to a reduction in poverty, inequality and famine, investments in health and adaptation to climate change. And under the SDG scenario, the level of SDG achievement is 67%. This performance is greatly influenced by the coherence between SDGs 1 to 5 and SDGs 11, 13 and 17,	ions, not precise predictions, and is made on aggregated indicators from different sectors and does not take into account local indicators. In addition, the lack of data for several indicators means that the model only takes into account 78 SDG indicat	or in the main sectors from 1990-2015 validated the model results. In terms of policy recommendations, the analysis suggests increased funding for adult population training, sustainable economic growth benefiting low-income populat

				NPS and additional policies recommended by the UN Agenda 2030 with funding of 15% of GDP.	due to the combination of several synergistic policies such as increasing healthcare spending, adapting to climate change, reducing poverty and inequality, and waste management. This combination of mixed policies enables populations to escape the poverty trap through the accumulation of human and financial capital, which is an important factor for economic growth.	ors instead of the 230 indicators proposed by the UN Agenda 2030. Finally, some of the target values used for the SDGs do not respect those established by the UN, so these target values are debatable at national level.	ion groups, efficient use of natural and water resources, improved good governance, promotion of sustainable mobility and renewable energies, and promotion of sustainable peace, as Côte d'Ivoire has experienced many political crises in its history.
Nig	Ach	The	Economic	Three	The simulation	The	More

eria (2019)	ieving the SDGs in nigeria: pathways and policy options Report of Simulation-based Scenario Analysis of SDGs Attainment using the Inte	simulation of the iSDG-Nigeria model covers all 17 SDGs, taking into account five of Nigeria's major problems: conflict, oil and gas exploitation, solid mineral exploitation, power sector problems and sub-local disaggregation.	Recovery and Growth Plan (ERGP) for the period 2017-2020. There is at least one intervention in each of the SDGs, which include combating poverty and food insecurity, improving the quality of education, developing industry, adapting to climate change and protecting natural resources, infrastructure and basic	analysis scenarios were developed: - non-ERGP scenario, which assumes no policy changes after 2015 with a continuation of pre-ERGP policies - ERGP optimistic scenario which estimates the potential impact of the policies included in the ERGP program for achieving the 2030 Agenda by maximizing on improved governan	shows that without the ERGP program only 2/64 of the indicators will be achieved by 2030, with only SDG 12 having a level of achievement above 50% and 12/17 SDGs having levels of achievement below 30% in the non-ERGP scenario in 2030. In the optimistic scenario with the implementation of the ERGP program 16/64 indicators will be achieved, only 9/17 SDGs have performance levels above 50% and only 4/17 SDGs have performance levels below 30%, and SDG 2 is almost achieved in 2030. Finally, under the ERGP's SDG policy optimization	major challenge of the study was the problems of data availability and quality in several areas, especially in conflict regions. As a result, the model consists of only 64 SDG indicators, due to the lack of data.	investment in data mobilization at national and local level by the State Bureau of Statistics and its partners, so that many sectors can be taken into account for future simulations.

	grated Sustainable Development Goals model for Nigeria		social services, governance and resource mobilization.	ce - an ERGP+ODD scenario that incorporates synergistic policies that can improve SDG performance in areas where the optimistic scenario's policies are ineffective and insufficient. This scenario optimizes spending, taxation and other additional policies.	scenario, 25/69 indicators are almost achieved, 3/17 SDGs are almost achieved and only 3/17 SDGs have performance levels below 50% in 2030. This scenario points to the prospect of achieving the SDGs by 2030 if new, effective and coherent policies are put in place and all sub-national governments are involved in implementing these development policies and programs.		

Malawi (2020)	Industry note: seeing through the SDG maze - the iSDG model, a simulation-based tool to aid SDG **planners**	The iSDG-Malawi model is applied in this report to MDG 2 through the fight against food insecurity and undernutrition.	The policy evaluated in this report concerns the effects of investing in water-use efficiency in irrigation through the conversion of existing irrigation to water-efficient technologies, and the expansion of efficient irrigation to previously unirrigated land to promote MDG 2. This ambition is financed through	Two scenarios have been simulated in this report: - a BAU scenario assuming no new irrigation policy after 2016 - an alternative scenario with the implementation of a water-efficient irrigation policy over the 2017-2030 period.	Under the BAU scenario, cereal production rose from 4 million tonnes to around 4.75 million tonnes in 2030, while under the alternative scenario it reached around 5 million tonnes, thanks to irrigation, land intensification and the exploitation of new areas. Under the alternative scenario, the increase in cereal production had a positive impact on GDP growth and GDP, with per capita cereal production rising from 0.1 tonnes per person to 0.4 tonnes per person in 2030. On the other hand, population growth constrains the benefits of this policy, with little reduction		There is coherence between MDG 2 and MDGs 1 and 6, so the introduction of efficient irrigation has led to an expansion of irrigated areas, which in turn has increased agricultural production (MDG 2) and slightly reduced the number of people living below the poverty line (MDG 1). Secondly, this irrigation policy has contributed to a deterioration in the water vulnerability index as a result of increased water consumptio

			an increase in annual investment to 1% of GDP in the irrigation sector.		in poverty and undernutrition over the 2017-2030 period. Secondly, land intensification increases the intake of nutrients that will impoverish the land, and the increase in water use through irrigation destroys the water vulnerability index during this period.		n by agriculture (MDG 6). The author of the paper therefore recommends that the government of Malawi find coherent policies capable of minimizing the negative effects of this policy on the other SDGs.

Source: The authors

The aim is to study the level that each SDG will reach by 2030, and to measure the overall performance of all the SDGs (Pedercini et al., 2020). The ISDG model has been applied in more than 40 countries around the world, producing interesting results on which public decision-makers have based their long-term decisions. The development of the iSDG model is the work of Millennium (MI), it provides public decision-makers with support for sustainability planning and policy evaluation to achieve the United Nations Agenda 2030 (Pedercini et al., 2018). In this way, it enables a set of policy strategies relating to the SDGs to be drawn up, and their relevance in terms of their contribution to development to be assessed at each stage of their implementation. Another important aspect of the model in the planning process is that it makes it possible to estimate the budget for policy implementation and, above all, the allocation of the national budget between different sectors.

Today, the use of the iSDG model is particularly appropriate at the national level, as its structure and calibration are based on national data that can be simulated. However, there are three main challenges to improving the model: (i) improving the robustness of the equations it uses, and (ii) applying the model at local level (particularly city level) for decentralized studies. Finally, the model needs to be applied to the regional scale of several countries, given that development is also an interaction between countries through the elaboration of common policies, the construction of common infrastructures and the pooling of investments.

The main results in Table 1.4 show that the model can be used to assess the effects of several (policy) scenarios relating to the SDGs, to estimate the budget for each scenario, and to guide policymakers towards tangible, achievable objectives. The Business As Usual (BAU) scenario is a reference scenario for comparing the impacts of adopted policies in terms of indicators and SDG performances. Alternative scenarios (simulated via supplementary or additional policies) are compared with the reference scenario. The difference between the levels achieved for the SDGs in the alternative scenarios and their levels in the reference scenario (by 2030) constitutes a kind of performance indicator for each SDG as a result of the new policies adopted.

In addition to its applicability at the scale of all 17 SDGs, the iSDG model can be used to develop policies dedicated to a single SDG, such as food security, access to water, education, health, and so on. Côte d'Ivoire used it in 2020 to study the relevance of investments in MDG 4 to achieve a prosperous economic and social situation by 2040, focusing on early childhood development in the "Étude Nationale Prospective Côte d'Ivoire 2040 (ENP)" plan based on the UN Agenda 2030. MDG 4 aims to ensure access to quality education for all, regardless of gender, and to promote lifelong learning. In fact, it is at the heart of all the MDGs, as it is connected to and has a positive influence on improving the performance of several MDGs. A well-educated population possesses a strong production capacity, with the acquisition of good individual and collective skills that guarantee economic development and social well-being. Indeed, investing in early childhood development is a lever for developing children's human capital, notably their physical, cognitive, linguistic and socio-emotional factors (Naudeau et al., 2012).

Table 1. 5: investment in the education sector in Côte d'Ivoire

Coast Ivory Coast	Investing in early childhood develop	The model simulates the	Three policies are evaluated in this	Three scenarios are simulated: - a	The results show that, in general, maternal and child health programs have a greater impact	Missing data were recorded for	In terms of policy recommendations, the poor performance

(2020)	ment and education for the socio-economic development of Côte d'Ivoire: an analysis based on the **iSDG** model	achievement of the 17 SDGs of the 2030 Agenda with a focus on improving health, education and economic indicators for National Prospective Study (ENP) adopted in 2015 for an industrialized Côte	report: - conditional money transfers and the creation of educational facilities for children under 5 - development of maternal and child health programs - the deployment of various quality education policies through teacher training and the reduction of pupil/te	BAU scenario, under which today's budget spending remain unchanged after 2019 - a moderate scenario under which the investments of these three intervention groupings are carried out as provided for in the ENP - a strong scenario in which these	on health indicators and on the other MDGs, while cash transfers to enroll children in pre-school improve their success in primary and secondary school, and increase the number of years of schooling, but have little impact on nutrition indicators due to their low territorial coverage and high cost. Quality education interventions reduce the dropout rate, increasing the number of years of schooling, which will undoubtedly have long-term economic effects and reduce inequalities. In terms of the performance of the SDGs under the BAU	the year 2020 for some indicators, the year in which the study was carried out, and also the total absence of data for some 1990-2020 indicators, such as the proportion of the total population living in rural areas.	of nutrition indicators, which are much more closely linked to agricultural production and household income, shows that the government needs to invest heavily in agricultural production programs and training for sustainable agriculture, which is both beneficial for income populations and for healthy eating. Secondly, the report's authors encourage the government to invest sufficiently in health,

		d'Ivoire by 2040	acher ratios.	investments are doubled after 2019	scenario, only SDG 13 is achieved by 2030 and 2040, while SDG 2, which is important in the study because it concerns nutrition indicators, is below 1%. MDGs 1, 3 and 4 show an improvement in 2030 and 2040, but their level of achievement is below 50%. In the moderate scenario, the cost of interventions is estimated at 0.89% of Ivorian GDP, or 197.8 million Fcfa over the period 2020-2040, when the three policies are combined. Only MDG 13 is still achieved. MDGs 3, 4 and 5 show a significant improvement by 2030 and 2040, while MDG 2, which was virtually non-	of the population aged 20 to 24 who have completed the secondary. In this case, some of the model's results are questionable.	pre-school and education and the reduction of gender inequalities, which are important areas for the development of children, young people's human capital and future economic benefits. Finally, other indicators such as governance, the human capital index and wealth distribution, which are not prioritized in the study but are important for improving SDG performance, should be

					existent, shows a slight improvement above 1% by 2040. The combination of the three interventions does not constitute a force for boosting the performance of the SDGs, as the synergy between them is -0.011%. In the strong scenario, investments represent 1.78% of GDP over the period 2020-2040, or 449.1 million Fcfa when the three interventions are combined. In this case, almost all the SDGs have seen an improvement in their performance, except for SDG 13, which had already reached its target value before 2030 and 2040. SDGs 1, 2, 3 and 4, which are the target SDGs of the		prioritized in public spending.

					study, recorded an improvement thanks to the combination of the three interventions, whose synergy is positive (0.002%).		

Source: the authors

The use of the iSDG model in this project is to analyze the cross-sectoral synergies that can emerge from the interaction between the MDGs that can improve early childhood development, accelerate MDG performance and maximize the effectiveness of investments. And the three forms of policy simulated in this project are expected to potentially influence MDG 2 through the reduction of malnutrition, undernutrition and stunting. MDG 3 with the reduction of maternal mortality, child mortality at birth and neonatal mortality. Finally, MDG 4, through inclusive education, reduces the dropout rate at all levels of the education system, and improves children's school performance. The table below summarizes the results of the study, on which two important recommendations were addressed to the Ivorian government: maximizing investment in the agricultural sector, which employs the majority of the workforce in Côte d'Ivoire. And sustained investment in the education sector, which contributes to reducing inequality and poverty, and improving the health and well-being of the population in general.

1.5. Conclusion

Since the early 1970s, simulation models have been used by governments as tools for long-term development planning. The World 3 model (Limits to Growth, 1972) is considered the forerunner of the Integrated Assessment Models. It also initiated, via a new methodology - system dynamics - a certain craze for national models. The T21 model, followed by the Millennium Institute's iSDG model, set out to define a country's various sustainable development trajectories, seeking to go beyond the objective of unlimited economic growth (with GDP as the main target). Indeed, since 2015, achieving the Sustainable Development Goals requires different strategies in different countries, and policymakers need to understand the interconnections between the 17 SDGs in order to best target the development strategies that need to be put in place. The iSDG model simulates the fundamental trends of the SDGs up to 2030 in a “Business As Usual” scenario (BAU), and then proposes alternative scenarios that could put different governments on the path to strong sustainability. This makes it easier to identify the leverage points (points of intervention) that can lead to rapid, positive change. In a way, the iSDG model updates the principle of optimizing public spending by broadening the scope of public intervention from the economic to the environmental and social spheres.

2. Modeling Economics and Sustainability: GDP as a goal vs GDP as a driver

Abstract[4]: In this paper, we are talking about the role of GDP as a goal vs driver in the four tools that are used to assess national policy impacts in developing countries. It consists of a benchmarking that concerns the Dynamic Stochastic General equilibrium (DGSE) model of the International Monetary Fund, the Long-Term Growth Model (LTGM) of the World Bank, the Stock-Flow Consistent Prototype Growth Model of Agence Frnçaise de Developpement, and the integrated Sustainable Development Goals (iSDG) of the Millennium Institute. The benchmarking considers four criteria of benchmarking which are important to describe the behavior of sector development such as feedback loop mechanisms (cause and effect relationships), the nature of elements that compose them (stock and flow variables consideration), the ability of the models to elaborate a large number of synergistic policies (prospection model), and to measure SDGs performances. View to the fast-changing socio-economic and environmental conditions, development planning becomes much more difficult for policymakers and governments. These models serve as a compass to guide policymakers in their choices of public policy implementation to improve populations living conditions and make progress toward long-term development for their countries. For this reason, we analyze the place of GDP in each model, and the structure of each to consider the main important sectors of development in the environmental, social, and, economic domains, and further measure the progression of the 17 SDGs for countries. The results of the analysis show that only the iSDG model meets all four requirements that we defined. Although the Stock-Flow Consistent Prototype Growth Model uses a feedback mechanism like the iSDG its structure is limited to an accounting analysis between economic agents. The two remaining models that are maximizing GDP with a Cobb-Douglas production function (GDP as a goal) models do not consider social and environmental sustainability meaning the adverse impacts of human activities and actions on social well-being and environmental quality.

Keywords: Sustainable Development Goals assessment tools, GDP as goal vs GDP as a driver, public policy modeling in developing countries.

[4] This chapter was written with Arnaud DIEMER, and published in the iBusiness Journal.

2.1. Introduction

The changing socio-economic and environmental conditions make development planning much more difficult for policymakers and governments. The modeling process as a practice or tool is useful for reconnecting the different parts of a national economy, but also for re-embedding them within social and ecological boundaries (McManners, 2015). The interconnectedness and complexity of the relationships between the economy, society, and the environment are now more than recognized by the United Nations (UN) and International Institutions (II). The 2030 Agenda for Sustainable Development adopted by all United Nations member States in 2015, provides a shared pathway for peace and prosperity for people and the planet. At its heart, the 17 SDGs are a call for action by all the countries - developed and developing. Ending poverty, improving health and education quality, securing the food system, and reducing inequalities, social services, and infrastructure access, … are the different objectives of the roadmap. Every year, the annual SDG progress report (from the UN Secretary General) uses data collected by national statistical systems to give an overview of the commitments of all the stakeholders. This implementation of global goals is an increasingly complex challenge, especially when the question is to achieve the targets set by the 17 SDGs (Khushik & Diemer, 2020). Firstly, environmental, social, and economic spheres are interconnected and interact dynamically (Anderson & Johnson, 1997). It means that the decisions and policies implemented to achieve one SDG (for example eradicating poverty) have repercussions on the others. Indeed, development is a dynamic process and adopting public policies without taking into account these interconnections in national development planning would make things even more complicated to address and jeopardize the desired objectives. Secondly, the challenge of development planning is to finance national policies to achieve the different goals of the UN 2030 Agenda because nowadays, investment funds have become rare, borrowing interest rates become higher and higher, and the derisory situations of the balances of accounts of the countries. This situation locks particularly developing countries into a trap to finance their development planning. A low rate of economic growth may become a disadvantage when it is necessary to accumulate more capital (human and technical) for financing public policies (Zeufack et al., 2016). Some countries have to support private and public debts at enormous costs to finance their policies. A simple causal loop diagram shows that a high cost of debt means more interest on the debt to pay and less return on investment for the government, so less income. If the government's revenues go down, the government budget will be reduced and there will be less investment in the future, whereas the level of capital accumulation of a state depends on its ability to invest. In the case of investment being low, there is less capital, which drives the government to the poverty trap. Thirdly, policymakers are facing a great challenge in finding planning models that can guide their public policy choices. Because development is an interactive process between the economic, social, and environmental domains, public decision-makers need planning tools that must be able to provide knowledge on the performances of sustainable development indicators, to prevent or anticipate shocks (endogenous or exogenous) on the overall system. It means that these methods that use mathematical symbols, letters, numbers and mathematical operators must be able to describe properly environmental, social and, economic problems that faced the policymakers (Olaosebikan et al., 2022) and to provide in-depth knowledge of the interconnections and interactions between different drivers of the system. The models must also be transparent in their structure and help policymakers to give effective communication about society problems description, the implementation of public policy for the fact that "communication plays an important role in all aspects of the development and use of public policy" (Quy & Ha, 2018). Finally, SDGs are not only new objectives or targets adopted by developed and developing countries for the future of the planet (and the human society), but they are also the universally agreed road map to bridge economic, environmental, social, and geopolitical divides, restore trust, and rebuild solidarity. As Antonio Guterres, Secretary General of the United Nations, mentioned in the Sustainable Development Goals Report (2023): "Failure to make progress means inequalities will continue to deepen, increasing the risk of a fragmented, two-speed world" (UN, 2023). No country can afford to see the 2030 Agenda fail. Many of the UN proposals are supporting acceleration towards achieving the Goals. Commitments must ensure progress in different areas, especially the reform of the international structure, going beyond Gross Domestic Product (GDP).

This reform is not limited to the efforts to create new financing models, new business models, or new metrics, the challenge is to keep using GDP as a goal in the economic system, and more generally in the global system. So, the reform also concerns the way to model sustainability, especially in the International Institutions (World Bank, IMF, …). The challenge is to switch from a system in which GDP is a goal to one where it is only a driver. As a driver, GDP should still have a key role in some causal loop diagrams (transforming education, securing social protection, reducing inequalities, improving infrastructures), but will not be anymore the goal to improve welfare. This paper has two objectives:

(1) Producing a benchmarking analysis of different models developed by International Institutions (Agence Française de Développement (AFD), the International Monetary Fund (IMF), and the World Bank) to highlight the role of GDP as a goal.

(2) Introducing the iSDG model, developed by the Millennium Institute (MI) and based on Systems Dynamics (SD), to take into account the 17 SDGs and introduce a new role for GDP, GDP as a driver of the overall system (including environmental, social and economics domains).

Our research has identified four types of dynamic models aimed to evaluate economic situations, the effects of public policies implemented by countries and to predict their development trend. The Dynamic Stochastic General

Equilibrium (DSGE) model is used particularly by international institutions such as the IMF, the World Bank, the OECD... The DSGE model is based on general equilibrium theory in the evaluation of the macroeconomic impact of fiscal and monetary policies. The World Bank's Long-Term Growth Model (LTGM) is an Excel-based tool to analyze long-term growth scenarios based on the Solow-Swan Growth Model. It helps developing countries to predict their economic growth until 2050 through the drivers of production, especially total factor productivity (TFP), labor, capital, investment and natural resources. The Stock-Flow Consistent Prototype Growth Model (SFCP-GM) of Agence Française du Développement (AFD) is a stock-flow growth model in continuous time in order to analyze the effects of policy rates in financial centres on a small open developing economy with an open capital account and a flexible exchange rate. Using a balance-sheet approach and explicitly modelling real-financial spheres interactions and propagation mechanisms, the model explains how a fall in global policy rates triggers appreciation-induced boom-bust episodes in the small open economy, driven by portfolio flows and cross-border lending. Finally, the integrated Sustainable Development Goals (iSDG) model of Millennium Institute (MI) is a system dynamics-based tool that has been designed to support national development planning and analyze medium-long term development issues at a national level. The model integrates into a single framework the economic, social and environmental aspects of development planning. iSDG model has been conceived to complement budgetary models, sectorals models and other short to medium-term planning tools by providing a comprehensive and long-term perspective on development.

The paper is organized as follows. The first part consists of presenting the DSGE and the LTG Models which trigger the GDP as a goal because both models focus only on its components and their economic dimension. The second part presents the AFD's SFCP-G Model which uses a systemic approach of stocks and flows to describe the interactions between the different agents of the economy. The third part is to present the structure of the iSDG model which focuses on the three domains of sustainable development and make the GDP as a driver of Sustained Prosperity for developing countries. The fourth part of the paper is a benchmarking of the four models which consists of focusing on four characteristics to compare them. Firstly, the capacity of each model to take into account the 17 SDGs developed by UN nations in its structure. Secondly, the use of stock and flow concepts to distinguish the types of variables. Thirdly, the use of feedback loops to show the interactions of different variables. Finally, the fourth characteristic is to analyze the type of the models to consider the future in the analyses of the development. This part will distinguish the models that analyze the development trend by using prediction methods and the models that analyze the development by using different scenarios of policies (prospective). And end, the paper concludes with a brief summary of the benchmarking results according to the four comparative criteria. We then propose a series of recommendations for international institutions to include certain sustainability criteria in their models for assessing the impact of public policies.

2.2. Research method

In this paper, the research methodology is theoretically based on a literature review of dynamic models used by international institutions such as the World Bank, the IMF, the AFD, the MI, … which work closely with countries. These institutions work with the governments of developing countries to help them implement effective policies to address their challenges. Our work is to describe the structure of each model, in order to make a comparison between them in terms of considering sustainability and assessing the performance of the SDGs. Thus, the first step of the research is to identify the most popular dynamic models used by international institutions to assess policy outcomes in developing countries. The identification is based on the ability of the models to consider different sectors in their structure, purpose and simulation period. Model identification allowed us to consider the DSGE, LTGM, iSDG and SFCP-G models for the study. We have focused on the main variables calculated in the structure of these models, presenting the mathematical equations for these variables in order to analyse the level of complexity of the model and the different parameters considered. Next, we studied the applications of these models in a number of developing countries by creating a synthetic table based on the literature review. The synthetic table for each model of application presents the reasons for using the model, the policy implemented and the results of the application according to the country. We then defined four comparison criteria, such as the ability of each model to track SGD performances, the dynamic interactions between sectors and variables, the type of each model, i.e., prospective or predictive model, and the distinction between accumulative and flow variables. The development sectors and variables are interconnected by many feedback flows of information, which could be described as feedback loops. However, ignoring these feedback loops in policy implementation is synonymous with a lack of information relevant to the implementation of synergistic policies (prospective policy scenarios) that could lead to high results in the medium term and long term. Based on these four criteria of benchmarking, we have made some recommendations to the international institutions on the elements to consider in the structure of their models for a better assessment of policy outcomes and problem solving in developing countries.

2.3. GDP as a goal

Gross Domestic Product (GDP) is one of the most widely used indicators of economic performance. It measures a national economy's total output in a given period. For policy makers and Business managers, GDP is a macroeconomic indicator for the estimation of annualized rate of national growth, it drives investment decisions. For economists, GDP represents the value of all goods and services produced over a specific period within a country's border. GDP is supposed to track the 'economic health' of a country. It determines whether an economy is growing or not (if the GDP goes down, the economist talked about recession). The culture of GDP identifies consumption, investments, exports and imports, and government expenses as the main drivers of economic growth. For the United Nations (UN), GDP is part of the SDG 8 "Decent Work and Economic Growth". Global real GDP per capita growth is forecast to map different economic challenges (labor productivity, unemployment rate, opportunities to get work, financial services to ensure sustained and inclusive economic growth…). Two models - using GDP as a goal- have been studied in this part: the Dynamic Stochastic General equilibrium (DGSE) model of IMF and the Long-Term Growth Model (LTGM) of the World Bank.

2.3.1. The Dynamic Stochastic General Equilibrium (DSGE) model, IMF, WB, …

DSGE models are econometric models based on Walrasian general equilibrium theory. They use microeconomic foundations (in the economy each agent has the objective of maximizing his utility function) to evaluate the macroeconomic impacts of monetary and fiscal policies (Zeufack et al., 2016). They are used to describe business cycles of economy (Comin et al., 2014) through productivity decreasing and make predictions about the future dynamics of macroeconomic aggregates (Del Negro & Schorfheide, 2013). These models are more widely used by monetary authorities in the assessment of monetary and fiscal policy (Christiano et al., 2010), notably the

IMF and WB. The acceptance of the DSGE model by economic institutions is related to its ability to take into account the rationality expectations of agents when they make their decisions (the DSGE model is spared by the criticisms of Lucas, who says that economic agents adapt to the economic policies conducted by the government and Central Bank) and its capacity to represent the intertemporal movement of economic variables (Junior, 2016) thanks to its stochastic character (Malgrange et al., 2008). Its stochastic character allows it to determine the dynamics of aggregated variables due to the random shocks (Sergi, 2015) (aid, fiscal policy, productivity, foreign interest rate, demand,...).

So, the DSGE model is a simple model that allows one to build an economy by working with some representative agents of households, firms, government, and financial sectors. It is a framework tool that gives an overview of the agent's interactions and also to see how an economic policy can affect the whole economy and the behavior of each agent. The model supposes a small economy which is initially in long term equilibrium and interacts with the rest of the world (IS-LM and Fleming-Mundell models). The economy cannot influence the international aggregates which are considered as exogenous. This is the case of developing countries which are highly dependent on the stability of the international market and whose economies are fragile to shocks. Indeed, the growth of developing economies depends heavily on the stability of the international market. Any shock like price, foreign interest rate, technology, demand and production affects considerably the stability of macroeconomics aggregates of countries. Thus, the reasons to use Dynamic Stochastic General Equilibrium (DSGE) models to assess the effects of these shocks, which are unpredictable and mostly random. First, they are able to capture the interactions between agents in the economy and the uncertainties arising from their choices through the dynamics of macroeconomic results (Junior, 2016). Second, they also have the ability to describe the transmission channels that shocks can use to affect the economy as a whole (Saxegaard & Shanaka, 2007) and modify agents' behaviors. And end, the model enables us to predict the evolution of the economy through the anticipations of agents about “the future evolution of the economy” (Saxegaard & Shanaka, 2007) and macroeconomics variables(Del Negro & Schorfheide, 2013). Economic growth depends on the interactions between agents and each agent has its own utility function that describes its needs and allows it to maximize its profit. Knowing that in equilibrium, the demand is equal to the production that is the sum of consumption of households, the private investments, government expenditures (development and no development), and the net balance of trade. So, in the following sentences, we will see the equations that are used in the DSGE model to describe the behavior of each agent.

2.3.1.1. Households

The basic DSGE model considers a representative household that maximizes its utility function through consumption and work effort under its budget constraints (Ahrend et al., 2011). The household makes trade-offs between savings and income consumption and between work and leisure of its time (Xu et al., 2014). Indeed, his utility function is presented as follows:

$$\max E_t \sum_{0}^{\infty} \beta^t U(C_t, \frac{M_t}{P_t}, L_t) = E_t \sum_{k=0}^{n} \beta^t \zeta_t (\log (C_t - hC_{t-1}) + \alpha \log \left(\frac{M_t}{P_t}\right) - \frac{\varphi}{1+\varphi} L_t^{1+\vartheta})$$

E_t is the expectation operator conditional on information available at period t (Khramov, 2012), C_t and M_t/P_t denotes the aggregate consumption and the real money balances held by households. L_t represents labor supply in hours of work. $\beta_t \epsilon (0,1)$ and P_t are respectively a constant discount factor of the household and the aggregate price level. ζ_t is a consumption shock due to the intertemporal preferences of the household. It is considered as a demand shock, inducing households to increase or reduce their consumption. $h \epsilon (0,1)$ denotes the degree of habit persistence which shows that household's marginal utility depends on the effect of the level of the last period's aggregate consumption C_{t-1} on the consumption of today. α , φ and ϑ represent respectively the share of Household real money for consumption, the level of labor supply, and the inverse of the Frisch elasticity of labor supply (Hall, 2015) (the variation of hours of work caused by a variation of wages).

The household budget constraint can be as follows:

$$P_tC_t + M_t + B_t + P_tI_t + e_tB_t^* \leq M_{t-1} + B_{t-1}(1+i_{t-1}) + (1-\tau)\varpi_t L_t + (1+i_{t-1}^*)e_tB_{t-1}^* + R_tK_{t-1} + T_t + Div_t + e_tRem_t$$

where the resources (revenues) of the Household are given by: M_{t-1} (savings) is the stock of the nominal value of consumer's holdings in domestic currency in period t-1, B_{t-1} and B_{t-1}^* are respectively the quantity of nominal bonds of the last period in national currency and foreign currency. ϖ_t is the real nominal wage, R_t, the real rental of capital and K_{t-1} the level of capital in the last period. And end, e_t, Rem_t , T_t and Div_t are respectively the exchange rate, foreign transfers, government transfers for Household and dividends which are the profits from firms activities (Matsumoto & Engel, 2005). The representative Household uses his revenues to finance his expenditures such as: B_t and I_t is respectively the number of nominal bonds (national and international) purchased in period t and the investments and new capital. M_t is the nominal value of consumer's holdings in domestic currency in period t, B_t^* is the quantity of foreign bonds in foreign currency at the period t.

2.3.1.2. Firms

The representative firm maximizes its profit through its production function under the constraints of capital, technology, and labor costs. The representative finished goods-producing firm Y_t uses intermediary goods from domestic and foreign firms in its production:

$$Y_t = \int_0^1 [Q_t(i)^{\frac{\mu-1}{\mu}} di]^{\frac{\mu}{\mu-1}}$$

where $Q_t$is the demand function of intermediary goods, μ >1, the elasticity of substitution between intermediary goods that can measure the degree of monopolistic competition between intermediary goods producers. A larger μ means less power for intermediary goods producers to set their price (Xu et al., 2014). $Q_t(i) = [P_t^i/P_t]^{-\mu} Y_t$, μ is the price elasticity of demand for each intermediary good.

The production function of the ith intermediate good producer is:

$$Y_t(i) = \theta_t \vartheta_t^{\gamma} (L_t^{\alpha} K_{t-1}^{1-\alpha})$$

Where θ_t is the productivity or technology that depends on government and the private sector investment in capital goods. ϑ_t^{γ} is the fraction of intermediate good input used to produce and α is the elasticity of the labor force. Private capital accumulates over time and its level depends on investment made and the depreciation rate of capital in the last period. So,

$$K_t = I_{t-1} + (1 - \delta) K_{t-1}$$

The intermediary firm uses physical capital and labor into the production process by minimizing its cost:

$$R_t K_{t-1} + (1 + \tau) \varpi_t L_t.$$

The firm program is:

$$\max \Pi_t = P_t^i Y_t(i) - R_t K_{t-1} - (1 + \tau) \varpi_t L_t$$

2.3.1.3. Government

The government is a regulator of economic activity and has a role of fiscal policy regulation (operating expenditures and investments). It derives its resources from taxes on the transactions of other agents, bonds emissions (B_{t-1}), net budgetary aid (A_t) in national currency, revenue of natural resources extractions (O_t), debt (D_t), and the profits (Π_t) generated by the Central Bank. It is in charge of resource allocation, public infrastructure and services construction and, public welfare optimization through social transfers and tax rate targeting. Its budget constraint is:

$$P_t G_t = B_t - T_t + \tau^{\omega} \omega_t L_t + \tau^{c} C_t + \tau^{\Pi} \Pi_t - R_t B_{t-1} + e_t A_t + O_t + D_t - D_{t-1} - i_t D_{t-1}$$

Under the budget constraint, the government chooses the expenditure and investment levels to maximize social welfare. So, the resource constraints of the overall economy are equal to:

$$Y_t = C_t + I_t + G_t$$

2.3.1.4. Central Bank

The role of the Central Bank is to regulate monetary policy through Taylor rules (Christiano et al., 2010). Monetary authorities target the nominal interest rate by taking into account the economy's performance, the real interest rate of the last period, and the level of future inflation (Vitek et al., 2022).

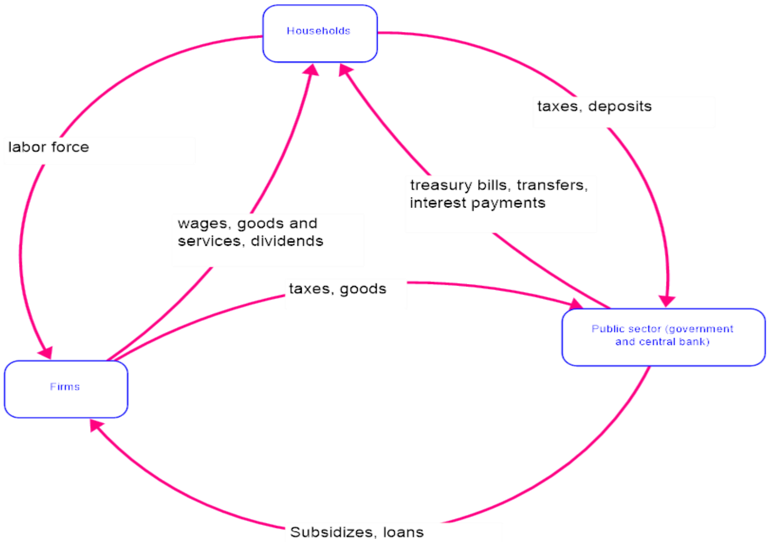
$$r_t = \varphi_r r_{t-1} + \varphi_\pi \pi_{t+1} + \varphi_y \hat{Y}_t + \varepsilon_t^r$$

Where $\hat{Y}_t$ is the growth gap between the real GDP and the potential GDP, and ε_t^r is a monetary shock.

2.3.1.5. The characteristics of the model

Thus, in general, we have the interaction between these agents that brings the national economy to a state of equilibrium and the exchanges with the rest of the world if the economy is open to the international market (Junior, 2016). And the calibration of the model parameters through econometrics methods is necessary to determine the value of variables at the steady state and the model simulation (Adjemian & Devulder, 2011).

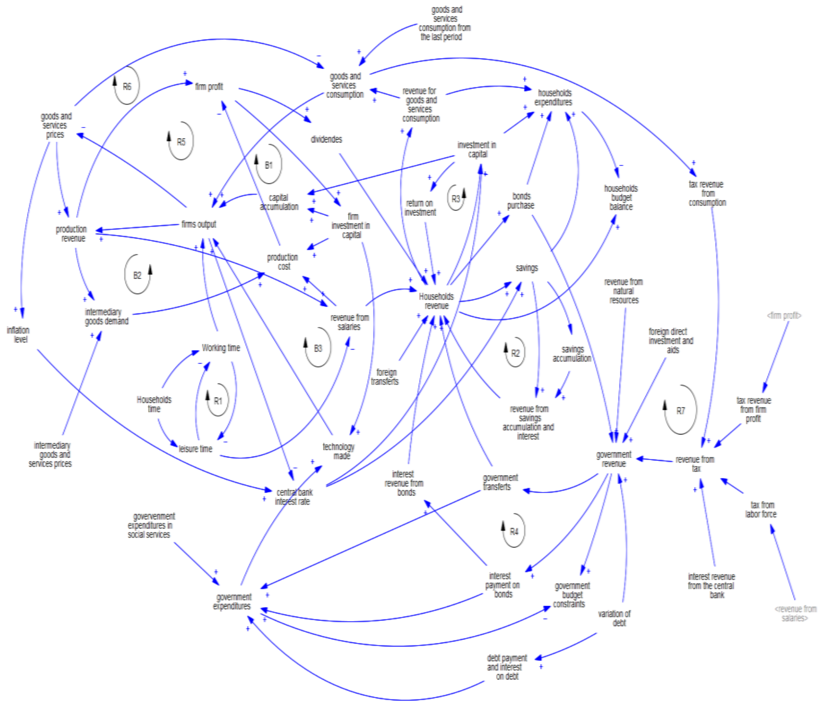
Figure 2. 1: transactions between actors in the national economy for the DSGE model



Source: the authors

The model is calibrated by setting values for the parameters (estimated econometrically) of the model's equations that lead the economy to a steady state or stationary state (Sergi, 2015). Most of the variables that are simulated by the DSGE model are GDP, consumption, output, investment, exports, imports, exchange rate, inflation, prices, employment, money supply, deposit rates, lending rates, foreign and domestic currency reserves, government bonds, aid, government spending, private sector lending, ... The arrows used in the model show only the origin and destination of transactions and not feedback loops referring to the dynamics of transactions. For example, the loop going from household toward firm signifies that households provide their labor force to companies in exchange for wages which allow them to buy goods for consumption. The following CLD explained the DSGE structure and the agents budget constraints in the system Dynamic view. The balancing feedback loops B1, B2, and B3 show the production costs (labor, capital, and intermediary goods costs) on firm profit and the reinforcing loops R6 and R5 describe the positive impacts of technology, household demand in goods and services on firm production. R3, R4 and R2 are the revenue obtained by households through their assets of savings, investment, bonds according to the impact of the central bank interest rate. And end, R7 explains the revenue earned by the government from tax on goods and services, salaries and firm profit, part of which will be used to improve social services, transfers towards households and technology for firms. This reinforcing loop (R7) is central in the DSGE model because it plays a key role in social well-being, firms activities growth, the capacity of the central government and economic growth in general.

Figure 2. 2: CLD for the DSGE model



Source: the authors

Thus, the dynamics taken into account by the DSGE model are only the uncertainty in the economy due to the choices and behaviors (anticipations, trade-offs, etc.) of economic agents. And given its strong forecasting capacity, the DSGE model is adapted to trace the transmission of the shocks. Indeed, it is a model allowing to predict the effects of shocks once the economy is in equilibrium, compared to the iSDG model, which is a forward-looking model based on policy scenarios to trace a country's evolution from a given point in time and then carry out simulations in the future to see how the country is progressing towards its development objectives. We note firstly that the variables taken by the DSGE model only concern those of the economy domain, which means that the application of the model is limited to macroeconomic aggregates and does not consider the variables of the other two development domains, namely social and environmental. It is a limit of the model's ability to take into account the 17 SDGs of the United Nations 2030 Agenda. In this case, the evaluation of the impacts of shocks and policies does not concern all sectors of economic, social, and environmental, whereas economic activities use social and natural resources to produce economic value (Pedercini et al., 2020) and at the end rejects waste in the nature which contributes to the degradation of the planet. Secondly, the model does not distinguish between so-called flow variables and so-called stock variables, although this distinction is crucial for describing the magnitude and speed at which shocks propagate through the economy. i.e., the variables that are most sensitive to shocks and those that determine the magnitude of boom and bust of the economy through their behaviors during time. Finally, the non-use of feedback loops means that the DSGE model does not show the cause-and-effect relationships between the variables, while the interactions between the variables are not linear. The interactions and relations are “reciprocal” (Richmond, 1994) leading to feedback loops. Thus, the DSGE model is not developed to take into account the nonlinear dynamics between the three social, economic, and environmental domains. But, to reproduce and predict the behavior of economic agents and real business cycles (RBC) through macroeconomic variables (Comin et al., 2014).

Table 2. 1: DSGE model applications

Country	Application goal	Results
The impact of foreign Bank deleveraging on Korea, (Shin et al., 2013)	The authors analyze the effects of external funding shocks, particularly focusing on the deleveraging actions of foreign banks during the 2008 global financial crisis (GFC), and how these actions impacted the Korean economy and its banking sector. They used the DSGE model to trace out the response of Korea's economy to deleveraging by foreign banks by considering two states of pre-GFC and post-GFC. Also, the analyze of the ratios of liabilities and trade to GDP, it appeared that the external debt-to-GDP ratio has decreased markedly since the crisis, while foreign reserves have increased, household and corporate debt-to-GDP ratios have risen, which has boosted the overall level of domestic liabilities in Korea and end, the ratio of exports and imports to GDP has increased.	The results of the simulation show that there are no large differences in consumption and investment between the two states, also the external variables such as foreign assets and the exchange rate have become less sensitive in the post-GFC state showing that the economy has become more resilient to the external funding shocks. This implies that despite a sharp decline in external funding due to foreign bank deleveraging, the domestic credit growth by Korean banks experienced a relatively modest decline. This was attributed to concerted policy efforts by the Korean government in 2008, which helped mitigate the impact of the crisis through the provision of foreign currency liquidity played a crucial role in limiting the adverse effects on the banking sector by higher foreign exchange reserves, bilateral and multilateral currency swap arrangements. Also, the adoption of macroprudential measures has reduced domestic banks' dependence on short-term wholesale funding, resulting in lower exposure to foreign banks.
An estimated DSGE model for monetary policy analysis in low-income	In the context of large volatile aid inflows and/or government revenues from natural resource exploitation combined with a strong development of	The main findings of the DSGE model regarding monetary policy (CPI inflation targeting, non-tradable inflation targeting and the crawling exchange rate peg) of

countries (the case of Mozambique), (Saxegaard & Shanaka, 2007)	commercial banks which are ate the center of a formal financial system and high level of information asymmetries in SSA, it is important to analyze how best the available instruments of monetary policy can address the shocks and stabilize economy. Then, the purpose of the study is to analyze the conduct of monetary policy in low-income countries, particularly in Sub-Saharan Africa (SSA), using a dynamic stochastic general equilibrium (DSGE) model. The study aims to address the challenges and trade-offs associated with different monetary policy rules in these economies. By estimating a DSGE model for Mozambique, the study seeks to provide insights into the effectiveness of various monetary policy frameworks, such as inflation targeting (CPI inflation, inflation in nontraded goods) versus exchange rate pegs, and to enhance the understanding of macroeconomic stabilization in low-income countries. In their model, they have included 18 key macroeconomic variables of households, firms, GDP, government, banks, private sector and tried to analyze their behavior following 14 sources of shocks.	some key macroeconomic variables volatility (standard deviations of them) show that inflation targeting performs well to stabilize the economy that exchange rate targeting. More precisely, CPI inflation targeting outperforms non-tradable inflation targeting, although the differences are small relative to the differences between inflation and exchange rate targeting. The exchange rate peg is associated with a significantly higher CPI inflation volatility which, despite lower nominal exchange rate volatility, leads to higher real exchange rate volatility. Overall, the findings emphasize the importance of adopting appropriate monetary policy frameworks that consider the unique challenges faced by low-income countries in order to achieve macroeconomic stability.
Oil windfalls in Ghana: A DSGE Approach, (Portillo et al., 2010)	Following the proven reserves of oil and the production that was expected to start at the end of 2010 in Ghana, the paper explores the effects of oil windfalls on Ghana's economy using a dynamic stochastic	The results of the study show that in the short run, if the government spending the oil revenue as it accrues leads to a sharp but short-lived spike in real GDP growth, an increase in the aggregate

	general equilibrium (DSGE) model. More precisely, it is to evaluate how the expected increase in government revenues from oil production will affect key macroeconomic aggregates, such as real GDP, inflation, competitiveness, public capital, and government spending. The revenues from this natural resource are expected to be relatively important for the country and is estimated at 4-6% GDP over the next five years. Thus, the model explores different scenarios and policies in terms of fiscal and monetary options to understand the macroeconomic implications of increasing oil revenues in order to avoid the "Dutch disease" phenomenon and mitigate inflationary pressures in both the short and medium term.	employment, and inflationary pressures in the non-traded sector. This reflects an immediate boost in economic activity due to increased government expenditure leading to a moderate demand-led expansion in output and an increase in non-traded goods inflation. The results also show a Dutch Disease effect resulting from the reallocation of labor from the tradable to the non-tradable sector, that could lead to a permanent or persistent loss in productivity. Also, in the medium term the increase in government spending from oil revenue creates real appreciation of the exchange rate that can lead to a decline in competitiveness in the tradable sector. Additionally, if the central bank tries to reduce the foreign exchange sales to limit the real appreciation it could amplify aggregate-demand pressures and result in higher inflation. In terms of policy implementation of mitigation of inflation and Dutch disease phenomenon, the authors suggest to the government to maintain a balance between tradable and non-tradable sectors in government spending. Also, a strategic public investment in particular public spending enhancing productive capacity can offset potential declines in competitiveness. In terms of monetary policy, if the central bank tightens monetary policy to control inflation, it may lead to lower output growth in the short run due to a temporary reduction in aggregate-demand but could stabilize the economy in the medium term. A tighter monetary policy could also contribute to a more favourable environment for private sector investment by

		maintaining lower inflation rates. Overall, the authors emphasize the importance of investment in productive infrastructure, consideration of fiscal policy options, and careful management of monetary policy to mitigate the adverse effects and maximize the benefits of oil revenues.

Source: the authors

2.3.2. The Long-Term Growth Model (LTGM)

The standard Long-Term Growth Model (LTGM) is a spreadsheet-based tool to analyze future long-term growth scenarios in developing countries (Devadas et al., 2020). Economic Growth is the foundation on which social and economic development get their roots. Economic growth is presented as a necessary condition for prosperity by creating jobs, fostering innovation, generating social and political stability, producing resources to governments, and reducing inequalities. For Loayza & Pennings, (2022, p. 1), economic growth is "the key to poverty alleviation, an essential objective of most, if not all, developing country governments and international development organizations, such as the World Bank". The LTGM was initially created as a basic way of assessing whether growth projections were realistic or not. It uses a standard neoclassical growth model (Solow, 1956). Exogenous saving/investment, total factor productivity (TFP), human capital, demographics (population aging, demographic dividend), labor force participation rates (by gender) and types of foreign savings are key drivers to formulate growth paths based on observable initial conditions and but reasonable assumptions on future growth drivers. In recent years, the standard LTGM has been extended to take into account the effect of growth on poverty reduction (Loayza & Pennings, 2022). It is applied in several countries such as Malaysia, South Korea, Bangladesh, Syria, Egypt, and Sri Lanka to analyze future growth in terms of TFP, human capital, physical capital, and labor according to GDP performances. Beyond analyzing GDP future growth paths, the model allows first, “to assess the effect of Public Capital on Growth, by separating the capital stock into public and private portions in order to analyze the effects of an increase in the quantity or quality of public investment on growth. Secondly, to analyze the patterns and determinants of productivity growth across the world such as innovation, education, market efficiency, infrastructure, and institutions. And thirdly to assess the Effects of Natural Resources on Long Term Growth” (Loayza et al., 2022). It evaluates how commodity price shocks and discoveries/depletion of natural resources affect a country’s economic growth, and how this depends on different fiscal policy frameworks. The model gives the possibility to calculate growth for a given investment-to-GDP profile (calculating growth implied by investment) or to calculate required investment to achieve a target growth path (calculating Investment Ratio to Achieve Output Target) or to calculate growth for a given savings-to-GDP profile (defining path for

Gross National Savings) (Pennings, 2020). As indicated in the model objective, the first main function of the LTGM is based on a Cobb-Douglas production function which is used to calculate gross growth rates of output per worker. The second main function concerns demographics and labor market variables notably, the total population, the labor force, the working-age population, and the labor force participation rate. These variables are used to calculate the output per capita and growth in output per capita. The last equation is the physical capital accumulation process. It is the physical capital that will be used in the future to produce goods and services. It is composed of new investments today and the depreciation of capital. This equation is used to calculate the capital-to-output ratio which is the productivity of capital used to produce.

Production function: $Y_t = A_t K_t^{1-\beta}(h_t L_t)^{\beta}$ where Y_t is GDP, A_t is the total factor productivity, K_t is the physical capital stock, $h_t L_t$is effective labor used in production, which h_t human capital per worker (based on the years of schooling), L_t the number of workers and β is the labor share (elasticity of GDP to Labor). So, GDP per worker is deducted by dividing Y_t to L_t:

$y_t = \frac{Y_t}{L_t} = A_t k_t^{1-\beta} h_t^{\beta}$ where k_t is the capital per worker.

From this equation, the gross growth rate of output per worker is:

$$\frac{y_{t+1}}{y_t} = \frac{A_{t+1}}{A_t}\left[\frac{k_{t+1}}{k_t}\right]^{1-\beta}\left[\frac{h_{t+1}}{h_t}\right]^{\beta}$$

by rewriting this equation in terms of growth rate GDP per worker $g_{y,t+1}$ from t to t+1

$1 + g_{y,t+1} = (1 + g_{A,t+1})[1 + g_{k,t+1}]^{1-\beta}[1 + g_{h,t+1}]^{\beta}$, this equation explains that the growth rate of GDP per worker is driven by the growth rate of total factor productivity, the growth rate of physical capital per worker, and the growth rate of human capital per worker.

Labor participation rate function:

Let's suppose that N_t is the total population, ϱ_t labor participation rate and ω_t the working age population to total population ratio. So, the output per capita is: $y_t^{PC} = \frac{Y_t}{N_t} = \frac{Y_t}{L_t}\varrho_t\omega_t = y_t\varrho_t\omega_t$

$y_t^{PC} = A_t\varrho_t\omega_t k_t^{1-\beta}h_t^{\beta}$, then the growth rate in output per capita is determined by demographic transition meaning growth in the working age to population ratio, an increase in labor force participation meaning growth in the participation rate, and growth rate in output per worker. That is described by the following equations:

$$\frac{y_{t+1}^{pc}}{y_t^{pc}} = \left[\frac{\varrho_{t+1}}{\varrho_t}\right]\left[\frac{\omega_{t+1}}{\omega_t}\right]\left[\frac{y_{t+1}}{y_t}\right]$$

$$1 + g_{y,t+1}^{pc} = (1 + g_{\omega,t+1})[1 + g_{\varrho,t+1}][1 + g_{y,t+1}]$$

Physical capital accumulation function:

$K_{t+1} = (1 - \delta)K_t + I_t$, here $K_{t+1}$is equal to the present investment in capital I_t that taking into account the current physical capital stock depreciation $(1 - \delta)K_t$ with δ that is the depreciation rate of capital. So, the capital-to-output ratio in the next period is equal to:

$$\frac{K_{t+1}}{Y_{t+1}}\left[\frac{Y_{t+1}}{Y_t}\right] = \frac{(1-\delta)K_t}{Y_t} + \frac{I_t}{Y_t}$$

The growth rate of capital per worker is obtained by dividing capital by the labor force:

$\left[\frac{K_{t+1}}{L_{t+1}}\right]\left[\frac{L_{t+1}}{L_t}\right] = (1-\delta)\frac{K_t}{L_t} + \frac{I_t}{L_t}$ in terms of growth rates and per worker dividing by k_t we have

$\frac{k_{t+1}}{k_t}(1+ g_{\varrho,t+1})\{1+ g_{N,t+1}\}\{1+ g_{\omega,t+1}\} = (1-\delta) + \frac{i_t}{k_t}$, by multiplying the second part of the equation by the output per worker y_t we have:

$(1+ g_{k,t+1})(1+ g_{\varrho,t+1})\{1+ g_{N,t+1}\}\{1+ g_{\omega,t+1}\} = (1-\delta) + \frac{i_t}{y_t}\frac{y_t}{k_t}$. Then, the growth rate of capital per worker is equal to:

$$1 + g_{k,t+1} = \frac{(1-\delta) + \frac{I_t}{Y_t} / \frac{K_t}{Y_t}}{(1+ g_{N,t+1})(1+ g_{\varrho,t+1})(1+ g_{\omega,t+1})}$$

The LTGM extension to integrate the poverty module:

The extension of the Standard LTGM to calculate the effect of economic growth on poverty reduction follows a log-normal distribution of income $ln(y^{PC}) \sim N(\mu, \sigma^2)$.

The proportion of people P with incomes below the poverty line L is a standard normal cumulative density function:

$P_t = \Phi\left(\frac{lnL-\mu_t}{\sigma_t}\right)$ where μ is the mean and σ the standard deviation of the normal distribution.

The Gini coefficient is then obtained by a transformation of the standard deviation σ:

$$G_t = 2\Phi\left(\frac{\sigma_t}{\sqrt{2}}\right) - 1$$

The Growth Elasticity of Poverty (GEP) that measures the percentage fall in the headcount poverty rate from a 1% increase in per capita income is equal:

$$\varepsilon_{p,t} \equiv -\frac{\partial lnP_t}{\partial ln\bar{Y}_t} = -\frac{\partial P_t}{\partial \mu_t}\frac{1}{P_t} = \frac{1}{\sigma_t}\frac{\Phi\left(\frac{lnL-\mu_t}{\sigma_t}\right)}{\Phi\left(\frac{lnL-\mu_t}{\sigma_t}\right)}$$

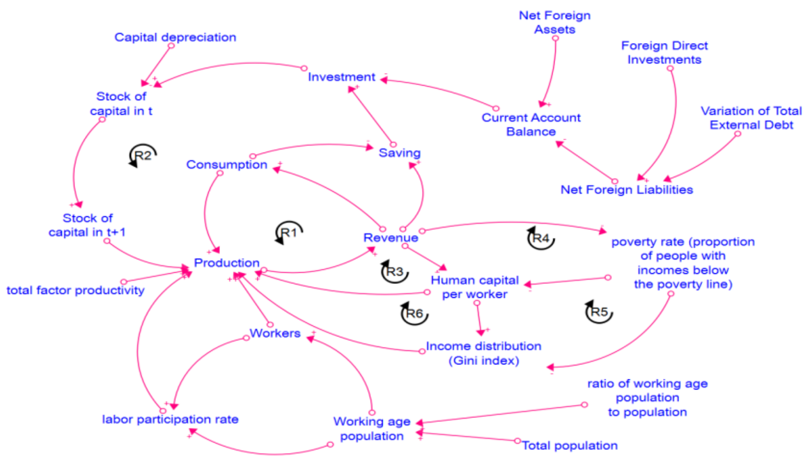
The growth semi-elasticity of poverty that is relevant for policymakers is also calculated in the spreadsheets:

$\Delta_t \equiv -\frac{\partial P_t}{\partial ln\bar{Y}_t} = \varepsilon_{p,t} \times P_t = \frac{1}{\sigma_t}\Phi\left(\frac{lnL-\mu_t}{\sigma_t}\right)$, it is the percentage point change in poverty for an extra 1% increase in per capita income.

One strength of the model is the very low data requirements so that the tool can be applied to many countries. It is built to automatically fill the country's data once the user changes the country name in the list of countries. Also, it is a prediction model that helps to track growth trends by 2100 and elaborate a scenario of growth paths by changing the values of the parameters and initial values from a range of data sources or simply filling their own values. Finally, when the values of some parameters or initial variables are missed, the model automatically interpolates their values based on income group averages.

Despite its ability to track the future growth paths in developing countries, its application is limited only to the economic domain. So, the model does not allow to elaborate a strategy of policies belonging to the three domains of sustainable development. It means that the LTGM cannot do a cross-impact analysis by considering the interrelated impacts of the environmental, social, and economic areas. The following CLD is the translation of the LTGM in terms of System Thinking approach. The feedback loops are all positive (more revenue mean more saving and more consumption, more investment, more stock of capital, more production, more workers…), it is clear that the model targets straight ahead the GDP growth paths and doesn't interest the availability of natural resources, energy use, labor working conditions, water consumption, water consumption, access to water and sanitation, food, climate change, infrastructure, …on which more of them interact and influence GDP performance.

Figure 2. 3: LTGM translation into Causal Loop Diagram (CLD)



Source: the authors

Table 2. 2: LTGM applications

Country	Application goal	Results
Malaysia's Economic Growth and Transition to High Income: An Application of the World Bank Long Term Growth Model (LTGM), (Devadas et al., 2020)	The study purpose is to analyze the potential for Malaysia's economy to achieve high-income status and assess the impacts of some key factors that contribute to economic growth such as investments, human capital and total factor productivity (TFP). The authors developed 3 levels of reform scenarios that will be compared to the BAU scenario and assess the impact of these reforms on GDP growth. The "weak" reform corresponds to 25th percentile of high-income countries, "moderate" reform, at the 50th percentile ; and "strong" reform, at the 75th percentile.	The results under the business-as-usual scenario show that Malaysia's GDP growth is expected to decline from 4.5% in 2020 to 2.0% in 2050 due to declining population growth, falling private capital effectiveness and declining TFP. However, this situation can be avoided with economic reforms to increase female labor force participation, human capital through the quantity and quality of education and health components, TFP through innovation, education, market efficiency, infrastructure and institutions, and an increase in public and private investments. The results demonstrate that GDP growth is higher in the strong reform than the other reforms for each driver. Also, it is shown that the outcome of GDP growth is higher in the strong reform than the other reforms when these drivers are implemented in combination.
Korea's growth experience and long-term growth model, (Jeong, 2017)	Following Korea's rapid and long-term growth process sustained at an average rate of 6% per year during the past six decades, the goal of the paper is to investigate the sources of such growth. The LTGM is applied to Korea's economic growth for the 1960-2014 to identify the main sources of growth (GDP per capita), such as productivity growth (the growth of the labor-	The decomposition of sources of Korea's growth of GDP per capita shows that the Korea "miracle" named by Lucas in 1993 was fairly balanced among different growth components. "The major contributing components to growth evolved over time from labor demography and human

	augmenting technology), human capital accumulation, capital deepening (the capital-output ratio), and labor market demographic changes, and to understand how these factors evolved over time as the main engines of economic expansion. The author calibrates first the model according to three periods 1970, 1980 and 1990 of simulation with a status-quo approach (no change in the parameters setted by period). Secondly, the author proposed two other time-varying scenarios of parameters where in the first scenario (average scenario) the annual growth rate of productivity of labor-augmenting technology, annual growth rate of human capital per worker, annual growth rate of population, investment rate, working-age population share and labor force participation rate are setted to their average growth rates during the period 1960-2014. And the second scenario He considers the changes of the value of these drivers of GDP per capita growth.	capital in the 1960s to capital deepening in the 1970s to productivity growth for the following three decades. In particular, the accelerated productivity growth after 1980 was a critical reason for the sustainable growth for Korea" according to the author. In terms of prediction, only the prediction starting in 1990 better explains the current evolution of Korean economic growth. Assuming constant parameters, the prediction 1970 and 1980 simulations fail to replicate the historical evolution of Korean economic growth. This is due to the fact that these predictions do not take into account temporal changes in the evolution of growth drivers such as investment and human capital. However, by considering the time-varying transitional growth policy such as demography and investment leads to capture the actual Korea's GDP per capita trend when the the two effects of labor market demographic composition changes and investment rate are combined.
Long-Term Growth Scenarios for Bangladesh, (Sinha, 2017)	Since 1976, Bangladesh economy has seen robust economic growth from 4% to more than 6% of real GDP growth during 2001-2015 on average every year and that acceleration of real GDP has contributed to an increase in real GDP per capita growth. The economic growth is driven mostly by gains in investment starting from 14.4% of GDP in 1980 to 28.9% in 2015. So, the purpose of the paper is to analyze if the country will be able to maintain such high levels of	The results of the simulation show that only the 1.5% annual growth rate of TFP in the High Growth II Scenario combined with 0.55 point of efficiency of public investment and 45% of female labor force participation rate leads to the 7.44% of the five year plan target. The average annual GDP growth for the period 2016-2020 is 7.75%, 7.30% during 2021 – 2025 and

	growth going forward. By using the LTGM, the author analyzes the growth trends by elaborating four scenarios of reforms in TFP growth to reach 7.44% of GDP growth during the period 2016-2020. In the Baseline Scenario, the public investment efficiency remains at 0.55 during the simulation time where there is no change in female labor participation rate setted at 34% in 2020. The efficiency + participation (E+P) Scenario, the efficiency of public investment grows linearly from 0.55 in 2015 to 1.00 in 2020 and the female labor force participation rate grows 34% in 2015 to 45% in 2020. In the High Growth Scenario I, the annual growth rate of TFP is set to 1% because its average during 2001-2011 has barely been upwards of zero. And end, in the High Growth II Scenario, the annual growth rate of TFP is set to 1.5%. In the two last scenarios, the level of public capital efficiency and female labor force participation follow the trend outlined in the E+P scenario.	6.64% for the period 2026 – 2030. The impacts of the other scenarios reforms on the average annual GDP growth is less than the plan target. That suggests that sustaining high GDP growth rates in the absence of TFP growth would require massive investments exceeding planned levels, which may become unrealistic over time regarding the public deficit. Also, the study indicates that female labor force participation growth can contribute meaningfully to economic growth in the medium term, with a potential increase of over 1 percentage point to GDP growth annually if the rate rises by 11% over five years.

Source: the authors

2.4. GDP as a driver

But the story is not so simple. Firstly, focusing exclusively on GDP and economic advantages to measure growth and development ignores the negative effects of economic growth on society, such as biodiversity loss, climate change, or income inequalities. Secondly, GDP is just a technical indicator about activities meaning the total of industry, service, and agriculture production. We know now that the story is not so simple – that focusing exclusively on GDP and economic gain to measure development ignores the negative effects of economic growth on society, such as climate change and income inequality. It's time to acknowledge the limitations of GDP and expand our measure of development so that it takes into account a society's quality of life and environmental good quality. Then, two models - using GDP as a driver - have been studied in this part: the Stock-Flow Consistent Prototype Growth Model of Agence Française de Developpement (AFD) and the integrated Sustainable Development Goals of the Millennium Institute (MI).

2.4.1. Stock-Flow Consistent Prototype Growth Modeling (AFD)

The interactions realized in the economy are financial and material and thanks to the development of currency, the exchanges and the banking sector have highly improved (Narassiguin, 2004). If we consider that each good and service is associated with a price, it means that policy rates targeted by the central bank and the money inflow in the economy impact the performance and the stability of macroeconomic aggregates. So, the Stock-Flow Consistent Prototype Growth Model of the Agence Française de Developpement analyzes "the effects of policy rates in financial centers on a small open developing economy with an open capital account and a flexible exchange rate" (Godin & Yilmaz, 2020).

The paper uses a stock and flow approach (Stock-Flow Consistent Modelling) to model the interactions and the propagation mechanisms that exist between real and financial spheres for a long time. This approach is close to the system dynamics approach which supposes that the economy, social, and environment sectors are interconnected and the changing of one sector's scores can lead to a change of the other sectors' scores. These interactions occur through feedback loops and persist over time. It supposes that the elements that are grouped in a common sphere constitute a system and interact together to produce a behavior. Taking the functioning of things in that kind means "Thinking in System" (Arnold & Wade, 2015). For this reason, we can consider that a national economy is a system. Within this system, we have actors who make decisions to buy and sell goods and services, who borrow and lend money to banks, who consume and save, who produce and seek profit, who build infrastructure and levy taxes. The system is constituted by "financial contracts through asset holder and liability emitter connections" between actors (Godin & Yilmaz, 2020). The decisions made by the central bank guide the decisions of the other actors who every time anticipate the policies that it will implement.

Nowadays, the global liberalization of capital leads to capital inflow toward countries that have higher interest rates contrary to the countries where the interest rates are lower. So, according to Godin & Yilmaz, (2020) "a fall in global policy rates triggers appreciation-induced boom-bust episodes in the small open economy, driven by portfolio flows and cross-border lending". This idea shows that the only way for a developing country to attract capital in the case where governance indicators are in the red zone is to raise interest rates. Raising interest rates leads to capital inflows from the rest of the world toward the national economy resulting in an appreciation of national currency, credit and asset-price booms, consumption and investment booms, and falling unemployment, inflation, and the improvement in public deficits. But this positive effect is countered by the increasing trade deficit due to reducing exports and increasing imports. Indeed, the AFD model is a continuous time monetary stock-flow consistent model that analyzes the interrelations between the balance sheets for firms, banks, households, government, central bank and the rest of the world by identifying stock-flow relationships. The economies are characterized by “multilayered networks of financial contracts through asset holder and liability emitter connections” (Godin & Yilmaz, 2020). Feedback mechanisms are emerging from the components of the balance sheets in such a way that, on the one hand, there is an accumulation of stocks following the dynamism of flows and, on the other hand, flows respond to the stocks accumulation which could be positive or negative meaning sector surplus or deficit. The dynamism of the model comes from the feedback interactions between economic agents through financial contracts on the markets characterized by continuous disequilibria between supply and demand implying price adjustments. The following Transaction-Matrix presents the overall structure of the model, and it shows the origin of the transactions and their destination in the economy. The flow represents the number of transactions taking place in a sector that is marked by a "-" sign and its destination marked by a "+"

sign. This means that the sum of all flows for each row is equal to "zero", except for the variables in square brackets [] which is each the sum of the above variables. These variables in square brackets are physical assets, inventories, and capital that do not have financial counterparts.

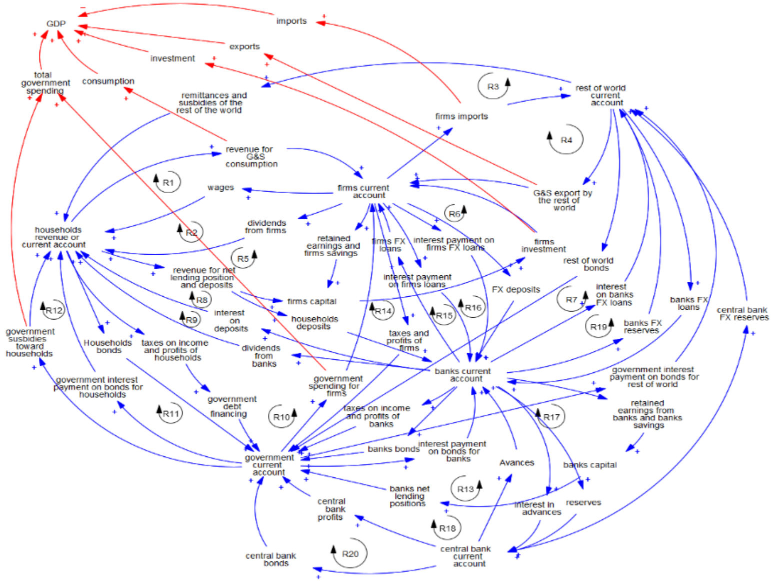
Figure 2. 4: Transaction Flow Matrix of the Stock-Flow Consistent Model

	Industry		Households	Banks		Central Bank		Government	RoW	Σ
	Current	Capital		Current	Capital	Current	Capital			
Consumption	$+C_H$		$-C_H$							0
Investment, capital	$+I^K$	$-I^K$								0
Govt Spending	$+G_D$							$-G_D$		0
Imports	$-IM$								$+IM$	0
Exports	$+X$								$-X$	0
[GDP]	$[Y]$									$[Y]$
Wages	$-WB$		$+WB$							0
Taxes on Imports	$-T^{IM}$							$+T^{IM}$		0
[Gross Operating Surplus]	$[GOS_F]$		$[GOS_H]$	$[GOS_B]$		$[GOS_{CB}]$		$[GOS_G]$		$[GOS]$
Int. on Deposits			$+IntD$	$-IntD$						0
Int. on Loans	$-IntL^D$			$+IntL^D$						0
Int. on Firms FX Loans	$-IntL_F^{FX}$			$+IntL_F^{FX}$						0
Int. on Banks FX Loans				$-IntL_B^{FX}$					$+IntL_B^{FX}$	0
Int. on Bonds			$+IntB^H$	$+IntB^B$		$+IntB^{CB}$		$-IntB$	$+IntB^W$	0
Int. on Advances				$-IntA$		$+IntA$				0
Dividends	$-Div_F$		$+Div$	$-Div_B$						0
[Gross National Income]	$[GNI_F]$		$[GNI_H]$	$[GNI_B]$		$[GNI_{CB}]$		$[GNI_G]$		$[GNI]$
Remittances			$+Rem$						$-Rem$	0
Central Bank Profits						$-F_{CB}$		$+F_{CB}$		0
Taxes on Income and Profits	$-T_F^F$		$-T^I$	$-T_B^F$				$+T^T$		0
Welfare Spending			$+G_B$					$-G_B$		0
Savings	$-RE_F$	$+RE_F$	$[S_H]$	$-RE_B$	$+RE_B$	0	0	$[S_G]$	$[S_W]$	0
[Capital]		$[\dot{K}]$								$[\dot{K}]$
[Inventories]		$[\dot{V}]$								$[\dot{V}]$
Deposits			$-\dot{D}^D$		$+\dot{D}^D$					0
Reserves					$-\dot{R}^D$		$+\dot{R}^D$			0
Loans		$+\dot{L}^D$			$-\dot{L}^D$					0
Bonds			$-\dot{B}_G^H$		$-\dot{B}_G^B$		$-\dot{B}_G^{CB}$	$+\dot{B}_G$	$-\dot{B}_G^W$	0
Advances					$+\dot{A}$		$-\dot{A}$			0
FX deposits		$-\dot{D}^{FX}$			$+\dot{D}^{FX}$					0
FX Reserves					$-\dot{R}^{FX,B}$		$-\dot{R}^{FX,CB}$		$+\dot{R}^{FX}$	0
Firms FX Loans		$+\dot{L}_F^{FX}$			$-\dot{L}_F^{FX}$					0
Banks FX Loans					$+\dot{L}_B^{FX}$				$-\dot{L}_B^{FX}$	0
Σ	0	0	0	0	0	0	0	0	0	0

Source : Godin & Yilmaz, (2020)

The Transaction-Flow-Matrix is composed of three main components separated by solid lines. As we can see in the matrix, the first component is non-financial transactions (first component) and presents the elements of GDP and revenue distribution accounts (primary and secondary). The second is the physical asset component is the physical counterpart of the two investment transaction flows for the industry sector (real investment and accumulation of unsold goods in inventories). And end, the third component is the financial assets flow which "represent the change in assets and liabilities used by each sector in order to either finance their spending or to buy assets as financial investment" (Godin & Yilmaz, 2020). The Transaction-Flow-Matrix uses a method very close to the dynamics of systems because it shows that there are some interactions between sectors, and the action taken by an actor affects positively or negatively the balance sheet of the other actors. These interactions between actors are continuously present in the economy and persistent in the long run. The feedback mechanisms emerge from the responses of flow interconnected to stock accumulation emerging out of flow dynamics. The following Causal Loop Diagram (CLD) presents the transcription of the Transaction-Flow-Matrix at the steady state in system dynamics. Although the model is based on an accounting approach to the asset balances of economic agents, there are some interesting loops about agent interactions. For example, the CLD, R1, R2, and R5 show that households spend part of their income on consumer goods, also lend to firms. In return, they receive wages and dividends which in return increase their income. R8, R9 concern the interest earned by households from their deposits and lendings to the banks, R14 represents the tax on firms' profits and production that the government will use to spend on firms later as subsidies or technology and innovation discoveries. R15 and R16 are firm debt repayment and the interests on foreign exchange debt towards banks. R13, R17 and R18, R20 are the revenue generated by the central bank for the government, also the tax of the government on the central bank activities. R4 describes that goods and services exports from the rest of the world provide revenue for national firms which in turn are going to import goods and services from the rest of the world. With R3, remittances and subsidies of the world to households are a source of revenue to increase households' revenue for goods and services consumption that leads firms to import goods and services to satisfy households' demand of consumption.

Figure 2. 5: Transaction-flow Matrix transcription into CLD



Source: the authors

First, it appears in the CLD that the model building is effectively based on an accounting approach through the assets and liabilities of households, government, firms, the rest of world, banks and central bank. Secondly, all the feedback loops are reinforcing meaning that the model doesn't consider the cause-and-effect relations between variables. So, it does not allow us to get goal-seeking loops (balancing loops) in the CLD. And end, the size of each variable is measured in monetary value which does not consider physics and information flow and accumulation. Beyond designing the interactions of macroeconomic variables of the different actors' balance sheets, we also added the GDP calculation (the arrows in red color) that is equal to the sum of household consumption, firms' investment, government spending, goods and services export minus goods and services imports. Then, we can conclude that the model targets only the behavior of economic variables but does not consider GDP growth as a priority. In that case the GDP is a driver for services improvement.

Table 2. 3: Stock-Flow Consistent (SFC) model applications

Country	Application goal	Results
Low-carbon transition and macroeconomic vulnerabilities: a multidimensional approach in tracing vulnerabilities and its application in the case of Colombia, (Moreno et al., 2023)	By using the Stock-Flow Consistent model, the authors on the low-carbon transition and its macroeconomic vulnerabilities, specifically in the case of Colombia. The transition to a low-carbon and climate resilient economy involves a heavy restructuring of the productive network, with declining and emerging industries. The study analyzes two scenarios of shocks: a 58.1% reduction in real fossil fuel exports of Colombia in a 10 year horizon and a 70% of global rise in interest	The results show that the longer the low-carbon transition is delayed, the greater the vulnerability of the Colombian economy compared with a smooth scenario involving a reduction of 58% in fossil fuel exports. A delayed transition scenario induces greater vulnerability, negatively affecting aspects such as the current account balance, country risk, external debt, public and private debt, and financial fragility and social indicators especially inflation, per capita income, households financial fragility and unemployment. Also, the combination of a smooth reduction in real fossil fuel exports with an increase in the interest rate of the rest of the world and country risk leads to the portfolio and other investment inflows into Colombia. So that contributes to higher exchange rate depreciation and domestic inflation. In this situation, the reaction of the Central Bank through higher interest rates implies an increase in the debt service and higher financial fragility. That impacts domestic demand leading more to low employment,

	rates. The macroeconomic vulnerability indicators include fiscal conditions, monetary and financial conditions, and external conditions measured by the balance of payment dominance.	income per capita and government revenue. So, the results of the study highlight the importance of taking immediate steps towards a smooth low-carbon transition in order to reduce the macroeconomic vulnerability of the Colombian economy, and underline the challenges associated with the transition to a greener economy in a context of multidimensional vulnerabilities.
Climate change, loss of agricultural output and the macroeconomy: the case of Tunisia, (Yilmaz et al., 2023)	The goal of the authors is to model the impacts of climate change and the long-term policies of climate change adaptation on agricultural production for theTunisian economy. The SFC model is calibrated according to the Tunissia economy balance sheet with an extension of crop yield projections (agricultural and processed food) based on FAO projections. Three scenarios results are simulated: in the BAU, there is no change in current macroeconomic policies, the optimistic scenario, they consider that food prices rise in line with general world inflation, and the pessimistic scenario they assume that food price inflation exceeds general world Consumer Price Index (CPI) inflation over the next three decades.	In general, the results of the simulation concerning the alternative scenarios comparatively to the BAU scenario show that a loss of agricultural production in Tunisia due to climate change leads to a reduction in jobs in the farming sector, which may contribute to increased unemployment in the country, a decrease in food supply, which can potentially lead to higher food prices and food inflation. A Reduction of agricultural production affects the country's internal macroeconomic balances, such as the balance of trade and balance of payments, due to dependence on food imports. Also, if global food inflation remains high and agricultural production continues to decline, this could lead to an imminent balance of payments crisis in Tunisia. Regarding these results, two scenarios of adaptation policy are envisaged by the authors: the reinforced tendency scenario (RTS) where economic growth is setted to 2.5% per year, the agriculture production growth is 1 per year and water elasticity of agricultural production is amused to fall to 0.2. The water and development scenario (WDS) where economic growth is set to 4.3% per year, the agriculture production growth is 3.5% per year and water elasticity of agricultural production is called to be 0.15 with a more efficient water use in all sectors (0.1 of water elasticity of each sector production). The WDS scenario that necessitates high investments (assumed 4.5% growth per year) in infrastructure, health, R&D and education to increase labour productivity have significant positive effects on

		macroeconomic variables comparatively to the RTS. The unemployment, inflation and food inflation, processed food inflation, food imports, public total debt/GDP, real exchange rate, country risk and public deficit will be low by 2050. While the real growth rate, trade balance, per capita income, propensity to consume improve comparatively to the BAU and the RTS scenarios by 2050.
Can Colombia cope with a global low-carbon transition?, (Godin et al., 2023)	In view of the contribution of coal and oil exports to the Colombia economy in terms of exports and fiscal revenues, this paper analyzed the implications that the global low-carbon transition may have on its economy during the period 2023-2050. Through consider three scenarios for oil fossil fuels: in the BAU there is no change in the fossil fuel exports, the conservative scenario assume a constant decrease of 3% of fossil fuel exports from 2023, and the global transition (GT) scenario, it is supposed a constant decrease of 8.5% of fossil fuel exports from 2023.	The simulation results show that both the two alternative scenarios exhibit similar dynamics with larger magnitudes for the GT scenario. In general, a reduction in fossil fuel leads to a deterioration of trade indicators, an inflationary pressures for production prices and consumer prices leading to consumption reduction and investment. The fall of these indicators leads to a reduction in real growth and an increase in unemployment. Unemployment raising leads to an increase in social transfers and the inflation push up to government expenditures and investment and that contribute to a worsening fiscal deficit due to a low taxes revenue from FDI flow reduction and firms reducing their demand for FX loans. However in the long run, the current account sees an improvement due to the increase in transfers and remittances leading to an increase in consumption and investment (households and government). So, unemployment starts decreasing further fueling the recovery. To cope with this dramatic situation and to avoid a currency crisis, the authors suggest increasing the Colombia economy to export via its integration in the Global Value Chains. i.e. a gradual increase in exports of non fossil fuels, starting from 2024 necessitating private investment and G.T. public investment. Then, by implementing industrial policies aimed at diversifying the country's export base allows to improve trade indicators and a lower real depreciation, an extra demand leading to a significant reduction in unemployment. Also, the fiscal account improves to lower social transfers and higher tax revenue reducing fiscal deficit. The GT investment scenario supposes international

		financial flows from firms which combined with lower trade deficit improve the country's risk due to more foreign reserves. However, the economy of Colombia performs under both scenarios of diversification (public and private) over time but the country still experiences a general impoverishment of its population in dollar terms.

Source: the authors

2.4.2. iSDG model, integrated Sustainable Development Goals (MI)

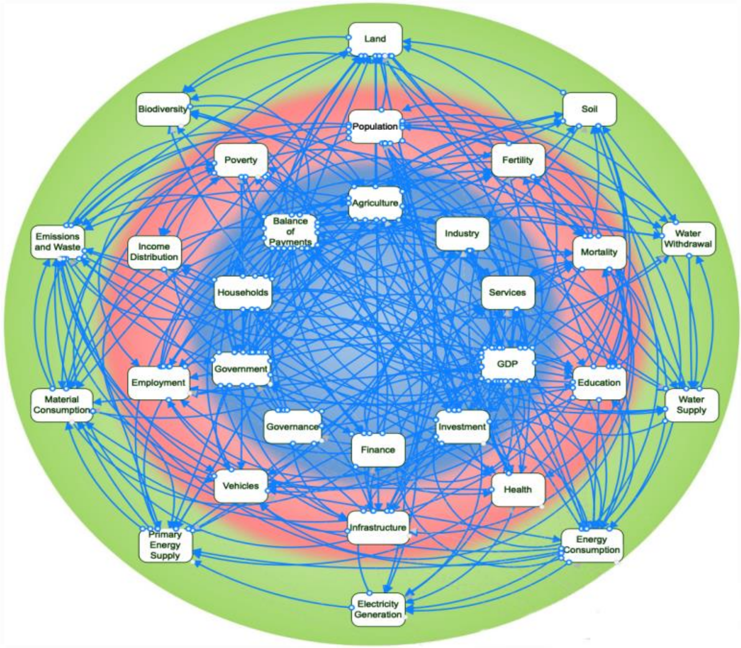
The iSDG model is a national development model (Millennium Institute, 2021), its structure and assumptions are based on system dynamics that is designed to support national planning. It includes all 17 Sustainable Development Goals (SDGs) (Figure 2.6) which allow us to understand the interconnectedness between SDGs and the public policies recommended by the UN Agenda 2030 to achieve them. What makes the iSDG model unique from sectoral models is that it integrates the three domains of development, namely economic, social, and environmental, and thirty (30) sectors of activity (Arquitt, 2020) (Figure 2.7). The interconnectedness between the sectors provides the opportunity to elaborate synergistic policies to improve the performance of the SDGs (Pedercini et al., 2020). Being a participatory model (interactive process to develop the model with all stakeholders), the model helps the policymakers to estimate the resource needs to be allocated to each sector or ministry. This approach is firstly a way to optimize the public budget and avoid creating large budget deficits. Secondly, it allows us to simulate policy effects on sectors before they are adopted, to prioritize the sectors that need more attention while knowing that each sector is important for the development (Millennium Institute, 2016). Finally, to avoid resource waste, absorptive capacity constraints, and inefficiency of public investment through synergistic policies implementation.

Figure 2. 6: an overview of 17 SDGs's performance

Source: Millennium Institute (MI)

Figure 2.6 shows the SDGs framework in the iSDG model. The 17 goals are interconnected, meaning that improving the performance of one SDG or a couple of SDGs will affect either positively or negatively the performance of the other SDGs (Pedercini et al., 2019). This interconnectedness approach empowers action levers (Abson et al., 2017) i.e., developing coherence between the SDGs to develop synergistic policies or target changes that are able to boost the performance of SDGs indicators or minimize the negative effects of public policies. The model is simulated on the basis of a business-as-usual (BAU) scenario based on SDG indicators historical data. The model can simulate the trend of SDGs performance until 2030 or up to 2050 to know the levels of achievement of each of the SDGs during the reporting period. This baseline scenario is a reference to compare the BAU trend with the trend of the other scenarios based on policies designed to achieve the UN 2030 Agenda either in isolation or in combination (Millennium Institute, 2021). In this case, the iSDG model is a prospecting and scenario model to find the right combination of relevant public policies to achieve the United Nations (UN) 2030 Agenda (Millennium Institute, 2017b).

Figure 2. 7: structure of the iSDG model from Millennium Institute by sector

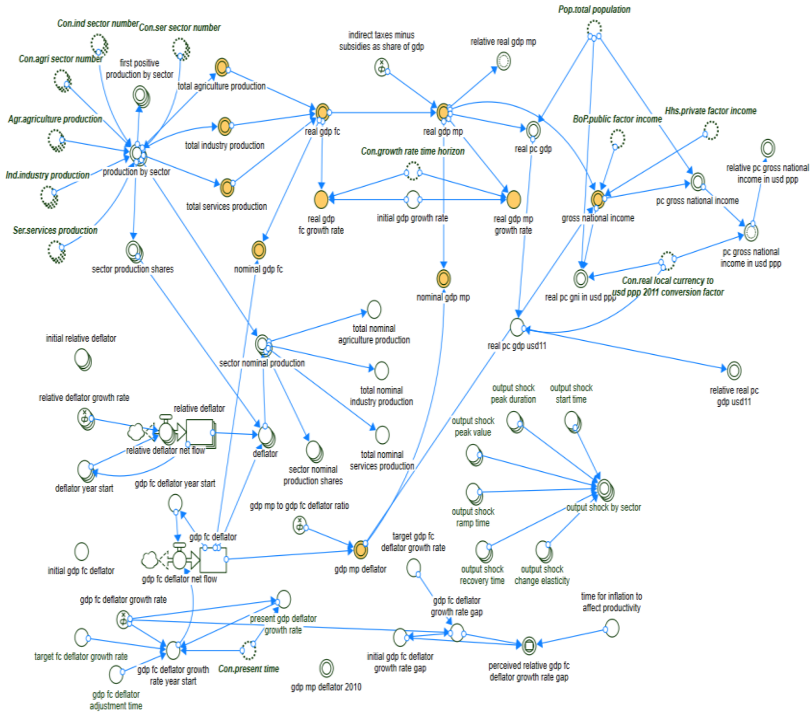


Source: Millennium Institute (MI)

Figure 2.7 presents the interactions in the form of a system of the 30 sectors (35 sectors for the updated version) via feedback loops, i.e., the changes that take place in one sector are transmitted to the other sectors and vice-versa. The blue circle, which is the core of the system, represents the 10 economic sectors. The red circle in the center of the system represents the 10 social sectors and the outer green circle is the 10 environmental sectors. In general, the figure shows that economic activities take place in society, we use social resources (labor force, social skills) to transform natural resources (mineral, oil, ...) that we draw from the environment to create economic value.

Thus, the simulation of the iSDG model is done through Stock-Flow Diagrams (SFD). These diagrams relate so-called stock variables (accumulating of resources and information) to so-called flow variables (reflecting the speed and direction of change in stock levels over time) via feedback loops that are cause-and-effect connections. The dynamic at which flow and stock variables change in the system (D. H. Meadows, 2008a) determines the behavior of the system and allows us to understand the development trend of sectors and therefore the performance of the SDGs. And end, the interactions between the three areas of social, economy, and environment determine the level of development of countries but also are at the origin of the different socio-economic and environmental crises that humanity is experiencing nowadays.

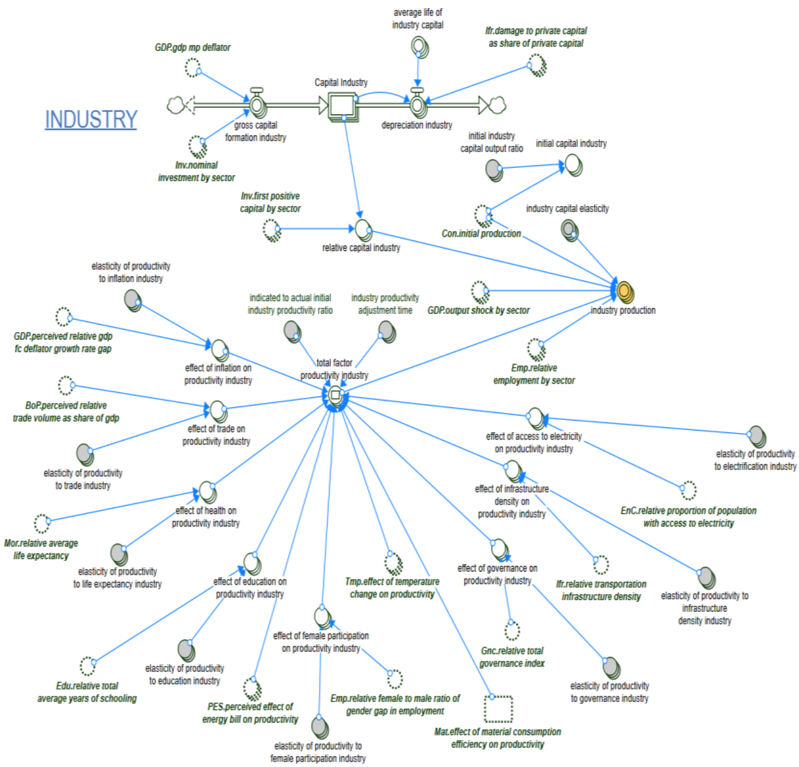
Figure 2. 8: GDP sector of the iSDG model



Source: Millennium Institute (MI)

The above module structure clearly shows that the GDP is the sum of agriculture, services, and industry productions. This sum is not limited to an accounting operation but considers the causalities, the input, and the drivers of these operations which are determinants for the growth rate of GDP. The following model shows the elements of the industry sector, the nature of these elements, (stock, flow, parameter) and interactions (feedback loops) which impact the score of the industry sector production. That visualization allows us to know the drivers of the sector performances, the delays of information and materials delays, and how kind of policy or action could be taken to increase industry sector performances.

Figure 2. 9: industry sector in the iSDG model



Source: Millennium Institute (MI)

Some main equations of the GDP module in the iSDG model

Here we are showing how the equations are written in the Stella model and try to transcribe it into mathematical form as well as possible.

Stocks variables:

$$gdp\ fc\ deflator(t) = gdp\ fc\ deflator(t\ -\ dt)\ + \int_a^b gdp\ fc\ deflator\ net\ flow(t) *\ dt$$

Or

$$gdp\ fc\ deflator(t) = gdp\ fc\ deflator_{t-1} \int_a^b gdp\ fc\ deflator\ net\ flow(t) *\ dt$$

$\zeta_t = \zeta_{t-1} + \int_a^b \Delta\zeta(t) * dt$, where ζ is the GDP FC deflator, ζ_{t-1} is the initial GDP factor cost deflator (constant) and $\Delta\zeta$ the GDP factor cost deflator net flow which is equal to:

$\Delta\zeta(t) = \zeta_{year\ start} * \sigma_{year\ start}$, and $\sigma_{year\ start}$ is the GDP factor cost deflator growth rate year start.

So, $\zeta_t = \zeta_{t-1} + \int_a^b (\zeta_{year\ start} * \sigma_{year\ start})(t) * dt$

$$relative\ deflator[sector]_i(t) = relative\ deflator[sector_i](t\ -\ dt) + \int_a^b (relative\ deflator\ net\ flow[sector_i]) * dt$$

Or

$$relative\ deflator[sector]_i(t) = relative\ deflator[sector_i]_{t-1} + \int_a^b (relative\ deflator\ net\ flow[sector_i]) *\ dt$$

$$\psi_{it} = \psi_{it-1} + \int_a^b \triangle\, \psi_i(t) *\ dt$$

ψ_{it} is the relative deflator of the sector i for the period t and ψ_{it-1} is the initial relative deflator. While $\triangle\,\psi_i$ the relative deflator net flow which is equal to: $\triangle\,\psi_i(t) = D_{i_{year\ start}} * \theta_i$.

$D_{i_{year\ start}}$ is the deflator year start by sector and $\boldsymbol{\theta_i}$ is the relative deflator growth rate by sector. So, $\psi_{it} = \psi_{it-1} + \int_a^b D_{i_{year\ start}} * \theta_i\,(t) * \ dt$

Economic sectors are divided into agriculture, industry, and services, more further, each sector is divided in five sub-sectors (agr 1, agr 2, agr 3, agr 4, agr 5, ind 1, ind 2, ind 3, ind 4, ind 5, ser 1, ser 2, ser 3, ser 4 and ser 5 respectively). Then, we have fifteen sub-sectors of production, **a** and **b** are the study period.

Converters and flows variables :

$$gdp\ fc\ deflator\ net\ flow_t = gdp\ fc\ deflator\ year\ start_t * gdp\ fc\ deflator\ growth\ rate\ year\ start_t$$

$$\Delta\zeta(t) = \zeta_{year\ start} * \sigma_{year\ start}$$

$$deflator[sector_i]_t = relative\ deflator[sector_i]_t * gdp\ fc\ deflator_t / \sum_1^{15}(relative\ deflator[sector_i] * sector\ production\ share[sector_i])$$

$D_{it} = \psi_{it} * \zeta_t / \sum_1^{15}(\psi_{it} * \Theta[sector_i])$, with Θ the sector i production share in the total production

$$gdp\ mp\ deflator_t = gdp\ fc\ deflator_t * gdp\ mp\ to\ gdp\ fc\ deflator\ ratio_t$$

$\vartheta_t = \zeta_t * \gamma_t$ where γ is the GDP mp to GDP fc deflator ratio

or $\zeta_t = \zeta_{t-1} + \int_a^b (\zeta_{year\ start} * \sigma_{year\ start})(t) * dt$

So, $\vartheta_t = \gamma_t * (\zeta_{t-1} + \int_a^b (\zeta_{year\ start} * \sigma_{year\ start})(t) * dt)$

$gross\ national\ income_t =\ real\ gdp\ mp_t + private\ factor\ income_t/$
$gdp\ mp\ deflator_t + public\ factor\ income_t/gdp\ mp\ deflator_t$

$GNI_t = \bar{y}_{mp_t} + [(\rho_{private} + \rho_{public})/\vartheta_t]$, where GNI is the gross national income, $\bar{y}_{mp_t}$the real GDP mp, and ρ the factor income.

$nominal\ gdp\ fc_t = real\ gdp\ fc_t * gdp\ fc\ deflator_t$

$Y_{fc_t} = \bar{y}_{fc_t} * \zeta_t$ or $\zeta_t = \zeta_{t-1} + \int_a^b (\zeta_{year\ start} * \sigma_{year\ start})(t) * dt$

So, $Y_{fc_t} = \bar{y}_{fc_t} *(\zeta_{t-1} + \int_a^b (\zeta_{year\ start} * \sigma_{year\ start})(t) * dt\ )$

$nominal\ gdp\ mp_t = real\ gdp\ mp_t * gdp\ mp\ deflator_t$

$Y_{mp_t} = \bar{y}_{mp_t} * \vartheta_t$ with $\vartheta_t = \gamma_t * (\zeta_{t-1} + \int_a^b (\zeta_{year\ start} * \sigma_{year\ start})(t) * dt)$ where γ is the GDP mp to GDP fc deflator ratio.

So, $Y_{mp_t} = \bar{y}_{mp_t} * (\gamma_t * (\zeta_{t-1} + \int_a^b (\zeta_{year\ start} * \sigma_{year\ start})(t) * dt))$

$pc\ gross\ national\ income_t =\ gross\ national\ income_t/total\ population_t$

$GNI_{pc_t} = GNI_t/TP_t$, with GNI_{pc_t} the gross national income per capita and TP the total population.

$total\ agriculture\ production_t =\ production\ by\ sector[agriculture]\ _t$

$$= \sum_1^5 agriculture\ production[agr_i]_t$$

$TAP_t = \sum_1^5 AP[agr_i]_t$ with TAP the total agriculture production, AP[agr], the agriculture sub-sectors production (agr 1, agr 2, agr 3, agr 4, agr 5)

$$total\ industry\ production_t = production\ by\ sector[industry]_t = \sum_1^5 industry\ production[ind_i\ ]_t$$

$TIP_t = \sum_{i=1}^5 IP[ind_i\ ]_t$ with TIP the total industry production, IP[ind] industry sub-sectors production (ind 1, ind 2, ind 3, ind 4, ind 5)

$$total\ services\ production_t = production\ by\ sector[services]_t = \sum_{i=1}^5 services\ production[ser_i]_t$$

$TSP_t = \sum_{i=1}^5 SP[ser_i]_t$ with TSP the total services production, SP[serv] services sub-sectors production (ser 1, ser 2, ser 3, ser 4 and ser 5)

$$total\ nominal\ agriculture\ production_t = \sum_1^5 sector\ nominal\ production[agr_i]_t$$

$TNAP_t = \sum_{i=1}^5 SNP[agr_i]_t$, with TNAP the total nominal agriculture production and SNP[agr], sector nominal production in agriculture sub-sectors.

$$total\ nominal\ industry\ production_t = \sum_{i=1}^5 sector\ nominal\ production[ind_i]_t$$

$TNIP_t = \sum_{i=1}^5 SNP[ind_i]_t$, where TNIP is the total nominal industry production and SNP[ind] is the sector nominal production in industry sub-sectors

$$total\ nominal\ services\ production_t = \sum_{i=1}^5 sector\ nominal\ production[ser_i]_t$$

$TNSP_t = \sum_{i=1}^5 SNP[ser_i]_t$, where TNSP is the total nominal services production and SNP[ser] is the sector nominal production in services sub-sectors

$$Sector\ nominal\ production[sector_i]_t = (\ IF\ deflator[sector_i]_t = \ 0\ THEN\ 0\ ELSE\ production\ by\ [sector_i]_t * deflator[sector_i]_t)$$

$SNP[sector_i]_t = (\ IF\ D_{it}\ =\ 0\ THEN\ 0\ ELSE\ P[sector_i]_t * D_{it}\ )$, P is the sector's production.

$$real\ gdp\ fc_t = total\ agriculture\ production_t + total\ industry\ production_t + total\ services\ production_t$$

$\bar{y}_{fc_t} = TAP_t + TIP_t + TSP_t = \sum_{i=1}^{5} AP[agr_i]_t + \sum_{i=1}^{5} IP[ind_i\ ]_t + \sum_{i=1}^{5} SP[ser_i]_t$ so,

$$\bar{y}_{fc_t} = \sum_{i=1}^{5}(AP[agr_i]_t + IP[ind_i\ ]_t + SP[ser_i]_t)$$

Or

$$nominal\ gdp\ fc_t = real\ gdp\ fc_t * gdp\ fc\ deflator_t$$

$$Y_{fc_t} = \bar{y}_{fc_t} *(\zeta_{t-1} + \int_a^b(\zeta_{year\ start} * \sigma_{year\ start})(t) * dt)$$

By replacing the real GDP fc by its value,

$$Y_{fc_t} = (\sum_{i=1}^{5}(AP[agr_i]_t + IP[ind_i\ ]_t + SP[ser_i]_t)) *(\zeta_{t-1} + \int_a^b(\zeta_{year\ start} * \sigma_{year\ start})(t) * dt)$$

$$real\ gdp\ mp_t = real\ gdp\ fc_t * (1 + indirect\ taxes\ minus\ subsidies\ as\ share\ of\ gdp_t)$$

$$\bar{y}_{mp_t} = \sum_{i=1}^{5}(AP[agr_i]_t + IP[ind_i\ ]_t + SP[ser_i]_t) * (1 + \alpha_t)$$

with α is the indirect taxes minus subsidies as share of GDP

$$nominal\ gdp\ mp_t = real\ gdp\ mp_t * gdp\ mp\ deflator_t$$

Y_{mp_t} =$(\sum_{i=1}^{5}(AP[agr_i]_t + IP[ind_i\ ]_t + SP[ser_i]_t) * (1 + \alpha_t)) * \vartheta_t$

by replacing GDP mp_deflator by its expression, we have:

Y_{mp_t} =$(\sum_{i=1}^{5}(AP[agr_i]_t + IP[ind_i\ ]_t + SP[ser_i]_t) * (1 + \alpha_t)) * (\gamma_t * (\zeta_{t-1} + \int_a^b(\zeta_{year\ start} * \sigma_{year\ start})(t) * dt))$

$real\ pc\ gdp\ mp_t = real\ gdp\ mp_t / total\ population_t$

$\bar{y}_{pc_t} = \bar{y}_{mp_t}/TP_t$ by replacing the real GDP mp by its expression,

$$\bar{y}_{pc_t} = (\sum_{i=1}^{5}(AP[agr_i]_t + IP[ind_i\ ]_t + SP[ser_i]_t) * (1 + \alpha_t))/TP_t$$

$real\ value\ added\ fc\ growth\ rate_t$
$= TREND(real\ gdp\ fc_t, growth\ rate\ time\ horizon, initial\ gdp\ fc\ growth\ rate)$
$\upsilon_{fc_t} = TREND(\bar{y}_{fc_t} = \sum_{i=1}^{5}(AP[agr_i]_t + IP[ind_i\ ]_t + SP[ser_i]_t), \mu = 1, \varepsilon)$ with μ the growth rate time horizon and ε the initial gdp fc growth rate.

$real\ value\ added\ mp\ growth\ rate_t$
$= TREND(real\ gdp\ mp_t, growth\ rate\ time\ horizon, initial\ gdp\ mp\ growth\ rate)$
$\upsilon_{mp_t} = TREND(\bar{y}_{mp_t} = \sum_{i=1}^{5}(AP[agr_i]_t + IP[ind_i\ ]_t + SP[ser_i]_t), \mu = 1, \varsigma)$, where ς the initial gdp mp growth rate.

Table 2. 4: iSDG model applications

Country	Application goal	Results
Dynamics analysis of Sustainable Development Goals: Achieving the SDGs with Uganda's Third National Development Plan, (NPA Uganda, 2020a)	The model examines the potential impact of 9 categories of interventions from the Third National Development Plan (NPD 3, which covers the period 2020-2025) for the period 1995-2030. These interventions concern the financing of agro-industrialization, industry, services, infrastructure, water and sanitation, health and education, environment and governance. The iSDG-Uganda model simulates the evolution of the 17 SDGs over the period 1995-2030 and for a 2040 vision of the SDGs, in order to identify leverage points for improving their performance. Three scenarios are analyzed: - A business-as-usual (BAU) scenario, which assumes that the current level of investment (2019 investment level) remains unchanged and that there are no policy changes after 2020 (no NPD 3). - A moderate scenario with average additional investment equal to half of the budget planned in NPD 3 for the period 20201/21-2024/25 is maintained after 2024/2025. - An optimistic scenario where the average level of additional investment planned in NDP 3 for the period 2020/21-2024/25 is maintained as a percentage of GDP after 2024/25.	The results show that under the BAU scenario, the average level of achievement for all SDGs is 32% in 2030, compared to 25.1% in 2020, 35.2% in the moderate scenario, and 35.9% in 2030 in the optimistic scenario. SDGs 10, 12, 15, and 17 have significant levels of achievement (above 50%) in all scenarios, unlike SDGs 2, 5, 11, and 14, which have the lowest levels of achievement. The performance of each scenario is around 7%, 10.1% and 10.8% respectively. These performances are driven in particular by SDG 9, through investments in roads, railways and infrastructure, which have a snowball effect on the other SDGs, and SDG 6, with the improvement of access to water and sanitation. On the other hand, SDG 12 generates a counter-performance (very weak) with the increased consumption of natural resources, which has a negative effect on the performance of the other MDGs due to the lack of environmental interventions provided for in NDP 3. To verify the validity of the results, the technical team proposed to compare the historical data with those simulated by the 2019-2030 model. This comparison validated the results of the analysis, which seem to represent reality. Finally, the poor performance of the

		SDGs led the authors to propose important leverage points, such as improving governance indicators, environmental investments, and investments in industry. And above all, the collective implementation of these interventions, which have a positive synergistic effect on all SDGs.
Toward achieving Sustainable Development Goals in Ivory Coast: Simulating pathways to sustainable development, (Pedercini et al., 2018)	The model assesses the impact of implementing the National Perspective Study (NPS) program on the performance of the 17 SDGs for the period 1990-2030 and a 2040 perspective in Côte-d'Ivoire. The T21-iSDG-Côte-d'Ivoire model integrates economic, social and environmental policies to achieve the 17 SDGs by 2030. Three scenarios are simulated: - A BAU scenario that simulates the achievement of the 17 SDGs by 2030 with current policies, without the implementation of the NPS; - An NPS scenario that assesses the impact of the policies included in the NPS with funding at 4.5% of GDP; - An SDG scenario that assesses the impact of policies included in the NPS and additional policies recommended by the UN Agenda 2030 with funding at 15% of GDP.	Under the BAU scenario, the level of achievement of all SDGs is estimated at 21% of the target of 100% achievement by 2030. This rather weak performance is due to a poor population with poor access to health infrastructure and low levels of education. However, under the NPS scenario, the level of SDG achievement is 50% due to a reduction in poverty, inequality and famine, investments in health and adaptation to climate change. And under the SDG scenario, the level of SDG achievement is 67%. This performance is largely influenced by the coherence between SDGs 1 to 5 and SDGs 11, 13, and 17, due to the combination of several synergistic policies, such as increased health spending, climate change adaptation, poverty and inequality reduction, and waste management. This combination of mixed policies allows the population to escape the poverty trap through the accumulation of human and financial capital, which is an important factor for economic growth. In terms of policy recommendations, the analysis suggests increased

		funding for adult education, sustained economic growth that benefits low-income population groups, efficient use of natural and water resources, improved good governance, promotion of sustainable mobility and renewable energy, and promotion of sustainable peace, as Côte d'Ivoire has experienced many political crises in its history.
Achieving the SDGs in Nigeria: pathways and policy options, (UNDP & OSSAP-SDGs, 2019)	The model assesses the impact of the Economic Recovery and Growth Plan (ERGP) for 2017-2020 on the performance of the SDGs. Each SDG has at least one intervention, including interventions to address poverty and food insecurity, improve the quality of education, develop industries, adapt to climate change and protect natural resources, infrastructure and basic social services, governance, and resource mobilization. The simulation of the iSDG-Nigeria model covers all 17 SDGs and takes into account five of Nigeria's major problems: conflict, oil and gas exploitation, solid minerals exploitation, power sector problems, and sublocal disaggregation. Three scenarios were analyzed: - No ERGP scenario, which assumes no policy changes after 2015, with a continuation of pre-ERGP policies. - An optimistic ERGP scenario, which estimates the potential impact of the policies included in the ERGP program on achieving the 2030 Agenda, maximizing improved governance. - An ERGP+ODD scenario, which includes synergistic policies that can improve SDG performance in areas where policies in the optimistic scenario are ineffective and insufficient. This scenario optimizes	The simulation shows that without the ERGP, only 2/64 of the indicators will be achieved by 2030, only SDG 12 has a performance level above 50% and 12/17 SDGs have performance levels below 30% in the non-ERGP scenario in 2030. In the optimistic scenario with the ERGP in place, 16/64 indicators are achieved, only 9/17 SDGs have levels of achievement above 50% and only 4/17 SDGs have levels of achievement below 30%, and SDG 2 is almost achieved in 2030. Finally, in the ERGP's SDG policy optimization scenario, 25/69 indicators are almost achieved, 3/17 SDGs are almost achieved, and only 3/17 SDGs have performance levels below 50% in 2030. This scenario points to the prospect of achieving the SDGs by 2030 if new, effective and coherent policies are put in place and all subnational governments are involved in implementing these development policies and programs.

	spending, taxation, and other additional policies.	

Source: the authors

Table 2. 5: benchmarking of dynamic models

Comparison criteria				
Model	**Consideration of the SDGs**	**Feedbacks loops using**	**Type of model (prospection/prediction)**	**Distinction of variables (flow and stock)**
integrated Sustainable Development Goals of the MI (iSDG)	The iSDG model simulates the interactions between the 17 SDGs and shows their interconnectedness by using SD tools. It has the power to simulate the performances of SDGs until 2030 or up to 2050 by using an integrated framework of SDGs to show the score of them under a BAU	The iSDG model uses System Dynamics (SD) tools. First, the SD method takes into account the cause-and-effect relationships between sectors by using feedback loops. Second, it shows the polarity of the direct relations between variables and overall the loop's polarity.	iSDG model uses different scenarios of policies to analyze the performance of sectors and SDGs in the medium and long terms for the purpose of policy advice and guidance. It allows us to simulate the performance of sectors and SDGs on the one hand, but also to analyze the efficiency of the policies to be implemented, and to estimate the costs of policy implementation on the other	The model uses an SD approach that distinguishes stock variables and flow variables. Stock and flow variables are the infrastructure of the system and the use of loops allows the system to operate. Stock variables are those which are measurable at a particular point in time. They accumulate over time. Flow variables are quantities that are measured concerning a period.

	scenario and when a couple of policies are implemente d.		hand. In that case, the iSDG model is a prospecting model to find the best combination of policies that are relevant to accelerate countries' development toward the UN 2030 Agenda.	
AFD dynamic model (Stock-Flow Consistent Prototype Growth Model)	The Stock-Flow consistent model considers only economic variables that are not sufficient to cover all of the 17 SDG. But we think that this model can involve and be improved to model the three domains of developmen t.	The Stock-Flow consistent model uses a feedback loop approach to show the exchanges taking place in the economy between actors through the different elements of their balance sheet (assets and liabilities). But it doesn't talk about the sense of the loops and the polarity of the feedback loops.	It is a predictive model that seems to be close to the DSGE model. Their objective is to determine the channels through which shocks affect the economy and to analyze the stability of macroeconomic variables following shocks in the long term. So, the Stock-Flow consistent model is a predictive model in line with the DSGE model.	The Stock-Flow consistent model uses feedback mechanisms between stock accumulation emerging out of flow dynamics, and flow responses to stock accumulation processes.
Long-Term	The LTGM doesn't	The LTGM uses a linear	The LTGM allows to	According to the nature of the

Growth Model of the WB	target sustainable development goals. By using a Cobb Douglas production function, its goal is to analyze the future long-term growth scenarios in developing countries. The model is just limited to GDP prediction and with the poverty module, it helps to calculate the effect of GDP growth rate on poverty by using the poverty line.	approach which does not allow to show cause and effect loops and to present the feedback loop principles.	analysis sustainability of the GDP growth rate according to a certain level of investment and also to know the level of investment required for a given GDP growth rate. So, it is a long-term prediction model contained in an Excel file where data is already prefilled by country but does not help to implement a scenario of policies that concern social and environmental areas.	variables, there is no difference between accumulated variables with a delay and flow variables for which their dynamic makes the system unstable and leads to adverse results of the model. So, the LTGM does not consider the nature of variables in terms of stock and flow and delays.
Dynamic Stochastic General Equilibrium model of the IMF	The DSGE model models only the utility functions of households, firms, central bank, and government through the interactions of macroecono	It uses econometric methods which are linear approaches to calculate the parameters and variables values at the steady state. Contrary to System	It is entitled firstly to reproduce historical movements of Reference Business Cycles (RBC) and secondly, to predict the steady state of macroeconomic aggregates for medium and long	The use of stock and flow variables is not appropriate for econometric methods. So, the DSGE model doesn't distinguish stock and flow variables during regressions and policy effects assessment. The

	mic variables. It is useful to simulate shock effects and predict the steady state of the economy when a shock is introduced. So, the DSGE model isn't interested in SDGs indicators modeling and the UN 2030 Agenda policies simulation.	Dynamics tools that use circularity relationships (cause and effect) between sectors leading to feedback loops. So, the DSGE model was therefore limited to econometric and linear relationships between variables.	runs. For these reasons, the DSGE is a predictive model allowing us to determine the trends of economic variables.	distinction between flow and stock variables is important in determining the macroeconomic variables that influence the stability of the economy following shocks and the performance of the economy following the implementation of public policies.

Source: the authors

2.5. Conclusion

This paper has consisted of discussing about four criteria to be considered in the public policy implemention and their effectiveness assessment in developing countries. Social and population problems are persistent, the environment is degrading so fast over time, the natural resources supplying economic activities become rare, and an inclusive growth economy is uncertain because inequalities persistence. While development sectors are interrelated and interact each with others, considering these interactions to highlight about systems's complexity, helps to understand policy inefficiency and the resistance of development indicators. Then, the essence of this work was to analyse the ability of the Dynamic Stochastic General equilibrium (DGSE), the Long Term Growth Model (LTGM), the Stock-Flow Consistent Prototype Growth Model, and the integrated Sustainable Development Goals (iSDG) to incorporate these complexities in their structure for a better assessment of public policies. The benchmarking analysis has revealed that only the iSDG structure can consider the feedback loop mechanisms, distinguish the nature of the system's elements, elaborate many synergistic policies, and measure SDGs performances are the four criteria defined. Also, the results have shown that the Stock-Flow Consistent Prototype Growth Model, and the integrated Sustainable Development Goals (iSDG) consider the GDP as a driver for sectors' performances that can be negative or positive. Contrary to the Dynamic Stochastic General equilibrium (DGSE), and the Long-Term Growth Model (LTGM) that aim to maximize GDP performance without considering the feedback interactions between economic, social, and environmental sectors. For a deeper evaluation of public policy and a good way to analyze GDP growth trends in the long run, we recommend International Institutions like the World Bank, IMF consider the interactions between sectors in the public policy modeling models because many drivers in social, economic and environmental areas influence GDP growth. In return GDP fast growth will impact positively or negatively the performances of these drivers in the short or long run. And end, these institutions have to develop models that can include Sustainable Development Goals indicators in their structure because measuring countries' development progress cannot be focused only on the trend of GDP growth. Then, it must consider the achievement of the most relevant indicators of development, and social, environmental, and economic sectors' performances.

3. Modeling the SDGs with a forward-looking approach: the iSDG model

Abstract[5]: Since 2016, the different governments of countries in the North and South have been attempting to match their sustainable development policies with the 17 Sustainable Development Goals (SDGs). Public decision-makers must thus define a roadmap that sets out their actions for the 2030 and 2050 horizons. The iSDG model, based on the Threshold 21 (T21) model, was designed and developed to enable policy makers to take advantage of the interconnections and synergies between the SDGs. The iSDG model is a systems dynamics-based tool, structured to analyze all medium- and long-term sustainability issues. Grounded in a strong sustainability framework (the economic sphere is embedded in the social sphere, which is itself embedded in the environmental sphere), the iSDG model proposes to assess effective strategies to achieve the SDGs based on three types of scenarios (BAU, medium, optimistic). An analysis of cross-impacts as well as positive and negative synergies between the SDGs allows for the visualization of the main results via an SDG achievement rate.

Keywords: iSDG, T21, SDG, Simulation, Systems Dynamics

[5] This chapter was written with Arnaud DIEMER and Matteo PEDERCINI, and a french version is published in the Current Science review.

3.1. Introduction

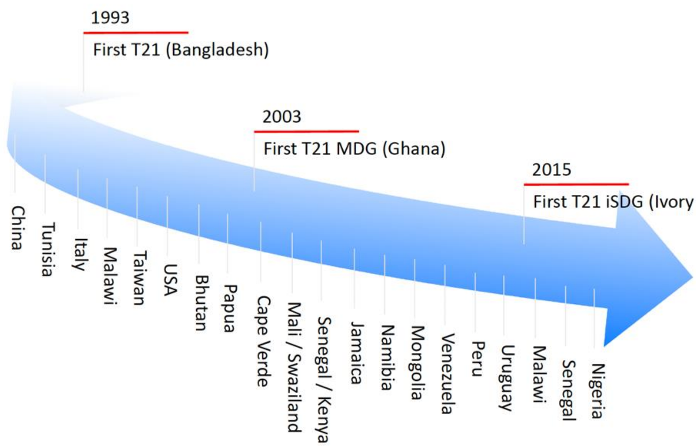
The United Nations 2030 Agenda for Sustainable Development, consisting of 17 goals, was adopted by world leaders at the United Nations Summit in 2015 (Gérardin et al., 2016). By aligning their national development policies with the 2030 Agenda and mobilizing both civil society and the private sector, states have set out to mobilize their human and financial resources to eradicate poverty and malnutrition, improve well-being and education and eliminate inequality and indecent work, provide clean energy and access to water, invest in sustainable infrastructure and cities, engage society in responsible consumption and production patterns, combat climate change and biodiversity erosion (terrestrial and aquatic), or promote the emergence of peaceful and inclusive societies (UN, 2015b). Each year, the Sustainable Development Goals report provides an overview of the efforts and progress made by different countries (UN, 2019, 2018, 2017, 2016), as well as the additional measures that need to be taken to achieve certain goals (improving girls' enrolment rates, reducing extreme poverty...). While global warming is a threat (IPCC, 2022) that is degrading the natural environment at an alarming rate (ocean acidification, land erosion, rising sea, and ocean levels, loss of biodiversity...) and undermining the progress that has been made, the 17 SDGs show us every year that it is possible to take advantage of the links that unite them to bring about an economic and social transformation of society (UN, 2019). All issues are interdependent, and solutions to climate change include reducing greenhouse gas (GHG) emissions, investing in clean energy, creating new jobs, greening most urban areas, and improving urban air quality. While the interdependence of the SDGs no longer needs to be demonstrated, states are somewhat at a loss when it comes to planning their sustainable development strategies (Riffon et al., 2016). In particular, policymakers need to answer questions such as: how many resources are needed to achieve the SDG targets? How should investments be allocated across the 17 SDGs? Where should investments be prioritized? How can these investments be financed? To improve the government's plan for sustainable development, the Millennium Institute designed and developed the Integrated Sustainable Development Goals (iSDG) model. Based on the Threshold 21 (T21) model, which has proven successful in the United States and many Asian and African countries, the iSDG model is a system dynamics tool structured to analyze medium and long-term development issues. The model is designed to complement the contributions of budgetary, sectoral, or other short- and medium-term planning models.

This article seeks to demonstrate that, beyond a simple modeling exercise, the iSDG model offers a new perspective on sustainable development policies, and in particular on the scenarios that need to be formulated to achieve all (or some) of the SDGs. To this end, we will present the structure and characteristics of the iSDG model through three prisms. First, we will show that the iSDG model - composed of 30 sectors (10 social, 10 economic, and 10 environmental) - is based on a strong sustainability approach, in which the economy is limited by the social sphere (society), itself embedded in the environmental sphere. The analysis of the SDGs is therefore part of the Planet's Boundaries framework (Rockström et al., 2009) and that of the Doughnuts economy (Raworth, 2017). As a result, some of the SDGs reflect constraints on the world, but also on local scales. Secondly, the iSDG model provides a framework for analyzing the interconnections (strong or weak) between the SDGs. The various sectors of the model interact with each other through a complex network of feedback loops. These representations show that it is possible to reproduce fairly faithfully most of the relationships that exist between the SDGs and to focus on the main leverage points. From a methodological point of view, the iSDG model is fully in line with World 2 (Forrester, 1972) and World 3 (D. H. Meadows, Meadows, & Randers, 1972) models, considered to be the first assigned integration models (Integrated Assessment Models). Industrial dynamics (Forrester, 1961) is a radical departure from the general equilibrium and optimization models prescribed by international institutions such as the IMF and World Bank. It is based on causal loop diagrams (CLD) and stock-flow diagrams (SFD) involving positive (reinforcing loop) and negative (regulating loop) polarity directions, as well as lag effects. In the third and final section, we return to the prospective dimension of the iSDG model. Scenarios refer to narrative forms (which made the World 3 model such a success) built on quantitative data. Behind the global perspectives proposed by the model, there are a large number of trajectories at the national level, which can be used by different governments. Ultimately, the iSDG model raises the question of planning sustainable development strategies.

3.2. The iSDG model, an integrated simulation tool

The iSDG model is first and foremost an integrated tool designed to support the design and evaluation of sustainable development strategies aimed at achieving the SDGs (A. Diemer, Sourgou, et al., 2022). As such, it fits perfectly into the five main stages of the public policy process (Howlett et al., 1995), namely (i) agenda setting and issue identification; (ii) policy design, formulation and assessment; (iii) policy adoption; (iv) policy implementation; and (v) policy evaluation and monitoring. The iSDG model is particularly well suited to stage 2, which can become very complex as alternative options for resource allocation in different sectors are evaluated, debated and negotiated (Basle & Pele, 1994; DELEAU, 1986). The model can provide quantitative support for exploratory discussions (Perret, 1991) on key areas of intervention, for assessing progress on each goal by 2030, or for highlighting SDGs in need of intervention (OCDE, 2016). The iSDG model also offers an interesting perspective in the final stage of the evaluation and monitoring of national policies. Experts use detailed sectoral models to refine how public policies should be implemented (Viveret, 1989), the iSDG model can simulate these policies in a targeted way (by SDG) or by combining different SDGs to assess cross-sectoral synergies and improve their effectiveness (Pedercini et al., 2019).

Figure 3. 1: from the Model 21 to the iSDG model



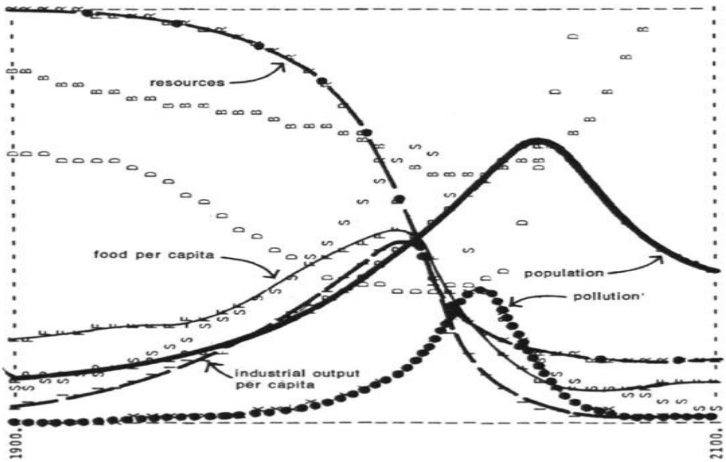
Source: Pedercini, (2022)

The iSDG model is the latest in a series of models called T21 (Threshold 21) developed by the Millennium Institute at the US level (A. M. Bassi & Shilling, 2010; A. Bassi & Pedercini, 2007), then in a large number of countries in Africa (Benin, Cape Verde, Egypt, Ghana, Malawi, Mali, Mozambique, Somalia, Tunisia), Asia (Bangladesh, Bhutan, Cambodia, China, Indonesia, Taiwan) or Europe (Italy, Lithuania). These models share several characteristic (A. Diemer, Sourgou, et al., 2022):

(i) They are part of the long tradition of Integrated Assessment Models (IAMs), in particular the World 2 (Forrester, 1972) and World 3 (D. H. Meadows, Meadows, & Randers, 1972) models. Over the past two decades, IAMs have become very popular as a result of climate change research and the early work of the IPCC (G. Diemer et al., 2019). Chapter 10 of the IPCC report (IPPC, 1995), entitled "Integrated Assessment of Climate Change: An Overview and Comparison of Approaches and Results," emphasizes that integrated assessment models are tools that combine knowledge from a variety of disciplines to provide information that would not be available through traditional disciplinary research. Such models would thus prove useful for exploring interactions between human and natural systems, for testing hypotheses from different disciplines, or for highlighting feedback effects (IPCC, 1995, p. 14).

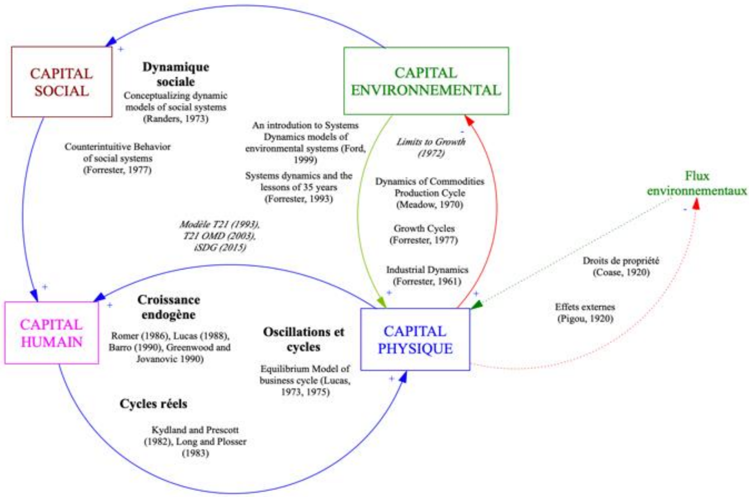
These models are based on narratives - what O'Neill et al., (2017) now call Narrative Shared Socioeconomic Pathways (NSSP). Narratives describe plausible future changes in population, natural resource use, economic activities (agriculture, industry...) or the environment (pollution). These narratives cover an element of uncertainty regarding the societal challenges of mitigating and adapting to climate change. One of the main results of the Limits to Growth model (1972) was to propose scenarios (figure 3.2) that articulate quantitative and qualitative data over a long period (1900 - 2100) through a flux-stocks (capital) approach. This approach contrasts with the theoretical work of the last 50 years on physical, social, human, and environmental capital and the impact of economic activities on the environment (figure 3.3).

Figure 3. 2: the Limits to Growth story



Source: D. H. Meadows, Meadows, & Randers, (1972, p.124)

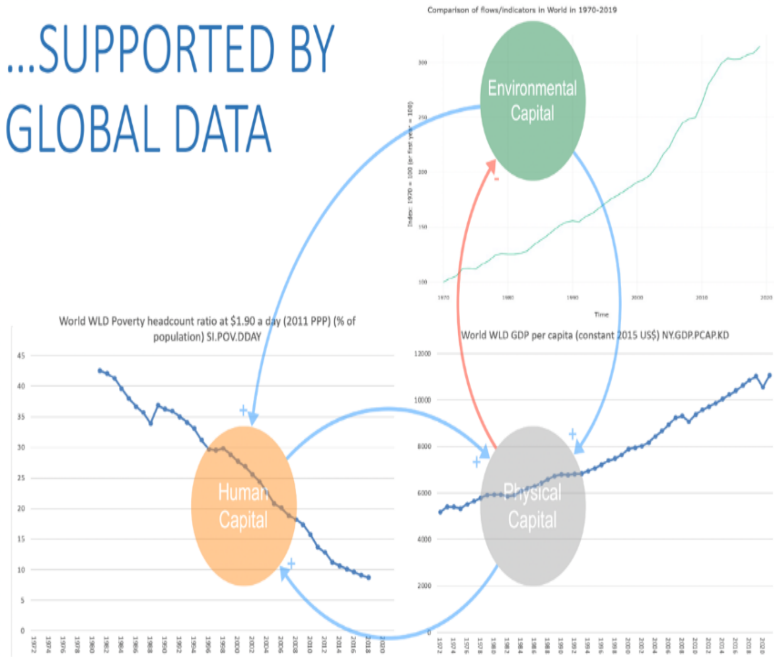
Figure 3. 3: a flow-stocks reading grid



Source: DIEMER, BATISSE, et al., (2022, p. 10)

The iSDG model takes up this narrative logic using global data (flows/stocks) over the period 1970-2022. It is also based on a detailed review of the modeling and scientific theory literature, from sources such as the World Bank, IMF, FAO, IPCC, and the US Department of Energy.

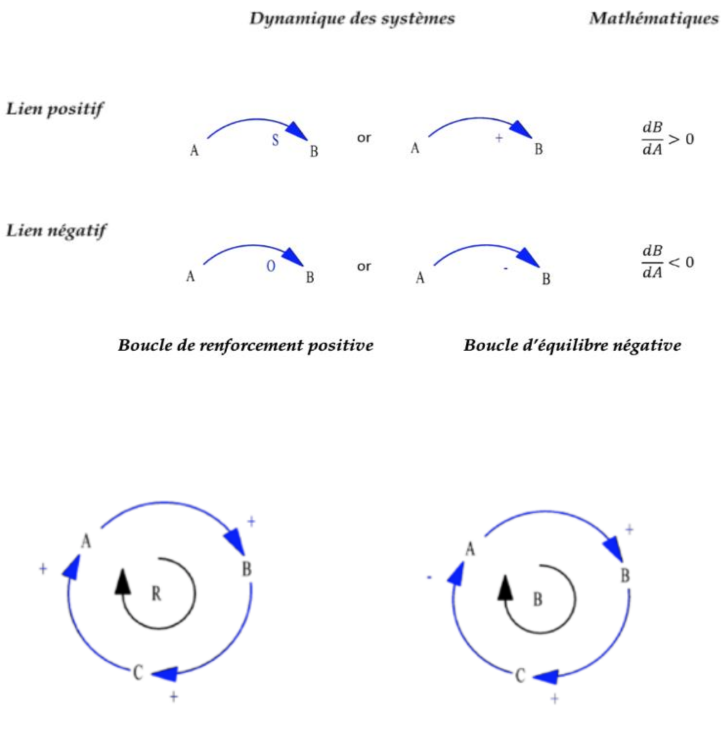
Figure 3. 4: the relationship between Flow/Stock indicators and global data



Source: Pedercini, (2022, P.5)

(ii) they are based on a method - system dynamics (Forrester, 1961, 1968b, 1969, 1972) - and simulation tools (Vensim and Stella software) capable of solving complex problems and producing quantitative results (graphs) over horizons ranging from 5 to 100 years. Systems Dynamics uses Systems Thinking (Checkland, 1981; Richmond, 1997, 2000; Senge, 1990) to map all the causal relationships in a complex system. A Causal Loops

Diagram (CLD) can thus be created (Lane, 2000). CLDs are based on a system delimitation to account for polarity directions (a positive polarity loop reinforces the system, a negative polarity loop regulates the system), time shifts and action levers (the famous Leverage points described by D. Meadows, (1999)).

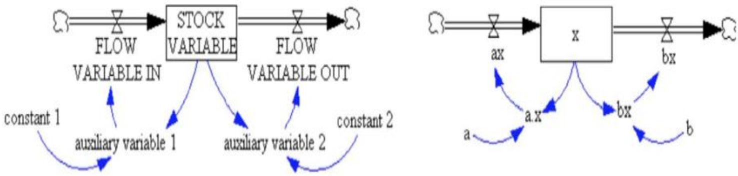


Source : Sterman (2000), Diemer (2004)

Leverage points play an important role when it comes to knowing how to modify a system (distinction between what we observe and what we would like to see). The transition from

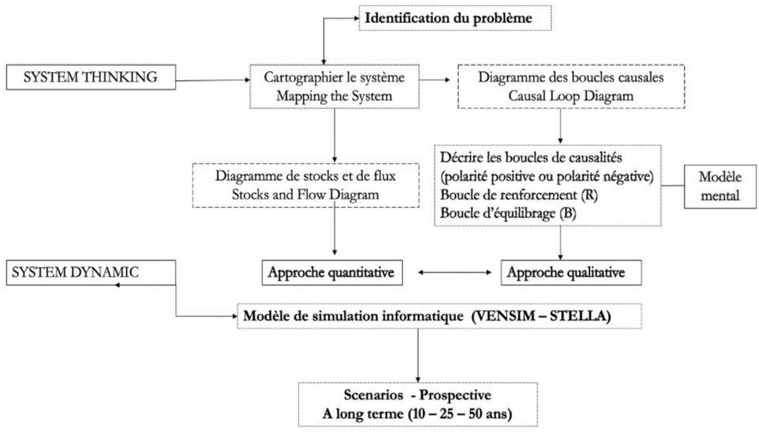
Systems Thinking to Systems Dynamics is achieved by modeling a problem (J. Sterman, 2000). The model is based on cause-and-effect links between flows and stocks (SFD, Stocks and Flows Diagram).

$$x = x_0 + \int_{t_0}^{t} (+ax - bx)\, dt$$

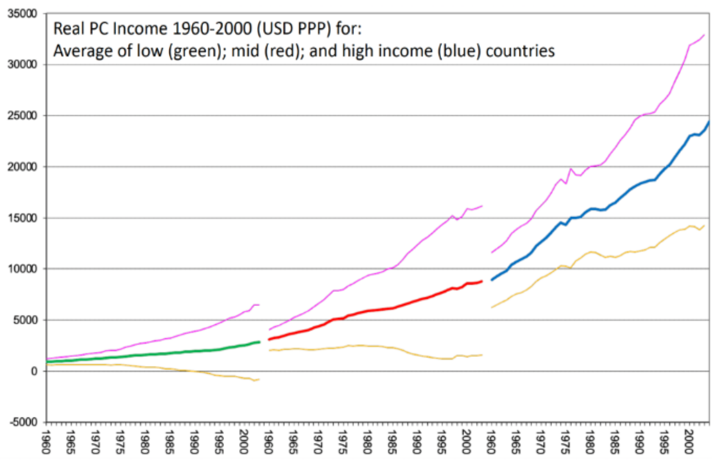


The question of data becomes crucial here, as we need to produce the first simulations over a given time horizon using software such as Vensim or Stella.

Figure 3. 5: the transition from Systems Thinking to System Dynamics



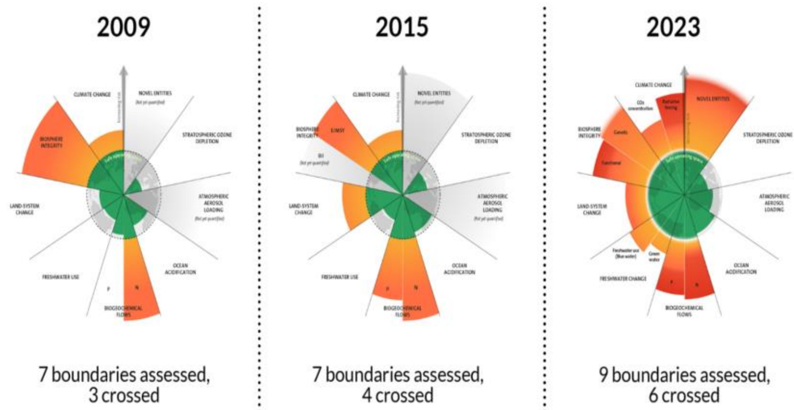
Source: (A. Diemer, 2004)



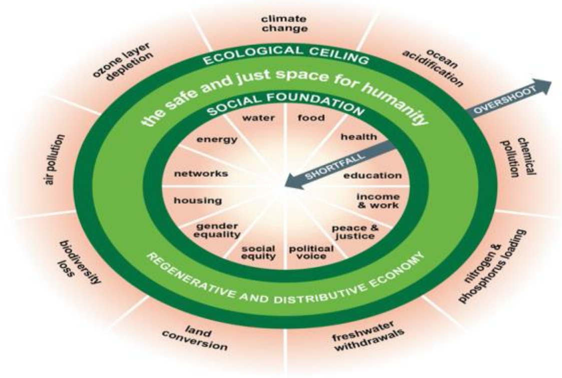
Source: Pedercini, (2022)

It is then possible to specify the impacts of public policies or structural changes, but also to generate dialogue on the options chosen with the various ministries of a government, partner expert agencies or even civil society. The iSDG model (like the T21 model) is part of a long line of models that emerged in the 70s and 80s following the computer revolution and computer-aided simulations (Barney & Wilkins, 1986; Garrett, 1990).
(iv) They place the impacts of national policies within a strong sustainability approach (non-substitution of production factors, preservation of natural capital stocks, consequences of investments in innovation). Human-nature interactions are part of the logic of planetary limits (Planet Boundaries Rockström et al., (2009)) and social floor (Doughnuts Economy, Raworth, (2017)). Consequently, public policy choices (and in particular the targets to be achieved in terms of the SDGs) must enable us to reduce our environmental footprint without compromising a certain level of well-being (Figure 3.6).

Figure 3. 6: Planet Boundaries and Doughnuts Economy



Source : Stockholm Resilience Centre[6]



Source:Raworth, (2017)

This strong sustainability approach plays a key role in the design and use of the iSDG model, reflecting the fact that strategic planning for sustainable development must rule out any Overshooting behavior, and a fortiori, a collapse scenario (note here that collapse need not be absolute, it can be relative via a steady decline in living standards or life expectancy).

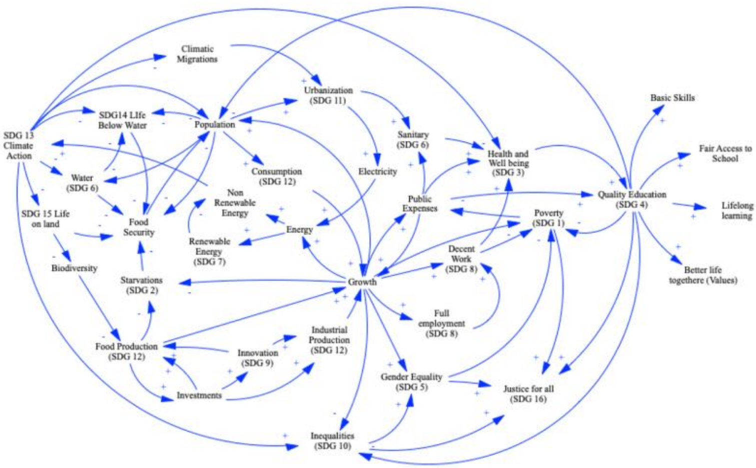
3.3. Structural features of the iSDG model

The iSDG model, based on system dynamics, is a tool for global, participative planning of sustainable development. Global, because it represents all the important elements of a system's complexity (limits, feedback relationships, non-linearity, consideration of delays, formulation of hypotheses, presentation of equations, integration of data, etc.). Participative, because it involves stakeholders in the modeling

[6] https://www.stockholmresilience.org/research/planetary-boundaries.html

process (choice of hypotheses and scenarios, design of data management, surveys to be carried out, etc.). In a way, systems dynamics is one of the methods that very early on integrated the role of stakeholders into the modeling process. Modeling with problem-owners" is one of the main characteristics of system dynamics (Lane, 2000; Rouwette & Vennix, 2006). This stakeholder engagement is present in many fields: marketing (Morecroft, 1984), team management in strategic decision-making (Richmond, 1997), methods for facilitating group decision-making (Lane, 2010), the practices of Group Model Building (Anderson & Johnson, 1997; Vennix, 1996). Community-Based Systems Dynamics (Hovmand, 2014) or Participatory System Dynamics Modeling (Antunes et al., 2015; Sedlacko et al., 2014; Videira et al., 2017). As a result, the iSDG model is particularly suited to analyzing the interactions between policies aimed at achieving the SDGs (Figure 3. 7). SDG 17, "partnerships for the achievement of the goals", even has a place in it via the inclusion of all stakeholders in a participatory modeling approach.

Figure 3. 7: reproducing the interdependencies between the SDGs



Source: A. Diemer et al., (2020)

The iSDG model includes indicators relevant to all 17 SDGs. The list below gives an overview of the targets selected for each SDG in the basic version of the model, i.e., a total of 78 indicators. However, it is possible to integrate customized indicators for a country's specific needs.

Table 3. 1: SDG indicators in the iSDG model

1 PAS DE PAUVRETÉ	1.1.1 Proportion of the population living below the international poverty line, by gender, age, employment status and	10 INÉGALITÉS RÉDUITES	10.1.1 Growth rate of household expenditure or per capita income of the poorest 40% of

	geographical location (urban/rural) 1.2.1 Proportion of the population living below the national poverty line, by gender and age 1.4.1 Proportion of the population living in households with access to basic services 1.5.1 Number of deaths, missing persons and people affected by a disaster by 100,000 people 1.5.2 Economic losses due to direct disasters as a proportion of global GDP.		the population and of the total population 10.2.1 Proportion of people living below 50% of median income, by age, sex and disability 10.4.1 Labor's share of GDP, including wages, transfers and social protection.
	2.1.1 Prevalence of undernourishment 2.2.1 Prevalence of stunting in children under 5 years of age 2.2.2 Prevalence of malnutrition in children under 5, by type (wasting and overweight)		11.5.1 Number of deaths, missing persons and people affected by disasters per 100,000 inhabitants 11.5.2 Direct economic losses due to

	2.3.1 Production volume per work unit by farm/pastoral/forestry business size classes 2.4.1 Proportion of agricultural land devoted to productive and sustainable agriculture.		disasters as a proportion of global GDP, including disaster damage to critical infrastructure and disruption to basic services. 11.6.1 Percentage of municipal solid waste regularly collected and whose final disposal is adequate in relation to the total waste generated by the city 11.6.2 Annual average levels of fine particles (e.g. PM2.5 and PM10) in cities (weighted by population)

	3.1.1 Maternal mortality rate 3.1.2 Proportion of births attended by skilled health personnel 3.2.1 Under-five mortality rate 3.2.2 Neonatal mortality rate 3.4.1 Mortality rate attributed to cardiovascular disease, cancer, diabetes or chronic respiratory disease 3.6.1 Mortality rate due to road accidents 3.7.1 Proportion of women of childbearing age whose family planning needs are met by modern methods 3.7.2 Teenage birth rate per 1,000 women in this age group 3.8.1 Coverage of essential health services.		12.2.1 Material footprint (MF) and MF per capita, by GDP 12.2.2 Domestic consumption of materials (DMC) and DMC per capita, by GDP
	4.1.1 Proportion of children and young people achieving at		13.1.1 Number of deaths, missing

	least a minimum level of proficiency in reading and mathematics, by gender 4.3.1 Participation rates of young people and adults in formal and non-formal education and training in the last 12 months, by gender 4.5.1 Parity indices (women/men, rural/urban, lower/higher wealth quintiles) and others, such as disability status, indigenous peoples and people affected by conflict, as data become available) 4.6.1 Percentage of the population in a given age group achieving at least a fixed level of competence in functional skills (a) literacy and (b) numeracy, by gender.		persons and people affected by disasters per 100,000 people
	5.5.1 Proportion of seats held by women in		14.4.1 Proportion of

	national parliaments and local governments 5.6.1 Proportion of women aged 15-49 who make their own informed decisions about sex, contraceptive use and reproductive health care.		fish stocks at biologically sustainable levels 14.5.1 Coverage of protected areas in relation to marine areas
	6.1.1 Proportion of population using safe drinking water services 6.2.1 Proportion of population using safely managed sanitation services, including hand washing facilities with soap and water 6.4.1 Change in water use efficiency over time 6.4.2 Water stress level: freshwater abstraction in relation to available freshwater resources.		15.1.1 Forest area as a proportion of total land area 15.1.2 Proportion of sites important for terrestrial and freshwater biodiversity covered by protected areas, by ecosystem type
	7.1.1 Proportion of population with access to electricity 7.2.1 Share of renewable energies in		16.1.1 Number of deliberate homicide victims per 100,000

	total final energy consumption 7.3.1 Energy intensity measured in terms of primary energy and gross domestic product		inhabitants, by sex and age 16.5.2 Proportion of companies that have had at least one contact with a public official and that have paid a bribe to a public official, or to whom these public officials have asked for a bribe, during the previous 12 months. 16.6.2 Proportion of the population satisfied with their last experience of public services
	8.1.1 Annual growth rate of real GDP per capita 8.2.1 Annual growth rate of real GDP per person employed		17.1.1 Total public revenue as a proportion of GDP, by source

	8.4.1 Material footprint (MF) and MF per capita, by GDP 8.4.2 Domestic material consumption (DMC) and DMC per capita, by GDP 8.5.2 Unemployment rates by gender, age and disability - 8.6.1 Proportion of young people (aged 15-24) not in education, employment or training		17.1.2 Proportion of the national budget financed by national taxes 17.3.1 Foreign direct investment (FDI), official development assistance and cooperation South-South as a proportion of total domestic budget 17.4.1 Debt service as a proportion of exports of goods and services
	9.1.1 Proportion of rural population living within 2 km of an all-weather road 9.2.1 Manufacturing value added as a proportion of GDP and per capita		

	9.2.2 Manufacturing employment as a proportion of total employment 9.4.1 CO_2 emissions per unit of value added		

Source: MI (2021) modified by the authors

The structure of the iSDG model represents the development mechanisms found in most developing and industrialized countries. The limits of the model are defined by the variables used, the level of aggregation, and the spatio-temporal scales.

The fundamental approach endogenously represents the variables that make up an essential part of the development mechanisms analyzed (in this case, GDP and its components, population and its determinants, resource supply and demand). Variables that have a significant influence on the issues analyzed, but are only weakly influenced by them, are exogenous (e.g. rain cycles, donations received, exchange rates). As the iSDG model focuses on long-term development issues, inflation and interest rates are also considered exogenous (in the case of a country-specific application, however, these variables can be endogenized). Finally, variables that are outside the scope of the analysis, have no quantifiable effect or are unlikely to change over the time horizon considered, are not explicitly represented in the model. Examples include earthquakes, ethnic issues, cultural diversity, etc.

The basic iSDG model is designed as a national model, from a geographical point of view, so data are aggregated. All variables refer to national averages or data. However, a form of disaggregation is present in the model via the existence of sub-components of a main variable. Thus, the population is divided into age classes and gender. The age/gender distinction is used to construct socio-economic indicators.

Finally, the spatio-temporal scales are analyzed from two angles. On the one hand, the iSDG model focuses on the country (internal issues). The question is how to commit to a policy of sustainable development. On the other hand, the model focuses on long-term development issues. It is based on simulations that go as far as 2030, 2050 or 2100. These timeframes far exceed the forecasts found in the economic models of the World Bank or the OECD.

In its class, the iSDG model is considered a large-scale model, comprising over 3,600 inventory variables and several thousand feedback loops. Its structure is organized into smaller logical units, called sectors. A sector corresponds to a mini model with internal mechanisms that can be taken into account independently of the rest of the model. The iSDG model is made up of 30 sectors. These sectors are classified according to their dimension (environmental, social and economic) while respecting the process of integrated circles of strong sustainability (the social sphere is contained within the environmental sphere, the economic sphere is contained within the social sphere). They interact with each other dynamically through a complex network of feedback loops.

Table 3. 2: iSDG model sectors

Environment	**Social**	**Economical**
Land use	Population	Agriculture
Soil	Fertility	Industry
Water withdrawal	Mortality	Services
Water supply	Education	GDP

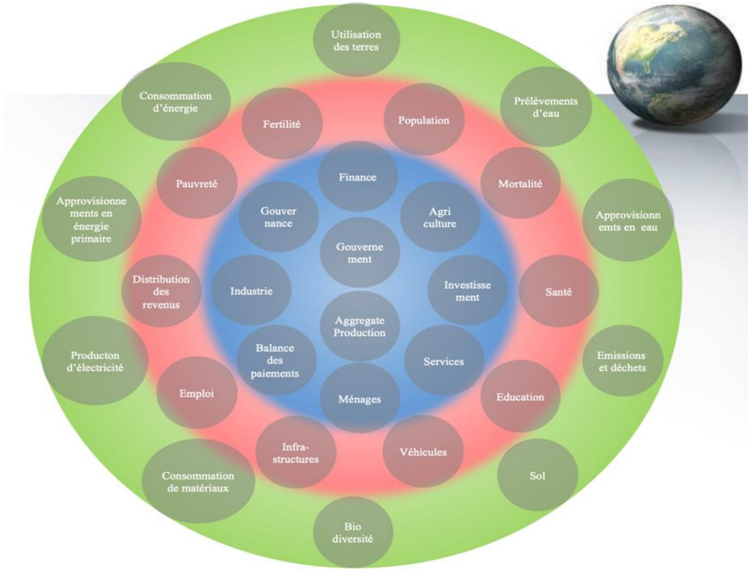
Energy consumption	Health	Investment
Power generation	Infrastructure	Households
Primary energy supply	Vehicles	Government
Material consumption	Jobs	Governance
Emissions and waste	Revenue breakdown	Finance
Biodiversity	Poverty	Balance of payments

Source: MILLENNIUM INSTITUTE, (2017a, 2021)

The indicators used to monitor one or more of the SDGs therefore integrate several sectors. Figure 9 gives an overview of the relationships between the 30 sectors in terms of their affiliation to the environmental sphere (outer green circle), the social sphere (central red circle) and the economic sphere (inner blue circle).

Ultimately, the iSDG model can be applied to any country through a process of calibration and customization. Calibration is carried out using partial model calibrations, including multi-parameter optimization cycles (model parameters are estimated based on the literature).

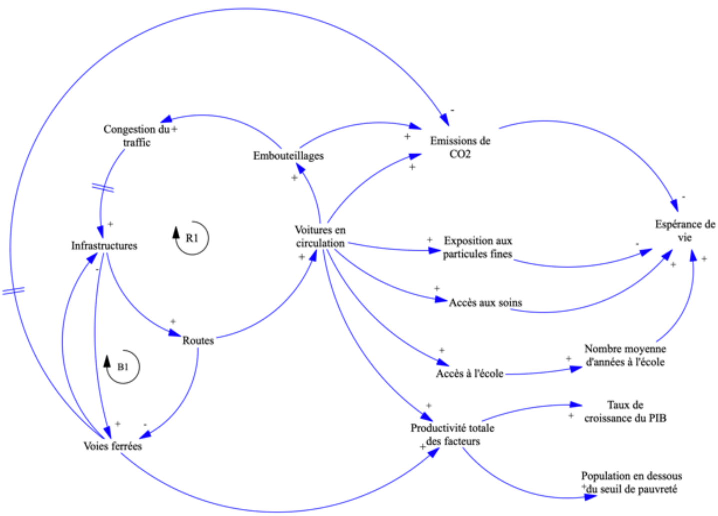
Figure 3. 8: affiliation of sectors with the three spheres



Source: MILLENNIUM INSTITUTE, (2017a, 2021) modified by the authors

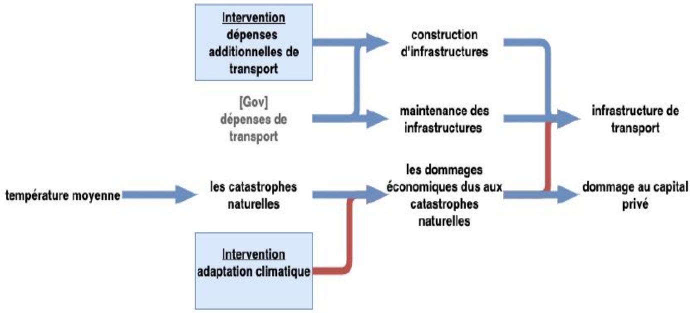
Without attempting to describe all the model's assumptions, it is possible to identify the characteristics of a sector using a causal loop diagram (CLD), causality and consequence trees, and a flow and stock diagram (SFD). For example, the transport infrastructure sector influences numerous sectors such as education, health, industry and services. Two loops (reinforcement R1 and regulation B1) create a dynamic in a simple model (Figure 3.9). An increase in road infrastructure increases the number of vehicles on the road, which can lead to traffic jams and congestion on certain lanes. This congestion calls for new public spending to increase road capacity and cope with rising traffic levels (R1). Road expansion can, however, lead to a decline in rail transport, reducing the maintenance and use of these infrastructures (B1). Infrastructure is highly exposed to climate change, via damage caused by natural disasters.

Figure 3. 9: infrastructure CLD



Source: the authors

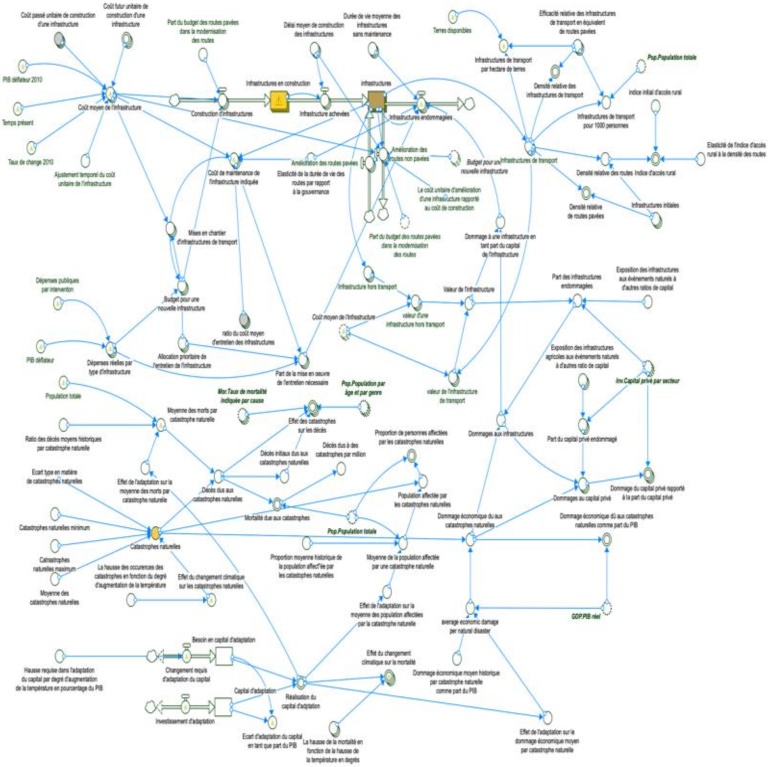
Figure 3. 10: causality tree



Source: the authors

Modeled with Stella software, the diagram of stocks (infrastructure under construction and repair) and flows (natural disasters, deaths in transport infrastructure) can take the following form (Figure 3.10). Its level of detail makes it possible to integrate the issue of infrastructure financing (budgetary decisions), the consequences in terms of access to health, food (logistics), or education, the economic damage caused by natural disasters, the impact on available land and the inequalities created with the rural world (areas not served by transport infrastructures).

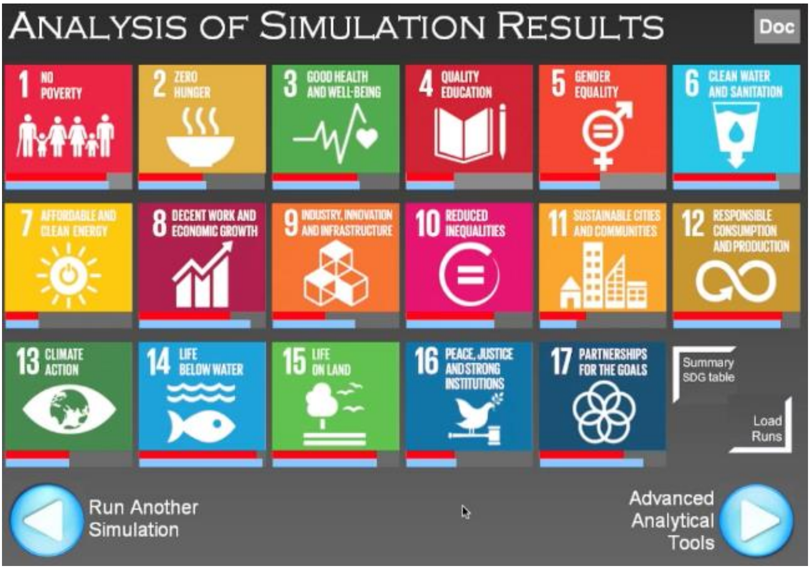
Figure 3. 11: stocks and flows Diagram (SFD) for the infrastructure sector



Source: the authors

Using this structural model and the “infrastructure” sector developed on Stella, it is possible to assess a country's performance in terms of sustainable development and the interventions required to improve an SDG (here, SDG 9 Industry, innovation and infrastructure) or a set of SDGs (SDG 3 Health, SDG 4 Education, SDG 8 Decent work and economic growth...). The Business As Usual (BAU) scenario enables us to analyze the situation without any change in policy in the event of an external shock (red in Figure 3.13). This makes it possible to identify which SDGs are making rapid progress and which are struggling to improve. In the case shown below, SDGs 4, 7, 11 and 16 are making less progress than SDGs 1, 3, 6, 8, 10, 12, 14, 15 or 17. Subsequently, it will be possible to select the necessary interventions, i.e., the leverage points (D. Meadows, 1999) on which action should be taken (blue color of the new scenario in Figure 3.13).

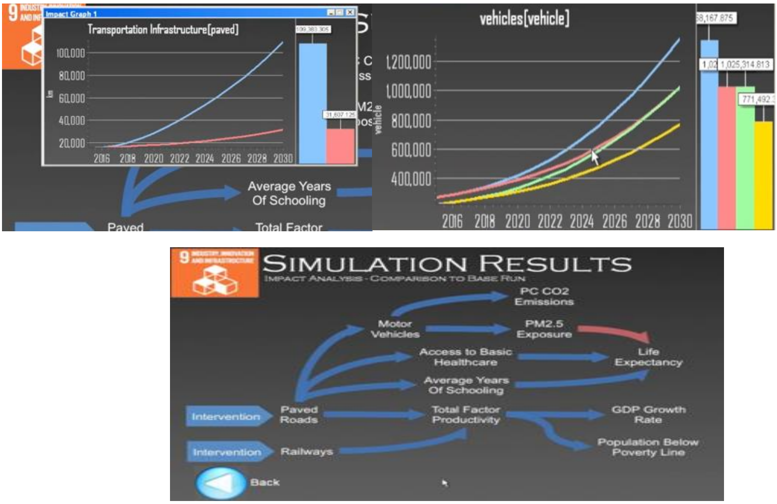
Figure 3. 12: model simulation

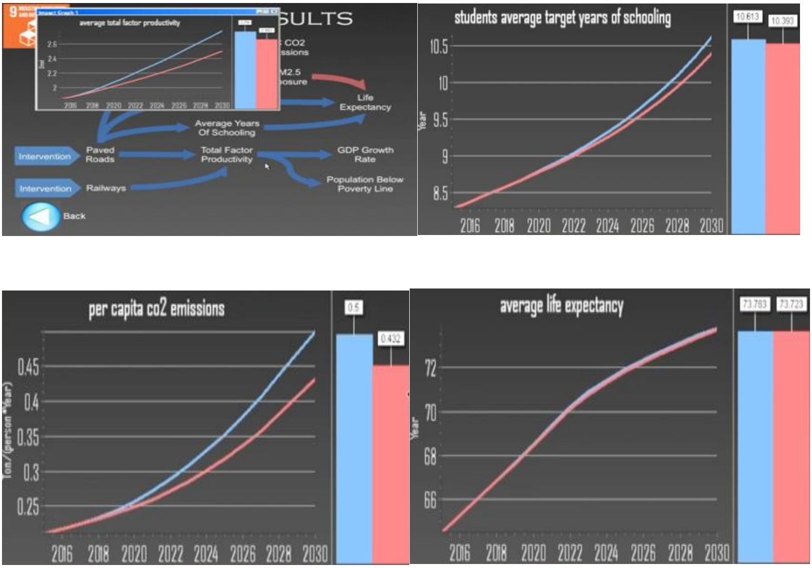


Source: the authors

In the case of the “Infrastructure” sector and its articulation with SDG 9, an increase in infrastructure suggests new expenditure (public, private or both), which may translate into an increase in road or rail transport infrastructure (see CLD in Figure 3.9). More paved roads will mean more cars on the road, which will improve access to healthcare and education, but will also worsen air quality via CO2 and fine particle emissions. This deterioration in air quality can have an impact on life expectancy.

Figure 3. 13: simulation results for an increase in transport infrastructure

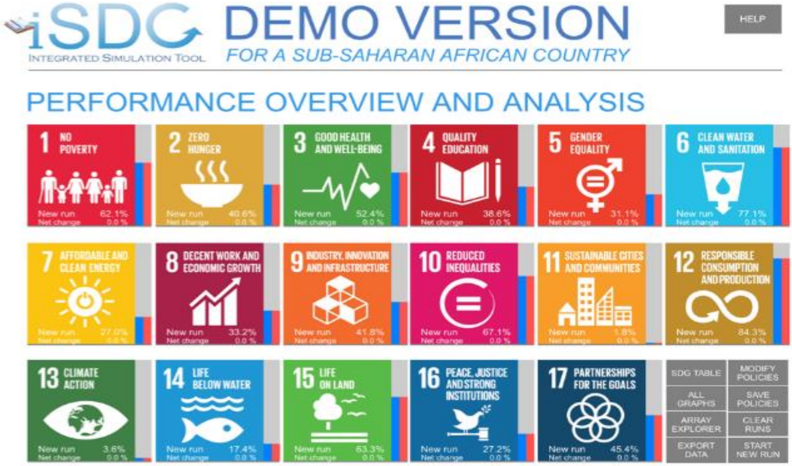




Source: the authors

An increase in public spending in one of the SDGs (financing of road infrastructure in SDG 9), a new tax revenue or a change in tax rates appear in SDG 17, depending on the type of financing (public, private or public-private partnership, PPP). The updated "demo" version of the iSDG model (available online) now includes a module to modify the rates and parameters on which public policies are based (Modify Policies), to display graphs corresponding to long-term simulations (all graphs), to run multiple scenarios and to integrate databases (the iSDG model is based on an Excel file containing a large amount of data).

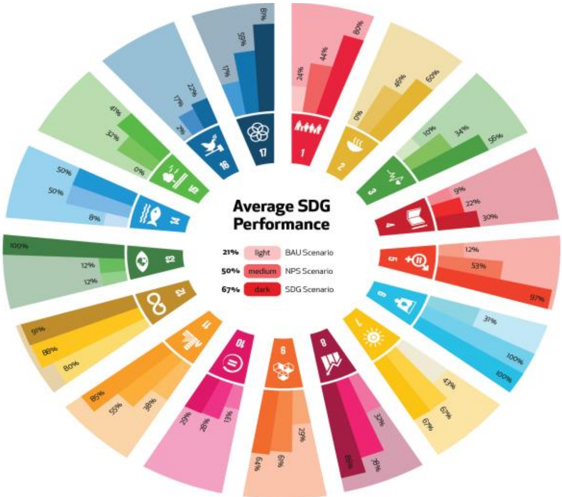
Figure 3. 14: iSDG in Demo version



Source: the authors

It is only following this simulation work and the choice of scenarios (iSDG selects three scenarios: Business As Usual (BAU), Medium Scenario and Optimistic Scenario), that it is possible to apprehend an average rate of achievement of the SDGs for the country concerned. An integrated analysis of the scenarios enables us to understand the consequences of additional investment (comparison based on the three scenarios described above).

Figure 3. 15: integrated scenario analysis



Source: the authors

Based on these scenarios and public investment choices, a performance indicator (for public spending) can be represented in terms of intersectoral impacts (between the different sectors of the iSDG model), the choice of targets (SDGs) and the tools mobilized (increased tax pressure, taxes on international trade, subsidies and transfers, standards, gender policy, interest rates on foreign debt, family planning, protection of natural areas, reforestation strategy, etc.).

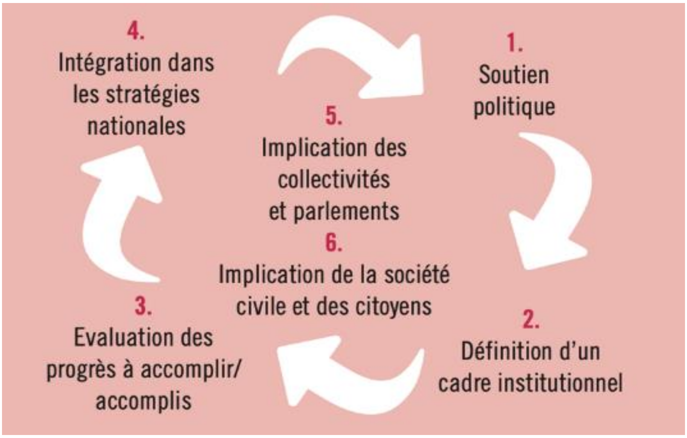
Figure 3. 16: impact Policy and Synergy Assessment (Côte d'Ivoire example)

Source: Pedercini et al., (2018)

3.4. The iSDG model, a foresight (prospective) tool for sustainable development planning

Since 2015 and the advent of the SDGs, countries in the South have made considerable progress in achieving the Sustainable Development Goals and integrating them into national planning and budgeting processes, even if data production has been a powerful brake. To date, most national development plans have succeeded in fully integrating the SDGs (75-85% targeting), adapting them to the national context. However, a major challenge remained: defining a guiding framework for implementing the Agenda 2030. Between 2016 and 2018, many countries embarked on drafting a roadmap aimed at creating an enabling environment for implementing the SDGs (Southern Voice, 2019). These actions defined at government level have established an institutional coordination framework (Brimont et al., 2016), which brings together all actors, whether State or non-State, including local governments, to achieve the SDGs (this appears at the level of SDG 17).

Figure 3. 17: schematic representation of the implementation of the SDGs



Source: Brimont et al., (2016, p. 2)

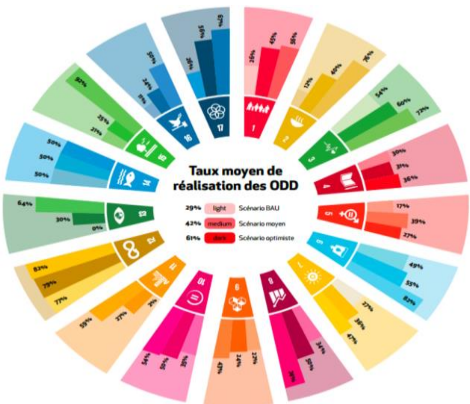
Despite significant progress, it became clear that we needed to further integrate the SDGs (targeting close to 100%) and, above all, to identify the complex links - both explicit and implicit - between them. Indeed, interventions aimed at achieving a particular SDG target could lead to the under-achievement or failure of another target (e.g., the choice of infrastructure investments in quality education at primary and tertiary level).

Furthermore, interventions that have an immediate desirable effect can also have an undesirable long-term impact (e.g., family planning). Some of the new national sustainable development plans (Uganda, Senegal, Malawi, Côte d'Ivoire...) have therefore sought to identify the approaches that need to be mobilized to better understand the interventions and activities that can be harnessed to rapidly achieve several SDGs simultaneously. Under the impetus of the UNDP (Nigeria, 2019; NPA Uganda, 2020b) but also of the OECD (via its platform: OECD Knowledge Platform on Policy Coherence for Sustainable Development[7]) and the relationships that the Millennium has forged with certain governments (Millennium Institute, 2017b), the iSDG model very quickly presented itself as a simulation tool meeting the expectations of national planning ministries. The 2030, 2040, and 2050 visions allow us to target the relevant interventions that have the greatest potential to be the accelerator of the SDGs and catalyze progress toward achieving the projected goals, ... In what follows, we would like to illustrate our remarks by drawing on two case studies (Côte d'Ivoire and Senegal) offering a summary of the rates of achievement of the SDGs. These reports - produced in close collaboration between the Millennium Institute and the various departments of the Ministry of the Economy, Finance and Planning - include the three scenarios (BAU, medium, optimistic) described above, the interventions that generate the greatest impact, the negative synergies indicating that better performance can be achieved through a reallocation of resources between the planned interventions, the positive synergies that make a substantial contribution to progress towards the SDGs, and also the sequencing and timing of implementation of the said interventions (to better benefit from them).

[7] https://www.oecd.org/governance/pcsd/toolkit/tools/

Figure 3. 18: SDGs achievement rates in Côte d'Ivoire and Senegal

Source : Pedercini et al., (2018), Côte d’Ivoire



Source : Millennium Institute, 2017b), Senegal

(1) Simulations conducted on the Côte d'Ivoire model (in particular, the BAU scenario) lead to an average achievement of 21% of the SDGs. With additional strategic adjustments (optimistic scenario), it is possible to achieve 67% of the SDGs. Achieving such results will require a significant mobilization of resources, i.e., an increase in spending (15% of GDP compared to 4.5% in the medium scenario), an increase in public revenues (12% of GDP compared to 4% in the medium scenario), and the strengthening of redistributive and gender policies. Policies to improve governance, health, education, gender, and adaptation to climate change have a significant impact on all goals. For SDGs 1, 2, 5, 10, 11, 14 and 15, the simulation results indicate positive synergies resulting from improved enabling conditions and reinforcing mechanisms created by policies in other areas. For SDGs 6, 9 and 17, the results show negative synergies, mainly because several individual policies would achieve more than 100% of these goals, so the additional improvement brought about by other policies is not visible in the overall SDG scenario.

(2) The T21 model was introduced in Senegal in 2009 through a partnership between the Senegalese government, the Millennium Institute, and the Biovision Foundation (BV). In 2017, an update of the T21 model was proposed to facilitate the integration of the SDGs into prospective analyses. The new model, called T21-iSDG-Senegal, was enriched with 19 specific sectors developed and included in the original model (30 sectors) to better capture development dynamics. The social sphere includes urbanization, migration, HIV/AIDS, health resources, nutrition, and food security. The environmental sphere consists of the ecological footprint and land degradation. The economic sphere consists of agricultural social factors, agricultural economic resources, agricultural insurance,

agricultural seeds, agricultural accounting, agricultural emissions and inputs, livestock, fisheries, forestry, mining, telecommunications and decentralization. The results of the three scenarios tested (BAU, medium, optimistic) show that the implementation of the optimistic scenario would have a significant impact on the level of achievement of the SDGs by 2030 (61.3% vs. 29% in the BAU scenario). However, in absolute terms, the level of achievement for SDGs 4, 5 and 9 remains quite modest. The interventions with the highest impact are those related to: (i) investments in climate change adaptation; (ii) increasing fiscal pressure; (iii) combining agriculture, livestock, fisheries and aquaculture, and agri-food policies; and (iv) good governance. The synergy analysis identifies cases where diminishing returns are slowing progress towards the SDGs, particularly for Goals 1, 3, 10 and 16. As a result, there is a need to identify alternative policies that benefit the target groups. Negative synergies for Goals 6, 7 and 11 indicate that better performance could be achieved by reallocating resources between planned interventions.

In conclusion, in the two case studies presented above, the overall contribution of the synergies induced by the iSDG model simulations is clearly positive, highlighting the importance of integrated planning and implementation of interventions aimed at achieving the SDGs simultaneously. These interventions mainly concern improved governance, income distribution, gender, and climate change adaptation policies, as well as additional spending on education, and training in sustainable agriculture, health, and family planning.

3.5. Conclusion

Since 2015, the countries of the North and the South have been under the obligation to have a road map for sustainable development. What are commonly known as the 17 SDGs (Sustainable Development Goals) are thus a call to action to promote a certain form of prosperity on a global scale. Eradicating poverty, meeting social needs (education, health, decent work...) and protecting the environment while combating climate change constitute a common vision for 2030. To help states mobilize all stakeholders and take urgent decisions, it is necessary both to propose solutions that simultaneously improve all SDGs and to demonstrate the many possibilities for implementation. The iSDG model is a policy simulation tool designed to help decision-makers and stakeholders understand the complex web of interconnections among the SDGs. Contrary to databases and macroeconomic indicators that provide a measure of a country's situation, the iSDG focuses on the dynamic interactions within the SDG system to identify the best pathways and progress towards achieving the SDGs. Based on a methodology called system dynamics, the iSDG model proposes long-term simulations to optimize public spending or revenues. As a result, the multiplier effect of an investment is no longer limited to the economic sphere, but also creates a dynamic in the social and environmental spheres.

4. National food security: towards a New Sustainable Food System (FS) in Burkina Faso

Abstract[8]: 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 allows 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 SDG 2 by 2030 and other SDG indicators linked to SDG2 through the implementation of synergistical public policy.

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

[8] This chapter was written with Arnaud DIEMER, and a version is published in the Modern Economy.

4.1. 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. In 1948, the Universal Declaration of Human Rights affirmed with the article 25 that “everyone has the right to a standard of living adequate for the health and well-being of himself and his family, including food, clothing, housing and medical care and necessary social services, and the right to security in the event of unemployment, sickness, disability, widowhood, old age or other lack of livelihood in circumstances beyond his control”. In 1967, the International Covenant on Economic, Social and Cultural Rights, described with more details, this right of food security in its article 11 : “ The States parties to the present Covenant, recognising the fundamental right of everyone to be free from hunger, shall take, individually and through international cooperation, the measures, including specific programmes, which are needed : (a) to improve methods of production, conservation and distribution of food by making full use of technical and scientific knowledge… (b) taking into account the problems of both food-importing and food exporting countries, to ensure an equitable distribution of world food supplies in relation to need”. But we have to wait for the middle of the 1970s, to catch the first definition of food security (Maxwell, 1996; Maxwell & Smith, 1992). As a process of negotiation leading to the World Food Conference of 1974 (the FAO resolution 3/73 recognized that the guaranteeing of world food security is the joint responsibility of the entire international community), FS 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 the basic conclusion of the Preparatory Committee that the solution of the food problem required co-ordinated 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 ultimate objective of the world food security should be to ensure that all people at all times have both physical and economic access to the basic food they need. Food security should have three specific aims, namely ensuring the production of adequate food supplies, maximizing stability in the flow of supplies, and securing access to available supplies on the part of those who need them” (FAO, 1983, P. 6). Three years later, the World Bank published its report Poverty and Hunger, issues and options for food security in developing countries (1986). The report outlines the nature and extent of food security problems in developing countries such as investment in human capital, the 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. Food security has to do with “access by all people at all times to enough food for an active and healthy life” (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. Seven commitments have been negotiated to ensure that "all people, at all times, have physical and economic access to sufficient, safe and nutritious food. This will entail: ensuring an enabling social and economic environment; implementing policies aimed at eradicating poverty and inequality; pursuing participatory and sustainable development practices; fostering a world trade system that is both fair and market-oriented; anticipating natural disasters and crises; encouraging the optimal application and use of public and private investments; and finally implementing, monitoring and following up the Plan of Action" (Discours of Jacques Diouf, Director General of FAO, 13 november 1996, World Food Summit Report, FAO, p. 15). By insisting on the fact that food security was a state of food and nutritious satiety, FAO considered that 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 Food System (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 has to 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, food security 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, 2015a). This induces the transformation of actual Food Security System (FSS) into a 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 the Ukraine war have shown that developing countries' FSs particularly Sub-Saharan African (SSA) are vulnerable to the global supply chain that is 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.

In addition, 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. People also need “food sovereignty”. 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 the 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 that are resilient to stochastic and international shocks (Ibrahim & Yanti, 2019). Food sovereignty aims to put the human and the peasant at the heart of the FS to produce foods by taking into account the right price that benefits the producer and the consumer, the dynamics of territory (jobs, public services, ...), the promotion of cultural values and culinary specialties, the preservation of ecosystemic services (land, biodiversity, ...).

The COVID-19 crisis and the Ukraine war are some examples showing the vulnerability of developing countries' FSs particularly Sub-Saharan African (SSA) countries to the international stability and the food production of developed countries. These shocks have shown firstly that the food systems of developing countries have huge production capacity limits to guarantee food availability at national and local levels. And secondly, the global food supply chain is not able to guarantee food supply everywhere in the world, especially with transport and logistic problems. Food prices increasing, the limited availability and access to certain foods (especially wheat) explain this international dependence of developing countries (Balineau et al., 2021). Thirdly, food production in developing countries depends highly on climate stability, and right now, farmers and breeders are losing their capacity for production due to the impacts of 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. The loss of production caused by climate change negatively impacts their livelihoods and further for the populations in general. The state of food security and nutrition in 2022 shows that hunger does not go down but jumps due to the increase in 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 number of undernourished people will grow from 280 to 310 million people (18% of the African 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, and investments in education, health, and public infrastructure. This means a sustainable transformation of national and local food systems which can 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 food system in which food chain stages are well interconnected and interact from food production to food consumption (Kopainsky et al., 2017). These connections can facilitate interventions in the food system and ensure better functioning of public policies. In addition, it helps to create synergy between actors towards a common goal (food security and nutrition achievement). The food system is composed of sub-systems according to FAO (e.g. farming system, waste management system, input supply system, irrigation system, financing of agriculture, etc.), and these sub-systems interact with some non-food systems (e.g. energy system, trade system, health system, etc.) (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 that can guide Burkina Faso policymakers to implement consistent and synergistic policies. These leverage points are susceptible to improve food security and nutrition and contribute further to reaching the SDG 2 of the UN 2030 Agenda.

We will answer the following questions: how System Dynamics Modeling may help to challenge food security and nutrition in Burkina Faso? What are the resistance factors that 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 food module that we built could help to analyze the interactions between these SDGs and SDG2 through the use of SDG 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 that 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, and 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 that 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, and 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. Then, the following parts of the paper present first, 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. The next part

provides a brief literature review on SD models' use in the agriculture sector and here we 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. The next part presents the results of the simulation. We use the statistics of fit 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. The second to last part discusses the relevance of results and proposes some leverage points and agriculture policy scenarios that can be implemented to improve the performance of Burkina's FS. The last part of the paper concerns the conclusion and here we tackle the different limits of the model calibration and propose some ways to overcome these limits for the model's robustness.

4.2. State of food security and nutrition in Burkina Faso (challenges and opportunities)

The actual context of Burkina impacts negatively the FS. It is characterized by a rapidly growing population (more than 21 million and 3.1% of population growth per year), a high level of poverty (36.2% of the population is under the poverty line), and irregular economic growth (3.92% in 2015, 5.69% in 2019, 1.93% 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, the degradation of the environment (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 to the detriment of agriculture activities and the occupation of agricultural land (Ouoba, 2018). These factors weigh on the FS which leads to extreme levels of food insecurity and malnutrition that contribute to bad health of the populations and juvenile mortality. Burkina's 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 volatile international market prices. 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. These results mean a low productivity of the labor force in the agriculture sector. There is an unbalanced distribution of food availability and food value added between rural and urban and between cultures. These disparities are related firstly to poverty, the unequal distribution of agricultural potential, and the unequal repartition of infrastructure, especially the concentration of processing industries and distribution around the big cities attract young people to migrate toward these cities. Secondly, agricultural policies of the government support cash crops disproportionately to the detriment of food crops (FAO, 2021a) while more than 80 percent of rural families' food production is based on cereals.

The prevalence of food insecurity and nutrition has decreased in the 2 decades but, since the advent of terrorism in 2015, the number of people undernourished started to increase to reach 3.8 million (18 percent of the 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). Even so, the cereal balance sheet of Burkina is positive, there are some differences between regions because some of them have a deficit cereal balance sheet, particularly for the North and Sahel regions. The food and nutritional vulnerability is also related to the agro-climatic conditions in the Sahel and North parts, social issues due to the low level of education (1/4 doesn’t have basic education), and economic causes due to rural poverty. This complicated situation is entertained by the population growth and population displacement due to insecurity (more than 2 million of PDI) which exerts competition on the use of resources causing conflicts. And end, the population faces diarrheal diseases due to the consumption of polluted water because of limited access to drinking water points and poor food quality consumption which contributes to food-related mortality.

The resource endowment of Burkina is limited especially in water, good quality soil, and forest. The fast growth of population and food demand lead to high pressure on land and water resources that are already limited (Nyamekye et al., 2018). Also, actors' activities play a key role in land degradation, forest land reduction, and soil erosion. In rural areas, agriculture and animal production techniques are characterized by low input of organic matter, excessive chemical inputs in the cotton zone, and overgrazing. The gardening production in proximity of cities uses excessive pesticides, household waste and processing industries are among the sources of water pollution. Concerning forest land reduction, cultivating land expansion, extensive breeding, bad agricultural practices and harvesting of non-timber forest products (NTFPs) are at the origin of soil degradation and forest cover loss driving the disappearance of some animal and vegetation species (Ouedraogo et al., 2010). These factors constitute in turn some obstacles to a durable socio-economic development and in particular for farmers whose crop productivity is highly dependent on the quality of the environment and good climate conditions. The bad situation of food security and nutrition in Burkina Faso is not only related to economic, social and environmental factors but also to political and governmental factors. There are some strong disparities between regions, agriculture sectors, crops, rural and urban (FAO, 2021b). The regional disparities lead to important migratory movements, which accentuate the conflicts throughout the country. The limited application of the new rural land standards leads to land grabbing and competition in production spaces that is exacerbated by a poorly controlled agricultural migration (Dedewanou & Kpekou Tossou, 2022). Livestock mobility which is a means of resilience and meat production for rural disadvantaged households benefits less support. This is related to the lack of management organism and competent administrative staff. There are some disparities between regions, rural and urban through the disparities of poverty, the unequal repartition of agriculture potentialities and to the unequal investments leading to an increasing intern and extern migration flows. Also, Processing infrastructures are concentrated around big cities and agropoles and this contributes to the unequal distribution of added value between rural (having low added value) and urban areas. The same phenomenon is observed between territories: the unbalanced spatial infrastructure creation policy slows down trading exchanges and increases prices due to transport costs, particularly in the Sahel and North regions. Agricultural policies disproportionately support cash crops at the detriment of food crops. This marginalizes family farming (Hébert et al., 2014), on which 80% of the population depends. In sum, the quality of institutions, the efficiency of agricultural policy implemented, the agriculture practices, climate conditions, investments, the population, insecurity and many other factors and drivers shape Burkina Faso FS, its efficiency and capacity to produce good results in terms of food security and nutrition. Beyond the environmental, climatic and social problems, credit access remains a key challenge for the agriculture sector (FAO, 2021b). There are few financial institutions especially dedicated to the agriculture sector and the most of government financing goes for the cotton sector. Some of the rest farmers benefit from funding from traditional banks, associations, and non-governmental organizations. Unfortunately, these financings are granted in the short term (maximum 2 years) with a high interest rate of repayment (7.75-15%). The problem that limits the development and 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).

4.2.1. Production

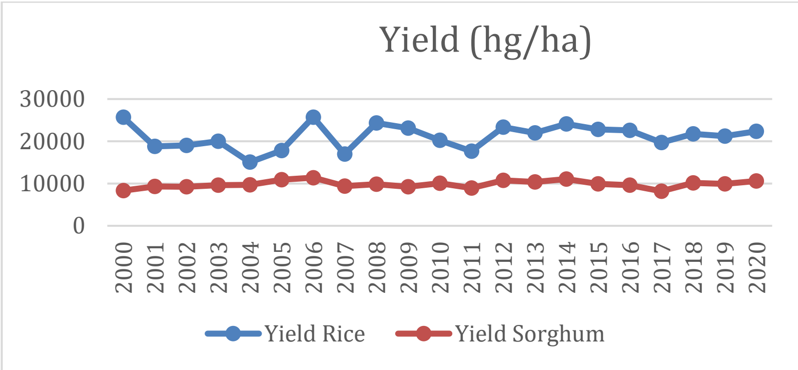
Burkina has a Sudano Sahelian climate with a long period of dry season. It is facing high temperature and rainfall variations (Villiers, 1963). The main cultures are cereals, fruits and legumes. The global food balance sheet of Burkina is positive, but it varies from one region to another. The western zones of the Sudano Guinean agro-climatic zone have a structural surplus, while the central, Sahelian and North zones in the Sudano-Sahelian zones have deficits leading to domestic trade. The western regions are important areas for cotton and cereals (rice particularly) production and benefit from a large amount of equipment, inputs, and training from the government while the Northern regions are important areas for livestock and benefit less support from the 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 crop 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 and adapt to climate change and livestock trading constitutes revenue for the local economy through taxes. However, breeding is more and more threatened nowadays by agricultural 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 a growing land insecurity in Burkina due to the non-respect of land law by actors leading to conflicts. Land ownership and the right of 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 large enterprises that acquire rural land for speculation. Burkina is a landlocked country and is not naturally endowed with surface water. Its original 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.

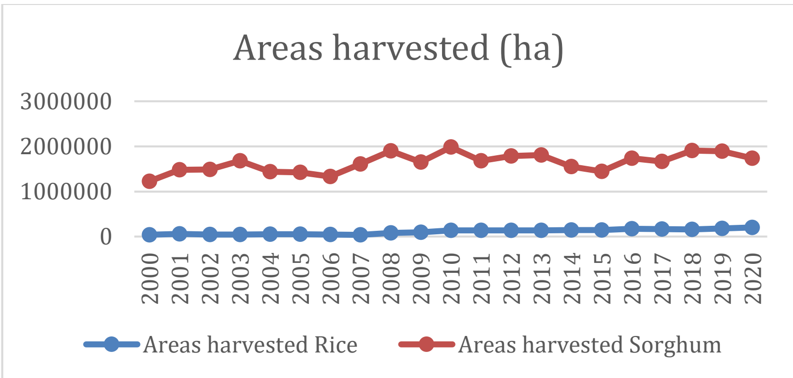
Despite the efforts of the government to increase food production and productivity to respond to food demand and ensure food security and nutrition, beyond land and water problems, the high intrants cost (Zahonogo, 2011), the low level of literacy of farmers, the bad organization of actors and insecurity 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 Western regions (Centre-East, Hauts-Bassins, Cascades and Boucle du Mouhoun). This potential can contribute to reducing poverty with revenue provided to fishers and farmers, to create jobs for the young and to respond to the high demand for food products. And for this reason, the sector of food production must maximize rice and aquaculture production (D'Alessandro & Tondel, 2021) which have higher productivity than sorghum and can 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 to contribute to improving the socioeconomic conditions of farmers and fishers. The national production covers only 44% of national demand and the challenges for the government are to increase rice productivity, and 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. Concerning the aquaculture sector, the national production covers only 5% of the national needs of fish and the rest of the demand is imported from 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 where the price is much lower than local production. To reach this goal, it is necessary to maximize the diversification of production, the productivity of existent fishing, promote intensive and integration of aquaculture and agriculture, the training actors for participative management of resources 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 (Zougmoré et al., 2018).

Figure 4. 1: comparison of rice and sorghum yields (hg/ha) in Burkina



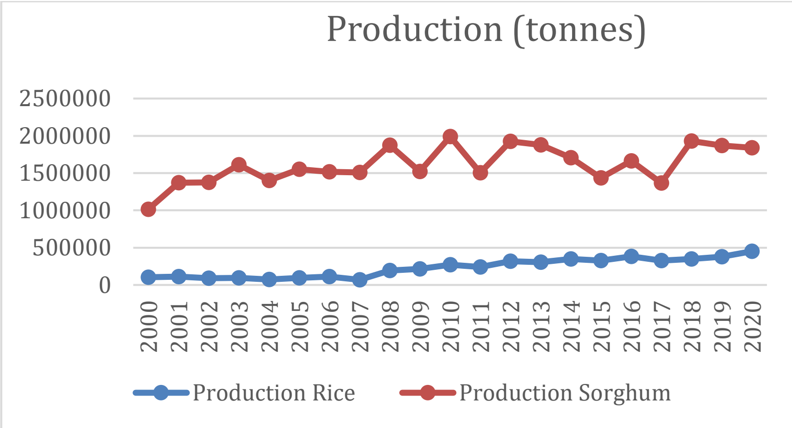
Source: FAOSTAT (April 11, 2024)

Figure 4. 2: areas harvested (ha) by rice and sorghum



Source: FAOSTAT (April 11, 2024)

Figure 4. 3: production quantity of rice and sorghum



Source: FAOSTAT (April 11, 2024)

4.2.2. Storage

One of Burkina Faso's 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 which 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. 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 government of Burkina Faso. 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 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.

4.2.3. 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), except a few large companies around the major cities (FAO, 2021b). 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 agriculture local products 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. Most 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 cannot 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 for 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, and the low technical level of processing (Hauer & Nielsen, 2020). Aquaculture was not a priority and was marginalized for a long period which explains the low development of the sector. However, since 1970, several measures have been implemented by the government in this sector to intensify and maximize fish production 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).

4.2.4. Distribution (marketing and logistic)

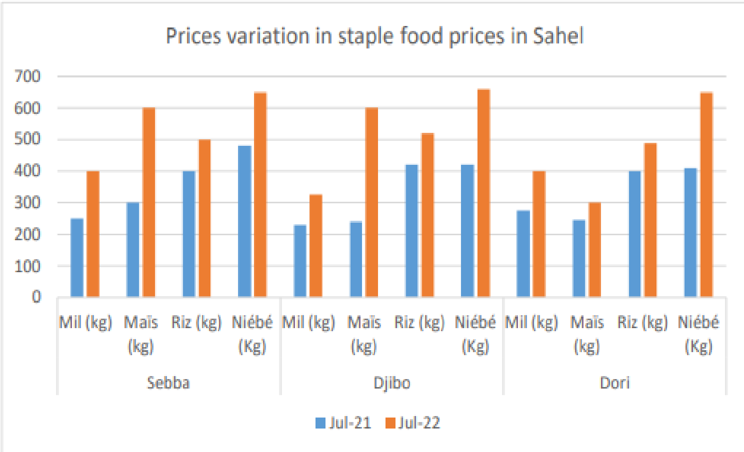
The food economy is dominated by informal trade networks linking rural areas and small towns (D'Alessandro & Tondel, 2021). These networks of small traders buy surplus food from local producers who then transport this food to the mass markets or resell it with SONAGESS (Pauw et al., 2023). They are responsible for most of the food trade except cotton and some institutionalized cereals and constitute a source of job's 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 infrastructure for 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 in 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 the food balance sheet, conditioning food quality through the storage, the logistic and reducing food losses (Balineau et al., 2021). Unfortunately, the 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 impassable roads especially in the 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 job creation, to support women's 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 to reduce the territorial disparities. In addition to private actors, SONAGESS is a major 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.

4.2.5. Consumption

With over 21 million people, food production in 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 a 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 the government to increase the imports of some products to respond to the nutrient needs of demand (D'Alessandro & Tondel, 2021). Indeed, 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 from 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 30684 FCFA/month (47 euros/month). The poverty line was 164955 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 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 (-154000 tons), 2015 (-35000 tons) and recently in 2017 with -47,7000 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 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 following figure shows price variations of cereals in three localities of the Sahel region in July 2021 and 2022. These variations are related to food availability problems due to the blockade of these towns by unidentified armed groups (Food Security Cluster, 2022b).

Figure 4. 4: prices variation in staple food prices in Sahel

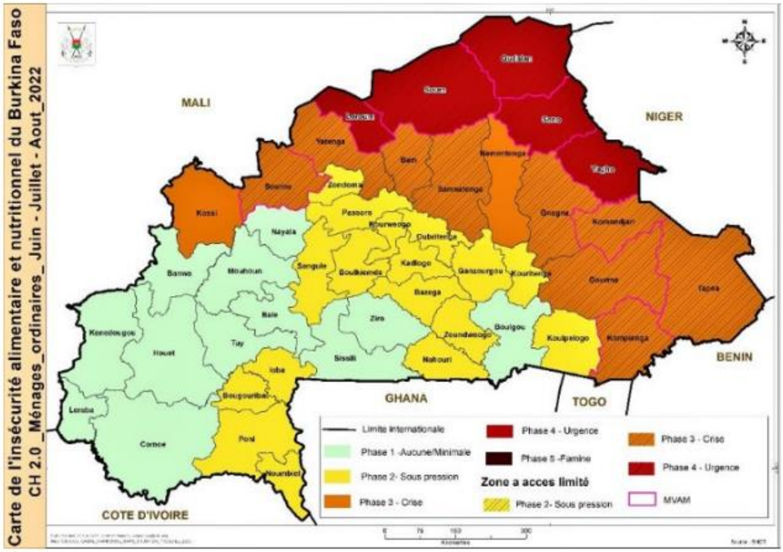


Source: Food Security Cluster / Sector

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 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, when 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. The following figure 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.

Figure 4. 5: Food Insecurity Map for Burkina Faso



Source: Food Security Cluster

4.2.6. Food sector actors and institutions

The characteristics and the development of the FS are shaped by the institutions that 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 durable food and nutritional security, economic growth, the improvement of households' livelihoods, and the reduction of population vulnerabilities to climate hazards. It was 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 example 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 that support FS actors through development projects and funds. Beyond policies taken at the national level, Burkina is part of the Economic Community of West African

States (ECOWAS) and the 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) which 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, strengthening the capacities of institutions, especially decentralized ones, developing 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 that 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 the

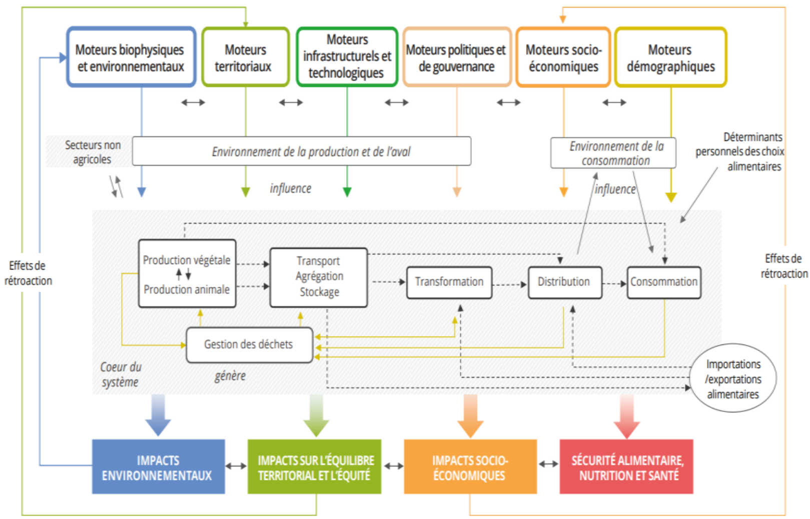
International Center for Research and Development on Livestock in Sub-humid Zones (CIRDES) which are responsible for the formulation, execution, and coordination of environmental, agricultural and livestock research in Burkina. Unfortunately, these institutions depend heavily on donors and development agency funding. The regional and international research institutions (IFPRI, CGIAR, CORAF, ...) are engaged to support climate change actions but few funds are put into agricultural policy analysis, actors training, and the overall analysis of the food system performance.

4.3. Designing Food Security Module with System Dynamics

4.3.1. State of literature on food security modeling with SD

Nowadays, the state of research on food system (FS) modeling by using system dynamics (SD) methods is quite developed. However, most studies are focused on the steps of food production, imports, and consumption. Throughout the food chain, many challenges 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 to understanding this complexity (Suryani et al., 2014). According to FAO, the FS is composed of different stages that 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 that helps to drive studies and research that 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). The following picture shows how a FS structure can be represented by FAO.

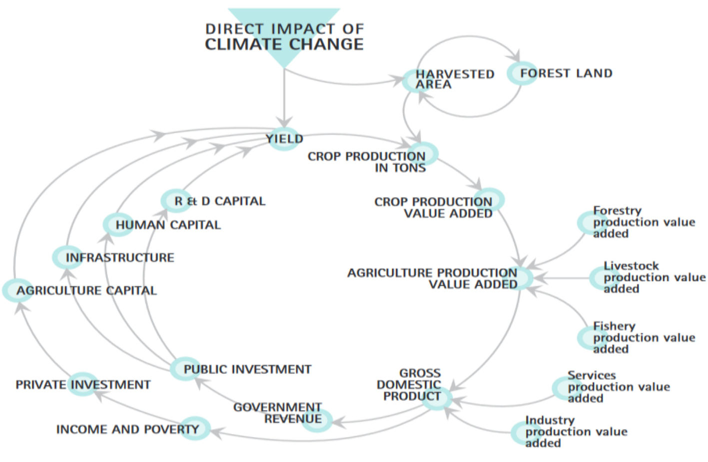
Figure 4. 6: conceptual architecture of the food system



Source : David-Benz et al., 2022

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 in the model below developed by FAO (Pedercini et al., 2012).

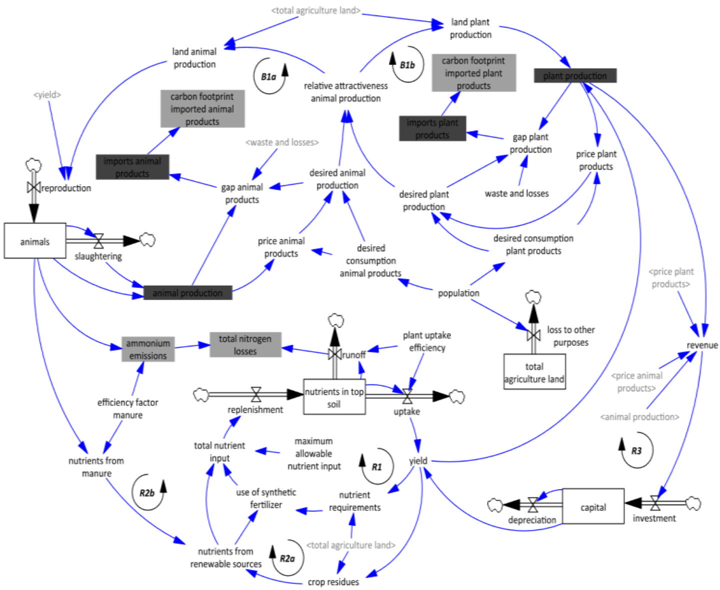
Figure 4. 7: Climate Change impact on Agriculture



Source: Pedercini et al., 2012

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 a short time.

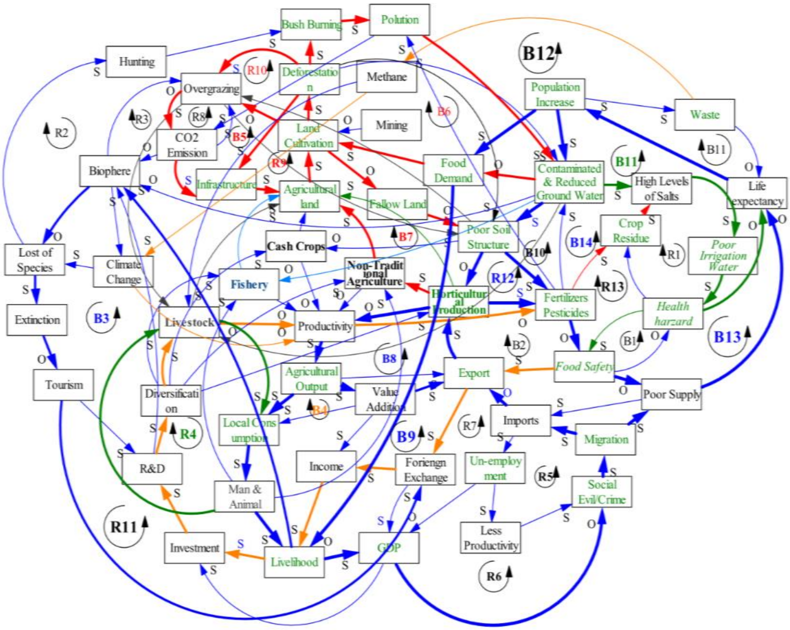
Figure 4. 8: food system activities with their corresponding social-ecological systems subsystems



Source : Kopainsky et al., 2015

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).

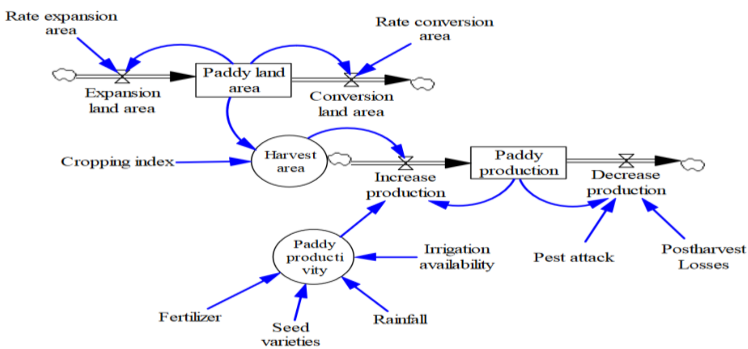
Figure 4. 9: the agricultural system web of Africa



Source: Banson et al., 2016

The previous figure shows the overview of the complexity and interconnectedness of different elements that compose the agriculture systems. It shows how SD can be used to build an understanding of FS to facilitate interventions, manage complexity, and 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, ecosystem 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 fertilizers and pesticides to revitalize land and increase yield. However, fertilizer and pesticide practices negatively impact food safety, water contamination and contribute to environmental pollution and soil degradation. These factors together negatively impact return agriculture productivity, livelihoods, life expectancy, and further GDP in the long term (Banson et al., 2016). Other problems 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).

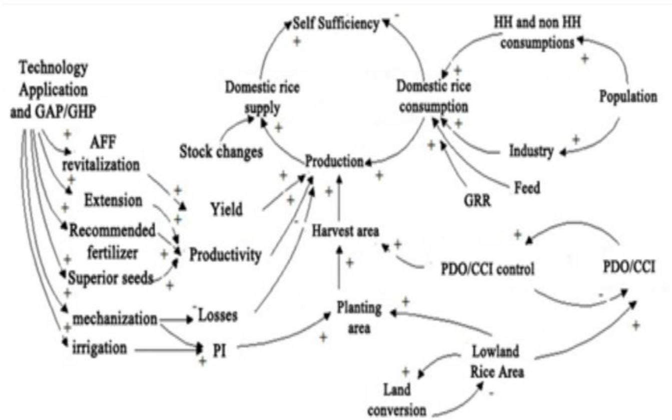
Figure 4. 10: Stock and Flow Diagram of Paddy Production



Source: 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 model below 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 the 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 to satisfy consumer demand.

Figure 4. 11: rice self-sufficiency causal loop diagram

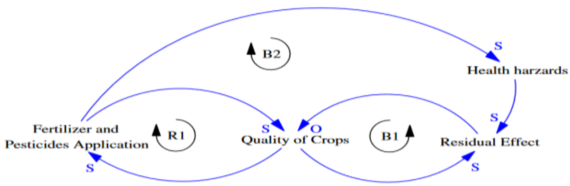


Source: Fristovana et al., (2020)

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 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" (D. H. Meadows, 2008a). 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 archetype models (shifting the burden, limits to growth, success to the successful, escalation, accidental adversaries, the 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 pesticide application leads in a short time to the improvement of the quality of crops and increasing export success. 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 crop productivity. The following figure shows the limits to the growth concept with the Ghana FS case.

Figure 4. 12: limits to growth system archetype



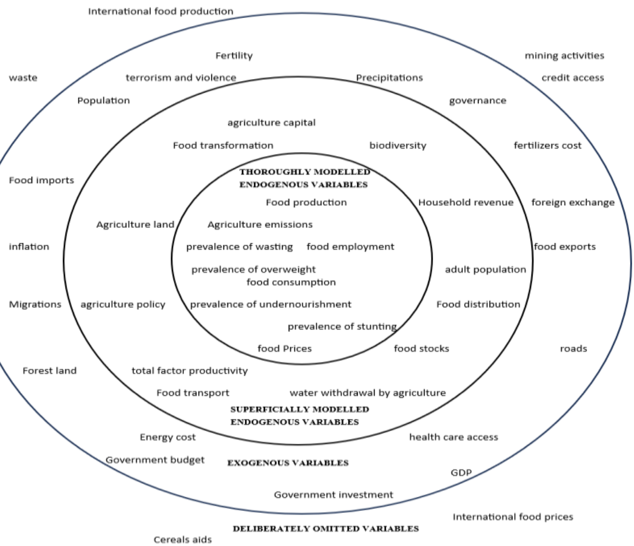
Source: Banson et al., (2016)

In sum, many drivers 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, quality, availability, accessibility, use, stability, and food price. According to FAO, the FS must: ensure the food security and nutrition, and health of the population, create decent works for 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).

4.3.2. Some CLD and SFD tracking Burkina Faso food system (FS)

The following Bull's Eyes diagram provides an overview of the variables used in the modeling process through the endogenous variables to the deliberately omitted variable (Pruyt, 1982, 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 superficial 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 the 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 that act in the system. And end, the deliberately omitted variables concern those we don't include in the system but can have some impacts on the food system performances.

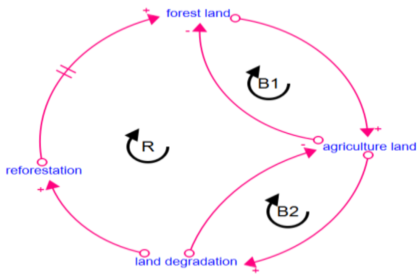
Figure 4. 13: bull's eyes Diagram for food system



Source: the authors

The following CLDs illustrate 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.

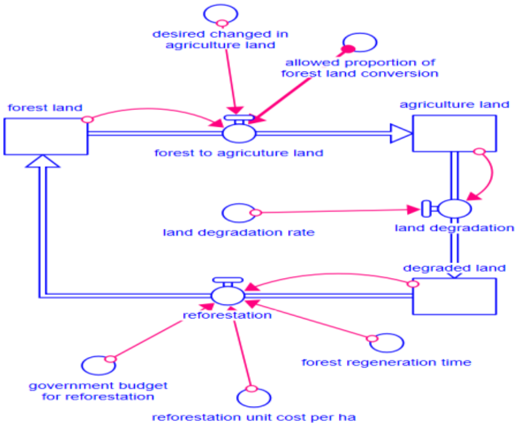
Figure 4. 14: Land CLD



Source: the authors

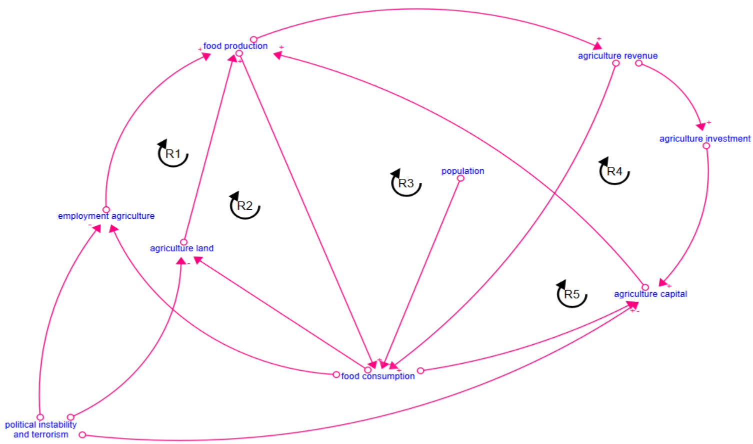
The land Causal Loop Diagram (CLD) describes the interaction between agricultural land (arable and permanent land and pasture land). The more forest land is available, the more we can convert it to agricultural land and that is going to decrease our forest land (B1). With time, we are going to lose agricultural 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 can be apprehended through the Stock and Flow Diagram (SFD) below:

Figure 4. 15: Land SFD



Source: the authors

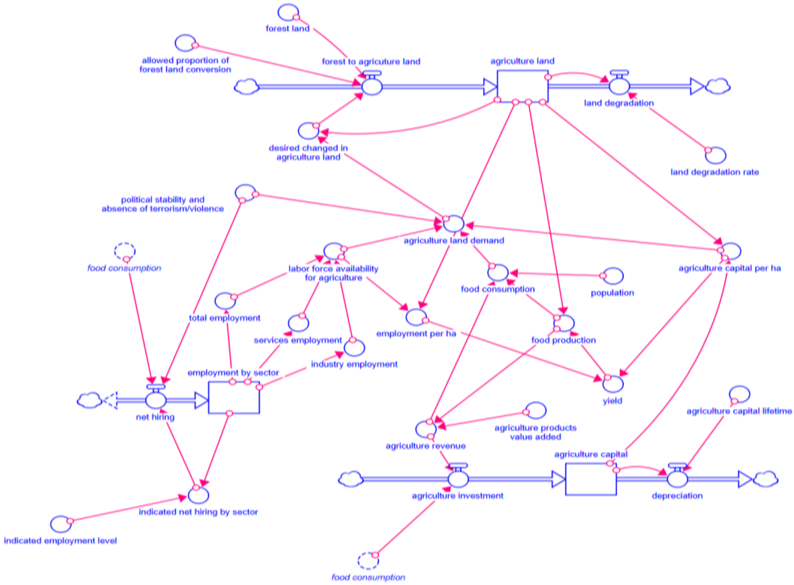
Figure 4. 16: food consumption and factors of production CLD (land, capital, labor)



Source: the authors

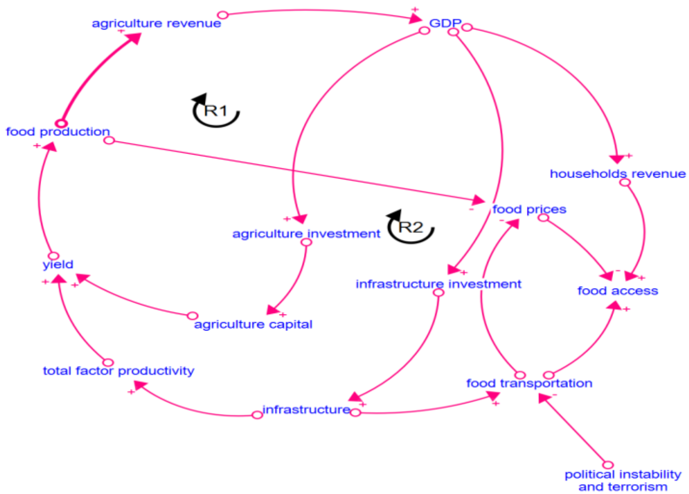
The CLD above characterizes factors of production demand (land, labor, capital) used in the step of food production. More we use food production factors, the more we increase the food supply to cover food consumption needs. Also, food consumption increasing leads producers to increase the demand of production 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. 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 is a simplified illustration of this situation:

Figure 4. 17: food consumption and factors of production SFD (land, capital, labor)



Source: the authors

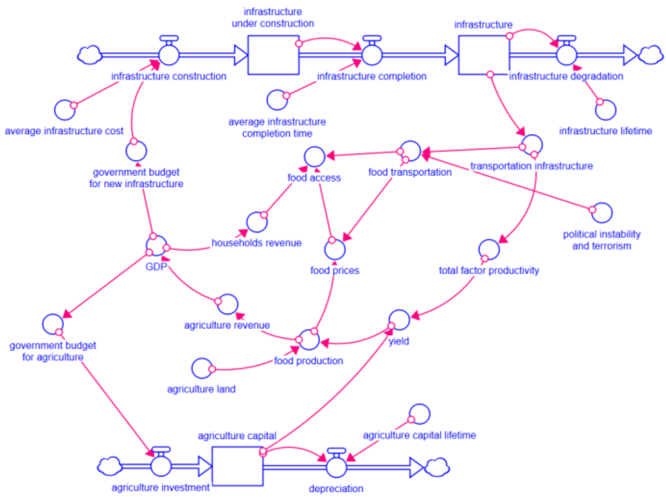
Figure 4. 18: infrastructure, household revenue, and food access CLD



Source: the authors

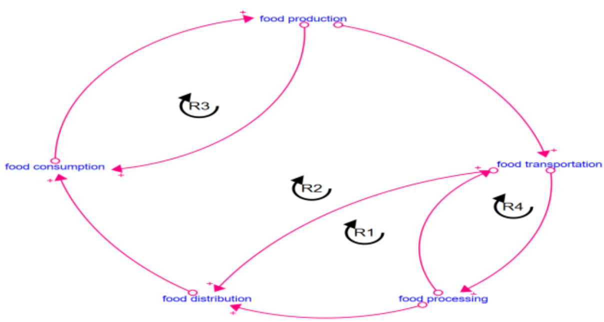
Here, the model describes how food access can be facilitated by food transportation and the improvement of household revenue in Burkina Faso. The analysis of the food balance sheet at the national level shows a surplus to meet the national food needs of the population contrary to local (by region) food 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 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. Terrorism has also contributed significantly to rising food prices in the red zones, where food production and supplies are low.

Figure 4. 19: infrastructure, household revenue, and food access SFD



Source: the author

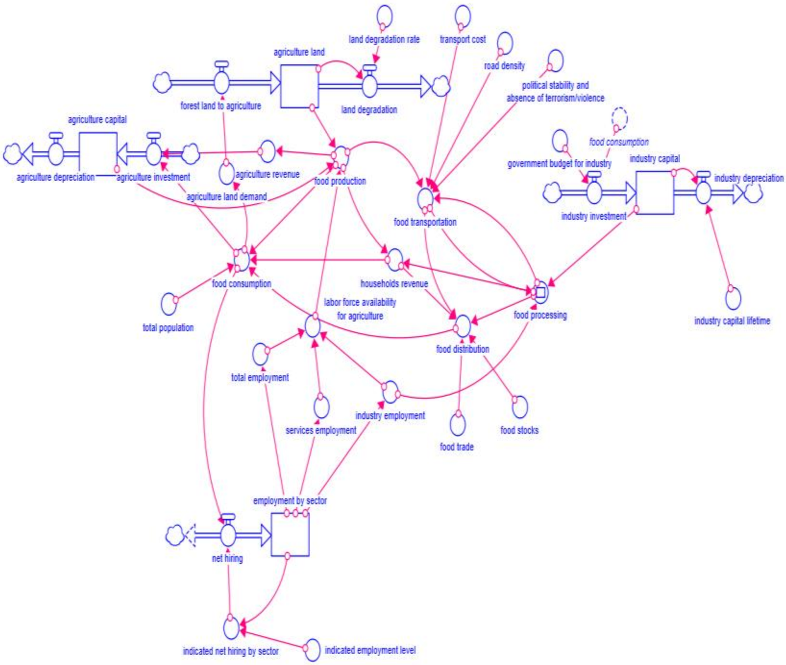
Figure 4. 20: food distribution, transportation, processing and consumption CLD



Source: the authors

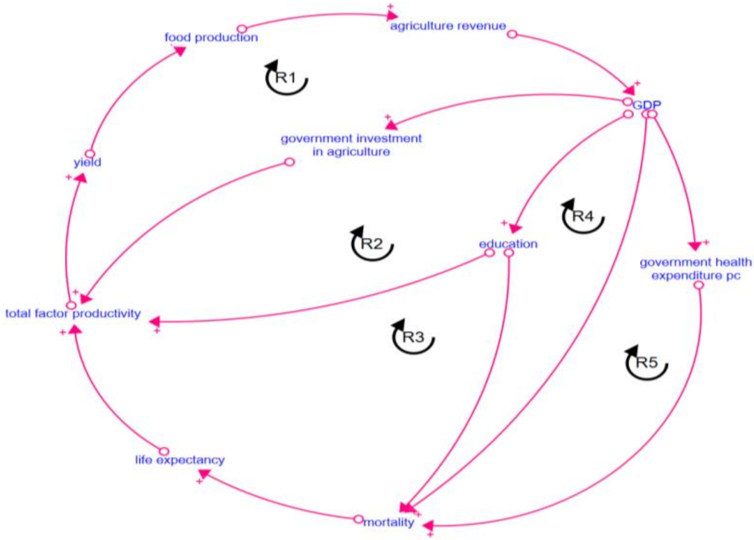
This CLD captures the links between the main stages of the food system. It shows that one part of the food produced is consumed directly by the farmers themselves, while the rest enters into the food market through the transport of food consumption areas. Some of the food transported is then sold directly 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.

Figure 4. 21: food distribution, transportation, processing and consumption SFD



Source: the authors

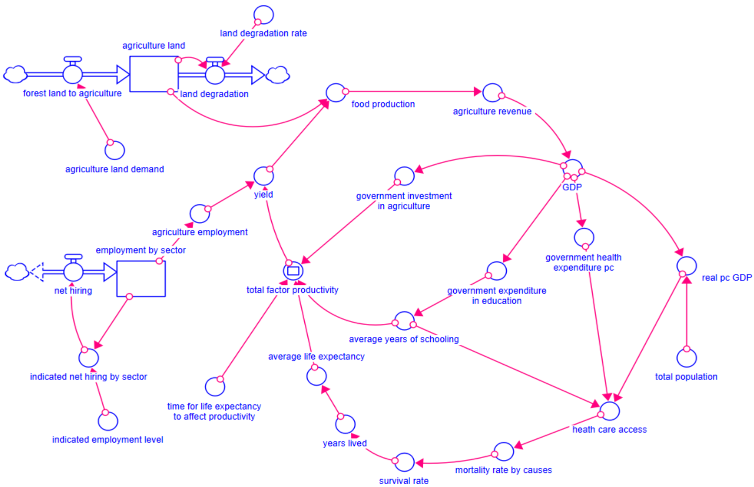
Figure 4. 22: total factor productivity, production and agriculture revenue CLD



Source: the authors

Here we want to emphasize the importance of factor productivity and the level of agricultural production and income. 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 technology and mechanization in the agricultural sector, it could boost the agricultural sector's performance.

Figure 4. 23: total factor productivity, production and agriculture revenue SFD

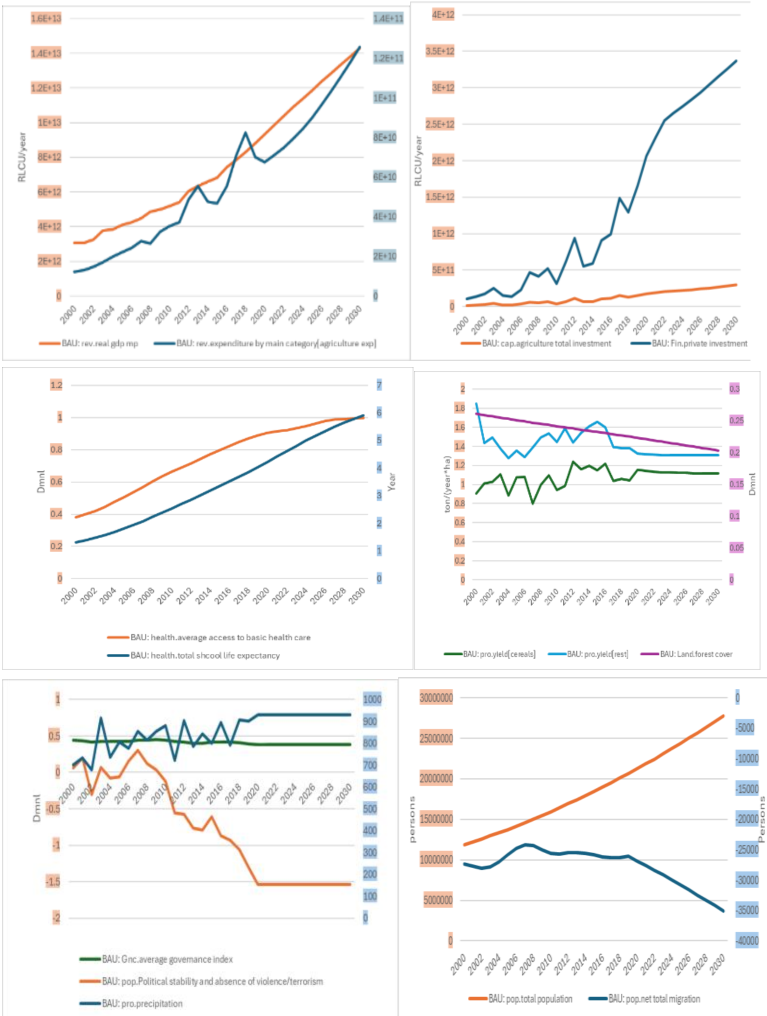


Source: the authors

4.3.3. Behavior over time of some key agriculture variables for the BAU scenario

The pictures above show 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, and 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 graphics below show the behavior of some key drivers from 2000 to 2020 and their trend until 2030 in the BAU scenario. 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.

Figure 4. 24: some key variables trend

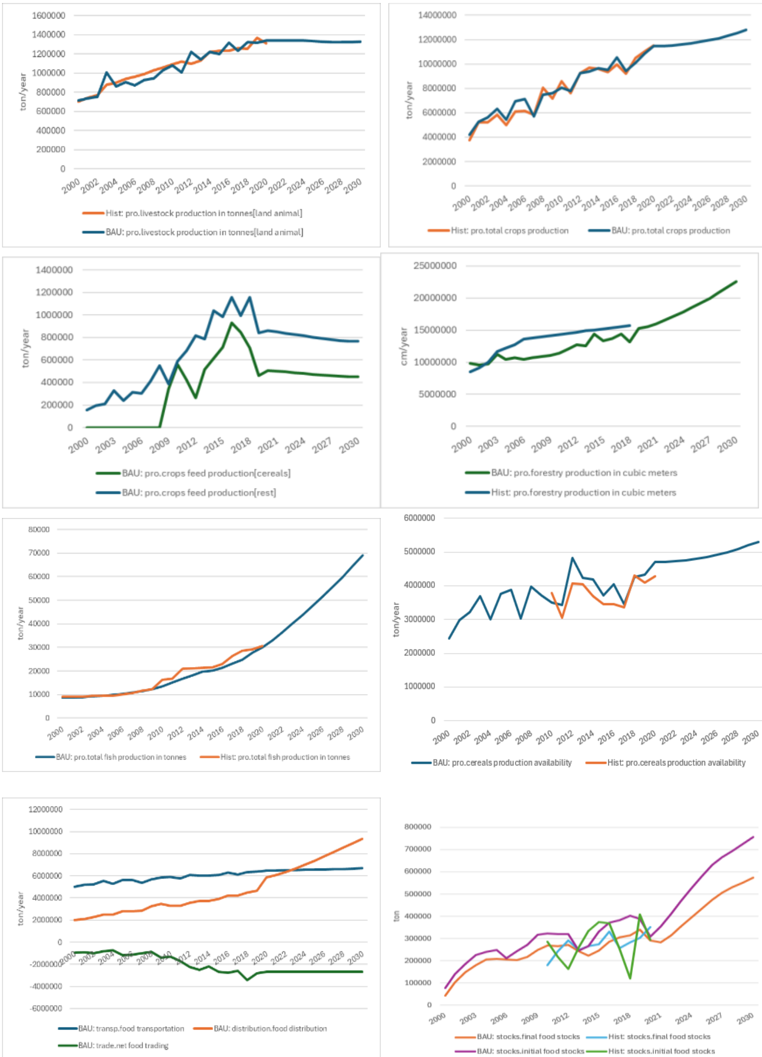


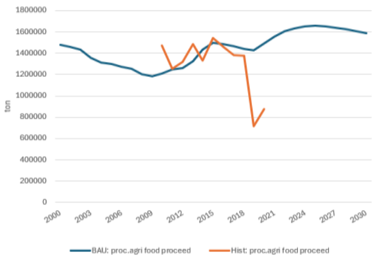
Source: the authors

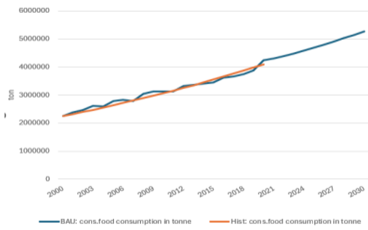
4.4. Results of the simulation

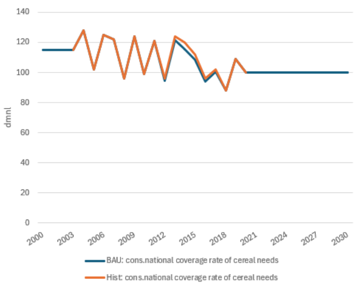
Here, the purpose is to analyze the ability of the model to replicate the historical and long term trend of some key variables of food security and nutrition. The use of the SD method enables us to calibrate the model for the purpose of fitting as well as possible the simulation results to the historical 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 Demographie (INSD)" and the missing data has been completed by international databases. The model considers twenty-three (23) 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 performances of every sector by considering its key 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 which are used to measure the 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 percent 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 (J. D. 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, U^M 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 in 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, the 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.

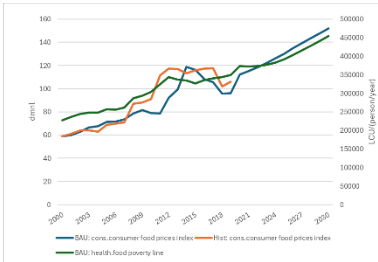
Figure 4. 25: historical and BAU results

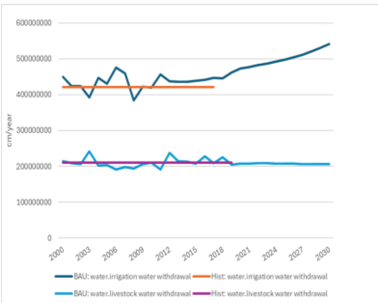


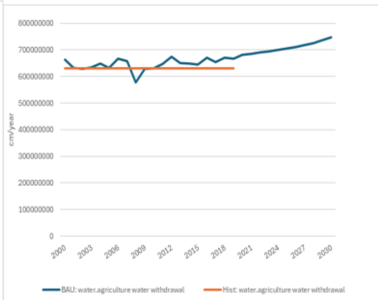

ton
BAU: proc.agri food proceed
Hist: proc.agri food proceed

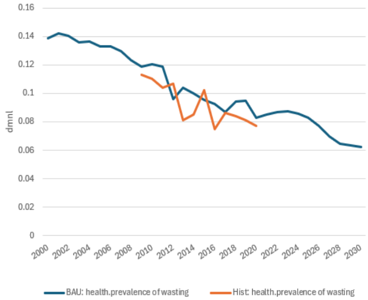

ton
BAU: cons.food consumption in tonne
Hist: cons.food consumption in tonne

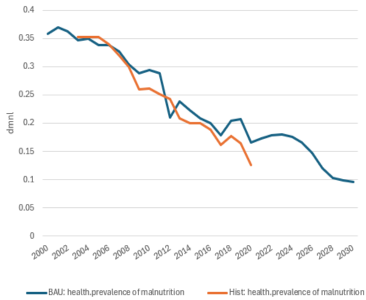

dmnl
BAU: cons.national coverage rate of cereal needs
Hist: cons.national coverage rate of cereal needs

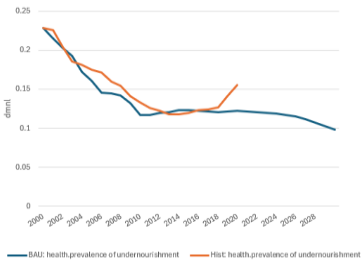

dmnl
LCU/(person/year)
BAU: cons.consumer food prices index
Hist: cons.consumer food prices index
BAU: health.food poverty line

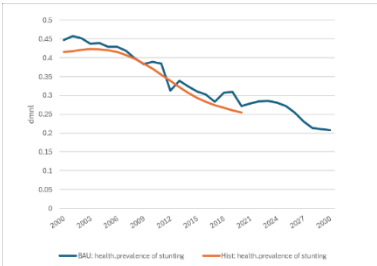

cm/year
BAU: water.irrigation water withdrawal
Hist: water.irrigation water withdrawal
BAU: water.livestock water withdrawal
Hist: water.livestock water withdrawal

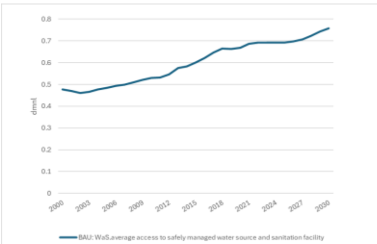

cm/year
BAU: water.agriculture water withdrawal
Hist: water.agriculture water withdrawal

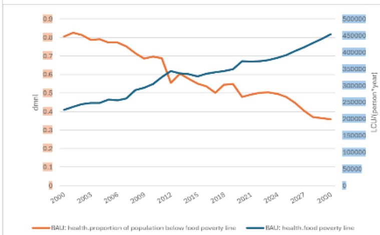

dmnl
BAU: health.prevalence of wasting
Hist: health.prevalence of wasting

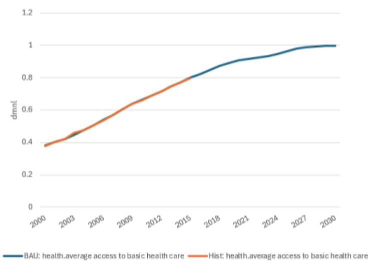

dmnl
BAU: health.prevalence of malnutrition
Hist: health.prevalence of malnutrition

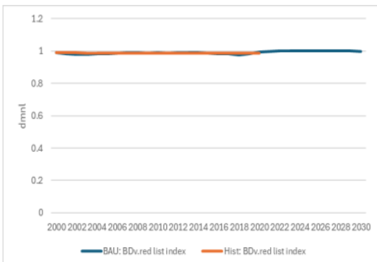

dmnl
BAU: health.prevalence of undernourishment
Hist: health.prevalence of undernourishment


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


dmnl
BAU: WaS.average access to safely managed water source and sanitation facility


dmnl
LCU/(person*year)
BAU: health.proportion of population below food poverty line
BAU: health.food poverty line


dmnl
BAU: health.average access to basic health care
Hist: health.average access to basic health care


dmnl
BAU: BDv.red list index
Hist: BDv.red list index

Source: the authors

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 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 proceeds 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 in 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 because in the iSDG model, the reference overweight to income is set to a constant value. That setting cannot consider the dynamic of all factors that impact income in Burkina Faso case.

Table 4. 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: the authors

However, we have some non-available (NA) values of statistics for pasture land, irrigated water and livestock withdrawal, and fish resource availability share. For the variables pasture land, irrigated water, and livestock 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 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.

4.5. Discussion

The simulation shows some interesting results of calibration for the main 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 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 in the prevalence of undernourishment, stunting, and wasting contrary to the prevalence of overweight in the total population which is increasing during the simulation period. But, between the period 2017-2019, there is a little divergence between the historical data trend and the simulation results that increased 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 policymakers 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 the agriculture and livestock sectors. Next, the effect of climate change on crop 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 to the fact more than 80% of the population is living with agricultural activities. So, the achievement of food security and a fair nutrition state requires the transformation of the actual FS to a new sustainable food system that interconnects the different actors belong the food value chains, good management of production factors, and 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 (D. Meadows, 1999) on which the government can base and take action. The more important things that we think it is important to maximize 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 can provide sufficient cereals and meat to cover national food needs. The food access problem is linked to 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 less development of internal trade between regions and also 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 to shift the 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 acquiring 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 cultural diversification toward vegetables and fruits.

Table 4. 2: leverage points for food system performance improvement

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	- national poverty reduction - reduction of population growth - reduction of rural young migra	- land use to reduce agriculture land losing - food storage network to cover all the country - reduce territorial inequ	- reduce crops growth time to face with short rainy periods through the production of improved seeds - increase water retenti	- reduce pesticides and fertilizers use to avoid soil depletion and water pollution in the long	- improve organic fertilizers use - raising awareness about the effects of good nutrition on health	- climate change, and sustainable agriculture practices information availability for food actors (food prices, tempe	- landlord to avoid speculation - food trade rules oriented towards local goods consumption and production - set up and strengthen	- connect banking system to FS to improve credit access - Build a strong interconnection between FS steps - collaboration	- self-sufficiency food towards food security and further food sovereignty	- shifting from subsistence agriculture in which agriculture revenue is low towards a modern sustai	- revolution of agriculture practices towards agroecology practices (cultures diversification and combination for example rice

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	tion to cities and traditional gold mining - material and infrastructure to reduce food losses during the harvest, transport and storage - development of agrifood sector to increase agrifood production - reforestation programmes for degraded land restoration	ality 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	on period of dams for off-season crops and irrigation - reduce administrative procedures for agribusiness creatives and agricultural policy implementation	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	- 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	ratures, 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, produ	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. - increase the rules for controlling the safety and quality of imported products and local produc	and strong interactions between farmers and policy makers 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		nable 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 labouring work programmes and counter season cultures to face lean seaso	and fish farming to optimize water), short-circuits to give a power to local producers, preserve natural resources and preserve food prices increasing - adopting a geographical and territorial integrated approach to valorize regional potentialities - actors participation in agriculture policy elaboration and implementation

long-term rainfall decline - subsidy intrants production particularly 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						ct quality assurance, training and technical support for the farmer, management of land, inputs, etc., and purchase of 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 involv	ts for the nutritional safety of foods intended for consumption - 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 reduction of agricultural land, which in turn reduces soil fertility. This leads farmers to	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 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		n for rural population	

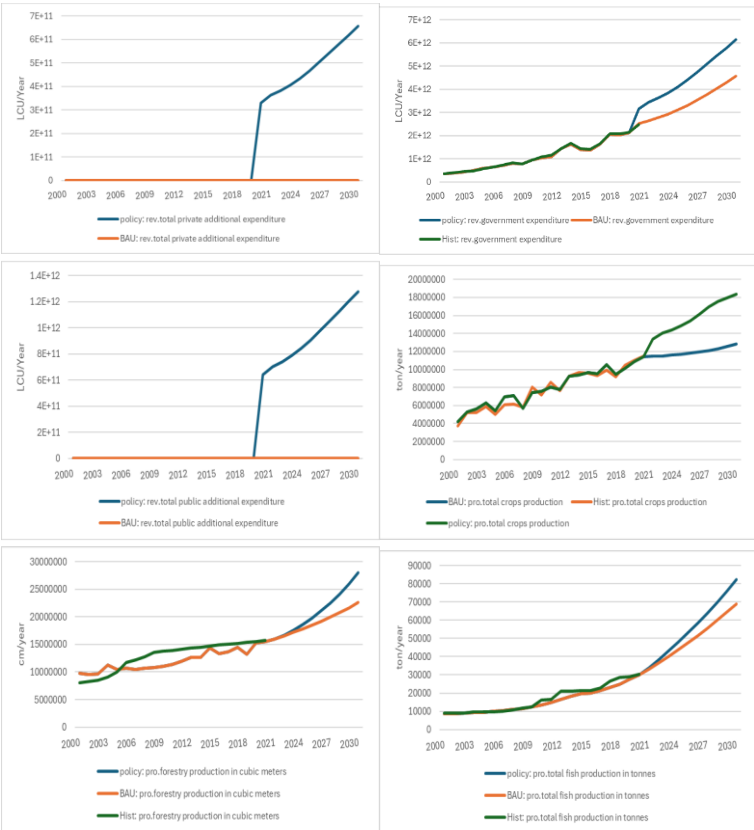
						ed, and contributes to job protection and the development of local communities. - create a feeling of trust in local products among the population to promote local consumption	use more chemical fertilizers to increase their production. A strategy of sanctions and rules therefore needs to be found to counter the expansion of traditional gold panning and also to prevent the use of cyanide.	in the government budget. - connect the FS to the energy system to reduce biomass use through gas and solar cooking strategies - support of mining sector to food system industrialization			

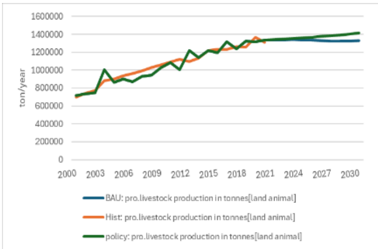
Source: the authors

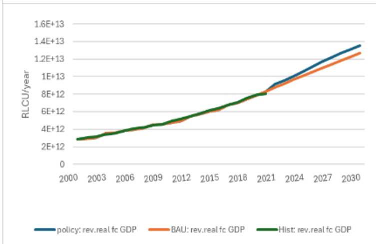
Through these leverage points, we have built a policy strategy or scenario that is setting on the future value of some agriculture sector policy variables such as reforestation, food actors training, fertilizers subsidies, irrigation water efficiency, general transfers into the agriculture sector to 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 enhancing 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.

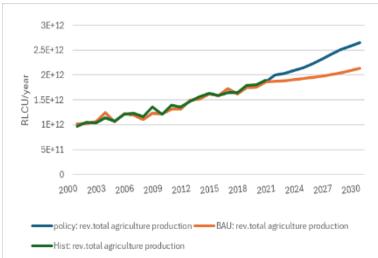
To assess these policies' impacts we made some assumptions. Given the importance of the agriculture, land, infrastructure, and poverty sectors to influence the FS performances, we assume a further increase in spending as a percentage of GDP to 4.5%, 0.5%, 2%, and 3% respectively. Nowadays, the participation of private investment is very low in the agriculture sector and road 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 expenditure level on future development and can be helpful to simulate SDGs or other objectives of development cost policies scenario which uses some policy variable settings. The following graphics (Figure 4.14) show the simulation results of the BAU scenario compared to those of the alternative scenarios for some main variables. The alternative scenario named "Policy" shows some more interesting and hopeful results than the BAU simulation results following the strategic policy intervention.

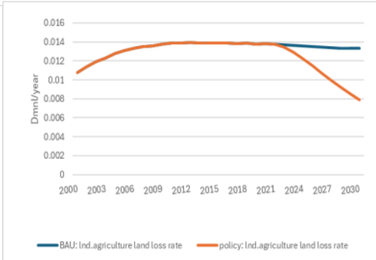
Figure 4. 26: results of scenario simulations

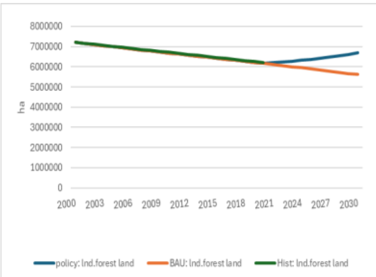


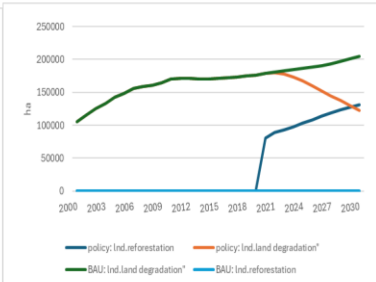

ton/year
BAU: pro.livestock production in tonnes[land animal]
Hist: pro.livestock production in tonnes[land animal]
policy: pro.livestock production in tonnes[land animal]

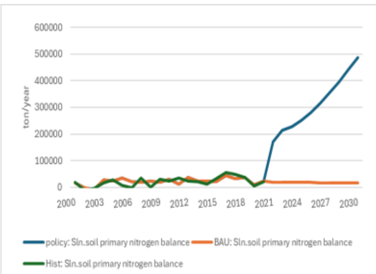

RLCU/year
policy: rev.real fc GDP
BAU: rev.real fc GDP
Hist: rev.real fc GDP

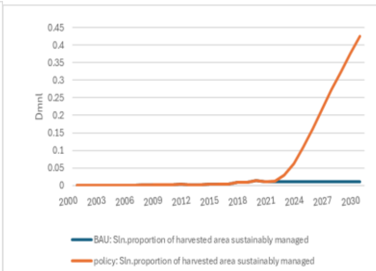

RLCU/year
policy: rev.total agriculture production
BAU: rev.total agriculture production
Hist: rev.total agriculture production

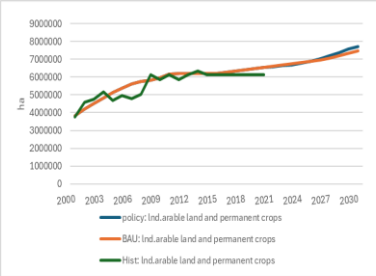

Dmnl/year
BAU: lnd.agriculture land loss rate
policy: lnd.agriculture land loss rate

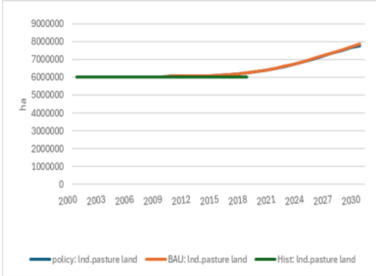

ha
policy: lnd.forest land
BAU: lnd.forest land
Hist: lnd.forest land

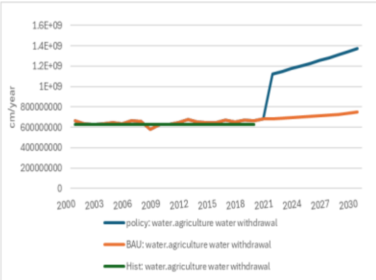

ha
policy: lnd.reforestation
policy: lnd.land degradation"
BAU: lnd.land degradation"
BAU: lnd.reforestation

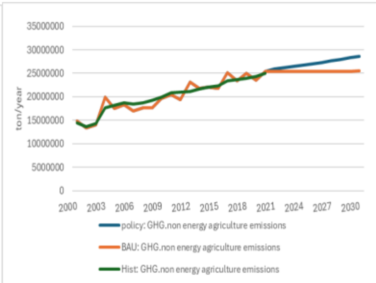

ton/year
policy: Sln.soil primary nitrogen balance
BAU: Sln.soil primary nitrogen balance
Hist: Sln.soil primary nitrogen balance

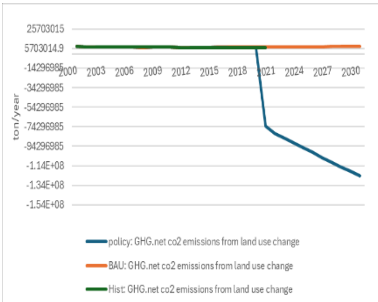

Dmnl
BAU: Sln.proportion of harvested area sustainably managed
policy: Sln.proportion of harvested area sustainably managed

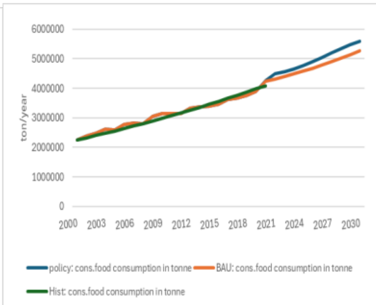

9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
ha
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
policy: lnd.arable land and permanent crops
BAU: lnd.arable land and permanent crops
Hist: lnd.arable land and permanent crops

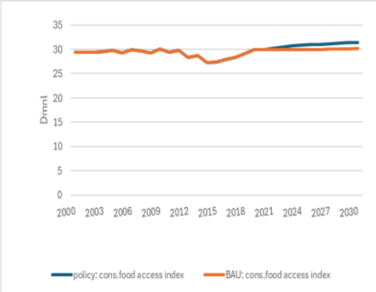

9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
ha
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
policy: lnd.pasture land
BAU: lnd.pasture land
Hist: lnd.pasture land

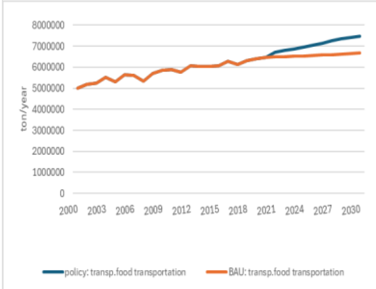

1.6E+09
1.4E+09
1.2E+09
1E+09
800000000
600000000
400000000
200000000
0
cm/year
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
policy: water.agriculture water withdrawal
BAU: water.agriculture water withdrawal
Hist: water.agriculture water withdrawal

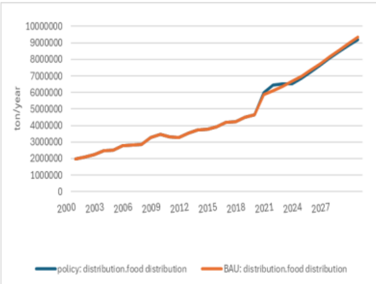

35000000
30000000
25000000
20000000
15000000
10000000
5000000
0
ton/year
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
policy: GHG.non energy agriculture emissions
BAU: GHG.non energy agriculture emissions
Hist: GHG.non energy agriculture emissions

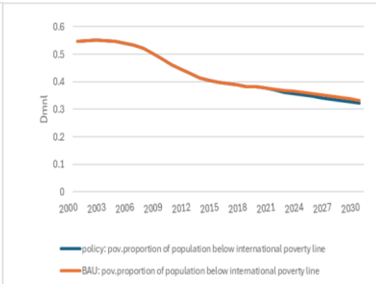

25703015
5703014.9
-14296985
-34296985
-54296985
-74296985
-94296985
-1.14E+08
-1.34E+08
-1.54E+08
ton/year
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
policy: GHG.net co2 emissions from land use change
BAU: GHG.net co2 emissions from land use change
Hist: GHG.net co2 emissions from land use change

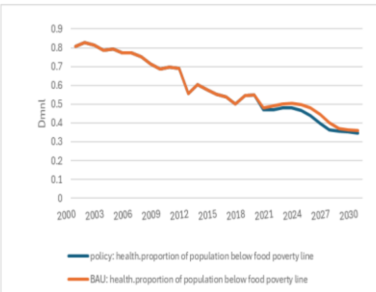

6000000
5000000
4000000
3000000
2000000
1000000
0
ton/year
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
policy: cons.food consumption in tonne
BAU: cons.food consumption in tonne
Hist: cons.food consumption in tonne

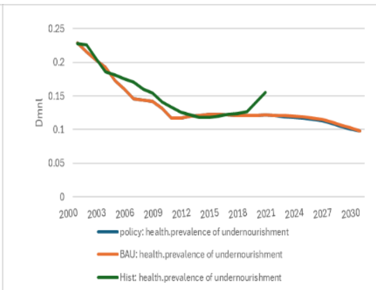

Dmnl
policy: cons.food access index
BAU: cons.food access index

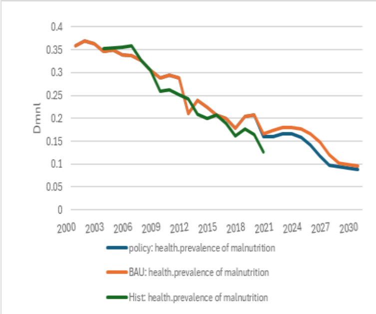

ton/year
policy: transp.food transportation
BAU: transp.food transportation

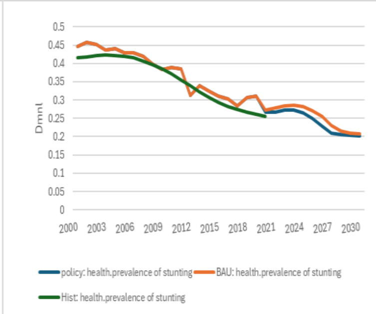

policy: distribution.food distribution
BAU: distribution.food distribution

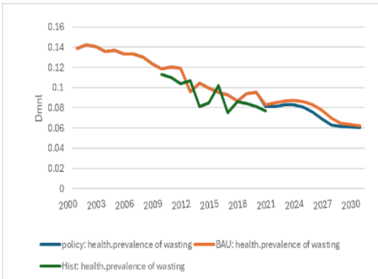

Dmnl
policy: pov.proportion of population below international poverty line
BAU: pov.proportion of population below international poverty line

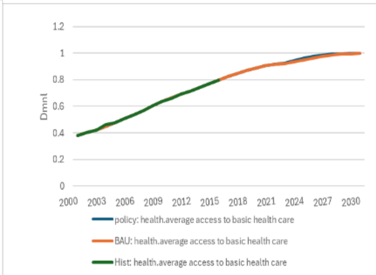

Dmnl
policy: health.proportion of population below food poverty line
BAU: health.proportion of population below food poverty line

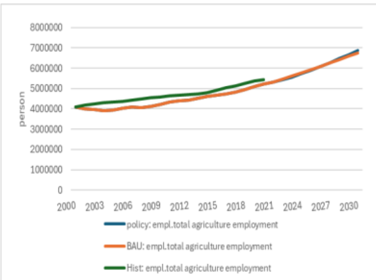

Dmnl
policy: health.prevalence of undernourishment
BAU: health.prevalence of undernourishment
Hist: health.prevalence of undernourishment

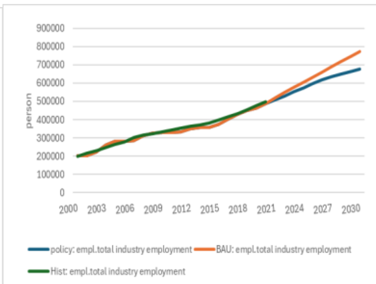

Dmnl
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
policy: health.prevalence of malnutrition
BAU: health.prevalence of malnutrition
Hist: health.prevalence of malnutrition


Dmnl
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
policy: health.prevalence of stunting
BAU: health.prevalence of stunting
Hist: health.prevalence of stunting


Dmnl
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
policy: health.prevalence of wasting
BAU: health.prevalence of wasting
Hist: health.prevalence of wasting


Dmnl
1.2
1
0.8
0.6
0.4
0.2
0
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
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
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
policy: empl.total agriculture employment
BAU: empl.total agriculture employment
Hist: empl.total agriculture employment


person
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030
policy: empl.total industry employment
BAU: empl.total industry employment
Hist: empl.total industry employment

Source: the authors

4.6. 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 result that influence the food system such as land, GDP, agriculture investment and expenditures, agriculture capital, biodiversity, agriculture water withdrawal or availability, infrastructure, employment, ...for the period 2000 to 2020. The modelling 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 non-agricultural sector influences the food system performances. 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 impacts on its performances. 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 can 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.

However, the model also 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 are not existing data such as food transported and distribution, we cannot validate the results of the simulation. Secondly, some variables like agri-food 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 the trend in reality. 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.

General conclusion

01. Summary and main takeaway

The UN 2030 Agenda and the Agenda 2063 are the referential roadmaps for African countries to go towards sustainable development. Both strategic frameworks include many aspirations of the 17 Sustainable Development Goals that aim to create a prosperous future for the populations in terms of poverty eradicating and household revenue improvement, ending food insecurity, health care access, human capital development, gender equality, infrastructures and necessities of life developing, an inclusive growth, decent works creation, environment, and ecosystems protection, the development of a peaceful and secure, good governance and the respect for human right and justice,...

Despite these aspirations and the willingness of African countries to transform the economy and the society to achieve sustainable development for their population, they face many challenges that reduce the different efforts of policy actions and the effectiveness of public investment. So, it is necessary for developing countries like Burkina Faso which is today suffering particularly from terrorism to have a national integrated model of SDG indicators that can guide policymakers to quantify policy impacts across priority sectors. One of the known Integrated Systems Models (ISMs) used in many countries across the world is the integrated Sustainable Development Goal (iSDG) model. It is useful for countries to assess their performances in the achievement of SDGs and also to optimize public resources in terms of investment and expenditures that benefit numerous sectors. Because of its proven effectiveness in developing countries, we have decided during our thesis to analyze the structure of the iSDG model how it is implemented and used, and its limits. Also, we have studied how this model can be used and helped Burkinabè authorities to improve food security and nutrition performances in the county to achieve the SDG2. This work contributes to the literature on system dynamics modeling and the proposal of integrated models to assess policy impacts in terms of SDGs performances. The thesis is organized into four chapters.

Chapter 1 analyzes firstly the structure of the iSDG model by presenting the different sectors included in its composition. Secondly, it presents System Dynamics (SD) which is the methodology used by the iSDG model to model SDGs indicators. And end the paper concludes by presenting the different results, limits, and policy recommendations in the application of the model in some developing countries to achieve the target SDGs. The results of the study show that the iSDG model is a powerful and helpful tool for the policymakers to assess policy effectiveness before implementing them and to elaborate synergistic strategies of policy to improve the performance of various SDGs and sectors.

Chapter 2 is a benchmarking analysis to determine the ability of four dynamics models such as the iSDG model of the MI, the World Bank's long-term growth model (LTGM), the DSGE model used by the WB, OECD, the IMF, ... and the AFD's Stock-Flow Consistent Prototype Growth Model (SFCP-GM) to do a sustainable development analysis by taking into account the 17 SDGs and the durability of systems in their structure. We are focused on three criteria of SDGs modeling, the use of loops and stock-flow variables, and the type of prospecting or prediction model to highlight the particularity of each model. The comparative analysis shows that only the iSDG model is the one that takes into account SDGs indicators assessment and can do a prospective analysis through the implementation of synergy policies. The other three are predictive models and their structure doesn't include social and environmental domains. Also, they do not consider the feedback effects between sectors apart from the AFD Stock-Flow Consistent Prototype Growth Model. In that case, the iSDG model considers the GDP as a driver contrary to the three models that consider it as a goal to reach.

Chapter 3 investigates how the iSDG model quantifies SDGs performances and its power to be a prospective and long-term national policy planning. Our findings show that the iSDG analysis framework is based on the planet's boundaries and the Doughnuts economy framework is composed of environmental, social, and economic domains. Each domain includes at least 10 sectors in which there are dynamic relationships between the elements of these sectors. The quantification of the interactions between the elements (stocks and flow variables) allows us to assess the performance of every sector by using the UN indicators within sectors. Next, the model uses the relevant indicators for each SDG to assess its performance of achievement by 2030. This process of modeling makes it possible to assess a country's performance in terms of sustainable development and the interventions required to improve an SDG or a set of SDGs through three scenarios of Business As Usual (BAU) scenario based on national actual policy implemented, a Medium Scenario and Optimistic Scenario based on additional and/or complementary policy implementing and additional investment.

Chapter 4 makes a summary description of the food security and nutrition state in Burkina Faso

by identifying the different actors who intervene in the system and their activities. This work helps us to identify the weaknesses and strengths sources to elaborate some leverage points on which agriculture policymakers can rely to improve food security and nutrition and reach the SDG2 by 2030. This work has been helpful for us to develop a food system model by using system dynamics tools (Causal Loops Diagram and Stocks and Flows Diagram) that includes the steps of food production to food consumption via food transportation, distribution, processing, and stocking. Our results show that the different steps of the FS are interconnected, and the Burkina Faso food system is interrelated with other driver systems which shape its structure and impact its performances in terms of food security and nutrition. These interactions are so strong that the actions of agricultural actors in terms of policy and practices play a key role in the transformation of the actual food system to a new Sustainable Food System (SFS). The use of R-squared, Root Mean Square Percent Error, and the Theil Inequality Statistics for error decomposition such as the Bias (U^M), Variation (U^S), and Co-variation (U^C) prove the ability of the model to reproduce the long-term trend of food key variables and the global behavior 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 during the period 2000-2020. It can be used to assess one or a set of public policies before implementing them by policymakers. The alternative scenario of the BAU scenario has shown some interesting results in food security and nutrition.

However, there are missing or lack of data for some variables, in that case, the model has had difficulties to reproduce very well the historical trend of the missing data. Also, the results proposed by the simulation for the non-existing data variables alone do not allow us to validate the power of the model to properly reproduce the trend of these variables. So, we have suggested that it is important to discuss with agriculture actors to improve or readjust these results and the model structure or its goals.

02. Avenue For Future Research

This work of the thesis was planned to take place at the national level of Burkina Faso but also at the local level. Indeed, we wanted to analyze how public policies can generate a mechanism for transforming the food system at the local level, but also how local community practices can influence public policies and lead them in the right direction. It is to calibrate the model at national level and the consideration of interactions with local territories by developing a local food model that interacts with the national food model. Here the purpose is to analyze the issue of food security based on the feedback effects of a local community approach on national public policies by (re)defining the main drivers and their dynamics via a bottom-up approach.

The importance of this study is to highlight the role of local agricultural practices such as agroecology and short circuits in Burkina Faso's FS in improving food supply and healthy diet.

The FS today are faced with several challenges of food security, environmental and natural resources protection, climate change adaptation, and poverty reduction in developing countries. So, familial farming and local agriculture play a key role to face these challenges. However, the complexity of interactions that exists between the FS and social, territorial, and environmental systems requires the use of Participatory System Dynamics modeling to get a shared representation of these challenges, and the sources of problems and to develop strong strategies to address them at the local level. Participatory system dynamics modeling is a strong framework that incorporates and engages stakeholders in society's problems analyzing, and describing the system, creating computer models by using SD methods, elaborating policy interventions and choosing the relevant solutions that provide positive outcomes.

Its goal is to construct social capital knowledge through a learning-by-doing approach of non-scientists in the scientific process. Indeed, in Burkina Faso, we have decided to practice this approach in food security analysis in the province of Boulkiemdé in the Centre-Ouest region, whose capital is

Koudougou. We had started the first interviews, but the current context of insecurity in Burkina and the lack of funding meant that we were unable to complete the work. So, we plan to resume this work once funding opportunities arise and the security situation improves. This work was to be the last paper in the thesis, but as the study did not go all the way, we were unable to write it.

In addition, it was in the plan of our thesis to calibrate an iSDG model for Burkina Faso by completing the agriculture sector which concerns food production by a food module that considers the different steps of the FS. Unfortunately, in the beginning of the thesis, we were confronted with a lack of data for many variables despite many discussions with the authorities and searches of international institutions' databases. So, it would be interesting to continue this work and to find a way to fill missing data and calibrate the model. We think that it will be helpful for policymakers to get a good understanding of the interactions between sectors and to be conscient of the medium and long-term impacts of the different policies they implement across sectors. Also, it will be helpful to prioritize investment and public expenditures towards growth sectors that have synergic effects on several sectors and the achievement of numerous SDGs.

With the FS model that we have developed to improve the country's food security situation and fight against malnutrition, we need to continue this work after the thesis to analyze how we can implement the different leverage points found in Chapter 4. It is assessing the outcomes of every leverage point to change the actual bad food security situation towards a more desirable one and also to avoid or face tipping points that the simulation results can reveal. This part will be an opportunity to discuss with Burkina Faso food policymakers to improve the model calibration and to elaborate some policy scenarios programmes. It will recommend improving data quality and completing the missing data for some variables. It was one of our difficulties when we started the model calibration. The capacity of the model to find the range of good values for our parameters depends highly on the historical data availability, so it is important to get a large availability of data for the variables. This is useful for the model to replicate as well as possible the model behavior and to predict variables' future behaviour. Also, engaging in discussion with policymakers is necessary to help stakeholders to understand the systemic interactions that lead to the actual situation, the responsibility of everyone and what kind of solutions they can make to change the food security situation soon. So, the discussion will be helpful in building a strategic policy scenario according to the objectives of the government by testing their potential effects to improve food access and availability for the populations. Scenario analysis allows us to project the level of improvement in food security by 2030, or the level of achievement of SDG2, simply with the current agricultural policies implemented by the government. And to compare the impact of these policies with alternative scenarios of public policies capable of achieving the SDG2 by 2030. Second, the scenario analysis helps the government to prioritize the sectors in which to invest and the amount of public and private resources to be mobilized to face this food security challenge. And that is good for saving the government budget and human resources.

Finally, the iSDG model is a tool that uses aggregated data at the national level for variables to assess policy impacts. We know that the use of aggregated data often ignores sub-national realities and that within countries, regions are highly heterogeneous in terms of geography, climate and socioeconomics. In this case, using a model based on the average of sub-regional data may not be effective in terms of impact assessment and public policy recommendation. It's true that at the sub-regional level, it's difficult to obtain data collected to carry out studies, but it makes sense to consider regional heterogeneities within countries. This is an area for improvement for the iSDG model to be effective in terms of impact monitoring, evaluation and advice.

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