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Modeling Economics and Sustainability: GDP as a Goal vs GDP as a Driver

Arnaud Diemer, Henri Sourgou

Post Growth Institute, Clermont Auvergne University, Clermont-Ferrand, France
Email: Diemera@aol.com

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Abstract

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 Française de Development, 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 lot 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

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. 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.

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.

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.

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:

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

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. $\beta_t \in (0,1)$ 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. $h \in (0,1)$ 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:

$$\begin{aligned} &P_t C_t + M_t + B_t + P_t I_t + e_t B_t^* \\ &\leq M_{t-1} + B_{t-1}\left(1+i_{t-1}\right) + \left(1-\tau\right)\varpi_t L_t + \left(1+i_{t-1}^*\right)e_t B_{t-1}^* \\ &\quad + R_t K_{t-1} + T_t + Div_t + e_t Rem_t \end{aligned}$$

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*.

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:

$$Y_t = \int_0^1 \left[Q_t\left(i\right)^{\frac{\mu-1}{\mu}} \mathrm{d}i \right]^{\frac{\mu}{\mu-1}}$$

where Q_t is the demand function of intermediary goods, $\mu > 1$, 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).

$Q_t\left(i\right) = \left[P_t^i / P_t\right]^{-\mu} Y_t$, μ is the price elasticity of demand for each intermediary good.

The production function of the i^{th} intermediate good producer is:

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

where θ_t is the productivity or the 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,

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

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:

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

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:

$$Y_t = C_t + I_t + G_t$$

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).

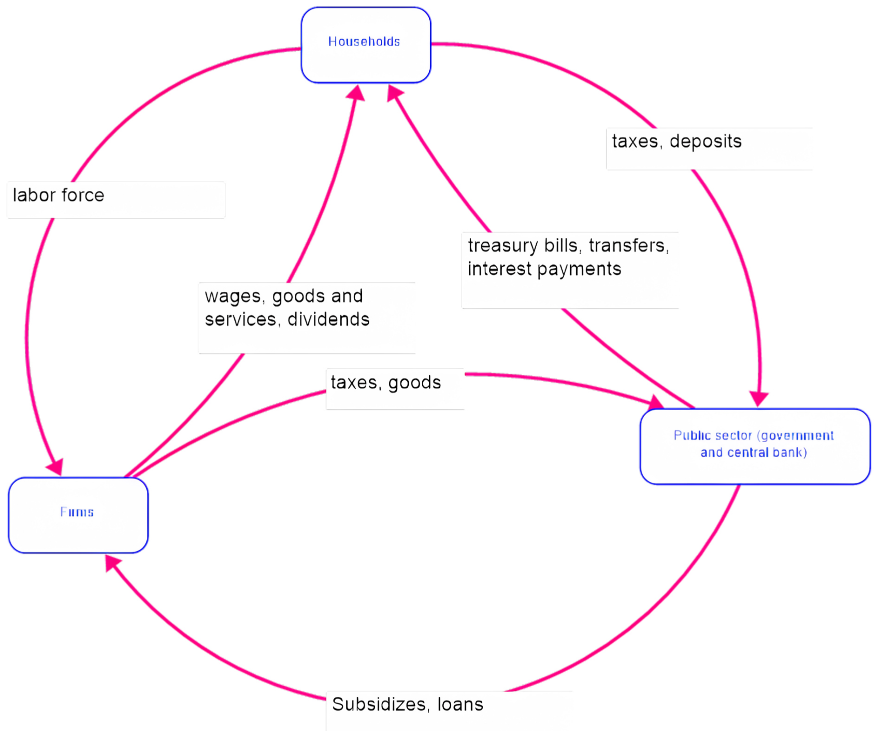
$$r_t = \varphi_r r_{t-1} + \varphi_\pi \pi_{t+1} + \varphi_y \hat{Y}_t + \varepsilon_t^r$$

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

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 1**).

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,

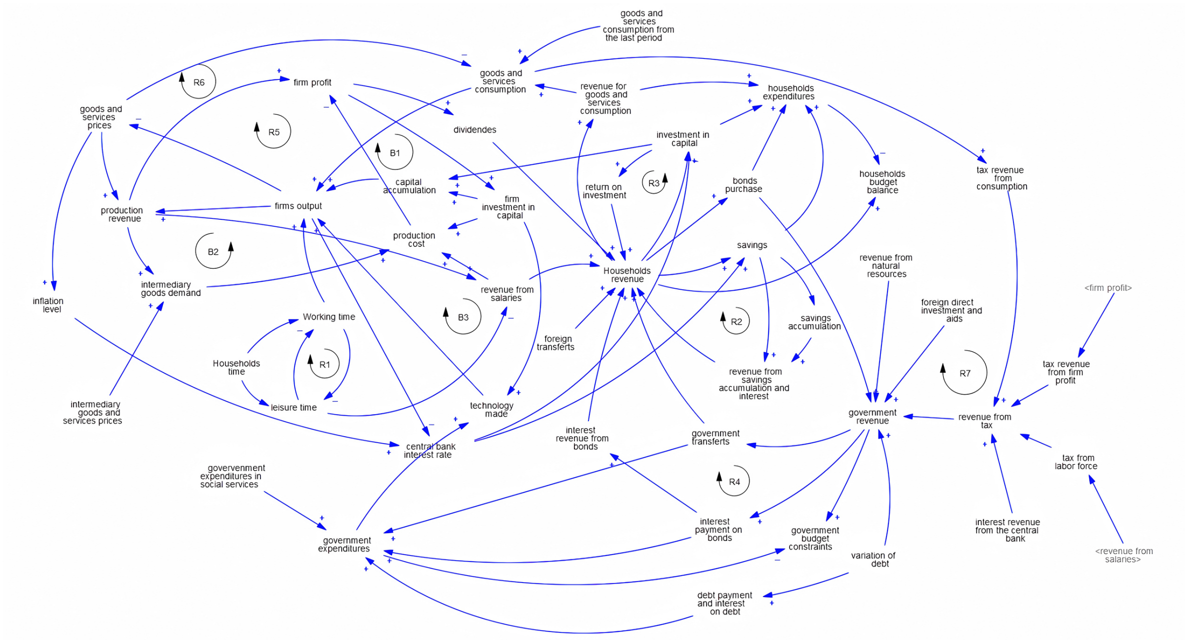


Source: the authors.

Figure 1. Transactions between actors in the national economy for the DSGE model.

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**).

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



Source: the authors.

Figure 2. CLD for the DSGE model.

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 1**).

Table 1. DSGE applications.

Country	Application goal	Results
The impact of foreign Bank deleveraging on Korea, (Jain-Chandra 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 countries (the case of Mozambique), (Saxegaard & Shanaka, 2007)	In the context of large volatile aid inflows and/or government revenues from natural resource exploitation combined with a strong development of 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.	The main findings of the DSGE model regarding monetary policy (CPI inflation targeting, non tradable inflation targeting and the crawling exchange rate peg) of 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.

Continued

Oil windfalls in Ghana A DSGE Approach, (Dagher 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 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.	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 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 try 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 favorable 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.

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: $Y_t = A_t K_t^{1-\beta} \left(h_t L_t\right)^{\beta}$ 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 $t+1$.

$1+g_{y,t+1} = \left(1+g_{A,t+1}\right)\left[1+g_{k,t+1}\right]^{1-\beta}\left[1+g_{h,t+1}\right]^{\beta}$, 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:

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

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

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:

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

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

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

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 $\ln\left(y^{PC}\right)\sim N\left(\mu,\sigma^2\right)$.

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

$P_t=\Phi\left(\frac{\ln L-\mu_t}{\sigma_t}\right)$ 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:

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

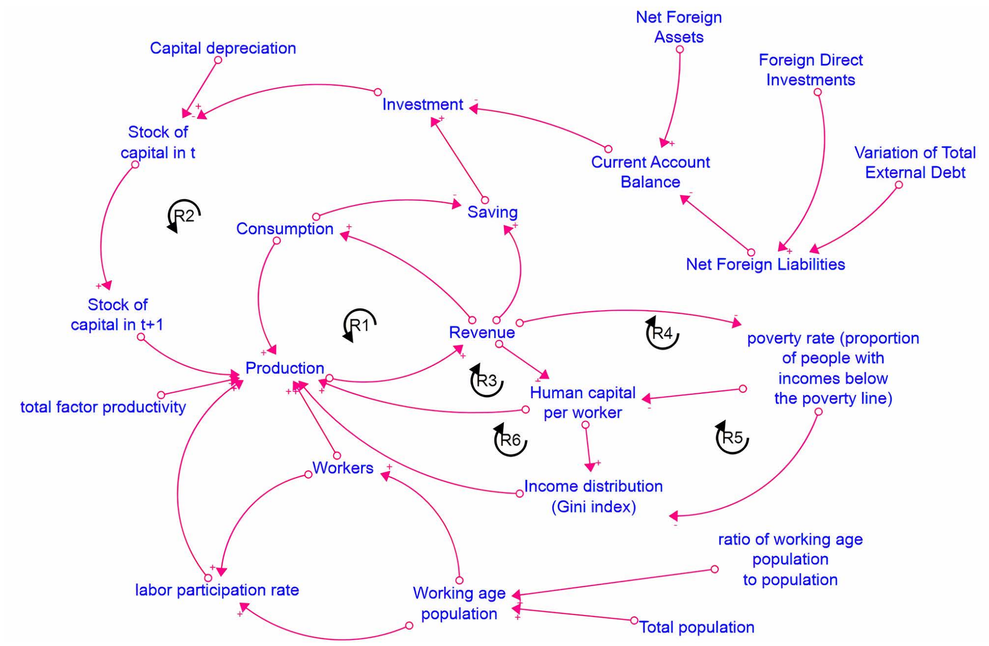
The Growth Elasticity of Poverty (GEP) that measures the percentage fall in the headcount poverty rate from a 1% increase in per capita income is equal:

$$\varepsilon_{p,t}\equiv-\frac{\partial\ln P_t}{\partial\ln\overline{y}_t}=-\frac{\partial P_t}{\partial\mu_t}\frac{1}{P_t}=\frac{1}{\sigma_t}\frac{\Phi\left(\frac{\ln L-\mu_t}{\sigma_t}\right)}{\Phi\left(\frac{\ln L-\mu_t}{\sigma_t}\right)}$$

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

$\Delta_t\equiv-\frac{\partial P_t}{\partial\ln\overline{y}_t}=\varepsilon_{p,t}\times P_t=\frac{1}{\sigma_t}\Phi\left(\frac{\ln L-\mu_t}{\sigma_t}\right)$, 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 3, Table 2).



Source: the authors.

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

Table 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.

Continued

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-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.	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 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 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.	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 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.

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).

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 Development 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 banks, 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 4**).

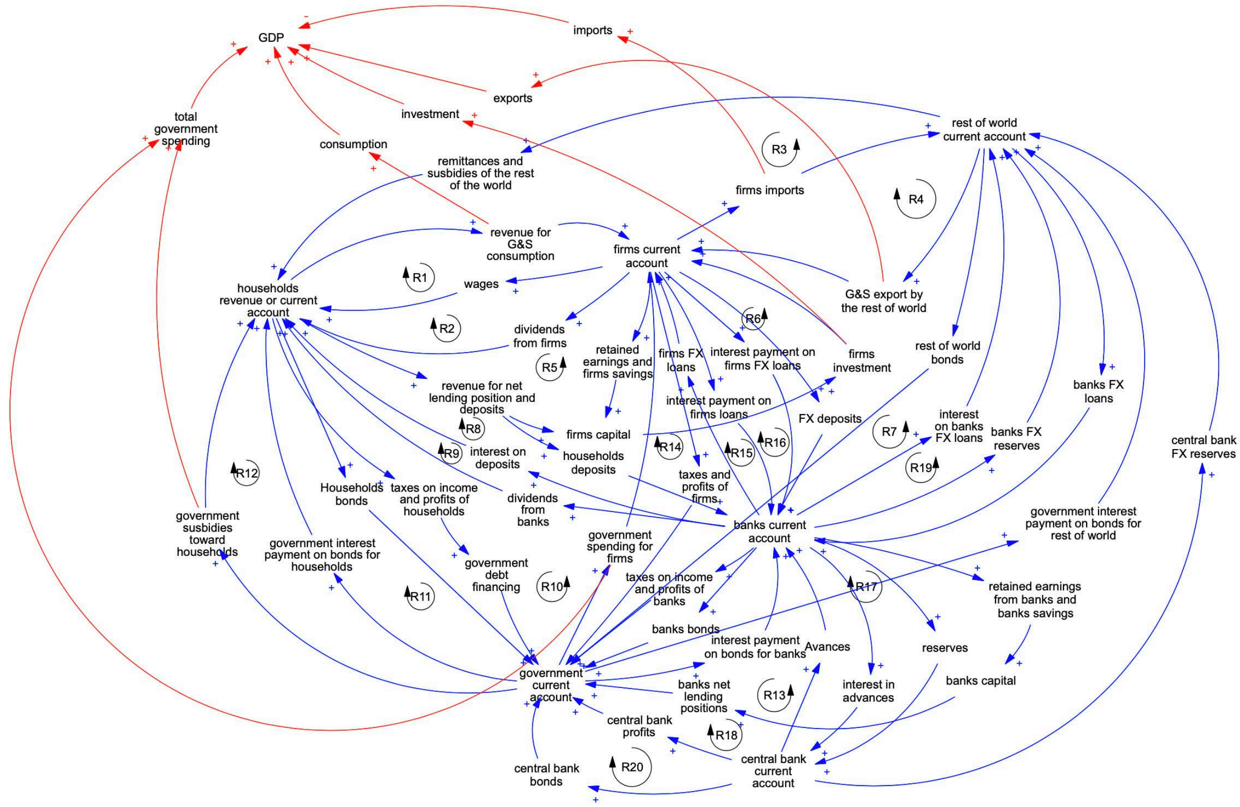
The Transaction-Flow-Matrix is composed of three main components separated by solid lines. As we can see in the matrix, the first component is non-financial transactions (first component) and presents the elements of GDP and revenue distribution accounts (primary and secondary). The second is the physical 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 (**Figure 5**).

	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			$+G_E$					$-G_E$		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).

Figure 4. Transaction flow matrix of the stock-flow consistent model.

Despite the fact that 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, and 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.



Source: the authors.

Figure 5. Transaction-flow Matrix transcription into CLD.

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 3**).

Table 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., 2024)	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 rates. The macroeconomic vulnerability indicators include fiscal conditions, monetary and financial conditions, and external conditions measured by the balance of payment dominance.	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, 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 the Tunisian 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.

Continued

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

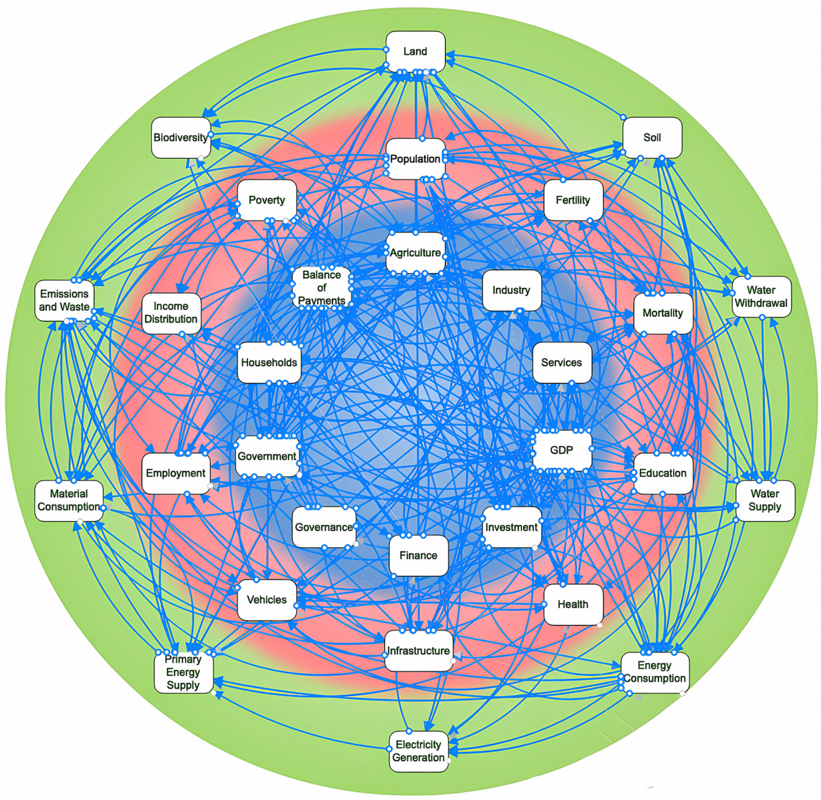
Source: the authors.

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 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 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 (Millennium Institute, 2017; Pedercini et al., 2019).

Source: Millennium Institute (MI).

Figure 6. An overview of 17 SDGs's performance.

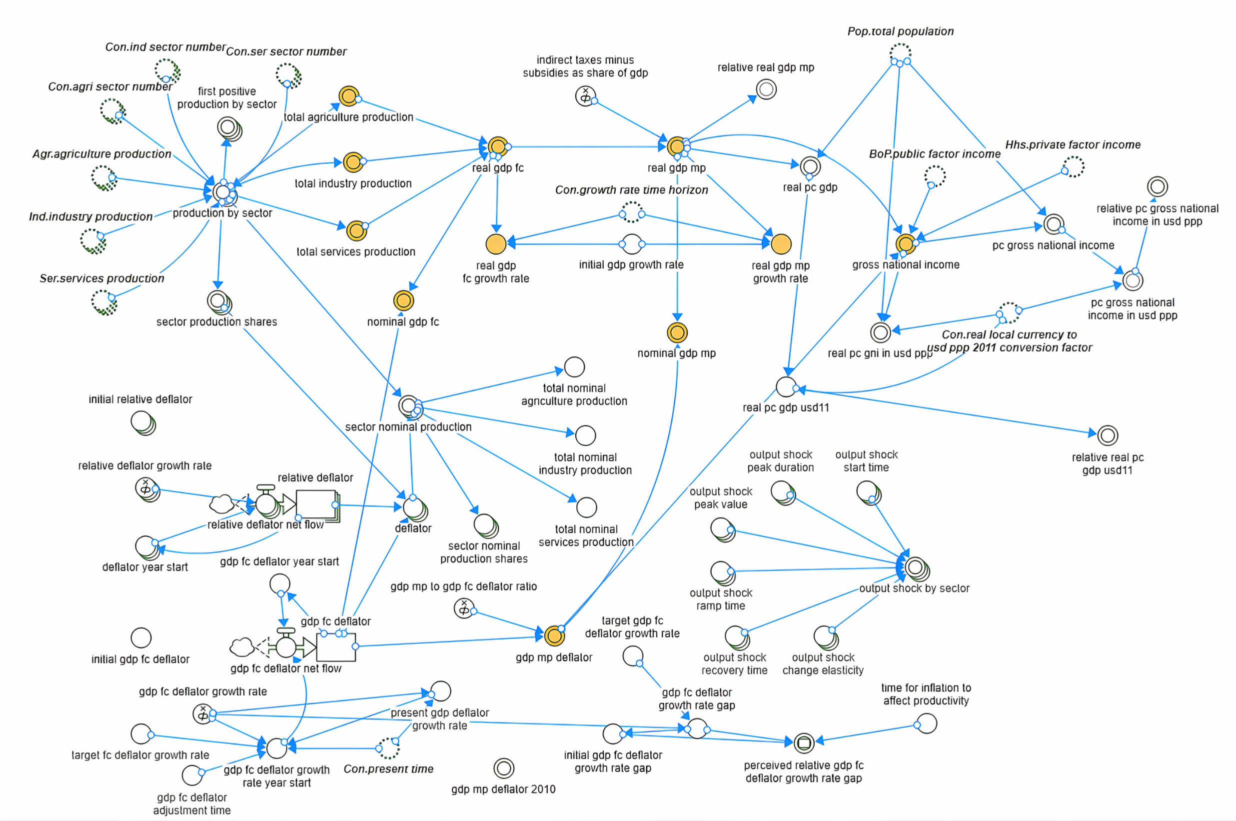


Source: Millennium Institute (MI).

Figure 7. Structure of the iSDG model from Millennium Institute by sector.

Figure 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.

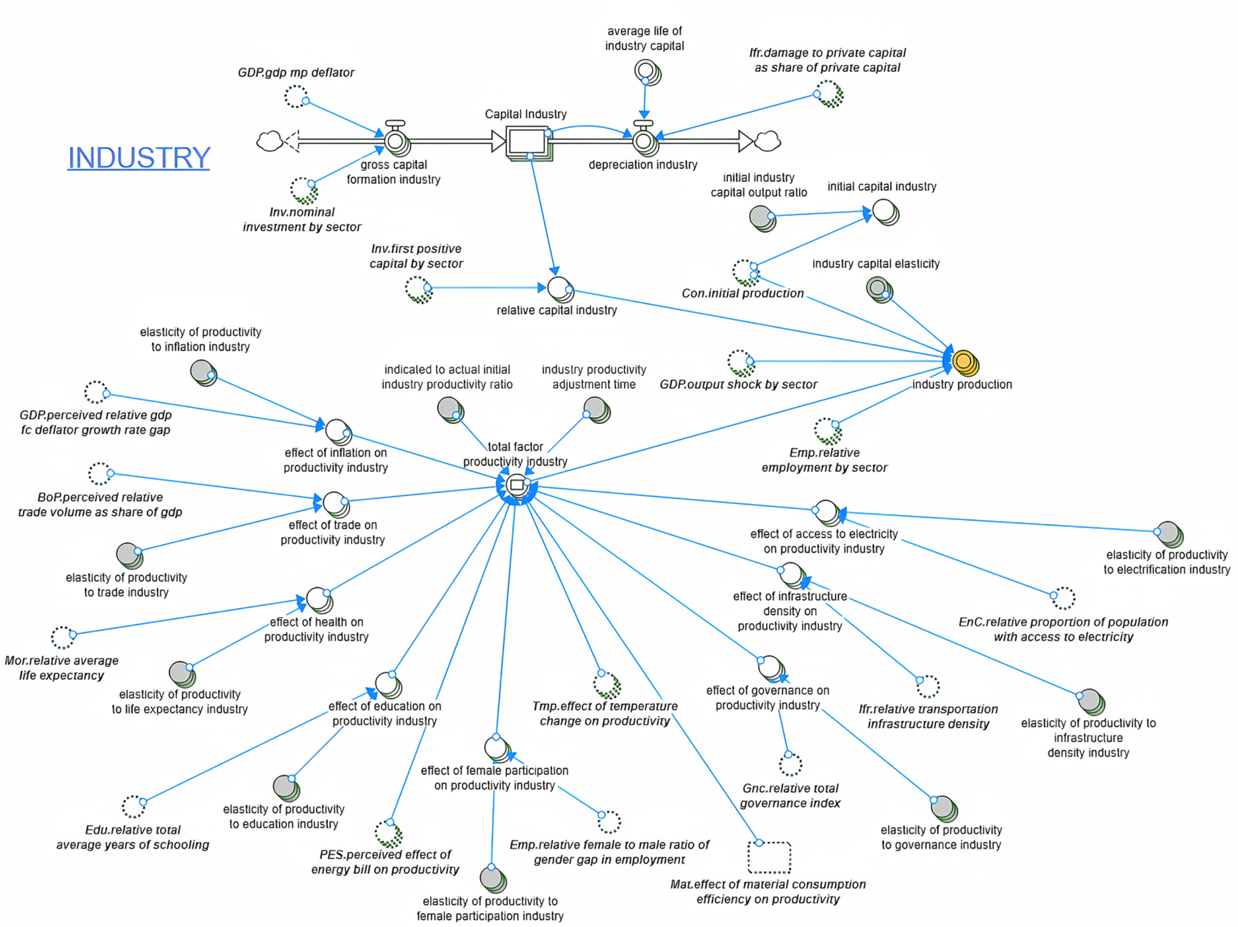
Thus, the simulation of the iSDG model is done through Stock-Flow Diagrams (SFD). These diagrams relate so-called stock variables (accumulating of resources and information) to so-called flow variables (reflecting the speed and direction of change in stock levels over time) via feedback loops that are cause-and-effect connections. The dynamic at which flow and stock variables change in the system (Meadows, 2008) 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 8**).



Source: Millennium Institute (MI).

Figure 8. GDP sector of the iSDG model.

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 9).



Source: Millennium Institute (MI).

Figure 9. Industry sector in the iSDG model.

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:

$$
\begin{aligned}
& gdp\ \ fc\ deflator(t) \\
& = gdp\ \ fc\ deflator(t-dt)+\int_a^b gdp\ \ fc\ deflator\ net\ \ flow(t)*dt
\end{aligned}
$$
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, $\zeta_t = \zeta_{t-1} + \int_a^b \left(\zeta_{year\ start} * \sigma_{year\ start}\right)(t) * dt$

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

Or

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

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

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

$D_{i_{year\ start}}$ is the deflator year start by sector and θ_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:

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

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

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

$D_{it} = \psi_{it} * \zeta_t / \sum_1^{15}\left(\psi_{it} * \Theta[sector_i]\right)$, 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

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

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

$$\begin{aligned} &gross\ national\ income_t \\ &= real\ gdp\ mp_t + private\ \ factor\ income_t / gdp\ mp\ deflator_t \\ &\quad + public\ \ factor\ income_t / gdp\ mp\ deflator_t \end{aligned}$$

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

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

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

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

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

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

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

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

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

$$\begin{aligned} total\ agriculture\ \ production_t &= production\ by\ sector\left[agriculture\right]_t \\ &= \sum_1^5 agriculture\ \ production\left[agr_i\right]_t \end{aligned}$$

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

$$\begin{aligned} total\ industry\ \ production_t &= production\ by\ sector\left[industry\right]_t \\ &= \sum_1^5 industry\ \ production\left[ind_i\right]_t \end{aligned}$$

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

$$\begin{aligned} total\ services\ \ production_t &= production\ by\ sector\left[services\right]_t \\ &= \sum_{i=1}^5 services\ \ production\left[ser_i\right]_t \end{aligned}$$

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

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

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

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

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

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

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

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

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

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

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

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

Or

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

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

By replacing the real GDP fc by its value,

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

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

$\bar{y}_{mp_t} = \sum_{i=1}^{5}\left(AP\left[agr_i\right]_t + IP\left[ind_i\right]_t + SP\left[ser_i\right]_t\right) * \left(1 + \alpha_t\right)$ with α is the indirect taxes minus subsidies as share of GDP

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

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

by replacing GDP mp deflator by its expression, we have:

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

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

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

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

$$real\ \ value\ \ added\ \ fc\ \ growth\ \ rate_t$$
$$= TREND(real\ \ gdp\ \ fc_t, growth\ rate\ time\ horizon, initial\ \ gdp\ \ fc\ \ growth\ rate)$$

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

$$real\ \ value\ \ added\ \ mp\ \ growth\ \ rate_t$$
$$= TREND(real\ \ gdp\ \ mp_t, growth\ rate\ time\ horizon, initial\ \ gdp\ \ mp\ \ growth\ rate)$$

$\upsilon_{mp_t} = TREND\left(\bar{y}_{mp_t} = \sum_{i=1}^{5} \left(AP[agr_i]_t + IP[ind_i]_t + SP[ser_i]_t \right), \mu = 1, \varsigma \right)$, where ς the initial GDP mp growth rate (Table 4).

Table 4. iSDG model applications.

Country	Application goal	Results
Dynamics analysis of Sustainable Development Goals: Achieving the SDGs with Uganda's Third National Development Plan, (National Planning Authority, 2020) https://www.zotero.org/google-docs/?WhJpyA	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 (Abson et al., 2017). 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.

Continued

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 spending, taxation, and other additional policies.	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.

Source: the authors.

5. Benchmarking of Dynamic Models (Table 5)

Table 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 scenario and when a couple of policies are implemented.	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 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.	The model uses an SD approach that distinguishes stock variables and flows 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 of time. They accumulate during the time. While, flow variables are quantities which are measured with reference to a period of time.
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 modelize the three domains of development.	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 Growth Model of the WB	The LTGM doesn't 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.	The LTGM uses a linear approach which does not allow to show cause and effect loops and to present the feedback loop principles.	The LTGM allows to analysis the sustainability of 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 pre filled by country but does not help to implement a scenario of policies that concern social and environmental areas.	According to the nature of the variables, there is no difference between accumulated variables with a delay and flows 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.

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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 macroeconomic 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 modelling and the UN 2030 Agenda policies simulation.	It uses econometric methods that are linear approaches to calculate the parameters and variables values at the steady state. Contrary to System 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.	It is entitled firstly to reproduce historical movements of Reference Business Cycles (RBC) and secondly, predict the steady state of macroeconomic aggregates for medium and long runs. For these reasons, the DSGE is a predictive model allowing us to determine the trends of economic variables.	The use of stock and flow variables is not appropriate to econometric methods. So, the DSGE model doesn't distinguish stock and flow variables during regressions and policies effets assessing. Or the distinction between flow and stock variables are 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.

6. 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 are able to include Sustainable Development Goals indicators in their structure because measuring countries' development progressing 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.

Conflicts of Interest

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

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