

# **The role of System Dynamics modelling to understand food chain complexity and address challenges for sustainability policies**

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## Abstract

In the current debate, policy makers, scientists and the non-academic community worldwide face the urgent challenge to implement a sustainability roadmap (i) to assure access to food to a growing, more urbanized and unequal population without overcoming the Planetary Boundaries, and (ii) to build resilience to climate change. Climate smart agriculture could provide a relevant contribution to meet such goals but need to be supported by a change in risk behaviour and by long term investment plans, which often go beyond the short term policy focus. The current sectorial models used to analyse the global food system are not able by construction to represent the complexity, non-linearity and time-dependent nature of the issues at stake, and their scenarios results are not fully accessible by non-academic stakeholders. In this paper, we show how System Dynamics models (SD) could provide a useful alternative to neoclassical, general equilibrium based models to study the complexity of the food system. By benchmarking the two most important SD models which include agriculture and land dynamics, i.e. World3 and Threshold 21, we provide insights for building a new SD for the food system including the relation between financial capital, investments into eco-innovation and resource resilience.

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## **1. Introduction**

Agriculture can play a key role to assure food security while contribute tackling climate change. Still, given the complexity, multidimensionality and uncertainty which characterize agri-ecosystems, and the interdependencies between actors and sectors which characterize the Climate Smart Agriculture approach (the World Bank, 2011), to assess the impact of the food system on sustainability we cannot rely on the current modelling approaches and tools. The complex general equilibrium neoclassical based models developed in the last decades are not able, by construction, to model the dynamics of a complex system characterized by non-linearity, multiple feedbacks, time delays, non-rational, short term thinking and free riders agents. Most important, their findings are not easy to communicate to the broad non-academic audience of decision makers.

This paper aims at filling in this gap by explaining how System Dynamics models (SD), which belong to the family of computational and simulation models, could help overcoming several limitations of neoclassical based sectorial models, and better communicating non-academic stakeholders and policy makers the key challenges for sustainable and inclusive development which characterize the relation between the food system and the dimensions of the global system.

In section two, we identify and analyse the changing characteristics of the food system in its sector specificity and in the interdependencies with the global sustainability challenges introducing the Climate Smart Agriculture approach (CSA). In section three we analyse the most used sectorial models for agriculture, explaining why they cannot properly display the challenges of the food system towards sustainability. Section four introduces the concept and characteristics of the SD approach and provides a comparison between the two most relevant examples of SD models, i.e., the World3 model by the Limits to Growth (1972), and Threshold 21 by Millennium Institute (2007). The final section provides insights on the further development of SD as a tool to improve modelling of food system complexity and better support decision making for targeted policy recommendations.

## **2. Assuring food security under risk of climate change: the issues at stake**

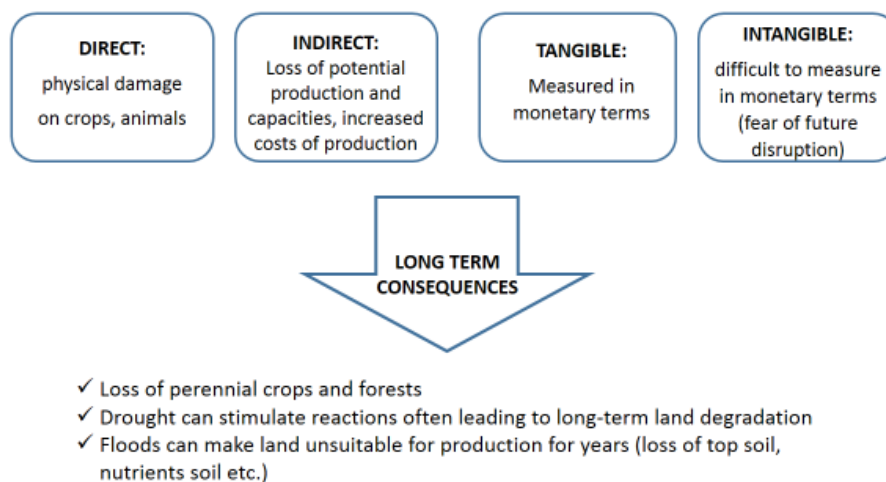
At the global level resources which are limited but fundamental for human activities (e.g., fossil fuels, water, land) are being depleted at a faster pace than the planet can replace (UNEP Annual Report, 2011; FAO State of Food Insecurity, 2012). Human activities are damaging ecosystems (WWF, 2014), causing an irreversible loss of biodiversity and worsening climate change (IPCC, 2013). In turn, growing evidence points out that the damaging impact of climate change on socio-economic development may reverse years of progress in fighting poverty and vulnerability (the World Bank, 2012). The last decade was characterized by more frequent and disruptive weather events and increased uncertainty over energy security and significant volatility in food prices which fuelled the risk of civil unrest and political instability. These issues have significant implications for global and local development, especially in a growing and warming planet (IPCC - the World Bank, 2012). Alarming forecasts evidence that increasing population (expected to rise to 9.6 billion in 2050 driven by higher fertility, rapid increase in life expectancy at birth in Sub Saharan Africa and India), urbanization (almost 70 percent by 2050) and

social changes (1.2 billion people joining the middle class in emerging economies) will exacerbate environmental pressure without a change in global policy towards resilience. Thus, meeting the sustainable development challenge of the Post-2015 Agenda means assuring timely access to key resources such as food, in a more unstable world. The last food commodity crisis which started in 2007 showed that food is deeply linked to other important but constrained resources such as water and energy. In fact, challenges to what we can define the food-water-energy nexus are interdependent: a shock on a single resource may have a cascading effect on the others, and define overall negative impacts on the human/environmental system.

Increasing difficulty to access key resources like food has several and multidimensional consequences such as uncertainty with regards to future economic growth, spread of systemic risks in highly indebted (and highly resource-intensive, i.e., countries consuming a lot of biophysical resources per capita and year) countries, volatility of commodity prices, increasing inequality and worsening living conditions and food security in vulnerable regions (the World Bank, 2012), and international political instability (e.g., the Arab Spring, see Lagi et al., 2011; Nomura, 2012).

Agriculture, Forestry, and Land Use (AFOLU) play a key role for meeting the environmental, economic and social dimensions of the Sustainable Development Goals (Contò et al., 2014), providing livelihood support for 40 percent of global population and 70 percent of rural poor in Least Developed Countries (LDC) (IAASTD, 2009). Moreover, agriculture provides a key contribution to poverty reduction with GDP growth originating in agriculture being two times more effective in reducing poverty than GDP growth outside agriculture (the World Bank, 2008). Agriculture displays a complex linkage with climate change. It contributes to one-third of global Greenhouse Gases emissions (GHG) (UNFCCC, 2009) but it is also negatively impacted by climate change, which has direct and indirect, tangible and intangible effects and long term consequences, as highlighted in Figure 1.

Figure 1 Impact of climate change on agriculture.



Source: adaptation from Contò et al., 2014.

An answer to the complex relation between agriculture, food security policy and climate was recently provided by the CSA, based on sustainable agricultural intensification for food security and resource resilience, by adopting mitigation and adaptation measures to curb GHG emissions linked to agriculture, waste and pollution.

### **3. Review of agricultural models**

During the years, in order to provide a more comprehensive representation of the food system, new models rooted on neoclassical theory assumptions were developed. Alongside with the number of models, the complexity of the methodological framework proposed increased. This is the case of widespread used Computational General Equilibrium Models (CGEs) which are often built on the construction of Social Accounting Matrices (SAM) used to estimate the interdependencies between actors. General and partial equilibrium models are built around the neoclassical concept of equilibrium, i.e., an economy is supposed to grow at its potential path unless it is disturbed, assuming linear growth and exogenously-driven changes in average behaviour. They use equations that specify supply and demand behaviours to simulate different markets, and the markets are brought to equilibrium by solving the model usually for a set of prices. They have some desirable characteristics. In particular, they can:

- Simplify the understanding of how our economies work/may work under ideal conditions;
- Model the elasticity of sectors and aggregates' response to a change in the explicative variables;
- Isolate the role of a model variable on the outcome, controlling for the influence of other determinants;
- Estimate the magnitude of the error term, i.e., what cannot be explained by the model in the analysed relation;

Provide policy scenarios in the medium to long term, given the model assumptions. At the same time, such approach presents relevant limitations which may reduce the representativeness of results because model results are sensitive to (i) the structure and specification of the model, (ii) the calibration of the parameters, (iii) the baseline year selected for the calibration, and (iv) the quality of data used for that baseline year.

A main example of such models is the Common Agricultural Policy Regionalized Impact (CAPRI) model, developed by a network of European research teams with the support of the European Commission. It is used for policy impact assessment of the Common Agricultural Policy on production, income, markets, trade, and the environment, downscaling from the global to the regional level, with a focus on the EU trade market. CAPRI is based on (i) Regionalized CGEs at NUTS 2 level for each European Country, (ii) a supply module covering about 280 regions, and up to ten farm types for each region, and (iii) a market module represented by a global multi-commodity model for agricultural products featuring 47 products (Britz and Witzke, 2014). The model depicts agricultural commodity markets and policies (administrative prices/tariffs/preferential agreements), premium systems/quotas/set-

aside at regional level, environmental policies (standards/market solutions) accounting for changes in exogenous drivers (e.g., consumption behaviour and technical progress). The linkages are disclosed using a SAM based on Economic Accounts of Agriculture (whose main data sources are Eurostat and FAOSTAT) to account for the exchanges between economic actors at the regional level. Then, SAM results are collapsed into regional CGEs.

An alternative to CAPRI is represented by FAPRI developed at Iowa State University and the University of Missouri (USA), and applied to the UK by Agri-Food & Biosciences Institute & Queen’s University Belfast (2011). The model aims at providing comparisons of alternative policies for the evaluation of alternative agricultural policy scenarios. FAPRI is composed by commodity sub-models combined into model of country agriculture. It is a dynamic, partial equilibrium model which:

- Focuses on the agricultural sector but includes interaction with the rest of the economy (other sectors/markets);
- Is characterized by an iterative equilibrating process which continues until all product markets are in equilibrium;
- Catches the dynamic interrelationships among variables affecting demand/supply in the main agricultural sub-sectors;
- Is composed by a system of equations developed for crops and livestock based on external information on supply/demand (products, inputs).

It includes 20 commodities, covering dairy, beef, sheep, pigs, poultry, wheat, barley, oats, rapeseed and biofuel. Single sub-models are developed for single commodities, and commodity production can be regionalized and the estimated coefficients adjusted. It accounts for trade, either within the European Union (EU) (common market for food/off food products) and the rest of the World (including EU trade commitments, export subsidies, tariffs). Being the goal the optimisation of net farm income, the model provides projections to determine income maximizing optimal farm plans for the representative farm, thus limiting the ability to shape structural and spatial farm heterogeneity and their changes as result of policy incentives. Baseline and scenario projections of agricultural activities are up to a ten year horizon and are used as a benchmark for comparison and interpretation of projections from alternative policy scenarios, which could be either externally defined (policy targets) or internally defined (endogenous prices).The characteristics of CAPRI and FAPRI are compared in Table 1.

Table 1 A comparison of the main characteristics of CAPRI and FAPRI

	CAPRI	FAPRI
Model type	CGEM + SAM	System of equations
Time	Comparative-Static	Comparative-Static
Unit of analysis	Farm type level (representative farm)	Macro-Regional / country level
Representativeness level	Sectorial	Sectorial

Product coverage	Crops and Livestock	Main arable crops and animal productions
Introduction of new activities and new technologies	Yes but very difficult	Indirect (from change in technical coefficients of estimated parameters, literature review or stakeholders consultation)
Structural change	No	No
Allocation of variables inputs across activities	Yes	Yes
Technological progress	Yes but complex (data and assumptions)	Yes but complex (data and assumptions)
Changes in management practices	Yes	No
Public goods and externalities	Yes	Yes
Interaction with the rest of the economy	Yes	Yes
Price support / Taxation (land or inputs)	Yes	Yes
Quota	Yes	Yes
Model output	Income effect (revenue, variable cost per crop); land allocation (cropping decision); output supply;	Income effect (revenue, variable cost per crop); land allocation (cropping decision); output supply;
Integration with other models	Yes exploiting GAMS statistical package	Yes exploiting GAMS statistical package
GHG emissions	Yes but very difficult	Indirect, from change in projections of agricultural activities (e.g., decline in animals number, decrease in fertilizers use)
Forecast estimation (scenario)	Long term	10 years

Source: own elaborations.

#### 4. System Dynamics models: theory and main applications

The models discussed in section three are not able by construction to represent the dynamics of a complex system characterized by non-linearity, causal feedbacks, time delays, non-rational elements and policy path dependency which characterize sustainable development. Most important, their findings are not easy to communicate to the broad non-academic audience of stakeholders.

In order to address such limitations, in the last two decades new models were developed (i.e., the Agent Based Models) or readapted (i.e., System Dynamics). We will focus here on system dynamics, which were applied to different sectors such as global dynamics (World3 by The Club of Rome; Threshold 21 by the Millennium Institute), energy (Sterman, 1982; Sterman et al., 2012), business (Forrester, 1973; Sterman, 2000), economics (Yamaguchi, 2013), and product-service sustainable business model (Tonelli et al., 2013).

SD is a modelling technique rooted on dynamic systems and control theory, which was first developed by Forrester (1961) who applied it to business solutions. It is used to model complex and non-linear socio-economic systems thanks to peculiar characteristics, in particular:

- Top-down (deductive) approach, i.e., modeling a system by breaking it into its major components and modeling the component interactions (Scholl, 2001);
- Focus on the macro-behaviour, i.e., the representation of the model structures (e.g., relationships, policies, incentives) that underlie behavior of systems through stocks and flows (Sterman, 2000);
- Interactions of state variables and parameters which produce feedback loops explaining fully define the system in the continuous by units of time steps (Macal, 2010);
- Non-linear properties of causal links among system components which produce emergent system-level counterintuitive behaviour (Forrester, 1971; Sterman, 2000).

The latter property is perhaps the most interesting because it allows us to identify the causal effects and map their impact on the system stocks and flows through time.

SD models are based on a set of discrete difference equations, i.e., differential equations with a fixed time step because that are recursively solved, where the current state of a variable depends on the previous system state. Through these equations, it is possible to describe, analyze and simulate the macro-level behavior of complex adaptive systems.

According to Sterman (2000), SD can be defined as a set of stocks (variables) which changes through the flows which characterize them (derivatives). Stocks can be discrete quantities representing homogeneous groups of well mixed elements. Flows represent the movement of agents between homogenous groups. In this way, stocks offer an aggregate representation of the system components. Stocks are connected by in and out flows, which return the mean rate at which elements of the SD change state.

At the same time, SD show some drawbacks which are still not easily overcome. First of all is the assumptions of well-mixed elements and homogeneous groups in which the population is grouped. It may be possible to specify better the complex system, dividing it into subgroups (e.g., according to geography, level of income) at the expenses of increasing the complexity of the system of equations, and the data requirement. Then, SD models could improve their role for policy simulation and forecasting by introducing statistical tool for behavioural model validation which would allow modellers to make sensitivity tests on the model parameters in the resulting scenarios. In fact, despite SD are mainly used for their explanatory power, in the last decade modellers started to explore the predictive power of SD, considering prediction the aim of every economic model.

#### **4.1 Key differences between SD and neoclassical based macro-econometric models**

Belonging to the family of simulation models, i.e., models that mimic the behaviour of the system they try to reproduce in its functional relationships, SD is very different from econometric or fully analytical models, which aim at approximating the reality to an

average form which answers some assumptions posed by the modellers, in order to reach the desired result.

SD is developed around the real characteristics of the phenomenon it aims to reproduce and simulate, limiting the use of assumptions. In this way, the SD approach is able to:

- Model non-linear events (continuous or discrete) addressed in their multidimensionality thanks to the ability to singularly shape heterogeneous system elements;
- Display the impact of indirect effects on the components of the model;
- Shape the causal relations among the system elements according to their governing feedback loops;
- Represent the role of the side effects into the system and show the pace, intensity of feedback loops and their determinants;
- Internalize the externalities linked to specific actors' behaviour and show how they affect the different elements of system, eventually displaying cascade effects;
- Represent as endogenous variables and sectors which are taken as exogenous by neoclassical models (e.g., prices, the financial sector and the environment);
- Model the unintended effects of the introduction of new policy measures, such as the rebound effect and policy path dependency;
- Provide timely and clear information to policy makers because SD simulations return robust results even in the short term, and scenarios are rather descriptive and intuitive as regards the causal relations.

Thanks to these desirable characteristics, SD provides an interesting platform for the development of models which are able to understand and explain the complexity of the food system and the causal and temporal results of the interactions among the different dimensions which affect it. Therefore, SD could support policy and decision makers during the planning and implementation of food security measures by providing them *what if* scenarios of the introduction of alternative policies in the food system, the drop down effects on the other dimensions of development, and eventually display their unintended effects.

#### **4.2 A comparison between World3 and Threshold 21 models**

World3 is a System Dynamics model published in *The Limits to Growth* in 1972, and updated in 1991 and 2004 (Meadows et.al. 1972, Meadows et.al. 1992, Meadows et al. 2004). It is aimed at showing how human society could reach the planetary limits in the 21<sup>st</sup> century. The complex set of relations and feedback loops involved in World3 is built around the dynamics of population and capital growth (including industrial, agricultural and service capital), and the dynamics of use of natural resources such as non-renewable resources (material and energy resources), total arable land, land fertility and persistent pollution (which shows how human activity leads to harmful quantity of pollutants to accumulate in the environment).



World3 models food production as endogenously generated from the feedback loops of a complex system which includes economic activities, which are divided into agriculture, industry and services, environment and population dynamics.

With a time horizon from 1900 to 2100, World3 shows how economic growth would peak before the year 2100 given one the three limits identified:

- Non-renewable resources availability;
- Persistent Pollution level;
- Arable Land erosion.

Figure 2 shows the main linkages of the food sector with the rest of the World3 variables. Food production is based on the availability of two natural resources: (i) arable land, which represents the total amount of cultivable land available measured in hectares needed to produce food, and (ii) land fertility, which is an aggregate measure of the base yield capacity of every hectare of land available.

The effect of technology improvements is considered to impact positively food production by increasing it while the loss of production capacity counteracts to decrease it. The resulting food availability is one of the drivers of the increase in population's life expectancy but at the same time it generates a negative feedback loop which erodes the arable land available.

Within this set of relations, the model shows how agriculture contributes to two important negative feedback loops, which in turn represent a limit to growth of capital and population within the model:

- Capital increase in the agricultural sector determines both increases in arable land and food production which in turn add on pollution, thus inducing decreases in land fertility and, eventually, in food production;
- The more arable land is available, the more the food production. However, the more food production, the more arable land erosion.

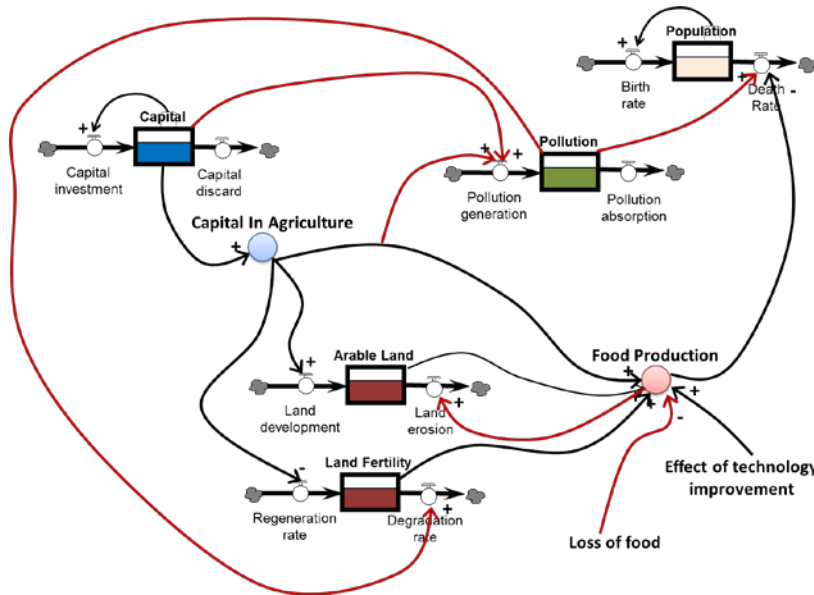
World3 model assumes that the expected economic growth would follow the typical path – from agricultural to industrial to services based economy. Whenever economic output per capita decreases (i.e., people become poorer) human society would allocate more industrial capital on the agricultural sector (food production) than in services.

The dynamics of population and food production are closely linked:

- Population increases at a different rate from food production, which is thus not able to cover population needs;
- Above certain limits, pollution would cause land fertility to fall thus limiting food production;
- The higher food demand, the higher land allocation to food production (arable land). When the limit of land conversion into arable land is reached, land erosion is the main factor negatively affecting food production (the less arable land, the less food production). Therefore, arable land represents a key limit to growth.

In World3, to counteract the effect of resource scarcity in relation to population the society would invest more in the agriculture sector, rather than being focused on other sources of output of the economy.

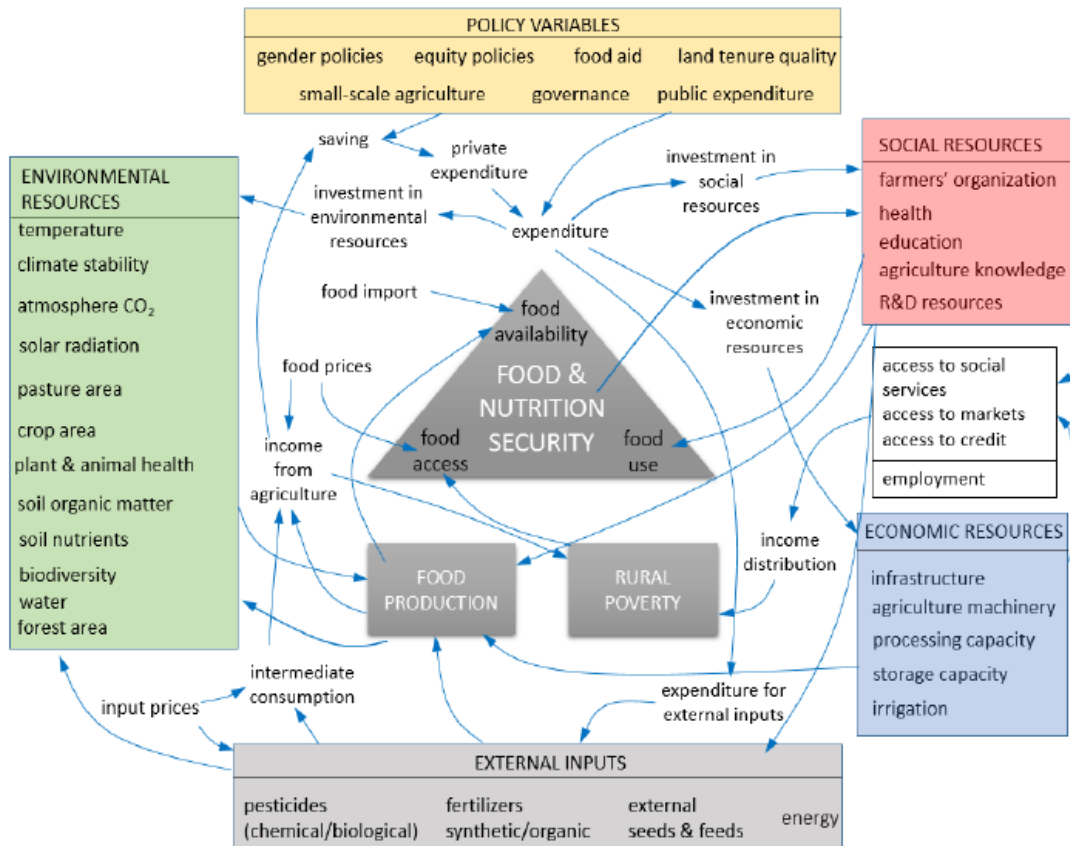
Figure 2 Representation of World3 Stock and Flow diagram for the agricultural sector



Source: own elaborations

The Threshold 21 model, instead, aims at supporting national development strategic policy planning preparing Poverty Reduction Strategies that emphasize the Millennium Development Goals (MDG), and for monitoring progress towards the MDG or other national goals at the country level. The innovativeness of the model is represented by the participatory approach to modelling, the capacity building orientation and the attempt to depict the meaningful relations of a country system. Inspired by World3 (Barney, 2002), Threshold 21 was built upon the reviews and evaluation of several among the forecasting models available, including the World Bank’s revised Minimum Standard Model-Extended (Millennium Institute, 2007). The level of model aggregation is defined to allow the simulation of resource allocation problems, and to complement budgetary models and other medium-long term planning tools by providing a comprehensive and long term perspective on country development. The time frame considered in Threshold 21 simulations is about 50 years. The model is centred on the present time and provides a 25 years forecast.

Figure 3 Threshold 21 Agriculture Structure



Source: Millennium Institute

Figure 3 shows the highly aggregate functioning and aspects of the Threshold 21 Agriculture model applied to the Kenya case study. It shows an agricultural economy based on three main pillars - food nutrition and security (composed by food availability, food access, food use), food production and rural poverty - which are modelled endogenously in the other dimensions (environmental resources, policy variables, social resources, economic resources, external inputs). Threshold 21 is targeted to low income countries and was also applied in Senegal, Ethiopia, and Swaziland. In these countries, high fertility rates - in comparison to the replacement rate of 2.1 children per woman - contribute to population growth, and agriculture still represents the main source of subsistence for the rural poor, as key income source able to avoid the fall of consistent parts of the population below the poverty line (the World Bank, 2008). This happens at the expenses of ecosystems because the available agricultural practices deplete natural resources which are limited (e.g., soil, water and forests). By using material inputs such as pesticides and fertilizers, the agricultural sector may increase the productivity of the lands, but at the same time it degrades environmental resources (soil and forests in particular) which determine a decrease in agricultural production in the long term. In the same way, the social sector components (education, health, R&D) are modelled looking at a more resilient use of land (for example farmers training could allow the introduction of low input agricultural practices). The model shows the contribution of agricultural support policies such as government subsidies and investments, both modelled as external factors, to development being drivers of the system towards economic growth.

Food and nutrition security stand in the middle of the causal loop diagram reflecting the importance and immediate effect of their change on the other dimensions (in particular, by influencing population's health). Food availability is the result of the country internal food production, food import, food aid and the initial stock of food. Access to food is a function of food prices, which are exogenously generated, and rural poverty, which affects rural households' ability to access food. Income distribution depends on several other soft variables including access to social services, access to markets, access to credit, which are the results of the interplay occurring among the different sub-dimensions in the economic sphere. Instead, food production depends on economic (physical capital, labour), social (education, health), and environmental resources (water availability, temperature, solar radiation, and soil nutrients) and external inputs (pesticides, fertilizers).

The main advantages of the model are (i) the ability to show the complex interdependencies between the food sector and the socio-economic-environmental dimensions, and (ii) the accessibility of model results to policy makers and non-academics.

### 4.3 Limitations of World3 and Threshold 21

Both models have advantages and limitations. World3 was built in few years by a group of modellers, and its results were continuously published through the years to raise awareness about a global issue to the great public. This makes the model simple in nature but still able to capture fundamental insights on the dynamics of real output growth within a finite planet. The current Threshold 21 version is the result of 30 years of continuous development and application which makes it able to represent the dynamics of a single economy. In order to reach such goal, client's engagement and interaction with the modellers is fundamental and involves long term commitment to assure the model outcomes correctly represent national development needs. A comparison of advantages and limitations of both models is provided in Table 2.

Table 2 – Key Advantage and limitation of World3 and Threshold 21

	World3	Threshold 21
Advantages	<ul style="list-style-type: none"> <li>- Provides simple but consistent structure resources allocation (capital and natural) among different sectors to depict the human-environment system.</li> <li>- Shows basic structure of land development and erosion, farmers' allocation decision in terms of capital resources to increase land yield and profitability.</li> </ul>	<ul style="list-style-type: none"> <li>- Shows the results of medium to long term policies and compare alternative policy.</li> <li>- Integrates quantitatively different aspects of national economies - economic, social and environmental spheres - linking natural and physical dynamics with social/policy variables.</li> <li>- Shows the effect of a policy simultaneously on different sectors returning quantitative scenarios.</li> <li>- Accounts for commodity prices (food, energy goods), allowing disaggregation according to different products.</li> </ul>
Limits	<ul style="list-style-type: none"> <li>- Doesn't include any financial aspect nor social</li> </ul>	<ul style="list-style-type: none"> <li>- Too complex to be used by non-specifically trained modellers.</li> </ul>

	<p>and economic variables (e.g., resources prices) thus limiting the potential for support to policy makers.</p> <ul style="list-style-type: none"> <li>- Very long term focus thus not flexible to assess specific policies effects.</li> <li>- Very general level of aggregation of key variables to support policy recommendations (see pollution, land fertility).</li> <li>- Technology is only indirectly represented as a tool able to decrease the negative impact of human activities on planetary limits (not based on quantitative data).</li> </ul>	<ul style="list-style-type: none"> <li>- Requires time and efforts from both government and consultants to be targeted to country needs.</li> <li>- The introduction of the financial sector and its relation to technology (intended as eco-innovation) and governance would add value to the model to better understand the interactions between climate mitigation and adaptation policies and the food system.</li> <li>- Potential role of showing the relation between different agricultural production practices with climate change by dividing the land sector in food/off food production, because the trade-off in allocation of limited arable land represents a constraint for food production, but also an income development and diversification opportunity for farmers, according to the evolution of relative food/off food commodity prices.</li> </ul>
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## 5. Conclusions

The policy solutions for food security which will be developed within the Post-2015 agenda to support sustainable and inclusive development will be crucial to shape the near future of our society. Most important, they will bring both short term effects and long term impacts at the global and local level, which are not easy to forecast given the complexity, uncertainty and risk linked to path-dependency and time delays which characterize the multidimensional nature of the food system. Therefore, in order to be timely, targeted and effective, policy measures for food security need to be supported by *what if* simulation analyses displaying different policy scenarios. The currently most used models for food systems analysis are limited in describing and forecasting food system shocks and the impact of a changing climate, also due to the limitations in data quality and availability in key dimensions (e.g., waste, processing emissions, and technology). Therefore, in this paper we show how a SD approach could better represent and analyse the characteristics of the food system accounting for the drivers of complexity, risk and uncertainty which characterize food security policies. We compared two most relevant SD models for sustainability, World3 and Threshold 21, and it emerged that they allow modellers and users:

- To develop a clear analysis of the agricultural system and its linkages with the socio-economic dynamics (in particular, the role of capital);
- To understand leverage points and the constraints they generate in the agricultural system, such as arable land availability, arable land erosion, decrease of land fertility due to pesticides and fertilizers use;

- To simulate how changes in farmers' behaviour may affect leverage points in order to maintain the system as productive as possible;
- To analyse the trade-off between agricultural productivity induced by capital investments and environmental depletion, showing how capital intensive agriculture processes, which may determine higher levels of food production, generate more pollutants which negatively affect the properties of the land system, thus limiting future arable land potential for food production.

At the same time, both World3 and Threshold 21 are characterized by several drawbacks which may limit their ability to support policy and decision makers. Thus, we moved from the identification of these limitations to develop the next step of our analysis, which consists of the introduction of a new SD model of the food system which includes:

- A financial dimension, which provides capital investments in green technology for the agricultural sector;
- A governance dimension, which provides different forms of public support (green fiscal policies and subsidies) to increase the resilience of the food system.

## 6. List of acronyms

AFOLU: Agriculture, Forestry, and Land Use  
 CAPRI: Common Agricultural Policy Regionalized Impact  
 CGEs: Computational General Equilibrium Models  
 CSA: Climate Smart Agriculture  
 EU: European Union  
 FAPRI: Food and Agricultural Policy Research Institute  
 GDP: Gross Domestic Product  
 GHG: Greenhouse Gases emissions  
 LDC: Least Developed Countries  
 MDG: Millennium Development Goals  
 SAM: Social Accounting Matrices  
 SD: System Dynamics.

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