Analyzing Food Supply and Distribution Systems using complex systems methodologies

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Abstract

This paper discusses how a complex-systems perspective can shed light on the analysis of complex food-systems meeting urban food needs. The common features between complex systems and Food Supply and Distribution Systems (FSDS) are explored. A brief review of the major approaches - agent-based models (ABM), social network analysis (SNA), and system dynamics (SD) - is developed in order to make an assessment on the analysis performance of different complex system methodologies while dealing with FSDS. After sifting out the most suitable methodology for the study of FSDS, a system archetype analysis of the FSDS dynamics is elicited from the methodological guide of FAO, the United Nations Food and Agriculture Organization. To finalize, three basic points for the analysis of FSDS obtained from the current research are explained. This content is part of the content leading the SD updates to FAO's FSDS methodological guide.

Keywords:
System Dynamics, Agent-Based Modeling, Social Network Analysis, rural and urban dynamics

1 Introduction

The rapid growth of urban populations, and related food demands, in developing countries and those in transition, has a strong impact on the extent to which good quality and safe food can be made available to urban households.

Urbanization affects urban food security in terms of competition between demand for housing and agricultural production, traffic congestion and pollution, changes in consumption behavior and habits, as well as food accessibility difficulties for low-income urban households. Effective, concerted and sustainable interventions, framed within local policy, strategy and planning perspectives, are required to increase the efficiency, dynamism, inclusiveness and sustainability of food supply and distribution systems (Aragrande and Argenti, 2001).

This paper discusses how complex-systems dynamics perspective can shed light on the analysis of complex food-systems meeting urban food needs, and contribute to the understanding of the formulation of development policies, strategies and investments plans. In the first section, the characteristics of food-systems are presented. In the second section, the key features of complex systems suggesting some relation with food-systems analysis will be discussed. In the third section, a brief review of the major approaches useful in understanding complex food systems are discussed: agent-based models, social network analysis and system dynamics. The fourth section discusses applications of system dynamics principles to the analysis of food systems. Finally, the contribution of current and future research to the review and update of the FSDS analytical framework developed by FAO, the United Nations Food and Agriculture Organization, following the System Dynamics approach proposed in this paper, will be discussed.

2 Food supply and Distribution Systems (FSDS) according to FAO

Aragrande and Argenti (2001) define food supply and distribution systems (FSDS) as the "complex combination of activities (production, handling, storage, transport, process, package, wholesale, retail, etc.) operated by dynamic agents, enabling cities to meet their food requirements". It is argued that in order to increase the efficiency and dynamism of FSDS for specific urban areas, an analysis of food systems in their entirety is required, not only to understand their current structure, conduct and performance and main constraints affecting them, but also in order to understand the major present and expected problems, as well as analyze the main constraints of the environment in which players are immersed.

According to the methodology and operational guide of the Food and Agriculture Organization (Aragrande and Argenti, 2001), a food supply and distribution system (FSDS) is principally divided in two main subsystems: food supply to cities, and food distribution inside the urban area. Each subsystem is concerned with different activities that form the overall system:

Food supply to cities: The "food supply" includes all the activities that generally take place outside the urban area: production (including urban agriculture), storage, marketing, processing and transport of food to the urban area (generally to a wholesale market). Some of the main constraints faced by actors in this subsystem are:

1) The scarcity of suitable lands, safe water and pesticides, or the latter's inadequate use, which can contaminate food crops;
2) Difficult evacuation of food crops - mostly by smaller producers - to markets, due to inadequate or non existing rural roads;
3) Inadequate handling, packaging and transport modalities;
4) Lack of cold storage facilities;
5) Unofficial taxation levied by authorities.

Urban food distribution: The "urban food distribution" subsystem consists of the activities required to distribute food within urban areas. They range from wholesale markets, to intra-urban transportation and formal-informal retailing. Some of the main constraints faced by actors in this subsystem are:

1) The capacity of existing wholesale markets in efficiently handling growing food quantities. In many countries, they were constructed in areas that now are densely populated.
2) Growing urban traffic congestion, being exacerbated by increasing lorries and vehicles for food transport;
3) Inadequate retail markets, many of which are often congested and unhealthy places;
4) Limited entrepreneurial mentality of food shops;
5) Higher food contamination risks caused by informal food sector activities.

In the following page, we present an illustration of the main items characterizing a FSDS according to FAO's methodological and operational guide: studying Food Supply and Distribution Systems to cities in developing countries and countries in transition (Figure 1; Argenti and Aragrande, 2001). In this representation, the supply sources are shown as three levels of territorial boundaries – rural, urban and peri-urban. The processes involved before meeting the food demand, which are part of the supply and distribution processes, are characterized by the type of food they belong to fresh, semi processed and processed food. In addition, there is the display of the desired criteria for FSDS and the transversal issues of the system functioning. Although this illustration is a simple representation of the main issues related to FSDS without the use of any complex system methodology or tool, it contains the fundamental information for the analysis of a FSDS.

In the following sections we will make use of FAO's methodological guide in order to understand the characteristics of the FSDS and evaluate how these characteristics can be perceived as examples of some of the complex system properties.

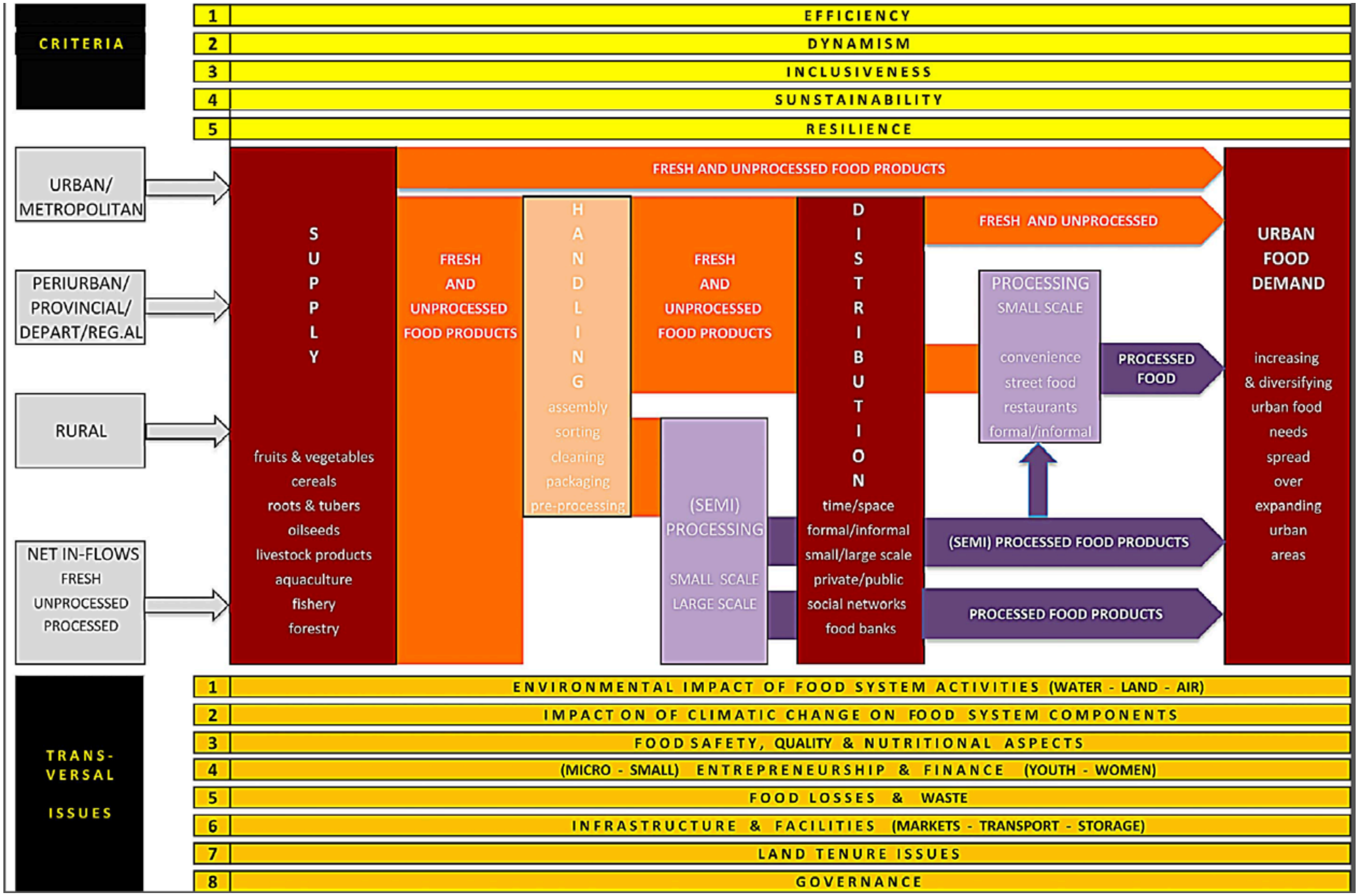

Figure 1: Food Supply and Distribution Systems flows representation based on: Studying Food Supply and Distribution Systems to cities in developing countries and countries in transition. Methodological and operational guide, revisited version (Argenti and Aragrande, 2001).-

3 Food Supply and Distribution Systems (FSDS) as complex systems

In the last 50 years, researchers have developed approaches to manage, simulate and analyze complex systems over time. FSDS present characteristics of complex systems, some of the underling key concepts are:

- **Entirety**: the complex-systems concept of emergence is strictly related to this concept in the way that "to understand the behavior of a complex system we must understand not only the behavior of the parts but how they act together to form the behavior of the whole" (Bar-Yam, 1992). The need of an analysis that takes into account the food system as a whole, rather than on specific chains, is underlined in the methodology of the Food and Agriculture Organization (FAO).

- **Interrelations**: the concept of interrelations is similar to the concept of interdependence. This property entails that a change in a component of a system may affect also other components as well. We can notice, in the food system, that a decision focused only on a specific chain aspect - as poultry, meat, or milk chains - can fail in the attempt to increase efficiency, dynamism, inclusiveness and sustainability of complex food systems given the effect of change of one variable on others due to the set of relations embedded in the system. A successfully intervention has to widen its view by taking into account the food system as a whole and unraveling the influences between variables.

- **Nonlinearity**: refers to an intervention (or effect) that is not proportional to the cause, so that what "happens locally in a system often does not apply in distant regions" (Sterman, 2001). This concept can allow policymakers to be able to foresee and (by using the right tools) also manage the multiple factors interacting in complex food systems.

- **Feedbacks**: when considering the suggestion of policies, strategies, and investment plans it is essential to tackle the consequences of the decisions. The close boundary around the system is from where the dynamic behavior arises, what is called endogenous point of view (Richardson, 1991), characterized by the existence of feedbacks. These feedbacks are the result of modes of variables interactions and show a behavior consequence of certain type of interaction structure. Complex-systems approaches provide unique opportunities to test actions and reactions of different and multiple interventions.

- **Self-organization**; the system structure and functions are result of the interaction between the system components, which does not respond to an external pressure to fundamentally become into the organization form it constitutes (Foerster and Zopf, 1962; Nicolis and Prigogine, 1977). Haken (2006) aggregates this spontaneous structure has a spatial, temporal and functional component. While analyzing FSDS we can observe how the current state of the food systems are not a result of a strict policy or commander that rules what the systems are and determines their behavior but an evolving organizations of agents – business, consumers, producers- interacting under certain conditions – institutional, economic, urban, environmental. Therefore countries and cities posse differentiated types of FSDS with specific characteristics.

- **Counter-intuitive nature**: it refers to the relation between causes and symptoms, which presents a prior analytical problem when dealing with complex dynamic systems. Often, causes are far in time and space from symptoms. Nevertheless, it also often occurs that an apparent cause meets an expected issue, framed as problem or solution, without being strictly the cause but presenting a coincident occurrence given the existence of feedback dynamics of the system (Forrester, 1975). According to Forrester (1971), there are three dangerous counterintuitive behaviors of complex social systems: 1) inherent insensitivity to the major part of policy changes intended to improve the system; given the wrong pre-analytical activity to analyze problem, 2) existence of a limited influence points to change significantly the system, 3) difference, often contradiction, between short-term and long-term effects of a policy change. The rural areas are the engine of the food production, in transition and developing countries the safety and security of the rural areas is a often the main cause that push people to cities both increasing urban food demand of low income communities and reducing the food production in the nearby. From a policy point of view it is not a specific problem of food production and distribution (Molina et al., 2014).

- **Time perspective**: a complex dynamic system is evolving through time, which means the system as a whole and its parts are in constant change. In complex-systems approaches the time perspective is essential because it allows assessing the system elements change individually, in a time step and to assess the transition of a system state to another. Without time perspective, it would not be possible to understand the system behavior and moreover, to address accurately the effects of any intervention. In practical terms, the use of a tool capable of addressing the dynamic component of a system can support the creation of powerful policies to build resilience capacity in the system. Nevertheless, most of the tools traditional used are constructed under a static perspective of the system and phenomena. A time horizon of 10 years was suggested (Aragrande and Argenti, 2001) for FSDS performance scenarios development. In order to increase the FSDS resilience, it is important to create system buffers able to sustain the changes of the world trade. Strong endogenous links among near areas of production and consumption can increase both food security and environment sustainability. Such a policy, for example, can only be constructed by analyzing the dynamic change -or change over time- of the variables determining the changes in the world trade and the system

- **Emergence**: although there is no single definition of emergence, the core point of this underlying concept is the unexpected behavior of a system whose parts have properties completely different from those effectively arising when the system is working (i.e.: water, has the emerging property of being wet, which hydrogen and oxygen, gases, do not possess). In very general terms, this can result in 1) the insufficiency of the theories or arguments explaining the structure-pattern relation of an organization after its conceptualization what signals the need of using higher or lower level of causality explaining that system (Casti, 1986); 2) a phenomenological property related with evolutional theory of complex systems. The emergent property arises from different system levels, interacting among them under changing conditions, and where the unexpected behavior cannot be attributable to any specific inner component of the system (Holland, 1995; Bar Yam, 1992). Regarding this second point, lately methodologies as Cellular Automata or Agent Based Modeling provide tools for approaching this property by *intrinsic computation*[1]. In the context of the analysis of FSDS, emergence would be considered as a property the system is presenting which is the result of a spontaneous change in structure, functions or dynamics upon particular conditions meeting in a specific period of time. In the study of FSDS, examples of this could be considered: 1) the constitution of very specific informal markets such as markets of medical products or 2) endogenous change in diet before the lack or over availability of certain product.

- **Adaptation**: often related to the emergence property and to the concept of dynamism (Aragrande and Argenti, 2001). A system has the capability to change decision rules and learn from experience. This characteristic allows the achievement of new goals and objectives not always related to benefits both in short and long term. This concept allows policy makers to be confident with intervention that can evolve in better ways or worsen the problems. Food markets usually born in specific places following the exigencies of buy and sell food according to

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[1] Refers to how historical and spatial information is stored, structured, and transformed by dynamical systems (Feldman et al., 2008)

the changes in number and habitus of the people in nearby, they can born as informal markets and then endogenously evolve into formal markets regulated by local laws and conventions until reach the adaptive equilibrium (Aragrande and Argenti, 2001). Another example of this property is the FSDS capacity to adapt to a new equilibrium after a shock or crisis in the system such as an emergency situation as wars, flooding or epidemics.

- **Hierarchical organization:** in complex systems different levels of organizations can be found. These levels constitute a hierarchy of levels and sub levels with specific properties interacting with the level above or below. Levels present certain similarities regarding symmetry, order or periodic behavior (Simon, 1962). For example, in FSDS the level of analysis can be organized at the individual's levels household's consumption habits, at the economic level -markets organization, distribution activities-, at the biophysical level - land, water, energy and resources of the socio-ecological system - where the FSDS is embedded -.

4 Methodologies to analyze complex systems

New scientific narratives and tools are required to integrate system understanding in a coherent way system and make strategic actions. In this section we will present a brief analysis of different approaches useful in understanding complex food systems that is also summarized in Table 1. We will provide a general definition of the approach and its characteristics.

4.1 Agent Based Modeling (ABM)

Considering the complex properties discussed in the previous sections, agent-based models are crucial in the understanding of how systems adapt to perturbations and changes, and how emergent processes may arise in complex systems**.**

Agent-based models are bottom-up approaches in which the dynamics are originated from the agents and their interaction. Agent-based models focus on individual behaviour following specific rules in a certain environment (Farmer and Foley, 2009). An intrinsic characteristic of agent-based modelling is the possibility to model and simulate individual heterogeneity, and to represent agents either in geographical order or in other spaces (Gilbert, 2008).

According to Holland (1995), agent-based models have specific underling properties and mechanisms. One of these properties has been discussed in the previous section and it is the possibility to tackle the nonlinear nature of a system. The other properties of agent-based models are: *aggregation*, that is the possibility to understand the formation of groups in a system and therefore can allow the understanding of the main elements or processes in it; the analysis of *flows* which makes possible to understand the transfer of information and resources; and the presence of *diversity* **(**may be considered the real strength of these models) because of the possibility to model different kind of agents within a system.

When considering agents, they are characterized by the following properties (Farmer and Foley, 2009; Gilbert, 2008):

- ✓ Agents are autonomous. They act independently from the top down rules imposed from entities as for example institutions. It is not to say that institutions do not matter but they are considered also as autonomous agents within the system. As an example, a possible role of institutions may be the introduction constraints to the behaviour of agents.
- ✓ Agents are interdependent. As complex-systems characteristics, the behaviour of an agent influences the behaviour of another agent and vice versa.
- ✓ Agents follow rules. Every agent has a specific role in the system and his role is related to actual

human behaviour.

- ✓ Agents behave accordingly to the information in their possession and adapt to circumstances.

Moreover, agents can be named and recognized, and can change their behaviour when interacting with their worlds (Holland, 1996). To sum-up, agent-based models are complex approaches well suited to the analysis of bottom-up processes with heterogeneous elements. For this reason, they are suitable for descriptive models analysing the state of a system (Macal and North, 2007).

These concepts may appear too abstract and may be difficult to think to application. Actually, agent-based models are widely used in several disciplines as economics, mathematics, sociology, social psychology, political science etc.

For example, agent-based perspective is suitable for the analysis of supply chain management (Lin, and Shaw, 1998). In this case, the different stakeholders involved in the chain are considered as agents and the flow of information and products is analysed in order to increase the efficiency of the system. Another example of application can be found in urban models, as in the study conducted by Schelling (1971) on social segregation, where agents are households, which move in their environment according to ethnic considerations.

Agent-based models are used in studies investigating opinion dynamics (Deffuant, 2006), in order to understand for example the propagation of information or the role of social aspects in influencing individual decision-making in a population. Other examples of application can be found in the analysis of consumer behaviour (Janssen and Jager, 2001), in the study of relation between firms (industrial networks, Gilbert et al., 2001) and so on.

ABM applied to food systems

In food supply and distribution systems, agents can be considered consumers, policy makers, as well as institutions, banks or governments.

One of the most recent and interesting applications of agent-based models to food system is the work of Gagliardi, Niglia, and Battistella (2014), which consider this type of approach ideal for the evaluation of policies in the agro-food sector. They propose a case study in which they assess different policies in the region of Puglia (Italy). In this paper, the authors analyse the effect of different policies on food systems based on the “programme for rural development” of Puglia region in Italy. The authors compare “light” approaches and “aggressive” ones and show three possible scenario of development of food systems. Their results reveal that light approaches have positive effects on smallholdings, associations and local retail sector whereas aggressive ones tend to marginalise them.

In addition, Stroink and Nelson (2013) presented an analysis of local food hubs in the province of Ontario. They study five hubs trying to understand the emergence and development of each hub through an agent-based perspective providing evidence of importance of local initiatives. In particular, they focus on: the emergence of the hubs; how hubs are self-organized; how these hubs adapt to changes.

These two studies are well examples of how agent-based models can be utilized in the analysis of food supply and distribution systems. The study of Gagliardi, Niglia and Battistella (2014) is an example of how agent-based model can be implement in order to understand the impact of specific policies. On the other hand, the study conducted by Stroink and Nelson (2013), analysing the current state of a specific food system, is an example of a descriptive model which allow a deep understanding of the main elements affecting the performance of the system.

4.2 Social Network Analysis (SNA)

Even if the widespread of network analysis has been in the last fifty years, the first work using the logic of social network analysis has been considered the studies conducted by Simmel (1908) in which social entities were analysed according interaction among individuals. For a review of the history of social network analysis see Scott and Carrington, (2011); other reviews on SNA can be found in Wasserman, Stanley and Faust, (1994) and in Knoke and Kuklinski, (1982).

Although the historical connection with the studies of Simmel (1908), SNA can be considered as a new field in sociological and economic research. In fact, as for other complex systems approaches it has been developed in the last fifty years due to the development of computational and computer techniques.

In SNA there is a focus on the social context in which agents are immersed. According to Knoke and Kuklinki (1982) and Mitchell (1969), networks can be defined as specific kind of relation joining different persons, objects or event.

Persons, objects and events are usually called *nodes* and the relations among them are called *linkages* or *edges* (Stanley and Faust (1994). In SNA, isolated elements are not important, because the focus is on the relations among the elements and how the structure of this relation can influence their behaviour. It is important either the analysis of the present relation among elements and the absence of it.

For this reason, we can say that SNA works on relational data in order to provide visual depictions of the network structures created by the social and economic interaction (Scott and Carrington, 2011).

In the design of an SNA based study the focus is mainly on five properties (Knoke and Kuklinki (1982):

- ✓ The choice of sampling units: they can be considered as the categories in which the elements are in relation. For example, when considering a corporation as sampling units, the elements can be the division within the corporation or otherwise we can focus on a specific division as a sampling unit and consider the different individuals as element of the network.
- ✓ The form of relations: a key feature of network analysis is the analysis of the form of relation among elements of a network. Through SNA is possible to understand the intensity and the join involvement between two or more nodes and the quality of their relation (e.g. if it is a market relation, or otherwise a friendship one).
- ✓ The relational content: this property refers to the directionality of the linkages between the nodes within a network.
- ✓ The level of analysis: After we choice of sampling units, we can decide to focus on different level analysis. We can focus on a singular element, on dyads of elements, triads or on the complete network (Van Duijn and Vermunt, 2006)

As for ABM, SNA has several applications. In general, it is considered suitable for the analysis of kinship patterns, community structure, interlocking or directorship (Scott and Carrington, 2011). Other applications of social network analysis can be found in studies on social media, the Internet, and the World Wide Web, and biology. Examples of applications can be found in Wellman and Berkowitz (1988).

SNA applied to food systems

In a study conducted by Lazzarini et al. (2001), SNA is used for the analysis of supply chain management. The authors consider the interdependencies that occur in the whole system focusing on both horizontal and vertical relations among firms in inter-organizational collaborations. The study reveals the importance of coordination and value creation according to different kinds of interdependences among agents. Finally, they provide some specific examples such as buyer-supplier relationships; information technology induced inter-organization collaborations, and the role introduction of the “macro hierarchy” organization structure.

Freedman and Bess (2011) analysed the global climate change through a social network analysis. This work shows how SNA can be useful to evaluate the trajectory of locally based coalitions, focused on the food security and adaptation to climate change. The findings of this investigation revealed that this coalition promoted and facilitated assistance seeking, and collaborative efforts among a group of stakeholders that were not connected in the network before the coalition.

Mendez and Semitiel-Garcia (2011) analysed the structure and relations of agro-food systems in Spain from 1980 to 2000. The evolution of agro-food system (AFS) is analysed according to the whole inter-industrial system. According to their analysis of the relation between the AFS and the elements of the inter-industrial systems, the authors revealed as the agro-food systems had a secondary role and a low impact to the others actor of the system. This is a nice example of how a complex approach can suggest counter-intuitive interventions because, according to their analysis, to increase the performance of agro-food sector the authors suggest the implementation of policies focusing on other sectors rather than to policies directed specifically to the agro-food one. This is possible because social network analysis allows the understanding of the main hubs of a network and therefore may promote interventions, which can affect more positively the whole system. Although the focus is on Spanish economy, Mendez and Semitiel-Garcia (2011) suggest that their analysis may apply to other food systems.

4.3 System Dynamics (SD)

SD is a methodology for understanding, discussing and simulating complex systems over time (Sterman, 2000). Jay Forrester created the SD methodology in 1956 at the Massachusetts Institute of Technology. It has been widely used in many management and engineering application areas, including the management of supply chain and food systems.

Some of the most important systems dynamics concepts are (Zock, 2004):

- **Stocks and Flows**: stocks (or levels) consist of accumulation within the systems while flows (or rates) are the transport of some content of one level to another.
- **Time delays**: as levels are changed only by the rates. The rates change is measured in a determined time interval.
- **Feedback loops**: a decision alters the state of the world, but at the same time indirectly influences itself, defines the situation we will face in the future, and triggers side effects and delayed reactions. Feedback loops can be positive or negative. Positive loops consists of reinforce or amplify what is happening in the system. Negative loops counteract and create balance and equilibrium.
- **Accumulation**: the levels or stocks are integrations. These are variables that cannot change instantaneously; they accumulate or integrate during time according the results of actions in the system.
- **Endogenous point of view**: it refers to the existence of a closed boundary which means the dynamic behaviour arises within the internal feedback loop structure of the system (Richardson, 1991).

In system dynamics methodology, the dynamics of a system can be conceptualized through Causal Loop Diagram (CLD), which is a map of the feedbacks present in the system. In SD, the system can also be analysed through a simulation, which is possible after the construction of a Stock and Flows Diagram (SFD). A SFD is a quantitative assessment of the system. The Dynamics are pictured in the SFD and the model formulation is done by the elaboration of equations that expresses how the variables are interconnected with others and how the accumulation process is determined by the change in the flows altering the state of the system levels. In the following section an example of a CLD and SFD each will be provided.

SD applied to food systems

SD models have been lately used in socio-ecological systems modelling and they are considered also as a tool for understanding the configuration and functioning of complex systems. Particularly, an interesting previous analysis of Food Systems using SD methodology is shown in the paper *Food Security in Development Countries: a Systemic Perspective (Giraldo et al. 2011)* where a description of models on Food Security and its approaches were analyzed concluding that projections and prediction were based on correlations, also known as black boxes because their lack of insights on the causal relationships in the system. In this same article, SD models are considered more appropriate for policy evaluation, providing an assessment of long-term effects and it is useful for the understanding of a phenomenon based on the causation of variables.

A recount on how SD has been used for the analysis of basic issues related to Food Systems such as resource availability, energy, food and population is described in Table 2 “Example of SD applications to food system”, included in the annexes. This list is an integration of a list reported originally reported in Giraldo’s article and other applications found in literature. From this recount, SD stands as a methodology with the capacity to be applied in combination with integrative frameworks for food systems resulting a suitable tool

Below we resume some of the examples on SD applications that are reported in “*Effects of Food Availability Policies on National Food Security: Colombian case”* and *“Food Security in Developing countries*, *a systemic perspective”,* both from Giraldo et al. (2011; Figure 2).

Figure 2a shows a CLD of the dynamics between food availability, basic needs, food production and total factor productivity. We can observe how population influence on the food production process and its relation with food security, level from which the land adequacy, road needs and irrigation area will be modified.

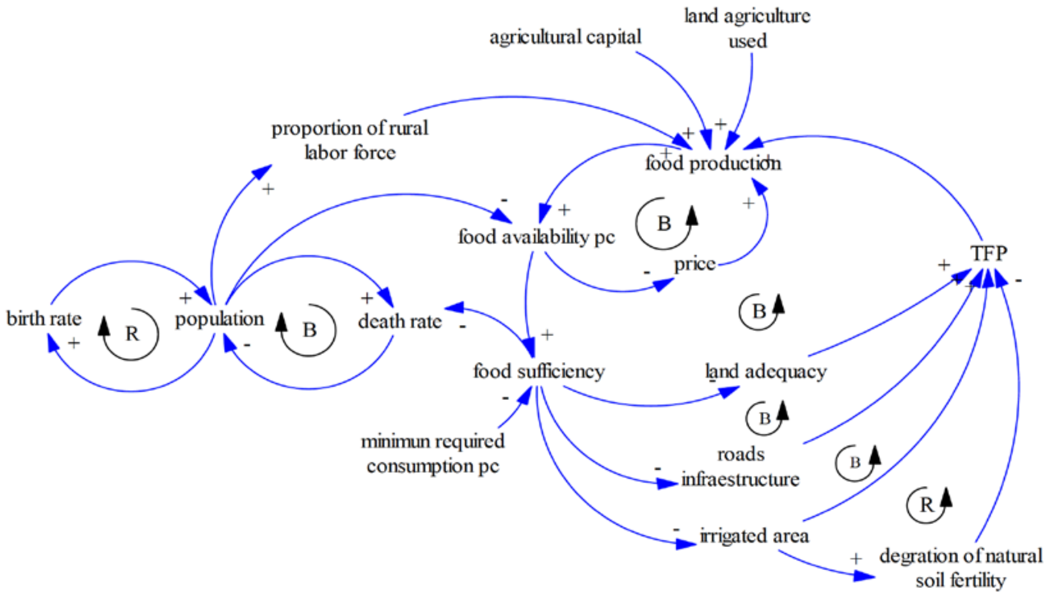

Figure 2a: **System dynamics approach applied to Food availability - Causal Loop Diagram (Source: Effects of Food Availability Policies on National Food Security: Colombian case, Giraldo et al., 2011, p.15)**

Figure 2b shows a SFD elaborated for the study of food security in developing countries. In this work, is focused the balance between food demand and supply at reasonable prices. In this sense, the model shows how prices are an important variable to achieve food security, which at the same time, depends on the food products available, and these depend on the sales, which depends on population with acquisition power, and the production process. This last one depends, among others, on the land available for production. In this way, the price is what determines the land use for food production and distribution.

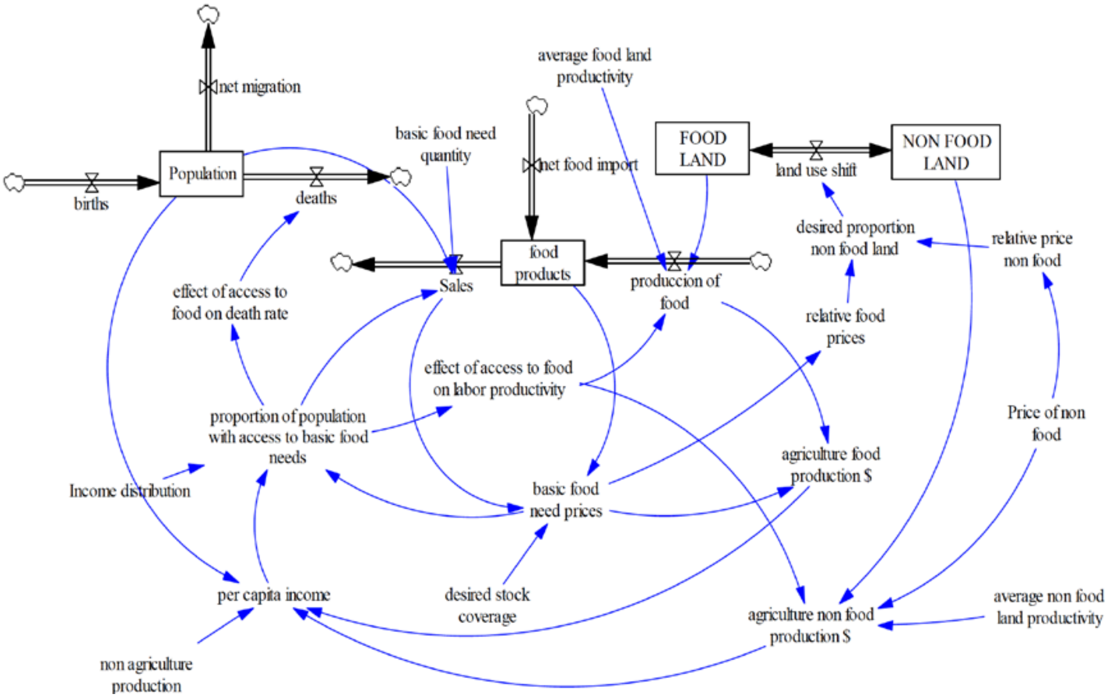

Figure 2b: **System dynamics approach applied to Food availability - Stock and Flow Diagram (Source: Giraldo et al., 2011, p.15)**

Figure 2c shows a simulation where the base run in red shows the perceived satisfaction of food demand and the blue run shows the impact on the satisfaction if the food demand increases in 10% and the production factors remain at the current level.

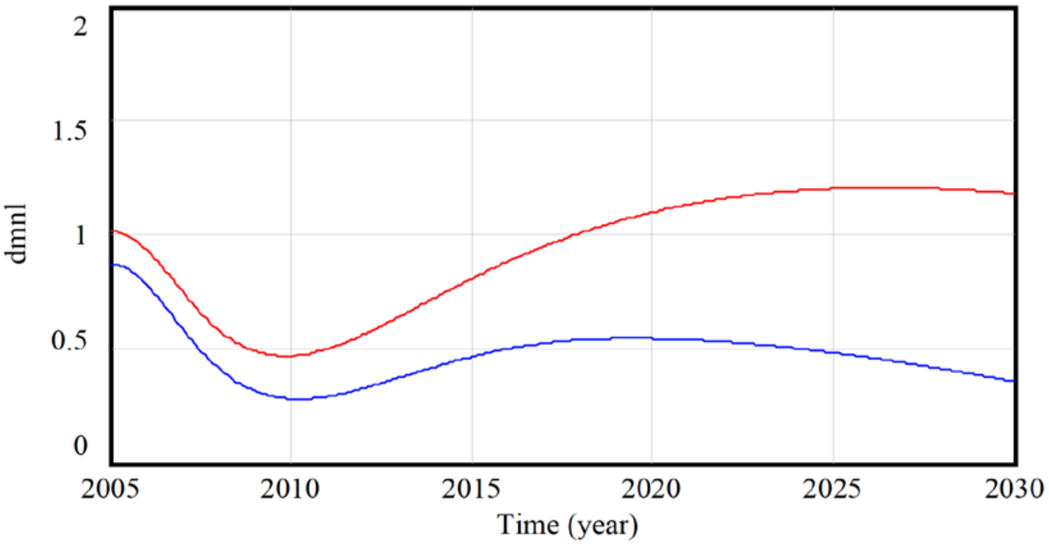

Figure 2c: **System dynamics approach applied to Food availability - Quantitative simulation and behavior of perceived satisfaction of food demand (Source: Giraldo et al., 2011, p.15)**

The work "*A system dynamics modeling framework for the strategic supply chain management of food chains"* (Georgiadis, et al., 2005) explains how prior researches "failed" in the analysis of complex food systems because they did not consider interdependencies among operations and partners involved in the whole food system. Standard methods are considered useful in the analysis of steady systems, having no variability in demand, but not able to manage systems with unique characteristics as the food supply ones. As an example of the peculiarity of food systems, the study previously mentioned takes into account the food perishability and shorter life cycles. Among others, this factor creates uncertainties both for the buyer and the seller, increases the need of frequent deliveries and requires the diversification of the modes of transportation. Others variables increasing uncertainties in food systems are mentioned as: seasonality, which affects delays management, food safety and legislative frameworks.

In the next table an assessment is performed on the capabilities of each of the presented methodologies in analysing FSDS, according to their main principles. Also, the main properties, application potentialities and tools that each methodology implies are provided.

Table 1: Assessment on Complex System Methodologies performance in the analysis of FSDS (Source: own elaboration).

Complex Systems features	Agent Based Modeling	Social Network Analysis	System Dynamics
Entirety	Medium	Low	High
Emergence	High	Low	Medium
Interrelations	Medium	Medium	High
Non-linearity	High	Low	High
Feedbacks	Medium	Low	High
Self-organization	High	Low	High
Adaptation	High	Low	Medium
Counter-intuitive nature	High	Medium	High
Time perspective	High	Low	High
Hierarchical organization	Medium	Low	High
General Assessment of the methodology	- Focus on emergent processes and adaptation - Bottom-up analysis - Attention to independence and heterogeneity of agents - Sensitive to initial conditions - Too difficult to analyze several combinations of attributes of agents	- Focus on relational data - Descriptive approach - No consideration of attributes of nodes in a complex system	- Focus on behavior of a complex system over time - Top-down analysis - Descriptive and normative analysis - Possibility of exclusion of important factors affecting the system (subjective bias in the choice of the appropriate model parts) - SD models cannot address spontaneous changes by agents in the system that might constitute an emergent behavior.
Possible applications	- Assess different policies - Understand the emergence of coalitions, local initiatives in FSDS	- Descriptive analysis of intensity, strength or absence of connection among the elements of a FSDS - Analysis of the main hubs of a food system in order to understand possible areas of intervention	- Simulation and analysis of the impact of different policies and interventions in order to increase the efficiency of a FSDS - Qualitative and quantitative analysis of performance of a FSDS

By analysing the data reported in the above table, it is possible to assess how the SD methodology, in comparison to the others, is capable of addressing, in an integrated way, different aspects of FSDS such as business organizational issues, households dynamics, national or regional policies, and capable of covering a broader scope of issues such as changes over time in land availability, natural resources, urbanization process and population growth, which moreover can be addressed all in a single model. SD seems to be particularly fit for the analysis of dynamic complex systems, as in fact it formally constitutes a methodology for the study of the logical relationships between structure and behaviour of systems. Of course, SD also presents limitations in addressing emergent behaviour, in the assessment of individual dynamics of agents or actors, and in carrying out a proper and detailed spatial-geographic assessment, generally also very important to analyse specific cases of FSDS.

Specifically, this last point was one of the findings of a further study on FAO's operational and methodological guide from an SD perspective that will be introduced in the next chapter.

5 Preliminary results of FSDS analysis based on FAO's methodology from a System Dynamics perspective

As seen in the previous sections, one of the methodologies that can improve the analysis of FSDS and bring tools for its management is System Dynamics. SD models are expected to be helpful in designing organizational interventions, to explore and make evaluations, and to find the most adequate actions as solutions for problems. When the model building process is related to implementation plans in organizations, it is applied as a tool for "action research", improving the scientific analysis of different sizes of complex systems or organizations, while at the same time giving practical possibilities of application (Milling, 2007).

Currently, a detailed analysis of FAO's methodological guide to understand the FSDS in developing or transition countries using a system dynamics perspective is under development. FAO's methodological guide has enabled the identification of main variables of FSDS, their characterization according to SD methodology as stocks, flows, other variables, and a preliminary boundary selection for the study of FSDS. The main dynamics of FSDS, always according to FAO's findings, have been identified. The following section will show a simplified system archetype elicited from the study of one set of identified dynamics.

5.1 Analysis of the FSDS Dynamics using System Archetypes

System archetypes are patterns of behavior of a system, understood as generic structures or typical system outlines. There are recognized structures that show recurrence in many different situations. Archetypes are presented as commonly occurring combinations of reinforcing and balancing feedback. They are frequently used to facilitate rapid understanding of a system because of their known and already studied properties and because of their insightfulness. Collections of system archetypes have been published by Senge (1990), Braun (2002) and by several other authors. As analytical features, they help people shift their thinking to a more systemic perspective to understand a phenomenon or dynamic and in some situations when real corrective actions are not taken. In this section we will show an example of application of one of the most common archetypes to FSDS analysis (Figure 3).

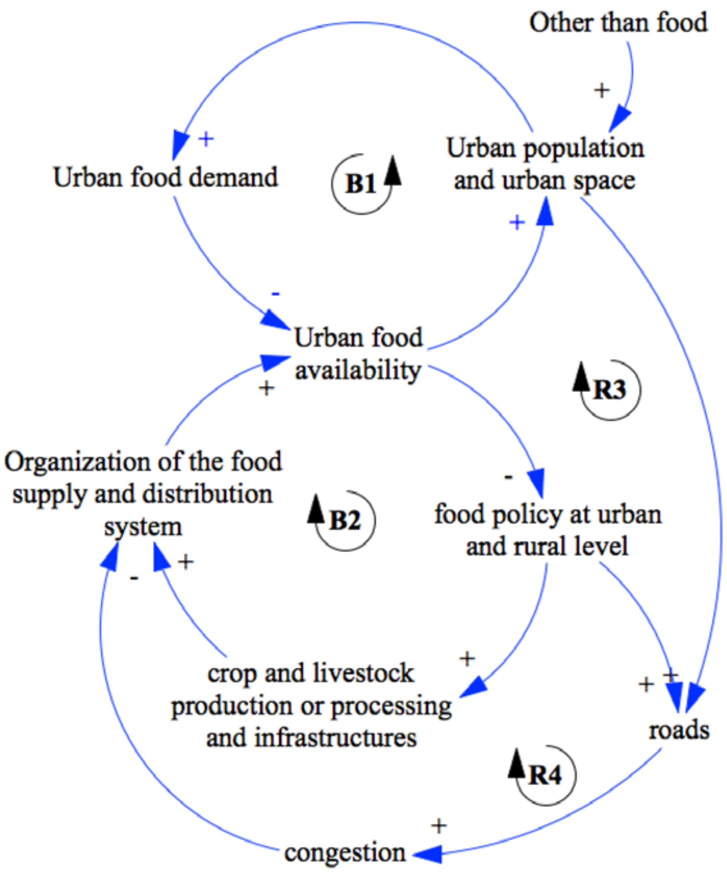

Figure 3: **System archetypes applied to food supply and distribution system (Source: own elaboration).**

A general "eroding goals" archetype was firstly identified. This archetype structure has two important balancing loops. One of them represents the pressure to reach a goal and the second the actions to improve the condition. In this dynamic the performance fails continuously to meet the stated goal because the corrective actions are what seems to be "rational" but in fact, are related to a symptomatic solution rather than to a fundamental one. In this case, the balancing loops are characterized as follows: B1) urban population growth and B2) food policies. Loop B1 appears like a balancing loop when considering that an increase of food availability increases the urban attractiveness for people, who increase the food demand. It in turn decreases food availability. This dynamic could be also driven by other reasons that might make the cities more attractive. In B2 low food availability increases the need of food policies perceived as investments on production, processing, transportations and retail, both in rural and urban areas. It improves the quality of the organization of the FSDS and improves the food availability favouring the urban growth and attractiveness.

Several mechanisms show that meeting the goals of supplying food present a limiting behavior. According to Braun (2002) the "eroding goals" archetype present into an organization becomes part of the organization's culture as "a justifiable and even reasonable thing to do" and with the time, turns off the critical thinking to examine the real causes of the problem and all policies are though in function on what the organization is capable to do but not in terms of what is needed. Governments tend to think that building roads will alleviate the distribution activities and boost the economy but in the long term this measure makes the system more inefficient given that roads reduces the space for production and markets and increase congestion.

The former situation considering urban dynamics, introduces two paradigms of reinforcing loop that can limit the success of the system. R3 represent an example of a “shifting the burden” archetype. This archetype presents a conflict between a fundamental and symptomatic solution. There is an attraction to take a symptomatic solution that ease a visible problem and represents a low cost measure. The effects of the progressively implementation of the symptomatic solution have significant negative influence on the state of the system in the long run. The urban growth, independently from its cause, increases congestion and traffic that in turn limit the organization of the FSDS, lowering food availability.

R4 indicates, within the structure of the “fixes that fails” archetype. “Fixes that fails” explains how the reductionist view of solution measures can contribute to the problem symptoms, increasing the apparent pressure for that solution and creating unintended consequences which besides, as mentioned before, increase the problem symptoms, distract the attention to the fundamental solution. In this case it is shown that roads are not the only solution to increase food supply to the cities. It is a confirmation that food availability is an issue belonging to the entire FSDS structure and functioning and not a stuff that can be treated as a renewable stock located out of the city boundary and which just need to be brought within the urban area.

A supplemental R4 can be drawn for policies that tend to increase production and industrial processing without take into account benchmarks of social metabolism and sustainability of natural resources (Giampietro et al. 2014) because they are in risk of stressing the natural resources use and generate a higher amount of food waste in distribution processes given the inefficiency of the system structure and the pressure in the wrong variable to increase food availability. In the long term, it will also cause the fail of the organization of the FSDS and reduce food availability at urban level as highlighted in the previous section.

In summary, B1 and B2 indicate the main balancing loop of a general Drifting goal archetype. R3 indicates the effect of a reinforcing loop within a shifting the burden archetype and R4 indicates a possible “Fixes that fails” archetypes associated with reductionist focus of food policies. A supplemental R4 can be drawn, from policies that tend to increase production and industrial processing without take into account benchmarks of social metabolism and sustainability of natural resources.

5.2 Remarks of the current research for FAO’s

It is important to clarify that Complex Systems methodologies have been created as analytical tool for the understanding of phenomena. Nevertheless, they do not constitute in themselves, a complete analysis or knowledge. Their usefulness in analyzing a system or a problem in a system depends on the quality of content and narratives under study. The former means that, complex system methodologies are a set of rational procedures under which information is organized. These procedures or methodologies come from different disciplinary or multidisciplinary contributions, and will provide support to analyze and understand different kind of problems. Each procedure or methodology, as shown in chapter 4, has its main properties, advantages and limitations.

The Meeting Urban Food Needs (MUFN) Initiative from FAO has called for other methodologies to improve the analysis and management of FSDS, using complex systems principles. The former, after the acknowledgement of FSDS as complex systems and, therefore, the need of more complete perspectives to organize the existing knowledge on FSDS and find more effective tools. In the current paper, we have first operated a methodology comparison and then we have performed a review of the knowledge contained into a methodological framework (the one from FAO) that allows the study of a multidisciplinary issue, such as FAO’s methodological guide. System Dynamics methodology has just offered a way of organizing this information based on underlying concepts like causation, accumulation, feedback and change over time. The collaboration of a good multidisciplinary narratives and/or knowledge of phenomena, such as FAO's framework, and a methodology with high performance in the analysis of complex systems, such as SD, can bring substantial benefits to the public policy implementation arena and thus allow solving complex problems.

As shown in chapter 5 of this paper, the integration between SD methodology and FAO's framework into the analysis of a FSDS was able to raise issues that were perhaps unseen or had been previously ignored with scientific solidity. Specifically, the archetype analysis has provided interesting insights on how the FSDS are responding over time to traditional policies, often selected to solve "symptomatic" issues and distracting the treatment of more fundamental ones, which, in the long run will erode the capacity of the system to reach the expected goal and make the system dependent to the symptomatic policies – see chapter 5.1.

In addition, this analysis pointed us into the direction of what seem to be some key points for the FSDS understanding, which are the following:

1. The functioning of the FSDS are embedded in the field or Urban Dynamics, where population, infrastructure growth and urbanization process have a high impact on the organizational capacity of the FSDS to provide food.
2. Therefore, the consideration of the population growth as the main problem to feed cities because it raises the food demand, is partial, thus, is wrong. Although population is a key issue, it is the structuring of the cities what also makes the system highly inefficient. The system has to be studied in an integrated way for the achievements of effective policies.
3. Supply and distribution systems are part of a single and integrated system, which implies close interrelations between rural, urban and peri-urban dynamics. Urban and rural dynamics cannot be longer treated in isolation if integral solutions or better policies are looked.

6 Conclusions

In order to face the challenges of growing cities and new perspectives have to be applied to the study of FSDS. FSDS are complex systems and posse characteristics such as: entirety, feedback, non-linearity, time perspective, counterintuitive nature and self-organization and adaptation capacities. Thus, complex system methodologies applied to the study of FSDS can bring new perspectives to understand and manage them more efficiently.

While comparing complex system methodologies, it was found how different approaches contribute to the treatment of different issues of FSDS. System dynamics stands out as methodology for its capacity to address, in an integrated way, different levels of aspects of FSDS and broader scope of issues. Formally it constitutes a methodology for the study of the relationship between structure and behavior of systems. Its limitations are on addressing emergent behavior, assessment of individual dynamics of agents or actors, a proper and detailed spatial-geographic assessment. Previous SD applications on the analysis of Food Systems consider SD models more appropriate for policy evaluation, providing an assessment of long-term effects and it is useful for the understanding of a phenomenon based on the causation of variables.

The first release of the study currently under development of FAO's methodological guide allowed the identification of the main dynamics of FSDS. In order to show a general analysis of these dynamics a system archetype was developed. In CLD we can observe several four main loops. B1 and B2 indicate the main balancing loop of a general Drifting goal archetype. R3 indicates the effect of a reinforcing loop within a shifting the burden archetype and R4 indicates a possible "Fixes that fails" archetypes associated with reductionist focus of food policies. A supplemental R4 can be drawn, from policies that tend to increase production and industrial processing without take into account benchmarks of social metabolism and sustainability of natural resources. In conclusion, this diagram shows how the balancing loops act in a way that the whole system tends to a poor development and the policy, in this case building more roads, fails as solution due the structure of the system and distract from the important issues to deal with.

Basic points elicited from the SD application to the analysis of FSDS are:

1. The functioning of the FSDS are embedded in the field or Urban Dynamics,
2. Population growth as the main problem to feed cities because it raises the food demand, is partial, thus, is wrong. The system has to be studied in an integrated way for the achievements of effective policies.
3. Urban and rural dynamics cannot be longer treated in isolation if integral solutions or better policies are looked.

Further work on FAO's methodological guide study will be contained in the article to Understanding the dynamics of FSDS where a quantitative assessment and a simulation of the main identified dynamics is developed. This work will be presented in the Meeting Urban Food Needs initiative in April 2015. A complete SD review on current FAO's methodology will be available in the work "System Dynamics updates to FAO's methodological guide on FSDS" by July 2015.

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9 Appendix

Table 2: **Examples (non-exhaustive) of SD applications to food system from the literature: an integration of the original list reported by Giraldo et al., (2011) p. 9, plus additional applications related to FSDS.**

Authors	Model	Emphasis
Bach et al. (1992)*	Food self-sufficiency in Vietnam: a search for a viable solution.	Studies various possible solutions to self-sufficiency on food (supply) in Vietnam.
Bala (1999)*	Computer Modeling of Energy, Food and Environment: The case of Bangladesh.	An integrative Vision of energy, food and environment applied to Bangladesh.
Briano et al. (2010)	Scenario development of an Italian food-company on short life cycle products.	Demand forecast and production times as key issues to maximize efficiency. Inclusion of different policies test related to safety stocks and demand planning
Gohara (2001)*	A System Dynamics Model for Estimation of Future World Food Production Capacity.	Analysis on supply and demand of food worldwide
Meadows (1976)*	Food and Population: Policies for the United States.	Analysis on supply and demand of food as well as demographic changes.
Meadows, (1977)*	The World Food Problem: Growth Models and Non-growth Solution.	Analysis of the global food problem as seen from both, growth models as well as non-growth models approach
Quinn (2002)*	Nation State Food Security: A Simulation of Food Production, Population Consumption, and Sustainable Development.	Model simulation that links food production, the requirements of the population consumption and sustainable development
Saeed, et al. (1983)*	Rice Crop Production Policies and Food Supply in Bangladesh.	Policy analysis applied to rice and food supply
Georgiadis et al. (2004)*	A system dynamics modeling framework for the strategic supply chain management of food chains.	Analysis on the food supply chain management.. Scenarios of long run operation food systems.
Minegishi and Thiel (2000)	Model on poultry production and processing. Application to the analysis of the dioxin infection effect on poultry supply chain	Improve expertise in complex logistic behaviour in food systems
Saeed (2000)*	Defining Developmental Problems for System Dynamics Modeling: An Experiential Learning Approach	Application of a model to constructing a reference mode addressing the food security problem in Asia
Ozbayrack et al. (2007)	Modelling framework to simulate supply network in order to manage complexity	Complex factors present in supply chains. Variables considered: inventory, WIP levels, backlogged orders and customer satisfaction
Vo & Thiel (2008)	Model on the chicken meat supply chain face with the bird flu crisis in France	Account the uncertain environment supply chain. shed light on both the shortages in up-stream supply capacity and also in downstream unforeseen consumer behaviour affected by the crisis.

* Examples reported by Giraldo et al. (2011)