A System Dynamics Approach towards Food Security in Agrifood Supply Networks: A Critical Taxonomy of Modern Challenges in a Sustainability Context

Keramydas Christos, Tsolakis Naoum, Vlachos Dimitrios & Iakovou Eleftherios
Department of Mechanical Engineering
Aristotle University of Thessaloniki
chkeramy@auth.gr; ntsolaki@auth.gr; vlachos1@auth.gr; eiakovou@auth.gr

Abstract
As defined by the Food and Agriculture Organization, food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their needs. Nevertheless, external forces as, indicatively, climate change, global population increase, rise of alternative energy sources, agricultural technological advances, and consumer dietary preferences changes shape the global contemporary food management landscape by disputing the aforementioned definition. Furthermore, the recent food security crisis of 2007-2008 brought food insecurity to the forefront of the global sustainable development agenda highlighting the need to reconsider the structure and operations of international agrifood supply networks (AFSN), and streamline the relevant policy-making.
In this manuscript, we provide a two-fold critical taxonomy of the food security challenges and future uncertainties. More specifically, we identify the major challenges that render food security with great volatility and we provide a taxonomy of existing research efforts, according to the four food security basic dimensions, i.e. availability, stability, accessibility, and utilization, as these are mapped on the relevant sustainability aspects (environmental, economic, societal, and governmental) of an AFSN. Our critical analysis demonstrates that food security and sustainable AFSNs have attracted the global research interest, focusing more on addressing case-dependent AFSN problems, and less on developing integrated methodological approaches for the optimization of the entire supply chain. Our analysis further incorporates a System Dynamics approach that captures the dynamic nature of the interrelations of food security aspects in a sustainability context and further allows the assessment of different policy interventions. This work is the first step towards the development of a quantitative strategic decision-making support tool that could be employed by policy-makers, in both the private and public sectors, including governments, international organizations, and food industry enterprises towards the effective design and efficient operation of AFSNs in a sustainable manner.

Keywords: agrifood supply chain, food security, sustainability, system dynamics

JEL classifications: I3, O2, Q1

Introduction

Food security arises as a precarious issue of modern world considering that humanity confronts a triple-facet challenge including: (i) the increasing global population and the associated dietary needs (global food demand is estimated to increase by 70 to 100% by 2050; Evans, 2009; FAO, 2009a) (ii) the limited physical capacity of the planet to produce food, and (iii) the necessity to sustain livelihood of humans (Ingram, Ericksen and Liverman, 2010; Power and Chapin, 2009; Rockström et al., 2009). Recently, a prominent incident that challenged global food security was the food crisis in 2008 that had detrimental effects on the welfare of the poor around the world (Kumar and Quisumbing, 2013). Specifically, the prices of some commodities had been continuously increasing since 2004, with the major surges occurring within the period 2006–2008 (Brahmbhatt and Christiaensen, 2008; FAO, 2008; World Bank, 2008a). Notably, the index of food prices provided by FAO indicates a relative price increase by 9% in 2006, 23% in 2007 and 54% in 2008 (FAO, 2008). As a consequence, the number of undernourished people in 2007 increased by 75 million over its previous value of 848 million (FAO, 2008).

Food security threats can arise by either higher prices, making food unaffordable for people, or due to food unavailability owing for example to embargo or food waste/losses (Defra, 2009; Hubbard and Hubbard, 2013). Furthermore, examples like the hunger crisis in 2011 and 2012 in the ecoclimatic and biogeographic zone of Sahel in Africa demonstrate the lack of effective strategies to secure the food supply (Maxwell and Fitzpatrick, 2012). Therefore, due to the complexity and the globalized character of modern food networks, it is important to identify the major challenges that can occur at each echelon of an agrifood supply chain (AFSC) (Fritz and Hausen, 2009; Tsolakis et al., 2014) as to enable effective policy-making.

Further, today there is clear evidence that international regulations and consumers express a continuous demand for environmental friendly products and services, which is associated to both opportunities and threats for many organisations (Validi, Bhattacharya and Byrne, 2014). The food industry is a prominent example of a complex environment where customers are highly aware of how food is produced and offered and where they express a growing demand for sustainably produced and distributed food (Beske et al., 2013). In addition, sustainability-related performance (i.e. environmental, economic, societal and governmental) is pivotal for providing unique benefits for all members of an AFSC (Bourlakis et al., 2013; Carter and Dresner, 2001)

Given the dynamic, stochastic, and multidisciplinary nature of the global food security problem, a system dynamics (SD) methodology seems proper to embrace food security issues from a SC perspective. Moreover, SD has been proven thus far a reliable modelling and simulation methodological tool for the analysis of complex systems and long-term decision-making management (Haffez et al., 1996; Tako and Robinson, 2012).

Therefore, this work is a first-time effort towards mapping the major food security challenges on a comprehensive SD framework. The rest of the paper is organized as follows. In Section 2, we provide a definition of food security and its major pillars. Following in Section 3, we identify major food security challenges as these are mapped on the relevant sustainability axes. Such a taxonomy is important for the drafting of appropriate management practices as to minimize risks that can render food security volatile. Moreover, in Section 4 we develop a conceptual SD framework that captures the identified food security challenges that could provide important managerial insights and policy-making implications. Finally, we wrap-up with summary and conclusions in the last Section.

Food Security Definition

Defining "food security" is rather a complex process as it is reported that there were more than 200 published definitions during the previous decade (Maxwell and Smith, 1992). The term "food security" was initially coined by Maxwell and Smith (1992) back to the 1970's where the abrupt increase in commodity prices and the energy shock of 1973 intensified the fears for a global food crisis. Today, a rather complex but inclusive definition of food security is as follows: "*Food security, at the individual, household, national, regional and global levels is achieved when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life*" (FAO, 1996).

According to the aforementioned definition, four (4) critical dimensions of food security are identified and need to be addressed: (i) food availability, (ii) food accessibility, (iii) food stability, and (iv) food utilization (FAO, 2009b). This deconstruction of the term allows for the holistic investigation of food security. A major drawback is that the pillars/dimensions that comprise food security have not yet been individually defined in an international context (Coates, 2013). To that end, in the subsections that follow we provide a short analysis of each pillar of the food security definition (Figure 1).

Food Availability

Food availability refers to the adequate supply of food via production, distribution and exchange processes (Gregory, Ingram, and Brklacich, 2005). The food production is impacted by a plethora of factors including land, water and energy sources, crop selection, livestock management, and harvesting. Moreover, due to limited natural resources and diversified consumer preferences, food has to be distributed in different regions. Therefore, appropriate processing, storage, transport, packaging and marketing of food are required to minimize food waste and price fluctuations (Godfray et al., 2010). As some societies are self-sufficient while other are not, an exchange or trade system is required to facilitate food accessibility to all (Gregory, Ingram and Brklacich, 2005; Tweeten, 1999).

Food Accessibility

Food accessibility refers to the direct and economic access to commodities meaning that households have the ability to either produce their own food supplies or procure/purchase them from other sources (FAO, 1997). Moreover, access to enough and nutritious food may not secure food accessibility as the food allocation within a household may not sufficiently meet the specific dietary requirements of each member (Ecker and Breisinger, 2012).

Food Stability

Food stability refers to the ability to sustain food security over time (FAO, 1997). Natural disasters, droughts, civil conflicts and market instabilities are few of the factors that may result in temporary or permanent food insecurity (Ecker and Breisinger, 2012; FAO, 1997).

Food Utilization

Food utilization refers to the proper preparation, processing, and storage of food in order to satisfy the physiological and nutritional requirements of each individual (Ecker and Breisinger, 2012; FAO, 1997). This pillar of food security further embraces the issues of education about food preparation and access to healthcare since an individuals' health status impacts the metabolism of food (FAO, 1997; Tweeten, 1999).

Supply Chain Food Security Challenges

The major challenge that governments and enterprises all around the globe have to deal with, within a food security context, stems from the following core particular characteristic of modern food security crises, i.e. despite

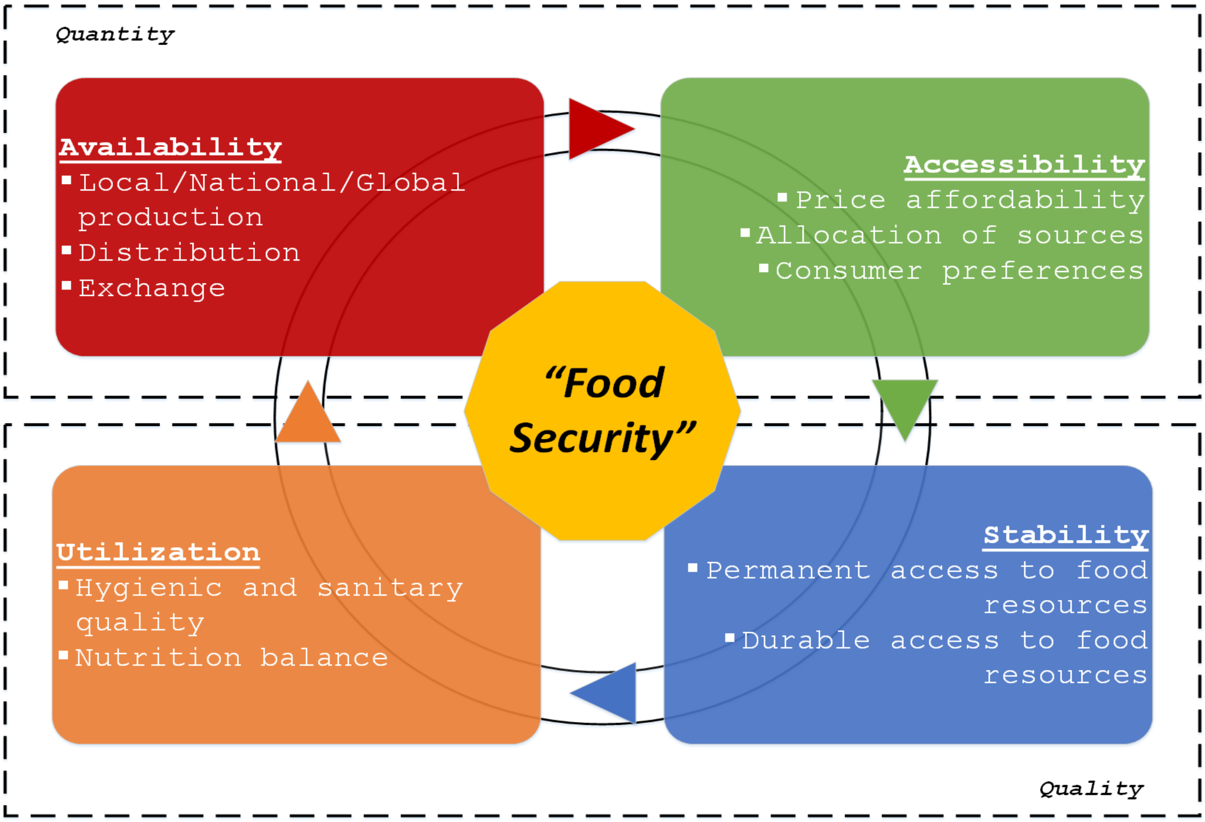

Figure 1: Food security dimensions

the fact that the world community has sufficient food to nourish the entire global population, as well as the means to substantiate it, a significant fraction of the overall global population is still living in poverty, lacking access to vital food products (FAO, 2011). In contrast to the traditional form of typical food crises, where the scarcity of food input was the predominant cause of insecurity, the aforementioned modern "Food Security Paradox" seems to be a multidisciplinary strategic policy-making and management issue of the globalized food markets and supply networks. Specifically, modern food crises proved to be the end-result of the corresponding decision-making processes and developments within a set of miscellaneous fields including national and international governance, demographics, agriculture, trade, sustainable development, energy, environment, natural resources, health, and of course food and nutrition. The main social, economic, environmental, and governmental food security challenges that governments, international organizations, and food industry companies have to deal with, within a sustainability context, in the upcoming years are presented in the following paragraphs (Table 1).

Initially, the rapid ongoing population growth accounts for a daily addition of 200,000 people to the global food demand (United Nations Environment Programme, 2009). According to the United Nations (UN), global population will rise up to 9.6 billion people by 2050 (United Nations, 2013), with developing countries being the main responsible for this growth. This fact introduces vital implications on food security that principally concern food availability, given that the current projections already speak of a required increase of 50% in food production so as to sustain the soaring demand (Godfray et al., 2010; Pretty et al., 2010; United Nations Environment Programme, 2009).

Furthermore, as the income of a significant part of the world's population is increasing (World Bank, 2008a), the subsequent increase in food consumption per capita exerts further pressure on global food availability. Additionally, another interesting point regarding the income per capita and consumption growth is their direct relation to the increase of food waste and spoilage (Henningsson et al., 2004) that further escalate social inequalities. A proper food waste management along with the adoption of efficient corporate social responsibility actions across the respective supply networks, elaborated by multinational or even local enterprises, could provide significant relief to the parts of population living in poverty.

The change in dietary preferences from traditional foodstuff towards higher consumption levels of meat, soya, bread, and processed foods in tandem with the high level of diversification of urban diet have significantly altered the global food production and distribution landscape (Dobermann and Nelson, 2011; Gandhi and Zhou, 2014; Kearney, 2010). The impact of these changes on food security becomes even more critical given that they are attributed to highly populated countries like China. Additionally, a remarkable increase is also observed regarding the average global food consumption in terms of energy (kcal) (Babu, Gajanan and Sanyal, 2014; Pérez-Escamilla 2012). For example, the daily average food energy consumption level in developing countries rose from 2,110 kcal per person, 30 years ago, to 2,650 kcal nowadays. This amount is estimated to exceed 2,960 kcal during the next 30 years. Moreover, it is estimated that, by 2050, 90% of the population will live in countries with a calory-intake limit of over 2,700 kcal, almost double in comparison with the present 51% and the 4% three decades ago. On the other hand, apart from the undernutrition, population in many developed and even developing countries suffer from overnutrition, including overweight, obesity and other chronic diseases that are related to dietary preferences (Foresight, 2007). Finally, in any case, either undernutrition or overnutrition, food and health safety should be ensured (Aung and Chang 2014; Gandhi and Zhou 2014; Lee, Palekar and Qualls, 2011).

Another critical fact regarding food security is the concurrent decline in agricultural investments and the lack of sufficient infrastructure around the globe that mainly prevents increase in crop yield (Bandara and Jayasuriya, 2009; Dorward and Chirwa, 2011; Kabunga, Dubois and Qaim, 2014; Louhichi and Gomez y Paloma, 2014; Mariano and Giesecke, 2014; Munro, 2003; Sastry, Rashmi and Rao, 2011; United Nations Environment Programme, 2009; World Bank, 2008b). At the same time, this lack in investments further inhibits the growth of domestic production, mostly in developing countries (e.g. Africa), while the existing funding schemes aim only at fostering self-sufficiency of domestic populations (Anderson, 2010).

Additionally, technological advances in agriculture, including seed technology (hybrids and genetically modified crops), fertilizers, and farm machinery, have a critical contribution in the increase of crop yield and agriculture productivity in general (Dobermann and Nelson, 2011). On the other hand, these beneficial effects are also debatable as concerns the way that they are achieved in practise, in terms that relate to economic and decision-making power concentration to just a few agrochemical companies and grain traders (Branford, 2011).

Another critical factor that affects food security, and was the main cause that brought food insecurity to the forefront in recent past (2007-2008), is the fluctuation in the global food prices (Gandhi and Zhou, 2014; Lawrence, Lyons and Wallington, 2009). During the last five decades, global food prices reached a peak in 2008, raising by 83% on average within a three year-time period. Also, the increasing food prices in conjunction with the economic crisis and the subsequent low household budgets, render urban and rural low-income households in developing countries incapable of meeting their essential dietary needs (Babu, Gajanan and Sanyal, 2014; D'Souza and Jolliffe, 2013). In general, higher food prices significantly limit the buying power of consumers in developing countries, where 60-80% of the household spending is directed to food products (10–20% in developed countries) (UNCTAD, 2009), imposing critical limitations to food accessibility.

Further, the environmental concerns raised globally during the last decades, regarding greenhouse effects and climate change in general, triggered significant changes in the energy landscape (Porter et al., 2014). In this context, the world-wide perception that biofuels, e.g. biodiesel and ethanol, could potentially play a key role in reducing greenhouse gas emissions, especially in the field of transportation (EU target: 10.0% share of the fuel mix by 2020), led to a rapid increase in their production and demand (FAO, 2006). Despite the green incentives behind the corresponding energy strategic planning, biofuels act competitively with agriculture production in terms of cropland use, which potentially could have critical implications on food availability.

Furthermore, given that 60% of the global population in developing countries will leave in cities by 2030, urbanization along with human settlement and urban infrastructure e.g. roads, housing, etc., play a key role in cropland reduction (Deutsch, Dyball and Steffen, 2013; Porter et al., 2009; Porter et al., 2014). It is estimated that the ratio of built-up area to cropland area will double since 2050 (from 3.5% in 2000 to 7.0% in 2050), creating a new threat to food availability and accessibility. Moreover, urban markets provide a fertile ground for the establishment of global supermarket chains with important implications for the food supply chains. Moreover, urbanization along with trade are prime factors in altering consumer preferences towards urban diets of high diversification. As a result, in many cases the traditional supply chains in the interior of many developing countries are unable to cater for urban population needs. Consequently, the gaps between urban and rural populations are increased in terms of transportation, prices, and market homogeneity.

The relationship between environment and food production is intrinsic, therefore global climate change directly affects food production, mainly in terms of crop yield, imposing a great degree of variability (Pangaribowo, Gerber and Torero, 2013). Specifically, storms of high intensity, forest fires, droughts, floods and heat waves occur more frequent, while still difficult to be predicted, thus threatening food stability around the globe, especially in developing countries which are more vulnerable due to their agricultural based economies. Also, given that agriculture accounts for 70%-85% of the total global water consumption, it is unnecessary to mention that the suspended threat of water scarcity endangers health, mainly of rural populations, and farmer productivity as well (United Nations Environment Programme, 2009). Further, melting glaciers in Central Asia, and droughts in Africa are just two examples that highlight the importance of water availability on farm production and livestock breeding. As water is considered one of the most limiting factors regarding food production increase, the current estimates highlight that water scarcity may account for a reduction on the world food production by at least 5% by 2050.

Trade is another critical factor that determines global food security (Pyakuryala, Roy and Thapa, 2010). In the current food trade terrain, developed countries and a few international corporations exert control over the food consumption in developing countries, through their export policies, or the food production, through the purchase of cropland (Branford, 2011). As a consequence, developing countries are gradually becoming more food-vulnerable in terms of low domestically produced food quantities, high prices, and land ownership. Furthermore, trade along with urbanization are two major factors that shape consumer preferences and diet around the globe (United Nations Environment Programme, 2009). Moreover, international wars, internal conflicts in countries or even economic embargoes introduce crucial

Table 1: Food security future challenges and uncertainties

	Dimension	Challenge	Sustainability Aspect				References
			Soc	Env	Eco	Gov	
Availability	Local/National/Global production	Obsolete and limited agricultural production infrastructure and inputs (i.e. training, facilities, knowledge, technologies, credit markets)			●	●	Bandara and Jayasuriya (2009); Dorward and Chirwa (2011); Louhichi and Gomez y Paloma (2014); Kabunga, Dubois and Qaim (2014); Mariano and Giesecke (2014); Munro (2003); Sastry, Rashmi and Rao (2011)
	Income	Limited income opportunities	●		●		Louhichi and Gomez y Paloma (2014)
	Income	Income growth			●		Kabunga, Dubois and Qaim (2014), UNEP (2009)
	Production	Limited agricultural sources	●	●			Gandhi and Zhou (2014); Qureshi, Hanjra and Ward (2013)
	Demographics	Population growth and food demand	●				UNEP (2009), Godfray et al. (2010); Pretty et al. (2010)
	Food disposal	Food waste management					UNEP (2009)
	Energy	Diversification of energy resources		●			Erb, Haberl and Plutzar (2012); Negash and Swinnen (2013); Thompson and Meyer (2013)
	Distribution	Trade liberalization				●	Pyakuryala, Roy and Thapa (2010)
	Climate change	Greenhouse gas emissions		●			Porter et al. (2014)
	Energy	Biofuels		●			FAO (2006)
	Exchange	Urbanization	●				Deutsch, Dyball and Steffen (2013); Porter et al. (2009); Porter et al. (2014)
	Investments & Infrastructure	Decline in investments and lack of infrastructure			●	●	UNEP (2009)
	Technology	Technological advances in agriculture		●	●	●	Dobermann and Nelson (2011), Branford (2011)
Access	Price affordability	Commodities' price	●		●	●	Babu, Gajanan and Sanyal (2014); D'Souza and Jolliffe (2013); UNCTAD (2009)
	Customer preferences	Substantial changes in the food consumption behaviour in developing countries	●				Gandhi and Zhou (2014); Kearney (2010); Dobermann and Nelson (2011)
	Investments & Infrastructure	Decline in investments and lack of infrastructure			●	●	World Bank (2008b)
Stability	Risk management	Supply chain disturbances	●		●		Vlajic, van der Vorst and Haijema (2012)
	Weather	Extreme weather phenomena		●			Pangaribowo, Gerber, and Torero (2013)
	Politics	Wars, conflicts, embargoes	●			●	UNEP (2009)
Utilization	Hygienic and sanitary quality	Inability to track the source of contamination	●			●	Lee, Palekar, and Qualls (2011)
	Health safety	Health safety incidents	●		●	●	Aung and Chang (2014); Gandhi and Zhou (2014)
	Nutrition balance	Food nutritional value	●			●	Babu, Gajanan and Sanyal (2014); Pérez-Escamilla (2012)
	Nutrition balance	Obesity levels in developed countries	●				Foresight (2007)
Symbols: Soc for Societal, Env for Environmental, Eco for Economic, Gov for Governmental.							

uncertainties to global food supply networks by vitally undermining their stability performance in terms of supply capacity and continuity (Vlajic, van der Vorst and Haijema, 2012; United Nations Environment Programme, 2009).

Finally, governance plays a key role in food security issues, given that policy-making and diplomacy are among the core factors that shape the global food security landscape (Branford, 2011). Issuing protective trade regulations, maintaining beneficial international affairs, protecting domestic cropland property rights, and ensuring food self-sufficiency are a few of the most challenging decision-making fields where governments have to take action in the near future. Especially, the developing countries appear to face critical weaknesses in almost all of the aforementioned priorities. On the other hand, food industry enterprises and supply networks should target to economic sustainability through their effective and social responsible strategic operation, as the increasing economic and social inequalities might prove to be a boomerang, seriously endangering corporate profitability.

System Dynamics Conceptual Framework

The SD approach has been successfully used in the past to tackle policy-making and strategic decision-making problems (Forrester, 1961; Sterman, 2000). SD is a simulation methodological tool which is appropriate to analyse and understand the development and the behaviour of complex systems over time. The SD approach was developed in MIT and was originally used to examine the instable employment environment in General Electric while over the years the tool had been employed to conduct simulations of diverse scientific and engineering systems (Forrester, 1969). According to Roberts (1978), the feedback control characteristics of the SD approach render it as the appropriate tool for decision-making at a strategic level regarding a broad range of problems, from managerial and socioeconomic to organisational ones.

Therefore, SD is a simulation-based technique that could be employed to model the feedbacks that both promote and limit food security. The integration of food security and the SD approach has only recently attracted the research interest in order to successfully capture the dynamics and the interdisciplinary nature of a food security system and its components (Ayenew, 2013; Muetzelfeldt, 2010; Shilling, 2012). To that end, in this Section we propose a SD modeling framework that could be employed as a useful tool for assessing the impact of various interventionary policies on promoting food security (see Figure 2).

The core concepts of SD are feedbacks, causal loop diagrams and stock and flow maps. Feedback loops and structures are necessary because systems rarely exhibit linear behaviour due to the interactions among the physical and institutional configuration of the systems. Feedback structures are fundamental because they capture the real patterns or modes of systems' behaviour as they dynamically evolve through the time. Causal loop diagrams are used in order to capture the mental models which managers conceive of a system. Except for the latter remark, causal loop diagrams assist modellers in representing the feedback structures of a system. In a causal diagram, arrows describe the causal influences among the variables of the system (Sterman, 2000). Each arrow is assigned a polarity that indicates the relation between dependent and independent variables. A positive (+) polarity denotes that the effect changes towards the same direction as the cause (reinforcing loop). On the other hand, a negative (-) polarity denotes that the effect changes towards the opposite direction of the cause (balancing loop).

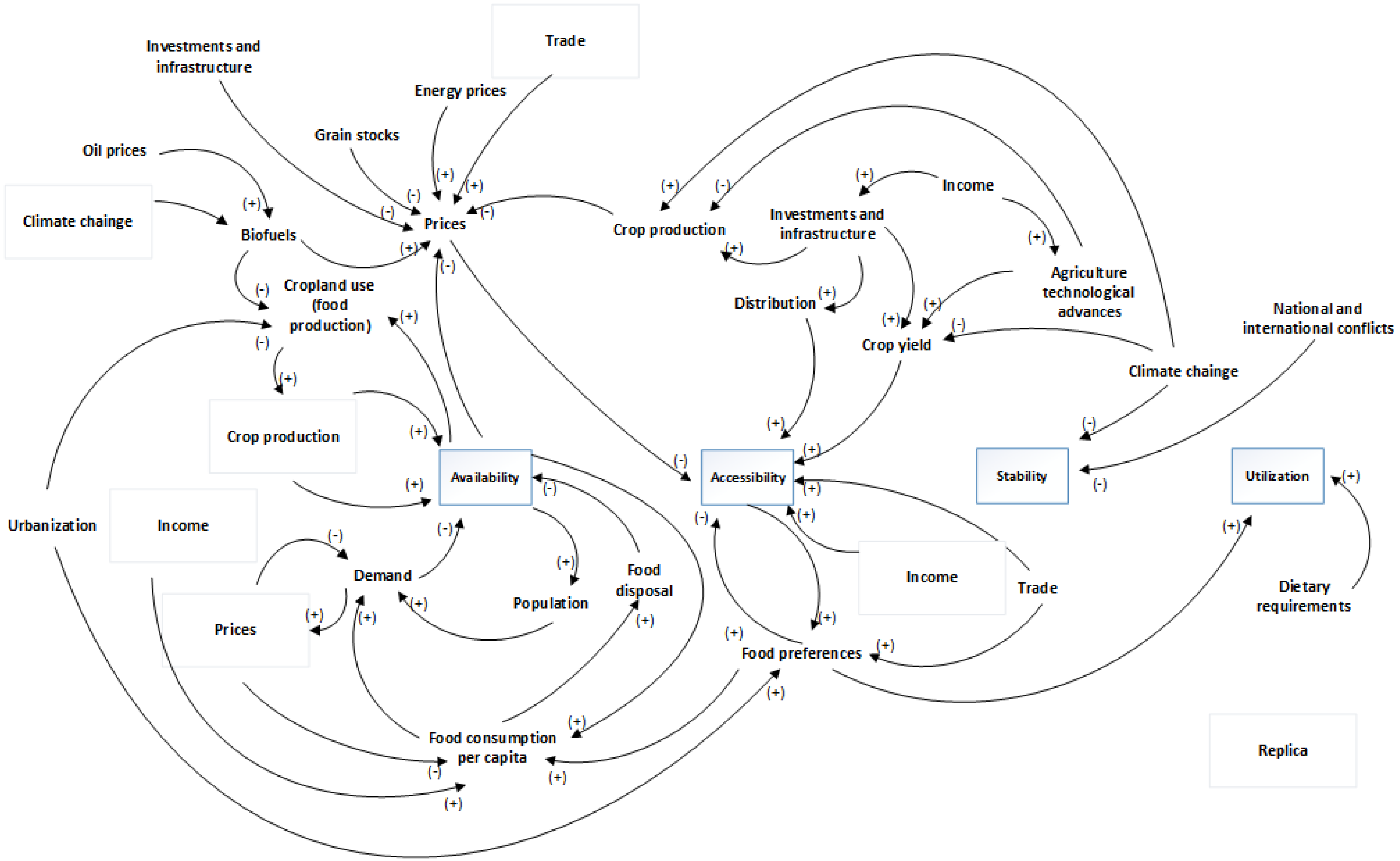

Figure 2: Food security conceptual framework (SD causal loop diagram)

Conclusions and Discussion

Generally, food security arises as a pivotal issue in the public agenda and a plethora of global initiatives supported by international organizations aim at eradicating extreme poverty and hunger. To that effect, this paper captures the associated challenges and the complex nature of the decision-making process for the promotion of food security within a sustainability context. We first presented a definition of food security and its components. Following that, we identified critical challenges, and presented a taxonomy of indicative existing state-of-the-art literature along the sustainability axes. Further, we developed a SD framework that captures the multidimensional nature of food security and its determinants.

Our critical analysis reveals that even though food security has been addressed by the research community, there is a lack of integrated systemic approaches that could incorporate sustainability aspects and might support the effective design and planning of the respective agrifood networks. Tackling food security and sustainability within an AFSC context is vital to ensure the consumers' confidence over the agrifood product security (Lee, 2004; Unnevehr, 2000) through promoting food security at each echelon of an AFSC network (Defra, 2006; Marucheck et al., 2011; Thirumalai and Sinha, 2011).

Further, the findings of our literature review highlight the dynamic and stochastic nature of food security. Consequently, the necessity for the development of tools to approach the dynamic and stochastic food security problems is recognised, since theoretical analyses that have been mostly employed thus far, focussing mainly on generic interventions. The provided SD modelling, along with the respective taxonomy, could provide important managerial insights about the drafting of robust policy interventions towards the promotion of food security and the efficient development and management of sustainable AFSCs.

Acknowledgement

This research has received funding from the European Union's Seventh Framework Programme (FP7-REGPOT-2012-2013-1) under Grant Agreement No. 316167, Project Acronym: GREEN-AgriChains, Project Full Title: "Innovation Capacity Building by Strengthening Expertise and Research in the Design, Planning and Operations of Green Agrifood Supply Chains", Project Duration: 2012–2016.

References

Anderson, K., 2010, "Globalisation's effects on world agricultural trade, 1960–2050," *Philosophical Transactions of the Royal Society, B, Biological Sciences*, 365, 3007–3021.

Aung, M., and Y.S. Chang, 2014, "Temperature management for the quality assurance of a perishable food supply chain," *Food Control*, 40, 198-207.

Ayenew, M.M., 2013, "Agricultural Production and Food Insecurity in Ethiopia: System Dynamics Approach," Master Thesis. Department of Geography, System Dynamics Group, University of Bergen.

Babu, S.C., Gajanan, S.N., and P. Sanyal, 2014, "Chapter 5 - Changes in Food Consumption Patterns: Its Importance to Food Security—Application of One-Way ANOVA," in S.C. Babu, S.N. Gajanan, and P. Sanyal (eds.), *Food Security, Poverty and Nutrition Policy Analysis* (Second Edition), San Diego, Academic Press, 117-138.

Bandara J., and S. Jayasuriya, 2009, "Distortions to agricultural incentives in Sri Lanka," in K. Anderson, and W. Martin (eds.), *Distortions to Agricultural Incentives in Asia*, Washington, D.C., World Bank, 409–440.

Beske, P., Land, A., and S. Seuring, 2013, "Sustainable supply chain management practices and dynamic capabilities in the food industry: A critical analysis of the literature," *International Journal of Production Economics*, In Press.
Bourlakis, M., Maglaras, G., Aktas, E., Gallear, D., and C. Fotopoulos, 2013, "Firm size and sustainable performance in food supply chains: Insights from Greek SMEs," *International Journal of Production Economics*, In Press.
Brahmbhatt, M., and L. Christiaensen, 2008, "Rising Food Prices in East Asia: Challenges and Policy Options," Washington D.C., Sustainable Development Department of the East Asia and Pacific region of the World Bank.
Branford, S., 2011, "Food sovereignty: Reclaiming the global food system," London, War on Want.
Carter, C.R., and M Dresner, 2001, "Purchasing's role in environmental management: Cross-functional development of grounded theory," *Journal of Supply Chain Management*, 37(3), 12-27.
Coates, J., 2013, "Build it back better: Deconstructing food security for improved measurement and action," *Global Food Security*, 2(3), 188-194.
D'Souza, A., and D. Jolliffe, 2013, "Conflict, food price shocks, and food insecurity: The experience of Afghan households," *Food Policy*, 42, 32-47.
Defra, 2006, "Food Security and the UK: An Evidence and Analysis Paper", London, Department for Environment, Food and Rural Affairs, Food Chain Analysis Group.
Defra, 2009, "*UK Food Security Assessment: Our Approach*". Department for Environment, London, Food and Rural Affairs.
Deutsch L., R. Dyball, and W. Steffen, 2013, "Feeding cities: Food security and ecosystem support in an urbanizing world," in T. Elmqvist, M. Fragkias, J. Goodness et al. (eds.), *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities*, Springer, Dordrecht.
Dobermann, A., and R. Nelson, 2011, *Opportunities and Solutions for Sustainable Food Production*, New York, Sustainable Development Solution Network.
Dorward, A., and E. Chirwa, 2011, "The Malawi agricultural input subsidy programme: 2005/06 to 2008/09," *International Journal of Agricultural Sustainability*, 9, 232–247.
Ecker, O., and C. Breisinger, 2012, "The Food Security System," Washington, D.C., International Food Policy Research Institute, 1–14.
Erb, K.-H., Haberl, H., and C. Plutzar, 2012, "Dependency of global primary bioenergy crop potentials in 2050 on food systems, yields, biodiversity conservation and political stability," *Energy Policy*, 47, 260-269.
Evans, A., 2009, *The Feeding of the Nine Billion: Global Food Security*, Chatham House.
FAO, 1996, "Rome Declaration on World Food Security," Rome, Food and Agriculture Organization.
FAO, 1997, *The food system and factors affecting household food security and nutrition. Agriculture, food and nutrition for Africa: A resource book for teachers of agriculture*, Rome, Agriculture and Consumer Protection Department.
FAO, 2006, "World agriculture: towards 2030/2050," Rome, Food and Agriculture Organization.
FAO, 2008, "The State of Food and Agriculture 2008," Rome, Food and Agriculture Organization.
FAO, 2009a, "State of Food Insecurity in the World," Rome, Food and Agriculture Organization.
FAO, 2009b, "Declaration of the World Food Summit on Food Security," Rome, Food and Agriculture Organization.
FAO, 2011, http://www.fao.org/fileadmin/user_upload/ISFP/High_food_prices.pdf <Accessed on: May 04, 2014>.

Foresight, 2007, "Tackling Obesities: Future Choices," London, Government Office for Science.
Forrester, J., 1961, *Industrial Dynamics*, Cambridge, MIT Press.
Forrester, J., 1969, *Urban Dynamics*, Cambridge, MIT Press.
Fritz, M., and T. Hausen, 2009, "Electronic supply network coordination in agrifood networks: Barriers, potentials, and path dependencies," *International Journal of Production Economics*, 121(2), 441-453.
Gandhi, V.P., and Z. Zhou, 2014, "Food demand and the food security challenge with rapid economic growth in the emerging economies of India and China," *Food Research International*, In Press.
Godfray, H., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J., Pretty, J., Robinson, S., Thomas, S., and C. Toulmin, 2010, "Food security: The challenge of feeding 9 billion people," *Science Express*, 28 January.
Gregory, P.J., Ingram, J.S.I., and M. Brklacich, 2005, "Climate change and food security," *Philosophical Transactions of the Royal Society B: Biological Sciences*, 360(1463), 2139–2148.
Haffez, K., Griffiths, M., Griffiths, J., and J. Nairn, 1996, "System design of a two-echelon steel industry supply chain," *International Journal of Production Economics*, 45, 121–130.
Henningsson, S., Hyde, K., Smith, A., and M.Campbell, 2004, "The value of resource efficiency in the food industry: A waste minimization project in East Anglia, UK," *Journal of Cleaner Production,* 12(5), 505-512.
Hubbard, L.J., and C. Hubbard, 2013, "Food security in the United Kingdom: External supply risks," *Food Policy*, 43, 142-147.
Ingram, J.S.I., Ericksen, P., and D. Liverman, 2010, *Food Security and Global Environmental Change*, Earthscan.
Kabunga, N.S., Dubois, T., and M. Qaim, 2014, "Impact of tissue culture banana technology on farm household income and food security in Kenya," *Food Policy*, 45, 25-34.
Kearney, J., 2010, "Food consumption trends and drivers," *Philosophical Transactions of the Royal Society, B, Biological Sciences*, 365, 2793–2807.
Kumar, N., and A.R. Quisumbing, 2013, "Gendered impacts of the 2007–2008 food price crisis: Evidence using panel data from rural Ethiopia," *Food Policy*, 38, 11-22.
Lawrence, G., Lyons, K. and T. Wallington, 2009, *Food Security, Nutrition and Sustainability* (eds.), London, Earthscan.
Lee, H.L., 2004, "Supply chain security – Are you ready?," Palo Alto, C.A., Stanford Global Supply Chain Management Forum, Stanford University.
Lee, H.L., and S. Whang, 2005, "Higher supply chain security with lower cost: Lessons from total quality management," *International Journal of Production Economics*, 96(3), 289–300.
Lee, J., Palekar, U.S., and W. Qualls, 2011, "Supply chain efficiency and security: Coordination for collaborative investment in technology," *European Journal of Operational Research*, 210(3), 568-578.
Louhichi K., and S. Gomez y Paloma, 2014, "A farm household model for agri-food policy analysis in developing countries: Application to smallholder farmers in Sierra Leone," *Food Policy*, 45, 1-13.
Mariano, M.J.M., and J.A. Giesecke, 2014, "The macroeconomic and food security implications of price interventions in the Philippine rice market," *Economic Modelling*, 37, 350-361.
Marucheck, A., 1987, "On product liability and quality control," *IIE Transactions*, 19, 355–360.
Marucheck, A., Greis, N., Mena, C., and C. Linning, 2011, "Product safety and security in the global supply chain: Issues, challenges and research opportunities," *Journal of Operations Management*, 29(7-8), 707-720.
Maxwell, D., and M. Fitzpatrick, 2012, "The 2011 Somalia famine: Context, causes, and complications," *Global Food Security*, 1, 5–12.
Maxwell, S., and M. Smith, 1992, "Household food security: A conceptual review" in Maxwell, S., and T. Frankenberger (eds.), *Household Food*

Security: Concepts, Indicators, Measurements: A Technical Review, New York and Rome, UNICEF and IFAD.
Muetzelfeldt, R., 2010, "Extended System Dynamics modelling of the impacts of food system drivers on food security, livelihoods and the environment," CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).
Munro, L.T., 2003, "Zimbabwe's agricultural recovery programme in the 1990s: An evaluation using household survey data," *Food Policy*, 28, 437-458.
Negash, M., and J.F.M. Swinnen, 2013, "Biofuels and food security: Micro-evidence from Ethiopia," *Energy Policy*, 61, 963-976.
Pangaribowo, E.H., Gerber, N., and M. Torero, 2013, "Food and Nutrition Security Indicators: A Review," Foodsecure Working Paper 04.
Pérez-Escamilla, R., 2012, "Can experience-based household food security scales help improve food security governance?," *Global Food Security*, 1(2), 120-125.
Porter, J., Costanza, R., ,H., Sigsgaard L., and S. Wratten, 2009, "The value of producing food, energy, and ecosystem services within an agro-ecosystem," *AMBIO*, 38(4), 186–193.
Porter, J.R., Dyball, R., Dumaresq, D., Deutsch, L., and H. Matsuda, 2014, "Feeding capitals: Urban food security and self-provisioning in Canberra, Copenhagen and Tokyo," *Global Food Security*, 3(1), 1-7.
Power, M.E., and F.S. Chapin, 2009, "Planetary stewardship," *Frontiers in Ecology and the Environment*, 7(8), 399.
Pretty, J., Sutherland, W.J., J. Ashby et al., 2010, "The top 100 questions of importance to the future of global agriculture," *International Journal of Agricultural Sustainability*, 8(4), 219–236.
Pyakuryal, B., Roy, D., and Y.B. Thapa, 2010, "Trade liberalization and food security in Nepal," *Food Policy*, 35(1), 20-31.
Qureshi, M.E., Hanjra, M.A., and J. Ward, 2013, "Impact of water scarcity in Australia on global food security in an era of climate change," *Food Policy*, 38, 136-145.
Roberts, E.B., 1978, *Managerial Applications of System Dynamics*, Acton, M.A., Pegasus Communications.
Rockström, J., Steffen, W., Noone, K., et al., 2009, "Planetary boundaries: Exploring the safe operating space for humanity," *Ecological Society*, 14, 2.
Sastry, R.K., Rashmi, H.B., and N.H. Rao, 2011, "Nanotechnology for enhancing food security in India," *Food Policy*, 36(3), 391-400.
Shilling, J., 2012, "Systemic Approach to Sustainable Development Strategies and Food Security," Millennium Institute.
Sterman, J., 2000, "Business dynamics: Systems thinking and modeling for a complex world," McGraw-Hill.
Tako, A.A., and S. Robinson, 2012, "The application of discrete event simulation and system dynamics in the logistics and supply chain context," *Decision Support Systems*, 52(4), 802-815.
Thirumalai, S., and K.K. Sinha, 2011, "Product recalls in the medical device industry: An empirical exploration of the sources and financial consequences," *Management Science*, 57, 376-392.
Thompson W., and S. Meyer, 2013, "Second generation biofuels and food crops: Co-products or competitors?," *Global Food Security*, 2(2), 89-96.
Tsolakis, N., Keramydas, C., Toka, A., Aidonis, D., and E. Iakovou, 2014, "Agrifood supply chain management: A comprehensive hierarchical decision-making framework and a critical taxonomy," *Biosystems Engineering*, 120, 47-64.
Tweeten, L., 1999, "The economics of global food security", *Review of Agricultural Economics*, 21(2), 473–488.
UNCTAD, 2009, "The 2008 food price crisis: Rethinking food security policies," G24 Discussion Paper Series.

United Nations Environment Programme, 2009, "The environmental food crisis – The environment's role in averting future food crises: A UNEP rapid response assessment," Norway, GRID-Arendal.
United Nations, 2013, "World Population Prospects: The 2012 Revision," New York, Department of Economic and Social Affairs.
Unnevehr, L.J., 2000, "Food safety issues for fresh food product exports from LDCs," *Agricultural Economics*, 23, 231–240.
Validi, S., Bhattacharya, A., and P.J. Byrne, 2014, "A case analysis of a sustainable food supply chain distribution system — A multi-objective approach," *International Journal of Production Economics*, In Press.
Vlajic, J., van der Vorst, J., and R., Haijema, 2012, "A framework for designing robust food supply chains," *International Journal of Production Economics*, 137(1), 176-189.
World Bank, 2008a, "Rising Food and Fuel Prices: Addressing the Risks to Future Generations," Washington, D.C., World Bank.
World Bank, 2008b, "World Development Report: Agriculture for Development," Washington, D.C., World Bank, 386.