Small Farm Agrifood Supply Chains and Sustainable Food Security in the Developed World: A System Dynamics Methodology

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Abstract— *The aim of the present research is to enhance food security and sustainability in developed countries through providing a simulation tool for supporting the impact assessment of interventionary policies for the support of smallholdings' farming. To this effect, we first discuss the role of small farms towards ensuring food security and sustainability in the developed world. Following, the System Dynamics methodology is employed to explore the effect of interventions on the diffusion of small farms' cultivated commodities to the specific Greek food market. Following, a simulation modelling tool is developed that specifically captures four external factors affecting the adoption rate of the refereed agrifood products, namely: (i) consumers' environmental awareness, (ii) social implications, (iii) economic incentives, and (iv) health and nutrition consciousness. The simulation results suggest that policy interventions that could play a critical role in ensuring food security and sustainable development in developed nations should mainly focus on the increase of advertising expenditure in promoting small-scale farming and locally cultivated products, on consumers' training and education, and on subsidies of investments in smallholdings.*

Keywords— Agrifood Supply Chains, Food Security and Sustainability, Simulation, Small Farms, System Dynamics.

I. INTRODUCTION

Food security and sustainable agricultural development emerge as key challenges to all nations [1; 2]. Projections about a global population growth to 9.1 billion by 2050 and a corresponding increase in food demand by 70% [3], in tandem with climate change, temperature rise and rainfall fluctuation [4], formulate a gamut of factors that position the food insecurity challenge at a prominent position in the international policy and research agenda. Nevertheless, evidence in the extant literature suggest that the actual concern does not apply to the increase of food production capacity by 70% within the forthcoming 40 years, but rather lies within the capability to configure efficient agrifood supply chains to increase households' accessibility to food commodities by 70% [3], and to meet the diverse dietary habits in the developed world [5].

Notwithstanding the extensive research on agrifood production and distribution systems, several figures justify the fact that food security concerns still predominate in public debates, both in developing countries and developed nations. For example, estimations indicate that nearly 870 million people around the world suffer from undernourishment or chronic hunger [6], while contemporarily around 2 billion people suffer from micronutrient insufficiency or hidden hunger [7] and approximately 500 million people suffer from obesity [8]. Furthermore, specific incidents appear to have a detrimental impact on the food availability and supply stability in industrialized nations [9], like the: (i) sudden and sharp increase in world food prices in 2007–2008, (ii) increased use of agricultural land for bioenergy crops, (iii) strict trade regulations and political uncertainty, and (iv) rapidly growing food demand in China and India. To that end, small farms (SFs) or smallholdings are suggested as a feasible approach tackle the developed world's food security and sustainability challenges [10]. This is further accentuated by the ongoing funding schemes of the European Union to support research initiatives for the development of short food supply chains and local food systems in the Community [11]. In addition, the European Union recognizes the significance of SFs in food and nutrition security and has already approved funds to support the development of smallholdings and related food business landscapes [12].

Europe hosts around 14 million farms with the SFs to account for 2.5% of the total used agricultural area [13]. Nevertheless, around 3 million farms in Europe (about 20% of the total number of farms) have disappeared during the last eight years, mainly SFs [10]. However, smallholdings could stimulate local business and job creation [14], while they have been found to reduce poverty gap more intensively than other sectors [15]. Additionally, SFs are reported to promote welfare through

effective nutrition intake [16], and are also documented to be more resource-efficient and productive per hectare compared to large-scale plantations [17].

However, the assessment of the SFs' appeal on food markets in the developed world lacks a comprehensive system perspective. Such a quantitative model would be of great interest to policy-makers and enterprises in order to devise effective regulations and interventions towards the development of SFs, while harnessing related economic, environmental and social sustainability benefits. In this work, the market diffusion of agricultural commodities produced in SFs is particularly addressed. The objective of this study is two-fold: (i) to develop a policy-making support tool at the strategic level, and (ii) to identify and assess interventions that could support the role of SFs for ensuring food security and sustainability in developed countries. The rest of the paper is organized as follows. In Section 2 major sustainability challenges that highlight the significance of SFs towards ensuring food security are discussed. Following, in Section 3 a System Dynamics (SD) modeling framework is developed for managing the consumers' adoption of agricultural commodities cultivated in SFs through incorporating an extension of the Bass diffusion model. The application of the proposed framework is further illustrated on the real-world case study of Greece while interesting policy-making interventions are also analyzed. Finally, in Section 4 conclusions and suggested future research avenues are discoursed.

II. FOOD SECURITY AND SMALL FARMS: A DEVELOPED WORLD'S PERSPECTIVE

Research and empirical evidence emphasizing food security related solutions in developing countries, along with policy interventions to foster the sustainability transition in the respective agricultural systems, is rather overwhelming. On the contrary, food security concerns have been insufficiently tackled for the case of developed countries with stakeholders often neglecting the economic, environmental and social challenges stimulating this phenomenon.

In the develop world, the continuously rising food prices along with the low economic recovery rates from the recent financial recession highlight potential food insecurity implications [18]. Particularly, consumers in Europe spend one fifth of their income on food supplies, thus further deepening social inequality in the region [19]. In addition, Europe is reported as being food insufficient implying that policy-makers for rural development need to promote the domestic production of protein crops at the expense of other arable crops [20]. Moreover, in Europe a 2% decrease in total agricultural output has been observed during the last decade [21], while in the United States a 20% decline in farm holdings is reported [22].

From an environmental perspective, climate change combined with loss of biodiversity, water scarcity, soil erosion and depletion are expected to reduce agricultural yield by at least 5-25% by 2050 [23]. Additionally, every year 1.3 billion tons of foods are wasted globally while in the industrialized world over 40% of food wastage occurs at the retail and consumer levels of the agrifood supply chains [24].

Moreover, in the developed nations live about 15.7 million people who suffer from chronic hunger and undernourishment [6]. Notably, an alarming increase by 15.7% since 1990 on the total rate of chronic hunger and undernourishment in developed countries is reported [6]. Obesity almost doubled between 1980 and 2008 globally and in Europe nearly 50% of both men and women are overweight [25]. Statistical figures also highlight that in Europe around 1 in 3 of 11-year-old children are overweight [18]. Furthermore, the ageing population in Europe [26] is associated with the increased trend towards a diet rich in carbohydrates and animal protein [21].

In view of the aforementioned challenges, a radical transformation to promote sustainable agricultural intensification is required [27]. To that end, the need to enhance the role of smallholders' farming towards food production and natural resource stewardship is critical. In this vein, sustainability implications of SFs are closely related to food security as smallholdings promote well-being through effective nutrition intake [16]. Indicatively, the issue of seasonal hunger patterns is documented to have been tackled by implementing governmental projects to foster the development of smallholding cooperatives. Additionally, small-scale farming in mountainous Norway contributes to the agricultural viability through promoting farm revenues and food security [28].

III. SYSTEM DYNAMICS FRAMEWORK

In this section, a novel modeling approach for managing the diffusion of commodities produced in SFs is developed, merging: (i) the theory of new product diffusion adapted from the field of marketing, and (ii) the theory of SD, which has a proven track record for tackling strategic decision-making problems. The main goals of the model are to (a) study the adoption of SFs products by consumers, (b) predict the SFs evolution during a given time horizon, and (c) evaluate the impact of alternative policy interventions on SFs.

The model is based on an extension of the Bass Diffusion Equation [29]:

$$\frac{dN}{dt} = \left\{\left[p + \frac{q}{m}N(t)\right][m - N(t)]\right\} x(t)$$

where, N(t) is the cumulative number of SFs products′ consumers (adopters) in a specific geographical region at time t, dN/dt is the rate of change for the SFs products' consumers (adopters) at time t, m stands for the sum of potential consumers (fraction of regional or national population), p is the coefficient of innovation, q is the coefficient of imitation, and x(t) is an general intervention function that describes the current effect of the time-dependent external decision variables on the probability of SFs product consumption at time t.

Fig. 1 presents a simplified conceptual model of the system under study. The input parameters include the innovation and imitation factors, p and q, that represent the corresponding trends for the first time consumers (innovators) of SFs products, and the word-of-mouth effect, i.e. consumers that purchase the product after being influenced by previous adopters (imitators), respectively. Moreover, the utilized agricultural area (UAA) that refers to the land used for farming in a given region is used as a measure of the aggregate large and small farms' size, while the standard gross margin (SGM), that is the difference between the value of the agricultural output (crops or livestock) and the cost of inputs required to produce that output, is used as a measure of the economic size of the agricultural holdings. The labor force employed in these farms is also an input parameter, as well as the productivity factor (α) that express the ratio of small farms to large farms productivity. Finally, the total population of a given region (P), and the target population, i.e. the total market size/sum of potential consumers, are also critical inputs for the diffusion model. The data regarding the aforementioned input parameters were obtained through Eurostat, FAO, and similar systems. The outcome variables of the model, which stand as the system's key performance and monitoring indicators, are the total employees in small farms, and the total profit of small farms across the region under study.

The model was applied in the case of Greece. The preliminary results (Fig. 2) indicate the positive future potential of small-scale farming, in terms of employment (total SFs employees) and profits (total SFs profits). Indicatively, given that no intervention is applied to accelerate the SFs products market diffusion, the total number of SFs' employees and the total SFs' profits, are estimated to rise by 45%, and 30% respectively within 20 years. This auspicious prospect could be further accelerated through appropriate interventions on the part of governments and smallholders in order to influence consumers' behavior regarding SFs products.

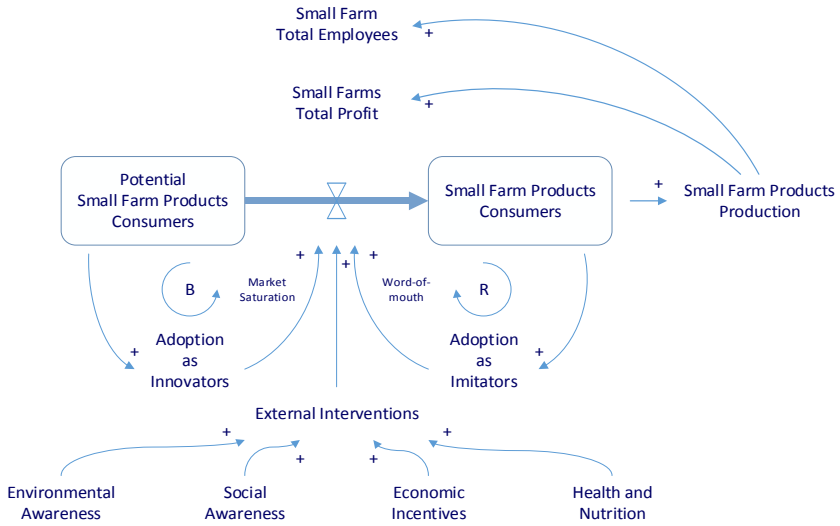

FIGURE 1. CONCEPTUAL MODEL OF THE SYSTEM UNDER STUDY.

Towards this direction and motivated by the EU's recognition of the need to enhance the role of SFs towards safeguarding sustainable development and food security across Europe, the proposed model allows for the simulated implementation, monitoring, and evaluation of a set of real-world policy-making interventions on the SFs products' diffusion rate, through the

general intervention function x(t). The scope of these policy-making actions is to increase the rate of consumption of agricultural products cultivated in SFs and consequently increase the SFs' market share in the developed countries. Specifically, four external factors that affect the adoption rate of SFs products in the Greek food market were identified: (i) environmental awareness, (ii) social awareness, (iii) economic incentives, and (iv) health and nutrition awareness. Indicative policy-making actions towards the direction of developing SFs products' production and consumption include the increase of advertising expenditure in promoting the sustainability aspect of small-scale farming (products and farming practices) (environmental awareness), the market promotion of local products, related training and/or educational interventions, the promotion of healthy food as a critical component of wellbeing (social awareness – health and nutrition), and the subsidy of investments in agriculture (new farmers) (economic incentives).

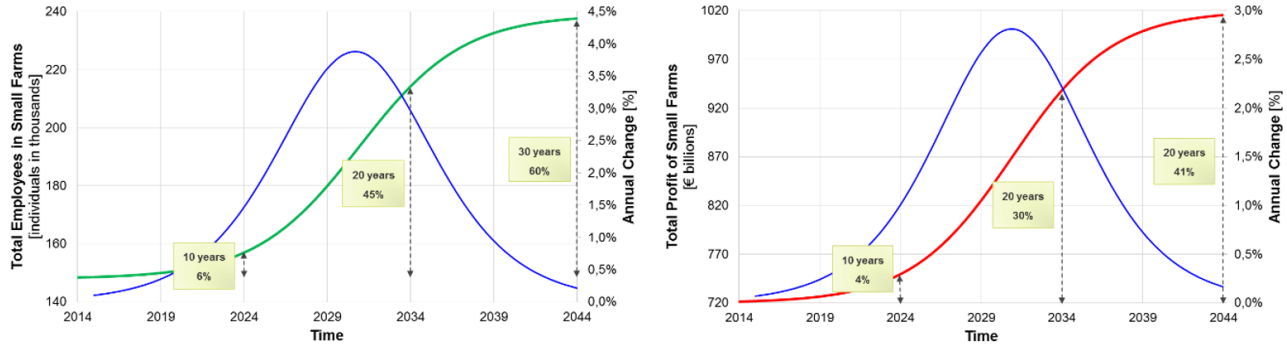

FIGURE 2. TOTAL EMPLOYEES AND TOTAL PROFIT EVOLUTION (SMALL FARMS).

IV. CONCLUSIONS

Food security has a multidisciplinary nature and it is an important issue not only for the developing world, but also in the developed countries. The prevailing farming practices are unsustainable. Small Farms could play a critical role in Food Supply Chains ensuring Food Security and Sustainable development at the same time. The operation of food markets is quite complex and perhaps, the (mainly social and environmental) merit of a small-scale agricultural production is not enough to build momentum for increase the number of small farms. Thus, (national and international) governance with selected interventions may have a key role. To this end, this paper provides a new quantitative policy-making support tool based on System Dynamics methodology, which has been used for the Greek food market. This is a first time effort and there is space for improvements. Future research directions include further validation and verification of the System Dynamics model based upon data from FAO and Eurostat, the examination of alternative diffusion models, the development of a multi-level model incorporating all the EU-27 countries and different agricultural products on a single-product basis (i.e. cereals, nuts, wheat etc.).

REFERENCES

[1] A. Q. Al-Amin and F. Ahmed, "Food security challenge of climate change: An analysis for policy selection", Futures, vol. 83, pp. 50-63, October 2016.

[2] United Nations, World Economic and Social Survey 2013: Sustainable Development Challenges, Department of Economic and Social Affairs of the United Nations Secretariat: New York, 2013.

[3] FAO, How to Feed the World in 2050, Food and Agriculture Organization of the United Nations: Rome, 2009.

[4] A. Borch and U. Kjærnes, "Food security and food insecurity in Europe: An analysis of the academic discourse (1975–2013)", Appetite, vol. 103, pp. 137-147, August 2016.

[5] B.-H. Lin, M. Ver Ploeg, P. Kasteridis, and S. T. Yen, "The roles of food prices and food access in determining food purchases of low-income households", J. Policy Model., vol. 36, pp. 938-952, September–October 2014.

[6] FAO, The State of Food Insecurity in the World – The multiple dimensions of food security, Food and Agriculture Organization of the United Nations: Rome, 2013.

[7] FAO, The State of Food Insecurity in the World – Undernourishment around the world, Food and Agriculture Organization of the United Nations: Rome, 2012.

[8] WHO, Global Status Report on Noncommunicable Diseases 2010, World Health Organization: Geneva, 2011.

[9] L. J. Hubbard and C. Hubbard, "Food security in the United Kingdom: External supply risks", Food Policy, vol. 43, pp. 142-147, December 2013.

[10] Eurovia, Land Concentration, Land Grabbing and People's Struggles in Europe, European Coordination Via Campesina: Brussels, 2013.

[11] EAFRD, Short Food Supply Chains and Local Food Systems in the EU. A State of Play of their Socio-Economic Characteristics, European Agricultural Fund for Rural Development: Seville, 2013.

[12] European Commission, Sustainable Food Security H2020-SFS-2015-2 – Small Farms but Global Markets: The Role of Small and Family Farms in Food and Nutrition Security, European Commission: Brussels, 2013.

[13] European Union, EU Farm Economics 2012, European Commission Directorate-General for Agriculture and Rural Development: Brussels, 2013.

[14] X. Diao, P. Hazell, D. Resnick and J. Thurlow. The Role of Agriculture in Development: Implications for sub-Saharan Africa – IFPRI Research Report No. 153, International Food Policy Research Institute: Washington, D.C., 2007.

[15] L. Christiaensen, L. Demery, and J. Kuhl, "The (evolving) role of agriculture in poverty reduction – An empirical perspective", J. Dev. Econ., vol. 96, 2011, pp. 239-254, November 2011.

[16] M. Faber and F. Wenhold, "Nutrition in contemporary South Africa", Water SA, vol. 33, pp. 393-400, 2007.

[17] S. M. Borras, C. Kay, and A. H. Akram-Lodhi, "Agrarian reform and rural development: Historical overview and current issues". In A. H. Akram-Lodhi, S. M. Borras Jr and C. Kay, Land, poverty and livelihoods in an era of globalization: Routledge, London and New York, 2007, pp. 1-40.

[18] A. Mohseni-Cheraghlou, "The aftermath of financial crises: A look on human and social wellbeing", World Dev., vol. 87, pp. 88-106, November 2016.

[19] FAO, The State of Food Insecurity in the World – How Does International Price Volatility Affect Domestic Economies and Food Security?, Food and Agriculture Organization of the United Nations: Rome, 2011.

[20] S. Noleppa and M. Cartsburg, Agricultural Self-sufficiency of the European Union: Statistical evidence, Agripol – network for policy advice GbR: Berlin, 2013.

[21] R. Floyd, Food Security in Europe in the Age of Global Climatic Change, International Relations and Security Network, Center for Security Studies, ETH Zurich: Switzerland, 2014.

[22] R. A. Hoppe, J. M. MacDonald, and P. Korb, Small Farms in the United States: Persistence Under Pressure, United States Department of Agriculture, Washington, D.C., 2010.

[23] C. Dimitri, A. Effland, and N. Conklin, The 20th Century Transformation of U.S. Agriculture and Farm Policy, United States Department of Agriculture: Washington, D.C., 2005.

[24] D. Gunders, Wasted: How America Is Losing Up to 40 Percent of Its Food from Farm to Fork to Landfill, Natural Resources Defense Council: New York, 2012.

[25] WHO, World Health Statistics 2008, World Health Organization: Geneva, 2008.

[26] Eurobarometer, Special Eurobarometer 378 – Active Ageing, European Commission: Luxembourg, 2012.

[27] UNEP/IFAD, Smallholders, Food Security, and the Environment, United Nations Environment Programme/International Fund for Agricultural Development: Kenya/Rome, 2013.

[28] K. Rønningen, B. E. Flø., G.A. Olsson, S. K. Hanssen, and S. When, Sustainability Assessment of Agro-eco-systems and Rural Development in Mountain Areas, Scenarios for Eastern Jotunheimen, Report 9/05, Centre for Rural Research: Trondheim, 2005.

[29] F. Bass, T. Krishnan, and D. Jain, "Why the bass model fits without decision variables", Mark Sci, vol. 13(3), pp. 203-223, 1994.