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A System Dynamics Approach to Food Security through Smallholder Farming in the UK

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The aim of this research is to investigate the role of smallholder farming in tackling food security and sustainability related challenges in the developed world. In this regard, the relevant literature is discussed and a System Dynamics modelling framework that captures self-sufficiency of cereals produced in the United Kingdom, as an indicator of national food security, is developed. The simulation results from a scenario analysis indicate that appropriate governance and effective policy-making interventions, supporting smallholding farming and short food supply chains in the developed world, provide promising grounds towards ensuring food security and social cohesion, while further promoting economic growth and environmental sustainability. Finally, this research is an initial approach towards the development of food security early warning systems and decision support tools that could be employed by policy-makers and regulators to design effective interventions for the sustainable development of food supply systems.

1. Introduction

Sustainability and security of food systems is a major global concern that mainly stems from projections indicating a global population growth to 9.1 billion people in 2050 with a corresponding increase in food demand by 70 %. Specific food related drivers that stress the food security state in the developed world include: (i) food price volatility due to climate change and extreme weather conditions (Tadesse et al., 2014), (ii) oil shortages (Reboredo, 2012), (iii) increased use of feed and biofuels (Hubbard and Hubbard, 2013), (iv) trade embargos and political instability cases (Rutten et al., 2013), and (iv) dietary norms characterized by consumption of food beyond physical need (Sage, 2013). At the same time, the malnutrition effect is evident in developed countries as the traditional diets dominated by regional staples are gradually replaced by processed food products rich in fats, salt and sweeteners that result in non-communicable diseases (Sage, 2013); hence, food insecurity in high income countries is primarily a public health issue and secondly a matter of food accessibility and availability (Kneafsey et al., 2013). In this sense, policy-makers in the developed world need to tackle the emerging challenges across the recognized food security constituents, namely –accessibility, availability, stability, utilization–, and mainly focus on the diverse dietary habits and the adequacy of the actual nutrient intake of the populations.
Smallholdings or small farms (SFs) could enhance the adaptive capacity of local and regional food systems towards modern challenges and foster food security at a local and national levels in the developed world (Eurovia, 2013). Estimations highlight that 2.5 billion people globally depend upon the agricultural production of 500 million smallholdings while in Europe the 69 % of all farms are considered to be small (EU, 2013). In this regard, decision-makers and regulators in the European Union encounter the challenge of composing policy schemes that support initiatives for the development of short food supply chains and local food systems in the region (EAFRD, 2013). Indicatively, the European Union recognizes the significance of smallholdings towards promoting food and nutrition security and has approved funds of over 100 € million, under the funding programme HORIZON 2020 (topic: "Small farms but global markets: The role of small and family farms in food and nutrition security", SFS-18-2015), to support small food businesses for the period 2014-2020.
Particularly for the United Kingdom (UK), food security related statistics available by the Food and Agriculture Organization of the United Nations indicate underlying challenges. More specifically, the adequacy of cereals

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supply in terms of calories accounts for 32 % of the dietary energy supply (availability constituent) with the domestic price index being 1.2 compared to 1.7 in other developed countries (accessibility constituent). The cereals import dependency ratio is -0.3 % compared to -16.8 % for the developed countries with the food price volatility index being 30 % greater than the rest of the developed countries (stability constituent). Regarding the utilization constituent, no warning signs are reported. Therefore, the UK is expected to face compelling food security challenges in the future unless policy interventions are effectively applied.

Despite the existing research, simulation approaches that assess different food security policies in developed countries are lacking. In this regard, the objective of this study is three-fold: (i) to critically discuss food security challenges in developed countries, (ii) to construct an initial food security early warning modelling approach for the UK focusing on cereals, and (iii) to assess the sustainability impact of a policy intervention that supports new SF initiatives in the UK. Considering the dynamic system between food supply and demand, along with the related sustainability ramifications, the paper applies the System Dynamics (SD) methodology.

The remainder of the article is organized as follows. First, in Section 2 we provide a critical discussion about food security and sustainability in the developed world while we emphasize the role of SFs in tackling the related challenges. Following, in Section 3 a SD modelling framework for investigating food security in a sustainable context is developed and the related impact of a SFs' oriented policy-making intervention is assessed. The application of the proposed framework is illustrated on the real-world case study of the UK, in terms of cereals production and consumption, while the associated economic and environmental sustainability performance is monitored. Finally, conclusions and future research areas are discussed in Section 4.

2. Smallholdings, sustainability and food security in the developed world

2.1 Definition of small farms

A major challenge about smallholdings stems from the fact that a single and consistent definition has not yet been adopted by the related stakeholders while a threshold to differentiate small from large farms does not exist. Over the years, academics have elaborated a variety of metrics to determine SFs. The most common metrics refer to: (i) size (turnover or cropland), with the World Bank's Rural Development Strategy and the Food and Agriculture Organization of the United Nations to adopt a 2 ha threshold as a generic measure for a SF, (ii) marginalization, meaning that smallholdings are defined as farms with limited access to resource endowments i.e. information, technology, capital and assets, (iii) labour characteristics, with SFs defined as family businesses that depend upon household members for most of the labour, and (iv) consumers of the agricultural production, meaning that a SF produces the bulk of a household's consumption of staple foods. In this paper we adopt the 2 ha size threshold to define SFs.

2.2 Sustainable food security challenges

The ageing population in Europe fosters food trade with the ratio of food imports to consumption to have increased considerably from 16 % in 1995 to 42 % in 2008 (Olper et al., 2014). In addition, the rising food prices along with the low economic recovery rates from the global financial crisis highlight potential food insecurity issues. Specifically, European citizens spend around one-fifth of their income on food supplies, hence deepening social inequalities in the region. Europe also suffers from 70 % animal feed deficiency and is indirectly vulnerable to extreme weather conditions and food price spikes. As to environmental sustainability challenges, loss of biodiversity combined with water scarcity from overuse, soil erosion and depletion, and climate change may reduce global agricultural yield by at least 5-25 % by 2050. Furthermore, one-third of the global food production is wasted annually while in the European Union 66 % of food waste occurs at the retail stage and 34 % at a household level (Schott and Andersson, 2015). In a social context, in developed nations live about 15.7 million people who suffer from chronic hunger and undernourishment. An ominous fact is that the rate of chronic hunger and undernourishment in developed countries has risen by 15.7 % since 1990 (FAO et al., 2014). In Europe, nearly 52 % of men and women are obese and statistics highlight that one-third of 11-year-old children in the region are overweight (WHO, 2014). Considering these challenges, a greater interaction between production and consumption at a local level could be argued as highly desirable to promote efficiency of supply and raise social awareness of the nutritional impact of food consumption. In this context, the need to enhance the role of smallholder farming towards local food production and natural resource stewardship is desirable as SFs are documented to promote (Badami and Ramankutty, 2014): (i) food and nutrition security, (ii) income generation, and (iii) social inequalities' alleviation.

2.3 The role of smallholdings

The interest in agricultural development and especially in SFs has waxed and waned through the years. This reoccurring interest is attributed to the food security and sustainability challenges that are associated with the development of smallholdings (Sage, 2013). Traditionally, SFs' development aimed to foster the economic growth and social wellbeing in developing countries. However, the multi-functional role of smallholdings in the developed world has been, thus far, ignored or devalued and only recently is being recognized.

Firstly, SFs are reported to implement environmental friendly agricultural methods, hence avoiding the costs associated with agrochemical-based supplies and generating increased income (Noltze et al., 2013). Furthermore, the agroecology approach that farmers often use enables smallholdings to cultivate a range of seasonal crops that cover the needs for diversified human-edible calorie intake (Kremen et al., 2012), and therefore contribute to local food security, regional ecological resilience and farmer economic autonomy (Altieri et al., 2012). In addition, Mesoamerican coffee SFs are reported to provide ecosystem services while contemporarily securing the local ecosystem biodiversity (Vandermeer et al., 2010). At a greater extent, smallholdings are a key component of the policies aiming to advance food sovereignty and create self-reliant local food systems that control production, distribution and consumption of food commodities (Wittman, 2011).

Secondly, SFs associate with a range of social implications. Governmental support to SFs' production could have better effects than other implemented social safety measures. Indicatively, each tonne of cereals as a food aid costs 250 US$, while the typical corresponding production in smallholdings costs about 100 US$ (IFPRI, 2007). In addition, smallholdings could promote effective nutrition intake (Wenhold et al., 2007) and assist in preserving the indigenous cultural heritage (Altieri et al., 2012), while the established SF cooperatives might affiliate with local enterprises to devise local fair trade networks. In Scotland, the crofts (i.e. small pieces of fenced or enclosed area of arable land) are a vital tool for community empowerment leading to the increase of population around smallholdings (Bryden and Geisler, 2007). Similar effects are achieved by the small-scale farming initiatives in the Norwegian mountainous and Upland areas (Flemsæter and Setten, 2009).

Thirdly, smallholders engage in local non-farm activities and foster local economic development and job creation (Wiggins et al., 2010). Smallholdings employ more labour per land unit and are reported to reduce poverty gap more intensively than other economic activity sectors (Christiaensen et al., 2011). In particular, SFs generate local income through exploiting a variety of sources. For example, smallholding farmers in the region of Gigha, Scotland, have fuelled the initiation of 13 new off-farm entrepreneurial initiatives (Shucksmith and Rønningen, 2011). Moreover, small-scale farming in mountainous Norway contributes to the agricultural viability through promoting farm revenues and food security (Rønningen et al., 2005).

3. A System Dynamics modelling framework

In this section, we consider a systems' engineering driven approach to food SC design. Specifically, we provide the analysis of the dynamic behaviour of the cereals production and consumption system in the UK, from a supply chain perspective. Below, the system under study is described in brief, the associated SD model is developed and finally the simulation findings for the UK case are discussed.

3.1 System description

We consider the total cereals production and consumption system in the UK to investigate the food security state of the sovereign country along with the associated economic and environmental sustainability ramifications. Regarding the farming level, the cereals total arable area and the average productivity per cultivated unit are considered. We assume that the crop production occurs during the entire year. We further assume that the agricultural production is independent from the consumers' demand while cereals imports and exports are neglected. Regarding the consumption level, we consider the entire population living in the UK along with the natural increase rate and net immigration flow. The average demand for cereals is uniformly distributed for every citizen, on an annual basis. In order to assess the food security state in the UK the self-sufficiency index, describing the annual ratio of cereals production to consumption, is adopted as the appropriate food security indicator (Xu and Ding, 2015). The resulting self-sufficiency index has ramifications to the social attractiveness of the UK subsequently affecting, with a rational time delay, the annual population growth and thus the annually generated gross domestic product. The social attractiveness factor is motivated by the green image factor described by Aivazidou et al. (2017) and is expressed as a logistic function (i.e. sigmoid curve) of the cereals self-sufficiency index. In case a policy for supporting the development of SFs is implemented, then SFs contribute to the total cereals production. Following that, the UK cereals self-sufficiency is impacted further affecting the social attractiveness and the national gross domestic product. The level of the annual gross domestic product determines the level of technological investments that affects the cereals productivity in SFs (Xu and Ding, 2015). The conceptual system under study is illustrated in Figure 1 via the relevant causal loop diagram. In a causal loop diagram, arrows describe the causal influences among the variables of the system (Sterman, 2000). Typically, 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 feedback loop). On the other hand, a negative (-) polarity denotes that the effect changes towards the opposite direction of the cause (balancing feedback loop).

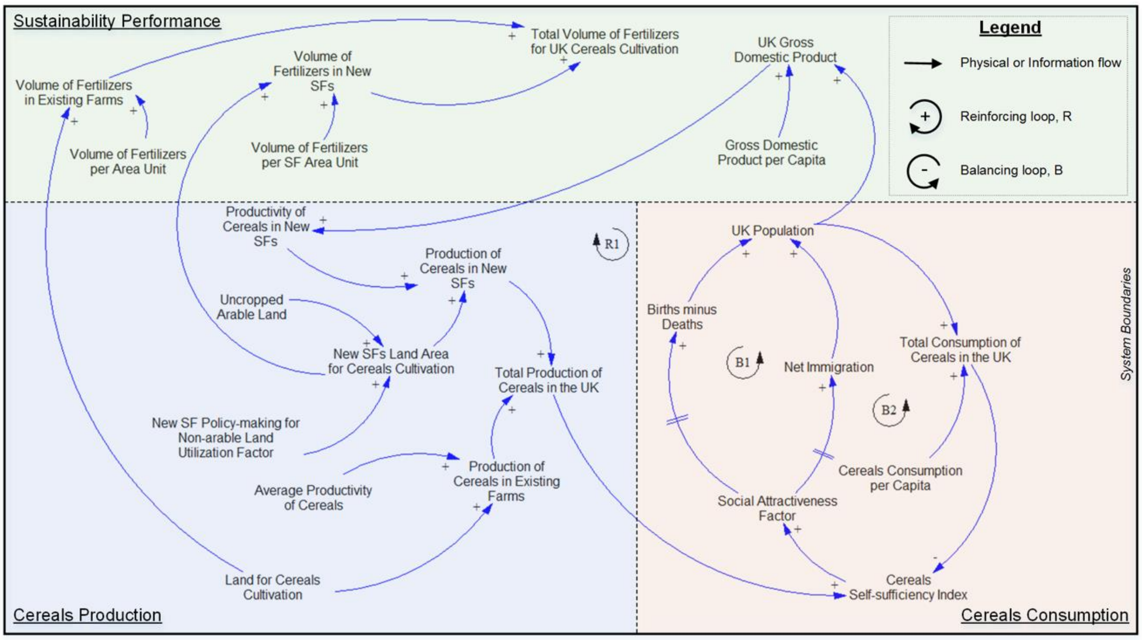

Figure 1: Causal loop diagram of the system under study.

3.2 Model development

The system is modelled using the SD methodology to capture the causal loops and feedback mechanisms that attach dynamic behaviour to the system. To model the system, we retrieved statistics for the period 2000-2014 by the Office of National Statistics and we calculated the mathematical functions describing the system's variables in relation to time. Specifically, the functions describing the cereals arable area (ha), births-deaths and net immigration (people), consumption of cereals (t/cap), and gross domestic product (£) measures were calculated based on the Holt's double exponential smoothing forecasting method as their historic time series exhibit a trend. The forecasting of productivity of cereals (t/ha) is calculated based on a logarithmic function. In addition, the annual cereals productivity and consumption are assumed to exhibit annual stochasticity.

To assess the food security state in the UK, the self-sufficiency index is calculated whereas economic and environmental sustainability performance are monitored through the annual gross domestic product (£) and the annual volume of utilized fertilizers (kg/ha), respectively. For the case of the developed SFs, the use of fertilizers per arable area unit is considered to be 30 % less compared to existing farms. The SD model is designed and constructed using the SD simulation package Powersim® Studio 10 Academic.

3.3 Results

The applicability of the developed SD model is presented through analyzing the specific case related to the production and consumption of cereals in the UK. More specifically, a strategic horizon of 30 years is selected in order to capture the dynamics with regard to self-sufficiency index and the associated social attractiveness factor whereas the simulation time step is set to 1 year. Moreover, the SD model is validated and verified through a series of tests described in Sterman (2000) including model structural tests, extreme condition tests, system's behavior sensitivity tests, and time and variable units' consistency. Thereafter, we investigated a "Base Scenario", where there is no policy intervention, and a "Policy Scenario", where incentives to convert 60 % of the nationwide available non-arable land into SFs are applied. As the model includes stochastic variables, we conducted 10,000 simulation runs per scenario to derive robust results. The profile of the system operations and the simulated self-sufficiency index are presented in Figure 2.

The simulation results indicate that the implementation of a policy intervention to develop new SFs could: (i) prolong the UK food security state by almost 3 years, and (ii) increase the average annual gross domestic product in the region by 2.33 %. From environmental perspective, SFs consume only 2.92 % of fertilizers compared to existing farming systems, on an annual average. Notably, only 0.033 t of cereals are cultivated per 1 kg of fertilizers, whereas for the case of SFs the respective volume is 0.071 t/kg. In case of the policy intervention, we may have not quantified the associated social impact of the developed SFs but the emerging employment opportunities and public health implications are evident. The results imply that emphasis should be placed on improving productivity of cereals cultivation.

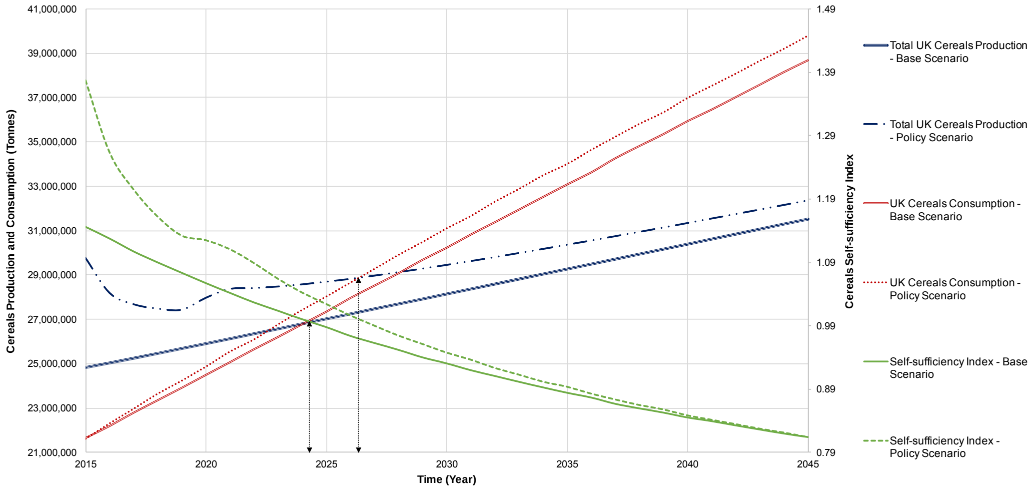

Figure 2: Cereals self-sufficiency index in the United Kingdom.

4. Discussion and conclusions

Generally, food security in the developed world arises as a pivotal issue in the public agenda and a plethora of global initiatives supported by international organizations aim at eradicating food insecurity through harnessing sustainable benefits. However, a lack of systemic approaches and tools that could capture the dynamic nature of the food security phenomenon is evident. Such modelling perspectives should incorporate early warning elements (Xu and Ding, 2015) and further allow for the monitoring and assessment of the impact of different interventions at each echelon of national food supply networks.

In this context, this paper initially discusses food security issues in the developed world and highlights the pivotal role of smallholdings in tackling food security challenges in a sustainable manner. Following that, we develop a first-effort SD modelling framework that captures the self-sufficiency level in the UK, in terms of cereals production and consumption, as the indicator of the national food security state. The analysis of a policy-making scenario indicates that stakeholders should focus on supporting SFs in the region to tackle food security and sustainability issues while contemporarily promoting social cohesion. Additionally, it is evident that emphasis should be placed on improving the cereals cultivation productivity.

The conceptual point of this study is not to provide accurate forecasting models about the cereals production and consumption system in the UK. Rather, it is that food security in developed countries is a multidimensional and complex issue requiring counterfactual analysis and a SD approach should be considered. We envisage that the provided SD modelling approach could motivate focused research on the field to outline robust policy-making interventions that promote SFs, sustainable short food supply chains and food security in the UK.

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Reference

Aivazidou E., Tsolakis N., Vlachos D., Iakovou E., 2017, Water footprint mitigation strategies for agrifood products: The application of System Dynamics in green marketing, Strategic Innovative Marketing - Springer Proceedings in Business and Economics, Eds. Kavoura A., Sakas D., Tomaras P., Springer, Cham, Switzerland, DOI: 10.1007/978-3-319-33865-1_35

Altieri M.A., Funes-Monzote F.R., Petersen P., 2012, Agroecologically efficient agricultural systems for smallholder farmers: Contributions to food sovereignty, Agronomy for Sustainable Development, 32(1), 1-13, DOI: 10.1007/s13593-011-0065-6

Badami M.G., Ramankutty N., 2014, Urban agriculture and food security: A critique based on an assessment of urban land constraints, Global Food Security, 4, 8-15, DOI: 10.1016/j.gfs.2014.10.003

Bryden J., Geisler C., 2007, Community-based land reform: Lessons from Scotland, Land Use Policy, 24(1), 24-34, DOI: 10.1016/j.landusepol.2005.09.004

Christiaensen L., Demery L., Kuhl J., 2011, The (evolving) role of agriculture in poverty reduction – An empirical perspective, Journal of Development Economics, 96, 239-254, DOI: 10.1016/j.jdeveco.2010.10.006

EAFRD, 2013, 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, Spain

EU, 2013, Structure and dynamics of EU farms: Changes, trends and policy relevance. EU Agricultural Economics Briefs No 9. European Commission, Brussels, Belgium

Eurovia, 2013, Land concentration, land grabbing and people’s struggles in Europe. European Coordination Via Campesina and Hands off the Land network, Brussels, Belgium

FAO, IFAD, WFP, 2014, The state of food insecurity in the world 2014 – Strengthening the enabling environment for food security and nutrition. Food and Agriculture Organization of the United Nations, Rome, Italy

Flemsæter F., Setten G., 2009, Holding property in trust: Kinship, law and property enactment on Norwegian smallholdings, Environment and Planning A, 41, 2267-2284, DOI: 10.1068/a41135

Hubbard L.J., Hubbard C., 2013, Food security in the United Kingdom: External supply risks, Food Policy, 43, 142-147, DOI: 10.1016/j.foodpol.2013.08.006

IFPRI, 2007, The future of small farms for poverty reduction and growth. 2020 Discussion Paper 42. International Food Policy Research Institute, Washington, DC, the United States of America

Kneafsey M., Dowler E., Lambie-Mumford H., Inman A., Collier R., 2013, Consumers and food security: Uncertain or empowered?, Journal of Rural Studies, 29, 101-112, DOI: 10.1016/j.jrurstud.2012.05.005

Kremen C., Iles A., Bacon C., 2012, Diversified farming systems: An agroecological, systems-based alternative to modern industrial agriculture, Ecology and Society, 17(4), 44, DOI: 10.5751/ES-05103-170444

Noltze M., Schwarze S., Qaim M., 2013, Impacts of natural resource management technologies on agricultural yield and household income: The system of rice intensification in Timor Leste, Ecological Economics, 85, 59-68, DOI: 10.1016/j.ecolecon.2012.10.009

Olper A., Pacca L., Curzi D., 2014, Trade, import competition and productivity growth in the food industry, Food Policy, 49(Part 1), 71-83, DOI: 10.1016/j.foodpol.2014.06.004

Reboredo J.C., 2012, Do food and oil prices co-move?, Energy Policy, 49, 456-467, DOI: 10.1016/j.enpol.2012.06.035

Rønningen K., Flø B.E., Olsson G.A., Hanssen S.K., Wehn S., 2005, Sustainability assessment of agro-eco-systems and rural development in mountain areas. Scenarios for Eastern Jotunheimen, Norway. Report 9/05. Centre for Rural Research, Trondheim, Norway

Rutten M., Shutes L., Meijerink G., 2013, Sit down at the ball game: How trade barriers make the world less food secure, Food Policy, 38, 1-10, DOI: 10.1016/j.foodpol.2012.09.002

Sage C., 2013, The inter-connected challenges for food security from a food regimes perspective: Energy, climate and malconsumption, Journal of Rural Studies, 29, 71-80, DOI: 10.1016/j.jrurstud.2012.02.005

Schott A.B.S., Andersson T., 2015, Food waste minimization from a life-cycle perspective, Journal of Environmental Management, 147, 219-226, DOI: 10.1016/j.jenvman.2014.07.048

Shucksmith M., Rønningen K., 2011, The Uplands after neoliberalism? – The role of the small farm in rural sustainability, Journal of Rural Studies, 27(3), 275-287, DOI: 10.1016/j.jrurstud.2011.03.003

Sterman J., 2000, Business dynamics: Systems thinking and modeling for a complex world. McGraw-Hill Higher Education, Boston, the United States of America

Tadesse G., Algieri B., Kalkuhl M., von Braun J., 2014, Drivers and triggers of international food price spikes and volatility, Food Policy, 47, 117-128, DOI: 10.1016/j.foodpol.2013.08.014

Vandermeer J., Perfecto I., Philpott S., 2010, Ecological complexity and pest control in organic coffee production: Uncovering an autonomous ecosystem service, BioScience, 60(7), 527-537, DOI: 10.1525/bio.2010.60.7.8

Wenhold F.A.M., Faber M., van Averbeke W., Oelofse A., van Jaarsveld P., Jansen van Rensburg W., van Heerden I., Slabbert R., 2007, Linking smallholder agriculture and water to household food security and nutrition, Water SA, 33(3), 327-336 <http://hdl.handle.net/2263/4873> accessed 19.01.2017

WHO, 2014, Obesity and inequities. Guidance for addressing inequities in overweight and obesity. The Regional Office for Europe of the World Health Organization, Copenhagen, Denmark

Wiggins S., Kirsten J., Llambí L., 2010, The future of small farms, World Development, 38(10), 1341-1348, DOI: 10.1016/j.worlddev.2009.06.013

Wittman H., 2011, Food sovereignty: A new rights framework for food and nature?, Environment and Society: Advances in Research, 2(1), 87-105, DOI: 10.3167/ares.2011.020106

Xu J., Ding Y., 2015, Research on early warning of food security using a System Dynamics model: Evidence from Jiangsu Province in China, Journal of Food Science, 80, R1-R9, DOI: 10.1111/1750-3841.12649