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Systems thinking in food security research

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Abstract

Reference to *systems thinking* is found in food studies more frequently, and the need for design interventions becomes more prominent as food security research increasingly acknowledges the *complexity* of the problem space. A systems approach allows a better grasp of the complex interconnections and stakeholders involved. However, the existing variety of approaches based on fundamentally different assumptions could lead to misconceptions, if not made explicit.

The purpose of the current literature review is to enhance the mutual understanding of systems thinking by food security and design researchers, investigating the adoption of systems notions, and uncovering their relevant positioning on the systems approaches spectrum. A three-step method was followed: selecting the papers, organizing them in thematic clusters and visualizing the papers' timeline succession, and mapping the degree of adoption and sociological paradigm of their *systemicity*. This process allowed for a more holistic perspective and enabled the emergence of significant issues: the increasing need of food security researchers for a combination of quantitative and qualitative approaches; the paradox of disciplinary bias; and the absence of emancipatory approaches. The generated "systemicity map" can serve as a tool for systemic designers to establish a common understanding of systems approaches when working alongside researchers and other stakeholders of food security. Furthermore, considering the map's topology could help systemic designers locate and prioritize the most "promising" candidates for interdisciplinary collaboration. Finally, the results advocate a pro-innovation bias.

Keywords: food security, systems thinking, interdisciplinarity, systemicity, sustainability, systemic design

1. Introduction

The issue of ensuring nourishment has always troubled society. However, entering the new millennium food security is now considered a complex global challenge. The rapid advancements in technology, communications, and transportations, have increased *complexity* to unprecedented levels, urging the need for appropriate interventions. The desired ideal state for *food security*, as defined by the United Nations' (UN) Food and Agriculture Organization (FAO), (FAO, 1996) is:

> "a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life".

Systems thinking is emerging as the appropriate conceptual framework to address the *complexity* of such wicked problems (FAO, 2019; Gill et al., 2018; UN Environment, 2019; Zhang et al., 2018). However, the multitude of systems worldviews results in a variety of systems approaches. For example, the more *structuralist* assumption that a system can be represented by mathematical models, results in the family of systems approaches labelled as *hard*. Conversely, acknowledging the pluralism of contexts and purposes led to the development of *soft* approaches that question the existence of a single objective reality (Jackson, 2003). Therefore, various applications of systems thinking may rely on fundamentally different assumptions.

Food researchers may tend to conceptualize the interconnected food systems as well-defined, pre-existing, and agreed upon entities, and assume that their interactions with one another form patterns that can be revealed with study. Indeed, Ericksen (2008) advocated for compiling a database of such interactions, that can then be abstracted away into typologies to be referenced by other researchers when faced with similar situations. The aim was that this database would guide those in charge of managing food security policies. Similarly, Horton et al. (2017) were interested in modelling and managing the agri-food economy by applying quantitative methods. Some of these assumptions may be at odds with the understanding of the everchanging and dynamic nature of systems embraced by Systemic Design. However, it is important to acknowledge the significance of these approaches that originate from reductionistic models of food systems and aim to embrace more holistic viewpoints.

Conversely, systemic designers focusing on starting with a *tabula rasa* prompted researchers representing stakeholders to create a holon, i.e. a description of the "whole" situation that is wide ranging. Then encouraging exploration of the interactions and connections, they invited speculation on the need to include other stakeholders (Darzentas et al., 2018). The purpose of encouraging this greater freedom is -in part- to move beyond disciplinary or professional boundaries as well as linear "food supply chains". This approach avoids reductionism and narrow focus, and allows for emergence of new ways of thinking and praxis that were previously not possible. In another example with a focus on circular economy, to understand how they are part of the regional system, all stakeholder groups of the region were drawn in. Then ways to exploit further existing links or to develop entirely new ones were sought, aiming at creating new opportunities (Barbero, 2015; Nohra & Barbero, 2019). In each case, the systemic designers helped the stakeholders explore and move into different configurations.

Due to its complex nature, the global challenge of food security needs to be addressed by multiple and diverse scientific disciplines working in accordance. Food researchers and systemic designers are therefore key stakeholders and determining the origin of their systems approaches is crucial. The purpose of this literature review is to investigate their systems thinking perspectives in order to uncover their fundamental assumptions. This will enhance interdisciplinary collaborations, by drawing attention to potential misconceptions and enabling transcendence of the initial hypothesis.

The next section (Section 2) explains the method used for selecting the papers, their subsequent organization in thematic clusters, and their timeline visualization. The systems approach of the selected papers are briefly presented within their clusters. Also, the notion of "systemicity" is introduced, as viewed from the perspectives of the degree of systems thinking adoption and the social theory paradigm. Section 3 details the outcome of the individual papers' systemicity assessment and introduces the two-dimensional map of *systemicity*. Furthermore, evidence of the bias arising from disciplinary traditions of viewpoints and analytical tools is noted.

2. Food Security Literature Review

One of this literature review's main assumptions is that food researchers are key stakeholders who have the potential to drive systemic change in food security. The food security literature was searched based on specific criteria. The selected papers were clustered, and their timeline was visualized. Last, their apprehension of the food security challenge from a systems perspective was explored, to examine the potential of systems thinking as a common basis of interdisciplinary collaboration. In the following sections those steps are described in more detail.

2.1. Literature search

The literature was searched for papers containing specific terms in their title, abstract, or keywords. The terms searched -illustrated in a logical representation- were: “food” AND (“security” OR “sustainability”) AND “system(s)”. in a further round, the term “design” was added to the representation to target the related design papers. From this first round of results, the papers that demonstrated substantial awareness of systems thinking were kept. This was done by further searching within the selected papers body for systemic terms, such as “complex”, “complexity”, “actors”, “drivers”, “(causal) loops”, and “feedback”, and evaluated their contextual use. In case such terms were not present, the full text was read to uncover underlying soft systems’ aspects. The papers that passed both filtering stages formed the body of the reviewed literature. More details on evaluating their systemic profile are described in the section of investigating the papers’ *systemicity*. It should also be noted that older papers were filtered out, unless there was a pertinent reason to retain them, since most of the turn to systems within the food community is of fairly recent origin, that is, in the last two decades or so.

The final selection of 27 papers was clustered based on thematic categories using terms from the relevant journals or conferences. Thus, the following six clusters were formed (Figure 1): Food security, Food and Nutrition, Sustainability, Environmental, Science and Engineering, Design.

Figure 1. The six thematic clusters. The generated clusters reflected the thematic area of the journal or conference from which the papers were selected. “Food Security” was distinguished from the more generic “Food & Nutrition” to emphasize papers directly targeting the issue of food security.

The final list of papers for this review is presented in detail in the following table (Table 1).

Cluster	Journal or Conference	Paper
Design	Cities	2019 Sonnino et al.
	City Food Governance	2019 Sonnino
	7th International AESOP Sustainable Food Planning Conference Localizing urban food strategies Farming cities and performing rurality	2015 Barbero and Tamborrini
	International Conference on Designing Food and Designing For Food	2012 Barbero and Tamborrini
	Proceedings of RSD7, Relating Systems Thinking and Design 7	2018 Darzentas et al.
	Relating Systems Thinking and Design (RSD4) Symposium	2015 Barbero
	The Design Journal	2019 Nohra and Barbero
Environmental	Environmental Management	2016 Allen and Prosperi
	GAIA - Ecological Perspectives for Science and Society	2018 Grant et al.
	Global Environmental Change-human and Policy Dimensions	2008 Ericksen
Food & Nutrition	Food Policy	1996 Maxwell
	Journal of Hunger & Environmental Nutrition	2018 Fleischer et al.
	Trends in Food Science & Technology	2014 van Mil et al.
Food Security	Food Security	2011 Ingram
	Food Security	2012 Pereira and Ruysenaar
	Food Security	2017 Horton et al.
	Global Food Security	2015 Tendall et al.
Science & Engineering	Journal of Systems Science and Systems Engineering	2010 Hipel et al.
	Proceedings of the National Academy of Sciences of the United States of America	2012 Hammond and Dubé
	Social Enterprise Journal	2017 Zivkovic
	Systems Research and Behavioral Science	2014 Banson et al.
	Systems Research and Behavioral Science	2016 Banson et al.
	World Development	2014 Foran et al.
Sustainability	International Journal of Agricultural Sustainability	2007 Bland and Bell
	Sustainability	2018 Zurek et al.
	Sustainability	2019 Grant et al.
	Sustainability	2019 Ruben et al.

Table 1. Papers organized into thematic clusters according to their publication outlet.

A visual representation of the reviewed papers is displayed in the following timeline figure (Figure 2) to showcase the dimension of time within and across clusters. This enabled a more holistic perspective of their critical review.

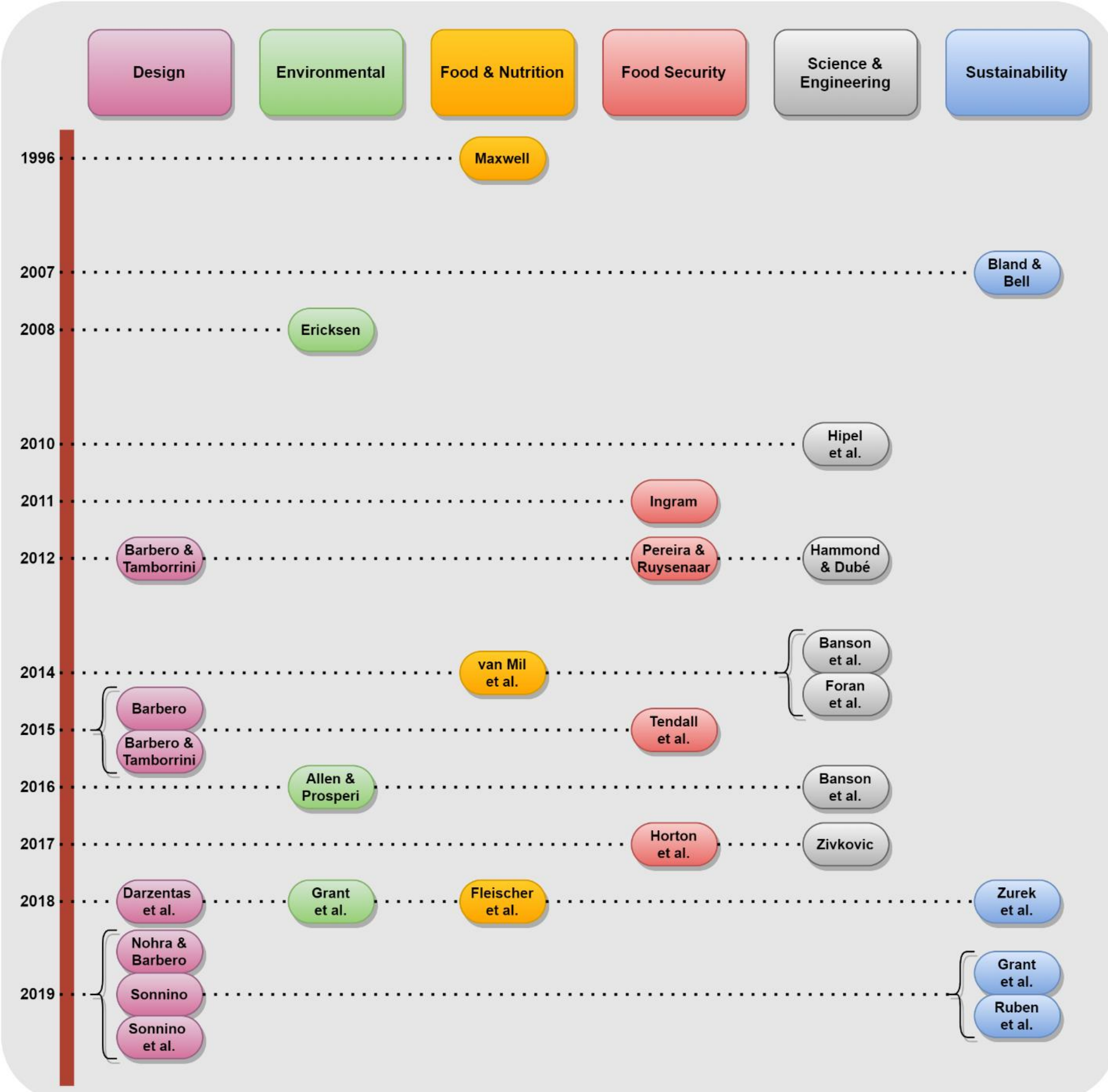

Figure 2. Reviewed papers' timeline. Graphical representation of the reviewed papers' timeline succession. The papers are sorted and justified under their thematic cluster. They are additionally highlighted in their cluster's color.

Examining the papers' timeline (Figure 2) three points emerge. The first systems approaches in food security research did not originate from a "directly related" thematic cluster. Bland and Bell (2007) first published in a Sustainability journal, then followed Ericksen's (2008) paper in an Environmental one, and then a Science & Engineering paper by Hipel et al. (2010). Second, regarding cross-references across clusters, Ericksen's conceptual framework (Ericksen, 2008) was first published in an Environmental journal and was three years later referenced in the Food Security cluster by Ingram (2011). Also, Grant et al. presented their work starting with an Environmental paper (Grant et al., 2018) and then following with one in Sustainability (Grant et al., 2019). Lastly, regarding systems approaches in food security within the Design cluster we see that although there are relatively abundant publications compared to the other clusters, they only come from a small number of design researchers dedicated to the subject.

In the following section (Section 2.2) the systems thinking perspective of the reviewed papers is outlined.

2.2. Overview of Systems Thinking per Cluster

While investigating the perception of systems thinking in the food security literature, it could be seen that -with the exception of the design cluster and regardless of their disciplinary origin- a similar perspective has been adopted, mostly employing *complex adaptive systems* and *system dynamics* approaches. Recently however, in disciplines closer to environmental issues there has been a growing appreciation of *soft systems* thinking. In these publications, the food system was viewed from an *open system* perspective, that appreciates the significance of the stakeholders' learning and inclusion in the problem definition process.

2.2.1. Food security & Food and Nutrition

The papers published in journals or conferences directly relevant to "food" were grouped in the two clusters of "Food Security" and "Food and Nutrition", to differentiate the ones directly referring to the current review's central notion of *food security*. Maxwell presented his findings on a shift of food security to postmodernism and called for an open-systems approach to food security policy (Maxwell, 1996). Maxwell's assumption on a post-modernist shift in food security was not fully affirmed by the succeeding systemic approaches. More specifically, Ingram introduced the conceptual framework of the "Global Environmental Change and Food Systems" project following a more structural approach (Ingram, 2011). Furthermore, Pereira and Ruysenaar investigating a more adaptive governance for South Africa, viewed food as a complex adaptive system and suggested a polycentric governance of cross-sectoral partnerships supported by analytical tools for decision making (Pereira & Ruysenaar, 2012). Van Mil et al. also adopted a complex systems approach supported by modelling to map the food system's structures and functionalities (van Mil et al., 2014). In their study, Tendall et al. proposed a conceptual framework for food system's resilience to provide a basis for a quantitative modelling (Tendall et al., 2015). Horton et al. further extended their modelling approach with the use of deliberative fora and public engagement to capture the existing ethical, legal, and political tensions (Horton et al., 2017). In addition, they proposed a research framework that combines examining both quantitative and qualitative aspects. Finally, (Fleischer et al., 2018) performed a system's qualitative mapping of childhood food security and further suggested simulation modelling.

2.2.2. Sustainability

In the "Sustainability" thematic cluster Bland and Bell first introduced a systems approach, acknowledging *complexity theory* and adopting Koestler's notion of *holon* (Bland & Bell, 2007). They portrayed it as an intentional entity within an ecology of contexts, addressed its *boundary* and *change* dilemmas, and suggested *flickering* as an epistemological tool to help perceiving it in both its *system* and *part* nature. On the other hand, Zurek et al. introduced a more structuralist perspective. They generated an integrative model of the EU food system with the stakeholders' participation, visualized policy metrics, and urged for a conceptualization of social equity mechanisms (Zurek et al., 2018). Ruben et al. also viewed food as a complex adaptive system, and further stated the need for approaches bridging the gaps between *hard* and *soft systems* analyses to combine dynamics of different levels and stakeholders (Ruben et al., 2019). Lastly, Grant et al. 2019 used rich pictures to help in visualizing complex systems' understanding and thus in evaluating learning during a sustainable food systems course for decision makers (Grant et al., 2019).

2.2.3. Environmental

The "Environmental" cluster's first paper was one of the most influential and broadly cited works on food systems reseach (Ericksen, 2008). Ericksen created a research framework conceptualizing the food system's major components and interactions. The framework's purely structural and thus easily reproducible nature helped forming a solid basis for all future modelling efforts. One of the examples building on and extending Ericksen's work was Allen and Prosperi's conceptual model (Allen & Prosperi, 2016). They focused on incorporating resilience factors adapted in modelling the food system's dynamics. On the other hand, Grant et al.'s more recent work followed a *soft systems* approach (Grant et al., 2018). They created a holistic conceptual framework for a food system course, integrating design and systems thinking, bringing young leaders and stakeholders together to codevelop sustainable solutions.

2.2.4. Science and Engineering

For the generic cluster of "Science and Engineering", Hipel et al. first provided a systems thinking approach to food security (Hipel et al., 2010). They adopted a System of Systems approach and applied it to food policy development. *Ethics* and *values* were included as part of the overall framework and were thus viewed from a systems' engineering perspective. Hammond and Dubé also adopt a *hard systems* approach based on systems dynamics and agent-based modelling (Hammond & Dubé, 2012). On the other hand, Ockie Bosch's Evolutionary Learning Laboratory (ELLab) process (Bosch et al., 2013) contributed to adding *soft systems* aspects to the cluster. More specifically, in two studies of the agricultural sector in Ghana the ELLab was used to capture the diverse stakeholders' mental models that formed the basis for systems dynamics modelling and probabilistic assessment of possible systemic interventions (Banson et al., 2014, 2016). Foran et al. on the other hand attained a holistic overview of the food system viewed from different disciplinary frameworks, and accentuated the diverse frameworks' abstract language and absence of the system's stakeholders in their development (Foran et al., 2014). Finally, Zivkovic followed a systems innovations approach and investigated how food security governance networks can develop steering strategies that enhance the adaptive capacity of their solution ecosystems (Zivkovic Sharon, 2017).

2.2.5. Design

Designers have been nurturing a growing interest in systems thinking particularly since the rapid development of *systemic design* within the last decade. Systemic design emerged as an integrated discipline of systems thinking and systems-oriented design (P. H. Jones, 2014; SDA, n.d.). Barbero has applied systemic design in multiple agri-food contexts. In her work with Tamborrini (Barbero & Tamborrini, 2012) they applied systemic design to render sustainable a bean production system in the Italian province of Cuneo. In 2015 (Barbero & Tamborrini, 2015), together with their investigation on "softer" aspects of the food system, they also demonstrated a more *structural* application on designing sustainable and circular food systems. Barbero further summarized her reflections on the application of systemic design on food sustainability and suggested some preconditions for sustainable food strategies (Barbero, 2015). In Darzentas et al.'s approach of building a *holon* for the food system, the experts' collaborative design of the food's holon helped gaining an integrated knowledge of the food security challenge and gave rise to richer understandings of the food system's resilience (Darzentas et al., 2018). Sonnino et al.'s study on food change in an urban context, related complex systems theory and urban governance and highlighted the challenges of modularity in systemic change targeted policy making (Sonnino et al., 2019). Sonnino further analyzed the *cultural dynamics* of urban food governance and justified the need for a more inclusive and reflexive approach (Sonnino, 2019). Last, Nohra and Barbero applied systemic design to support transitioning of the urban post-industrial area to a circular economy with sustainable consumption as one of the key goals (Nohra & Barbero, 2019).

2.3. Investigating Systemicity

In addition to their thematic categorization, the various food research papers were also distinguished by their systems-related features. The intended purpose was to provide a means of capturing both the degree and the essence of their relation to systems thinking, reflecting their *systemicity*. As approached in this review, *systemicity* serves as a feature that captures the systems thinking engagement in two dimensions: its degree of systems thinking adoption and its social theory perspective.

2.3.1. Systems Thinking Adoption

Systems thinking is transdisciplinary and thus not exclusive to any specific scientific discipline. It has been accompanying respected areas of scientific inquiry for almost a century now, so in that sense it may not be considered as something "new". However, it has not yet been adopted in a similar way or to a similar degree by various disciplines.

In order to reflect each paper's engagement with systems thinking, a scale was devised to assess the presence of systems concepts and methods based on the "diffusion of innovation" work of Rogers (2003). Rogers was interested in the way innovation is adopted and offered a useful set of classifications. Thus, exploring the diffusion of systems thinking in the reviewed literature, this perspective was chosen to represent how systems approaches were manifested and to group them accordingly.

During the investigation, each paper was assigned to one of the following categories based on the described criteria:

- **Late Systems Majority**: simple acknowledgment of systems concepts, with no significant/substantial awareness of systems theories and/or methodologies
- **Early Systems Majority**: high degree of systems concepts and theories' awareness, but without application in practice
- **Early Systems Adopters**: high degree of systems concepts and theories' awareness, and application in practice
- **Systems Innovators**: high degree of systems concepts and theories awareness', and application that serves to the further advancement of systems thinking

The "Late Systems Majority" accommodated the papers that, despite including systems thinking concepts, did not evidence familiarity with the underlying theories and principles, at least as presented in their text. It should be noted here that systems thinking terms have increasingly gained a broader popularity and in some cases their use with alternative meanings can be observed. Indicatively, the term "system" can be associated with an established set of *rules*, or the *status quo*, and "systemic" with a vague, broader, coordinated effort. Since this would create a "noise effect" in the current investigation, while searching the literature, papers with simple references to "food systems" and other "systemic" references were omitted, if the context did not indicate a deeper, and closer to theory, systems thinking reference.

The other three categories encompassed papers demonstrating significant depth in systems thinking mastery. They differentiated between them depending on their degree of engagement, namely non-application within the paper's context for the "Early Systems Majority", clear application for the "Early Systems Adopters", and application in a way that contributes to advancing systems thinking itself for the "Systems Innovators".

2.3.2. Social Theory Paradigm

Capturing the degree of systems thinking adoption alone would provide an indicator of the reviewed papers' level of systems thinking maturity, but it would not reflect their positioning on the spectrum of systems approaches. To this end, an additional dimension of a more qualitative nature was introduced. Food systems are acknowledged as complex systems with social, economic, and environmental perspectives (FAO, 2019). Their social aspect holds a key role in the sensitive issue of food security. Therefore, to highlight their underlying social theory worldview, a set of sociological paradigms was introduced as a second dimension in assessing *systemicity*.

For this dimension, the paradigm classification of Jackson was used. In his book that introduced systems thinking to management practice, Jackson suggested four paradigms: functionalist, interpretive, emancipatory, and postmodern (Jackson, 2003). Briefly, the functionalist systems thinking puts an emphasis on the mechanistic worldview and lies on the assumption that reality can be captured, re-engineered, and controlled. The interpretive methodologies acknowledge *values* and *beliefs* and therefore grasp “softer” aspects of reality that are not easily modelled. In the emancipatory case, emphasis is put on the existence of underlying *coercion* that needs to be uncovered and expressed, in order to realize the extent of its influence and how to move beyond that to fulfil potential. Last, the postmodern approaches criticize the other three’s rationalistic worldview and empirical testing, turn to subjective interpretation, and put an emphasis on highlighting and preserving *diversity*. These four paradigms as discrete worldviews with specific assumptions and beliefs are often incommensurable.

In the current review, the papers were evaluated and assigned to a social theory paradigm that better matched their approach. More specifically, papers following a *complex adaptive systems*, *systems dynamics*, or *cybernetics* approach were assigned to the functionalist paradigm. The approaches favoring *pluralism* were assigned to the interpretive paradigm. Researchers who would systematically and in an explicit manner address the issue of *coercion* would be assigned to the emancipatory paradigm. Lastly, the papers that did not explicitly exhibit any of the previous features yet promoted *diversity* and treated the system’s inherent *coercion* as non-addressable through rational thinking, were assigned to the postmodern paradigm. In cases where elements of more than one paradigm were present, the papers were assigned to both paradigms with the dominant one being first to report in a relevant list of paradigm attributes.

3. Findings

The reviewed food security papers' findings on the "systems thinking diffusion" and social theory paradigm are presented in the following table (Table 2).

Cluster	Paper	Systems Thinking Adoption	Social Theory Paradigm
Design	2012 Barbero and Tamborrini	Systems Innovators	Interpretive
	2015 Barbero	Systems Innovators	Interpretive
	2015 Barbero and Tamborrini	Systems Innovators	Interpretive, Functionalist
	2018 Darzentas et al.	Systems Innovators	Interpretive
	2019 Nohra and Barbero	Systems Innovators	Interpretive
	2019 Sonnino	Systems Innovators	Interpretive
	2019 Sonnino et al.	Systems Innovators	Interpretive
Environmental	2008 Ericksen	Systems Innovators	Functionalist
	2016 Allen and Prosperi	Early Systems Adopters	Functionalist
	2018 Grant et al.	Early Systems Adopters	Interpretive
Food & Nutrition	1996 Maxwell	Late Systems Majority	Postmodern
	2014 van Mil et al.	Early Systems Majority	Functionalist
	2018 Fleischer et al.	Early Systems Adopters	Interpretive, Functionalist
Food Security	2011 Ingram	Early Systems Adopters	Functionalist
	2012 Pereira and Ruysenaar	Early Systems Majority	Functionalist, Interpretive
	2015 Tendall et al.	Systems Innovators	Functionalist
	2017 Horton et al.	Systems Innovators	Functionalist, Interpretive
Science & Engineering	2010 Hipel et al.	Early Systems Adopters	Functionalist
	2012 Hammond and Dubé	Early Systems Majority	Functionalist
	2014 Banson et al.	Systems Innovators	Functionalist, Interpretive
	2014 Foran et al.	Late Systems Majority	Interpretive
	2016 Banson et al.	Systems Innovators	Functionalist, Interpretive
	2017 Zivkovic	Systems Innovators	Postmodern
Sustainability	2007 Bland and Bell	Systems Innovators	Postmodern
	2018 Zurek et al.	Systems Innovators	Functionalist, Interpretive
	2019 Grant et al.	Early Systems Adopters	Interpretive
	2019 Ruben et al.	Early Systems Majority	Interpretive, Functionalist

Table 2. Systemicity assessment.

In Table 2, the reviewed papers are assigned a relevant social theory paradigm. However, contrary to the paradigms' assumed incommensurability some papers have been assigned to more than one. This is due to either an explicit use of additional methods or to implicit perspectives, that were assessed by this review to belong to a different paradigm. Therefore, for papers with more than one paradigm assigned, the primary is the first assigned followed by the more secondary paradigm.

3.1. Assessing Systemicity

The following map (Figure 3) visually summarizes the review's findings on assessing the two dimensions of the papers' *systemicity* as described in the previous section (Section 2.3) and helps gain a better understanding of the papers' interrelations in terms of *systemicity*.

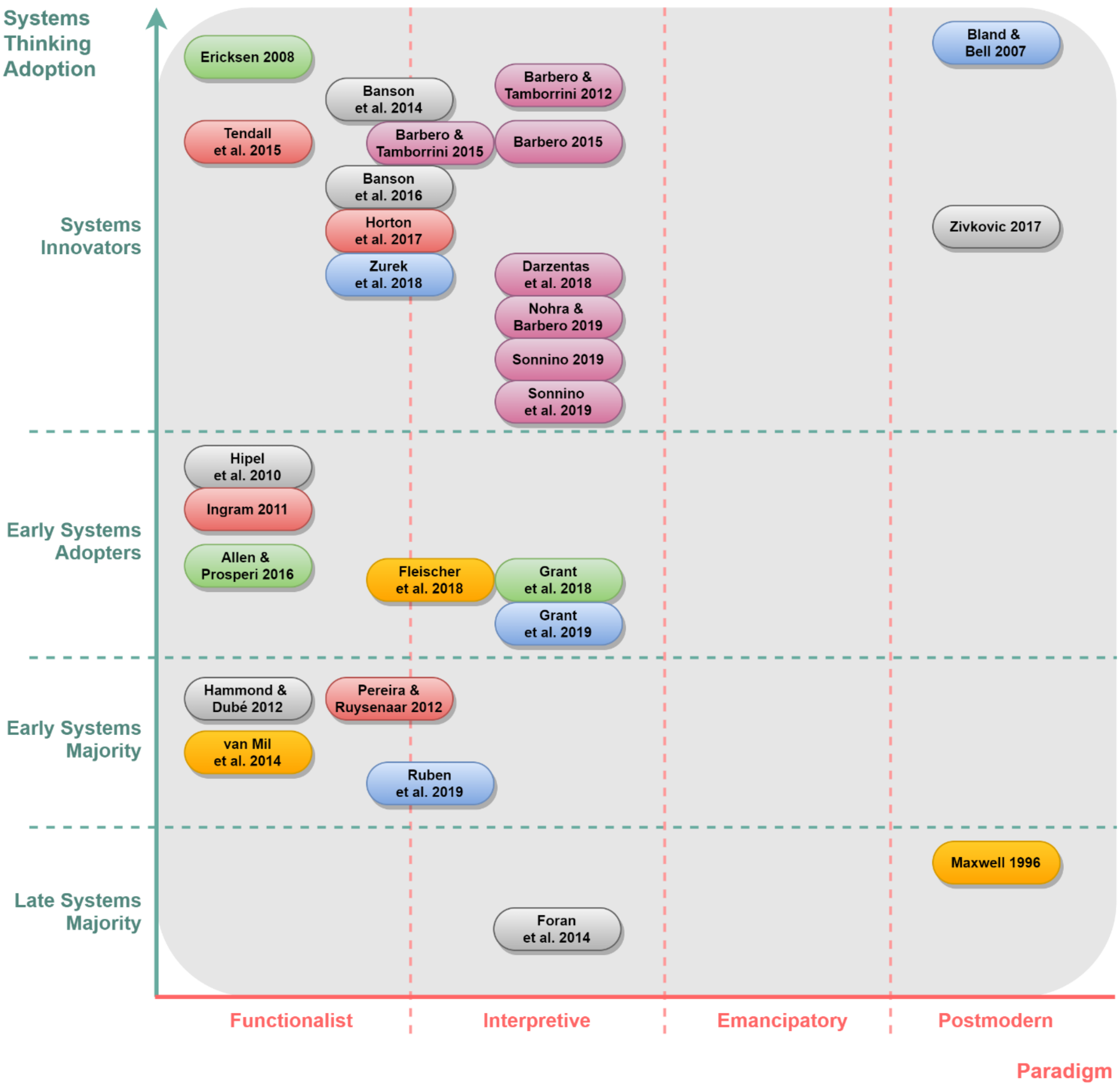

Figure 3. Two-dimensional map of the reviewed papers' systemicity. The reviewed papers are organized on the vertical axis according to their degree of "Systems Thinking Adoption" and on the horizontal axis according to their assigned sociological "Paradigm". The colors correspond to the initial colors assigned to their thematic clusters for ease of reference. Within each *Systems Thinking Adoption* group the papers are sorted and justified to illustrate their timeline succession. A paper's crossing of *Paradigm* borders visualizes the paper's dual sociological perspective: its localization proportions, reflecting primary and secondary perspectives, also insinuate "motion" from the primary towards the secondary paradigm and the relevant tendency to equilibrate them.

Overall, examining Figure 3 one could make two significant observations: there were no emancipatory paradigm papers found and there was an over-representation of Systems Innovators. The former can either signify the food security systems thinkers' deliberate avoidance of the emancipatory paradigm or may insinuate an implicit coercion within the research community. Regarding the latter, the term "coercion" as used here does not refer to a direct and explicit expression of force. The term rather signifies an implicit constraint through the underlying "micropolitics of organizational life" (Jackson, 2003) in research, and/or the researchers' restrain by more broadly propagated social repression mechanisms of the status quo. Regarding the Systems Innovators' abundance, one could infer an implicit "pro-innovation bias" (Rogers, 2003) emphasizing papers that embrace systems thinking. This could be justified by the systematic efforts of the design research community during the last decade to blend systems thinking and design thinking into *systemic design* (P. Jones, 2017; P. Jones & Kijima, 2018).

Future research could further illuminate the significance of both findings. An investigation of social theory trends within both the food research and the broader academic community could help reveal the underlying values and power play dynamics. Furthermore, a systematic investigation of the fifth category of "Systems Laggards" and of the reasons why the food community has not yet adopted systems thinking, whether it being "ignorance about" or "rejection of" systems thinking could shed light on the Innovators over-representation.

The remainder of this section details the findings from the systemicity assessment of the reviewed papers. To present both dimensions of their *systemicity*, the papers are grouped according to their degree of adoption categories. Then, within each category the criteria for their sociological paradigm assessment are summarized.

Systems Innovators

In total 15 papers, i.e. nearly half of the collection, were classified in the Systems Innovators group. They all innovated by applying systems thinking to the issue of food security in a way that raises challenging questions and contributes to the systems thinking expansion in new areas of inquiry. Among them the majority adopted an *interpretive* paradigm, or a primarily *functionalist* one extending to an *interpretive*. This indicates the innovators' need to capture the *variety* of the stakeholders' purposes through inclusion.

More specifically, the introduction of systemic design in ensuring sustainability of the food system helped decipher the underlying complex interconnections and allowed the system's diverse purposes to emerge (Barbero, 2015; Barbero & Tamborrini, 2012; Nohra & Barbero, 2019). Likewise, in Darzentas et al. process of building a food holon the system's constantly changing nature and the stakeholders' diverse setting are emphasized (Darzentas et al., 2018). Also, in her recent study on food governance cultural dynamics, Sonnino captures the multitude of values driving urban food policies (Sonnino, 2019) and in a cities' food policy study the authors uncover politically fragile innovations and a need for cultural change (Sonnino et al., 2019).

On the other hand, Barbero and Tamborrini although being mainly *interpretive*, did recognize the necessity of a more *functionalist* perspective, by designing the functionalities and flows of a circular coffee grounds' system (Barbero & Tamborrini, 2015).

Conversely, although having a clearly *functionalist* basis, other systems innovators extended towards the *interpretive* paradigm. Banson et al. followed a systems dynamics approach in both of their studies towards a more sustainable agriculture in Ghana (Banson et al., 2014, 2016). However, due to the soft systems aspects of Bosch's ELLab process (Bosch et al., 2013), namely its acknowledgment and inclusion of stakeholders' diverse mental models, it enriches a primarily structural approach with interpretive elements. Likewise, Horton et al. introduce a modelling approach, yet acknowledging the importance of ethical, legal, and political tensions in the agri-food system's complexity they introduce deliberative fora (Horton et al., 2017). Last, Zurek et al. integrate different models to provide a more holistic visualization tool, also including the stakeholders in various stages of the framework development process (Zurek et al., 2018).

Ericksen's highly cited work innovated by introducing systems thinking to the theme and was based on the assumption that a conceptual framework can reflect the food systems' complex interactions (Ericksen, 2008). Tendall et al. also remained solely in the *functionalist* paradigm, and contributed by thoroughly investigating the concepts of resilience and sustainability (Tendall et al., 2015).

Bland and Bell were the first to present a *postmodern* approach (Bland & Bell, 2007). They introduce *holonic thinking* extending the systems approach to embrace indeterminacy. They further suggest *flickering* as a mental tool that can help conceiving the food system's multiple and incommensurable contexts. Last, Zivkovic's online tool helps circumventing the complex adaptive food system's wicked specificities (Zivkovic Sharon, 2017). The author redirects the governance's steering strategies to enhancing the adaptive capacity of food security's solution ecosystems, bypassing rationalization of the system's functionalities and its diversity of purposefulness.

Early Systems Adopters

The six papers of the Early Systems Adopters group all demonstrated a high degree of systems thinking awareness and have demonstrated a practical application in their work.

In their study, Hipel et al. applied a System of Systems approach and adopted a *functionalist* paradigm. Although they acknowledged the existence of values and incorporated the stakeholders in the process, they considered them a potential source of instability for the overall system (Hipel et al., 2010). Ingram together with Allen and Prosperi adopted a food system's modelling approach and were thus also grouped as functionalists (Allen & Prosperi, 2016; Ingram, 2011).

On the other hand, Grant et al. clearly followed an *interpretive* paradigm, as they applied a soft systems approach to their complex food system educational program (Grant et al., 2018, 2019). Fleischer et al. were also based on an interpretive paradigm (Fleischer et al., 2018). However, they also suggested combining with a quantitative model to test their qualitative observations, and thus received a secondary *functionalist* grouping.

Early Systems Majority

The Early Systems Majority comprises four papers that have a high awareness of systems thinking concepts but did not proceed to applying them in their specific work. Two of them were grouped as *functionalist*, having adopted a systems modelling approach (Hammond & Dubé, 2012; van Mil et al., 2014), and the other two demonstrated duality. More specifically, Pereira and Ruysenaar adopt a complex adaptive systems approach, but also acknowledge the stakeholders' diversity and the need for their inclusion (Pereira & Ruysenaar, 2012). Conversely, Ruben et al. are primarily *interpretive* but also suggest a combination with *hard systems* approaches (Ruben et al., 2019).

Late Systems Majority

Finally, in the late systems majority area, although the terms "system" and "complexity" appear quite frequent in the text of Foran et al. (2014), their use was not supported by systems concepts that would demonstrate a high level of systems thinking awareness. However, exploring the underlying assumptions of four conceptual frameworks they were classified as *interpretive*. Last, although Maxwell was grouped in the late systems majority based on the current review's criteria, overall he should have been included in the Systems innovators if the year of publication would be considered, which is more than a decade before the first innovator in the field (Maxwell, 1996). However, for a correct content comparison with that of the other publications the paper remained classified as "late" systems majority. The author clearly adopted a *postmodern* paradigm, and he is the first in the reviewed food security papers to have combined a postmodernist paradigm with systems thinking.

3.2. The paradox of disciplinary bias when applying Systems Thinking

A significant finding of the current food security literature review is the paradoxical presence of a disciplinary bias in the various research teams' application of -or reference to- systems thinking. The majority of the food security researchers applied systems thinking largely influenced by, and showing preference to, their disciplinary tools. This constitutes a paradox since systems thinking is inherently inter-/trans- disciplinary and assumes transcending one's own disciplinary boundaries.

More specifically, researchers lying on the structural side of the systems thinking spectrum, predominantly originated from engineering, environmental, and agri-food research, and some from socioeconomic backgrounds. (Allen & Prosperi, 2016; Ericksen, 2008; Hammond & Dubé, 2012; Hipel et al., 2010; Ingram, 2011; Tendall et al., 2015; van Mil et al., 2014). They focused their research on generating food system models and frameworks that provided structure, functionality, and quantifiable metrics.

Respectively, the researchers adopting the "softer" side of systems thinking were ones that mostly came from an equivalent scientific background, such as architecture, design, and sociology (Barbero, 2015; Barbero & Tamborrini, 2012; Bland & Bell, 2007; Darzentas et al., 2018; Nohra & Barbero, 2019; Sonnino, 2019; Sonnino et al., 2019) or applying it within a management and educational context (Grant et al., 2018, 2019; Zivkovic Sharon, 2017) they focused more on qualitative aspects, stakeholders' inclusion and diversity, learning, and innovation.

It is noteworthy that especially in the last five years there are publications that have begun to overcome this methodological dualism, acknowledging the value of adopting a combination of approaches. In most of those cases the authors combined modelling and other approaches providing quantifiable metrics with methods and processes that tackle "softer" aspects (Banson et al., 2014, 2016; Barbero & Tamborrini, 2015; Horton et al., 2017; Zurek et al., 2018). Fleischer et al. performed a qualitative analysis but concluded by also recommending a quantitative analysis (Fleischer et al., 2018). Lastly, there were two papers not applying systems methods but demonstrating high awareness of systems concepts, that acknowledged the necessity of combining both qualitative and quantitative approaches (Pereira & Ruysenaar, 2012; Ruben et al., 2019).

Therefore, it is apparent that when engaging in interdisciplinary collaborations applying systems thinking, it is essential to reflect on -and highlight- the basic assumptions of reality comprising one's own worldview. Remaining biased towards disciplinary tools and approaches opposes the essence of systems thinking. The absence or vague presence of systems concepts and methodologies in the various disciplines hinders attaining a clear reflection. To this end, the systems thinking "communication channels" that could support its diffusion to the active food research communities are primarily conferences and academic curricula. Therefore, as has been noted (Dubberly, 2014; Tuddenham, 2017) there is still a need for a coordinated and clear presence of systems thinking across disciplines in the form of systemic tools, curriculum, and language, that would serve as a means of transcending disciplinary boundaries.

4. Conclusions

The increasing references to systems notions in food studies indicates a growing recognition of systems thinking in appropriately addressing complex global challenges. The current review explored the presence of systems thinking in the food security literature following a three-step method and investigating two dimensions of *systemicity*.

In assessing the food security papers' systemicity, the dimensions considered were their systems thinking level of diffusion and their assigned sociological paradigm. The observed absence of emancipatory paradigm approaches in the set of selected papers could either signify its non-preference from the authors or an implicit coercion within the research community. Furthermore, the emergent overrepresentation of Systems Innovators in the results potentially implies a pro-innovation bias in forming the reviewed set of papers. Future research could help further decipher both these findings.

Another significant finding of the current literature review is the papers' underlying disciplinary bias, contradicting the inherent interdisciplinarity of systems thinking. This could be ameliorated by the adoption of commonly acknowledged systemic tools, curricula, and language across disciplines. Finally, the presence of papers on the border of the functionalist and interpretive paradigms, highlights the researchers' increasing need for a combination of quantitative and qualitative approaches.

Systemic designers were uniformly distributed within the Interpretive paradigm area of the "systemicity map", showing a non-preference to modelling and quantification. In one of the Design cluster papers reaching out to a more structural approach (Barbero & Tamborrini, 2015), this was done within a life cycle context to address the production/consumption needs of the projects. Therefore, overall, there was no design paper trying to capture a holistic viewpoint of the food system's dynamics.

Considering the systemicity map's topology (Figure 3) could help systemic designers locate and prioritize the most "promising" candidates for interdisciplinary collaboration, i.e. the ones requiring a smoother learning curve from both sides. The first to consider would be the functionalist "Systems Innovators" that cross the border towards the interpretive area (Banson et al., 2014, 2016; Horton et al., 2017; Zurek et al., 2018) showing direct interest to soft systems aspects, together with the postmodern "Systems Innovators" (Bland & Bell, 2007; Zivkovic Sharon, 2017) that share a closer perspective on diversity. Furthermore, the very recent interpretive "Early Systems Adopters" (Fleischer et al., 2018; Grant et al., 2018, 2019) reside on the same area of the paradigm spectrum and have already demonstrated an applied knowledge of systems thinking.

Overall, the two selected systemicity dimensions in this review, capturing both the degree and the essence of the reviewed papers' relation to systems thinking, position the reviewed literature on a two-dimensional "systemicity map". Visualizing the reviewed papers in such way provides a more tangible measure of reference in the review's comparative analysis and allows reaching a more holistic viewpoint. Therefore, the current review's method and the selected systemicity criteria could serve as a basis for future literature reviews seeking to elucidate systems thinking engagement across disciplines. Furthermore, the use of the two-dimensional systemicity map as a common reference point could enhance interdisciplinary collaboration, by providing a mutual understanding on the variety of systems thinking perspectives and degrees of adoption.

References

Allen, T., & Prosperi, P. (2016). Modeling Sustainable Food Systems. Environmental Management, 57(5), 956–975. https://doi.org/10.1007/s00267-016-0664-8

Banson, K., Nguyen, N., & Bosch, O. (2016). A Systems Thinking Approach to the Structure, Conduct and Performance of the Agricultural Sector in Ghana. Systems Research and Behavioral Science. https://doi.org/10.1002/sres.2437

Banson, K., Nguyen, N., Bosch, O., & Nguyen, T. (2014). A Systems Thinking Approach to Address the Complexity of Agribusiness for Sustainable Development in Africa: A Case Study in Ghana. Systems Research and Behavioral Science. https://doi.org/10.1002/sres.2270

Barbero, S. (2015). Systemic Design for Food Sustainability Interpretation of real cases and reflection on theories. Relating Systems Thinking and Design (RSD4) Symposium, 4.

Barbero, S., & Tamborrini, P. (2012). Systemic Design in AgroFood Sector: EN.FA.SI project. International Conference on Designing Food and Designing For Food, 285–296.

Barbero, S., & Tamborrini, P. (2015). Systemic Design goes between disciplines for the sustainability in food processes and cultures. 7th International AESOP SUSTAINABLE FOOD PLANNING CONFERENCE Localizing Urban Food Strategies Farming Cities and Performing Rurality, 517–525.

Bland, W., & Bell, M. (2007). A Holon Approach to Agroecology. International Journal of Agricultural Sustainability, 5, 280–294. https://doi.org/10.1080/14735903.2007.9684828

Bosch, O. J. H., Nguyen, N. C., Maeno, T., & Yasui, T. (2013). Managing Complex Issues through Evolutionary Learning Laboratories. Systems Research and Behavioral Science, 30(2), 116–135. https://doi.org/10.1002/sres.2171

Darzentas, J., Darzentas, J., De Bruin, A., Power, M., Prado, P., Carmien, S., & Hobbs, E. (2018, October 23). Systemic design in food security and resilience: Building a holon. Proceedings of RSD7, Relating Systems Thinking and Design 7, Turin, Italy. http://openresearch.ocadu.ca/id/eprint/2694/

Dubberly, H. (2014, October 17). A systems literacy manifesto. Proceedings of RSD3, Third Symposium of Relating Systems Thinking to Design, Oslo, Norway. http://openresearch.ocadu.ca/id/eprint/2058/

Ericksen, P. (2008). Conceptualizing Food Systems for Global Environmental Change Research. Global Environmental Change-Human and Policy Dimensions - GLOBAL ENVIRON CHANGE, 18, 234–245. https://doi.org/10.1016/j.gloenvcha.2007.09.002

FAO. (1996). Rome declaration of world food security. World Food Summit. http://www.fao.org/3/w3613e/w3613e00.htm

FAO. (2019). FAO framework for the Urban Food Agenda. Food and Agriculture Organization of the United Nations. http://www.fao.org/publications/card/en/c/CA3151EN/

Fleischer, N. L., Liese, A. D., Hammond, R., Coleman-Jensen, A., Gundersen, C., Hirschman, J., Frongillo, E. A., Ma, X., Mehta, N., & Jones, S. J. (2018). Using systems science to gain insight into childhood food security in the United States: Report of an expert mapping workshop. Journal of Hunger & Environmental Nutrition, 13(3), 362–384. https://doi.org/10.1080/19320248.2017.1364194

Foran, T., Butler, J., Williams, L., Wanjura, W., Hall, A., Carter, L., & Carberry, P. (2014). Taking Complexity in Food Systems Seriously: An Interdisciplinary Analysis. World Development, 61, 85–101. https://doi.org/10.1016/j.worlddev.2014.03.023

Gill, M., den Boer, A. C. L., Kok, K. P. W., Breda, J., Cahill, J., Callenius, C., Caron, P., Damianova, Z., Gurinovic, M. A., Lähteenmäki, L., Lang, T., Laperrière, A., Mango, C., Ryder, J. Sonnino, R., Verburg G., Westhoek. H., Regeer, B. J., Broerse, J. E. W., & den Boer, A. C. L., Kok, K. P. W., Breda, J., Cahill, J., Callenius, C., Caron, P., Damianova, Z., Gurinovic, M. A., Lähteenmäki, L., Lang, T., Laperrière, A., Mango, C., Ryder, J. Sonnino, R., Verburg G., Westhoek. H., Regeer, B. J., Broerse, J. E. W. (2018). A systems approach to research and innovation for food system transformation (p. 6) [Policy brief]. FIT4FOOD2030. https://fit4food2030.eu/eu-think-tank-policy-brief/

Grant, M., Gilgen, A., & Buchmann, N. (2019). The Rich Picture Method: A Simple Tool for Reflective Teaching and Learning about Sustainable Food Systems. Sustainability, 11, 4815. https://doi.org/10.3390/su11184815

Grant, M., Shreck, A., & Buchmann, N. (2018). Tackling Food System Challenges through Experiential Education: Criteria for Optimal Course Design. GAIA - Ecological Perspectives for Science and Society, 27, 169–175. https://doi.org/10.14512/gaia.27.1.13

Hammond, R., & Dubé, L. (2012). A systems science perspective and transdisciplinary models for food and nutrition security. Proceedings of the National Academy of Sciences of the United States of America, 109, 12356–12363. https://doi.org/10.1073/pnas.0913003109

Hipel, K., Fang, L., & Heng, M. (2010). System of systems approach to policy development for global food security. Journal of Systems Science and Systems Engineering, 19, 1–21. https://doi.org/10.1007/s11518-010-5122-1

Horton, P., Banwart, S. A., Brockington, D., Brown, G. W., Bruce, R., Cameron, D., Holdsworth, M., Lenny Koh, S. C., Ton, J., & Jackson, P. (2017). An agenda for integrated system-wide interdisciplinary agri-food research. Food Security, 9(2), 195–210. https://doi.org/10.1007/s12571-017-0648-4

Ingram, J. (2011). A food systems approach to researching food security and its interactions with global environmental change. Food Security, 3. https://doi.org/10.1007/s12571-011-0149-9

Jackson, M. (2003). Systems Thinking: Creative Holism for Managers. John Wiley & Sons Ltd.

Jones, P. (2017). The Systemic Turn: Leverage for World Changing. She Ji: The Journal of Design, Economics, and Innovation, 3(3), 157–163. https://doi.org/10.1016/j.sheji.2017.11.001

Jones, P. H. (2014). Systemic Design Principles for Complex Social Systems. In G. S. Metcalf (Ed.), Social Systems and Design (pp. 91–128). Springer Japan. https://doi.org/10.1007/978-4-431-54478-4_4

Jones, P., & Kijima, K. (2018). Systemic Design. Springer Japan.

Maxwell, S. (1996). Food security: A post-modern perspective. Food Policy, 21(2), 155–170. https://doi.org/10.1016/0306-9192(95)00074-7

Nohra, C. G., & Barbero, S. (2019). Systemic Design for territorial thinking. Circular urban transitions for post-industrial cities. The Design Journal, 22(sup1), 915–929. https://doi.org/10.1080/14606925.2019.1595408

Pereira, L., & Ruysenaar, S. (2012). Moving from traditional government to new adaptive governance: The changing face of food security responses in South Africa. Food Security, 4. https://doi.org/10.1007/s12571-012-0164-5

Rogers, E. M. (2003). Diffusion of innovations (Fifth). Free Press.

Ruben, R., Verhagen, J., & Plaisier, C. (2019). The Challenge of Food Systems Research: What Difference Does It Make? Sustainability, 11, 171. https://doi.org/10.3390/su11010171

Sonnino, R. (2019). The cultural dynamics of urban food governance. City Food Governance, 16, 12–17. https://doi.org/10.1016/j.ccs.2017.11.001

Sonnino, R., Tegoni, C. L. S., & De Cunto, A. (2019). The challenge of systemic food change: Insights from cities. Cities, 85, 110–116. https://doi.org/10.1016/j.cities.2018.08.008

Systemic Design Association. (n.d.). SDA. https://systemic-design.net/

Tendall, D. M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q. B., Kruetli, P., Grant, M., & Six, J. (2015). Food system resilience: Defining the concept. Global Food Security, 6, 17–23. https://doi.org/10.1016/j.gfs.2015.08.001

Tuddenham, P. (2017). Observations on Systems Literacy at the International Society for Systems Sciences (ISSS) 2016 Conference. Systems Research and Behavioral Science, 34(5), 625–630. https://doi.org/10.1002/sres.2491

UN Environment. (2019). Collaborative Framework for Food Systems Transformation. A multi-stakeholder pathway for sustainable food systems. UN Environment. https://www.oneplanetnetwork.org/resource/collaborative-framework-food-systems-transformation-multi-stakeholder-pathway-sustainable

van Mil, H. G. J., Foegeding, E. A., Windhab, E. J., Perrot, N., & van der Linden, E. (2014). A complex system approach to address world challenges in food and agriculture. Trends in Food Science & Technology, 40(1), 20–32. https://doi.org/10.1016/j.tifs.2014.07.005

Zhang, W., Gowdy, J., Bassi, A. M., Santamaria, M., deClerck, F., Adegboyega, A., Andersson, G. K. S., Augustyn, A. M., Bawden, R., Bell, A., Darknhofer, I., Dearing, J., Dyke, J., Failler, J., Galetto, P., Hernandez, C. C., Johnson, P., Kleppel, P., Komarek, P., … Wood, S. L. R. (2018). Systems thinking: An approach for understanding 'eco-agri-food systems.' In TEEB for Agriculture and Food: Scientific and Economic Foundations (pp. 17–55). United Nations Environment. https://ezproxy2.utwente.nl/login?url=https://webapps.itc.utwente.nl/library/2018/chap/willemen_tee.pdf

Zivkovic Sharon. (2017). Addressing food insecurity: A systemic innovation approach. Social Enterprise Journal, 13(3), 234–250. https://doi.org/10.1108/SEJ-11-2016-0054

Zurek, M., Hebinck, A., Leip, A., Vervoort, J., Kuiper, M., Garrone, M., Havlík, P., Heckelei, T., Hornborg, S., Ingram, J., Kuijsten, A., Shutes, L., Geleijnse, J., Terluin, I., Veer, P., Wijnands, J., Zimmermann, A., & Achterbosch, T. (2018). Assessing Sustainable Food and Nutrition Security of the EU Food System—An Integrated Approach. Sustainability, 10, 4271. https://doi.org/10.3390/su10114271