Sustainability and food and nutrition security: An indicator-based vulnerability and resilience approach for the Mediterranean Region

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Abstract

Recurrent food crises and global change are critical issues that pushed food security and environmental sustainability to the top of the political agenda. Using the lens of a broad sustainability approach and recognizing the systemic dimension of sustainability, the thesis developed a multidimensional framework to identify metrics for assessing the sustainability of food systems and diets. Building on the theories of vulnerability and resilience, the Mediterranean Region presents a set of socioeconomic and biophysical drivers of change affecting the sustainability of the food system in its main functions providing food and nutrition security. Formalizing the food system as a dynamic complex system, several causal models of vulnerability were identified, describing the interactions where drivers of change directly affect food and nutrition security outcomes, disentangling exposure, sensitivity, and resilience. This theoretical approach was operationalized through the identification of a first suite of indicators. A reduced pool of metrics was then obtained through an expert-based Delphi survey, moving beyond subjective evaluation and reaching consensus.

Keywords
Food systems, Food Security, Sustainability, Resilience, Mediterranean, Metrics.

Introduction

The latest FAO estimates indicate that approximately 805 million people are chronically undernourished worldwide (FAO, 2014). Considering that the global population is projected to reach 7,3 billion in 2015 (UN, 2014), it is possible to estimate that 11% of people are chronically undernourished (FAO, 2014). Concurrently, nearly 2.1 billion people are affected by malnourishment related to unhealthy food consumption and dietary trends, which is reflected in the spread of food-related diseases like obesity and nutrient deficiency (Ng et al., 2014). At the same time food production and consumption exert a huge impact on the environment and are significant sources of green house gases. Furthermore, agriculture is responsible for 70% of water withdrawal (FAOSTAT, 2012) and represents a main driver of deforestation and loss of biodiversity. Food systems rely on physical resources such as land, water, biodiversity, and fossil fuels which are becoming ever more fragile and scarce. Efforts need to be focused on the creation of food systems that are more efficient in the use of

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resources and reduce food waste, at every stage, from primary production to transformation and consumption (UNEP, 2012).

Sustainability of the Food System

Recurrent food crises and global change - along with habitat loss and micronutrient deficiencies - placed food security and environmental sustainability at the top of the political agenda. The scientific and international debate on sustainability of diets and food systems is gaining increasing recognition (FAO & Bioversity International, 2012), and the analysis of the dynamic interlinkages between food consumption patterns and environmental concerns recently received considerable attention from the international community. Interconnected environmental sustainability and food and nutrition security topics, and the debate about strengthening the links between food, health, and environmental research, are gaining increasing intensity (Freibauer et al., 2011).

The sustainability of food system is at risk, with socioeconomic and biophysical changes affecting the food system functions, including food and nutrition security. Building sustainable food systems has become a key effort to redirect our food systems and policies towards better-adjusted goals and improved societal welfare. Food systems involve multiple interactions between human and natural components. The systemic nature of these interactions calls for systems approaches and integrated assessment tools. Identifying and modeling the intrinsic properties of the food system can help tracking progress towards sustainability and setting policies towards positive transformations (Fanzo et al., 2012).

Scientific analyses of contexts, systems and their properties inform the political process on how to achieve sustainability, and diversification of knowledge, integration of methods and inclusiveness in decision-making and governance are key (Scoones et al., 2007). For the food system, the potential answers can be found in the analyses of the quantitative nexuses between diets, the environment and human health, through the contribution of nutritionists, agriculturists, public health professionals, educators, policy makers and the food industry sector (Tilman & Clark, 2014). In such a dynamic scenario, measures of food and nutrition security that only focus on outcomes, such as hunger and malnourishment, might be too narrow for a comprehensive understanding of the food system and its changing causal mechanisms. However, at now, there is no consensus and there are presently no precise and reliable global common metrics in use to measure the sustainability of food systems (Vinceti et al., 2013).

Understanding what needs to constitute the assessment of the sustainability of food systems and diets is key for providing decision- and policy- making with knowledge of action, and having a systemic rationale and a framework to build a metric system is indispensible (Fanzo, 2014). It is then necessary to investigate the impact of the determinants on the sustainability of diets and identify the appropriate tradeoffs related with recommendations and actions towards the sustainability of the food systems (Johnston et al., 2014).

Aims

The general aim of this thesis was to analyze and explore the sustainability of the food system through identifying a structured system of metrics at the Mediterranean level.
This broad aim involved three specific goals that have been identified through a sequential logic.
The first specific goal was to develop a multidimensional framework to evaluate the sustainability of food systems and diets, applicable to countries of the Mediterranean region, linking concepts, methods, and metrics, for a multidimensional joint analysis.
The second specific goal was to identify the main variables to formalize and operationalize the abstract and multidimensional concept of sustainable food systems, and to define the food system characteristics and fundamental systemic properties that make the food system capable of sustaining food and nutrition security outcomes.
The third specific goal was to identify metrics for assessing the sustainability of food systems and diets, at a subregional level, combining a vulnerability and resilience framework and a Delphi elicitation process.

Method

Through a broad understanding of sustainability, the methodological approach of this thesis builds on the theories of vulnerability and resilience. Following the steps of the global change vulnerability assessment a causal factor analysis is presented at a transnational and subregional level concerning three Mediterranean countries, namely Spain, France and Italy (the Latin Arc). Formulating "what is vulnerable to what" hypotheses, eight causal models of vulnerability were identified. A three-round Delphi survey was then applied to select indicators on the basis of the vulnerability/resilience theoretical framework.

The Vulnerability/Resilience framework

Vulnerability – as the degree to which a system is likely to experience harm due to exposure to a perturbation or stress – is a function of exposure, sensitivity, and resilience. Exposure is the nature and degree to which a system is likely to be affected by the occurrence of a change. Sensitivity is the degree to which a system is affected either adversely or beneficially, by a change. Resilience is the ability of a system to anticipate, absorb, accommodate, or recover from the effects of a potentially hazardous event in a timely and efficient manner, through ensuring the preservation, restoration, or improvement of its essential basic structures and functions (IPCC, 2012).
The system-oriented approach that is proposed, for the assessment of sustainable diets and food systems, incorporates elements from the vulnerability and resilience theories. The Turner et al.'s (2003) vulnerability/sustainability framework is one of the most quoted integrated conceptual models for vulnerability assessment (Gbetibouo et al., 2010). Exposure, sensitivity and resilience provide the concepts to identify the system's properties

that shape a causal pathway towards food system's outcomes, and these are the variables that this study aims to proxy through a Delphi expert elicitation process.
Vulnerability per se is considered unobservable; since it does not express an observable phenomenon it is a theoretical concept that cannot be measured (Patt et al., 2008). Thus, before measuring vulnerability it is necessary to make the concept operational, providing a method for framing it into observable concepts. This operational definition can be identified as vulnerability assessment, and indicators represent an appropriate approach to operationalize the theoretical concepts (Hinkel, 2011).

Indicator based approach

The selection of indicators is a crucial step and need to be realized beyond individual subjectivity and single value judgments. Once that a framework defines the phenomenon to be measured, ideally the selection of the individual indicators should be based on what is desirable to measure and not on which indicators are available (OECD, 2008).
Vulnerability and resilience indicators, in this thesis, were identified through deductive arguments (i.e. building on existing theories, models and frameworks). In particular the general framework of Turner et al. (2003), for social-ecological systems, was adapted to the food system framework of Ericksen (2008a), fostering the operationalization of the theories of vulnerability and resilience through a set of causal models and the combination with literature review and expert judgment. Since data availability has not been the central criterion for identifying indicators, this work can be considered to be based on a theory-driven approach (instead of a data-driven one) (Hinkel, 2011; Niemeijer, 2002).

The Delphi method

Several decision support tools have been identified and applied for providing guidance to decision makers for solving problems in social-ecological systems and global change contexts. It is usually recommended to use expert elicitation to offer solutions for decision-making (de França Doria et al., 2009). The Delphi method is a popular social research technique and implies the participation of a broad and transdisciplinary range of experts. This technique can be applied on a global scale, is based on anonymous responses, and can generate interactions between experts having different opinions and coming from different geographical backgrounds (Frewer et al., 2011). The aim of this forecasting method is to obtain a reliable common opinion from a group of individual experts who can each provide anonymous valuable contributions in order to resolve a complex problem on the basis of free opinions and knowledge, avoiding personality and authority's influences (Landeta, 2006; Linstone & Turoff, 1975). Following the protocol of the Delphi Survey, in this study, participants were asked to discuss and complement the vulnerability/resilience framework proposed for the food system (and the underlying assumptions), and to test the framework by selecting proxy indicators. Succeeding rounds were designed to bring the group to focus on consensus.
There is one crucial question the panel of experts were asked to answer: Vulnerability/resilience of what to what? Three questionnaires, over three iterative rounds,

were used and included the proposed indicators of exposure, sensitivity and resilience of four context-specific food and nutrition security issues, against four drivers of change affecting the food system.

Results

A conceptual hierarchical framework was identified for modeling the complex relationships between food and nutrition security and sustainability for developing potential indicators of sustainable diets and food systems. A feedback-structured framework of the food system formalized eight selected causal models of vulnerability and resilience and identified intrinsic properties of the food system, shaping the interactions where a set of drivers of change directly affect food and nutrition security outcomes at a subregional level. Each interaction was disentangled in exposure, sensitivity and resilience. This theoretical framework was operationalized through the identification of a set of 136 indicators. The Delphi study revealed low, medium, and high consensus and majority level on indicators in 75% of the interactions out of the 24 initial ones. The results obtained in terms of global response, expert participation rates, and consensus on indicators, were then satisfactory. Also, experts confirmed with positive feedback the appraisal of the components of the framework.

Development of a conceptual framework

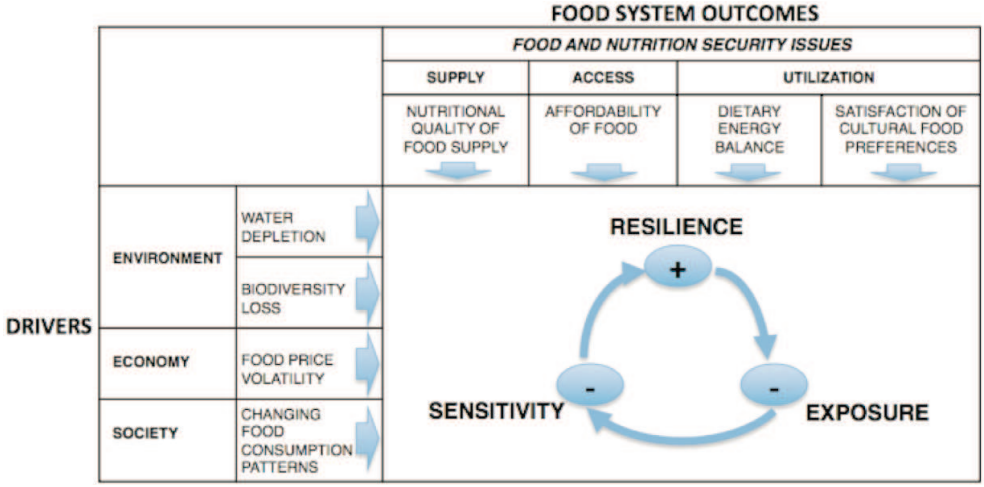
Developing a conceptual multidimensional framework, to explore the sustainability of the food systems, implied adopting a broad sustainability approach that was reached through an extensive literature review on problems related to food and nutrition security. The understanding of the food systems as social-ecological systems helped answering questions about the sustainability problems that affect the functions of the food system (Food system framework: Ericksen, 2008a). Food and nutrition security is considered the principal outcome of any food system and is a multidimensional concept and relies on the several properties and activities of food systems (Ingram et al., 2010). Various elements of food systems are altered by - and actively impact - the socioeconomic and environmental conditions of the system across local, regional and global levels. These interactions are featured by - and bring with themselves - high uncertainties, that can be explored through a vulnerability and resilience analysis, being vulnerability the propensity or predisposition of a system to be adversely affected by a change (IPCC, 2014). Food systems can be vulnerable, and resilient, to a set of stressors (Adger, 2006) such as environmental pressures, socioeconomic instabilities and institutional and policy factors (Vulnerability framework: Turner et al., 2003; Ericksen et al., 2010). A food system is considered vulnerable when it fails in delivering one or many of its intended outcomes, because of even small stresses that might bring to significant social-ecological consequences (Adger, 2006; Eakin, 2010). Fulfilling the food system outcomes remains challenging because of socioeconomic and biophysical stressors affecting the food system. Food systems are then considered social-ecological systems that comprise biophysical and social factors linked through feedback mechanisms (Ericksen, 2008a). Theories of vulnerability and resilience proved helpful in several researches to

understand the complex dynamics involving socioeconomic and biophysical aspects, to implement sustainable development strategies and research programs.
A causal-factors approach allowed to study the sequential pathway defined by the relationship between exposure, sensitivity and resilience. Understanding the causal mechanisms that regulate the interactions between drivers of change and vulnerable food and nutrition security issues can help analyzing and interpreting available information, developing metrics, and anticipating new hazards and changes. The investigation on causes, effects and response to socioeconomic and biophysical changes can provide analytical tools to further understand the problems that affect the sustainability of the food system (Turner et al., 2003).
This approach proved helpful for a general causal analysis of the vulnerability of the food system outcomes at a regional level, in the Mediterranean area.

Food System dynamics in the Mediterranean Latin Arc

Several global and regional drivers of change affect the structure and processes of the food systems (Brunori et al., 2008) putting at risk context-specific food and nutrition security outcomes (Ericksen, 2008a).
The research targeted the identification of the main variables to formalize and operationalize the abstract and multidimensional concepts of sustainable food systems. A feedback-structured framework of the food system, combined with a large literature review, helped formalize eight causal models of vulnerability and resilience, and identified intrinsic properties of the food system, shaping the interactions where four external drivers of change (Water depletion; Biodiversity loss; Food price volatility; Changes in food consumption patterns) directly affect food and nutrition security outcomes at a subregional level (Nutritional quality of food supply; Affordability of food; Dietary energy balance; Satisfaction of cultural food preferences) (Figure 1) (Brunori et al., 2008; Brunori & Guarino, 2010; Freibauer et al., 2011; HLPE, 2011; Ingram and Kapadia, 2010; Kearney, 2010; PARME, 2011; UNEP, 2012; UNSCN, 2000; UNWATER, 2014; WHO, 2014).

Figure 1. Interactions Drivers of change / Food and Nutrition Security Issues in the Latin Arc



Adapted from Prosperi et al., 2014

The challenge for social-ecological system frameworks analysis, here, was to identify the pathways leading to vulnerability, and the characteristics and opportunities ensuring resilience of the food system in a context of change. The identification of a causal pathway (adapted from Metzger and Schroeter, 2006; Fussel and Klein, 2006) allowed locating the role of the three variables (exposure, sensitivity, and resilience), with exposure referring to relational variable between the system and its environment.
Exposure represents the first point of contact between the perturbation and the system. The understanding of exposure, as interface with a specific driver of change, helps differentiating it from the sensitivity or resilience components, which might be influenced by other drivers of change. Building on the GECAFS food systems approach (Ericksen, 2008a,b; Ingram et al., 2010), coupled with Turner et al.'s (2003) conceptualization of vulnerability, the suggested framework represents the modeling of food systems' dynamics, with feedback from outputs to inputs. The three components of vulnerability – exposure, sensitivity, and resilience – are the intrinsic features of the system that mediate the impact of the drivers of change on the food system's outcomes.
The formalization of these food system dynamics allowed shaping the eight causal models where the drivers of change and the food system outcomes of interest have been evaluated through the analysis of their potential causal relationships.
In particular, these sets of characteristics are indicating how changes in water, biodiversity, food prices and food consumption patterns are transmitted through the food system, including the sequence of events and the scale of interactions; how the food system is sensitive to these changes; and the subsequent adaptive capacity of the food system.

Results form a Delphi expert elicitation process

The identification of crucial interactions within a complex food system and the identification of a causal model allowed the definition of a set of metrics for assessing the sustainability of the food systems. The principal aim was to select metrics for assessing the sustainability of food systems and diets, at a subregional level. Part of the aim was also to involve the participation of the scientific community in the selection of metrics. Whether several expert elicitation processes exist, Delphi studies are considered performing tools that provide a common understanding and consensus on unraveled problems, avoiding problems related to institutional or authority influence between the experts. The vulnerability and resilience framework was used as an analytical lens to provide a sequential list of sustainability indicators, while the Delphi method was used to determine which indicators are perceived as more relevant according to a selected group of participants. The Delphi study was here conducted according to the recommendations of several scholars (Landeta, 2006; Frewer et al., 2011), to achieve a consensus on a set of metrics of sustainable diets and food systems. This involved also the selection of the invited researchers on the basis of their characteristics. A crucial factor was the selection of metrics for the initial set of metrics. Each indicator was identified through a hypothesis. Each hypothesis described the behavior of a variable (exposure, sensitivity, resilience) lying underneath the causal mechanism occurring in each interaction between a driver of change and a food and nutrition security issue (Figure 1).

Only eight interactions, within a set of sixteen potential ones (Figure 1), were studied. Consensus was finally reached for 15 of the 24 desired indicators: 8 indicators have met the high threshold consensus criteria (80%), 3 the medium threshold consensus criteria (70%) and another 4 the low threshold consensus criteria (60%). Another 4 indicators have been selected by the majority of the participants (above 50%). For 5 dimensions, clear bipolarity can be reported. The results, in terms of global response and participation rates and consensus on indicators, were judged acceptable (Landeta, 2006). These results partially confirmed the validity of the conceptual framework and methodology applied.

Inputs from the multidisciplinary group of Delphi participants globally acknowledged the importance of analyzing the potential impacts of a set of global and regional biophysical and socioeconomic changes on a set of food and nutrition security issues specific to the area considered, and the related recovery potentials.

In particular, the analysis of issues related to the nutritional quality of food vis-a-vis biophysical changes, such as water depletion and biodiversity loss, allowed the identification of specific metrics. Also, the study of issues related to the affordability of food confronted with food price volatility has brought to the definition of the indicators needed.

Still, further research is needed for analyzing the potential impacts of the loss of biodiversity on issues related to the satisfaction of food preferences, and the potential interactions between the changes in consumption patterns and the dietary energy balance, in order to identify the most valuable and specific metrics.

Conclusions

This thesis aimed at developing a multidimensional framework, to identify metrics for assessing the sustainability of food systems and diets, applicable at a subregional level. Building on Social-Ecological Systems frameworks, the Mediterranean Latin Arc presents several socioeconomic and biophysical drivers of change making the food system vulnerable in its functions. A vulnerability/resilience approach was applied to analyze the main issues related to food and nutrition security. Formalizing the food system as a dynamic system, a model originates from this framework. Several causal models of vulnerability were identified, describing the interactions where drivers of change directly affect food and nutrition security outcomes, disentangling exposure, sensitivity, and resilience.

The theoretical modeling exercise and the expert-based Delphi survey allowed the identification of a reduced suite of indicators, moving beyond single and subjective evaluation, and reaching consensus on metrics of sustainable diets and food systems for supporting decision-making. The operationalization of the theories of vulnerability and resilience, through an indicator-based approach, can then contribute to further analyses on the socioeconomic and biophysical aspects and interlinkages concerning the sustainability of diets and food systems.

The Delphi-variant used in this study were useful in providing transparent tools for exploring the complexities of the assessment of sustainable diets and food systems, and consensus was reached for a number of dimensions. This study highlighted the challenges and the interest for further researches, through combining expert elicitation processes and a dynamic

and analytical vulnerability and resilience framework, to generate a common working language and a set of metrics supporting decision-making for sustainable diets and food systems.

Scientific standing

This thesis deals with several research domains and pertains to three research fields such as: the assessment of sustainability of diets and food systems, the operationalization of vulnerability and resilience theories, and the Delphi expert consultation method.
With regards to assessing sustainability of diets and food systems, it still does not exist a shared consensus on a set of metrics (Vinceti et al. 2013). Research institutions, and governmental and non-governmental bodies produced a host of valuable efforts, both at national and international level, for identifying tools for the assessment of the sustainability of food systems (Feenstra et al., 2005; DEFRA, 2009; FAO, 2013; UNSDSN, 2014). This work is meant to propose a scientific theory-driven contribution, to the assessment of sustainable diets and food systems, building on robust theories (vulnerability/resilience within the social-ecological systems frameworks) and methods (vulnerability assessment, indicator approach, and Delphi) that already proved appropriate for food systems or social-ecological systems analyses.

Limitations

Since the theories of vulnerability and resilience pertain to the social-ecological systems frameworks, it is acknowledged that the application of these theories to the analysis of the sustainability of the food systems interests mainly the scientific community rather than the development practitioners; its systemic nature may complicate and discourage the agency options (Foran et al., 2014). However, practitioners might consider metrics to measure sustainability as more important than scientists might do (Dicks et al., 2013).
Within this broad systemic approach this thesis attempted a reductionist and operational analytic approach, refined through multidisciplinary and multi-stakeholders dialogue and interaction (i.e. the Delphi study), and aimed at contributing to the perspective of a science for sustainability (Holling, 1998; Scoones et al., 2007) in food systems. However the risk of inducing a certain degree of linearity in the dynamic causality persists.
This study wants mainly to fill the theoretical and methodological gaps that are generally beneath a numeric assessment of sustainable diets and food systems combining a theory-driven approach built on deductive arguments with expert judgment, rather than data-driven processes and inductive arguments (Hinkel, 2011). Since "What is badly defined is likely to be badly measured" (OECD, 2008), efforts are here concentrated on the operationalization of theories (vulnerability and resilience) in order to build a prior solid basis for defining a set of metrics, before an accurate and robust statistical analysis.
Further food systems' outcomes could have been studied, such as environmental and socio-economic outcomes related to employment or equity. Food systems, in fact, are responsible for various environmental, economic and social outcomes. The set of food systems'

outcomes and defining elements could be extended to other dimensions to further develop the modelling approach.

Implications for further research

The gaps in the theoretical background, results, and limits of this work can help identify further research perspectives. This research may offer a set of opportunities for further analyses on the sustainability of the food systems, thanks to a dynamic theory-based framework.
Further current key socioeconomic and biophysical changes, acting on the food systems, and the food and nutrition security problems specific to the Latin Arc could be explored. The set of interactions might provide further original and inspiring research developments since the framework proposed is a dynamic structure, opening to further integrations with different drivers and issues. In particular, the expert consultation results call for a deeper analysis of environmental externalities and social equity, as well as food safety and governance issues, and their potential interactions with current drivers of change such as technological innovation, policy actions, or changing agrofood patterns and structures.
With regards to the availability of data, according to the list of 15 selected indicators presenting low, medium, and high consensus, at least 9 of them are not computed in the geographical area considered. This might encourage further retrieval of data for these indicators, to assess not yet measured food system drivers and issues.
Moreover, since this south-west Mediterranean area of Europe (the Latin Arc) presents several demographic and socioeconomic data that are considerably different from other subregions of the Mediterranean Basin (such as North-west Mediterranean Africa, the Middle-East, or the Euro-Mediterranean Balkans), as well as considerable gaps for food and nutrition security related indicators (Share of Dietary Energy Supply derived from cereals, adult literacy, child-stunting, -wasting, -underweight, global obesity, and overweight), further research could be oriented towards the assessment of the different impacts that common global and regional drivers of change (water scarcity, biodiversity loss, etc.) might have depending on the local and context-specific food and nutrition problems (food preferences, food access, etc.).

In conclusion, food systems are systems of variables connected to each other through causal pathways operating at different geographical or time scales. It is, therefore, desired to develop interventions that treat the underlying causes, rather than the symptoms of the unsustainability deriving from food systems, and the concepts of vulnerability and resilience can bring food security into consideration in a different way than in the past. Through the vulnerability and resilience theories and approach it is suggested to capture the food system as a whole, think prospectively and identify the system elements that policy can control or mitigate. The distinction in three components - exposure, sensitivity and resilience - allows the model specifying which attributes need to be measured and how to structure the different indicators in a coherent assessment framework for improved decision-making and policies for sustainable food systems.

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