New methodological frontiers for sustainability assessment: A multidimensional vulnerability framework for the agrofood system

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New Methodological Frontiers for Sustainability Assessment: a Multidimensional Vulnerability Framework for the Agrofood System

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Abstract
Sustainable Food Security and Sustainable Diets are widely acknowledged and studied by the international community. The links between food regimes of populations and the environmental and socioeconomic issues concerning individuals, countries and geographical areas, are nowadays recognized and proved. Nevertheless, identifying metrics for a multidimensional analysis remains a challenging task. This methodological paper proposes a revisited vulnerability approach for an innovative application to food security and sustainability issues in the agrofood system. The aim is to identify qualitative and quantitative methods to consider the interrelating factors leading to vulnerability, in order to inform decision-making and adaptive strategies. An original methodological framework of the integrated vulnerability approach to analyze food insecurity and unsustainability is presented together with a metric methodology.
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Keywords: Causal-factors, Decision-making, Food systems, Metrics, Resilience.

Introduction

Food Security, Sustainable Development and Sustainable Diets
In the last 25 years, the international political and scientific communities have been officially tackling the sustainability issues, as the Brundtland Report was agreed in 1987 (United Nations). The Sustainable Development definition "Sustainable Development meets the needs of the present without compromising the ability of future generations to meet their own needs" underlines the necessity to implement a human economic, social, environmental and institutional progress respecting the durability over the time. The worldwide debate about sustainable development passes naturally through the global food security concerns, as it was stated in the 1996's World Food Summit (WFS) declaration that "Food Security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (FAO, 1996). The 1996's Food Security definition shows the determinants assuring - or threatening if they are lacking - food security for people, identifying four main dimensions: food availability, access to food, food utilization, and the stability over the time of the three previous dimensions.
The result of the normative junction of the pillars that emerge from these two definitions (Figure 1), has led to the identification of several interconnected dimensions that specify the numerous fields comprising sustainable food and nutritional security and sustainable diets. The participants of the International Scientific Symposium on *Biodiversity and Sustainable Diets* agreed in defining sustain-

able diets as "those diets with low environmental impacts which contribute to food and nutrition security and to a healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy while optimizing natural human resources" (FAO & Bioversity International, 2012).

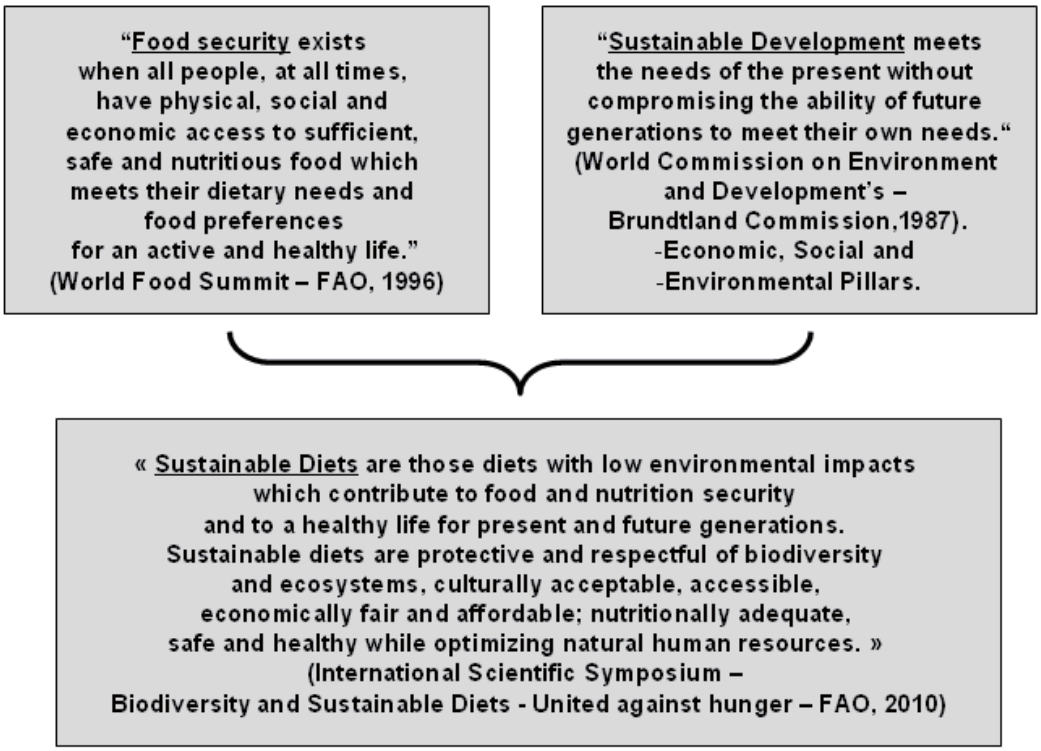

Figure 1. Conceptual evolution of Sustainable Food Security and Sustainable Development towards Sustainable Diets.

It is clear that in the latter definition, the whole food security issue is analyzed through a strong multidimensional approach. Particular crucial issues are mentioned, as the importance of biodiversity not just for the agriculture and the environment, but also for nutritional adequacy, cultural acceptability, functional services and market factors.
The analysis of food and nutritional security moves towards an approach aiming the sustainability of the whole agrofood system. This approach refers to the need of disaggregating the concept into different types of food and nutritional insecurity, varying on the nature and relevance of the problem and the kind of solution necessitated (Colonnelli & Simon, 2013; Pinstrup-Andersen, 2009). In the sustainable diets discussion process, four main

goals for the governance of a future sustainable food system are identified: nutritional health, cultural acceptability, economic affordability and environment protection (Fanzo, Cogill, & Mattei, 2012). Whatever the sequence of the definitions is, sustainable food is key for assuring food security (FAO, 2012), as it cannot be pursued in the absence of food security (Butriss & Riley, 2013). Food security and food sustainability are then indispensable prerequisites to each other and they need to be analyzed conjointly.

Watching back into the 1948 Declaration of Human Rights (United Nations, 1948), all these definitions represent some partial consequences of the 25th article that assures the human right to food security.

Decisions taken by policy makers should then assure the perpetual right of human beings - as individuals and in all their various forms of communities and societies - for a physical, ecological and socioeconomic access to sufficient, safe, bio-diversely nutritious and adequate food, issued by an agrofood system that is respectful of natural resources, peoples, incomes, local cultures, while protecting viable economic and political conditions and respecting the sustainability public criteria for healthy and ecological food and nutrition, in order to avoid geographical regions, countries, and people to be vulnerable but holistically resilient for all the critical socioeconomic and ecosystem hotspots of insecurity and unsustainability of the agrofood chain.

Policy and decision makers, stakeholders and the actors at a national and regional scale, play a key role in governance that is clearly identified in the stability dimension of sustainable food security and in the fourth "institutional" pillar of sustainable development.

Methodology

Causal factors for a vulnerability analysis

The several issues, related to food insecurity and unsustainability, are here multidimensionally considered as hotspots of vulnerability, of the countries' agrofood systems, integrated in a conceptual framework linking concepts, methods and metrics.

The UNDP in 1991 defined vulnerability as "the degree of loss to each element should a hazard of a given severity occur". Vulnerability is considered as the extent to which a community, structure, service, or geographic area is likely to be damaged, in relation to the probability of occurrence of a specified natural hazard at a specified severity level, in a specified future time (UNDP, 1991). The concept evolved as term of art and solid base to implement assessment methods in different research milieus such as climate impact analysis (Timmerman, 1981), disaster management (UNDRO, 1979), food security (Chambers, 1989; Dilley & Boudreau, 2001), and sustainability research (Turner et al., 2003).

In the food security context, the FAO specified that vulnerability is the relationship between three elements: risks, resulting shocks and resilience (FAO, 2004). The coupled risk-shock system affects the population wellbeing and the food security, while resilience concerns the strategies implemented to avoid the impact of shocks. Consequently, vulnerability is positively correlated to shocks' impacts and inversely correlated to resilience (FAO, 2004). If, on the one hand - in the natural disaster management approach to vulnerability - the degree of damage was found in the functioning of the socioeconomic assets, on the other hand food security specialists applied vulnerability for measuring the intensity of famines (Dilley

& Boudreau, 2001). Hence, it is possible to define the FAO approach to vulnerability in food security analysis as a direct *outcomes-approach*, whilst the natural disaster method is rather a *causal factors-approach*, describing the interconnectedness succeeding until the outcome. This different vision led to a lack of common understanding on the definitions of the central concepts, and to further disagreements about data needs and interpretations of vulnerability assessment (Dilley & Boudreau, 2001).

In order to explain this dichotomy of vulnerability approaches (between *outcomes-* and *causal factors-approaches*) we refer to the notions introduced by Sen in 1981. The access dimension, as determinant of famines, was added to analyze food security, reaching far beyond the availability factors. Then it was acknowledged the shifting from the natural causes to the societal causes of famines (Blaikie, Cannon, Davis, & Wisner, 1994) and vulnerability was indicated for assessing the multifaceted network of socioeconomic determinants of food insecurity (Borton & Shoham, 1991; Maxwell & Frankenberger, 1992; Middleton & O'Keefe, 1998; Ribot, 1995; Swift, 1989). Coherently, Chambers (1989) and Downing (1991) made considerable efforts in converting the Sen's analysis into assessment methods, but a lack of developed theory and of accepted indicators emerged. A main consequence was the wide acceptation of the expression "vulnerability to famine", which included the direct relation to the final outcome, becoming a protracted notion in food security literature, largely applied for assessments. Therefore, the adaptation of the concept of vulnerability to assessment methodologies became more complicated because of the a priori *outcome-approach*, making harder the identification of the causal factors (Dilley & Boudreau, 2001).

The definition of Downing (1991) strengthens the causal factors-approach, by stating that vulnerability is "a relative measure, for a given population or region, of the underlying factors that influence exposure to famine and predisposition to the consequences of famine" (p. 9). Causal factors are then identified in exposing and predisposing a "given population or region" to the causes-related final results of famine, taking into account the specific features of exposure and sensitivity. Therefore, an adequate solution is here identified in a deeper specification of the particular vulnerabilities and on the related causal factors of a wide and complex sequential phenomenon. This causal-factors specification will allow a dynamic analysis of the vulnerability hotspots instead of a static identification of the vulnerability to a broad and general final outcome. A broad vulnerability analysis leads to policy interventions that are not enough focused to determine the specific requirements for implementing actions. Diversely, the specific vulnerability assessment targets precisely the singular identified problems, in order to recommend the related interventions and scales of policies needed to reduce the vulnerabilities (Ionescu, Klein, Hinkel, Kumar, & Klein 2009; Luers, 2005). A vertical fragmentation of the broad vulnerability in an integrated general framework - where the particular vulnerabilities are adequately specified - represents a first response to the problem of lacking of a causal factor analysis.

One key conceptual element required is a clear separation between selected causal events and outcomes (Dilley and Boudreau, 2001). Further analyzing the concept of vulnerability, Downing (1991) specified that "vulnerability is the composite of two prospects: risk of exposure and risk (or magni-

tude) of consequence". For this, the exposure to the risk of experiencing a dangerous circumstance is distinguished from the likelihood of enduring specific magnitudes of possible consequences that result from the exposure. Since vulnerability is a relative measure, the exposure of individuals/households/countries/regions is related to their specific conditions face to a risk. Coherently, the magnitude of the consequence is linked to the particular predisposition and sensitivity expressed face to the exposure, and resilience integrates the responses that it is possible to implement, considering the exposure and the sensitivity degree. Accordingly, the causal sequence is identifiable in the exposure-risk component of vulnerability, and the outcome, is recognizable as part of the sensitivity-shocks component.

Nevertheless, the strengths and success of a vulnerability approach depend strictly on the quality of the application. So, in order to prevent erroneous applications of the vulnerability analysis, Dilley and Boudreau (2001) give some fundamental indications than consist in avoiding four main detrimental *modi operandi*:

- The use of vulnerability related to the final consequences rather then to the causal factors;
- The lack of specificity in the definition of sensitivity and hazards exposure;
- The inaccuracy in the characterization of the relationship of connectivity between sensitivities and the susceptible targeted elements;
- The imprecision in identifying measurable outcomes, by using thresholds.

Vulnerability analysis for multidimensional sustainability

The vulnerability approach evolves with Turner et al. (2003), who acknowledge that vulnerability analysis is necessary to implement the research on sustainability, referring in particular to the coupled human-environment systems. So, the analysis and assessment of vulnerability are supposed to provide a conceptual and methodological valid approach to the understanding of (un) sustainability.

According to the definition of sustainability of the agro-ecosystems coined by Conway (1985) "Sustainability is the ability of a system to maintain productivity in spite of a major disturbance, such as caused by intensive stress or a large perturbation" (inventoried by Hansen, 1996), and to the UNDP (1991) definition of vulnerability as the "degree of loss to each element should a hazard of a given severity occur", the vulnerability concept can be applied for its capacity to give a specular negative but constructive analysis of sustainability. Then, if sustainability is the dynamic condition of a given system to reproduce itself over the time and in the space, then the vulnerability - as sequence of phenomena due to a change that involves the system over the time and in the space[1] - provides the elements to understand the characteristics and the mechanisms affecting the system and those permitting to perpetuate its reproduction.

Moreover, the above-mentioned need of causal-factors analysis calls for a necessary multidimensionality of vulnerability, and the sustainability approach to the analysis of food insecurity already involves the segmentation in several specific dimensions that can be considered as vulnerability issues. Indeed, food insecurity and the unsustainability in food systems are both multidimensional

1. Time and space represent the "places" where the system "meets" the changes, as the "movement" occurs with vulnerability and for, or against, sustainability.

issues that need a wide-spectrum analysis in order to target theirs several main critical hotspots and causal factors. A multidimensional vulnerability approach to the analysis of (un)sustainability answers and adequately fits the multisectoral demand of assessment.
Furthermore, Turner et al. (2003) reaffirmed the need for robust vulnerability analysis and the role of sustainability and global change science in improving the bonds between the science problem and the decision-making needs. Previously, Dilley and Boudreau (2001) manifestly underlined the importance of adopting an experimented and efficient framework for informing and guiding policy makers: "Practitioners may wish to consider applying the general disaster formulation in actual situations to evaluate its relevance for program decision-making" (p. 245).
Therefore, the vulnerability approach is here considered as a double functional tool. It provides a logical conceptual basis and the method to build up a framework that leads the attention on: vulnerable people or entities to shocks; how and where the shocks changed the living conditions; which are the response strategies; the identification of the multiple metrics that assess the phenomena.

Results

Identification of a multidimensional vulnerability framework
According to the recent application by Hughes et al. (2012), the methodological approach to vulnerability assessment, by mean of a national-level vulnerability index, identifies three components of indicators interacting with vulnerability and confirms what it is widely acknowledged: the assessment of vulnerability is composed of exposure, sensitivity, and adaptive capacity indicators (Adger, 2006; Adger & Vincent, 2005; Allison et al., 2009; Cinner et al., 2011; Gallopin, 2006; Grafton, 2010; Kelly & Adger, 2000; Smit & Wandel, 2006).

Framework functioning
Vulnerability has been repeatedly calculated through multidimensional score systems, as in Cinner et al. (2011), Hughes et al. (2012), Manarolla (1989), and in Rastoin, Ayadi, and Montigaud. (2006).
In particular, in Cinner et al. (2011) and Hughes et al. (2012), vulnerability was calculated as Exposure + Sensitivity – Adaptive Capacity (as in Fig. 2). Lower levels of the final score indicate lower levels of vulnerability. Following the original structure designed by Hughes et al. (2012) for describing the practical calculation of vulnerability, we modified the outline keeping the same logical sequence of the signs. The order and the signs used for the calculation of vulnerability explicit the relationships between the three components. Several *n* vulnerabilities and components are listed, to underline the deep specification of the multidimensional vulnerability approach.

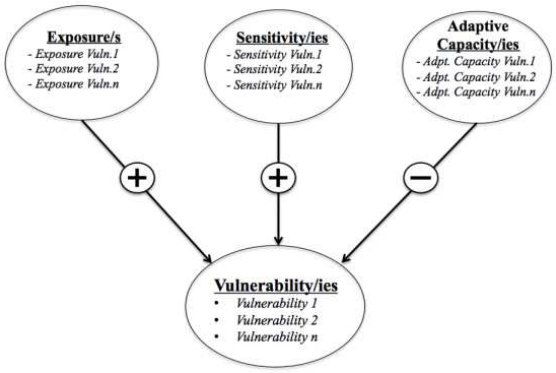

Figure 2. Calculation of Vulnerability (modified from Hughes et al., 2012).

In a metric-identifying approach for the vulnerability assessment, the indicators are expressed in different units of measurement. One analytical aim of studying vulnerability on a geographical scale is to obtain a ranking between several countries. Therefore, in several cases, the values of the vulnerability indexes are standardized. For instance, Hughes et al. (2012) normalized data of a specific geographical set of 27 countries, while Cinner et al. (2011) standardized the values of 29 local communities in 5 different countries and in the Global Food Security Index (GFSI) the data of 105 countries were harmonized (The Economist Intelligence Unit, 2011). In these three examples (two of them analyze vulnerability and the latter one tackles food insecurity) the standardization process operates on maximum values in the dataset, distributing them on a scale from zero to one (in the GFSI from 0 to 100), and using the classic normalization method "min-max" (Adger & Vincent, 2005; OECD, 2008):

$$X = (X - Xmin)/(Xmax - Xmin)^2$$

In this formula, Xmin and Xmax are, respectively, the lowest and highest values for any given indicator. The normalized value is then transformed from a 0 to 1 value (from 0 to 100 in GFSI) to make it directly comparable with other indicators expressed in the same scale. That means that the indicator with the highest raw data value will score 1 (or 100 in GFSI), while the lowest will score 0.
In these examples, the scores are normalized and then aggregated across categories to enable a comparison of broader concepts across countries. Normalization rebases the raw indicator data to a common unit so that it can be aggregated.
Finally, in our particular case the *n* specific vulnerabilities will be calculated following this formula:

$$V = (E - Emin / Emax - Emin) + (S - Smin / Smax - Smin) - (AC - ACmin / ACmax - ACmin)$$

Where:
V = Vulnerability
E = Exposure
S = Sensitivity
AC = Adaptive capacities
Another aspect that has to be considered is the weight, or quantitative relevance, that is associated to different domains and metrics. In Hughes et al. (2012) each component and the various metrics used to measure each component were equally treated. It was not used any weighting system. This choice was explained by the fact that weights reflect a value system specific to a given policy context, since the goal was not to guide country specific policies but rather to demonstrate the identification of a vulnerability index. In the GFSI the weighting assigned to each category and indicator can be changed to reflect different assumptions about their relative importance. In fact, two sets of weights are provided in the index. The first option, called "neutral weights", assumes equal importance for all the indicators and evenly distributes weights. The second option, called "peer panel weights", averages the weights that have been suggested from five members of the panel of experts, opening decisions to a participatory approach.
In a regional-geographic vulnerability assessment, several hypotheses can be developed for establishing common national domains of vulnerability and then the related weights. Therefore, it is possible to rank the countries in relation to their exposure, sensitivity and adaptive capacity vis-à-vis of a food unsus-

2. For the indicators where a higher value indicates a negative environment for food security, the normalization function takes the following form: X = - (X - Xmax)/(Xmax - Xmin).

tainability and insecurity in the agro-food system.

Relevance of a Vulnerability framework

It is possible to identify many opportunities of applying, through a suitable framework, the vulnerability approach to a large multidisciplinary, multidimensional and multisectoral approach for food insecurity and unsustainability.

The conceptual and methodological vulnerability approach allows improvements in developing metrics and information analysis through quantitative and qualitative data and novel methods, increasing the scientific knowledge through the vulnerability assessment (Adger, 2006; Dilley & Boudreau, 2001; Fussel, 2007; Locatelli et al., 2008; Sonwa, Somorin, Jum, Bele, & Nkem, 2012; Turner et al., 2003;).

Through a causal factors analysis – a further overture to the causal interpretation rather than analyzing the final outcomes - it is possible to identify the complexity and interconnectedness of the phenomena of change (Dilley & Boudreau, 2001; Watts & Bohle, 1993) and to provide dynamic tools, suitable for sustainability science (Turner et al., 2003).

The consequent gathering of information leads to a deeper interpretation of the phenomena for decision-making and for identifying response opportunities. This allows involving regional stakeholders in a place-based analysis and collaborative assessment (Adger, 2006; Dilley & Boudreau, 2001; Rastoin et al. 2006; Sonwa, 2012; Turner et al., 2003), understanding the vulnerability of a particular place (Turner et al., 2003) and opening to a geographical approach, in a given physical space where several environmental, social and economic food security vulnerability hotspots persist.

Furthermore this approach increases the multiple factor analysis for an interdisciplinary understanding of vulnerability, through a common general methodological framework suitable for different sectors, enlarging the range of expected outcomes compared to a one-dimensional vulnerability analysis (Adger, 2006; Sonwa et al., 2012; Turner et al. 2003).

Finally, one of the main goal-opportunity of a vulnerability approach consists in anticipating and predicting new hazards and changes to which a system may be exposed (Adger, 2006; Dilley & Boudreau, 2001; Rastoin et al., 2006; Turner et al., 2003).

Supporting decision-making

Policy responses and adaptive management strategies at the national-regional level need to be guided by vulnerability assessment. Vulnerability analysis is comprehensive, able to handle not only for a given system, but also for its many and varied linkages (Turner et al., 2003), as – for instance - for the whole sphere of activities linked to the agrofood system, comprising the agrofood chain (Ingram, 2011). In the case of food security and sustainability, the vulnerability approach allows finding, in a measurement framework, an opportune tool to practically evaluate, separately and conjointly, the main hotspots that lead to critical issues of the agrofood system. Hence, through a multi-level intersectorial and geographical analysis, a food chain approach allows a further ramification of a vulnerability framework to the unsustainable hotspots affecting, by means of specific stressors, the overall productive and supply agrofood activities, opening large opportunities in the research metrics starting by food security and sustainability. The results may suggest several different ways to develop context-specific policies and actions

to build adaptive capacities, or to decrease sensitivity and exposure.
The vulnerability assessment framework, in a given geographical region, proposes an innovative and transdisciplinary method for evaluating in multiple sectors and perspectives – as food security, sustainable diets and agrofood system - the stressors and the causal sequential factors where decision making and policy interventions are needed (Fig. 3).

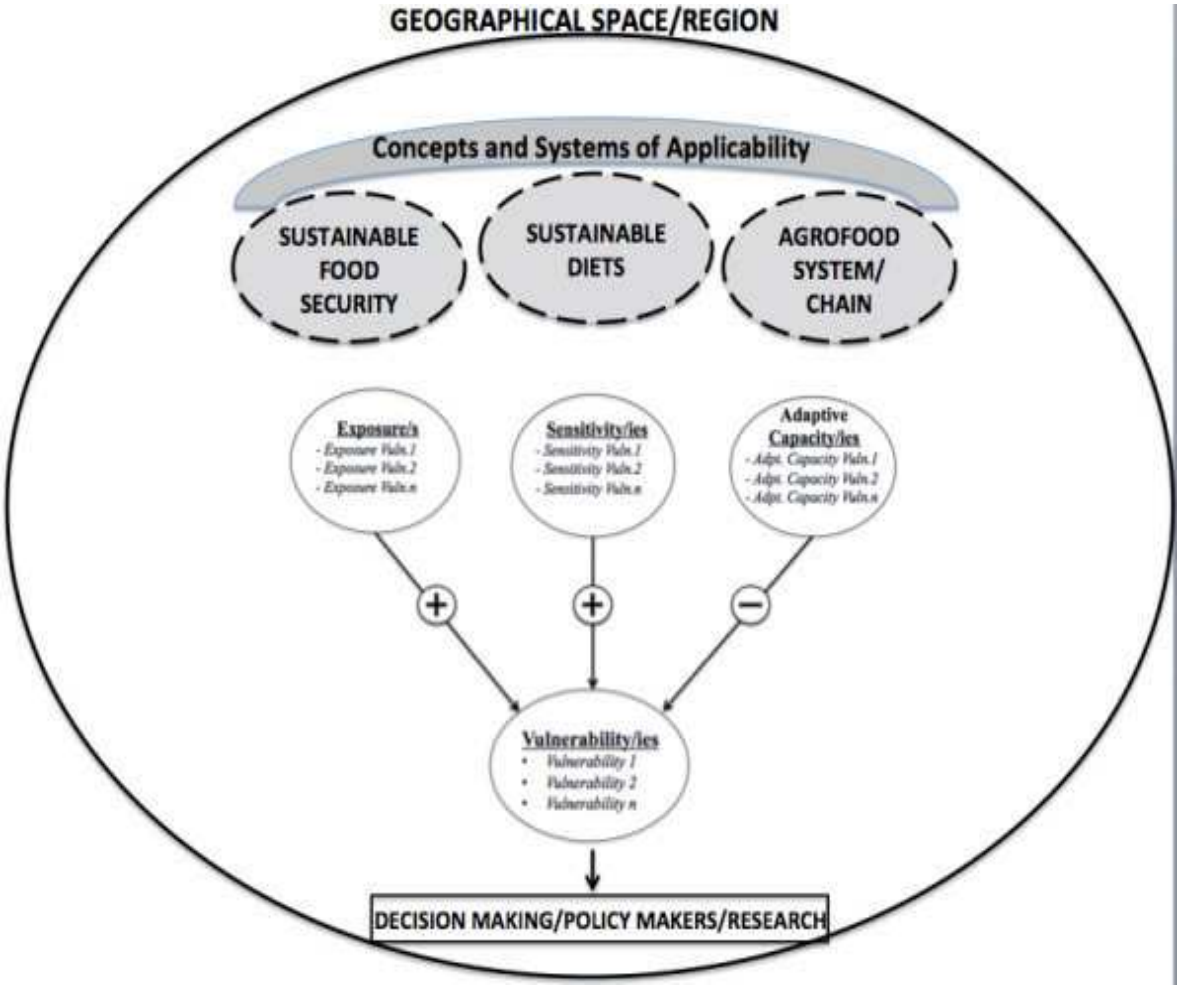

Figure 3. Potential fields of application of a vulnerability approach to critical domains in a given time and geographical space for informing decision-making strategies.

Conclusions

Food security and sustainability issues require precise definitions for multidimensional concepts, methodological approaches and metrics applications. Regarding the multidimensionality of the approach, it is acknowledged that the assessments based on one temporal-local scale, or just on one indicator, are no more considered as enough pertinent, since they act just on one component and can generate parallel or indirect undesired effects (Aubin, Donnars, Supkova, & Dorin, 2013; Vindigni, Peri, & Prosperi, 2011). Indeed, since the sustainability agenda grows further, there is a rising call for new types of system analysis and modeling tools that are able to simulate the future conditions of systems while capturing essential nonlinearities and complex behavior (Kates et al. 2001; Nicholson et al. 2009). However innovative analysis frameworks and system modeling that are able to largely understand and comprise the systems dynamics, are often challenged for accuracy.

A vulnerability conceptual and methodological approach for investigating on food insecurity and unsustainability domains is strictly linked to the identification of a methodological framework functioning as an architectural net for the assessment of exposure, sensitivity and adaptive capacities.

As several previous scientific experiences confirm, different specific advantages emerge from applying a vulnerability approach. The vulnerability-based development of novel methods, metrics and information analysis supports the scientific knowledge and the understanding of the phenomena of change occurring in local food systems, providing elements for implementing response opportunities and decision-making interventions, improving the predictive capacities to new hazards and changes, and increasing the regional involvement of stakeholders through participative context-based assessment. The analytical frameworks that take into account the causal and sequential factors of vulnerability, in an interdisciplinary perspective, provide dynamic tools for sustainability science and for understanding different sectors of activities through multidimensional lens.

Still, a deep and multidimensional understanding, of the causal factors engendering vulnerability related to food insecurity and unsustainability, represents the mean to get an evidence-based scientific knowledge of the agrofood dynamics and to get quantitative and qualitative information. So, the conceptual and methodological phases must lead to the identification of a suitable system of variables and appropriate metrics.

Sustainability assessments open three big challenges for scientific research: decision-making, participation and resilience. Since indicators inform action (Barrett, 2010), they are essential to establish the communicative link between science and policy-makers. However, it is important to define issues and challenges of food security and sustainability before choosing methods (Aubin et al., 2013). Targeting geographical areas, local actors and institutional stakeholders are key in order to define the hotspots of vulnerability of a specific region within a participative framework. Stakeholders can respond with coping strategies to rule the economic, financial, social and institutional changes, and managing the opportunities coming from risks effects, searching in their human, physical and social assets, and transforming changes and resources in capabilities to overcome the shocks impacts and be prepared for the next risks. Furthermore, since resilience represents - for institutional and actors' contexts and dynamics - the stakeholders' capacity of reactivity to institutional changes towards

sustainability (Conway, 1985; Strunz, 2012), the implementation of adaptive capacities still remains a major challenging opportunity for sustainable food security.

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