Conference paper for the XIV International Conference of the European Society for Ecological Economics, 14-17 June 2022. Pisa, Italy.

Research paradigms and the assessment of food system sustainability

Michael Curran[1]

[1]Dept. of Socioeconomic Sciences, Research Institute of Organic Agriculture, 5070 Frick, Switzerland

Abstract. The concept of "sustainable development" is inherently complex, multidimensional and value-laden. It is typically defined in as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (UN Brundtland Report). This leaves much room for interpretation, and recent research from the diffuse field of sustainability sciences has attempted to bring consensus and clarity to what counts as "sustainability assessment" (SA), beyond the simple combination of indicators across environmental, social and economic dimensions. In the context of growing (mis-)use of the term sustainability across research, consultancy, commercial and policy circles, building a clear consensus on what SA entails is an urgent undertaking to counter dubious claims and widespread greenwashing. This is a pressing task in the agri-food sector, where drastic, urgent and transformational changes are required across the food system to remain within planetary boundaries, enhance wellbeing and support resilient food economies. In this paper, conceptual and applied research on SA within and outside food system research is reviewed to identify elements of a research paradigm for conducting SA. A research paradigm is understood as a set of interrelated elements covering ontology (the environmental and social reality to be assessed), axiology (how values influence the mobilization of knowledge systems), epistemology (the nature of knowledge and validity of knowledge claims), and methodology (principles that determine the use of specific methods to construct knowledge). To do this, key paradigm positions in ecological economics, namely critical realism and post-normal science, are drawn upon to contrast existing conceptual and operational approaches in the literature.

1 Introduction

Food systems can be conceptualized as all activities involved in farming, food production, processing and packaging, distribution, retailing, and consumption (Ericksen 2008, Ericksen et al. 2012). Food systems, both large and small, face multiple (un-)sustainability challenges spanning environmental, social, economic and political dimensions (Schader et al. 2014, Poore and Nemecek 2018, Janker and Mann 2018, Augstburger et al. 2019, Béné et al. 2019). There is need for urgent transformation along all of these dimensions of food systems to achieve a just food future for the world's population in the context of rapidly contracting environmental limits (Campbell et al. 2017). The field of sustainability science has emerged in recent decades to address these interrelated problems in a comprehensive, solution-orientated and interdisciplinary way (Sala et al. 2013). A key appraisal method within sustainability science is "sustainability assessment" (SA), which has a broad aim of identifying whether systems or system interventions are developing towards or away from sustainability (Sala et al. 2015). While this is a laudable end in itself, the definition of SA is tightly linked to our understanding of sustainability as a theoretical concept and sustainable development as a policy goal, two highly contested terms in the literature (Hugé et al. 2013, Purvis et al. 2019). For the following argument, the traditional three "pillars" or "dimensions" of sustainability are used for convenience as a basis for discussion, although it is important to recognize their lack a theoretical basis (Purvis et al. 2019).

Three major discourses linked to sustainability and sustainable development were identified by Hugé et a (2013): "limits", "integration" and "transformation". The "limits" discourse emphasizes ecological sustainability and a nested model of society and economy bounded by environmental limits. Research in this area is dominated by natural-science approaches such as footprinting, social metabolism and resilience (i.e. a strong sustainability standpoint). The "integration" discourse emphasizes linking traditional perspectives on development (a.k.a. growth) with the natural sciences to balance trade-offs, an is dominated by the ecosystem services approach and capital theory (i.e. weak sustainability). The final "transformation" discourse emphasizes sustainability as a process of societal change with no defined end point, and is characterized by social science approaches from transformations research, where weak and strong sustainability perspectives vary in prominence by context.

Like these evolving discourses, methods and approaches to assess sustainability have evolved in turn. Initial methods focusing on biophysical limits and energy/resource flows were extended to integrate monetary accounting and valuation (Ness et al. 2007, Singh et al. 2009). Social issues were represented as simplified wellbeing and development indices, which expanded to cover topics such as worker rights and working conditions driven by new datasets on social accounting (Benoit-Norris et al. 2014, D'Eusanio et al. 2019). However, the shift from an individual to societal perspective has been slow, with lacking theory of social systems persisting to the present day, impacting the ability to include the social dimension in sustainability assessment (Janker and Mann 2018, Janker et al. 2019). In this context, a recent paper by Sala et al. (2015) published in the journal *Ecological Economics* has attempted to bring concreteness to the definition of SA and to establish it firmly in the realm of social transformation and transdisciplinary research. This is a positive step in differentiating SA as a *whole* from the multitude of narrower tools might act as its *component parts*. However, it brings with it several challenges in constructing a coherent approach that attempts to unite disparate theories and disciplines under one transdisciplinary umbrella. Ecological economics, as a related "transdiscipline", has undergone a similar evolution (Shi 2004). Critics have rightly highlighted the difficulty in simply repackaging disparate methods and tools under a single roof without serious consideration of theoretical consistency and foundational assumptions (Spash 2012).

The present paper attempts to bring new theoretical insights to the definition of SA by critically analysing recent literature, taking the Sala et al. (2015) paper as a starting point. The theoretical foundations of SA are investigated based on the concept of a "research paradigm", understood as a combination of interrelated standpoints regarding *ontology*, *axiology*, *epistemology* and *methodology* (Hart 2010, Haigh et al. 2019), which are referred to as "levels" of a paradigm. The term research paradigm is similar to what Clive Spash (2012) refers to as "foundations" or a "preanalytical vision" (in regards to field of ecological economics). The value in making paradigm positions explicit in research is that it permits an opening up of debate and promotes "theoretical reflections about the type of ontology, epistemology and methodology which appear most suited" (Spash 2012 p. 37) to (in this case) a transdisciplinary approach to SA. Specifically, the paper aims to identify which paradigm positions existing approaches in SA have adopted, and where future research challenges lie to make such positions more explicit and applied. The context is the application of SA to food systems at multiple scales, which provides a suitably complex setting to illustrate the concepts discussed.

2 Methods

I review literature on SA and related fields using the paper of Sala et al. (2015) as a starting point. The generic features of SA are contrasted to applications of SA-like methods to agri-food systems. This requires a broad focus due to the wide scope of the topic, including developing a definition of food systems at multiple scales and accounting for different perspectives and discourses on sustainability. The goal of the review is to reveal implicit or explicit positions regarding the different levels of a research paradigm (ontology, axiology, epistemology and methodology) to identify common or unifying strands as well as divergences. The work is exploratory in nature, designed to identify areas of future research. In this text, axiology is considered alongside epistemology because the two are often combined in the literature. While earlier sociological research considered axiology a meta worldview that influences knowledge production (e.g. Hill 1984), values are often considered a *form* of knowledge in more recent work, characterized as part of "moral knowledge" (Wynne 1992) or "target knowledge" alongside social (i.e. transformation) and scientific (i.e. systems) knowledge; the "three types of knowledge" approach (Hirsch Hadorn et al. 2006, Pohl et al. 2017).

Secondly, the paper makes tentative links to two foundational paradigm positions in ecological economics and sustainability sciences: Critical Realism (CR; Bhaskar 2008, Archer et al. 2013) and Post-Normal Science (PNS; Funtowicz and Ravetz 1993). Critical realism provides a strong ontological basis for conceptualizing society-nature interactions, social reality and transformation, and has been put forth as a suitable paradigm theory for ecological economics (Spash 2012, Buch-Hansen and Nesterova 2021). Post-normal science has had a historically profound influence in the transdiscipline as an epistemic critique of natural science approaches under conditions of uncertainty, urgency, power imbalance and risk, but does not adopt an explicit ontological position (Funtowicz and Ravetz 1994). The links between SA and CR/PNS in the present paper are tentative and designed to identify areas for future research and elaboration.

3 Results and discussion

3.1 Conceptual approaches to sustainability assessment

Sustainability assessment (SA) has been defined in simple terms as a way of determining whether and to what degree systems are developing towards or away from sustainability (Sala et al. 2015). It is however highly complex as an appraisal method and possess a combination of elements that differentiate it from other types integrated assessment. Following Sala et al. (2015), the elements of SA are organized along the levels of a research paradigm covering ontology, epistemology/axiology) and methodology. These have been reproduced with adaptations in Table 1, and form the basis for the following discussion.

3.1.1 Worldview and social-ecological reality in SA of food systems

Ontology refers to mental models of social-ecological reality, generally spanning the divide between realist views of an independent and observable reality to constructivist/relativist views of a relational reality, emerging from social processes and interactions. Sala et al. (2015) highlight several elements under the banner of ontology, including the initial steps of describing the system that is to be assessed/sustained, the ontological status of its components, diagnosing a societal problem and describing causality. This initial worldview frames the kinds of impact pathways and evaluation criteria that are possible to assess. Their specific selection involves moral knowledge embodied in values and beliefs (i.e. axiology/epistemology). Söderbaum (2007) refers to "*failures of ideas*" about science and specific disciplines in reflecting social and ecological reality and calls for pluralism in exploring different theories of science in SA, including ontological considerations. An example would be the inclusion of "wild" nature and "wilderness" values in SA as a measure of biodiversity. Impact assessment methods for biodiversity from LCA, ecology and conservation commonly use a target (reference) state of "pristine" or "untouched" nature as a yardstick (Curran et al. 2016). Critiques of this perspective challenge the *ontological* status of wilderness, claiming that it is a socially-constructed concept based on a misreading of the history of human migration, land use and disturbance patterns (Fletcher et al. 2021). Thus, SA can be constrained by a particular worldview that renders some concepts as "real" to some observers, but "constructed" to others.

In this regard, it is useful to review how food system scholars have conceptualized the food system, what elements are included and how they relate to ontological frameworks. To do this, a critical realist perspective is used as a basis. In proposing "new foundations" for ecological economics, Spash (2012) arrives at a set of "ontological presuppositions" using a critical realist framework. These combine realist and constructivist perspectives to balance acknowledgement of an objective reality with recognizing the role of social processes in shaping this reality:

- An objective reality exists independent of humans;
- Humans create social reality;
- Facts about social reality are inseparable from values;
- Biophysical and social realities are distinct but are interconnected;
- A hierarchical ontology is accepted in which there is an ordered structure (e.g. biophysical, social, economic);
- Society and the individual are distinct in that the former cannot be reduced to the latter nor the latter merely aggregate to create the former;
- Complex systems and their interactions create emergent properties and are inherently unpredictable;
- Systems are continually subject to change and interaction.

Such presuppositions may appear both simple and obvious, but the value is in making the worldview transparent and thus open to criticism and debate. Ontological assumptions are always present in research, but often only implicitly (i.e. can be reconstructed based on epistemological or methodological choices). In the SA literature, aspects of worldview and ontology are present in the first four "sustainability assessment principles" that accompany a "sustainability assessment procedure" (Pintér et al. 2012, Sala et al. 2015). It has particular relevance at the phase of conceptualizing the societal problem and representing the system under study, what Binder et al. (2010) refer to as the "systemic dimension" of sustainability assessment. Regarding food system studies, several definitions and depictions appear in use either in academia or in practice. Table 2 summarizes food system definitions adopted by major agricultural organizations. These range from an emphasis on social interactions between actors, institutions and policy, with little inclusion of the biophysical world (IFPRI 2022, Unicef 2022), to more complete accounts that explicitly consider human-nature interactions in both directions (HLPE 2014, FAO 2022, OECD 2022). In the academic literature, food system accounts can be varied, and there is considerable overlap between food systems and concepts such as "food chains", "value chains", "supply chains" and "supply networks" (Kaplinsky and Morris 2001, e.g. Soosay et al. 2012, Braziotis et al. 2013, Brunori and Galli 2016, Kirwan et al. 2017, Jacobi et al. 2020b). The seminal paper of Ericksen (2008) claims that food systems were previously defined as a "set of activities ranging from production through to consumption", and broadens the definition to encompass:

- the interactions between and within biogeophysical and human environments, which determine a set of activities;
- the activities themselves (from production through to consumption);
- outcomes of the activities (contributions to food security, environmental security, and social welfare); and
- other determinants of food security (stemming in part from the interactions in bullet one).

This conceptualization is strongly biophysical and realist, with the interaction between natural and social systems determining potential activities, and little in the way of constructivist concepts (values, beliefs, cultural norms, institutions, laws, regulations etc.). The conceptualization of Jacobi and Llanque (2018) illustrates an expanded conceptualization of the food system that adds crucial representation of actors and institutions. They base their conceptualization on a translated definition by Rastoin and Ghersi (2010): "*Interdependent networks of stakeholders (companies, financial institutions, public and private organizations, and individuals) in one or various geographical areas (region, state, multinational region) that participate, directly or indirectly, in the creation of flows of goods and services geared toward satisfying the food needs of one or more groups of consumers in the same geographical area or elsewhere*". This is combined with a biophysical component that is lacking in the source material and the resulting graphical depiction is shown in Figure 1 (left). While several relations between elements of the system are unclear, the "Natural resources sub-system" bounds all other subsystems, indicating a hierarchical ontology of distinct but nested natural and social systems. However, in a later publication by the same lead author (Jacobi et al. 2019), the natural system becomes embedded within the "information and services sub-system", which in turn is embedded within the "political sub-system" (Figure 1; right). If the arrangement of elements is intended to convey information about ontological structure, both depictions are highly confusing, indicating a vague and incomplete conceptualization of the food system to form the basis of an assessment. The resulting set of criteria and indicators that emerges from this conceptualization, spanning 5 dimensions and many sub-indicators, does not explicitly link to this initial conceptualization. The aggregation of indicators and criteria to final food system performance scores further lacks any major hierarchy or methodological rigour (Jacobi et al. 2020b), with a simple averaging or median scores taken across indicators and higher level scores (e.g. ignoring aspects of incommensurability, nestedness and uncertainty; Lindfors 2021). This example, while not uncommon in the SA literature, underpins the need to clearly describe the structure of the system under study and the relation of its elements to one another (i.e. an ontology).

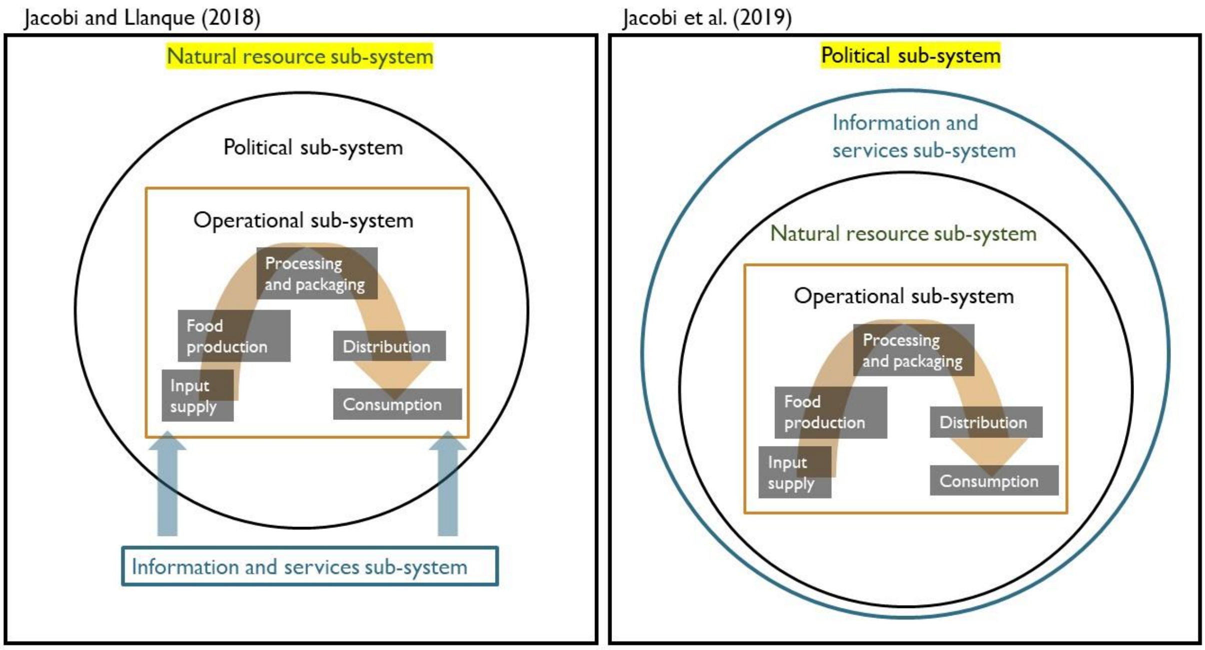

Figure 1. Two depictions of a food system by the same lead author indicating different hierarchies of system elements.

Drawing on critical realism, a more comprehensive account of a food system might be found by making a structural analysis of the entities that make up the reality in questions, such as asking key generic questions about these "entities" (Sayer 1992, Haigh et al. 2019): What does the existence of the food system presuppose? What are its preconditions? Can/could object A exist without B? If so, what else must be present? What is it about the food system, that enables it to do certain things (there may be several mechanisms at work and ways need to be found to distinguish their respective efforts)? What cannot be removed from the food system without making it essentially cease to exist in its present form? This type of analysis would predefine the biophysical basis as essential to the functioning of the food system, but confirm that the social system has a particular flexibility in design and thus redundancy within the food system (e.g. markets may or may not exist, but seeds, energy sources and suitable pedoclimatic conditions are non-negotiable). These generic questions can be combined with consideration of universal "laminations" of social systems as structured, hierarchical and emergent. Laminations refer to the interaction of distinct, irreducible social mechanism across scales (Bhaskar 2010), adapted from Haigh et al. (2019):

1. Psychology of the individual (norms, values, beliefs, interests, desires, sense of self, reflexive thought, habits etc.)

2. Individual material circumstances (individual or biographical level, experiences, skills, income, education, occupation, level of human rights etc.)
3. Human face to face interaction (interpersonal rights involve respecting the others personal space, time and integrity, exercise of power - creative, emancipatory and transformative vs destructive, coercive and oppressive, individuals or small group interactions with stakeholders, decision makers and, communities, interested actors etc.)
4. Structures and culture (human rights culture, structural relations, social class, institutions, ideas, policy-making frameworks, decision-making processes etc.)
5. Society as a whole (the economy, governance, policies, inequalities, politics, laws, level of development, physical environment and resources, access to services, resources etc.)
6. Geo-historical trajectories (traditions, colonisation history, past decisions, experiences of actors, history of activism and resistance etc.)
7. Global trends (patterns of inequality, transnational organisations, international agreements and rules, climate change, migration, resource distribution, international social actors, international civil society organisations etc.)

This type of critical realist approach illuminates key entities of social-ecological reality that must form part of the pre-analytic vision of the food system. It forms the initial steps of SA, namely description of key aspect of the system to be sustained ("Sustainability of what?") along with the actors, interactions and institutions at play ("Sustainability for whom?"). Such an ontological approach does not imply all entities must be studied at all times in SA, but it brings context to the artificial system boundaries that are established for any operational SA, offering the user, target group or stakeholder participants (not to mention other researchers) a perspective into what is *not* assessed but *does* play a role in determining food system sustainability.

Table 1. Key elements of "sustainability assessment" as an appraisal method found in the literature. Adapted from Sala et al. (2015).

Paradigm level	**SA element**	**Description**	**Examples**
Ontology	Object of assessment, sustainability principles	Unit of assessment (e.g. a development plan, policy shift, product innovation, dietary alternative, regional scenario or new policy) and societal problem is clearly defined, model of reality is	(Schader et al. 2014, Patterson et al. 2017)
	Scope of coverage	Breadth of system elements and evaluation criteria in SA is suitably large to address plural perspectives on the nature of reality the problem addressed ("sustainability of what"?)	(Singh et al. 2009, Schader et al. 2014)
	Comprehensiveness in representation	Quality of representation of system elements across dimensions in the assessment is sufficient for the purpose, along with their interactions and hierarchies	(Ness et al. 2007, Schader et al. 2014)
	Level of integration, centrality	Disciplinary methods are highly integrated within a transdisciplinary (rather than inter/multidisciplinary) approach, avoiding conflicting theories across disciplines	(Binder et al. 2010, 2020, Purvis et al. 2019)
	Kinds of impacts covered, context	The scope of impacts reflected in the assessment, the context and type of change considered (both positive and negative), mechanisms and causality (both biophysical and social), reflect the plurality of disciplines and perspectives on the problem	(de Olde et al. 2017, Binder et al. 2020)
Axiology and epistemology	Ability to bridge knowledge forms	Integration of knowledge systems, such as systems knowledge (scientific, fact-based), target knowledge (political, value-based) and transformation knowledge (situated, agency-based)	(Funtowicz and Ravetz 1993, Hirsch Hadorn et al. 2006)
	PNS science-policy interface	SA adopts a post-normal science (PNS) approach to the science-policy interface, where uncertain or value-laden results are treated as "evidence" rather than "facts" within an "extended peer review" by the lay community (actor groups)	(Funtowicz and Ravetz 1993, Ravetz 2006)
	Transparency, communication	The procedure of SA, including problem framing, identification of alternatives, inputs, models and outputs, are transparently communicated, from conceptualization to communication and real-world impact	(Singh et al. 2009, Pintér et al. 2012)
	Value pluralism	SA must make explicit the values and perspectives considered and allow these to be deliberated in a participatory setting (with attention to procedural quality and justice)	(Alrøe and Noe 2016, Alrøe et al. 2017)
	Power and politics	Power influence how SA is implemented to generate knowledge, and how that knowledge is mobilized for social-ecological transformation; consideration of power relationships among actors should be explicit (e.g. using the "powercube" or related methods)	(Pantazidou 2012, Fritz and Meinherz 2020)

Paradigm level	SA element	Description	Examples
Methodology	Transformative and participatory	Rather than searching for a single optimum “solution” based on expert knowledge (analytic), SA procedurally navigates societal problems with stakeholders (participatory)	(Stirling 2008, Haysom et al. 2019)
	Boundary-orientation	Type of change reflected in the assessment aims for a distance-to-target (“where to”) threshold approach with science/policy-based targets rather than a relative (“what if”) approach using scenarios (status quo as reference) or absolute change (no reference),	(Bjørn and Hauschild 2013, Bjørn et al. 2020)
	Metrics and aggregation	Selection, normalization, weighting and aggregation method for indicators or other data/information are appropriate with underlying plural value systems (e.g. commensurability, compensability, comparability); type of data (qualitative/quantitative, subjective/objective, etc.) is varied based on disciplinary needs	(Singh et al. 2009, Gasparatos 2010, Gan et al. 2017, Lindfors 2021)
	Uncertainty and complexity	Reflection and accounting for the level (risk, uncertainty, ambiguity, ignorance), nature (epistemic, stochastic), and sources (context, model, input) of uncertainty	(Walker et al. 2003, Stirling 2010)
	System boundaries and scalability	Definition of what is within and outside the assessment, consisting temporal/spatial scale and life cycle coverage (cradle to grave)	(Binder et al. 2020)

Table 2. Food system definitions by a selection of major agricultural policy institutions

Source	**Food system definition**	**Reference**
UN Committee on World Food Security	"…all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the outputs of these activities, including socio-economic and environmental outcomes."	HLPE (2014)
UN FAO Food System Dashboard	"…all of the people and activities that play a part in growing, transporting, supplying, and, ultimately, eating food. These processes also involve elements that often go unseen, such as food preferences and resource investments. Food systems influence diets by determining what kinds of foods are produced. They also influence what foods people want to eat and are able to access. The different parts of the food system include food supply chains, food environments, individual factors, and consumer behaviour, as well as external drivers (factors that push or pull at the system)."	FAO (2022)
Organisation for Economic Co-operation and Development	"…all the elements and activities related to producing and consuming food, and their effects, including economic, health, and environmental outcomes."	OECD (2022)
International Fund for Agricultural Development	"…all the aspects of feeding and nourishing people: growing, harvesting, packaging, processing, transporting, marketing and consuming food. It encompasses all the interactions between people and the natural world – land, water, the climate, etc. – and the natural world's effects on human health and nutrition. It also includes the inputs, institutions, infrastructure and services that support the functioning of all these aspects, as well as the role of diets and cultural practices in shaping outcomes."	IFAD (2022)
Unicef	"…the public policy decisions; the national and global systems and supply chains; and the individuals and groups – public and private – that influence what we eat."	Unicef (2022)
International Food Policy Research Institute	"…the sum of actors and interactions along the food value chain—from input supply and production of crops, livestock, fish, and other agricultural commodities to transportation, processing, retailing, wholesaling, and preparation of foods to consumption and disposal. Food systems also include the enabling policy environments and cultural norms around food."	IFPRI (2022)

3.1.2 Knowledge systems for SA

There are several assessment methods that combine indicators across sustainability dimensions or apply multi-/interdisciplinary methods. These include Life Cycle Assessment (LCA), Life Cycle Sustainability Assessment (LCSA) and the “three pillars”/“triple bottom line” approach (Sala et al. 2013a, 2013b, Sala 2020). SA differs from these in being explicitly *transdisciplinary* and *solution-orientated*, meaning it should be participatory by design and transformative in nature. Employing SA to address societal problems requires generating and mobilizing different types of knowledge, such as systems knowledge (scientific, fact-based), target knowledge (political, value-based) and transformation knowledge (situated, agency-based) (Pohl et al. 2010, 2017). These knowledges emerge from a co-production process between scientific and non-scientific actors and between researchers across disciplines (Marin et al. 2016). This explicitly moves away from an epistemology based around positivism, or more specifically logical empiricism, as a basis for knowledge creation (i.e. characterized by a minimum criterion of the validity for knowledge claims and a methodology based around neutral observation and hypothesis falsification).

In aiming for transdisciplinarity, SA adopts this broad epistemological foundation. Sala et al. (2015) categorize SA as a post-normal science (PNS). PNS claims that (natural) science is an appropriate tool for knowledge creation about the physical world in controlled circumstances. However, as systems become more complex, facts and values mix and information becomes more uncertain. Under such conditions, “normal” science must be replaced with a “post-normal” approach that includes an improved “quality assurance” for knowledge claims. An “extended peer community” of specialists and lay people is used to review results as “evidence” rather than “facts”. This extended review process integrates target (situated) and transformation (moral) knowledge via the participants (Funtowicz and Ravetz 1993, 1994). However, while PNS is an established framework for making the scientific process more robust for decision-making (i.e. filtering it by the situated knowledge and implicit values of the extended peer community), it is not a complete epistemology in itself and does not detail exactly how different knowledge forms from non-scientific epistemological positions should be combined. For example, while formal scientific knowledge is very difficult to generate in open social-ecological system, there is still an element of minimal standards for making valid knowledge claims (i.e. based on testing laws through observation and weighing of probabilities, while controlling for known confounding factors). Should analogous factors also apply to non-scientific knowledge forms? What standards and quality assurance procedures are present in alternative epistemologies and which takes precedence when conflicts between knowledge forms emerge?

With regards to SA of food systems, epistemic concerns can be found throughout the literature. In a review of transdisciplinary research projects on sustainability transformations, Jacobi et al. (2020a) emphasizes the need to empower non-western epistemologies in sustainability transitions of food systems by giving a voice to marginalized groups and their representative "change makers". The goal is to create "socially robust" knowledge through co-production with non-scientific actors in research. This echoes the goal of PNS of increasing quality assurance in scientific research. However, like PNS, this does not directly bridge diverse epistemologies, but rather assumes that greater participation and empowerment of non-scientific actors will resolve tensions if they arise. The authors explicitly recommend "assessing the deliberative opportunities that projects offer stakeholders" as a measure of epistemic rigour in transdisciplinary research. Similarly, Marin et al. (2016) emphasize the role of knowledge co-production with scientists (academic actors), specialists (aligned actors) and lay persons (non-aligned actors). Again, the approach echoes that of PNS, with a goal to produce more "robust knowledge" in the research process that targets more societally relevant research gaps. Involving non-academic actors is also intended to reflect more diverse norms and interests along with "lived experiences and social practices" (p. 94).

Regarding the use of multi-criteria methods, Alrøe et al. (2016) highlight the balancing of different types of knowledge as one of three key challenges in the SA of food systems (alongside dealing with plural values and effectively communicating complex results to achieve change). They highlight the danger that "…what is most well-known, precise, or easiest to measure gets the most weight". Adding multiple disciplinary perspectives or forms of knowledge in the selection of criteria, methods, indicators and weights etc. does not necessarily resolve the epistemic tension, but makes differences in perspective more transparent (e.g. de Olde et al. 2017). Alrøe and Noe (2016) describe this tension between two fundamentally opposing perspectives as "complementarity" (in the sense of the physicist Niels Bohr), such as "…between two modes of science, one characterized by a detached observer stance focusing on describing the world as it is and producing general knowledge, and the other characterized by an involved observer stance focusing on enabling action and change in concrete contexts". Participation in this case will only lead to transformation if "the participation involves stakeholder perspectives in the form of explicitly incorporating their values and in the form of assessments from within instead of from without", implying the type of knowledge forms to prioritize is linked to the purpose of SA. A transdisciplinary SA should hold bottom-up forms of knowledge embedded in practice and values at the same level of scientific knowledge (i.e. no hierarchy of knowledge forms). However, this is very challenging in practice, with three major challenges identified as 1) unequal power relations, 2) integration of viewpoints to ensure common understanding and 3) ensuring that the knowledge produced actually creates a change *towards* sustainability (Pohl et al. 2010). Considerations of procedure and justice during deliberations and knowledge co-creation thus appear paramount to a successful process and should form the basis of SA theory and practice. This participatory nature of SA means it is open to normative, value-laden and political influences that emerge in the process of knowledge creation. Issues may framed differently by different social actors in the form of narratives about problems, causes, solutions and transition/transformation pathways (Stirling 2008, Scoones 2016, Slätmo et al. 2017). Navigating a plurality of narratives and perspectives requires attention to concepts of power and its inequalities across the SA procedure (from framing to real-world impact).

3.1.3 Use of methods and tools in SA

At the level of methodology, the present paper does not attempt to inventory current specific methods or tools (see Ness et al. 2007, Singh et al. 2009, Schader et al. 2014, Janker and Mann 2018). At a minimum, the considerations above imply existing methods must be employed in a participatory and deliberative way. A deeper analysis should attempt to identify epistemological and ontological assumptions within existing methods and ensure the combined approaches in any SA are theoretically consistent with each other in their framing rather than contradictory. Further analysis is beyond the scope of the present paper.

4 Conclusion

The paper has critically analysed a proposed definition of sustainability assessment (SA) as a transdisciplinary appraisal method presented in the literature. It reviewed key elements of SA from the perspective of research paradigms ranging from ontology to methodology. The findings indicate a lack of clear theory in SA, particularly at the level of defining the social-ecological systems under study in a clear way (ontology) and mobilizing the relevant forms of knowledge to stimulate sustainability transformations. Drawing on critical realism and the extensive literature from post-normal science represent key avenues to proceed in these aims.

5 Acknowledgements

This work was supported by two grants from the Swiss National Science Foundation (SNSF): the National Research Program 73 on Sustainable Economy [grant number 407340172451] and the Sinergia programme [grant number CRSII5_202300].

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