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Regional food system sustainability: Using team science to develop an indicator-based assessment framework

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Abstract

Food system sustainability, and ways of measuring it, are widely explored and discussed in academic literature. Measurement efforts are challenging because food systems are inherently complex and multifaceted, spanning diverse components, industries, sectors, and scales. Several systems of indicators and metrics have been proposed to measure sustainability; however, most existing research focuses either on narrow scales (e.g., farm level or within a single supply chain), expansive scales that can gloss over complexity (e.g., national or global assessments), or limited scopes (e.g., only considering environmental factors). A gap in the literature is a holistic local or regional approach to food system sustainability that integrates components across the system at a regional scale. In this reflective essay, we describe our development of a framework to measure and track sustainability in such systems. We use a tiered framework that includes five sustainability dimensions and a system of indices, indicators, and metrics that allows for the measurement of important food system characteristics in a feasible and reproducible way. We employ a collaborative, transdisciplinary, facilitated team science process to first propose, and then refine, a sustainability assessment framework, using the U.S. state of Vermont as a case study. This paper details our process and progress, as well as reflections on challenges and recommendations for other team scientists. We further propose a plan to implement the framework, collect data, and engage with community members. The experiences and findings described here serve as a foundation for our own team's continued work, as well as a springboard for other similar research efforts.

Note: All author details are on the next page.

Keywords

sustainability, food systems, team science, metrics, transdisciplinary, indicators, local, regional

Introduction

Sustainable food systems (SFS) are critical for society to meet its food, fuel, and fiber needs over the coming decades (Willett et al., 2019). Yet characterizing precisely what is meant by and how to measure food system sustainability is plagued by challenges in scale, definition, variable measurement, and data acquisition. Here we present and reflect on our development of a regional food system sustainability assessment framework using a transdisciplinary team science approach (Cross et al., 2022; Feenstra, 1997). To date, our team has established the structure of the framework, formed consensus around a set of important indicators, and grappled with many critical theoretical questions. While the work is ongoing, we believe it is important to publish at this stage to help guide other practitioners undertaking similar research efforts.

Several high-level efforts have been made to define food system sustainability. For example, the Food and Agriculture Organization of the United Nations (FAO) defines an SFS as "a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised" (Nguyen, 2018, p. 1). Similarly, since 1990, the U.S. Department of Agriculture has defined an SFS as:

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Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

SW, BB, and MN contributed to conceptualization and design of the study. All authors were involved with the series of meetings and actions toward framework development described in this paper. SW consolidated findings to form the current framework, performed data visualizations, and wrote the first draft of the manuscript. LC, DT, and SW collaboratively drafted the narrative document; and DN, MN, and HD reviewed it. All authors contributed to manuscript revision, read, and approved the submitted version.

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> an integrated system of plant and animal production practices having a site-specific application that will, over the long term: satisfy human food and fiber needs; enhance environmental quality and the natural resource base upon which the agricultural economy depends; make the most efficient use of nonrenewable resources and on-farm resources, and integrate, where appropriate, natural biological cycles and controls; sustain the economic viability of farm operations; and enhance the quality of life for farmers and society as a whole. (U.S. Department of Agriculture [USDA], 2024)

As researchers within the Food Systems Research Center, a joint effort between the University of Vermont and the U.S. Department of Agriculture's Agricultural Research Service (USDA ARS), we aim to develop a framework that is rooted in current sustainability definitions yet expands upon them by adopting a regional perspective. Regional food systems stem from the geographic fixity of primary production factors like topography, climate, and natural resources (Clancy & Ruhf, 2010). The boundaries of a region can be difficult to define, but it has been suggested that an approximate 400-mile (644-km) radius is a good place to start (Clancy & Ruhf, 2010). Others conceive of a regional food system as being centered around and providing for a large urban area (Blay-Palmer et al., 2018).

More important than strict physical size, however, is the fact that regional food systems foster a shared sense of place based on common experiences of crop options, farm and food business scales, distribution networks, and consumer markets, which lead to tight-knit community connections. Regional food systems have been defined as "collaborative networks that integrate sustainable food production, processing, distribution, consumption, and waste management in order to enhance the environmental, economic and social health of a particular place" (Feenstra & Campbell, 2014, p. 1). Through this lens, a sustainable regional food system is one in which "as much food as possible to meet the population's food needs is produced, processed, distributed, and purchased at multiple levels and scales within the region, resulting in maximum resilience, minimum importation, and significant economic and social return to all stakeholders in the region" (Clancy & Ruhf, 2010, p. 1).

Our conception of regional food system sustainability builds on existing sustainability definitions that primarily emphasize food, fuel, and fiber production; viable business models; nutrition outcomes; and environmental health. In addition to these, our framework captures co-benefits like aesthetics, recreation, and cultural values to better understand how farms and other food businesses contribute to the well-being of farm families and local communities. Following others, we also consider factors like regional self-reliance, self-organization, and resilience to outside disruptions as core tenets of regional food system sustainability (Prosperi et al., 2016; Worstell & Green, 2017). Our framework aims to improve the measurement and documentation of sustainability outcomes within local and regional food systems, which has not been a primary focus in many existing studies.

Scholars have long debated how best to conceptualize sustainability and how to break the overall concept into its components, often called "dimensions" (Vos, 2007). The most common framework is the "three pillars" model, in which sustainability is split into economic, environmental, and social dimensions (Purvis et al., 2019). However, due to the complex, interconnected nature of coupled human and natural systems (of which the food system is an example), it can be difficult to cleanly subdivide sustainability into discrete components. For example, questions remain as to whether the "overall sustainability" of a system is even measurable, because there are inherent tradeoffs between dimensions (Morrison-Saunders & Therivel, 2006). Positive movement in one dimension may lead to negative movement in another, so decisions about what to prioritize are often required, which leads to further questions about who has the power to decide and who does not.

Food systems scholarship explicitly recognizes and grapples with the complex interconnections between its various elements (Feenstra, 1997). Food system components include production on farms, distribution, marketing and sales, consumption (including nutrition outcomes), as well as social factors like community vibrancy, employment opportunities, labor conditions, resource access, social justice, etc. It is critical to note that a food system is not simply a linear chain of processes, but rather a network of interacting components defined by multiple tradeoffs and feedback loops that is embedded in a broader institutional and environmental context (Chaudhary et al., 2018; Jones & Tobin, 2018; Low et al., 2015; Meadows, 1998). The inherent social-ecological nature of food systems also presents challenges for cleanly subdividing sustainability outcomes into distinct categories (Prosperi et al., 2016). Any attempt to assess food system sustainability across dimensions and components requires a wide range of expertise spanning various academic disciplines as well as other modalities of knowledge creation, that is, a truly transdisciplinary approach.

Stemming from concepts in systems thinking, the use of data-driven indicator frameworks to assess complex outcomes has been increasingly preferred (Meadows, 1998). An indicator is simply a variable describing the state of a system; a good indicator is both feasible to measure and reflects a specific desirable, yet complex, outcome within a system (Walz, 2000). Applied specifically to food system sustainability, there has been a historical shift from a focus on regulations, to standards and certifications, and finally to indicators and metrics as a mechanism to incentivize sustainable practices (Konefal et al., 2022; Ludden et al., 2018). Developing a system of indicators for a complex food system requires uniting expertise from a variety of domains, for example using a Delphi process (Allen et al., 2019; Campbell et al., 2022), or another team science approach (Cross et al., 2022; Hall et al., 2012).

The use of indicators should allow the ability to measure and reward progress toward specific outcomes, such as by establishing performance benchmarks or through payments for ecosystem services. This approach can help farmers, consumers, and policymakers make sense of agricultural sustainability by offering an apples-to-apples method of comparing different systems, as well as tracking performance of one system over time. A system of indicators also makes assessment of tradeoffs more obvious, providing opportunities to discuss the inherent complexity of sustainability.

Project Overview and Goals

This project is among the first to develop a sustainability indicator framework focused specifically on local and regional food systems (Allen et al., 2019; Low et al., 2015). We aim to produce a reliable and repeatable method to identify, collect, and interpret sustainability data at a middle scale, and across diverse system components, to inform local and regional decisions that require robust information about the current and future state of their food systems. To do this, we began by funding concept papers proposing sustainability indicators across multiple aspects of local and regional food systems through USDA ARS funding. We then brought those diverse groups together into a team with deep expertise in all key knowledge areas. To develop the framework, we used a transdisciplinary team science process, with a core facilitator group guiding the efforts of the wider team, integrating feedback and synthesizing results (Cross et al., 2022; Hall et al., 2012). The process and progress presented in this reflective essay serve as a foundation for further work by our team and others. Although the framework itself is still undergoing development, we wish to share our team science process so that important lessons can be passed on to other research teams.

Our experience contributes to the literature on food systems sustainability in several important ways. Following others, we reiterate the importance of expanding the scope of sustainability dimensions. While the three-pillar model has been used most often (Purvis et al., 2019; Schader et al., 2014), scholars have increasingly identified additional dimensions beyond environmental, economic, and social components (Reganold & Wachter, 2016; Spiegal et al., 2022). We build on this, especially regarding the development of new types of social and human indicators, which have historically presented challenges (Bacon et al., 2012).

Additionally, this study is set apart by its unique scope and scale of analysis, specifically focusing on a holistic conception of food systems and thus incorporating farms, food businesses, communities, and individuals at a regional scale. Existing sustainability assessment frameworks differ across their primary purposes, levels of assessment, and geographical, sectoral, and thematic scopes (Schader et al., 2014). While there is no shortage of research assessing the sustainability of food systems and/or agricultural producers, a general overview of existing studies, detailed below, indicates that they typically fall within one of three categories of scale: (1) farm, field, or household scale, (2) single-sector supply chain, or (3) national or international.

The first common type of sustainability assessment is the analysis at the farm, field, or household scale, which largely focuses on biophysical and/or microeconomic dimensions. This type of framework may assess individual agricultural production or management strategies, asking questions like "is organic agriculture more sustainable than conventional agriculture?" (Haas et al., 2001; Nemecek et al., 2011; Reganold & Wachter, 2016). Similarly, frameworks like the sustainable livelihoods approach assess how different agricultural management strategies influence livelihood outcomes at the household level (Serrat, 2017). Several efforts in this category have taken the form of computer applications with front-facing interfaces that can be used by individual farm businesses (Eichler Inwood & Dale, 2019). Examples include the Fieldprint Calculator (Gillum et al., 2016), Stewardship Index for Specialty Crops (McIntyre, 2010), and COMET-Farm (Paustian et al., 2017).

The second common style of sustainability assessment focuses on supply chains within a specific agricultural sector. These studies measure outcomes within individual food supply chains, for example, assessing the sustainability of palm oil against other cooking oils (Boons & Mendoza, 2010; Choong & McKay, 2014), or whether local supply chains necessarily confer sustainability advantages over national supply chains (Born & Purcell, 2006; Coley et al., 2009).

Finally, the third common category of sustainability assessment is the large national or international study. These projects use a global lens in which the units of analysis are typically countries, and they employ broad-scale statistical metrics (Béné et al., 2019; Chaudhary et al., 2018; Gustafson et al., 2016; National Research Council, 2010). While useful at a macro level, this scope can wash out important regional differences and limit the utility of results for policy creation at smaller scales.

Our study goes beyond these three common assessment types to fill a gap in the existing scholarship. Developing a system of indicators to measure food system sustainability regionally is novel and nascent. While some attention has been given to community food system planning (e.g., Pothukuchi, 2004), our inclusion of diverse food system actors and consideration of complex interactions at the regional scale is a contribution to the academic literature, as suggested by Dale et al. (2013) and others. While our framework is intended to be widely applicable to multiple regional food systems, as a first step, we focus on the northeast U.S., using the state of Vermont as a case study for framework development.

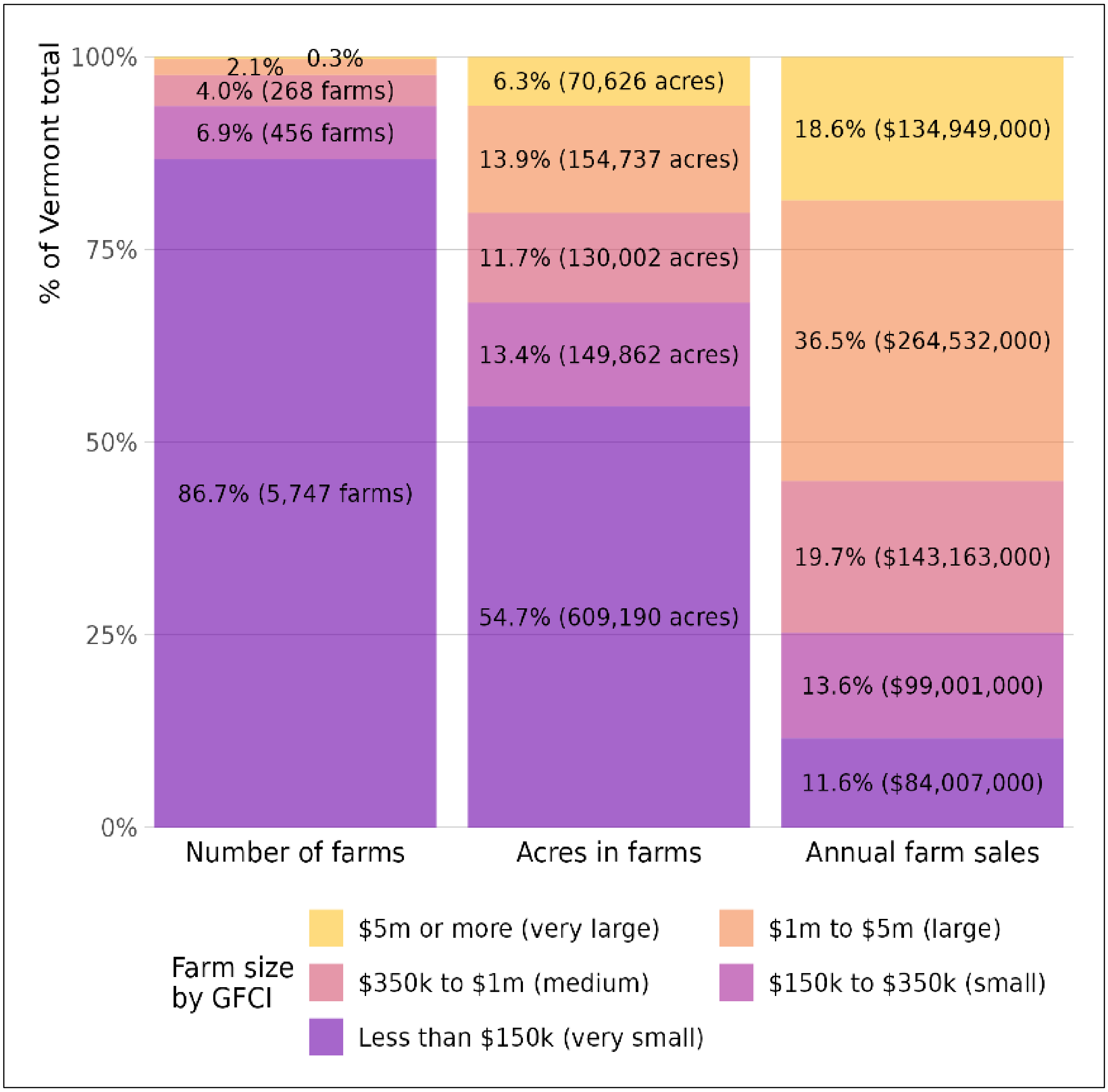
Our midscale focus presents data challenges not present with the three commonly used scales described above. For example, small-scale analyses can use direct field sampling and/or farms' or households' economic data; supply chain analyses can employ existing industry data provided by food companies; and global analyses can leverage statistical datasets made available by governments, nongovernmental organizations (NGOs), intergovernmental organizations (IGOs), and university researchers. To characterize regional sustainability, new methods for data collection and processing must be identified.

Vermont's Food System

With the overarching goal being to develop a regional food system sustainability framework that can be applied widely, we began by utilizing our back yard. Vermont's food system is reflective of the midscale network we are interested in. For example, Vermont is characterized by numerous small and medium farms driving production (Figure 1). Among farms in Vermont, 98% are classified as small or medium, encompassing 80% of farmland and accounting for 45% of farm sales (USDA National Agricultural Statistics Service [USDA NASS], 2017). While dairy is the primary agricultural industry (accounting for 65% of total farm revenue), Vermont's farms are quite diverse: out of 6,627 farms, only 11% produce cow's milk (USDA NASS, 2017). The prevalence of diversified small and medium-sized farms makes assessing sustainability in smaller regions like Vermont somewhat different from studies focused on larger (e.g., U.S. national) scales, which primarily reflect large monocultural farmers selling into commodity markets.

We acknowledge that Vermont's food system differs from many other regional food systems. Our region is relatively rural, so applying our framework to regions centered around an urban center or centers will require additional consideration. Further, due to its positionality within the U.S. context, Vermont's food system differs in important ways from similar-sized regions in developing countries. However, despite these limita-

Figure 1. Key Statistics on the Vermont Agricultural System Stratified by Gross Farm Cash Income (GFCI)



Data from U.S. Census of Agriculture (USDA National Agricultural Statistics Service, 2017).

tions, an initial focus on Vermont offers a practical lens through which to begin developing an assessment framework.

A goal of this project is to focus on a holistic network of food system components, rather than narrowly on production statistics, because it is at the systems level that landscape-level benefits related to nonfood ecosystem services, community livability, and other factors emerge (Bacon et al., 2012). Vermont is characterized by strong interpersonal connections among food systems actors within the region. Many producers sell into alternative supply chains and leverage nontraditional income streams, including agritourism, direct-to-consumer marketing, regional distribution networks, and others (Chase et al., 2021). This interwoven fabric of actors across different components of the food system is important for regional food system sustainability and has been widely recognized as a strength in the Vermont context (VT Farm to Plate Network, 2019).

Materials, Methods, and Results

Here we present our process and progress toward a regional food system sustainability assessment tool. We used a transdisciplinary team science approach to develop an indicator framework that meets our goals. Our team is composed of a diverse group of researchers and extension professionals with deep experience in Vermont's food system. Areas of expertise include rural sociology, plant and soil science, watershed science, landscape ecology, agricultural and community economics, agricultural management, nutrition, data science, computational modeling, and group facilitation.

Our process followed the four phases of team-based research proposed by Hall et al. (2012): development, conceptualization, implementation, and translation. This paper focuses primarily on the development and conceptualization phases. Following the experiences of other research teams who have used similar transdisciplinary approaches to study complex food systems issues (Cross et al., 2022), we endeavored to make our process inclusive and collaborative, allowing space to step back and reflect on our progress and goals, and flexible to adapt to challenges as they arose (Figure 2). Below we provide detailed descriptions of each research phase. While we are not suggesting that this is the only way the problem could have been resolved, we hope these descriptions and reflections will offer guidance to other practitioners. We conclude by discussing challenges, lessons learned, and recommendations for other team scientists, as well as plans for this ongoing long-term project.

Concept Papers

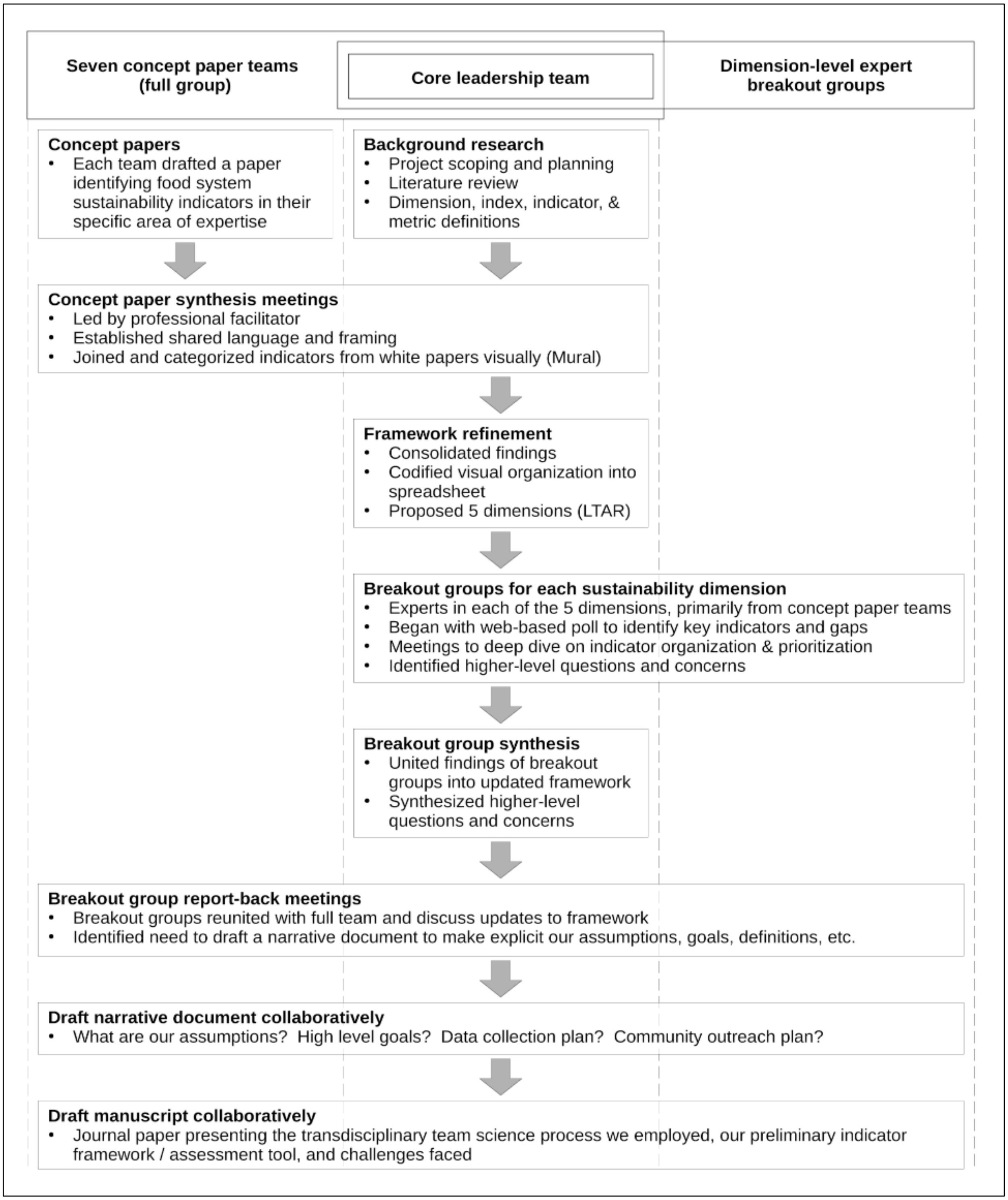
In the first stage of the process, The University of Vermont's Food Systems Research Center (FSRC) developed a request for proposals for interdisciplinary teams to generate concept papers proposing ways to measure sustainability in local and regional food systems. Seven teams were funded for their work, collectively representing more than 50 faculty, post-doctorates, students, and external collaborators. All the concept paper teams were based in the U.S. state of Vermont, although external collaborators were in other U.S. regions including Puerto Rico and Appalachia. The papers' subject areas included farm business benchmarking (Cannella et al., 2021), agroecology (Caswell et al., 2021), agritourism and direct-to-consumer sales (Chase et al., 2021), participatory research (Estrin et al., 2021), a case study on hemp production (Kolodinsky et al., 2021), soil health (Neher et al., 2021, 2022), and community embeddedness (Ament et al., 2021, 2022).

These concept papers were critical for generating a multiplicity of indicators of food systems sustainability; however, without a single unifying framework provided to teams *a priori*, their collective work represented a diverse and free-form set of potential ways to measure sustainability. As a result, the FSRC developed a facilitated process consisting of three workshops with representatives from all seven concept paper teams to aggregate the concepts into a unified framework.

Synthesis Meetings

Representatives from the seven concept paper teams came together in a series of initial meetings, led by a professional facilitator, to discuss what a combined indicator framework should look like in our specific regional context, and to synthesize findings from the concept papers. The major task of these meetings was to summarize, consolidate,

Figure 2. Team Science Process Diagram for the Collaborative Development of Our Sustainability Assessment Framework



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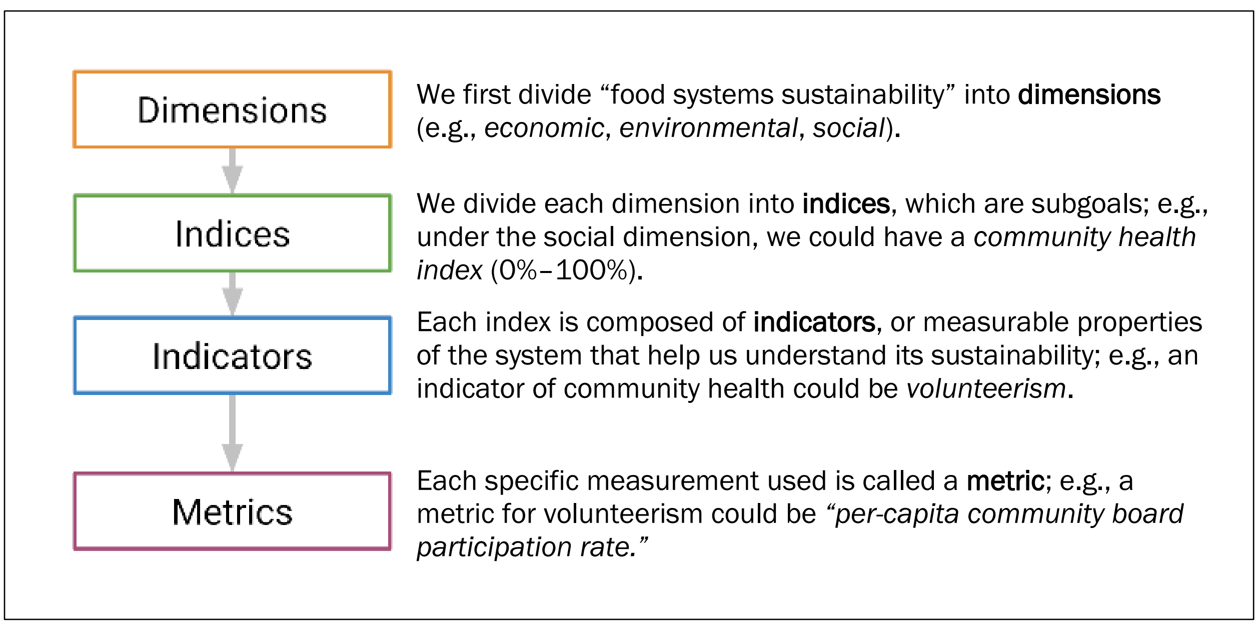
and organize proposed indicators from the concept papers into a unified system. A core leadership team composed of a postdoctoral researcher (SW), a professor (BB), and the associate director of the FSRC (MN) undertook background research to suggest how the teams' interdisciplinary studies could be combined coherently. Based on this initial research, we used a nominal group technique (Delbecq & Van de Ven, 1971) with the full team to refine concepts and definitions iteratively, eventually landing on a sustainability framework established through a consensus process, composed of dimensions, indices, indicators, and metrics (Fiksel et al., 2012). Relationships between these components are visualized in Figure 3, and each is described in more detail below.

To facilitate joining indicators into a wider sustainability framework, we needed to group them thematically. Following many others, we use the term "dimensions" for the primary, high-level goals of sustainability (Fiksel et al., 2012). Historically, three dimensions of sustainability have been proposed (environmental, economic, and social), although in theory any number of dimensions are possible (Vos, 2007).

Within each dimension, one can identify important subgoals that contribute to sustainability in that dimension. The system's performance on each of these subgoals can be represented as an "index," or a value derived by combining several key indicators within that category (Mayer, 2008). Indices are sometimes referred to as compound- or complex-indicators. We define an index as an amalgamation of multiple indicators that reflects a certain general property or goal of the system. An index is more granular than a top-level dimension, yet more generalized than an individual indicator. The index is the level at which outcomes will typically be communicated in the overall framework. For example, within the environmental dimension of sustainability, soil health is an important criterion. To quantify this, we could formulate a "soil health index" based on a set of individual indicators like soil organic matter content, CO_2 flux, and aggregate stability.

An indicator in our framework defines a specific aspect of the system we wish to measure (Walz, 2000). The sheer number of possible indicators is a notable challenge when trying to create a usable framework (Schader et al., 2014). Because the system is so complex, we sought to identify a succinct set of indicators that, together, provide an accurate picture of the state of the system across all dimensions.

Figure 3. Definitions of Dimensions, Indices, Indicators, and Metrics that Compose Our Assessment Framework



Selecting indicators is nuanced and riddled with complexity. Effective indicators should be responsive to management, affect or correlate with outcomes, and be capable of being measured precisely within feasible technical and economic constraints (Doran & Parkin, 1994). Indicators may be qualitative or quantitative, as long as a standardized method is established to unite different types of indicator data. Indicators can be neutral (a simple description) or value-laden (normatively describing progress toward a given goal) (Heink & Kowarik, 2010). In the case of sustainability, we are typically dealing with normative indicators, i.e., the indicators are helping to answer the question, "how sustainable is the system?" This means value judgments must be made about the elements of sustainability that are prioritized, which we discuss in the Recommendations section.

Whereas an indicator identifies the system characteristic to be measured, we define a metric as the specific method, procedure, dataset, or assay used to implement the measurement itself. To be useful, the sustainability assessment framework must be repeatable, both through time in the same region, and across different regions. For each indicator, one or more standardized measurement methods along with applicable units must be identified. For example, to measure soil carbon, an active-carbon POXC (ppm) test could be employed. Identifying specific metrics for each indicator will eventually be necessary as the framework is rolled out, but this is beyond the scope of the current phase of the project.

While the index is the level at which outcomes are typically reported, our assessment framework is tiered, meaning different levels of abstraction are possible. We could formulate an outcome value for each dimension, e.g., an environmental sustainability score composed of all the indices under the environment dimension. We could even unite all the dimensions into an overall sustainability score for the full system. However, it is important to maintain the ability to "drill down" into the individual indicators, because forming a compound indicator involves subjective decisions about the weighting of different components and can obscure the critical tradeoffs inherent to sustainability.

A method to report and visualize this type of tiered data is a class of plot called a radar, petal, spider, or sunburst. Figure 4 shows how we propose to use such a plot to illustrate outcomes in our sustainability assessment framework. In this case, the length of each labeled bar in the outer ring represents an index value, and colors correspond to sustainability dimensions.

Once the full team had agreed on a basic framework structure, we used an online collaboration platform called Mural to visually organize the proposed indicators from the concept papers (MURAL, 2022). This collaborative, bottom-up approach was chosen to aid in the consensus-building process using a nominal group technique (Delbecq & Van de Ven, 1971). This technique allowed for individual idea generation, idea sharing, group discussion, and consensus. The facilitator first placed indicators from each concept paper into Mural as "sticky notes," and team members were able to reorganize them, add notes and connecting arrows, etc., individually and then through discussion. After a first pass by the full team, three subgroups convened individually, each focusing on one of the categories of environmental, economic, or social sustainability. At the end of the meeting series, we arrived at a rough visual organization of proposed indicators within a set of dimensions and indices, which was agreed upon by the participants (Figure 5).

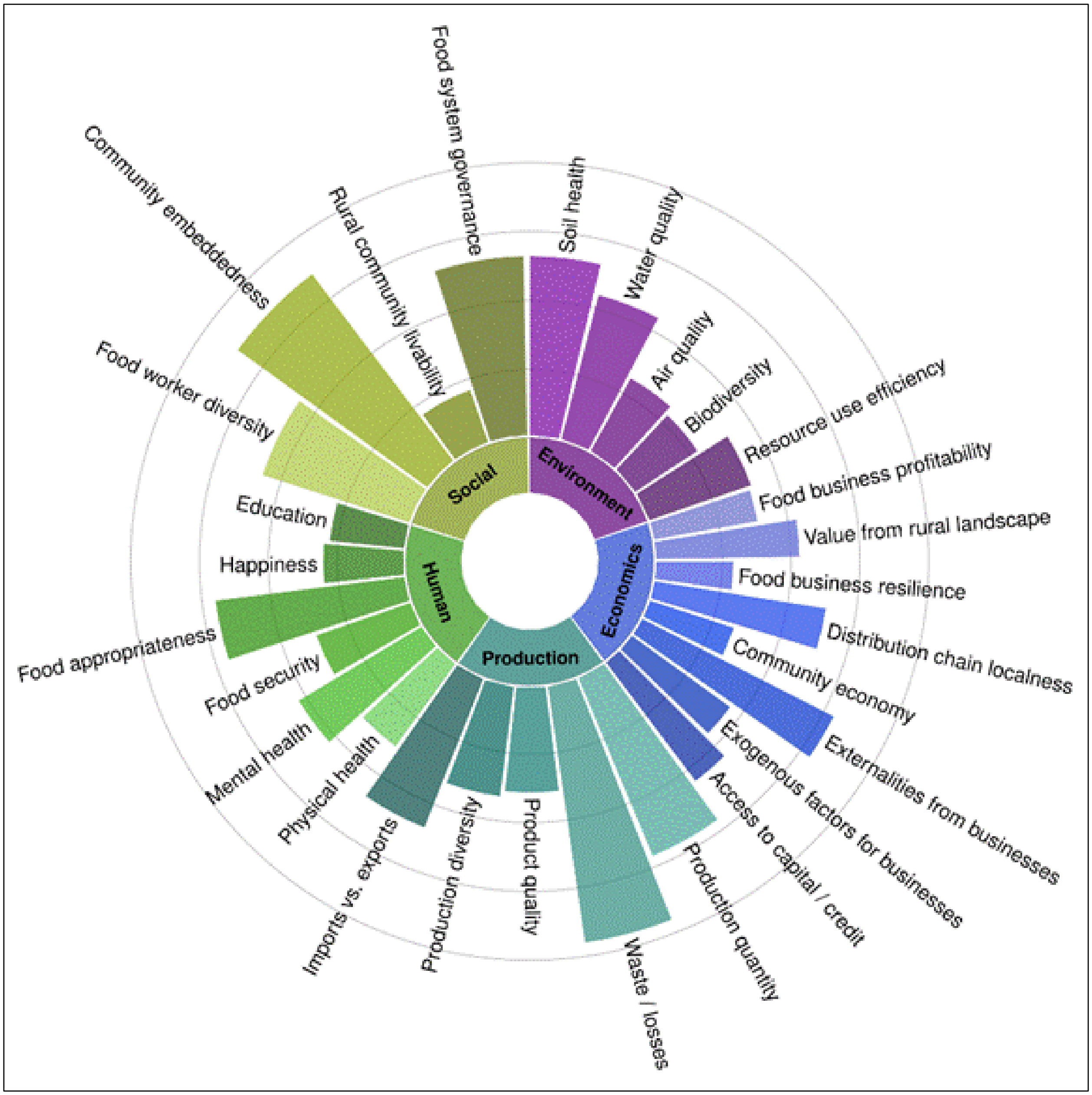
In addition to indicator refinement, several theoretical considerations emerged from this meeting series. For example, we needed to define the boundaries of the food system more specifically. This included the spatial scale of the system (in our case regional); which elements of the food system we capture (e.g., production, distribution, retail, nutrition, human well-being, social cohesion, etc.); and by whom the assessment framework is meant to be used (Fiksel et al., 2012). We also discussed inherent complexities within the system, such as cases in which an indicator does not fit cleanly into a single dimension but instead bridges multiple dimensions. The theoretical considerations and inherent limitations we identified are discussed in the Recommendations section.

Framework Refinement

After the initial meeting series, the core team refined the visual organization of indicators into a more organized spreadsheet format. Through this process, we became aware of a sustainability indicator project currently in progress by the USDA Long-Term Agricultural Research (LTAR) group, and the core team joined LTAR's meetings to identify synergies between our projects. While LTAR focuses on a slightly different aspect of sustainability (specifically, sustainable intensification), it has faced many similar challenges (Spiegal et al., 2022). One of these fundamental issues is the limitation imposed by the typical "three pillars" model. Fol-

Figure 4. Sunburst Plot of the Type Proposed to Communicate Sustainability Outcomes

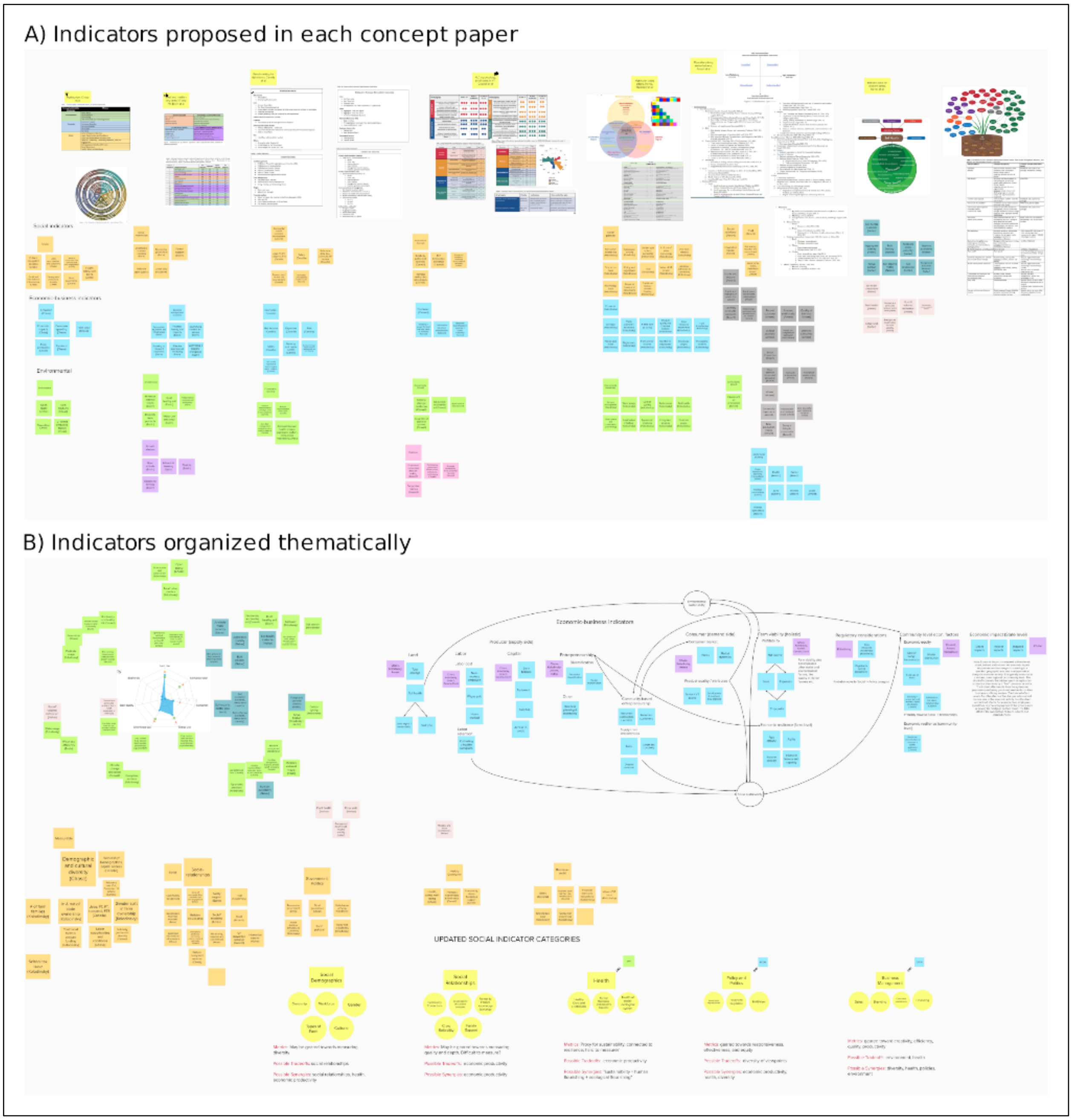
Shows the five dimensions at the center, indices under each dimension grouped by color, and values for each index corresponding to the length of each bar. In this example plot, the dimensions and indices are taken directly from our framework, but the values are random for illustrative purposes only.



lowing LTAR and others, we opted to recategorize our indicator framework into five dimensions (Figure 6).

The reorganization into five dimensions was an improvement, but upon reflection we realized we still had too many overall indicators to be feasible, identified gaps where important aspects of food system sustainability were not covered, and noted an uneven distribution of indicators between dimensions. Additionally, different indicators sometimes had different scopes and scales of analysis. We concluded that we needed a more rigorous method by which to select and unify indicators. For the next phase of framework refinement, we collaboratively identified four fundamental criteria by which to weigh indicators for inclusion:

Figure 5. Visual Indicator Organization Process Using the Mural Platform



- **Completeness**: Adequately captures important system characteristics without emphasizing one dimension over another;
- **Parsimony**: Identifies a succinct set of indicators, as the goal is to make the tool usable and not overly burdensome;
- **Compatibility**: Ensures indicators are compatible in scale and scope; and
- **Feasibility**: Ensures indicators are theoretically possible to measure and integrate into the framework.

With these criteria in mind, our goals for the next phase were to identify redundancies and gaps in indicators, organize and prioritize indicators in the framework, ensure indicators are compatible with one another in scale and scope, and evaluate data collection feasibility.

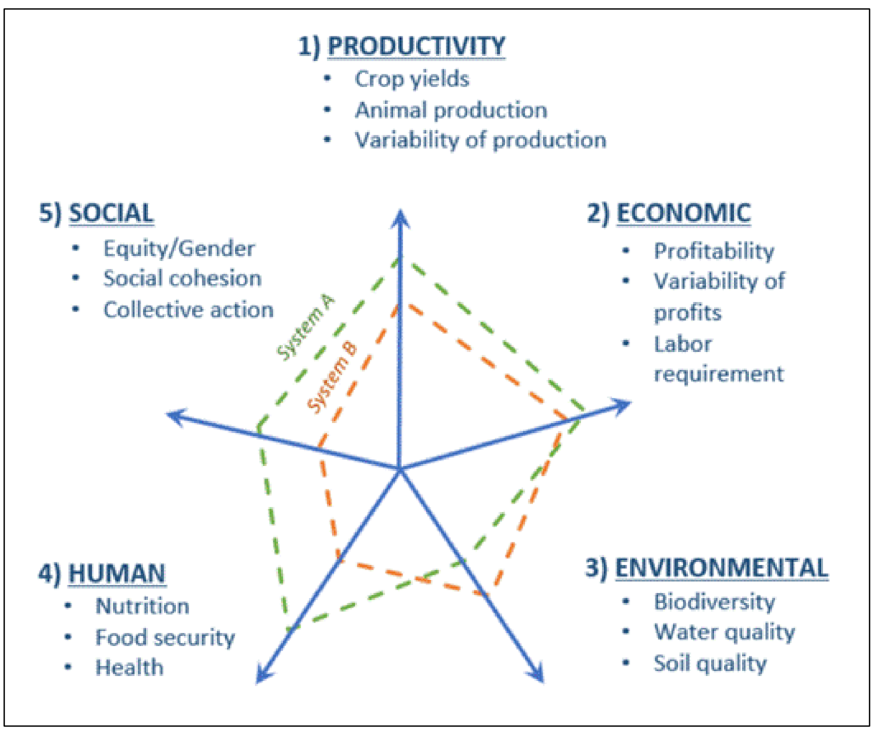
Breakout Groups

Five teams were convened, each with deep expertise in one of the five dimensions. The overall goal of these groups was to hone indicator selection according to the above criteria and refine thematic organization. Before convening, we conducted a preliminary online survey that allowed members to prioritize existing indicators and propose new ones based on identified gaps. During breakout sessions, the primary task was to reach consensus on a set of indicators by winnowing, combining, and adding new indicators if necessary. We also wanted to better establish a shared understanding of the basic definitions of sustainability within each dimension (Table 1).

Report-Back Meetings

After the breakout process, we reconvened as a full team to synthesize findings and identify next steps. Changes proposed by the breakout groups to indicators and indices in each dimension were integrated into the overall assessment framework. The full team had a chance to critique and form consensus around all the proposed updates, as well as identify ongoing challenges.

Figure 6. Five-Dimensional Sustainability Framework Used by USDA LTAR Indicators Team and Others, Illustrating Outcomes for Two Theoretical Food Systems



Reprinted from Spiegal et al. (2022).

For example, a specific need we identified, which has also been noted in the literature, was to develop better indicators of sustainability in the social dimension (Bacon et al., 2012). This is a challenge because social, institutional, and ecological contexts and processes can constrain and mediate other aspects of food systems, which the concept of “embeddedness” can help explain (Polanyi, 1975). We worked to incorporate a set of embeddedness indicators to reflect how the values, norms, and relationships of a regional food system promote or restrict the motivations, decisions, and actions of those operating within it (Ament et al., 2022).

We also identified a need to form consensus around our preconceived goals and assumptions for the framework. A narrative document—essentially a statement of researcher positionality to be used internally—was drafted collaboratively, with the core team assigning roles, after which several rounds of feedback from the full team were incorporated. The document helped us to refine our shared definitions of sustainability, why measuring it is important, our assumptions regarding who the tool is meant to be used by, how to engage with stakeholders beyond academics, and our plans for both qualitative and quantitative data collection and analysis.

Finally, the core leadership team synthesized revisions from the breakout groups into an updated assessment tool framework. Figure 7 gives an example of how the framework is structured, illustrating the tiered layout. The full framework as it currently stands, including all dimensions, indices, and indicators, is shown in the Appendix, Table A.

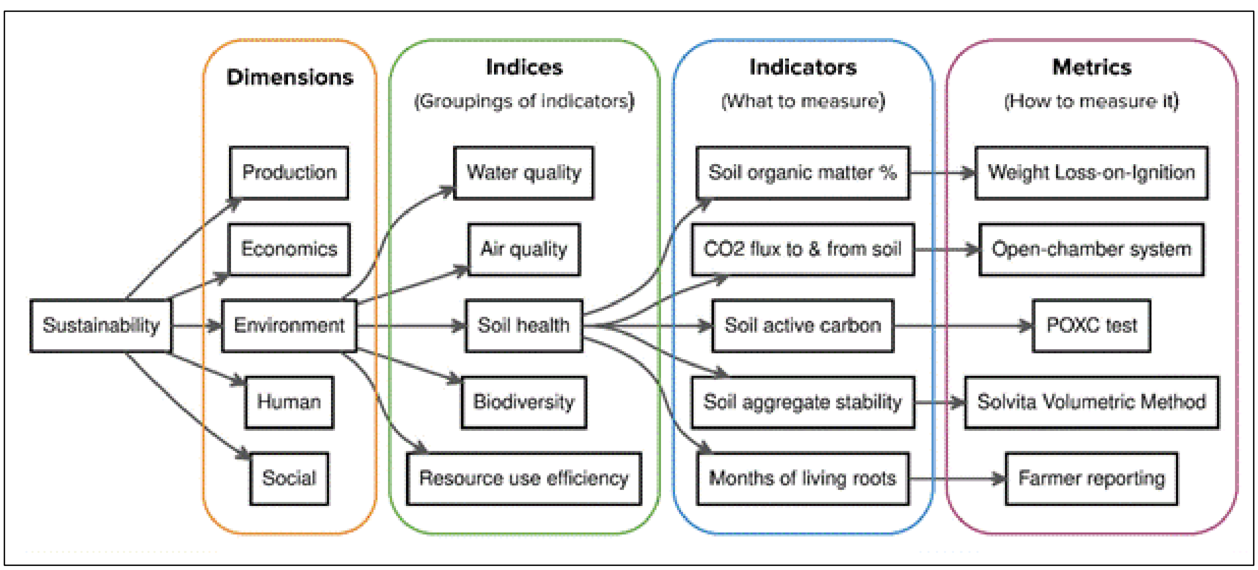
Discussion

The ultimate goal of this long-term project is to develop an indicator-based assessment tool to measure and track sustainability outcomes in regional food systems. This is a challenging task, and to tackle it we employed a transdisciplinary team science approach to facilitate critical thinking and consensus building throughout the framework development process. To date, we have focused primarily on the development and conceptualization stages, incorporating plentiful opportunities to

Table 1. Proposed Sustainability Definitions for Each Food System Dimension

Dimension	Sustainability definition
Environment	Interactions between food systems activities and environmental processes contribute to ecological health.
Economics	Individuals and firms can build and maintain financial value and thrive in the marketplace and community resources are distributed equitably.
Production	The food system supports the essential food, fuel, and fiber needs of its community.
Human	The food system supports the wellbeing of individuals in the community while wellbeing is equitably distributed.
Social	The social fabric of the food system and the social institutions that govern the system are inclusive, resilient, and robust.

Figure 7. Structure of the Sustainability Assessment Framework, Focusing on a Single Index (Soil Health) Within One Dimension (Environment) as an Example



address more theoretical aspects of the project, e.g., drafting a document outlining our positionality, implicit assumptions, and goals (Cross et al., 2022; Hall et al., 2012). It is important to prioritize this type of foundational work to ensure team members' diverse views are captured adequately in the final framework. We made substantial progress, iteratively honing the framework through the collaborative actions described in this paper. Our process brought us much closer to operationalizing our regional food system sustainability assessment tool. However, the primary purpose of this paper is to reflect on our successes and the lessons we have learned to help guide others. Below, we describe the challenges we faced, detail our plans to bring the framework to fruition, and provide suggestions to other teams undertaking similar research efforts.

Next Steps

To operationalize our assessment tool, we need to finalize the selection of indicators and metrics that compose the framework. This will involve further scrutinizing each proposed indicator relative to the four criteria identified for indicator selection (completeness, parsimony, compatibility, and feasibility) by involving the wider community in the process. We must also identify one or more metrics (methods of measurement) for each indicator. Some of the metrics will leverage existing data, while others will need to be collected directly. The next steps for developing the metrics include compiling relevant existing datasets and engaging with community members to determine the challenges and feasibility of collecting original data.

To facilitate this process, the FSRC held a series of workshops in the fall of 2022, followed by team planning grants, to develop full proposals for multiyear grants to hone indices and indicators, identify metrics, and fund the collection of data and community engagement necessary for the baseline assessment of local and regional food system sustainability. In July 2023, the FSRC funded five three-year grants for this process, which are deeply engaging with regional food system stakeholders. These grant teams are further refining and testing the indicators initially proposed here.

Through these new projects, the teams are being expanded to include more practitioners, policymakers, and other stakeholders. The project members are working with community members to evaluate the tool and implement data collection and assessment in a way that is respectful, not burdensome, and considers diverse experiences and needs (Baum et al., 2006). Community members will have an opportunity to provide perspectives on questions surrounding definitions of sustainability and how best to prioritize indicators to reflect diverse lived experiences. Ultimately, following further framework development and data collection, we envision the tool to be capable of tracking results through time and exploring how sustainability outcomes may change in the region based on policy, climate, economic pressures, supply chain issues, and other factors.

Recommendations for Other Team Scientists

While our process is ongoing, we summarize in Table 2 and below a series of early recommendations about the process, framework, and data for other scientists engaging in similar efforts.

Process recommendations

While the transdisciplinary team science process offers the invaluable opportunity to escape individual academic "silos," it can also present challenges. As tends to be the case with this type of project, many people are involved, with different ideas about the most important aspects of food system sustainability, and different focus from their respective academic disciplines. Uniting these diverse perspectives is difficult, but critical. We have achieved success in this area by allowing ample space throughout the process for collaborative reflection and consensus formation. This included time within the teams to present disciplinary differences and try to develop a common language. As well, this included a process that first brought together interdisciplinary teams focused on a specific topic, but then a facilitated process to bring those teams further together as well. Through multiple additional activities and engagement across these teams with an external professional facilitator, we were able to arrive at a more integrated, albeit evolving, framework. Furthermore, these efforts continued through additional planning grants and multi-year grants to advance these initial efforts. Thus, our process required teams to work beyond their own determined groups, and engage not only across disciplines, but also across topics of interest, scales, and methods, which began the process of having more detailed and challenging conversations to converge on indicators, metrics and the overall framework.

Another common challenge is defining an endpoint for the project. To address this, we embrace a "living document" mentality, in that we acknowledge flexibility to adjust indicators that may be lacking and to improve metrics over time as new data become available and understandings of sustainability shift. This type of science can't be rushed, and in our case, we are funding the next phase of projects in this space for three years, and possibly many years after. As such, we hope to develop a framework that can serve as a baseline, which could then evolve over time as methods and approaches change, and provide opportunity for additional modules to "plug and play" within the framework. For example, some systems (e.g., animal versus cropping systems) may have additional metrics or indicators which could be integrated in addition to the baseline framework.

Additionally, it is critical to ensure perspectives outside academia are fully integrated into the process (Baum et al., 2006). Projects like ours that originally stem from academia need to give community stakeholders a voice to ensure outcomes are practical and relevant. One key aspect to ensuring this with our projects was to require the participation and incorporation of non-academic community partners in funding applications. This included requiring funding within the budgets of these projects to be allocated to these partners, as well as a one-page community narrative document to be submitted with the project proposal, which detailed the community engagement. Furthermore, a specific review criterion in the evaluation of submitted project proposals considered the extent to which community partners were included and funded for their participation.

Framework recommendations

Framework development naturally presents chal-

Table 2. Suggested Recommendations for Sustainability Framework Development Among Interdisciplinary Team Scientists

Component	Recommendations
Transdisciplinary science	Allow ample time
	Use external professional facilitator
	Make time to present disciplinary assumptions and develop common vocabulary
	Have multiple interdisciplinary teams convene beyond their own groups
	Provide tiers of engagement (planning grants, multiyear grants)
Defining an endpoint	Utilize a living document approach
	Develop a core framework with "plug and play" modules
	Revisit over time
Community engagement	Require community partners
	Provide significant funding for community partner engagement
	Include community narrative document in funding proposal
	Establish explicit review criteria for community engagement in project evaluation
Scale of the system	Focus initially on a specific scale, but be flexible about including other scales in the future
Level of reporting	Be explicit on scale of reporting (e.g., metric, index, "score")
Complexity	Core framework with "plug and play" modules
Data integration	Map how data fit together
	Normalize and standardize scales for quantitative data if possible
	Determine and be explicit about weighting and what informs any weighting

lenges, especially as such efforts tie themselves to indicators and metrics, which often necessitate a clear need for understanding the scale and scope of their measurement. Furthermore, in agriculture and food systems, the diversity of production systems, regionality, and even climate and geographical differences make efforts for frameworks that are "universal" especially challenging. We encountered many aspects of these challenges as we considered the framework's level of analysis.

First, there is the question of delineating a "local/regional food system." Further, how should we account for imports and exports from the region? Relatedly, what is the extent to which we should focus primarily on farms versus other food system actors? We overcame this by building flexibility into our framework's scope and scale. We began by focusing on a single U.S. state that we know well, and from there we can expand the applicability of the framework to wider regions and incorporate more complex intraregional interactions.

Secondly, reporting sustainability outcomes involves a level of abstraction. Multiple levels of abstraction are possible, with higher levels (e.g., an "overall sustainability score") making outcomes simpler to understand, but potentially neglecting important tradeoffs. In our case, we arrived at a middle ground, reporting primary results at the level of indices, which we hope will offer sufficient detail to capture fundamental properties of the system without overloading the audience.

Thirdly is the size and complexity of the framework. While many aspects of sustainability were identified as important to include for a full accounting, some team members have proposed that it may be useful to identify a core set of indicators—perhaps fewer than ten—that should be included in all assessments, with the rest serving as supplementary indicators used to tailor specific studies to their contexts. As noted earlier, this provides a "module" approach that could allow for industry- or region-specific metrics and indicators to supplement the framework.

Data recommendations

A core challenge of such large and multifaceted studies concerns data ontology, data storage, and data integration across disciplines and scales. To this end, we identified the need to develop an online portal including (a) public data, for example collected by governments or NGOs; (b) private data, for example through multistakeholder initiatives like the Fieldprint Calculator (Gillum et al., 2016) or SISC (McIntyre, 2010), and (c) academic data, including those gathered through our process. These data will take the form of quantitative and qualitative metrics that encompass different scales, data collection methods, and sources. For example, some metrics may be self-reported by farmers, while others are measured by outside observers.

With many different datasets and collection processes, teams need to carefully consider how to combine datapoints (Mayer, 2008). We suggest developing methods to normalize metrics into a standardized scale, for example from 0–100%, although other options are possible. A key priority in this process is to include and recognize qualitative data as equally valid and useful, and to find a suitable way to incorporate the nuances of this type of data, which has been a challenge historically (Bacon et al., 2012).

Teams must then establish how to best combine metrics into indices, e.g., is a simple mean of a set of normalized performance metrics sufficient, or is something more complex required? Additionally, teams need to consider how to weight each indicator within indices. Issues of data weighting and prioritization are normative and depend on factors such as the decision-makers' position in society, expertise, and identity; thus these decisions require careful consideration as well as input from diverse stakeholders.

Theoretical questions

Several more theoretical questions also presented themselves, each of which will require reflection by teams undertaking this type of study. We cannot claim to have unequivocally solved these puzzles, but they are certainly worth considering. First is whether sustainability goals should be normative or descriptive, i.e., should we examine how some outcomes are *more sustainable* and others *less sustainable*, or instead should we focus solely on non–value-laden descriptions (Heink & Kowarik, 2010)? Second, how are cross-cutting links handled, i.e., where an indicator's outcomes are tied to another indicator, even if they are categorized in different dimensions?

Finally, incorporating community embeddedness into the framework presents a challenge because the theory of embeddedness holds that many aspects of the system (especially the economic ones) are underpinned by social factors (Ament et al., 2022; Jones & Tobin, 2018; Polanyi, 1975). Whereas the ecological economics perspective holds that social and economic factors are constrained by biophysical limitations, some sociological perspectives view human interactions with each other and the environment as fundamentally social (i.e., the way we understand biophysical limitations is social in nature). Thus embeddedness is expansive, requiring a full accounting of all dimensions of sustainability, but if it can be operationalized effectively, it may capture the (thus far) elusive social processes that help explain why certain sustainability outcomes result.

Ultimately, sustainability is a complex concept with many feedback loops and interconnections, making it a difficult subject to study and characterize. However, we believe these inherent complexities and difficulties do not mean scholars should avoid studying and quantifying sustainability outcomes. On the contrary, these challenges make it even more important that team scientists endeavor to develop and apply the most rigorous and inclusive methods possible to the problem at hand.

Conclusion

This reflective essay outlines the transdisciplinary team science process we used to develop a regional food system sustainability framework. While much progress has been made toward an actionable assessment tool, this work does not represent a finished product, but rather an opportunity to reflect on and learn from our process and progress, and a springboard for continued efforts in this area by our own team and others with similar goals. Going forward, the FSRC will continue to support new funding opportunities, leading to further investigations and publications, refinement of the framework, and collection of data to track and assess food system sustainability both in our region and further afield.

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Table A. Regional Food System Sustainability Assessment Framework as It Currently Stands with Proposed Dimensions, Indices, and Indicators

Dimension	Index	Indicator
Environment		
	Soil health	
		Soil organic matter %
		CO_2 flux to & from soil
		Soil active carbon
		Soil aggregate stability
		Months of living roots
	Water quality	
		Agrochemical runoff
		Nutrient runoff
		Soil loss/sedimentation
	Air quality	
		Dust/particulates
		Odors
		GhG emissions
	Biodiversity	
		Insect, plant, & animal diversity
		Acres in conservation practices
		Land use diversity
	Resource use efficiency	
		External nutrient use efficiency
		Energy efficiency
		Waler use/irrigation efficiency
Economics		
	Food business profitability	
		Total sales / revenue
		Total costs
	Value from rural landscape	
		Acreage in production
		Diversity *of* farm types
		Open acres
		Forest cover
		VT *terroir*/VT brand
	Food business resilience	
		Balance sheet (assets & liabilities)
		Operational diversification
		Business growth/fixed mindset
		Enterprise agility/flexibility
		Income stability
		Climate adaptation

continued

Dimension	Index	Indicator
	Distribution chain localness	
		% local sales
		% of farm / business inputs bought locally
		% direct-to-consumer sales
		Consumer awareness of VT products
	Community economy	
		Wealth/income distribution
		Availability or good-paying jobs in food systems
		Business failure rate of food businesses
		In vs. out-of-state ownership
	Externalities from businesses	
		Ecosystem services
		Ecosystem disservices
	Exogenous factors for businesses	
		Commodity price fluctuation
		Impacts of climate change/variability
	Access to capital/credit	
		Access to credit
		Access to land
		Capital markets
Production		
	Production quantity	
		Total qty. food products
		Total qty. forest products
		Total qty. non-food agricultural products
	Waste/losses	
		Food wasted
		Food losses
		Crop failure
		"Waste" converted to usable biproduct
	Product quality	
		Marketability
		Livestock product safety
		Agrochemical residue on crops
		Recalls in each industry
		Certificates of assurance
		Food safety
	Production diversity	
		Richness
		Nutritional staples
	Imports vs. exports	
		Total qty. imported
		Total qty. exported

continued

Dimension	Index	Indicator
Human		
	Physical health	
		Nutritious diets
		Presence of obesity
		Presence of metabolic disease
	Mental health	
		Stress & anxiety
		Access to social support
		Uncertainty
		Risk aversion (e.g., social stigma)
	Food security	
		Food access
		Food affordability
	Food appropriateness	
		Access to culturally appropriate food
	Happiness	
		Happiness index
		Finding meaning in life
	Education	
		Educational attainment
Social		
	Food worker diversity	
		Gender diversity
		Race/ethnicity diversity
		Age diversity
	Community embeddedness	
		Trust
		Reciprocity
		Social connectedness
		Feeling of belonging to community
		Collective action
		Tradition/ heritage
		Common goals
	Rural community livability	
		NIMBYism
		Community safety
		Population drain (outmigration)
		Open space & natural beauty
	Food system governance	
		Participatory governance
		Government responsiveness
		Fair regulations & incentives