From Progress to Transformation: A Systems-Based Index for Measuring Agrifood Systems Transformation

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Abstract

This paper introduces the Agrifood Systems Transformation Index (AFSTI), a systems-based framework for measuring agrifood systems transformation as a multidimensional, goal-oriented, and interdependent process. Existing measurement approaches often fail to capture the systemic nature of transformation, relying on fragmented indicators or additive aggregation methods that mask imbalance across key dimensions. The AFSTI addresses these limitations by combining distance-to-target normalization, arithmetic and geometric aggregation, and an adjacency-matrix approach to model interactions among system components. Using data from the Food Systems Countdown Initiative, the paper illustrates how the index captures not only the level of progress, but also its balance, coherence, and interaction effects across pillars such as productivity, investment, nutrition, inclusion, resilience, and governance. The results show that agrifood systems transformation is moderate but uneven across countries, and that accounting for imbalance and interdependence materially alters performance assessments. By distinguishing between progress and transformation, the AFSTI provides a more analytically rigorous and policy-relevant tool for monitoring agrifood systems change.

1. Introduction

Agrifood systems are central to global development, shaping outcomes related to food security, nutrition, livelihoods, environmental sustainability, and economic transformation. Yet, despite their importance, these systems remain under increasing strain from multiple and interacting pressures, including climate change, resource degradation, population growth, market volatility, and persistent inequalities. Addressing these challenges requires not only sector-specific interventions but also system-wide transformation, in which progress across production, consumption, resilience, inclusion, and governance is coordinated and mutually reinforcing (Fanzo et al., 2021).

In response, there has been growing recognition of the need for integrated frameworks to monitor agrifood systems transformation. Global initiatives such as the Sustainable Development Goals (SDGs), the UN Food Systems Summit, and regional policy frameworks—including the Comprehensive Africa Agriculture Development Programme (CAADP)—have all emphasized the importance of tracking progress across multiple, interconnected dimensions. However, existing measurement approaches often remain fragmented, focusing on individual sectors or outcomes rather than capturing the systemic nature of transformation. A recent systematic review confirms that most food systems assessment frameworks still lack explicit treatment of interactions, trade-offs, and synergies across domains, limiting their ability to inform holistic policy design (Crossland et al., 2025).

Composite indicators provide one promising approach to addressing this challenge by synthesizing multidimensional information into interpretable metrics. Widely used indices such as the Human Development Index (HDI) and SDG indices have demonstrated the value of such tools for benchmarking and communication. However, conventional composite indicators face important limitations when applied to agrifood systems. In particular, additive aggregation methods often allow compensation across dimensions, meaning that strong performance in one area can mask weaknesses in another. This is problematic in systems contexts, where deficiencies in key domains—such as governance or resilience—can constrain overall performance and limit the effectiveness of improvements elsewhere (OECD, 2008; Mariani & Ciommi, 2022).

This paper introduces the Agrifood Systems Transformation Index (AFSTI) as a general framework for measuring agrifood systems transformation in a way that explicitly reflects its multidimensional and interdependent nature. The AFSTI advances existing approaches in three key respects. First, it adopts a distance-to-target framework, measuring progress as the proportion of the gap closed between current performance and defined benchmarks. This enhances policy relevance by linking measurement directly to transformation objectives (Sachs et al., 2022). Second, it incorporates balance-sensitive aggregation, using both arithmetic and geometric means to distinguish between overall progress and the coherence of that progress across dimensions. Third, it introduces an explicit treatment of interdependence, modeling interactions among system components through an adjacency matrix and deriving diagnostic metrics that capture balance, synergy, and transformation dynamics.

Together, these features allow AFSTI to move beyond conventional scorecards and provide a more nuanced assessment of transformation. The framework distinguishes between progress and transformation, recognizing that improvements in average performance do not necessarily imply systemic change. It also captures the extent to which different components of the agrifood system reinforce—or constrain—each other, thereby offering new insights into the structure and quality of transformation processes.

To illustrate the empirical implementation of AFSTI, this paper applies the framework to data from the Food Systems Countdown Initiative (FSCI). The FSCI provides a comprehensive, globally comparable dataset covering multiple dimensions of food systems, including nutrition, environment, livelihoods, and governance (Schneider et al., 2023). While the AFSTI framework is applicable to a wide range of policy contexts—including regional initiatives such as CAADP—the use of FSCI data allows for a transparent and globally relevant demonstration of the methodology. The results should therefore be interpreted as illustrative of the framework's capabilities, rather than as official benchmarks for any specific policy process.

The remainder of the paper is structured as follows. Section 2 reviews the literature on food systems measurement, composite indicators, and systems-based approaches to agrifood transformation, and identifies the analytical gaps that motivate the development of the AFSTI. Section 3 then outlines the conceptual and theoretical foundations of the index, drawing on systems theory, results-based measurement, and composite indicator methodology. Section 4 presents the data and explains the rationale for the empirical implementation. Section 5 describes the methodological framework, including normalization, aggregation, diagnostic metrics, and the incorporation of interdependence through an adjacency matrix. Section 6 presents the empirical results and discusses their implications for understanding agrifood systems transformation. Section 7 draws out the policy implications of the findings. The final section concludes by summarizing the contribution of the AFSTI and highlighting its potential applications in both research and policy.

2. Literature Review

The measurement of agrifood systems performance and transformation has received increasing attention in recent years, reflecting growing recognition that food systems are central to achieving multiple development objectives, including food security, nutrition, environmental sustainability, and inclusive economic growth. However, despite this expanding body of work, significant challenges remain in developing integrated, coherent, and policy-relevant metrics capable of capturing the multidimensional and interconnected nature of agrifood systems. This section reviews three strands of literature relevant to the development of the Agrifood Systems Transformation Index (AFSTI): (i) food systems measurement frameworks, (ii) composite indicator methodology, and (iii) approaches to capturing interdependence and system dynamics.

2.1 Food systems measurement frameworks

A growing body of literature has sought to develop frameworks for assessing food systems in a holistic manner. Early approaches focused primarily on agricultural productivity and food availability, often measured through indicators such as yields, caloric supply, and trade balances. While these metrics remain important, they provide only a partial view of food system performance, as they do not capture outcomes related to nutrition, equity, environmental sustainability, or resilience (Fanzo et al., 2021).

More recent frameworks have adopted a broader perspective, conceptualizing food systems as interconnected networks encompassing production, processing, distribution, consumption, and governance. Initiatives such as the Food Systems Dashboard and the Food Systems Countdown Initiative (FSCI) have advanced this approach by compiling indicators across multiple domains, including diets, environmental impacts, livelihoods, and enabling conditions (Schneider et al., 2023). Similarly, global efforts such as the Sustainable Development Goals (SDGs) have emphasized the need for integrated monitoring across sectors.

Despite these advances, the literature highlights persistent limitations. A systematic review by Crossland et al. (2025) finds that while many frameworks incorporate multiple dimensions, relatively few explicitly account for interactions, trade-offs, and synergies across them. Most existing approaches rely on sets of indicators reported separately or aggregated using simple additive methods, which may obscure important structural relationships within food systems. As a result, current measurement frameworks often capture the breadth of food systems but not their systemic properties.

2.2 Composite indicators and multidimensional measurement

Composite indicators have emerged as a widely used tool for synthesizing multidimensional information into a single metric. Prominent examples include the Human Development Index (HDI) and various SDG indices, which have been influential in shaping policy debates and enabling cross-country comparisons. The methodological foundations of composite indicators are well established, with key contributions emphasizing the importance of normalization, weighting, and aggregation choices (Nardo et al., 2005; OECD, 2008).

A central issue in this literature is the degree of compensability across dimensions. Arithmetic aggregation allows high performance in one dimension to offset poor performance in another, which can be problematic when the underlying concept requires balanced progress. In response, alternative approaches such as geometric aggregation have been proposed to reduce substitutability and penalize uneven performance (Mariani & Ciommi, 2022). This approach has been adopted in several multidimensional indices to better reflect the idea that development outcomes are constrained by their weakest components.

In the context of agrifood systems, composite indicators have been used to measure aspects such as food security, sustainability, and agricultural performance. However, most existing indices remain limited in two respects. First, they often treat dimensions as independent, ignoring the possibility that improvements in one area may influence outcomes in another. Second, they typically focus on levels of performance rather than on progress toward transformation goals, reducing their relevance for policy monitoring.

2.3 Interdependence, systems thinking, and network approaches

A third strand of literature emphasizes the importance of systems thinking in understanding complex development processes. Agrifood systems are increasingly viewed as complex adaptive systems, characterized by feedback loops, non-linear dynamics, and interdependencies among components (Fanzo et al., 2021). Within this perspective, outcomes cannot be fully explained by examining individual variables in isolation; instead, they emerge from the structure and interactions of the system as a whole.

Recent research has begun to explore methods for capturing these interactions. Network-based approaches, input-output models, and systems dynamics frameworks have been used to analyze linkages among food system components. For example, the Food Systems Countdown Initiative incorporates an expert-informed interaction matrix to represent relationships among indicators, reflecting both empirical evidence and domain knowledge (Herforth et al., 2022). Such approaches recognize that interventions in one domain—such as governance or infrastructure—may have cascading effects across the system.

However, these insights have not yet been fully integrated into composite indicator design. Most indices continue to assume independence across dimensions, even when underlying theory suggests otherwise. As a result, they may fail to capture synergies and trade-offs, leading to incomplete or misleading assessments of system performance (Crossland et al., 2025).

2.4 Gaps in the literature and contribution of this study

Overall, the existing literature highlights three key gaps. First, while food systems frameworks increasingly recognize multidimensionality, they often lack tools for integrating dimensions into a coherent measure of transformation. Second, composite indicator methodologies provide techniques for aggregation but typically do not incorporate interdependence or systems dynamics. Third, approaches that explicitly model interactions have not been systematically linked to policy-relevant measurement frameworks.

This paper addresses these gaps by introducing the Agrifood Systems Transformation Index (AFSTI), which integrates insights from all three strands of literature. The AFSTI contributes to the literature in three main ways. First, it adopts a distance-to-target approach, enabling the measurement of transformation as progress toward defined goals rather than as static performance levels. Second, it incorporates balance-sensitive aggregation, distinguishing between overall progress and the coherence of that progress across dimensions. Third, it explicitly models interdependence through an adjacency matrix, allowing the index to capture how interactions among system components shape transformation outcomes.

By combining these elements, the AFSTI advances existing approaches to food systems measurement and provides a more comprehensive framework for assessing agrifood systems transformation. It bridges the gap between multidimensional indicator sets and systems-based analysis, offering a tool that is both analytically rigorous and relevant for policy and research.

3. Conceptual and theoretical foundations

The Agrifood Systems Transformation Index (AFSTI) is grounded in the view that agrifood transformation is a multidimensional, dynamic, and interdependent process. It is designed to capture not only the extent to which countries are improving across key agrifood system dimensions, but also whether those improvements are balanced, mutually reinforcing, and aligned with longer-term transformation objectives. In this sense, the AFSTI moves beyond conventional performance metrics by treating transformation as both a matter of direction—progress toward defined goals—and structure—the quality and coherence of progress across system components.

3.1 Conceptual foundation

Agrifood systems transformation refers to sustained changes in the way food is produced, processed, distributed, consumed, and governed, such that outcomes improve simultaneously in areas such as productivity, nutrition, inclusion, resilience, and sustainability. This understanding reflects a growing consensus that food systems must be assessed as integrated wholes rather than as collections of isolated sectors or outcomes (Fanzo et al., 2021; Crossland et al., 2025). Improvements in one domain, such as agricultural productivity, may support gains in others, including food access, dietary quality, and livelihoods, but they may also generate trade-offs if other dimensions are neglected. A meaningful measure of transformation must therefore account for both multidimensional progress and the relationships among dimensions.

The AFSTI is built around this principle. It defines transformation not simply as high performance in a subset of indicators, but as simultaneous and balanced progress across interdependent pillars. Under this logic, a country that performs strongly in productivity but poorly in resilience, inclusion, or governance cannot be regarded as fully transformed, because weaknesses in those domains may constrain the durability or inclusiveness of gains achieved elsewhere. The AFSTI therefore places analytical emphasis on the extent to which progress is broadly distributed across pillars rather than concentrated in a few areas. This feature distinguishes the framework from conventional additive scorecards that can mask structural bottlenecks through compensating averages (Mariani & Ciommi, 2022).

A second conceptual feature of the AFSTI is its goal-oriented interpretation of change. The framework adopts a distance-to-target approach in which performance is expressed as the proportion of the gap closed between a baseline and a defined benchmark. This makes the index directly interpretable in terms of transformation progress: higher values indicate that a larger share of the intended transformation has been achieved. Such approaches are increasingly used in sustainability and development monitoring because they allow heterogeneous indicators to be normalized onto a common scale while maintaining a clear link to policy goals or normative benchmarks (Sachs et al., 2022). In the AFSTI, this approach ensures that measurement remains focused not on isolated changes in indicator levels, but on movement toward desired agrifood system outcomes.

These elements define the AFSTI as a framework that measures both the extent and the quality of agrifood systems transformation. The extent of transformation refers to how much progress has been made toward relevant goals. The quality of transformation refers to whether that progress is balanced, coherent, and systemically reinforcing. This distinction is central to the AFSTI's contribution, because it recognizes that fragmented gains do not necessarily amount to transformation.

3.2 Systems theory and agrifood transformation

The first theoretical pillar of the AFSTI is systems theory, which views agrifood systems as complex adaptive systems characterized by feedback loops, interdependence, and non-linear dynamics. Agrifood systems comprise interconnected activities and institutions linking production, markets, food environments, consumer behavior, natural resources, and governance. Changes in one component often affect others, sometimes positively and sometimes negatively, through pathways that are neither immediate nor uniform (Fanzo et al., 2021).

From a systems perspective, outcomes cannot be fully understood by examining indicators in isolation. For example, increases in agricultural productivity may improve food availability and incomes, but without corresponding gains in market access, dietary diversity, social inclusion, or ecological resilience, those improvements may not translate into broader system transformation. Similarly, stronger governance may enhance the effectiveness of interventions across multiple domains, making it an enabling condition rather than simply another outcome variable. These interdependencies mean that agrifood transformation is inherently relational: the significance of progress in one area depends partly on progress in others.

Recent evidence supports this perspective. A systematic review by Crossland et al. (2025) shows that although many food systems assessments recognize the importance of multiple dimensions, relatively few explicitly account for interactions, synergies, and trade-offs across them. This gap in existing measurement practice reinforces the need for indices such as AFSTI that are intentionally designed to capture system-wide relationships rather than merely aggregate sectoral outcomes.

3.3 Results-based measurement and distance-to-target logic

The second theoretical pillar of the AFSTI is results-based measurement, which evaluates performance relative to defined goals rather than in purely absolute terms. Within this approach, transformation is interpreted as a process of closing the gap between a baseline condition and a desired future state. This logic is operationalized through distance-to-target normalization, whereby each indicator is translated into a score representing the share of progress achieved toward a benchmark.

This approach provides two important advantages. First, it enhances interpretability. A normalized score can be understood as the proportion of transformation achieved, rather than as an arbitrary index value. Second, it increases policy relevance by linking measurement directly to targets or benchmarks that are meaningful within a specific analytical or policy context (Sachs et al., 2022). In other words, the AFSTI does not simply describe where countries are; it assesses how far they have moved toward where they intend, or ought, to be.

This goal-oriented perspective also distinguishes transformation from change more generally. Not all change is transformative. A country may improve on selected indicators while still falling far short of broader agrifood system objectives. The AFSTI therefore treats transformation as progress that is both directional and purposeful, anchored in explicit benchmarks rather than undifferentiated indicator movement.

3.4 Composite indicator theory and non-compensatory aggregation

The third theoretical pillar of the AFSTI lies in the literature on composite indicators, which provides methodological guidance for combining multiple dimensions into a single summary measure. Composite indices are valuable because they translate complex, multidimensional phenomena into interpretable metrics that can support benchmarking, comparison, and communication. At the same time, the literature emphasizes that the validity of such indices depends critically on choices related to normalization, weighting, and aggregation (OECD, 2008; Nardo et al., 2005).

A central issue in composite indicator design is the degree of compensability across dimensions. Arithmetic aggregation allows high performance in one dimension to offset weak performance in another. While this may be acceptable in some contexts, it is problematic when the underlying concept requires balanced progress. In agrifood systems, weaknesses in resilience, governance, or inclusion may substantially constrain the value of gains in productivity or investment. A purely additive index may therefore overstate transformation by obscuring critical structural deficits.

To address this problem, the AFSTI incorporates balance-sensitive and partially non-compensatory aggregation principles. In particular, geometric aggregation is used alongside arithmetic aggregation to reflect the idea that transformation requires concurrent progress across pillars and that imbalances should be penalized (Mariani & Ciommi, 2022). The coexistence of the two aggregation methods is analytically valuable: arithmetic aggregation captures the general level of progress, while geometric aggregation captures the extent to which that progress is evenly distributed. The gap between the two therefore provides insight into the structure of transformation.

3.5 Interdependence, balance, and transformation quality

Building on these theoretical foundations, the AFSTI introduces a further innovation by explicitly incorporating interdependence into the assessment of transformation. Agrifood systems are not simply multidimensional; they are also networked. Progress in one dimension may reinforce or constrain progress in another, depending on the structure of the system. To reflect this, the AFSTI framework models interdependencies through an adjacency matrix and complements the aggregate index with diagnostic measures such as the Pillar Balance Metric (PBM), the Synergy Index (SI), and the Annual Transformation Rate (ATR).

These additions are conceptually important because they shift the focus from aggregate performance alone to the quality of transformation. A country may have a moderate or even high average score, yet still exhibit weak balance or poor interaction among pillars. Conversely, a lower-performing system may possess strong latent synergies, indicating that improvements in one domain could trigger broader gains. By making such distinctions visible, the AFSTI extends standard composite indicator approaches and provides a more complete account of transformation dynamics.

Overall, the conceptual and theoretical foundations of the AFSTI define agrifood transformation as a process that is goal-oriented, multidimensional, and systemically interconnected. Systems theory emphasizes that agrifood outcomes emerge from interactions among multiple domains. Results-based measurement provides a way to track progress toward desired outcomes. Composite indicator methodology offers the tools to combine these domains into a coherent framework, while non-compensatory and interaction-sensitive features ensure that the resulting measure reflects the structure as well as the level of progress.

The AFSTI integrates these perspectives into a unified framework that measures both how much transformation has occurred and how that transformation is organized across the agrifood system. In doing so, it provides a more rigorous basis for assessing whether observed changes amount to genuine agrifood systems transformation rather than isolated or uneven gains.

4. Data

This study uses data from the Food Systems Countdown Initiative (FSCI) as the empirical basis for illustrating the construction and application of the Agrifood Systems Transformation Index (AFSTI). The choice of FSCI is deliberate. The objective of the paper is not to evaluate performance against a single regional policy framework, but to develop and demonstrate a generalizable methodology for measuring agrifood systems transformation. In that context, the FSCI provides a particularly suitable empirical foundation because it offers a globally comparable, multidimensional, and systems-oriented dataset that aligns closely with the conceptual logic of AFSTI.

The FSCI was developed to support accountability for food systems transformation by bringing together indicators that span multiple domains, including diets, nutrition, environment, livelihoods, governance, and resilience (Herforth et al., 2022, 2023). This breadth is important because AFSTI is designed to capture transformation as a process that unfolds across interconnected dimensions rather than within isolated sectors. A dataset confined to agricultural production or food security outcomes alone would be insufficient for that purpose. By contrast, the FSCI makes it possible to illustrate how a transformation index can integrate diverse but interrelated dimensions into a single analytical framework.

A second advantage of the FSCI is its harmonized cross-country structure. The dataset provides internationally comparable indicators across a large number of countries and enables empirical testing of the AFSTI under real-world conditions of variation in coverage, scale, and interdependence. This is especially valuable for a methodological paper, where the central task is to show that the proposed index can be operationalized transparently, interpreted meaningfully, and stress-tested under alternative assumptions. The FSCI therefore serves not merely as a convenient data source, but as an appropriate empirical platform for demonstrating the feasibility and analytical value of the AFSTI framework.

This choice also has an important practical justification. Although the AFSTI was initially motivated in part by policy demand for agrifood systems monitoring, including in Africa, newly adopted policy frameworks often precede the development of dedicated monitoring systems. In such cases, methodological innovation must initially rely on existing multidimensional datasets that approximate the underlying domains of interest. This is consistent with established practice in composite indicator research, where proxy datasets are frequently used to test normalization procedures, aggregation rules, weighting assumptions, and sensitivity before purpose-built reporting systems are fully operational (OECD, 2008; Nardo et al., 2005). The FSCI is therefore used here as an illustrative and globally relevant application dataset, rather than as a substitute for any future policy-specific monitoring architecture.

The empirical implementation uses the FSCI indicator architecture to populate the main components of the AFSTI. Indicators are mapped into the AFSTI pillars in a manner that preserves conceptual consistency with the index design, while allowing flexibility for context-specific applications. Because the FSCI includes variables across a wide range of food-system outcomes and enabling conditions, it is particularly well suited for demonstrating the AFSTI's emphasis on multidimensionality, balance, and systems interaction.

A distinctive feature of this study is the use of an adjacency matrix to model interdependence across agrifood system dimensions. The adjacency matrix used here was developed by the FSCI team through an expert elicitation process involving more than 30 scholars and practitioners with expertise spanning food policy, epidemiology, environmental science, agricultural economics, governance, and systems modeling. These experts were drawn from international organizations, universities, and national research institutes across six continents, including institutions such as FAO, WHO, and IFPRI.

Structured elicitation workshops, peer review of proposed linkages, and consensus scoring were used to define and validate the directed connections among variables (Herforth et al., 2022). This is an important strength of the empirical implementation because it allows the AFSTI to incorporate interdependencies based not only on statistical association, but also on expert knowledge of how food systems function in practice.

The use of this expert-informed adjacency matrix reinforces the systems orientation of the AFSTI. Rather than assuming that each dimension contributes independently to overall transformation, the matrix recognizes that progress in one domain may reinforce, enable, or constrain progress in others. This is particularly relevant in agrifood systems, where interactions among governance, nutrition, resilience, production, and environmental conditions are often non-linear and context dependent. By combining the FSCI dataset with the FSCI team's expert-derived interaction matrix, the empirical analysis is able to move beyond a conventional composite index and illustrate how system structure can be incorporated directly into measurement.

The results presented in this paper should therefore be interpreted as an illustrative demonstration of the AFSTI methodology using a globally relevant food systems dataset. They do not constitute official benchmarks for any specific policy initiative. Their value lies instead in showing how agrifood systems transformation can be measured in a way that captures not only overall progress, but also the balance and interdependence of that progress across system dimensions. As more specialized monitoring systems emerge in different policy contexts, the AFSTI framework can be recalibrated to those contexts while retaining the core logic demonstrated here.

5. Methodology

The Agrifood Systems Transformation Index (AFSTI) is constructed as a composite indicator designed to operationalize agrifood systems transformation as a multidimensional, goal-oriented, and system-dependent process. The methodology integrates three key elements: (i) distance-to-target normalization, (ii) balance-sensitive aggregation, and (iii) explicit modeling of interdependence across system dimensions. Together, these components translate the conceptual framework outlined in Section 3 into an empirically implementable index.

5.1 Indicator structure and pillar aggregation

The AFSTI is composed of a set of indicators grouped into six conceptual pillars: productivity, investment, nutrition, inclusion, resilience, and governance. These pillars capture the core dimensions of agrifood systems transformation identified in the literature and reflected in global food systems frameworks (Schneider et al., 2023; Crossland et al., 2025).

Each indicator is assigned to a single pillar based on its primary contribution to system outcomes. Let s_{ict} denote the normalized score for indicator i, country c, and year t. Indicators are first aggregated within each pillar j to generate pillar-level scores. Two aggregation methods are used:

Arithmetic aggregation:

$$P_{jct}^{arith} = \sum_{i \in j} w_i \, s_{ict}$$

Geometric aggregation:

$$P_{jct}^{geo} = \prod_{i \in j} s_{ict}^{w_i}$$

where w_i represents indicator weights. In the baseline specification, equal weights are used for transparency, though alternative weighting schemes are explored in robustness analysis.

The use of both aggregation methods reflects different interpretations of transformation. The arithmetic mean captures the average level of performance, while the geometric mean penalizes imbalances across indicators, capturing the internal coherence of progress within each pillar (Mariani & Ciommi, 2022).

5.2 Distance-to-target normalization

To ensure comparability across indicators with different units and scales, AFSTI employs a distance-to-target normalization approach. Each indicator is transformed into a standardized score representing progress between a baseline and a benchmark value.

For indicators where higher values represent improvement:

$$s_{ict} = \frac{x_{ict} - x_i^{min}}{x_i^{max} - x_i^{min}}$$

For indicators where lower values represent improvement:

$$s_{ict} = \frac{x_i^{max} - x_{ict}}{x_i^{max} - x_i^{min}}$$

where:

- x_{ict} is the observed value
- x_i^{min} is the baseline
- x_i^{max} is the target or benchmark

Normalized scores are bounded within the interval $[0, 1]$, where 0 indicates no progress relative to the baseline and 1 indicates full attainment of the benchmark. This formulation allows all indicators to be interpreted as the proportion of the transformation gap closed, consistent with results-based monitoring approaches (Sachs et al., 2022).

In the absence of universally defined targets for all indicators, empirical benchmarks derived from the data distribution are used as proxies, following established practice in composite index construction (OECD, 2008).

5.3 Aggregation to overall AFSTI

Pillar scores are aggregated to produce the overall AFSTI score for each country-year observation.

Arithmetic aggregation:

$$AFSTI_{ct}^{arith} = \sum_{j=1}^{6} w_j P_{jct}$$

Geometric aggregation:

$$AFSTI_{ct}^{geo} = \prod_{j=1}^{6} P_{jct}^{w_j}$$

where w_j represents pillar weights, set to equal values in the baseline specification.

As pointed out earlier, the distinction between arithmetic and geometric aggregation is central to the AFSTI framework. While the arithmetic index reflects aggregate progress, the geometric index captures transformation quality, emphasizing the importance of balanced and simultaneous advancement across pillars. The divergence between the two measures therefore provides insight into structural imbalances within agrifood systems.

5.4 Modeling interdependence through an adjacency matrix

A key innovation of the AFSTI is the explicit incorporation of interdependence across system dimensions. This is achieved through the use of an adjacency matrix A, which represents directed relationships among indicators or pillars.

Let s_{ct} denote the vector of normalized indicator scores. The adjacency matrix is defined as:

$$A = [a_{ij}]$$

where a_{ij} captures the influence of dimension j on dimension i. Positive values indicate reinforcing relationships, negative values indicate trade-offs, and zero values indicate no direct interaction.

Using this matrix, adjusted scores are defined as:

$$s_{ct}^* = \alpha s_{ct} + (1 - \alpha) A s_{ct}$$

where $\alpha \in [0,1]$ is a parameter that determines the relative weight of direct performance versus system effects.

In the baseline specification, α is set to give greater weight to direct performance, ensuring that the AFSTI remains interpretable as a performance index while incorporating system interactions. Alternative values are explored in sensitivity analysis.

For empirical implementation, the adjacency matrix used in this study is derived from the Food Systems Countdown Initiative (FSCI) and constructed through a structured expert elicitation process (Herforth et al., 2022). This ensures that interdependencies reflect both empirical relationships and expert knowledge of food system dynamics.

The adjusted scores s^* are then aggregated using the same procedures described above to produce an interaction-adjusted AFSTI, allowing comparison between direct and system-informed measures of transformation.

5.5 Diagnostic metrics

To complement the composite index, AFSTI includes three diagnostic metrics that capture different dimensions of transformation quality and dynamics.

Pillar Balance Metric (PBM)

The PBM measures the dispersion of pillar scores:

$$PBM_{ct} = 1 - \frac{\sigma(P_{ct})}{\sigma_{max}}$$

where $\sigma(P_{ct})$is the standard deviation of pillar scores. Higher values indicate more balanced progress across pillars.

Synergy Index (SI)

The Synergy Index captures the relationship between arithmetic and geometric aggregation:

$$SI_{ct} = \frac{AFSTI_{ct}^{geo}}{AFSTI_{ct}^{arith}}$$

Values closer to 1 indicate stronger alignment between overall progress and balanced progress, reflecting greater system coherence.

Interdependence Effect (IE)

To quantify the impact of system interactions, an interdependence effect is defined as:

$$IE_{ct} = \frac{AFSTI_{ct}^{adj} - AFSTI_{ct}^{base}}{AFSTI_{ct}^{base}}$$

This metric measures the extent to which accounting for interdependence enhances or reduces observed performance.

Annual Transformation Rate (ATR)

The ATR captures the speed of transformation over time:

$$ATR_{ct} = \frac{AFSTI_{ct} - AFSTI_{c0}}{1 - AFSTI_{c0}}$$

where $AFSTI_{c0}$is the baseline value.

Together, these metrics provide a richer understanding of transformation by distinguishing between level, balance, interaction, and dynamics.

5.6 Sensitivity and robustness analysis

To evaluate the stability and credibility of the Agrifood Systems Transformation Index (AFSTI), the analysis incorporates a series of sensitivity and robustness checks designed to examine whether the results depend excessively on specific methodological choices. This step is particularly important in the construction of composite indicators, where decisions regarding weighting, aggregation, missing-data treatment, and indicator selection can materially influence country scores and rankings (OECD, 2008). The purpose of the robustness analysis is therefore to ensure that the AFSTI reflects underlying patterns in agrifood systems transformation rather than artifacts of model specification.

First, the index is tested under alternative weighting schemes. In addition to the baseline equal-weighting approach, a PCA-based weighting scheme is applied to assess whether the relative importance assigned to indicators affects the overall structure of results. This comparison helps determine whether the index is highly sensitive to normative weighting assumptions or whether the main findings remain broadly stable under a more data-driven specification.

Second, the analysis compares alternative aggregation methods, specifically arithmetic and geometric aggregation. This distinction is central to the AFSTI framework because the two approaches embody different assumptions about compensability across dimensions. While arithmetic aggregation allows stronger performance in one dimension to offset weaker performance in another, geometric aggregation penalizes imbalance and places greater emphasis on simultaneous progress across pillars. Comparing the results under these alternative methods provides insight into the extent to which observed country rankings depend on assumptions about substitutability.

Third, sensitivity tests are conducted on the interdependence parameter α, which governs the relative weight assigned to direct performance and network effects in the interaction-adjusted specification of the AFSTI. Varying this parameter allows assessment of whether the interaction-adjusted results are robust to alternative assumptions regarding the strength of interdependencies across agrifood system dimensions. This is especially important because interdependence is a central innovation of the AFSTI and should not be allowed to dominate the index mechanically.

Fourth, the treatment of missing data is examined to assess whether alternative approaches to incomplete observations materially alter the results. Because cross-country multidimensional datasets often contain uneven coverage, robustness to missing-data assumptions is essential for maintaining the reliability and transparency of the index.

Finally, the analysis assesses indicator redundancy by examining the extent to which highly correlated indicators may overrepresent particular dimensions of transformation. This step helps ensure that the index captures genuinely distinct aspects of agrifood systems rather than reproducing the same signal multiple times through overlapping variables.

These robustness checks strengthen confidence in the AFSTI by demonstrating whether its main results remain stable across plausible alternative specifications. They also enhance the transparency and methodological credibility of the framework, which is a critical requirement for any composite index intended for analytical and policy use (OECD, 2008).

6. Results and discussion

Table 1 presents indicators by pillar**.** The AFSTI is constructed from 58 indicators grouped into five pillars: diets, nutrition, and food security; production and environmental sustainability; livelihoods and social inclusion; governance and enabling environment; and resilience and stability. Indicator selection and pillar assignment follow the uploaded metadata and the empirical implementation used in this study.

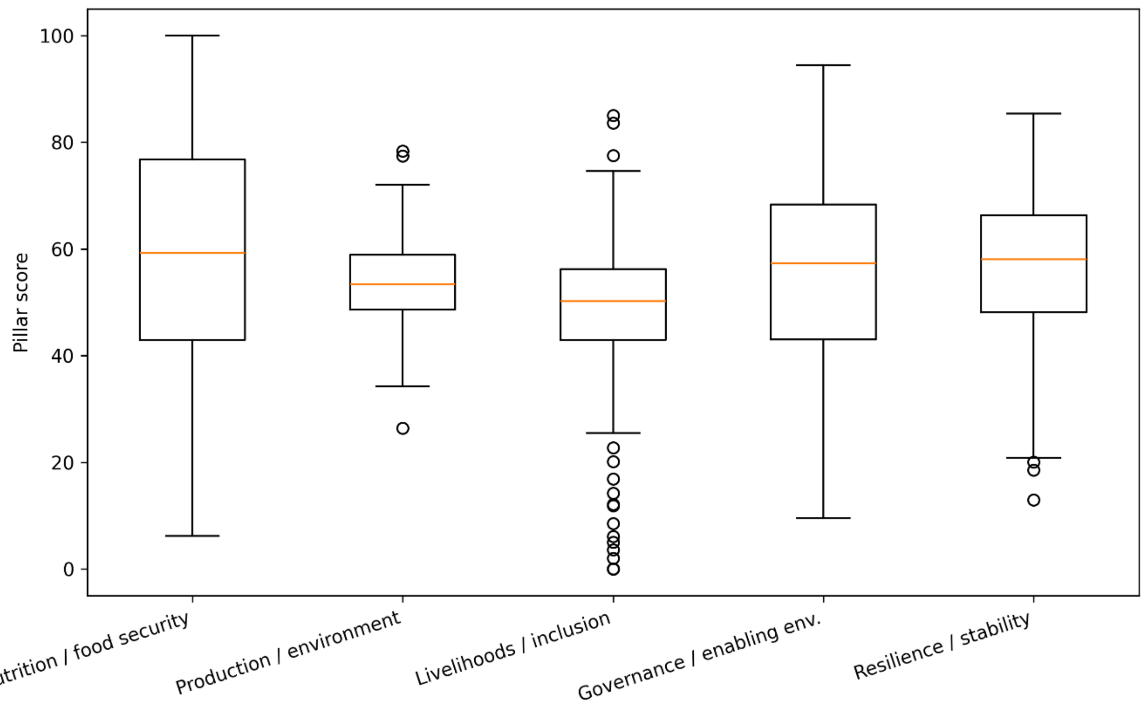
Table 1. Indicators by pillar

Pillar	No. of indicators	Indicators
Diets, nutrition, and food security	15	Percent of the population using safely managed drinking water services (SDG 6.1.1); All-5: Consumption of all five food groups; Percent of the population who cannot afford a healthy diet; Cost of a healthy diet; Percent of the population experiencing moderate or severe food insecurity (SDG 2.1.2); Availability of fruits; Availability of vegetables; MDD-C: Minimum Dietary Diversity for Children (SDG 2.2.4); MDD-W: Minimum Dietary Diversity for Women (SDG 2.2.4); Age 15+: NCD-Protect; Age 15+: NCD-Risk; Prevalence of undernourishment (SDG 2.1.1); Age 15+: Soft drink consumption; Age 15+: Zero vegetable or fruit consumption; Children (6–23 months): Zero vegetable or fruit consumption

Production and environmental sustainability	19	Agriculture water withdrawal as percent of total renewable water resources; Number of animal genetic resources for food and agriculture secured in either medium- or long-term conservation facilities (SDG 2.5.1b); Number of plant genetic resources for food and agriculture secured in either medium- or long-term conservation facilities (SDG 2.5.1a); Cropland area change; Greenhouse gas emissions intensity for beef; Greenhouse gas emissions intensity for cereals (excluding rice); Greenhouse gas emissions intensity for cow's milk; Greenhouse gas emissions intensity for rice; Fishery health index progress score; Agri-food systems greenhouse gas emissions; Functional integrity: Agricultural land with minimum level of natural habitat; Proportion of agricultural land with minimum level of species diversity (crop and pasture); Cropland nitrogen use efficiency; Pesticide use per area of cropland; Beef yield; Cereals yield; Cow's milk yield; Fruit yield; Vegetable yield
Livelihoods and social inclusion	7	Percent of children 5–17 years engaged in child labor; Share of women among owners or rights-bearers of agricultural land (SDG 5.a.1); Underemployment rate; Unemployment rate; Share of agriculture in GDP (SDG 2.a.1); Social protection adequacy; Social protection coverage
Governance and enabling environment	10	Guarantees for public access to information (SDG 16.10.2); Civil society participation index; Food safety capacity; Presence of a national food system transformation pathway; V-Dem accountability index; Government effectiveness index; Presence of national health-related food environment policies; Percent of the urban population living in cities signed onto the Milan Urban Food Policy Pact; Open budget index score; Degree of legal recognition of the right to food
Resilience and stability	7	Dietary sourcing flexibility index; Ratio of total damages from all disasters to GDP; Food price volatility; Food supply variability; Mobile cellular subscriptions; Prevalence of severe coping strategies; Social capital index

Figure 1 shows that cross-country dispersion is not uniform across pillars. The widest spread appears in diets, nutrition, and food security, where countries range from very low to very high scores. This suggests that basic outcome conditions such as affordability of healthy diets, food insecurity, and dietary quality remain highly uneven across countries. That pattern is consistent with the broader food-systems literature, which shows that access to healthy diets and nutrition outcomes are shaped jointly by income, prices, infrastructure, and public policy rather than by food availability alone (HLPE, 2017; FAO et al., 2024).

Figure 1. Distribution of pillar-level AFSTI scores



A second notable feature is the relatively low central tendency of livelihoods and social inclusion. In the AFSTI sample, this pillar has the lowest mean score, and Figure 3 shows a concentration of countries in the lower-middle range with a long lower tail. Substantively, this suggests that labor-market conditions, underemployment, child labor, land rights, and social protection remain persistent bottlenecks even where other parts of the food system perform moderately well. This is important because food-system transformation is not only about productivity or nutrition outcomes; it also depends on whether benefits are broadly shared and whether vulnerable groups are protected during structural change (HLPE, 2020; Fanzo et al., 2021).

By contrast, production and environmental sustainability appears somewhat more compressed around the middle of the distribution. That pattern may indicate partial convergence in agricultural production capacity, but it should not be read as evidence of sustainability convergence in a strong sense. Composite sustainability pillars often combine efficiency-oriented indicators with environmental-pressure indicators, so countries can arrive at similar aggregate scores through quite different underlying pathways. A country with strong yields but weak environmental performance can resemble a country with more moderate productivity but better ecological stewardship once indicators are aggregated. This is one reason why pillar-level interpretation remains essential in multidimensional food-system assessment (Béné et al., 2019).

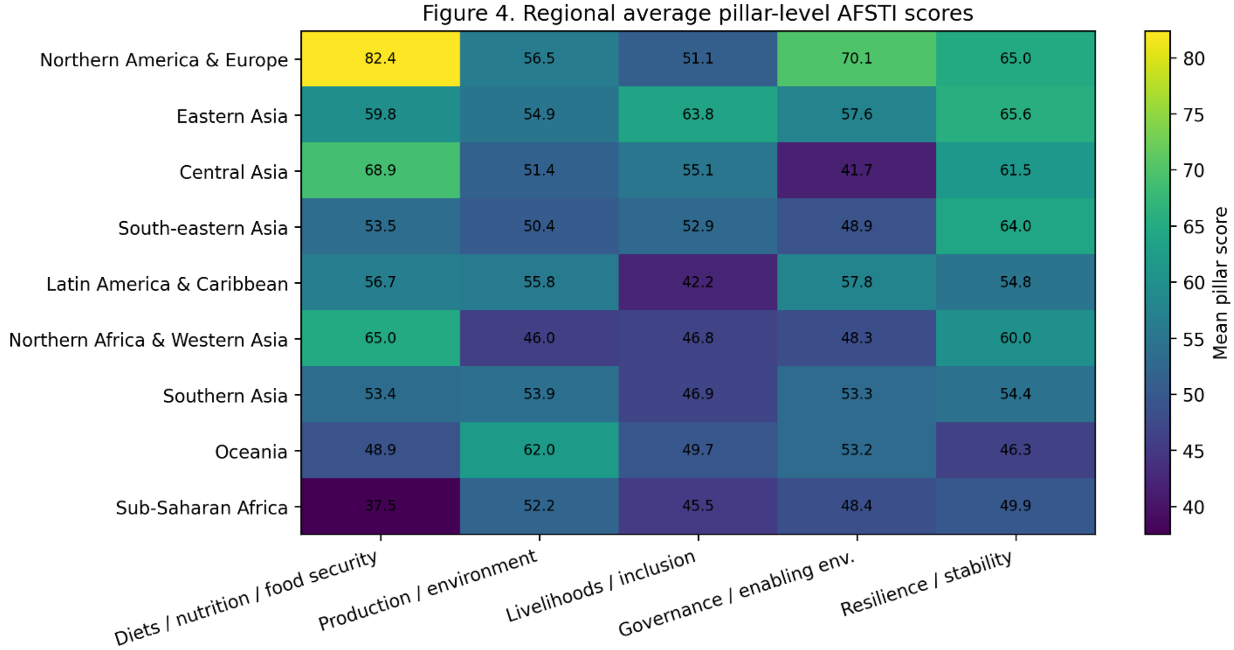
The distribution for governance and enabling environment is also wide, with both low-scoring and very high-scoring observations. That is unsurprising: governance indicators often capture institutional capabilities, transparency, policy coordination, and legal protections, all of which vary sharply across countries and tend to move more slowly than market outcomes. In food-systems research, governance is frequently identified as a key "enabling" dimension because it conditions whether gains in one domain can be sustained or scaled across the system (HLPE, 2017; Candel, 2014).

Finally, resilience and stability shows a relatively high median but also substantial spread. This suggests that many countries perform reasonably well on average, yet a nontrivial set remains exposed to instability through price volatility, disaster losses, limited coping capacity, or weaker social capital. That interpretation aligns with recent work emphasizing that resilience is not reducible to production alone; it depends on diversification, institutional preparedness, infrastructure, and household coping capacity (Tendall et al., 2015).

Figure 1 reveals a strongly uneven regional pattern. Northern America and Europe records the highest regional means in diets and governance and remains strong in resilience. This profile is consistent with a combination of higher incomes, stronger public institutions, broader social protection systems, and more mature food safety and regulatory environments. At the same time, its score in livelihoods and social inclusion is notably lower than its diets and governance scores, which suggests that even relatively high-performing food systems may continue to face distributional and inclusion challenges. That point matters because high average system performance does not automatically imply equitable outcomes across workers, gender groups, or rural populations (Fanzo et al., 2021).

Figure 2. Regional average pillar level AFSTI scores

Figure 4. Regional average pillar-level AFSTI scores



Eastern Asia stands out for comparatively strong performance in livelihoods and social inclusion and resilience and stability, with more moderate scores in diets and governance. This may reflect the region's strong record in poverty reduction, state capacity, logistics development, and supply-chain integration, even though diet quality and food-environment challenges remain substantial in parts of the region. In other words, Figure 4 suggests a profile of relatively robust system functioning without uniformly high dietary outcomes.

Central Asia presents a more uneven pattern: relatively high diets and resilience scores, but weaker governance. That gap may indicate that some food-system outcomes are being sustained despite more limited institutional depth in the policy environment. For interpretation, this is precisely the kind of cross-pillar imbalance that a multidimensional index is designed to uncover. It shows why high scores in outcome pillars should not be assumed to reflect equally strong enabling conditions.

Latin America and the Caribbean appears mixed: middling diets and governance, moderate production and sustainability, but weaker livelihoods and social inclusion. This is consistent with a long-standing regional pattern in which food availability is often less of a constraint than inequality, labor informality, and uneven access to social protection. The region's challenge is therefore not simply raising aggregate supply, but improving inclusion and translating food-system capacity into more equitable welfare outcomes.

Northern Africa and Western Asia shows relatively strong diets and resilience, but weaker production/environment and livelihoods. One plausible interpretation is that some countries in the region sustain food access through imports, subsidy systems, or urban food-distribution networks, while structural pressures remain in domestic production systems and labor-market inclusion. This kind of pattern illustrates how countries can maintain acceptable food access outcomes while remaining vulnerable in the underlying productive base.

Southern Asia scores close to the middle across most pillars, without a single dominant strength. That profile can be read as one of broad-based but incomplete transition: improvements are visible, yet no pillar has fully broken away from the others. Given the region's large population and persistent burdens of malnutrition, informality, and climate exposure, this middle-ranking profile is substantively meaningful rather than neutral.

Oceania shows relatively strong production/environment performance but weaker resilience. Because the regional category often includes a number of small island states, the average may partly reflect structural exposure to trade shocks, natural hazards, and logistical constraints. This is a case where regional means should be interpreted carefully, since country size and composition can strongly influence averages.

The clearest concern in Figure 2 is Sub-Saharan Africa, which records the lowest regional average in diets and one of the weakest profiles overall. The combination of low diets, weaker livelihoods, and only moderate resilience is consistent with the broader literature on persistent affordability constraints, infrastructure gaps, exposure to climatic shocks, and uneven institutional capacity in the region (FAO et al., 2024). The key analytical point is that the shortfall is not confined to one pillar. Rather, it appears systemic: weaker performance spans outcomes, enabling conditions, and social inclusion. That kind of multi-pillar deficit is exactly what composite food-system indices are meant to make visible.

6.1 Overview of agrifood systems transformation performance

The underlying indicator database spans 1961–2025. The AFSTI is implemented as a latest-available cross-sectional index, with indicator vintages ranging from 1977 to 2025 and a median reference year of 2023. The empirical implementation of the Agrifood Systems Transformation Index (AFSTI) reveals a moderate but uneven level of agrifood systems transformation globally, with substantial heterogeneity across countries and regions. As shown in Table 2, across countries with complete pillar coverage (n = 191), the mean AFSTI score is 54.53, with a median of 54.73, indicating that, on average, countries have closed just over half of their transformation gap. However, the distribution is wide, ranging from 25.72 in South Sudan to 74.45 in the United Kingdom, highlighting persistent disparities in agrifood system performance.

Table 2. Summary statistics of AFSTI

Statistic	AFSTI (Arithmetic)
Mean	54.53
Median	54.73
Max	74.45
Min	25.72
Countries	191

Regional patterns further underscore this heterogeneity. As shown in Table 3, countries in Northern America and Europe exhibit the highest average performance (65.00), while Sub-Saharan Africa records the lowest (46.71). These disparities reflect persistent structural differences in institutional capacity, infrastructure, and vulnerability to shocks, which continue to shape agrifood system outcomes (Fanzo et al., 2021); (Schneider et al., 2025)

Table 3. Regional AFSTI performance

Region	AFSTI (Arithmetic)	AFSTI (Geometric)
Northern America & Europe	65.00	28.18
Eastern Asia	60.34	17.23
Sub-Saharan Africa	46.71	9.89

A striking feature of the results is the substantial divergence between arithmetic and geometric aggregation across all regions. While arithmetic scores suggest moderate levels of progress, geometric scores are markedly lower, indicating that progress is unevenly distributed across pillars. This divergence is not merely a statistical artifact; it reflects a structural reality that transformation requires simultaneous advancement across multiple domains, and that imbalances can significantly constrain overall system performance (Mariani & Ciommi, 2022). In this sense, the gap between arithmetic and geometric AFSTI can be interpreted as a measure of structural inefficiency in transformation.

6.2 Country-level performance and structural imbalance

At the country level, AFSTI results reveal a clear stratification between high- and low-performing systems, but also highlight important differences in the structure of performance. Table 4 presents top five performers.

Table 4. Top 5 countries by AFSTI

Country	AFSTI	PBM
United Kingdom	74.45	64.55
Denmark	73.99	62.17
Germany	73.46	73.95
Switzerland	72.99	63.91
Norway	71.98	74.38

Top-performing countries—predominantly high-income economies—combine high AFSTI scores with moderate to high pillar balance (PBM), suggesting that their performance reflects broad-based system strength rather than isolated excellence . This indicates that advanced agrifood systems are characterized not only by high levels of performance but also by relatively coherent distribution of progress across pillars.

In contrast, the lowest-performing countries exhibit low AFSTI scores alongside relatively high PBM values. This pattern suggests that weak performance is often uniformly distributed across pillars, rather than driven by extreme imbalances. In such cases, systems are not only underperforming but also lack strong domains that could catalyze broader transformation.

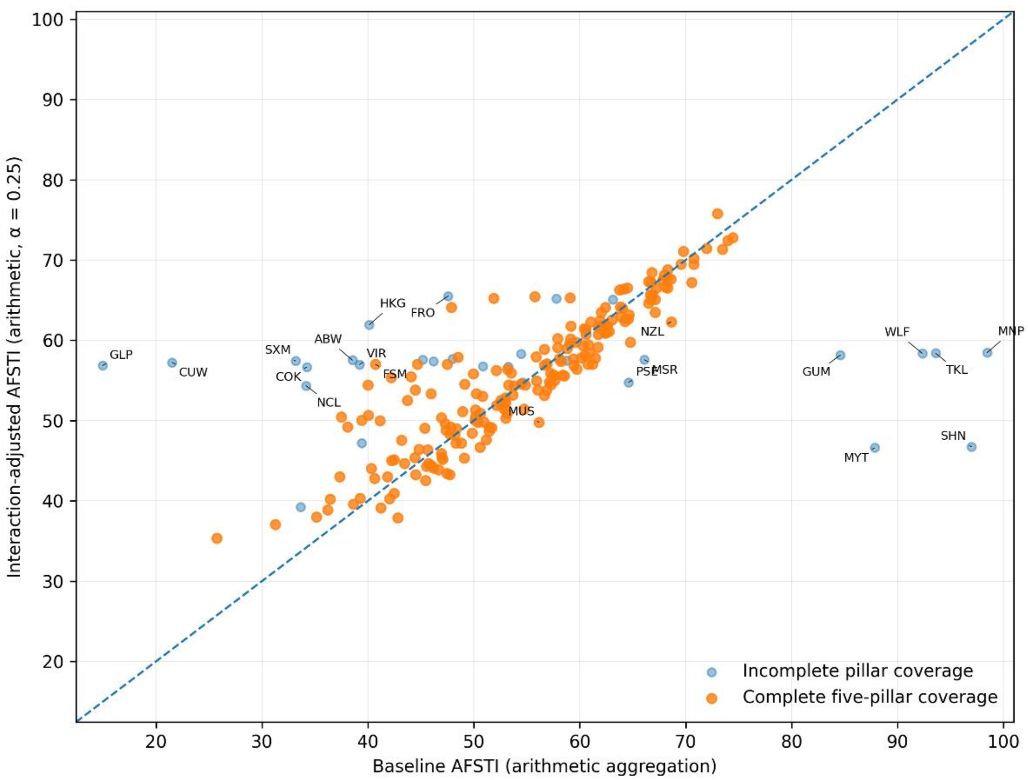
This distinction leads to an important conceptual insight: balance is necessary but not sufficient for transformation. A system can be balanced at a low level of performance, reflecting systemic stagnation rather than coordinated progress. This finding reinforces the AFSTI framework's emphasis on distinguishing between level and structure, and aligns with systems theory, which highlights that both the magnitude and configuration of system components determine outcomes (Fanzo et al., 2021).

6.3 Interdependence and interaction-adjusted performance

A central contribution of this study is the incorporation of interdependence through an adjacency matrix, allowing the estimation of an interaction-adjusted AFSTI (IAFSTI). The results demonstrate that accounting for system interactions materially alters both scores and rankings, confirming that agrifood transformation is shaped by cross-domain linkages rather than independent progress across pillars.

Figure 1 presents the relationship between baseline AFSTI and interaction-adjusted AFSTI. While the two measures are positively correlated, deviations from the 45-degree line capture the extent to which countries benefit from—or are constrained by—system interactions .

Figure 1. Baseline vs interaction-adjusted AFSTI



Two distinct patterns emerge. First, low-performing countries tend to experience substantial positive interaction effects. For example, South Sudan's score increases from 25.72 to 35.36, while Djibouti and Afghanistan also record notable improvements. This suggests that these systems possess latent transformation potential, whereby improvements in one domain can generate spillovers across others which is in line with literature identifying governance and resilience as highly connected entry points capable of generating broader spillovers across food systems (Schneider et al., 2025; Leeuwis et al., 2021)

Second, many high-performing countries experience neutral or negative interaction effects (Table 4). Countries such as Australia, New Zealand, and Mauritius exhibit declines in their adjusted scores, indicating that their strengths may be less interconnected or subject to trade-offs. This implies that high aggregate performance does not necessarily reflect strong system integration.

Table 4. Countries with largest interaction effects

Country	AFSTI	IAFSTI	Interaction Effect
Micronesia	40.71	57.00	16.29

South Sudan	25.72	35.36	9.64
Libya	38.10	49.23	11.13
Mauritius	56.16	49.79	-6.37
New Zealand	68.65	62.32	-6.33

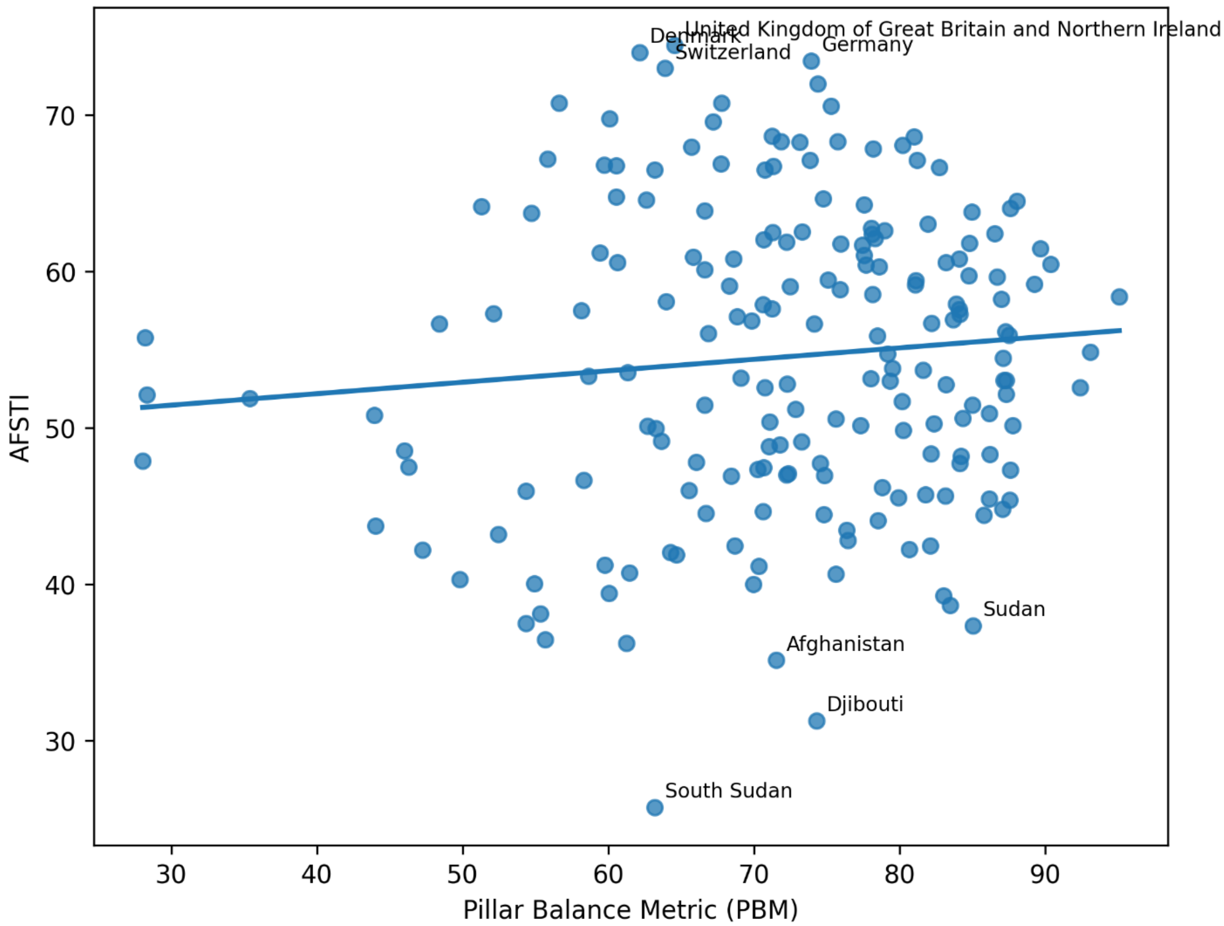
These findings provide strong empirical support for the systems perspective underlying AFSTI. They demonstrate that transformation outcomes depend not only on individual pillar performance but also on the structure of interactions among system components, a dimension that is typically overlooked in conventional composite indices (Crossland et al., 2025).

6.4 Balance, synergy, and transformation quality

The diagnostic metrics—Pillar Balance Metric (PBM), Synergy Index (SI), and interaction effects—provide further insight into the quality of transformation.

Figure 2 plots baseline AFSTI against the Pillar Balance Metric (PBM) for countries with complete five-pillar coverage. The solid line shows the fitted ordinary least squares relationship. The association is positive but very weak, indicating that more balanced pillar performance is only loosely related to higher overall AFSTI scores. While higher-performing countries tend to exhibit greater balance, the relationship is non-linear, indicating that balanced progress must be accompanied by sufficient depth across pillars to translate into higher overall performance .

Figure 2. AFSTI vs Pillar Balance Metric



More importantly, interaction results reveal substantial variation in system coherence. Countries with similar AFSTI levels can exhibit markedly different interaction effects, reflecting differences in how effectively their system components reinforce one another. This highlights a key limitation of traditional composite indicators: by assuming independence across dimensions, they fail to capture the extent to which system structure amplifies or constrains outcomes (OECD, 2008).

The AFSTI framework addresses this limitation by explicitly modeling interdependence, thereby distinguishing between observed performance and system-enabled performance. This distinction is critical for understanding transformation dynamics and identifying leverage points for policy intervention.

6.5 Robustness and sensitivity

As shown in Table 5, the robustness analysis indicates that the AFSTI framework is generally stable but sensitive to specific methodological choices, particularly those related to aggregation and interdependence.

Table 5. Robustness summary

Scenario	Spearman correlation	Mean rank change
Equal vs node weights	0.969	10.1
Geometric aggregation	0.664	37.8
Interaction (α=0.25)	0.773	28.9
Redundancy pruning	0.999	2.2

Rankings are highly robust to redundancy pruning and alternative weighting schemes, suggesting that results are not driven by indicator duplication or weighting assumptions . However, they are more sensitive to geometric aggregation and interaction parameters, indicating that assumptions about balance and interdependence materially affect outcomes.

These findings underscore the importance of transparency in composite index construction. While the AFSTI framework is robust in its overall structure, interpretation of results—particularly rankings—should account for sensitivity to key modeling choices.

In sum, the AFSTI results demonstrate that agrifood systems transformation is multidimensional, uneven, and deeply interdependent. By integrating balance-sensitive aggregation and explicit modeling of interactions, the AFSTI provides a more comprehensive and analytically robust framework than conventional composite indices. It captures not only the level of progress achieved, but also the extent to which that progress is balanced, coherent, and capable of generating system-wide change.

7. Policy Implications

The empirical findings from the Agrifood Systems Transformation Index (AFSTI) underscore the need for a fundamental rethinking of how agrifood policies are designed, implemented, and evaluated. By distinguishing between the level of performance, the balance of progress across system dimensions, and the interdependence among them, the AFSTI framework reveals structural features of agrifood systems that are largely invisible in conventional monitoring approaches. These insights carry important implications for policy, particularly in the context of increasingly complex and interconnected food systems.

A first implication is the inadequacy of siloed policy approaches. The results show that improvements in individual pillars—such as productivity or investment—do not necessarily translate into overall transformation when other dimensions lag behind. The consistent divergence between arithmetic and geometric AFSTI scores demonstrates that imbalances across key domains can significantly constrain system performance, even when average progress appears substantial. This finding aligns with a growing body of literature emphasizing that food systems outcomes emerge from interactions among production, consumption, environment, and governance, rather than from isolated sectoral interventions (Fanzo et al., 2021; Crossland et al., 2025). In practical terms, this suggests that policies narrowly focused on increasing agricultural output or expanding infrastructure are unlikely to yield sustainable gains unless they are complemented by measures that address nutrition, inclusion, resilience, and institutional capacity. Effective transformation therefore requires integrated policy frameworks that explicitly account for cross-sector linkages and trade-offs (Fanzo et al., 2021;Bedeau et al., 2021; Hunecke et al., 2025).

Closely related to this is the importance of balance and coherence in policy design. The AFSTI results indicate that countries with relatively high average performance but uneven progress across pillars tend to exhibit weaker transformation outcomes when assessed using non-compensatory aggregation. Conversely, some lower-performing countries display relatively balanced profiles, albeit at low levels of achievement. This suggests that while balance alone does not guarantee transformation, it is a necessary condition for translating gains in individual domains into system-wide improvements. Policymakers should therefore treat balance not merely as a descriptive characteristic but as an explicit policy objective. Monitoring tools such as the Pillar Balance Metric (PBM) can help identify structural imbalances and guide resource allocation toward underperforming domains. This is consistent with composite indicator theory, which cautions against excessive compensability across dimensions and highlights the importance of maintaining coherence in multidimensional systems (OECD, 2008; Mariani & Ciommi, 2022). This is consistent with broader work showing that sustainable agrifood transformation depends on aligning multiple system objectives rather than maximizing single outcomes in isolation (Pryor et al., 2024; Qaim & Parlasca, 2025).

Perhaps the most significant policy insight emerging from the AFSTI framework concerns the role of interdependence and system spillovers. The interaction-adjusted results show that countries differ not only in their level of performance but also in the extent to which improvements in one domain reinforce progress in others. In particular, lower-performing countries often exhibit strong positive interaction effects, indicating the presence of latent transformation potential. This suggests that well-targeted interventions in key domains—such as governance, infrastructure, or resilience—can generate disproportionate gains by triggering spillovers across the system. Such findings resonate with systems-based approaches to development, which emphasize leverage points where small changes can produce large system-wide effects (Fanzo et al., 2021); particularly governance action (Schneider et al., 2025).

At the same time, the presence of negative interaction effects in some high-performing countries indicates that trade-offs and fragmentation can emerge even in advanced systems. This highlights the need for continuous policy coordination to ensure that progress in one domain does not undermine outcomes in others. For example, intensification of agricultural production may generate environmental or nutritional trade-offs if not accompanied by appropriate regulatory and institutional frameworks. The AFSTI framework, by making these interactions explicit, provides a tool for identifying such tensions and informing more coherent policy design.

The results also point to the need for differentiated policy strategies based on countries' positions within the transformation process. Low-performing systems, which often exhibit uniformly low but balanced scores alongside strong positive interaction effects, may benefit most from interventions that build foundational capacity while leveraging system complementarities. In contrast, middle-performing systems typically face structural bottlenecks that require targeted efforts to improve coherence across pillars. High-performing systems, meanwhile, may need to focus on optimizing integration, managing trade-offs, and sustaining gains through innovation and resilience-building. This differentiated perspective reinforces the idea that agrifood transformation is not a linear process but a stage-dependent trajectory, requiring context-specific policy responses reflecting the fact that national food-systems transformation pathways are context-specific and shaped by different institutional and political processes (Guijt et al., 2021; Leeuwis et al., 2021).

Beyond immediate policy design, the AFSTI framework also has important implications for monitoring and evaluation systems. Traditional approaches often rely on sets of indicators reported independently, without integrating them into a coherent analytical structure. As a result, they may fail to capture the systemic nature of transformation, particularly the roles of balance and interdependence. By combining distance-to-target normalization, balance-sensitive aggregation, and interaction modeling, the AFSTI offers a more comprehensive approach to monitoring agrifood systems. It enables policymakers to track not only progress toward specific goals but also the quality, coherence, and sustainability of that progress. This is consistent with broader calls for more integrated and accountable food systems monitoring frameworks (Schneider et al., 2023).

Importantly, the AFSTI is designed to be adaptable across contexts. While this study illustrates its application using a global dataset, the framework can be calibrated to reflect different policy priorities, data availability, and institutional settings. This flexibility enhances its relevance for both global benchmarking and country-specific analysis. As such, it provides a bridge between conceptual discussions of food systems transformation and the practical requirements of policy design and implementation.

These implications point toward the need for a shift from sectoral to system-based policy design in agrifood systems. Transformation cannot be achieved through isolated improvements, but requires coordinated actions that enhance both the performance and the integration of system components. By making these relationships visible and measurable, the AFSTI contributes to a more informed and effective policy process, capable of addressing the complex challenges facing global agrifood systems.

8. Conclusion

This paper has introduced the Agrifood Systems Transformation Index (AFSTI) as a systems-based framework for measuring agrifood systems transformation in a way that is multidimensional, goal-oriented, and explicitly attentive to interdependence across system components. Building on the literature on food systems measurement, composite indicators, and systems thinking, the AFSTI was designed to move beyond conventional scorecards that capture progress in isolated domains without adequately reflecting balance, coherence, or system-wide interactions. Its central contribution is to distinguish between progress and transformation: progress may be observed in average performance, but transformation requires that improvements be broadly distributed across pillars and mutually reinforcing over time.

The empirical illustration using data from the Food Systems Countdown Initiative shows the analytical value of this approach. The results demonstrate that global agrifood systems transformation is moderate on average, but highly uneven across countries and regions. They also show that arithmetic measures of performance can overstate transformation when progress is unbalanced across pillars, while interaction-adjusted measures reveal how cross-domain relationships can either amplify or constrain observed performance. By incorporating distance-to-target normalization, balance-sensitive aggregation, and an adjacency matrix of system interactions, the AFSTI provides a richer account of transformation than conventional composite indicators. It captures not only how much progress has occurred, but also how that progress is structured across agrifood systems.

At the same time, several limitations should be acknowledged. First, the empirical application relies on the Food Systems Countdown Initiative as an illustrative dataset rather than on a purpose-built monitoring architecture tailored to a specific policy framework. Although this is appropriate for methodological demonstration, it means that the resulting scores should not be interpreted as official benchmarks for any one regional or national process. Second, as with all composite indicators, the AFSTI is sensitive to methodological choices, including the specification of targets, weighting structures, aggregation rules, and missing-data treatment. The robustness analysis suggests that the framework is generally stable, but also confirms that assumptions regarding balance and interdependence can materially affect rankings. Third, the adjacency matrix used to model interdependence is expert informed. While this is a major strength from a systems perspective, it also introduces a degree of subjectivity, since alternative expert judgments or empirical estimation strategies could produce different interaction structures. Finally, the current empirical implementation is largely cross-sectional in its presentation, even though transformation is inherently dynamic and unfolds over time. This limits the ability of the present application to fully capture path dependency, feedback loops, and temporal sequencing in agrifood systems change.

These limitations point directly to important directions for future research. One priority is to adapt and calibrate the AFSTI to specific policy contexts, including regional frameworks such as CAADP or country-level food systems strategies, so that targets, pillar definitions, and interaction structures reflect local priorities and institutional realities. A second priority is to deepen the treatment of dynamics by extending the AFSTI into a genuinely longitudinal framework capable of tracking trajectories of transformation over time, identifying tipping points, and distinguishing short-term progress from sustained structural change. A third avenue is methodological: future studies could compare expert-informed adjacency matrices with empirically estimated network structures, test alternative weighting strategies, and explore hybrid approaches that combine theory-driven and data-driven specifications. In addition, further work is needed on uncertainty analysis, especially regarding benchmark selection, missing data, and cross-country comparability. Finally, research could examine whether AFSTI scores and diagnostic metrics are associated with downstream development outcomes such as poverty reduction, dietary improvement, resilience to shocks, or environmental performance, thereby strengthening the framework's explanatory and policy value.

Overall, the AFSTI offers a conceptually grounded and policy-relevant framework for measuring agrifood systems transformation as a process that is not only multidimensional but also relational and structural. By making visible the level, balance, and interdependence of progress, it provides a stronger basis for diagnosing bottlenecks, identifying leverage points, and designing more coherent transformation strategies. As agrifood systems face mounting pressures from climate change, inequality, and shifting development demands, tools that better reflect the systemic nature of transformation will become increasingly important. The AFSTI is intended as one such tool: not as a final measure, but as a flexible and evolving framework for advancing both research and policy on agrifood systems transformation.

References

Bedeau, J. V., Rezaei, M., Pera, M., & Morrison, J. (2021). Towards food systems transformation in the Mediterranean region: Unleashing the power of data, policy, investment and innovation. *New Medit, (3)*. https://doi.org/10.30682/nm2103a

Béné, C., Oosterveer, P., Lamotte, L., Brouwer, I. D., de Haan, S., Prager, S. D., Talsma, E. F., & Khoury, C. K. (2019). When food systems meet sustainability: Current narratives and implications for actions. *World Development, 113*, 116–130. https://doi.org/10.1016/j.worlddev.2018.08.011

Candel, J. J. L. (2014). Food security governance: A systematic literature review. *Food Security, 6*(4), 585–601. https://doi.org/10.1007/s12571-014-0364-2

Crossland, M., Coe, R., Lamanna, C., Chiputwa, B., Orero, L., Adoyo, B., Kumar, S., Mwangi, V. M., Anyango, E., Fuchs, L. E., Kuria, A., & Geck, M. (2025). *Measuring the holistic performance of food and agricultural systems: A systematic review*. *Frontiers in Sustainable Food Systems, 9*, 1472109. https://doi.org/10.3389/fsufs.2025.1472109

Fanzo, J., Haddad, L., McLaren, R., Marshall, Q., Davis, C., Herforth, A., Jones, A., Beal, T., Tschirley, D., Bellows, A., Miachon, L., Gu, Y., Bloem, M., & Kapuria, A. (2020). The Food Systems Dashboard is a new tool to inform better food policy. *Nature Food, 1*, 243–246. https://doi.org/10.1038/s43016-020-0077-y

Fanzo, J., Haddad, L., Schneider, K. R., Béné, C., Covic, N. M., Guarin, A., Herforth, A., Herrero, M., Sumaila, U. R., Talsma, E. F., et al. (2021). *Viewpoint: Rigorous monitoring is necessary to guide food system transformation in the countdown to the 2030 global goals*. *Food Policy, 104*, 102163. https://doi.org/10.1016/j.foodpol.2021.102163

FAO, IFAD, UNICEF, WFP, & WHO. (2024). *The State of Food Security and Nutrition in the World 2024: Financing to end hunger, food insecurity and malnutrition in all its forms*. FAO.

Global Panel on Agriculture and Food Systems for Nutrition. (2016). *Food systems and diets: Facing the challenges of the 21st century*.

Guijt, W. J., Wigboldus, S. A., Brouwer, J. H., Roosendaal, L. C., Kelly, S., & Garcia-Campos, P. (2021). *National processes shaping food systems transformations: Lessons from Costa Rica, Ireland and Rwanda*. FAO. https://doi.org/10.4060/cb6149en

Herforth, A., Bellows, A. L., Marshall, Q., McLaren, R., Beal, T., Nordhagen, S., Remans, R., Estrada Carmona, N., & Fanzo, J. (2022). *Diagnosing the performance of food systems to increase accountability toward healthy diets and environmental sustainability*. *PLOS ONE, 17*(7), e0270712. https://doi.org/10.1371/journal.pone.0270712

High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. (2017). *Nutrition and food systems*. FAO.

High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. (2020). *Food security and nutrition: Building a global narrative towards 2030*. FAO.

Hunecke, C., Thom, F., Vogt, J. H.-M., Bellingrath-Kimura, S. D., Brück, T., Gaupp, F., Geppert, F., Grune, T., Herzfeld, T., Kulling, S. E., Ojha, S., Piorr, A., Regierer, B., Renner, B., Schlüter, O., Schreiner, M., Springmann, M., Weith, T., & Wiedmer, P. (2025). Sustainable and resilient agrifood systems (SARAS): A Leibniz position. *Sustainable Development, 33*(5), 6871–6884. https://doi.org/10.1002/sd.3468

Leal Filho, W., Dinis, M. A. P., & Ben Hassen, T. (2025). Trade-offs among SDGs: How the pursuit of economic, food, and urban development goals may undermine climate and equity targets? *Sustainable Development*. Advance online publication. https://doi.org/10.1002/sd.70029

Leeuwis, C., Boogaard, B. K., & Atta-Krah, K. (2021). How food systems change (or not): Governance implications for system transformation processes. *Food Security, 13*(4), 761–780. https://doi.org/10.1007/s12571-021-01178-4

Mariani, F., & Ciommi, M. (2022). *Aggregating composite indicators through the geometric mean: A penalization approach*. *Computation, 10*(4), 64. https://doi.org/10.3390/computation10040064

Nardo, M., Saisana, M., Saltelli, A., Tarantola, S., Hoffmann, A., & Giovannini, E. (2005). *Handbook on Constructing Composite Indicators: Methodology and User Guide*. OECD Statistics Working Papers.

OECD. (2008). *Handbook on Constructing Composite Indicators: Methodology and User Guide*. OECD Publishing.

Organisation for Economic Co-operation and Development, & European Commission, Joint Research Centre. (2008). *Handbook on constructing composite indicators: Methodology and user guide*. OECD Publishing. https://doi.org/10.1787/9789264043466-en

Pryor, S., Casey, T., & Dietz, W. H. (2024). Conceptualizing agrifood systems for a healthy, sustainable, and just transformation: A systematic scoping review. *Sustainability, 16*(22), Article 9862. https://doi.org/10.3390/su16229862

Qaim, M., & Parlasca, M. C. (2025). Agricultural economics and the transformation toward sustainable agri-food systems. *Agricultural Economics, 56*(3), 327–335. https://doi.org/10.1111/agec.70023

Rockström, J., Williams, J., Daily, G., Noble, A., Matthews, N., Gordon, L., Wetterstrand, H., DeClerck, F., Shah, M., Steduto, P., de Fraiture, C., Hatibu, N., Unver, O., Bird, J., Sibanda, L., & Smith, J. (2017). Sustainable intensification of agriculture for human prosperity and global sustainability. *Ambio, 46*(1), 4–17. https://doi.org/10.1007/s13280-016-0793-6

Sachs, J., Lafortune, G., Kroll, C., Fuller, G., & Woelm, F. (2022). *From Crisis to Sustainable Development: The SDGs as Roadmap to 2030 and Beyond. Sustainable Development Report 2022*. Cambridge University Press.

Schneider, K. R., Fanzo, J., Haddad, L., Herrero, M., Rosero Moncayo, J., Herforth, A., Remans, R., et al. (2023). *The state of food systems worldwide in the countdown to 2030*. *Nature Food, 4*, 1010–1028.

Schneider, K. R., Remans, R., Bekele, T. H., Aytekin, D., Conforti, P., Dasgupta, S., DeClerck, F., Dewi, D., Fabi, C., Gephart, J. A., Masuda, Y. J., McLaren, R., Saisana, M., Aburto, N., Ambikapathi, R., Arellano Rodriguez, M., Barquera, S., Battersby, J., Beal, T., … Fanzo, J. (2025). Governance and resilience as entry points for transforming food systems in the countdown to 2030. *Nature Food, 6*, 105–116. https://doi.org/10.1038/s43016-024-01109-4

Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B. L., Lassaletta, L., de Vries, W., Vermeulen, S. J., Herrero, M., Carlson, K. M., Jonell, M., Troell, M., DeClerck, F., Gordon, L. J., Zurayk, R., Scarborough, P., Rayner, M., Loken, B., Fanzo, J., & Willett, W. (2018). Options for keeping the food system within environmental limits. *Nature, 562*(7728), 519–525. https://doi.org/10.1038/s41586-018-0594-0

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

United Nations Children's Fund. (2023). *The State of the World's Children 2023: For every child, vaccination*. UNICEF Innocenti – Global Office of Research and Foresight.

United Nations Development Programme. (2024). *Human Development Report 2023/2024: Breaking the gridlock: Reimagining cooperation in a polarized world*. UNDP.

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L. J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J. A., de Vries, W., Sibanda, L. M., … Murray, C. J. L. (2019). Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet, 393*(10170), 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4