Trends in Food Science & Technology 171 (2026) 105633

Contents lists available at ScienceDirect

Trends in Food Science & Technology

journal homepage: www.elsevier.com/locate/tifs

Unveiling hidden costs in agrifood systems: A systematic review of true cost accounting

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ARTICLE INFO

S. Charlebois

Keywords:
True Cost Accounting (TCA)
Agrifood systems
Externalities
Valuation methods
Food systems transformation

ABSTRACT

Background: Global agrifood systems generate substantial environmental, health, social, and economic externalities that remain largely invisible in market prices. True Cost Accounting (TCA) is an emerging framework to make these "hidden costs" visible and inform more sustainable food system decisions. However, studies on TCA remain fragmented across framework development, methodologies, and empirical applications.
Scope and approach: We conducted a systematic literature review to (i) trace the evolution of TCA, (ii) compare methodological practices, and (iii) synthesize empirical application patterns. Our review started with around 3600 records for initial screening, narrowing to 53 papers on TCA related to agrifood systems.
Key findings and conclusions: We first consolidated dispersed TCA initiatives into an integrated three-phase timeline: conceptual framework (before 2019), operational guidelines (2020–2022), and mainstream applications (after 2021). Methodologically, we found four TCA steps that are unevenly developed across environmental, social, economic, and health dimensions. Integration approaches are typically hybrid, combining monetary and non-monetary elements, but remain weakly standardized. Empirical applications of TCA clustering at national and local scales focus on the production and consumption stages and most often integrate environmental outcomes with health or economic outcomes, while social equity and distributional aspects are seldom explicit. Our review highlights that TCA has the potential to transform agrifood systems by revealing hidden costs and promoting sustainable decision-making. However, doing so requires further research to standardize methodologies and embed TCA more directly into policy instruments.

1. Introduction

Global agrifood systems are essential to providing food security and economic opportunities, employing approximately 1.3 billion people worldwide, i.e., about 40% of the global workforce (Davis et al., 2023; FAO, 2024b). However, they also generate substantial externalities (Li et al., 2026), which are positive or negative impacts of an economic activity that affect others without being reflected in the price of goods or services transacted (Varian, 2003). In terms of environmental impact, agrifood systems are responsible for a third of global anthropogenic GHG emissions (Crippa et al., 2021; Rosenzweig et al., 2020), and they occupy about 40% of the earth's land and use 70% of all freshwater resources (Bank, 2024; Mbow et al., 2019). Beyond environmental pressures, current dietary patterns generate significant hidden health costs through diet-related non-communicable diseases and unsustainable resource use (Report, 2021). FAO estimates that around 8 trillion US dollars come from unhealthy diets and related non-communicable diseases such as heart disease, stroke, and diabetes (FAO, 2024a). Agrifood systems also create negative social impacts, such as food insecurity, poor working conditions (Kurtz et al., 2021), discrimination, and social injustice (Asai & Antón, 2024), particularly affecting vulnerable groups, e.g., small-scale producers and women (Costa et al., 2023).

The environmental, health, and social externalities highlighted above have become an increasingly significant issue in agrifood systems. Although markets are intended to allocate resources efficiently, market prices rarely internalize these externalities. As a result, price signals are distorted, inadvertently incentivizing unsustainable production and consumption patterns and obscuring what are commonly referred to as "hidden costs" (Gemmill-Herren et al., 2021). These hidden costs represent losses to society that are not reflected in market prices or included in conventional economic indicators such as gross domestic product. The magnitude of hidden costs is considerable: FAO (2024a) estimates that global agrifood systems incur around USD 12 trillion

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https://doi.org/10.1016/j.tifs.2026.105633
Received 11 December 2025; Received in revised form 17 February 2026; Accepted 18 February 2026
Available online 26 February 2026

in hidden costs per year, equivalent to 10% of world GDP. Therefore, making these costs visible and transparent through rigorous accounting is essential to guide the sustainable transformation of agrifood systems.

A first step to address externalities and make them visible is to expose them and redefine the value of food. This can be achieved through True Cost Accounting (TCA). TCA is a framework for the systemic measurement and evaluation of environmental, social, health, and economic costs and benefits to facilitate sustainable choices by governments and stakeholders in the food system (Baker et al., 2020; Gemmill-Herren et al., 2021). TCA is an emerging economic assessment and goes beyond traditional research on externalities by providing a comprehensive, integrative, and decision-oriented framework. It quantifies and internalizes environmental, social, and health impacts into economic analysis, moving from identifying externalities to actively redesigning systems based on their true value and cost (Baker et al., 2020; Sandhu et al., 2021). Traditional externalities research laid the groundwork by demonstrating that many costs and benefits are not reflected in market prices, both in theoretical analyses (Coase, 1960; Pigou, 1920) and in syntheses specific to agrifood systems (FAO, 2023; TEEB, 2018). TCA builds on externalities research by offering a comprehensive, integrative approach to make these hidden costs visible and actionable. The development of TCA marks a shift from understanding individual impacts to accounting for integrated impacts in a way that can inform sustainable transformation. Therefore, a systems analysis approach and the use of TCA are crucial tools to understand the complex synergies and trade-offs within agrifood systems, enabling better decision-making for a more sustainable food future.

Despite the rapid momentum of TCA, the evidence base remains scattered across framework development, methodologies, and empirical applications. Conceptually, the development of TCA in agrifood systems has been largely institution-driven yet fragmented. Multiple organizations, such as the Natural Capital Coalition (Capitals Coalition, 2016, 2019), the Economics of Ecosystems and Biodiversity (TEEB) (TEEB, 2018), the FAO (FAO, 2023, 2024a), and others, have issued parallel frameworks and guidance documents over time. As a result, the historical trajectory of TCA has often appeared discontinuous and scattered across various initiatives. Thus, there is still a need to clearly map the historical evolution of TCA. Understanding this would both reveal how these institutional efforts relate to one another and provide researchers, policymakers, and practitioners with a coherent basis for positioning new applications and identifying remaining gaps.

Methodologically, while TCA frameworks have matured, operational guidelines vary widely. TEEB (2018) provides overarching principles that all TCA applications should follow. de Adelhart Toorop et al. (2023) identifies and compares 35 initiatives that align with the definition of TCA, of which five were specifically designed for agrifood systems. However, the guidance issued by these initiatives diverges in how they define system boundaries, and select indicators and valuation methods. Although a few studies highlight the similarities and differences among existing TCA frameworks (de Adelhart Toorop et al., 2021), important gaps remain regarding how to operationalize each step of TCA consistently. In addition, measurement and valuation methods are advanced — for example, Life Cycle Assessment (LCA) (Hauschild et al., 2018) and valuation methodologies for externalities (Cost, 2022) — but how to integrate these methods into TCA remains underexplored. Therefore, clearer and more consistent methodological guidance is needed to support practitioners in robustly and comparably implementing TCA.

On the application side, FAO (2023) provided the first official global quantification of the hidden costs of agrifood systems. FAO (2024a) deepened this analysis, combining six national scenario case studies — Australia, Brazil, Colombia, Ethiopia, India, and the United Kingdom (UK). These studies demonstrate the policy relevance of TCA at the national scale. Still, systematic reviews of the wider empirical literature are missing. The existing review papers focus on specific decision levels, such as products, diets, or policies. For example, True Price concentrates on the true price of products (Galgani et al., 2023; Price, 2021), the WWF report targets the true cost of dietary patterns (T.M.G. and WWF, 2021), and an FAO background paper discusses TCA for policymakers (de Adelhart Toorop et al., 2023). Therefore, a holistic and robust evidence synthesis of how TCA is applied across agrifood systems is needed, particularly one that systematically maps spatial distribution, cross-dimension integration, and value chain stages.

To address these gaps, we conducted a systematic review of TCA applications in agrifood systems. Specifically, we: (i) traced the evolution of TCA by mapping the development timeline of key frameworks and institutional milestones; (ii) compared methodologies according to the four main steps of TCA (scope, measurement, valuation, and integration); and (iii) assessed how studies cover and integrate environmental, health, social, and economic dimensions, synthesizing common integration patterns and reported trade-offs and synergies. In doing so, our review clarifies the foundations and integration patterns of the framework, identifies methodological convergence and divergence, and highlights opportunities for harmonization to advance TCA's application in transforming agrifood systems.

2. Methods

We conducted a systematic literature review to understand the methodologies and applications of TCA in agrifood systems. It comprised three steps: (i) systematic search for peer-reviewed publications; (ii) screening of the searched publications for inclusion in the review; (iii) extraction of relevant information.

2.1. Search strategy

Our systematic literature review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Page et al., 2021). We conducted a primary literature search across Scopus and Web of Science, two comprehensive multidisciplinary databases with extensive coverage of peer-reviewed journals. The final search was updated on January 20, 2025. The search strategy for each database was developed using a combination of keywords, Boolean operators, and proximity operators to ensure a comprehensive and reproducible search. We designed the search strings to capture a broad range of studies on TCA while remaining specific to agrifood systems. The keyword string consisted of three components: (i) TCA-related framing terms, (ii) cost and valuation terms, and (iii) agrifood context terms.

First, to capture TCA and related approaches, we combined the term true with alternative framings including "real", "full", "multiple", "hidden", "external", "indirect", and "environment*". Second, to reflect economic valuation, we included "cost*", "price*", and "capital*". Third, to restrict the search to food and agriculture, we used "food", "agri*", "animal*", "livestock*", and "aquat*". For Scopus, the final search string was: *TITLE-ABS-KEY(((true OR real OR full OR multiple OR hidden OR external OR indirect OR environment*) W/1 (cost* OR price* OR capital*)) W/15 (food* OR livestock* OR animal* OR agri* OR aquat*))*, with search adjusted for Web of Science. The search strategies applied to each database are presented in the supplementary materials (Table A1). Within each component, search terms were combined with the Boolean operator OR, and proximity operators (W/1, W/15 in Scopus; NEAR/1, NEAR/15 in Web of Science) were used to limit results to records in which TCA-related terms and cost terms occurred in close proximity to agrifood terms, thereby enhancing the relevance of retrieved records to TCA in agrifood systems.

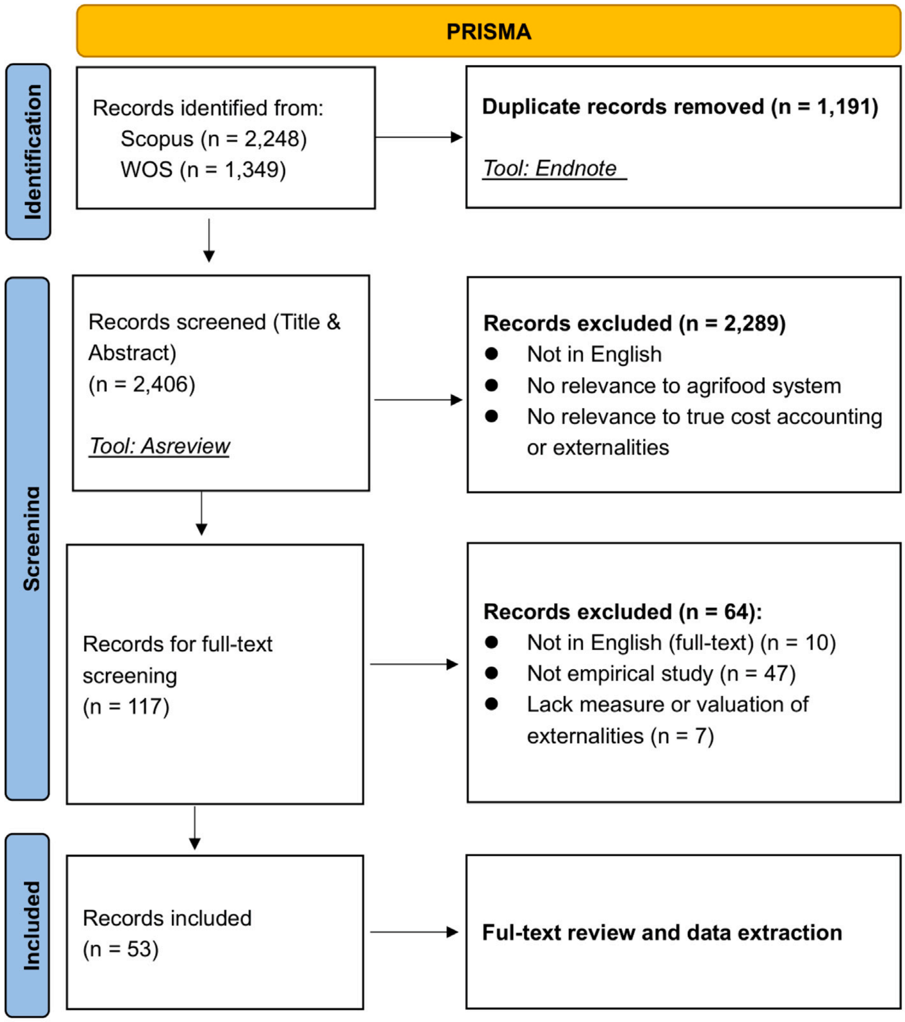

Fig. 1. PRISMA flow diagram for the systematic review implemented in this study.

2.2. Eligibility criteria and selection process

We screened the outcomes of our primary literature search against the following criteria. They are: (i) only articles written in English were included; (ii) existing reviews and articles not based on an empirical study design were excluded; (iii) studies not related to agrifood systems were omitted; (iv) studies lacking either the measurement or the valuation of externalities were excluded.

Our selection process is displayed in the PRISMA flowchart (Fig. 1). A total of 3597 papers were identified by the database searches. After removing 1191 duplicates, we screened the remaining 2406 papers using the ASreview tool (ASReview L.A.B. developers, 2024) based on title, keywords, and abstract. Full-text screening of 117 papers that met eligibility criteria was then undertaken. In doing so, we obtained a list of 53 relevant papers, which was used for the extraction process.

2.3. Data extraction and synthesis

We developed a standardized extraction code aligned with our study objectives and research questions. The code captured the following categories: spatial scale, food type, value-chain stage, impacts included, and TCA methodologies by step (Table A2). We also recorded a small set of operational fields to analyze (i) the development timeline of TCA, (ii) the methodological steps of TCA, and (iii) how TCA is applied in empirical studies.

To assess methodological practice, we coded each study along four commonly recognized TCA steps: (i) scope, (ii) measurement, (iii) valuation, and (iv) integration (Cost, 2022; de Adelhart Toorop et al., 2023; Galgani et al., 2023; TEEB, 2018). For scope, we focused on the functional unit. We classified functional units into five categories: product, diet, farm, supply chain, and policy. Then we coded each study into one category based on its primary unit of analysis. Studies covering multiple functional levels were coded according to their primary functional unit, defined as the level at which impacts were aggregated, monetized, and interpreted for decision-making.

For measurement, we drew on the FAO classification of indicators across four dimensions and 14 categories (de Adelhart Toorop et al., 2023). For each study, we identified reported indicators and assigned them to these dimensions and categories. For valuation, we recorded whether indicators were monetized, including the type of monetization factor applied. For integration, synergies and trade-offs were coded using a direction-of-effect rule in dimensions. A dimension was coded as a synergy when the reported effect indicated an improvement (benefit or cost reduction) and as a trade-off when it indicated a deterioration (cost increase or negative impact). Coding followed the sign of monetized estimates where available, or otherwise the stated direction of non-monetary indicators. Importantly, the baseline conditions and measurement approaches varied across studies, so the coded synergies and trade-offs reflect relative effects within each study rather than absolute comparability between studies.

To analyze how TCA is used in practice, we extracted: (i) spatial scale (global, regional, national, subnational, or local), (ii) food type (plant- or animal-based product), (iii) value-chain coverage (production, processing, distribution, retail, consumption, or waste), and (iv) impact dimensions included (environmental, health, social, or economic).

2.4. Selective criteria for institutional milestones

To construct the development timeline of TCA in agrifood systems, we compiled a selective set of institutional outputs (e.g., frameworks, guidance documents, protocols, and reports) from major initiatives, including FAO, TEEB, UN bodies, and the Capitals Coalition. The initial pool of 85 institutional outputs was identified through targeted searches of official documents and publication databases of major international organizations active in TCA, using keyword combinations related to "true cost accounting". This was complemented by backward reference checking to capture influential grey literature. These documents were not treated as review evidence and were therefore excluded from the systematic screening and synthesis. Instead, they were used solely to contextualize the evolution of TCA and to support the construction of a narrative development timeline.

Broad uptake and relevance were assessed through qualitative screening based on three aspects: (i) repeated citation in subsequent institutional or policy documents across organizations; (ii) formal adoption by international organizations or multi-stakeholder initiatives; and (iii) documented downstream use in national assessments, pilot studies, or cross-sector applications. Applying these criteria to the initial pool resulted in 8 documents that met the uptake threshold without overlapping in scope. Each of these documents introduced a distinct advance corresponding to one of three phases in TCA development—conceptual framing ("what to include"), operational guidance ("how to practice"), or mainstream application ("how to apply") (Table A3). These milestones were then aligned with annual counts of empirical TCA studies identified in the systematic review, and change points were used to delineate distinct phases of development.

3. Results

3.1. Evolution of true cost accounting

The development of TCA in agrifood systems has been largely institution-driven yet fragmented (Fig. 2 and Table A3). We find multiple organizations, including the Natural Capital Coalition, TEEB, the UN, and the FAO, issuing parallel frameworks and guidance documents over time. As a result, the historical trajectory of TCA has often appeared discontinuous and scattered across initiatives with overlapping objectives. By systematically reviewing and synthesizing these sources, we identify three main developmental phases that illustrate TCA's progression from conceptual framing to practical application.

Phase 1 (conceptual framework,2016–2019). This formative period established the conceptual foundations of TCA. The Natural Capital Protocol (2016) introduced a methodological framework (Capitals Coalition, 2016). The subsequent Social & Human Capital Protocol (2019) extended these principles toward integrated multi-capital frameworks (Capitals Coalition, 2019). TEEB (2018) provided foundations specific to agrifood systems. These initiatives articulated the theoretical basis for incorporating environmental, social, and human capital into the valuation of agrifood systems, laying the groundwork for a comprehensive multi-capital approach.

Phase 2 (operational guideline,2020–2022). During this phase, emphasis shifted from conceptual framing to operational guidance. The TEEB Agrifood Evaluation Framework (Eigenraam et al., 2020-09) and the TCA Handbook (Cost, 2022) introduced standardized procedures for data collection, valuation, and reporting. These documents improve comparability across case studies and sectors. This operationalization marked a critical step toward methodological consistency and scalability.

Phase 3 (mainstream applications,2021–2024). The third phase is characterized by quantified evidence and policy integration. The 2021 UN Food Systems Summit elevated TCA to the global agenda, positioning TCA as a tool for transforming agrifood systems (UNEP et al., 2021). FAO (2023) provided the first official global quantification of the hidden costs of the agrifood systems, while FAO (2024a) deepened this analysis, proposing concrete policy pathways. Furthermore, the growing availability of relevant data, such as LCA (Hauschild et al., 2018), valuation methodologies for externalities, and metrics for social (Huertas-Valdivia et al., 2020), and health-related impacts, has enhanced the empirical analyses of TCA studies and facilitated the use of quantitative modeling approaches. This progression reflects the growing maturity of TCA as both an analytical approach and a practical policy tool for transforming agrifood systems.

Published papers on TCA in agrifood systems have increased substantially over the past decade (Fig. 2). Before 2015, publications were sporadic and exploratory, primarily focused on externality valuation and theoretical discussions. From 2016 to 2020, studies increased modestly in step with the framework development (Phase 1). An acceleration occurred after 2021. Among the 53 studies reviewed, 36 (68%) were published after 2021, coinciding with the 2021 UNFSS (UN Food Systems Summit) and the FAO's institutional endorsement of TCA (Milestones 5–8). This surge in TCA studies is driven by growing global awareness, institutional momentum, and methodological advances.

3.2. Methodology of true cost accounting

Our review highlights that TCA methodologies cluster around four steps — scope, measurement, valuation, and integration — but these steps are unevenly developed across the dimensions (Fig. 3). At the scope step, we identify five functional-unit types that form a hierarchy from micro- to macro-level analysis. In terms of measurement, environmental indicators are relatively standardized. However, health, social, and economic dimensions rely on more heterogeneous indicators and data sources. We also identify a broad set of monetization factors. We find that integration is typically hybrid, combining monetary with non-monetary approaches.

3.2.1. Scope: from micro- to macro-level functional units

Product, diet, farm, supply chain, and policy are the five types of functional units commonly used in the TCA scope. This classification reflects a nested hierarchy from micro-level (product) to macro-level (system and policy), with an increasing scope of impacts and externalities considered. The functional unit describes what is assessed and measured by a TCA study, thereby defining its analytical boundaries (de Adelhart Toorop et al., 2021).

Product level. At the product level, TCA studies evaluate the externalities of individual food items such as plant-based oils or protein sources. The functional unit is usually defined in physical terms (e.g., per kilogram and per liter) or nutritional terms (e.g., per 1000 kcal and per 100 g protein). This enables comparability between products that serve similar dietary functions. For example, de Groot Ruiz et al. (2017) estimates the true price of bananas per kilogram, and Hoehnel et al. (2022) compared protein-rich foods on a per-100 g protein basis.

Diet level. Diet-level analyses externalities to complete diets or dietary baskets, thereby linking TCA to nutrition and health outcomes. Typical functional units include one person's daily RDA-based diet or an annual per capita diet basket. This level captures the cumulative costs of entire eating patterns. For example, T.M.G. and WWF (2021) assesses diet transitions, and Springmann et al. (2021) analyses the health and environmental costs of global dietary shifts.

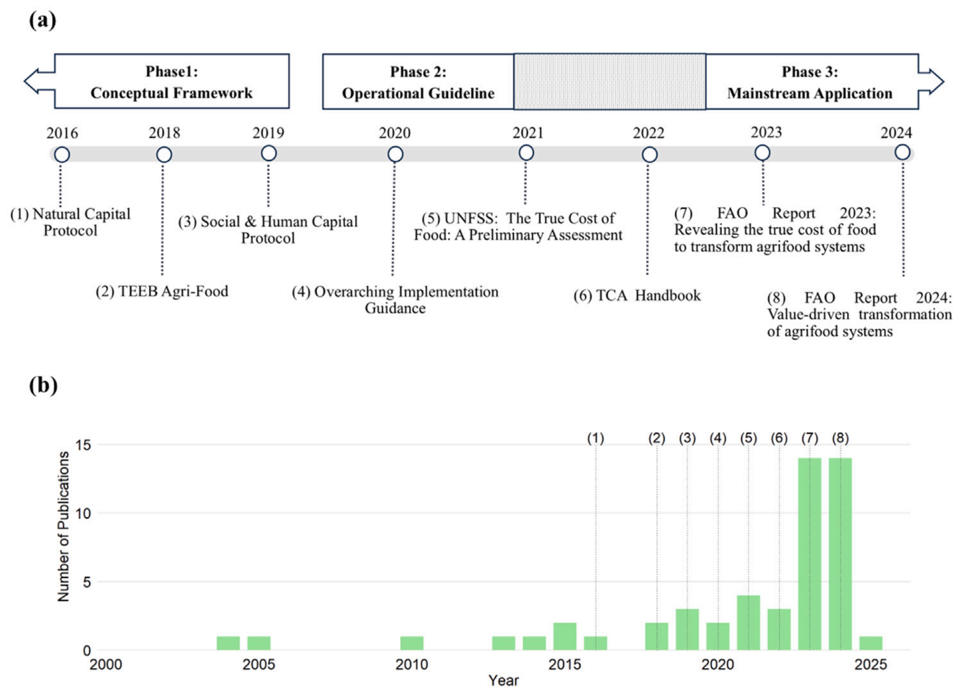

Fig. 2. Evolution of True Cost Accounting (TCA) in agrifood systems. (a) Timeline of key milestones: Chronological synthesis of major institutional initiatives advancing TCA, consolidated into three developmental phases. Phase 1: Conceptual Framework, Phase 2: Operational Guideline, and Phase 3: Mainstream Application. This integrated timeline clarifies the previously fragmented evolution of TCA driven by multiple organizations and marks the transition from conceptual frameworks to application. **(b) Publication trends:** Annual number of empirical TCA applications in agrifood systems (n = 53) identified in this review. Vertical dashed lines mark the publication years of milestones (1)–(8) shown in panel (a).

Farm level. The farm-level functional unit evaluates externalities associated with land use, production practices, and ecosystem services. Common units are per hectare of land or per farm per year. These measures allow for the assessment of impacts such as soil degradation, biodiversity loss, and greenhouse gas emissions. For instance, Bellon, Hanley et al. (2024b) estimates the non-market values of US rangeland cow-calf operations per hectare. Frem et al. (2023) uses EU Farm Accountancy Network data to evaluate the environmental impacts and estimate the societal costs of four different Italian grapevine cultivation systems: organic and non-organic practices for producing common and quality wines.

Supply chain level. At the supply chain level, TCA assigns externalities across processing, distribution, and retail stages. Typical units are per ton of output or per value chain. This scope enables cumulative assessment of costs along supply chains and supports corporate accountability. For example, Pretty et al. (2005) analyses the full costs of foods in the average weekly UK food basket by calculating the costs arising at different stages from farms to consumers' plates.

Policy level. At the policy level, externalities are aggregated to entire agrifood systems for macroeconomic and policy analysis. TCA is applied to evaluate the effects of policy interventions, such as total annual national agrifood systems costs, fiscal measures (e.g., taxes and subsidies), or dietary guidelines. Functional units are often expressed as per capita annual diet costs or as changes per intervention scenario, allowing results to be directly linked to policy decisions. For example, Springmann, Mason-D'Croz et al. (2018b) assesses the impacts of diet-related taxes and subsidies, and FAO (2023) estimates the global true cost of food.

This five-level typology clarifies that the functional unit is the primary lever that links the research question to system boundaries and integration choices. Product-level functional units enable like-for-like substitution and benchmarking. Diet-level functional units capture cumulative, nutrition-adequate patterns. Farm-level functional units align with land-based management and ecosystem services. Supply-chain functional units surface stage-specific hotspots and corporate accountability. Policy-level functional units translate externalities into terms that are fiscally and macroeconomically relevant.

In addition, while each study was assigned a single primary functional unit, the review finds that multi-level analytical designs are common. Several studies combine higher-level functional units (e.g., policy or diet) with more granular units (e.g., product) to enhance policy relevance. For example, policy- or diet-level functional units are used to assess system-wide impacts, while product-level analyses are subsequently applied to identify specific leverage points (Springmann, Mason-D'Croz et al., 2018b). This sequential approach allows aggregate results to be decomposed into actionable insights while remaining embedded within a broader policy-relevant framework (T.M.G. and WWF, 2021).

3.2.2. Measurement: indicators

We find that environmental indicators are the most standardized through LCA, while health, social, and economic indicators draw on more heterogeneous data sources and methods (Table A4). Measurement translates conceptual dimensions of sustainability (i.e., environmental, social, economic, and health) into operational indicators.

Environmental. Commonly assessed environmental indicators cluster into four categories: climate, water, land, and ecosystems (de Adelhart Toorop et al., 2023; Gemmill-Herren et al., 2021; Hendriks et al., 2023), while the exact metrics selected vary by application context. These indicators are typically quantified using LCA and related environmental modeling frameworks, which offer standardized, comparative methodologies for evaluating the environmental performance of different food products and systems (Springmann, Clark et al., 2018). Currently, research on the environmental dimension tends to focus on climate change-related indicators (n = 38), particularly GHG emissions, due to their quantifiability and alignment with global climate

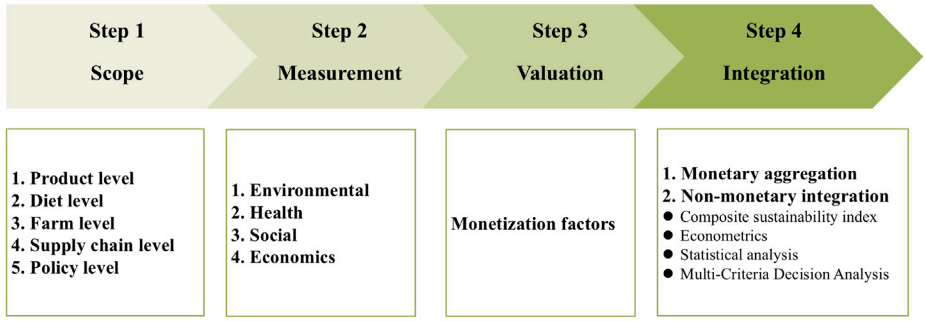

Fig. 3. Overview of True Cost Accounting (TCA) methodology steps. The process follows four steps: (i) scope (choice of functional unit), (ii) measurement (environmental, health, social, and economic indicators), (iii) valuation (conversion into monetary values where applicable), and (iv) integration (combining results through monetary aggregation or non-monetary methods).

targets. However, other critical environmental impacts, such as soil degradation, pesticide toxicity, and loss of ecosystem services, are comparatively underrepresented (Chaudhary et al., 2018; Sala et al., 2017).

Health. The health dimension typically combines human health outcome indicators and nutrition-related indicators. Human health outcomes include disease incidence and mortality (e.g., cardiovascular disease, type 2 diabetes, and selected cancers), Disability-Adjusted Life Year (DALY), and their associated direct medical costs, productivity losses, and caregiving costs. For example, national cost-of-illness and DALY studies in Canada quantify the macroeconomic burden of failing to meet dietary recommendations and show substantial potential savings from dietary improvements (Lieffers et al., 2018). Nutrition indicators often include composite diet-quality scores aligned with national guidelines and nutrient density metrics. In TCA applications, these are usually expressed per person-day or per serving and then combined with environmental and health externalities to compare diet scenarios and quantify trade-offs. For instance, Conrad et al. (2023) assesses diet quality with the Healthy Eating Index and links it to GHG emissions and daily cost across specific dietary patterns in the United States. Wrieden et al. (2019) combines household purchase data with LCA and costs, measuring "healthiness" via a Diet Quality Index (DQI) aligned with UK national guidelines.

Social. Social indicators typically cover animal welfare, working conditions, cultural acceptance, and socio-economic development and equity. Animal welfare is usually valued with stated-preference methods. For example, Belgian stated-preference surveys elicit willingness to pay for higher-welfare standards, thereby translating welfare losses into monetary terms (Bruers, 2023). Working conditions and broader livelihood effects are often proxied by socio-economic indicators (e.g., value-added distribution, income security, or job quality). Kurtz et al. (2021) discusses the incorporation of dignified labor into TCA methods and lessons drawn from two worker-driven models operating in the United States. Cultural acceptance appears in appraisals of traditional foods where heritage and identity are part of the benefit set (Hooker et al., 2024). Currently, there is no objective measurement of the social and cultural acceptability of diets or foods. However, the frequency with which foods are consumed may yield insights into their acceptability or preference within a given population (Drewnowski & Hann, 1999). Some studies also integrate socio-economic and food security metrics (Skaf et al., 2019, 2021).

Economic. Economic indicators tend to link accounting results to price signals and policy levers, supporting scenarios that compare current market outcomes with counterfactual "true cost" pricing. Market price vs. true cost measures the gap between observed prices and "true" prices that internalize external costs (e.g., environmental damages and health burdens), often by applying monetization factors to emissions, resource use, or DALYs (Hendriks et al., 2023). Taxes consider tax burdens and VAT exemptions that distort relative prices. Subsidies capture agricultural support that shifts private and social costs. Willingness-to-pay (WTP) surveys the maximum price a customer is willing to pay for non-market attributes (e.g., animal welfare and cultural heritage), facilitating the integration of social preferences into valuation. For example, Michalke et al. (2022) analyses a German case on informational campaigning and responsible implementation that elicits WTP for price corrections. Taufik et al. (2023) shows that building trust and perceived consumer value can increase WTP for true-price food products.

3.2.3. Valuation

Regarding the main monetization factors, environmental valuation is relatively standardized and often relies on established monetization factors (Table A5). However, health valuation is more heterogeneous and sensitive to epidemiological assumptions. Moreover, social valuation remains the least developed, with emerging efforts to monetize labor and animal-welfare impacts.

Environmental. Typical methods for conducting TCA link LCA with monetization factors. For carbon costs, typical examples include the Social Cost of Carbon (SCC) applied to GHG emissions in life-cycle assessments and abatement or avoidance costs for pollution. For instance, using SCC with LCA, European "meat basket" studies find animal products are underpriced relative to their climate costs by converting product-level GHG inventories into euro-denominated climate damages (Pieper et al., 2020; Springmann et al., 2021). Beyond carbon, other studies using Ecosystem Service Valuation (ESV) to monetize non-carbon impacts (e.g., land, water, and biodiversity) by linking LCA outputs to agri-environment payments or damage-cost factors, as seen in studies of Italian viticulture (Frem et al., 2023) and UK agriculture (Pretty et al., 2000).

A broader set of monetization factors is also used in practice. The Monetization Factors for True Pricing compendium provides factors for 20 impacts (10 environmental and 10 social) alongside corresponding footprint indicators, enabling direct multiplication of inventories by prices (Price, 2021). Similarly, Cost (2022) specifies footprint indicators and calculation methods for 16 impact indicators and has been applied in product-level evaluations. At a regional scale, the EU-28 Handbook offers harmonized price estimates that can be matched to LCA flows for consistent cross-country valuation in EU (Bruyn et al., 2018; Delft, 2023).

Health. Across the included studies, health externalities are monetized mainly through two families of methods: Cost-Of-Illness (COI) and DALY monetization. COI studies translate diet-attributable morbidity and mortality into direct medical expenditures and indirect productivity losses (Seidel et al., 2023; Springmann et al., 2021). DALY monetization multiplies attributable DALYs by a unit value grounded in human-capital, consumption-value, or WTP literature (Arrigoni et al.,

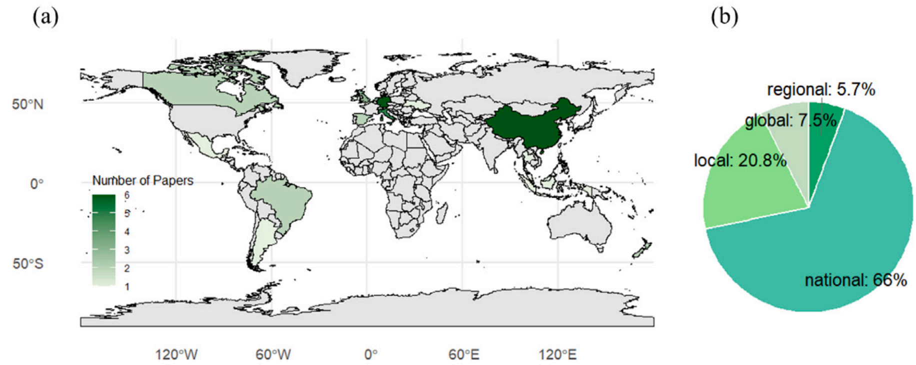

Fig. 4. Spatial distribution and scale of empirical True Cost Accounting (TCA) applications in agrifood systems. (a) Geographic distribution of case-study countries: Choropleth map showing the number of empirical TCA studies per country (n = 53), with darker shading indicating more studies. **(b) Spatial scale:** Proportion of studies conducted at different spatial scales, dominated by national-level applications (66%), followed by local (20.8%), global (7.5%), and regional (5.7%) scales.

2023; Bellon, Benard et al., 2024a; Lucas et al., 2023). COI-based global assessments (Springmann et al., 2021) and country-level burden-of-disease applications (Lieffers et al., 2018; Loewen et al., 2019) consistently find sizable health-related external costs attributable to dietary risks. In contrast, product-level LCAs that monetize DALYs (Arrigoni et al., 2023; Bellon, Benard et al., 2024a) provide finer resolution for comparative claims but are more sensitive to the chosen DALY price and to attribution assumptions. Nevertheless, ethical and distributional questions remain, such as how to value a DALY across populations with unequal incomes and health baselines, and how to avoid double-counting between medical costs and welfare losses.

Social. Capturing social impacts in a systematic and comparable way remains methodologically challenging. There is no standardized framework for valuing social externalities in food systems. Many social outcomes are qualitative, context-specific, or non-market (e.g., labor rights, living-wage gaps, child/forced labor risk, and gender equity). Monetization also raises ethical concerns, such as whose preferences are being reflected and how to weigh the interests of vulnerable groups. Recent reviews note that rigorous evaluation of labor impacts remains elusive, hindered by limited data quality and less mature methodologies (Kurtz et al., 2021). Interestingly, we find two studies that monetize the externalities of animal welfare using an inclusive welfare function (Bruers, 2023; Kuruc & McFadden, 2023).

3.2.4. Integration

We find most TCA studies combine monetary and non-monetary integration, which helps explain both convergence and variability across dimensions (Table 1). Drawing on seven applications that integrate three or more dimensions, we identify two dominant approaches: (i) monetary aggregation to derive true costs and (ii) non-monetary integration to compare heterogeneous outcomes when credible prices are scarce.

Monetary aggregation. It sums internal costs with monetized externalities to yield a per-unit "true cost", typically followed by uncertainty analyses. Monetization supports comparability across dimensions and policy-relevant thresholds, although it remains sensitive to valuation factors. However, credible prices are lacking sometimes, particularly for social outcomes. So, a mix of monetary and other non-monetary methods is often necessary.

Non-monetary integration. When robust prices are unavailable, studies integrate dimensions via other integration methods and hybridize with monetary aggregation to report the results. For example, Bellon, Benard et al. (2024a) monetizes environmental and health impacts but overlays a non-monetary social scorecard. Based on our analysis, we group non-monetary integration into four categories: composite sustainability index, econometrics, statistical integration (correlations and group-difference tests), and Multi-Criteria Decision Analysis (MCDA).

A composite sustainability index uses standardized indicators, combined with explicit weights or rules, to produce a composite score or identify an "optimal set". This is useful when absolute costing is infeasible, but decision support is needed. For example, Hooker et al. (2024) constructs a four-dimensional "optimally sustainable foods" index to compare environmental footprint, nutrition/health, affordability, and social acceptability across and within food groups.

The econometrics approach uses regression models to link capitals/indicators to economic or performance outcomes, quantifying marginal contributions and revealing structural heterogeneity. Bellon, Hanley et al. (2024b) estimates Ordinary Least Squares models that relate market value in cow-calf systems to bundles of nonmarket (environmental/social) indicators, decomposing how rangeland/ecosystem attributes associate with observed economic performance.

Statistical integration (correlations and group-difference tests) focuses on standardized indicators across dimensions or categories. Correlation analysis tests alignment or tension between dimensions (synergies vs. trade-offs). For example, Bai et al. (2021) computes Pearson rank correlations between water-footprint indicators (e.g., blue water) and economic outcomes to assess whether lower impacts coincide with lower costs in maize systems. Group-difference tests compare standardized indicators across categories. Another example is Drewnowski and Conrad (2024), who use one-way ANOVAs by protein-food subcategory to test differences in nutrient density, affordability, and environmental impact for pulses and comparators.

MCDA with replacement analysis evaluates alternatives under explicit weights and substitution scenarios, mapping net-effect frontiers and making trade-offs and conditionality transparent. For example, Springmann (2024) uses MCDA with explicit weights and scenario-based replacement analysis. Alternatives are scored per criterion, normalized, and aggregated under different weighting schemes to identify feasible choices for meat and milk alternatives.

Together, these integration methods provide policy-relevant synthesis while exposing the assumptions under which synergies hold and the conditions that give rise to trade-offs. Using monetization where credible, complemented by indices, econometrics, and statistical tests where prices are weak, provides a pragmatic integration pathway that preserves comparability while keeping key assumptions visible for policy.

3.3. Application of true cost accounting

We find that TCA empirical applications are dominated by national-level studies and focus mainly on environmental impacts, with only selective inclusion of health, social, and economic dimensions (Fig. 4). Most studies focus on the production or consumption side, whereas midstream value-chain stages (i.e., processing, storage, distribution,

Table 1
Examples of integration approaches and trade-off/synergy synthesis across True Cost Accounting studies.

Study	Integration approach	En	H	S	Ec	Key findings
Bai et al. (2021)	Monetization & Pearson's rank correlation	+	+	+	+	Improving resource efficiency and fertilizer use cuts blue-water footprint and ecosystem losses while also lowering production costs.
Bellon, Benard et al. (2024a)	Monetization & score	−	+	+		The environmental impacts of production are small in comparison to the potential nutritional health benefits of consuming one oil over another.
Bellon, Hanley et al. (2024b)	Ordinary Least Squares regression	−	+	+	+	Nonmarket factors linked with human and social capital support market performance by contributing to the market value of cow-calf production.
de Jong et al. (2024)	Monetization	+	+		+	Semi-skimmed milk is the best choice to obtain a certain intake of nutrients, both from an environmental cost view and a consumer budget view.
Drewnowski and Conrad (2024)	One-way ANOVA	+	+		+	Pulses provide high nutrient density with lower greenhouse-gas emissions and generally favorable affordability.
Hooker et al. (2024)	Sustainability index	+	+	+	+	Plant-protein foods tend to balance environmental, health, social, and economic criteria better than other options.
Springmann (2024)	Multi-Criteria Decision Analysis	+	+	+	+	Unprocessed plant-based foods performed best in the assessment across all domains.

Notes: En = Environmental; H = Health; S = Social; Ec = Economic.
"+" = synergy; "−" = trade-off; blank = not assessed. A dimension was coded as a synergy when the study reported an improvement (benefit or cost reduction), and as a trade-off when it reported a negative effect (cost increase or deterioration).

and retail) remain sparsely assessed. To this end, we synthesize how TCA is applied across spatial scales, impact dimensions, and value chain stages in agrifood systems.

3.3.1. Spatial scale pattern

We find that empirical TCA applications are heavily concentrated at the national scale, with far fewer studies at local, regional, and global levels. This pattern highlights the central role of national policy in implementing TCA, the use of local cases as implementation pilots, and persistent gaps in global coordination and Global South representation.

Our results reveal that 66% of studies (n = 35) on TCA in food systems are conducted at the national scale, indicating a dominance of top-down policy influence (Fig. 4). This trend reflects the strong role of national governments in shaping TCA adoption through environmental valuation frameworks and dietary guidelines (FAO, 2023; TEEB, 2018).

A closer look at the country level reveals that European countries such as Germany (n = 6), Italy (n = 5), and the Netherlands (n = 3) are doing TCA studies at both national and local levels. Some examples include Italy's LCA-based estimates of the environmental and health external costs of meat with policy recommendations (Arrigoni et al., 2023). Germany's modeling of dietary change and land-use change to quantify preventable climate and biodiversity damages from meat consumption (Hentschl et al., 2023). In addition, studies from these countries play a significant role in methodological innovation, with institutions such as the True Price Foundation (Taufik et al., 2023) and the Sustainable Food Trust (Fitzpatrick et al., 2019), developing and testing new frameworks for internalizing externalities.

Notably, 20.8% of studies are conducted at the local scale — predominantly in Europe — and serve as practical entry points for applying TCA. Local applications are generally more feasible and directly useful for producer decisions and policy pilots (Springmann et al., 2021). We find farm-level studies (n = 6) dominate the local subset and span diverse production contexts. Some examples include integrated crop–dairy systems that explore strategies to meet environmental targets (Alderkamp et al., 2025); Italian viticulture that links environmental evaluation with societal cost estimation using EU FADN data (Frem et al., 2023); assessments of the environmental advantages of coproducing beef in dairy systems (Laca et al., 2023); and analyses that align farm economics with environmental costs under the Common Agriculture Policy (CAP) (Vassallo et al., 2024). In addition to these production-focused applications, some local-scale studies emphasize consumption-side approaches to enhance the feasibility of TCA. For instance, two supermarket-level studies — a German retail campaign on "responsible implementation" (Michalke et al., 2022) and an analysis of trust and consumer value for true-price products (Taufik et al., 2023) — suggest that transparent price communication can build acceptance and market uptake.

In contrast, only 5.7% of studies operate at the regional scale and 7.5% at the global scale, underscoring fragmented international coordination in TCA. Despite initiatives such as the 2021 UNFSS and the One Planet Network (Hendriks et al., 2023), the absence of a globally accepted methodology limits cross-country comparability (Springmann et al., 2021). Global examples show both promise and challenges. Pelletier and Tyedmers (2010) integrates dietary shifts with environmental and health externalities to estimate worldwide savings, and Lucas et al. (2023) forecasts potential global environmental costs of livestock production. Together, these cases indicate that global-scale TCA can guide international targets but still depends on harmonized valuation factors, consistent baselines, and transparent treatment of uncertainty.

In addition, the spatial distribution highlights a pronounced underrepresentation of countries from the Global South, with most studies originating in high-income countries. This may reflect structural inequities in data availability, institutional capacity, and access to funding, leading to Global North-centric metrics that may overlook region-specific issues.

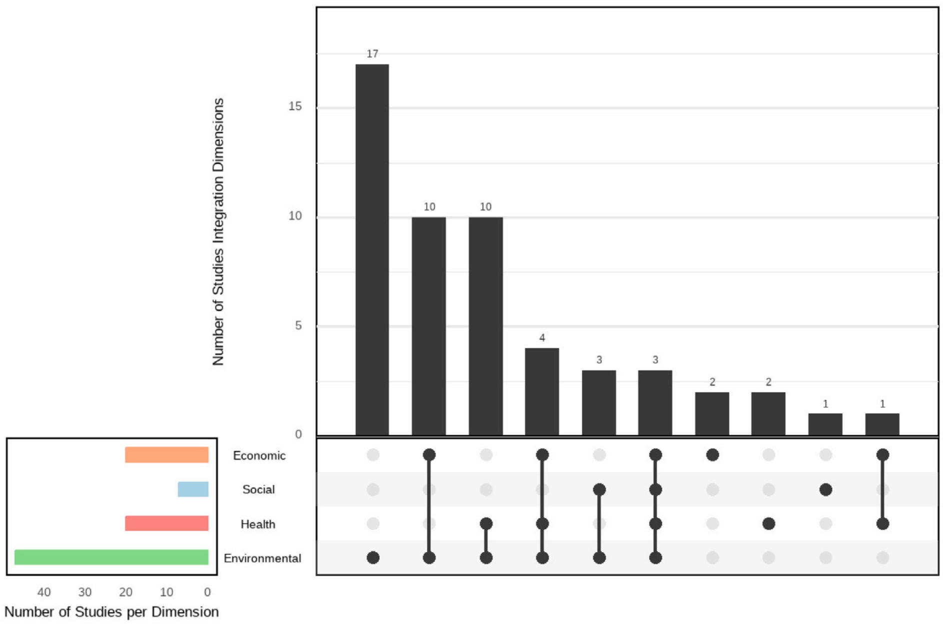

Fig. 5. Integration of four dimensions in the reviewed literature. This upset plot visualizes the number of studies that integrate different impact dimensions, i.e., environment, health, social, and economic. The vertical bars represent the number of studies integrating different dimensions (indicated by the connected dots below each bar), while the horizontal bars at the bottom left show the total number of studies that consider each individual dimension. The environmental dimension was most assessed (present in 47 studies), followed by health (20), economic (20), and social (7). Only 3 studies assessed all four dimensions simultaneously.

3.3.2. Synthesis patterns across dimensions

We find that integration of the four dimensions is still partial (Fig. 5): most applications link two dimensions, especially environment–health (n = 10) or environment–economic (n = 10), while only a few cover three or all four (n = 7). In addition, we find that social impacts are usually integrated through non-monetary methods.

Individual dimension patterns. In terms of individual dimensions, environmental impacts dominate the literature (n = 47), followed at a distance by health (n = 20), economic (n = 20), and social (n = 7). First, environmental impacts are the most frequently included dimension. This strong representation reflects both the methodological maturity of environmental assessment tools and the global prioritization of sustainability and climate mitigation within agrifood systems. In addition, the environmental dimension is the most quantifiable and widely standardized in the TCA literature, often serving as the cornerstone for multi-dimensional assessments. However, its scope remains dominated by climate-related analysis (n = 38), with comparatively fewer studies addressing ecosystem services (n = 11), suggesting room to broaden beyond carbon-centric metrics.

Second, the health dimension appears less frequently than the environmental one (n = 20), and health assessments concentrate at the consumption stage (n = 17) (Fig. 6). This underscores the central role of diet quality and composition in shaping public-health outcomes. Production-stage health is covered only sporadically and tends to focus on occupational risks rather than population health.

Third, social impacts are the least assessed (n = 7). Coverage is patchy and concentrated at the production stage (e.g., animal welfare and working conditions). The culture, equity, and community development are seldom addressed across the value chain. When social indicators are used, they are often qualitative or categorical, limiting their comparability and integration with monetized results.

Fourth, the economic dimension rarely appears in isolation. It most often accompanies environmental or health assessments. The aim is to make hidden costs visible when they are not reflected in market prices, thereby informing more rational and equitable food-policy decisions. Typical analyses compare market and non-market costs across production systems — e.g., monetizing externalities to contrast organic vs. conventional farming (Ischenko et al., 2021; Michalke et al., 2023) and explore policy levers at retail and farm levels, including true-price/VAT adjustments and the alignment of CAP-style subsidies and taxes with external costs (Vassallo et al., 2024). However, limitations remain. Data availability differs by country and value-chain stage; monetization entails normative choices (e.g., discount rates, and willingness-to-pay); and distributional equity (i.e., who pays vs. who benefits) is rarely made explicit. Despite these caveats, the economic lens is a critical integrator that enables cross-dimensional comparison and supports instruments such as tax reform, subsidy redesign, and sustainability labeling.

Dimensions integration patterns. We find integration is still partial: 24 studies combine two dimensions, 4 combine three, and only 3 assess all four dimensions (Fig. 5). The most frequent pairings are environment–health and environment–economic, consistent with the maturity of LCA-based methods that can be linked either to health endpoints or to monetary valuation of externalities.

Environment–health integration (n = 10) appears largely in consumption-stage analyses of diet shifts and product substitution, for example, multi-criteria assessments of meat and milk alternatives that jointly consider health, environmental, and economic outcomes (Springmann, 2024). Environment–economic integration (n = 10) is the next most common approach and is concentrated in production-stage applications, where pricing, taxes/subsidies, and affordability translate biophysical impacts into market signals (e.g., maize systems) (Bai et al., 2021). By contrast, social dimensions are rarely co-assessed. When present, they typically rely on mixed-method designs that combine monetary aggregation for environmental/health outcomes with non-monetary scorecards for social aspects (Bellon, Hanley et al., 2024b). Overall, the evidence base is environmentally led, health- and economics-enabled, and socially thin, underscoring the need for standardized social metrics and their integration into full TCA.

Integrated results indicate that synergies are common in consumption-stage analyses (Table 1). They mainly explore options that

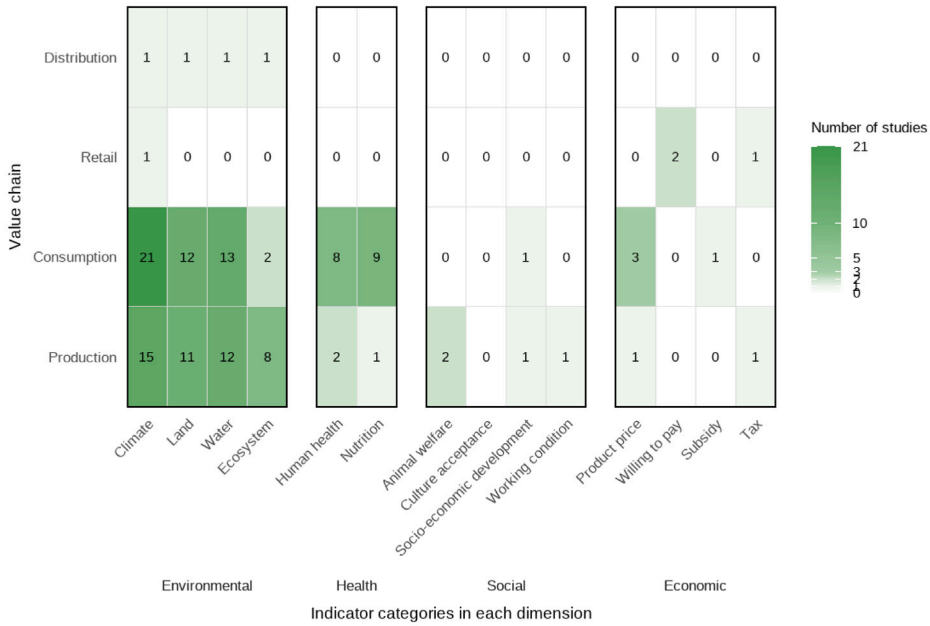

Fig. 6. Heatmap of indicator categories across the agrifood value chain. The heatmap shows study counts (numbers in tiles) for each indicator category across four value chain stages (rows). Columns are grouped by dimension: Environmental (Climate, Land, Water, Ecosystem), Health (Human health, Nutrition), Social (Animal welfare, Cultural acceptance, Socio-economic development, Working condition), and Economic (Product price, Willing to pay, Subsidy, Tax). Darker green denotes more studies (0–21). Research is heavily concentrated on environmental indicators in the production and consumption stages, while social and economic indicators and the other stages are seldom assessed.

improve diet quality, especially pulses and many plant-based alternatives, often lower environmental impacts while maintaining adequate nutrition at competitive costs. For instance, pulse-forward patterns score well on nutrient density, affordability, and emissions (Drewnowski & Conrad, 2024; Hooker et al., 2024), MCDA rankings place unprocessed plant-based foods at or near the top across assessed domains (Springmann, 2024), and semi-skimmed milk provides a cost-efficient route to meet nutrient targets at moderate environmental cost (de Jong et al., 2024). By contrast, production-side changes more often expose dimension-specific trade-offs once social indicators (e.g., wages, working conditions, and adoption costs) are considered. Nevertheless, targeted management can still deliver win-wins, for example, improved resource-efficiency and fertilizer practices that reduce blue-water use and ecosystem losses while lowering production costs (Bai et al., 2021). Category-specific comparisons also show cases where health gains outweigh small environmental differentials (e.g., edible oils) (Bellon, Benard et al., 2024a), while econometric evidence links social and market outcomes by demonstrating that human and social capitals are positively capitalized into cow-calf market value (Bellon, Hanley et al., 2024b). Taken together, these patterns justify hybrid integration, i.e., monetization where defensible, complemented by non-monetization, to transparently integrate outcomes when credible prices for social effects are lacking.

3.3.3. *Patterns across the value chain*

Our review reveals a strong concentration of measurement at the production and consumption stages, with very limited coverage of other value chain stages (Fig. 6). Environmental categories (e.g., climate, land, water, and ecosystem) account for most observations at both ends of the chain. The most populated cell is consumption — climate (n = 21), followed by production — climate (n = 15). Land and water metrics are also common at these stages, whereas ecosystem service indicators remain comparatively scarce. Typical production-side examples quantify water scarcity and profitability implications in maize systems by coupling water-footprint metrics with economic impact assessment (Bai et al., 2021), and translate land-use change and biodiversity pressure in palm oil supply chains into true-cost price signals to inform policy levers such as levies or certification premia (Bellon, Benard et al., 2024a). At the consumption side, climate footprints are often linked to product substitution, such as plant-based beverages compared with cow's milk, where studies report environmental footprints alongside nutrition and price information (de Jong et al., 2024).

Health impacts cluster almost entirely at the consumption stage, reflecting diet-focused applications and burden-of-disease modeling. Illustrative cases include pulse-forward diet analyses that combine nutrient density, affordability, and environmental impact to identify "win–win" options for consumers (Hooker et al., 2024), and evaluations of meat and milk alternatives using integrated multicriteria frameworks that bring health, environment, and cost into a single decision space (Springmann, 2024). By contrast, production-side health coverage is sporadic and primarily occupational.

Social impacts are the sparsest across the value chain. When present, they most often appear at production, for instance via animal-welfare scoring and worker-conditions checks embedded in farm-level TCA pilots. These are commonly integrated through non-monetary scorecards alongside monetized environment and health results (Bellon, Hanley et al., 2024b). Culture, equity, and community-development measures are rarely assessed at any stage, limiting comparability and synthesis.

The economic dimension spans multiple stages but is most visible at the consumption stage. Studies frequently quantify the gap between market prices and "true prices", or model tax/VAT adjustments to internalize externalities at the point of purchase. Retail-facing pilots show how price transparency shapes acceptance and demand. A German supermarket campaign on "responsible implementation" demonstrates feasibility and consumer response in-store (Michalke et al., 2022), while experiments on trust and perceived value for true-price products highlight conditions under which shoppers accept higher shelf prices (Taufik et al., 2023). On the production side, analyses align farm economics with environmental costs. For example, exploring how CAP-style subsidy and tax reforms could internalize externalities and shift incentives (Vassallo et al., 2024). Retail-stage work beyond WTP experiments remains scarce, and distribution receives minimal attention, despite its potential to influence costs through transport and waste management.

4. Discussion

Our systematic literature review provides a solid foundation for mainstreaming and applying TCA in agrifood systems. We synthesize how TCA has evolved conceptually and how it is being operationalized across agrifood contexts. We find a shift from isolated pilots to a rapidly expanding evidence base. Methodologically, convergence is emerging around a four-step TCA process, yet substantial heterogeneity in valuation choices and integration approaches continues to limit comparability. Empirically, multidimensional assessments reveal recurrent synergies and trade-offs across environmental, health, social, and economic dimensions. Still, applications remain unevenly distributed across regions and value-chain stages. Together, these findings help consolidate a fragmented field, support methodological standardization, and accelerate empirical application of TCA.

4.1. Advancing methodological standardization

Our first novelty lies in advancing methodological standardization by unpacking the TCA procedure both theoretically and operationally. In doing so, this review contributes to advancing methodological standardization, improving cross-study comparability, and providing a way forward for future research and policy.

Theoretically, we provide a systematic synthesis of TCA's fragmented development in agrifood systems and organize it into a clear evolution timeline. We find a marked acceleration in TCA applications after 2021, coinciding with key institutional milestones. Earlier conceptual work established foundational principles (Capitals Coalition, 2016, 2019; TEEB, 2018), whereas more recent guidance translates these principles into operational protocols (Cost, 2022; Eigenraam et al., 2020-09). Our contribution is to integrate these dispersed initiatives into three progressive phases — framework development, operational guidance, and mainstream application — and to show how institutional leadership has shaped methodological maturation. This structured overview clarifies TCA's historical trajectory and supports TCA as a practical tool for sustainability accounting and food-system transformation.

Operationally, we compare how the TCA steps are implemented in practice and unpack the operational choices embedded within them. Existing guidance diverges across sources, leaving gaps in how each step of a TCA assessment should be implemented (de Adelhart Toorop et al., 2021). To make each step explicit, we build a hierarchy from micro- to macro-level functional units, map indicator categories across dimensions, synthesize commonly used valuation factors, and summarize integration strategies. We first find that the functional unit is the primary lever linking research questions to boundaries, data needs, and feasible integration. Second, we highlight that integration across dimensions remains partial. Environmental indicators dominate. Health is increasingly incorporated. Social impacts lack harmonized indicators and defensible prices at scale. This may lead to systematic under-representation of data-poor but important dimensions. Third, our mapping of integration approaches reveals two complementary logics: monetary aggregation produces comparable policy totals, while non-monetary integration clarifies synergies or trade-offs, enables robustness to weights, and reduces false precision where prices are weak. Therefore, combining both offers a pragmatic route to comparability and decision relevance.

4.2. Patterns and gaps in true cost accounting applications

Our second novelty is to synthesize empirical TCA applications. We highlight patterns and gaps in TCA applications. Our review reveals a rapidly growing, yet uneven, application of TCA in agrifood systems. Three core patterns emerge from our synthesis: (i) a strong national focus with limited international coordination; (ii) cross-dimension synthesis of trade-offs and synergies; and (iii) a concentration of measurement at production and consumption, with processing, distribution, and retail comparatively neglected. Taken together, these patterns help explain why TCA already informs policy debates and pilot programs, yet still struggles to provide fully comparable, decision-grade evidence across countries, supply chains, and stakeholder groups.

The predominance of national-scale applications underscores the role of central governments in shaping indicators and piloting fiscal instruments (FAO, 2023, 2024a). This top-down leadership is consistent with the need for coherent tax/VAT reforms and national dietary guidelines. The emerging local pilots in Europe suggest a viable bottom-up path: they are implementable, close to decision-makers, and useful for testing true-price communication and practice changes. For example, farm-level studies can align agronomic practices with external cost reductions (Baltussen et al., 2019), while supermarket pilots show how transparent communication of "true prices" can affect acceptance and demand Michalke et al. (2022), Taufik et al. (2023). Yet there are still two gaps. First, international coordination is thin, limiting cross-country comparability and the calibration of trade-relevant instruments. Second, the underrepresentation of Global South countries suggests structural inequities in data availability, institutional capacity, and access to funding.

Across dimensions synthesis, applications most often pair environment with health or economics, while social indicators lag. Synergies are common at the consumption stage (pulses and many plant-based substitutes) (Springmann, 2024; Springmann, Mason-D'Croz et al., 2018b), whereas trade-offs typically arise in production settings once social impacts are accounted for. Crucially, distributional reporting remains rare (FAO, 2024c). Future applications should state who bears the costs and who benefits across stakeholders (e.g., consumers, farmers, workers, and taxpayers), rather than only presenting aggregate totals.

Along the value chain, evidence clusters at production and consumption, where data and methods are mature and can build on established LCA and health-assessment tools (Hauschild et al., 2018; Huijbregts et al., 2017; Malik et al., 2018). Processing, transport, and waste are comparatively neglected, although they generate substantial environmental and health burdens through energy use, transport emissions, packaging, and food loss (Pradhan, 2022, 2023). In addition, retail practices influence product pricing and consumer choice. Undercoverage at these mid-chain stages weakens end-to-end scenarios and may mis-signal policy interventions (Eigenraam et al., 2020-09).

4.3. Policy implications: operational pathways for embedding TCA into policy

Food systems transformation is crucial for achieving the Sustainable Development Goals (Herrero et al., 2021; Pradhan et al., 2021) and limiting the transgression of planetary boundaries (Li et al., 2026, 2024). The ongoing nutrition transition undermines long-term targets for food security, public health, and environmental protection. Therefore, ambitious combinations of food system interventions are required to keep human activities within planetary boundaries (Hadjikakou et al., 2025). In this context, TCA can support integrated policy design by revealing where current prices most diverge from social costs and benefits.

Once TCA accounts are established, policymakers and stakeholders gain a clearer understanding of current and future challenges and opportunities in agrifood systems. Integrating TCA results into scenario analysis supports the assessment of policy impacts and effectiveness, helping identify synergies, trade-offs, and key entry points to improve sustainability. Policy levers can act across different supply-chain stages and stakeholder groups, ranging from economic instruments (e.g., taxes and subsidies) to non-economic measures (e.g., labeling and certification). While these levers are not new, the innovation lies in their coordinated and evidence-based use, guided by TCA outcomes and context-specific priorities and constraints.

4.3.1. Fiscal subsidies to producers and consumers

Fiscal subsidies to producers and consumers are key policy levers for shaping agrifood-system outcomes, yet their effectiveness depends on whether they internalize the social, health, and environmental externalities that market prices fail to reflect. Producer subsidies, including income support, input subsidies, and payments for ecosystem services, are widely used to increase agricultural production and productivity, stabilize farm incomes, or reduce production costs (FAO, 2023). Such subsidies can also incentivize environmentally beneficial practices such as reforestation in Costa Rica (Rosendal & Schei, 2014) and Guatemala (Sales et al., 2016).

By contrast, consumer subsidies aim to advance the right to adequate food by lowering food prices, increasing purchasing power through cash or voucher transfers, or ensuring direct access to food via in-kind interventions such as school feeding programmes (Foundation, 2021). Targeted TCA assessments can inform the design and evaluation of both producer- and consumer-oriented subsidies by identifying dominant externalities, quantifying trade-offs across nutrition, environmental sustainability, and equity, and helping redirect public support toward foods and production practices with net positive societal value (Organization, 2023).

4.3.2. Taxes on unhealthy and unsustainable food

Taxes on unhealthy and unsustainable foods complement subsidies for healthier and more sustainable options by correcting distorted food price signals. While dietary choices reflect consumer preferences, relative prices are decisive under income constraints, and the low cost of fats and sugars has contributed to unhealthy diets. Targeted TCA assessments can guide the design of food taxes by translating health and environmental externalities into differentiated rates that shift relative prices. Recent European evidence shows that VAT reforms which increase rates on meat and dairy products while reducing rates on fruits and vegetables can simultaneously improve health and environmental outcomes, providing a concrete entry point for applying TCA-informed fiscal policy (Springmann et al., 2025).

4.3.3. Labeling and certification scheme

TCA can also be operationalized through labeling and certification by translating complex valuation results into consumer-relevant signals. Evidence from real-world "true price" information pilots suggests that disclosing true costs can influence consumer behavior under certain conditions, indicating that labeling can complement fiscal and regulatory instruments (Research, 2023). Certification schemes may also use TCA to define eligibility thresholds based on aggregated impacts. To avoid shifting responsibility solely to consumers, TCA-based labeling should align with upstream incentives and, where possible, report impacts by supply-chain stage, thereby strengthening accountability for the often-overlooked mid-chain externalities. For example, agricultural cooperatives and producer organizations can increase producer incomes by meeting demand for certified specialty products, such as coffee produced under conservation agreements (Association, 2021).

4.4. Future research directions

TCA has expanded rapidly over the past decade and has reached a level of maturity that allows it to inform concrete decisions in agrifood systems. However, it has not yet evolved into a fully standardized, globally comparable, or routinely operationalized evidence framework. Building on the insights of this review, future research should focus on consolidating methodological foundations, addressing persistent data and contextual gaps, and strengthening pathways from accounting to action. Advancing TCA along these dimensions is essential for improving practical application across diverse agrifood contexts.

First, advancing TCA methodology requires the development of standardized yet flexible protocols, with clearer articulation of minimum data and methodological requirements. Methodological work is needed to specify which indicators, valuation approaches, and levels of resolution are essential for producing policy-relevant results, and which elements can be adapted or approximated under data constraints, supported by minimum reporting standards and systematic uncertainty and sensitivity analysis. At the same time, TCA remains highly data-intensive, while existing databases largely capture visible market flows and selected environmental impacts, and provide limited coverage of social dimensions such as working conditions, social relations, and cultural knowledge. This data scarcity, particularly acute in the Global South, constitutes a major barrier to scaling up TCA applications and increases uncertainty in assessment outcomes. Future research should therefore focus on reducing the resource intensity of data collection, developing transparent methods to integrate secondary and modeled data (Snoek et al., 2024), and clarifying under what conditions data of limited quality can still meaningfully inform policy and decision-making (de Adelhart Toorop et al., 2023).

Second, future work should prioritize inclusive and context-sensitive TCA applications, through a two-phased assessment approach (FAO, 2023). The first phase is to undertake initial national-level assessments that quantify and analyze, to the extent possible, the hidden costs of agrifood systems across the different capitals using readily available data. The main role of the first phase is to raise awareness of the magnitude of the challenges, and it can serve as a starting point for breaking down the hidden costs of national agrifood systems to inform discussions and dialogues with stakeholders in a given country. This phase helps to link the hidden costs to the most urgent national priorities. It also identifies hidden cost categories that may be important but are not yet quantified, and considers the data needed to fill these gaps. Building on this first phase, the second phase should focus on targeted, in-depth TCA studies of specific value chains, sectors, or interventions, to guide transformational policy actions and investments in a specific country. These more detailed assessments are intended to reduce uncertainty, account for local specificities, and directly support transformational policy actions and investment decisions within a given national context.

Third, strengthening the translation of TCA insights into action requires closer collaboration between different stakeholders. Research institutions and academia play a central role in advancing TCA by developing robust methodologies, indicators, and valuation approaches, and by underpinning them with transparent and credible data infrastructures. Governments, through policies, public investment, regulation, and data provision, are pivotal in creating an enabling environment for the wider uptake of TCA and its integration into decision-making processes. At the same time, accounting firms and business consultancies act as key intermediaries by translating TCA methods into applied tools and practices, supporting agrifood producers, firms, and other actors in implementing TCA as part of a broader food system sustainability transition.

4.5. Limitations of our study

Our analysis has some limitations stemming from the scope and methodology of our review. First, our review does not include grey literature on TCA because our search was limited to only two databases. Since our aim is a systematic analysis, it is a challenge to cover grey literature systematically, including its quality control, to ensure the replicability of the study. Nevertheless, major reports by international organizations and key initiatives were considered qualitatively in framing the evolution of TCA. Second, our review was also restricted by our keyword search strategy, and the selection of English papers. We could have used various synonyms of TCA during the keyword search. Despite these limitations, we were able to cover a substantial amount of literature, including studies from different countries worldwide. Third, studies on TCA often publish their findings in policy reports or conference proceedings, which can delay publication due to the peer review process. This leads to a lag in the visibility of emerging patterns in the journal-based literature. Fourth, this review excludes empirical work that addresses measurement without monetization. Consequently, the findings reflect monetization-oriented TCA applications rather than the broader TCA literature. Despite these limitations to our analysis, we believe that the patterns identified in our review are robust and unlikely to change significantly with the inclusion of more grey literature. However, future developments in the field may naturally refine or extend the findings presented here.

5. Conclusion

This systematic review synthesizes how TCA has evolved and is applied in agrifood systems, and assesses its readiness to inform food system transformation. Based on 53 peer-reviewed studies, we trace the transition of TCA from fragmented conceptual work toward more application-oriented assessments, compare methodological practice across the four core steps of scope, measurement, valuation, and integration, and map empirical applications by spatial scale, value-chain stage, and impact dimension. Our findings indicate substantial progress since 2021, supported by the consolidation of frameworks and guidance and a rapid expansion of empirical studies. However, this progress remains uneven. Methodological heterogeneity continues to limit comparability; social impacts are weakly represented; and applications remain concentrated in upstream stages, high-income regions, and data-rich contexts. These imbalances constrain TCA's capacity to capture system-wide trade-offs and inform equitable decision-making. Advancing TCA will require greater methodological convergence with contextual flexibility, broader empirical coverage — particularly of mid-chain stages and the Global South countries — and closer alignment with policy levers. Overall, this review provides a foundation for moving TCA from a promising assessment framework toward a robust, policy-relevant tool capable of supporting sustainable and just agrifood system transformation.

CRediT authorship contribution statement

Jingyu Zhang: Conceptualization, Methodology, Formal analysis, Data curation, Visualization, Software, Writing – original draft. **Eugenia Rosca:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Prajal Pradhan:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

J.Z. gratefully acknowledges financial support from the China Scholarship Council (Grant No. 202409120014). P.P. acknowledges funding from the European Research Council (ERC) Starting Grant 2022 for the BEYONDSDG project (Grant Agreement No. 101077492).

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.tifs.2026.105633.

Data availability

Data will be made available on request.

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