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Towards European food systems transition monitoring framework and indicators

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Summary

This report explores the development of a framework and indicators for monitoring transitions in European food systems, highlighting systemic changes essential for sustainability. Using a scoping study approach, it evaluates 18 selected indicator frameworks to identify key elements, relationships, and sustainability considerations. The study emphasises the need for comprehensive frameworks that encompass environmental, social, and economic dimensions while addressing gaps such as feedback loops, cross-system interactions, and governance structures. Concrete proposals for indicators are provided, complemented by expert-driven recommendations to fill data gaps. The report also offers broader lessons for improving sustainability transition monitoring, including integration with policy and actor relations. Insights aim to support the advancement of food systems monitoring and inform future European environmental reporting.

Keywords: Food system, Indicators, Sustainability, Transformative change, Transition monitoring

1 Introduction

1.1 Background and aim of the report

The urgent need for more sustainable food systems has been recognised by numerous international policies. Notably, the UN 2030 Agenda for Sustainable Development and the Sustainable Development Goals (SDG) emphasise the need to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture (SDG2). They also highlight the need to shift towards responsible consumption and production practices throughout the food system (SDG12). On a European level, the Farm to Fork Strategy forms a central component of the European Green Deal and aims to make the European food systems more sustainable by 2030. Various regional and national policies have also recognised the need to renew food systems, and different grassroot initiatives aim to support local changes in food production and consumption.

Food systems serve a basic human need – nutrition – and has a major economic, social and environmental importance. For example, some 13 million enterprises and 29 million workers produce, process, distribute, prepare and sell food and beverages in the EU (EPRS, 2020). The food and drink industry is the largest manufacturing sector in the EU economy. Agriculture is the source of 11% of all greenhouse gases emitted in the EU, and it remains a significant contributor to biodiversity and habitat loss and to the emissions of harmful air pollutants, such as ammonia as well as the most significant pressure impacting both surface and groundwaters (EEA, 2017, 2024). Moreover, unhealthy diets, exposure to chemical residues in food and packaging, and contamination of drinking water affect human health.

A rich array of issues needs to be addressed in order to successfully guide the food systems towards a more sustainable direction. Abundant research has focused on identifying the key components of change (Eakin et al., 2017; EEA, 2017; Kennedy et al., 2021; Maynard et al., 2020), including environmental issues of food production and consumption, such as combating climate change and biodiversity loss, resource overuse, and promoting circular economy. Social well-being also plays a crucial role, encompassing fair working conditions throughout the food chain, promoting healthy diets for all, and reducing food waste. Furthermore, ensuring economic viability of food systems involves keeping agriculture and aquaculture competitive and resilient, supporting farmers and fishers in adopting sustainable practices, and generating new economic opportunities through regeneration and renewal.

This complexity and diversity of issues pose a challenge for monitoring and assessing change but at the same time they make food systems an interesting case. The overall goal of this scoping review is to support the development of sustainability transition monitoring. More specifically, the aim is to build a prototype framework featuring criteria, characteristics, and logic for monitoring systemic changes in food systems. To achieve this, the report reviews various indicator sets, academic studies and case reports. It utilises and builds on previous EEA and ETC ST (European Topic Centre on Sustainability Transition) work on food systems sustainability measurement and assessment, while reviewing a variety of other selected cases (see below). Particular emphasis is given to comprehensive or "holistic" indicator frameworks that aim to characterise drivers and dynamics of systemic change throughout the food value chain, covering the agriculture, aquaculture, and fisheries sectors. Sustainability indices aiming to aggregate multidimensional issues into a single figure are not considered here.

This study employs a scoping study approach aiming for a wide-based overall picture. Instead of conducting a systematic review focused on specific topics, perspectives or approaches, or an analysis delving deep into individual cases or methods, it aims to select and compare a diverse set of cases that illustrate different, potentially useful ways to use indicators to describe food systems transitions. Food systems' studies are considered a promising field that is highly relevant for sustainability transition, but that remains relatively uncharted. For example, energy or transportation systems are much more often addressed by transition studies and have more advanced and internationally established reporting and monitoring schemes.

The scoping utilised the snowballing method, drawing on existing ETC work (e.g. Lorenz et al., 2024; Haraldsson et al., 2024) and team members' expert knowledge on relevant publications to review. The project team initiated the mapping based on previous ETC ST work and other pertinent reports suggested by EEA project managers (Chapter 2). Selection criterion during the pre-screening phase included the capability to describe food systems in a comprehensive manner, potential for cross-country comparisons, policy relevance and data availability. The chosen cases prioritise diversity in conceptual backgrounds, institutional settings, and data sources, while avoiding overlaps.

The list of pre-screened cases is presented in Annex 1: From this list, the 18 most prominent and promising cases were selected for analysis. A set of criteria to evaluate the selected cases was developed, aiming to capture the essence of food systems transition (Chapter 3). The criteria emphasise (i) the elements of food systems identified, (ii) the relationships between the elements, and (iii) sustainability considerations.

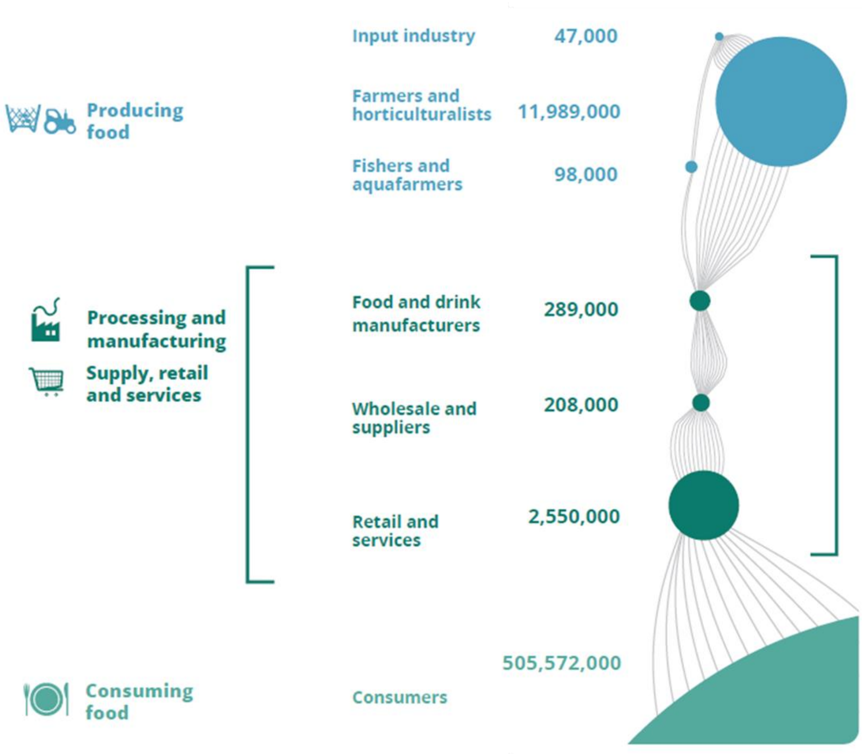
Based on the evaluation, concrete proposals for food systems transition indicators are made (Chapter 4). It should be noted that the main bulk of proposed indicators are already in use and represent readily available cross-national and reliable data. This is supplemented with the project team's indicator proposals per evaluation criteria. The selection also indirectly highlights further development needs and data gaps – various experimental indicators currently not capable of providing reliable cross-national picture exist. Overall, the challenges and opportunities of sustainability transition monitoring faced in the food sector provide lessons applicable to other sectors as well. Lessons for developing the European state of the environment reporting beyond 2025 are drawn in Chapter 5.

1.2 Basic characteristics of food systems

In this study, we adopt a broad definition of food systems, encompassing all elements, activities, and outputs related to food and nutrition (EEA, 2017). Food systems include all stages of the value chain—such as production, processing, distribution, consumption, and disposal—of food products originating from agriculture, livestock production, forestry, fisheries, or the wider environment (FAO, 2018).

The distribution of actors within a food system is uneven (see Figure 1). A relatively small number of food and drink manufacturers and wholesale suppliers suggests potential power imbalances within the food chain, where these actors may exert significant influence both upstream (food production) and downstream (retail, services, and consumers).

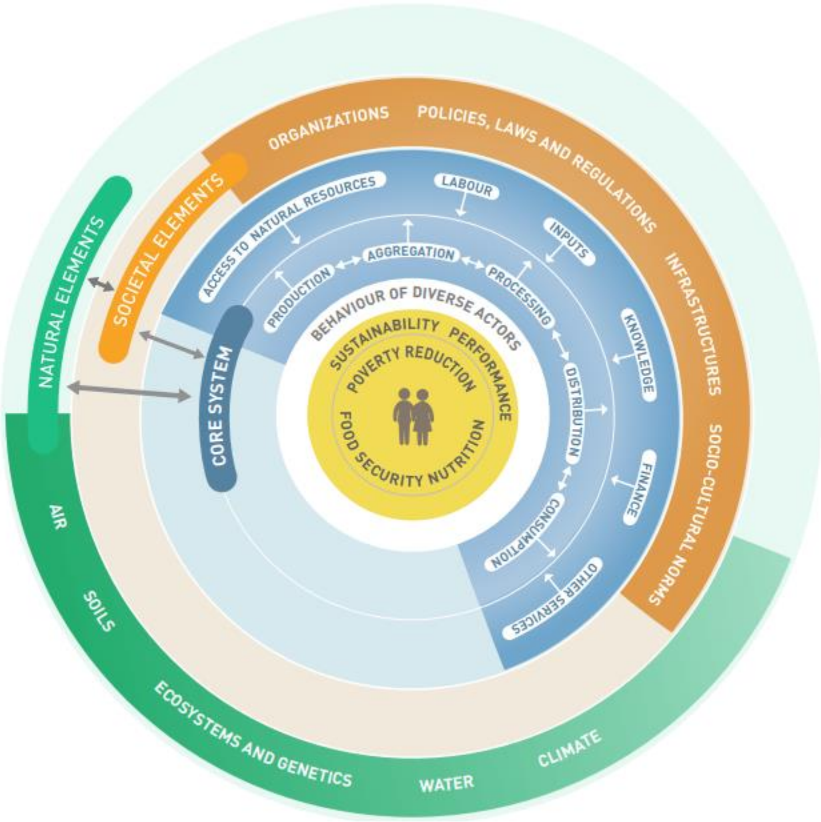
Figure 1. Number of actors in the European food value chain



Source: EEA (2017).

Beyond the core value chain, food systems also encompass the broader societal and natural systems within which they operate (Figure 2). For example, energy and transport systems are closely linked to food systems (Haraldsson et al., 2024), with transport alone contributing between 5–20% of the total carbon footprint of food systems (Crippa et al., 2021; Li et al., 2022). Social systems, including health, economic, income and social protection, housing, and households, also play a critical role by shaping demand, availability, accessibility, and modes of production of food products. Education and media systems – including social media, marketing and advertising – are also highly relevant for food systems transition.

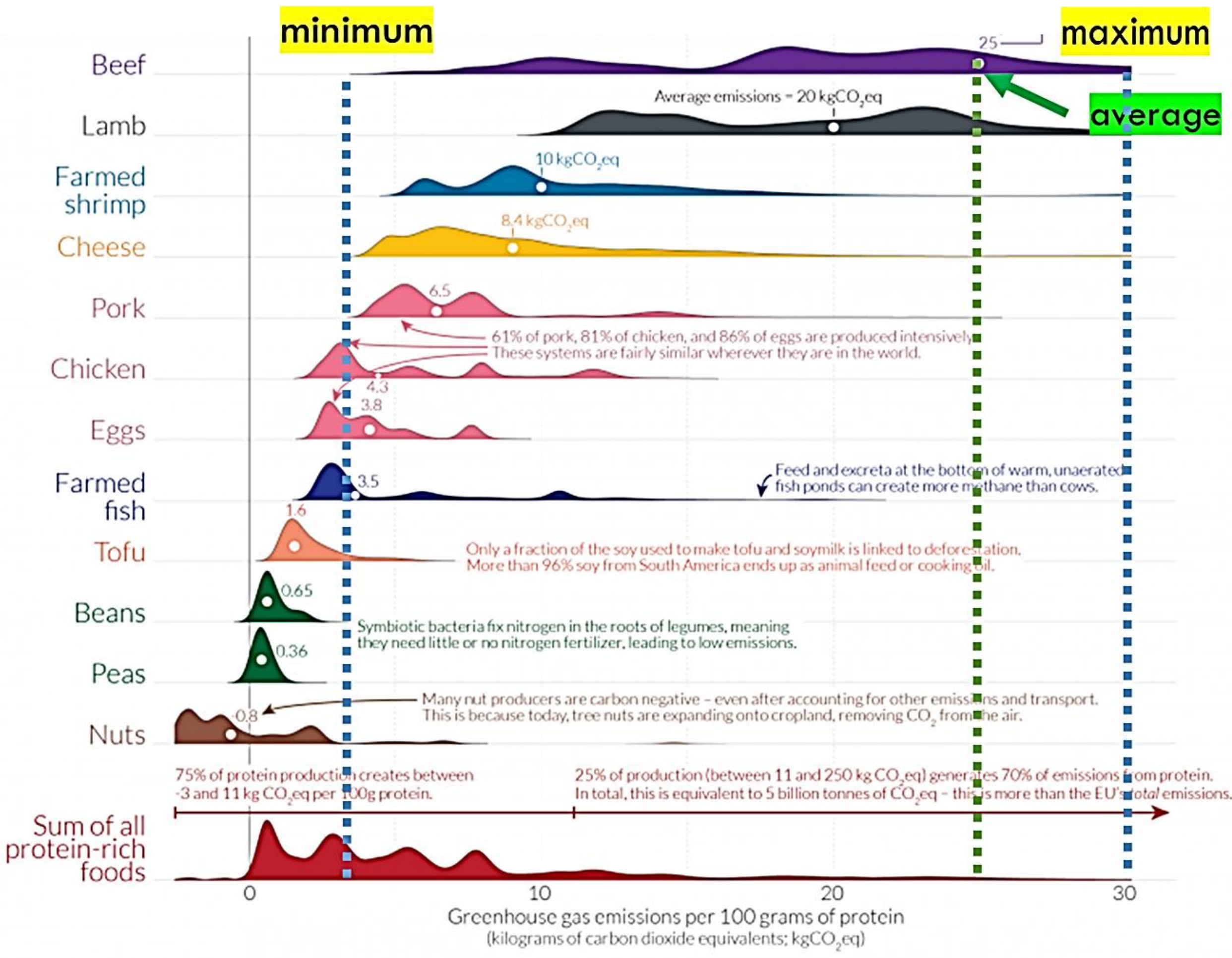
Figure 2. Food systems wheel that entails the core system, societal and natural elements and their interactions.



Source: FAO (2018).

An important aspect of food systems, particularly food production, is the diversity of systems in place. Food production ranges from extensive to super-intensive systems and from indoor (e.g., greenhouses, vertical systems, hydroponics) to outdoor farming. It includes choices between grass-fed versus feed-fed animals, different manure management practices, and fishing versus aquaculture. Each of these can significantly alter the environmental impacts of food production. Consequently, the impact of food production depends not only on the product itself but also on the production process. For example, beef has high variability in environmental impact due to the diverse production methods, resulting in significant differences (see Figure 3). In such cases with high standard deviations, relying on average data is meaningless and can misrepresent the actual impacts. This can lead to justice and equality issues for producer who have modes of production with lower environmental impacts.

Figure 3. Variability in the GHG emissions of different protein sources



Source: Our World in Data

Food systems transition formation is here understood as a radical change in how food systems operate to reduce their adverse impacts on the environment and human and animal health and well-being and improve livelihood outcomes for society (EEA, 2022). Future food systems need to be in line with planetary and environmental boundaries, secure, equitable, resilient to shocks and stresses, uphold human dignity, ensure food security and optimal nutrition for all, and be built on inclusive decision-making processes (GAFF, 2021; Woodhill, 2023). Commonly shared vision of sustainable food systems encompasses intergenerational food security, ecosystem preservation, social acceptability, economic viability, resilience, and the need for systemic approaches and inclusive governance (JRC, 2024). A sustainable food systems is profitable throughout, broadly beneficial for society, and has a positive or neutral impact on the natural environment (FAO, 2018). Transition to such a system necessitates wide-ranging changes in the operation of the current system: behaviour of consumers (consumption shift), investors, agri-food sector firms (equitable economic shift), farmers and other primary producers (shift towards nature-positive approaches), researchers and political leaders (shift towards resilience) along economic and social incentive systems (Woodhill, 2023) all need consideration. As such, the role of all such food systems' aspects in the transition process is considered in this scoping study.

1.3 Sustainability transitions, indicators and the food sector: a brief review

Various approaches have been proposed to capture the key elements and processes of sustainability transitions (e.g., Edler et al. 2021 and Dethier and Roman 2024) and different interpretations exist on how the concept of transition or transformation should be understood (see Hölscher et al., 2018). The central aim of transitions research is to explore how socio-technical systems fulfil a societal function and how they can change (Köhler et al., 2019). The scope of the socio-technical system under examination can include geographical/political units or functions across several sectors (e.g., the bioeconomy), but the starting point is the delivery of a function (e.g., food, mobility or energy). Transformative changes can either be emergent, through societal and market dynamics or intentional, resulting from political intervention because of political and discursive processes. Most often, these dynamics will interplay, re-enforce or counteract. Markets provide directions to system transformations by working as selection environments for radical innovations (Grin, 2010) and by providing responses to changes in societal preferences. This contrasts with state-led directions, which are purposefully set by public authorities together with societal actors to achieve desired outcomes (Weber and Rohracher, 2012).

The starting point for analysing the transition process is to define the object of study, the socio-technical system, to be considered (function, system elements and system boundary). Given that the focus is on radical change towards a new system, the processes of change, i.e., the dynamics of the transformation, and emergent or directed, are the other main area of consideration.

Although the transitions literature has concentrated on energy and transport, there are some case studies of the agriculture/food socio-technical system. Several of these papers use quantitative data or propose quantitative indicators for transitions' case studies. However, this literature typically covers changes in specific food system elements and does not address questions related to more comprehensive system change monitoring.

An early study is by Wiskereke (2003), who looked at Dutch wheat and bread supply chains. Smith (2006) used data on the proportion of organic food in food sales to look at niche developments. Elzen et al. (2011) used a combination of production data and qualitative assessment of dynamics. Raman and Mohr (2014) discussed quantitative indicators for biofuels. Schermer et al. (2015) show time series data on the number of bio-farms for milk production in Austria. Cohen and Ileva (2015) have data on sales at farmers markets. Konefal (2015) proposes a range of social and economic metrics i.e. indicators for multi-stakeholder initiatives in US agriculture. Stahlbrand (2016) uses data on meals sold to study food procurement in universities. Belmin et al. (2018) use price data. Nygaard and Bolwig (2018) use investment and production data. Zwartkruis et al. (2020) use a biodiversity index and revenues to study agricultural nature conservation in the Netherlands. These papers show the quantitative indicators that have been used for transitions case study analysis in food systems from a socio-technical perspective. Overall, these studies highlight the need for quantitative data relative to the context of the case study, often at a national level.

A more qualitatively oriented review is provided by Gaitán-Cremaschi el al. (2019) who aim to characterise the diversity of food systems in view of sustainability transitions. In a context of beef industry, Davidson et al. (2016) provide a case study focusing on disruptive events affecting the emergence or expansion of alternative food movements. Sutherland et al. (2014) provide an earlier collection of case studies focusing on sustainable agriculture in Europe. Such case studies can be instructive also for the selection of quantitative indicators.

In summary, transitions' cases use a combination of quantitative and qualitative data. The quantitative data shows production and consumption (or supply and demand) statistics and environmental indicators (biodiversity, land use, emissions, water quality etc.). Qualitative data is used to characterise the dynamics and institutions of transitions.

Much like the transitions literature, the studies focusing on food-related sustainability indicators show the abundance of potential indicators to describe food systems. Numerous studies have been published, focusing on the representation of food systems under the UN's 2030 Agenda and Sustainable Development Goals (SDG) framework. For example, Chaudhary et al. (2018) presents a global-scale analysis quantifying the status of national food systems performance of 156 countries, employing 25 sustainability indicators across 7 domains, including nutrition, environment, food affordability and availability, sociocultural well-being, resilience, food safety, and waste.

Various other studies highlight indicators capable of describing specific countries or regions, rural or urban settings (Moragues-Faus & Marceau, 2018), indicators describing food production in a comprehensive manner (Movilla-Pateiro et al., 2021), indicators focusing on aquaculture and other specific types of food production (Valenti et al., 2018) or different contexts of food consumption, such as catering and food services (Maynard et al., 2020). Some studies focus on indicators describing production-consumption chains of selected food products (de Sadeleer et al., 2024). Food systems indicators have also been addressed within various other frameworks and concepts, including circular bioeconomy (Kardung & Drabik, 2024) and food security (Manikas et al., 2023).

A comprehensive and detailed review of all quantitative indicators included in these studies – and other academic papers focusing on food systems change – is beyond the scope of this working paper. Instead, the focus in the next chapter will be on more practice-oriented reports and indicator sets aiming to concretely describe food systems change.

2 Review of selected food systems indicator frameworks

This scoping study aimed to present diverse cases illustrating potential uses of indicators to describe food systems transitions, rather than conducting a systematic review on specific topics or approaches. The snowballing method was employed, leveraging team members' expertise, literature searches (e.g., FAO, Eurostat, Scopus, WoS), and grey literature. The team also utilised previous ETC ST deliverables, EEA reports, and other relevant materials suggested by EEA project managers.

Key selection criteria during the pre-screening included the capability to describe food systems in a comprehensive manner, potential for cross-country comparisons, policy relevance, and data availability. The set of cases aimed for diversity in conceptual backgrounds, institutional settings and data sources, as well as avoidance of overlapping cases.

First, a list of potential indicator frameworks, concepts, or guidelines was identified and 28 of these were reviewed using a key findings summary Table 1 (see Annex 1:). After removing conceptual or theoretical works and guidelines from the list, each framework was analysed on whether they provide a set of quantitative sustainability indicators. Based on the expert judgement by the research team, the results were then combined to narrow the list down to 18 most promising frameworks. The resulting shortlist covers a diverse set of approaches to measuring different aspects of food systems sustainability and provides a basis of what should be measured and how.

All the shortlisted frameworks include more than one environmental dimension, accounting for a variety of environmental impacts. The frameworks include EU institutional frameworks, EEA and ETC works, UN institutional frameworks, academic studies, and other global and national frameworks. The shortlisted frameworks are presented in Table 1.

Table 1. List and summary of the 18 shortlisted, most promising food systems indicator frameworks. Links to online resources are embedded

Indicator framework	Summary
Eurostat	
Dataset on agriculture, forestry and fisheries (Eurostat, 2024)	Existing datasets on primary production sectors, available via Eurostat statistical database.
Key figures on the European food chain (Eurostat, 2023)	Based on statistical Eurostat datasets, the paper broadly describes the European food chain, from primary production in agriculture and fisheries, to processing and consumption, in quantitative terms.
DG Agri	
Context indicators (European Commission, 2024a)	Provides numerical & visualized data on social, economic, sector-specific and environmental indicator categories in the EU Food systems.
Sustainability Compass (European Commission, 2024b)	The compass provides a comprehensive 3-dimensional overview (economic, social and environmental categories) consisting of 20 key indicators.
EC	
The Farm to Fork monitoring framework (European Commission, 2020)	The *Farm to Fork Strategy* outlines a comprehensive plan to create a fair, healthy, and environmentally sustainable food systems in the EU, emphasizing the integration of sustainable practices across the entire food supply chain to benefit public health, biodiversity, and climate resilience. The monitoring framework covers the three main dimensions of sustainability: environmental, economic, social with 340 indicators in total.
JRC	
Concepts for a sustainable EU food system (European Commission. Joint Research Centre., 2022)	Via a broad, systemic stakeholder-perspective, summarises the key factors that should be considered in a legislative framework to improved food systems sustainability in the EU.
Food system sustainability compass (Hebinck et al., 2021)	Provides a framework for the systematic comparison of food systems sustainability state via a scoring framework.
Quantifying the impact of sustainable farming practices on environment and climate (European Commission. Joint Research Centre., 2024)	Highlights that sustainable farming practices significantly contribute to reducing environmental degradation and mitigating climate change while enhancing ecosystem services and agricultural resilience. The following indicators are used: GHG emissions, SOC, ammonia emissions, nutrient balance, nutrient leaching and run-off.
ETC	

Indicator framework	Summary
Cross-systems analysis of KPIs and policy levers (Haraldsson et al., 2024)	The report focuses on a cross-system analysis for a sustainable Europe in 2050, specifically in the food sector. The analysis employs a multi-method approach, combining qualitative and quantitative systems modelling, including causal loop diagramming (CLD).
UN	
UN Sustainable Development Goals indicators (United Nations Statistics Division, 2020)	Global policy framework outlining 17 general level goals and 169 more detailed targets described with 247 indicators.
The FAO SDG Food and Agriculture related indicators (FAO, 2023)	The report assesses progress on 8 SDGs: 1 (no poverty), 2 (zero hunger), 5 (gender equality), 6 (clean water and sanitation), 10 (reduced inequalities), 12 (responsible consumption and production), 14 (life below water) and 15 (life on land).
FAO's guidance on core indicators for agrifood systems(FAO, 2021)	Features a set of indicators (economic, environmental, social, institutional) for the contribution of private sector agents in the food systems to UN SDGs, while guiding data collection and reporting related to them.
Academic studies	
The state of the food systems worldwide in the countdown for 2030 (Schneider et al., 2023)	The report covers UN Member States over five transition themes: (1) diets, nutrition and health; (2) environment, natural resources and production; (3) livelihoods, poverty and equity; (4) governance; and (5) resilience and 50 indicators.
The EAT Lancet Commission Report (Willett et al., 2019)	Highlights the importance of changing our diets to improve both human health and the health of the planet. The methodology used in this report is an "adapted" safe and just space. Single evaluation with a global scope, including sub-global regions: Sub-Saharan Africa, North America and South Asia.
"Global map and indicators of food"(Béné et al., 2019)	The study presents the first global map of food systems sustainability. An aggregate sustainability score was computed based on 27 indicators organized into four dimensions: environment, social, food security & nutrition and economic.
Other studies	
Food systems dashboard (GAIN, 2024)	The dashboard has a global scope and covers over 275 indicators, whereas 50 indicators were selected for The Food Systems Countdown Initiative (FSCI).
A just food system transformation (Kaljonen et al., 2022)	Assesses the effects of 3 transition pathways (diet, technology- and land-use driven) on the sustainability of Finnish food systems, emphasizing justice aspects.

Indicator framework	Summary
A framework for measuring sustainability in the Swedish food system (Hansson et al., 2023)	Provides a detailed categorization & selection of indicators with which the sustainability of the Swedish food systems can be measured.

3 Evaluation criteria for food systems sustainability transition

We outlined a set of criteria to analyse the 18 indicator frameworks. The starting point for analysing the transition process is to define the socio-technical system to be considered, namely, its function, system elements and system boundary (Edmondson et al., 2018; Geels, 2004). Based on this, criteria were defined in terms of: (i) food systems elements identified by the frameworks, (ii) the relationships between these elements, and (iii) the function or purpose of the system, in a strict sense, encompasses nutrition, food security, and food safety. However, in this report, we adopt a broader perspective, considering its role in providing health, livelihoods, ecosystem regeneration, and services. In this wider sense, we interpret the purpose of food systems as achieving sustainability. These groupings reflect also Meadows' (2008) definition of “systems”.

The objective of this analysis was not to identify a single "best-fit" indicator framework but rather to explore how each framework addresses the aspects represented by the criteria. The criteria focus on theoretical concepts related to food systems (from a systems perspective), food systems sustainability (from the perspective of a safe and just operating space), and transitions theory.

It is assumed that all the analysed frameworks meet essential quality standards, such as accuracy, reliability, and robustness; therefore, these aspects were not explicitly addressed by the criteria. The criteria are detailed below.

3.1 Criteria on food systems elements

By "food systems elements" we refer not only to the actors operating within these systems but also to the components of the food systems value chain included in the frameworks, the cross-systems represented by the indicators, and the diversity of systems covered. A brief description of each element is provided in the bulleted list below.

These criteria do not directly address the sustainability of systems or their transitions. Instead, they ensure that the systems are correctly represented, thereby enhancing trust in the sustainability criteria applied.

- **Number of actors per value chain stage or type of actor:**
  This criterion provides insight into the size of the systems under analysis and can serve as a proxy for power relations within the food value chain. Ideally, an indicator framework should present the number of actors (e.g. employees, enterprises) operating at different value chain stages. (Score: yes/no)
- **Type of actors in the food value chain:**
  This criterion indicates the diversity of actors in the value chain, including small producers, large corporations, cooperatives, non-governmental organisations, and the public sector. It primarily facilitates the description/characterisation of the food systems rather than assessing sustainability. Indicators for this criterion could highlight the diversity of actors operating in the system, offering insights into potential power dynamics or control in the food chain. (Score: yes/no)
- **Number of value chain phases included:**
  These phases may include primary production, manufacturing/processing, transport and distribution, retail, services, consumption, and final treatment/disposal. Excluding certain phases can obscure significant impacts within the food value chain, resulting in incomplete assessments. Indicator frameworks should aim to include the entire value chain to accurately capture its full effects. (Score: number of phases included)
- **Number of cross-systems included:**
  Cross-systems, such as energy or transport, significantly impact food value chains (Haraldsson et al., 2024). Omitting these systems may lead to misrepresentation of food systems implications

and overlook critical leverage points for reducing environmental impacts. The more cross-systems included in an indicator framework, the more comprehensive it becomes. (Score: number of different systems)

- **Diversity of food production systems:**
  Food production systems vary widely in environmental impact based on factors such as animal feeding practices, manure management techniques, organic versus conventional farming, and the intensity of production systems (extensive, intensive, or super-intensive). Transition studies emphasise stimulating and accelerating niches, making it crucial for indicator frameworks to reflect this diversity. (Score: yes/no)
- **Treatment of diversity and uncertainty:**
  Given the diversity of food systems and their environmental impacts, this criterion evaluates how indicator frameworks address variability and uncertainty. Relying solely on average values likely obscures this diversity and uncertainty. Instead, alternative approaches such as standard deviations, marginal values, and ranges (minimum and maximum values) should be employed. This criterion assesses whether diversity and uncertainty are transparently disclosed within the framework. (Score: yes/no)

3.2 Criteria on relationships between the elements

Criteria describing the relationships are meant to understand how the frameworks capture the interactions between the elements of the food systems, to characterise the system behaviour. Systemic effects such as rebound effects and burden shifting via supply chains are two main aspects. Feedback loops, power relationships and social contestation are also a result from relationships between the elements. The list below describes briefly the criteria considered.

- **Burden shifting via supply chains or countries**, also referred to as "spill-over effect" or "leakage": Is intrinsically linked with whether the indicators are measuring aspects in a territorial based approach only (undesirable), thus neglecting supply chain effects that happen outside of their territories, or if they consider other wider approaches such as consumption-based or income-based approaches, where the impacts of the whole value chain are attributed to the country/consumer where consumption occurs or where the income went into, respectively (Domingos, 2015). Territorial based approaches (the most common) favour countries that do not produce their own food, thus opening the door to the spillover effects. This is the most common used approach and it the one followed by the UNFCCC in terms of GHG emission targets for ratified countries. Countries who are food exporters and not intense consumer will be favoured by consumption-based approach. Ideally, a mixture of approaches should be present, or at least, the consumption based or income base approaches. (score: yes/no if it considers any approach apart from the territorial approach)
- **Geographical location of imports**:
  The geographical location of imports helps identify potential risks in product supply, such as water stress or social conflicts in specific regions. It also enables tracking monetary flows, which is important for understanding power dynamics and identifying who benefits economically from certain processes. This offers an alternative perspective on indicators compared to consumption- and territorial-based approaches. Including the geographical location of imports is a positive feature of the indicator framework. (score: yes/no)
- **Monetary flows**:
  Does the framework describe monetary capital flows (where the money is going/accumulating, what actors or regions are gaining or losing)? (score: yes/no)
- **Social contestation:**
  Does the indicator allow for identifying potential social contestations or conflicts arising linked with food systems? (score: yes/no)

3.3 Sustainability criteria

In sustainability terms, indicator frameworks were checked to see if and how they include environmental and social aspects of food chains, but also, social and environmental boundaries. The criteria considered are:

- Relevant **functional units considered**,
  E.g., does it account for the nutritional value of different types of foods? (score: yes/no)
- **Relevant social dimensions of food systems**,
  Such as nutritional value, food safety, food security, food availability, accessibility, costs of food, water access, energy access, livelihoods/income, work conditions. (score: number of dimensions)
- **Relevant environmental dimensions of food systems**,
  Based on the Planetary Boundaries dimensions, in particular, studies applied to food systems (e.g. Conijn et al., 2018; Cooper and Dearing, 2019; Willett et al., 2019; Gerten et al., 2020); climate change, novel entities (i.e., pesticides, GMO, etc.), N and P releases (fertiliser use, ammonia use), freshwater use, aerosol emissions (Ammonia, $PM_{2.5}$), land use changes (includes soil carbon), biodiversity (includes HANPP), any other. (score: number of dimensions)
- **Waste:**
  Is waste generated in the value chain included? (score: yes/no)
- **Weak and strong sustainability and trade-offs**:
  Weak sustainability assumes that natural capital can be totally substituted by manufactured capital (Ekins et al., 2003; Neumayer, 2003, 2012) Strong sustainability assumes that there is a limit to this substitutability (Constanza and Daly, 1992). Indicators, indexes and monitoring frameworks under weak sustainability consider trade-offs between the economic and environmental indicators. Thus, these criteria relate to how social, environmental and economic dimensions are integrated. Are economic issues summed with environmental issues, allowing for complete substitutability of economic aspects and environmental aspects? Is there some critical natural capital safeguarded? Evaluation based on whether the framework is based on strong sustainability paradigm. (score: "yes", for a framework based on string sustainability principles / "no", for a framework based on weak sustainability principles).
- **Inclusion of environmental limits:**
  does the framework address e.g., carrying capacity, land productivity (how much can be produced based on soil, how N or P fertilizers can be used without damaging local ecosystems, how much water can be used without causing water stress). (score: yes/no).

In addition to the selected criteria described above, several other potential criteria were considered but left out from the evaluation either because they were considered less relevant, or unfeasible to evaluate with the shortlisted cases and the resources available for the evaluation. For example, power relations (control, class struggles, gender inequalities, ethnicity) or justice (Kaljonen et al., 2023) are relevant aspects of transition processes. However, based on the initial screening, these are generally not covered by the examined frameworks, and the likelihood of finding fully operational quantitative indicators describing them is, therefore, low. Nevertheless, these criteria should be addressed in further development of the indicators for transition monitoring.

3.4 Assessment of the evaluation criteria in terms of transitions

3.4.1 The "dimensions" approach to sustainability transition

Here, we utilise the dimensions framework, originally developed by Fraunhofer ISI and intended to provide a structure for assessing the status of transitions in socio-technical systems. The framework highlights that change can be analysed from the perspective of different dimensions (Edler et al., 2021). Here, it is tested as a tool to provide a common methodology for more detailed case study work and analysis, enabling different cases to be compared and analysed consistently. Thus, systems and transformations are the two main categories of the framework (see Table 2).

Table 2. Overview of the "dimensions" framework

SYSTEM DIMENSIONS		
Meta-category	**Dimension**	**Questions for analysis**
General	Societal function	Which societal function does the system address?
	Relevant sectors	Which sectors are involved?
Characteristics	Geographical scope	What is the geographical scope of the system? Are system phenomena globally similar or locally specific?
	Policy and regulations	Which policies and regulations are relevant – in the focal sector and in other involved sectors?
	Infrastructures: Physical, knowledge, financial	Which physical, financial, and knowledge infrastuctures are involved?
	Interactions with other systems	With which other socio-technical systems can interactions be observed? Which levels and/or components of the focal system are interacting with other systems? What types of interactions can be observed (competitive, cooperative, functional, spill-over, neutral)?
	Actor constellations and their capacities	Which actor groups are involved to what extent? What networks are relevant? What are actors' and networks' capacities (resources, strategies, skills?)
	Power structures	What are existing power constellations (e.g. politically, financially, industrially, in civil society) that hinder greater sustainability of the system?

TRANSFORMATION DIMENSIONS		
Meta-category	**Dimension**	**Questions for analysis**
General	Societal need	Which societal need does the transformation address? How strong is societal support for the transformation?
Coordination & contestation	Policy and regulations	Which policies and regulations need to change (in terms of both new policy formulation and phase-out of old policies)?
	Governance structures	Do governance structures alllow for the inclusion of non-state actors into decision-making processes?
	Financing	What financing is needed? What investment opportunities exist? What are risks?
	Degree of coordination	Is a high or low degree of coordination amongst actors necessary for the transformation? How successful are actors in mobilizing and coordinating resources?
	Nature of contestation	What is the potential for social conflict (distribution, ethics, etc.)?
	Degree of (national) autonomy	To what extent is there a national degree of freedom to act on the technological, economic, and political sides?
Dynamics	Development over time	Which transformative learning processes are needed by which actors? Which future windows of opportunity are possible and what is needed to take advantage of them?
	Emergent vs intentional	Is the transformation driven by market forces or politically/societally?
	External shocks	How can the transformation be resilient to and/or take advantage of external shocks?
	Innovations	Which innovations (e.g. technological, organisational, social) are necessary for the transformation?
	Demand articulation & market development	To what extent is demand articulated by users? How is market development progressing (who is involved, what is happening)?

Source: Adapted from Edler et al. (2021).

The system can be delineated and qualified by its (1) function, (2) constituent elements (its technologies, practices, socio-cultural factors, the economic sector(s) and their properties, its geographical scope) and (3) institutional, relational and infrastructure context. The narrative of the main transitions theories (Strategic Niche Management, Multi-Level Perspective, Technological Innovation Systems, and Transition Management) is one of contestation/power struggles between the regime and niche(s) responding to changes in the landscape environment. Therefore, it is necessary to understand the niche and regime actors in each system as well as power relationships between them. In addition, both agency and the roles taken by actors are dynamic and may change during the transformation process.

Processes of transformative changes are often analysed by identifying drivers and barriers (internal or external to the system). Grin et al. (2010) identify problems of sustainability that drive change while the innovation system/TIS approach supports the identification of how to overcome barriers (Bergek et al., 2008).

Those drivers are either bottom-up changes in societal preferences and needs as well as technological development, or they are politically constituted through policy and regulation. Transformations necessitate coordination of interests, visions, goals, and expectations. A successful transformation will also depend upon the capacity of actors to mobilize - and coordinate - resources.

Given that major transformations produce winners and losers, they are, in general, highly political. We thus also pay particular attention to the properties and dynamics of political structures, contestation and coordination of actors in policy (Mazzucato, 2018). National autonomy in influencing a transformation may be limited due to landscape factors, such as limited economic resources, weak institutions, corruption, or being dependent on transnational economic, financial, or political forces.

The categories of factors influencing the dynamics of socio-technical systems change can be summarised as the drivers or social need, politics (and governance), together with the description of the dynamics of the system.

Finally, while all those categories determine largely how a system changes, a concept to grasp the progress in a transformation will have to carefully analyse if and how those drivers and barriers, as well as context, may develop over time, e.g., in the different transition phases (Geels, 2002; Geels and Schot, 2007). Different patterns in the dynamics of transformation processes can be observed (Geels et al., 2016; Geels and Schot, 2007). The 'maturity' and 'phase of development' of socio-technical systems have been used in the Neo-Schumpeterian literature on Kondratiev Waves as well as in the MLP to describe the development over time (Freeman and Louçã, 2001). Geels and Schot (2007) and Geels et al. (2016) theorize that the dynamics are determined by interactions between landscape pressures and niche pressures.

External shocks may cause recalibrations in various aspects of systems, or even in multiple systems, and hence may also create space for innovations to emerge and transformations to unfold (Roberts and Geels, 2019).

Comprehensive research has shown that bottlenecks on the demand side can severely hamper the diffusion of innovation (Edler and Fagerberg, 2017), and thus transformation. We can observe two central actors that can influence a system transformation through demand articulation: users and state authorities. Users can lead to a change in systems through new patterns of consumption. Different kinds of demand side policy tools such as public procurement, demand subsidies or training and awareness measures can overcome those bottlenecks.

3.4.2 *Assessment of the evaluative criteria*

A variety of approaches for examining the sustainability transition process exists (e.g., Edler et al. 2021 and Dethier and Roman (2024). The evaluative criteria include key elements of transitions as showed in the Table 3.

Table 3. Comparison table between the transition dimensions framework and the selected evaluation criteria

Transitions Dimensions (from Edler et al., 2021)	Correspondence with the evaluation criteria
Societal function	**Social (and economic) issues** **Functional unit**
Sectors involved	**Type of actors** **Number of actors** **Number of cross systems**
Geographical scope	**Money flows**
With which other socio-technical systems can interactions be observed? Which levels and/or components of the focal system are interacting with other systems? What types of interactions can be observed (competitive, cooperative, functional, spill-over, neutral)?	**Geographical location of inputs** **Number of cross systems**
Which actor groups are involved to what extent? What networks are relevant? What are actors' and networks' capacities (resources, strategies, skills?)	**Type of Actors** **Number of actors**
Power constellations	**Type of actors** **Number of actors**
Which societal need does the transformation address? How strong is societal support for the transformation?	**Functional unit** **Social (and economic) dimensions**
Is a high or low degree of coordination amongst actors necessary for the transformation? How successful are actors in mobilizing and coordinating resources?	**Type of Actors** **Number of actors** **Money flows**
Which innovations (e.g. technological, organisational, social) are necessary for the transformation?	**Treatment of diversity and uncertainty**
General - societal function: Which societal function does the system address?	**Social (and economic) dimensions**
General - relevant actors: Which sectors are involved?	**Waste generated** **Type of actors** **Number of cross systems**
Characteristics - geographical scope: What is the geographical scope of the system? Are system phenomena globally similar or locally specific?	**Geographical location of inputs** **Money flows**
Characteristics: interactions with other systems - With which other socio-technical systems can interactions be observed? Which levels and/or components of the focal system are interacting with other systems? What	**Burden shifting** **Number of cross systems**

Transitions Dimensions (from Edler et al., 2021)	Correspondence with the evaluation criteria
types of interactions can be observed (competitive, cooperative, functional, spill-over, neutral)?	
Characteristics: actor constellations and their capacities - Which actor groups are involved to what extent? What networks are relevant? What are actors‘ and networks‘ capacities (resources, strategies, skills?)	**Types of actors**
Characteristics: power structures - What are existing power constellations (e.g. politically, financially, industrially, in civil society) that hinder greater sustainability of the system?	**Number of actors**
General: societal need - Which societal need does the transformation address? How strong is societal support for the transformation?	**Social (and economic) dimensions**
Coordination and contestation: degree of coordination - Is a high or low degree of coordination amongst actors necessary for the transformation? How successful are actors in mobilizing and coordinating resources?	**Money flows** **Number of Actors** **Type of Actors**
Dynamics: innovations - Which innovations (e.g. technological, organisational, social) are necessary for the transformation?	**Treatment of diversity and uncertainty**

The evaluative criteria do not cover the following questions from the transitions dimensions framework described in Section 3.4.1:

- *Characteristics: policy and regulations* - Which policies and regulations are relevant – in the focal sector and in other involved sectors?
- *Characteristics: infrastructures (physical, knowledge, financial)* - Which physical, financial, and knowledge infrastructures are involved?
- *Coordination and contestation: policy and regulations* - Which policies and regulations need to change (in terms of both new policy formulation and phase-out of old policies)?
- *Coordination and contestation: governance structures* - Do governance structures allow for the inclusion of non-state actors into decision-making processes?
- *Coordination and contestation: financing* - What financing is needed? What investment opportunities exist? What are risks?
- *Coordination and contestation: nature of contestation* - What is the potential for social conflict (distribution, ethics, etc.)?
- *Coordination and contestation: degree of national autonomy* - To what extent is there a national degree of freedom to act on the technological, economic, and political sides?
- *Dynamics: development over time* - Which transformative learning processes are needed by which actors? Which future windows of opportunity are possible and what is needed to take advantage of them?
- *Dynamics: emergent vs intentional* - Is the transformation driven by market forces or politically/societally?
- *Dynamics: external shocks* - How can the transformation be resilient to and/or take advantage of external shocks?
- *Dynamics: demand articulation and market development* - To what extent is demand articulated by users? How is market development progressing (who is involved, what is happening)?

These questions are often difficult to cover with quantitative indicators. A reflection on these is included in section 4.3 of this report.

4 Results based on the shortlisted cases

4.1 How do current indicator frameworks cover the criteria?

Each of the shortlisted frameworks was assessed on how well they describe the developed monitoring criteria. Scores were assigned to each framework based on its performance. Table 4 presents the results from the evaluation. Each indicator framework (numbered IF1 to IF18) is listed in the columns, while evaluation criteria are listed in the rows. The legend below the table describes the correspondence between the framework number and the name. The numeric value in each cell denotes the evaluation score for each criterion. For each criterion of “yes/no”, the value “1” is attributed to “yes” and “0” otherwise. In some cases (e.g., IF16 in the “number of actors per life cycle stage”), there is no perfect “yes”, and on those situations the value of “0,5” was attributed. Coloured cells denote the high-scoring frameworks in each criterion. The table should be read vertically, i.e., the results per criterion, rather than the results per indicator framework. This is because scores in each criterion have not been normalised. Also, cross-criteria comparisons involved the definition of relative weights to the criteria, which were not considered in the present work. Having said this, it is still possible to identify the indicator framework that presents the highest number of indicators meeting the criteria. This was the case for the ETC ST work “Cross-systems analysis and KPIs” (IF 8 in Table 4). The framework received maximum scores concerning seven criteria (corresponding to 39 % of studied criteria) (Table 4) and scored highly (six points out of at maximum nine) concerning social and environmental criteria as well. As such, this framework had the highest number of good examples on how to implement the criteria into a transition framework.

The results indicate that existing sustainability and transition monitoring frameworks offer a solid knowledge base, even though indicators meeting the criteria were unequally divided among many existing frameworks. Despite the large variation in overall score between the frameworks, each of them contained some useful insight on what indicators should be considered in an improved food systems transition monitoring framework and was capable of accounting for most of the developed monitoring criteria. For example, most frameworks approached sustainability from a broad perspective, including e.g. economic, social, and environmental aspects discretely, with each encompassing multiple sub-themes and proposed indicators. In four cases there was a significant overlap in the indicators as the frameworks relied on the same sources or databases (e.g., frameworks 13 and 14 based on UN SDG indicators, frameworks 18 and 5 based on Eurostat data).

Nevertheless, the analysis identified striking data gaps regarding some of the criteria. Feedback loop mechanisms, cross-systems, and social contestation receive almost no attention in the existing frameworks, as most frameworks (94 %, 72 %, and 50 % of frameworks, respectively) scored zero points concerning these criteria. Additionally, less severe gaps were identified for two criteria, namely waste generated in the food chain and number of actors per life cycle stage, for which no framework obtained maximum scores. This indicates that a relevant information gap exists regarding these within the existing frameworks. The situation was similar for the environmental dimensions criterion, but in this case, only one point was missing from the maximum possible score. Just two frameworks scored highly for the ‘Treatment of variability and uncertainty’ criterion. This is indicative of the fact that most frameworks utilized a conceptual approach and rarely reported numerical example values or data source recommendations.

Table 4. Evaluation results for the performance of each framework to fit the developed evaluation criteria. Rows denote sustainability criteria and columns correspond to frameworks analysed. Colour highlights denote frameworks that scored the highest points for each criterion

Criteria	Indicator Frameworks																	
	IF1	IF2	IF3	IF4	IF5	IF6	IF7	IF8	IF9	IF10	IF11	IF12	IF13	IF14	IF15	IF16	IF17	IF18
Number of actors per life cycle stage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,5	0	0
Type of actors	0	0	0	1	0	0	0	0,5	0	0	0	1	0	0	0	0	0	1
Number of value chain phases	1	1	4	10	5	0	2	5	2	0	2	2	6	4	2,5	4	1	8
Number of cross systems	1	0	0	14	0	0,5	0	1	0	0	0	0	0	0	0	0	1	0
Inclusion of the diversity in food systems	0	1	0	0	0	0	0	1	0	0	0	1	1	0,5	0,5	1	0	0
Treatment of variability and uncertainty	0	1	0	0	0	0	0	0	1	0,5	0	0	0	0	0	0	0	0
Burden shifting via supply chains or countries	0	1	0	1	1	1	1	1	1	0	1	0	0	0	0	1	0	1
Geographical location from imports	0	0	0	1	1	0	0	1	1	0	1	0	0	0	0	0,5	0	1
Money flows	0,5	0	0	1	1	0	0	1	1	0	1	1	0	0,5	0	1	0	1
Feedback loop mechanisms (including resilience)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Social contestation	0	0	0	0	0	0	0	0,5	0	0	0	0	0	0	0	0	0	0
Functional unit	0	0	0	0	0	0	0,5	1	1	0	1	1	0	0	0,5	0	0	0
Environmental dimensions	4	3	8	7	4	7	5	6	1	7	1	8	4	3	3	5	5	4
Waste generated in the food chain (per stage)	1	0	0	1	1	0	1	1	0	1	0	1	1	3	3	0	0	1
Social dimensions	9	0	9	6	3	4	1	6	2	6	6	9	2	6	7	2	0	2
Sustainability trade-offs	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0,5	1	1
Social and environmental limits	0	0	1	1	0	1	1	1	0	0	0	0	1	0,5	1	1	0	0

Indicator Frameworks: IF1 – Global map and indicators of food (Béné et al., 2019); IF2 – JRC: Quantifying the impact of sustainable farming practices on environment and climate (European Commission. Joint Research Centre., 2024); IF3 – JRC: Food System Sustainability Compass (Hebinck et al., 2021); IF4 – JRC: Concepts for a sustainable EU Food System (Bock et al., 2022); IF5 – EUROSTAT: Key Figures on the European food chain (Eurostat, 2023); IF6 – "A framework for measuring sustainability in Swedish food system" (Hansson et al., 2023); IF7 – The EAT Lancet Commission report (Willett et al., 2019); IF8 – ETC ST: Cross-systems analysis of KPIs and policy levers (Haraldsson et al., 2024); IF9 – A just food system transition (Kaljonen et al., 2022); IF10 – The state of food systems worldwide in the countdown for 2030" (Schneider et al., 2023); IF11 – Food system dashboard (GAIN et al., 2024); IF12 – EC: The Farm to Fork monitoring framework; IF13 – FAO: Guidance on core indicators for agrifood systems; IF14 – FAO: SDG Food and Agriculture related indicators; IF15 – UN: UN Sustainable Development Goals indicators; IF16 - DG Agri: Sustainability compass; IF17 - DG Agri: Context indicators; IF18 – EUROSTAT: Dataset on agriculture, forestry and fisheries.

4.2 Proposal for food systems sustainability transition monitoring indicators

Based on the assessment presented in the previous section, we compiled a list of specific example indicators that fittingly describe the evaluation criteria developed. Due to the large variety of available examples befitting each criterion, examples that i) describe the evaluation criteria well, ii) were prevalent in the studied frameworks, and iii) can be readily quantified, were chosen instead of aiming for full coverage of the findings. The examples were selected from the shortlisted frameworks, considering only such that provided good data coverage at the Member State and European Union level. As seen previously, the indicator frameworks do not cover perfectly all the evaluation criteria, thus, additional indicators were proposed, leveraging expert input to address unmet evaluation criteria.

Table 5 presents the selected examples. The first column lists the evaluation criteria, while the second column lists an example framework that performed particularly well regarding each of the criteria. The third column presents an example indicator from the shortlisted frameworks that fits the criteria in question. The last column presents the authors' illustration of indicators that could satisfy the evaluation criteria.

The indicators could not be provided for some of the criteria (other feedback loop mechanisms and social contestation). These areas need further assessments on what an indicator for these areas could be, or whether they should be covered by other means of monitoring than quantitative indicators.

Table 5. Proposals for specific indicators to describe the evaluation criteria

Evaluation criteria	The high-scoring framework	Examples of how these have been addressed by the indicator frameworks	Additional team proposition of indicators [(a)]
Number of actors per life cycle stage	DG Agri: Sustainability compass	Total farm number	Number of agricultural producers, fishers and aquafarmers; Number of food and drink manufactures, wholesale suppliers, retail and services; Country population (i.e., consumers).
Type of actors	JRC: Concepts for a sustainable EU Food System	Separation of the actors can be accomplished e.g., by using NACE categories	Average size of the farms, retail spaces, manufacturers, suppliers; Number of SMEs and Les; Number of cooperatives involved; Number of NGOs involved per value chain phases.
Value chain phases	JRC: Concepts for a sustainable EU Food System	Overall number of value chain steps/actors included.	Inputs for food production, production itself (agriculture, fishing and aquaculture), processing and manufacturing, transport and distribution, retail and services, consumers, waste treatment
Cross systems	JRC: Concepts for a sustainable EU Food System	Number of identified cross-systems can be derived from the paper and might constitute a potential indicator similarly to	GHG emissions from transport and distribution; transport km of food products; Energy GHG emissions, energy consumption and energy type consumed in the

Evaluation criteria	The high-scoring framework	Examples of how these have been addressed by the indicator frameworks	Additional team proposition of indicators [(a)]
		that of the previous criteria (value chain phases).	food value chain; Education level of the actors involved in the different stages of food value chain; Relative difference between food prices and citizen's purchase power, evolution of diet related diseases.
Inclusion of diversity of food systems	DG Agri: Sustainability compass	Farming intensity (% agricultural area w. high intensity); share of land for organic agriculture (% agricultural area)	Area of organic farming; extensive grazing (vs. intensive grazing); Environmental impacts discriminated by type of food systems (extensive/ intensive, manure management, feeding practices).
Treatment of diversity and uncertainty	JRC: Quantifying the impact of sustainable farming practices on environment and climate	Standard deviations are presented along with the (average) values for the indicators used.	Values presented in ranges (rather than crisp value); Uncertainty ranges presented; Standard deviations presented.
Burden shifting via supply chains or countries	ETC ST: Cross-systems analysis of KPIs and policy levers	Share of agricultural area under organic farming; Net GHGs Emissions from LULUCF sector; Per Capita Agri-Food PRODUCTION emissions, for all countries & EU27, etc.	Indicators measured in a consumption-based approach (rather than territorial-based)
Trade between countries	ETC ST: Cross-systems analysis of KPIs and policy levers	Import; Export; Throughput; Import Dependency Ratios	Imports and exports (amount, revenues) discriminated by origin/destination, respectively
Money flows	JRC: Concepts for a sustainable EU Food System	Distribution of income/value added in the food value chain; Distribution of cost/risk. At country-level, import/export statistics (see the previous criterion regarding geographical location) offer a usable indicator for monetary/product flows between countries.	Distribution of income/value added in the food value chain and by country
Other feedback loop mechanisms (including resilience)	The state of food systems worldwide in the countdown for 2030	Nine indicators on resilience: Ratio of total damages of all disasters to GDP; Dietary sourcing flexibility index; Mobile cellular subscriptions (per 100 people); Social capital index; Proportion of	n.a.

Evaluation criteria	The high-scoring framework	Examples of how these have been addressed by the indicator frameworks	Additional team proposition of indicators [(a)]
		agricultural land with minimum level of species diversity (crop and pasture); Number of (a) plant and (b) animal genetic resources for food and agriculture secured in either medium or long-term Conservation facilities (SDG 2.5.1); Coping strategies Index; Food price Volatility; Food supply variability.	
Social contestation	n.a.	No direct measurement by indicators of contestation	Number of different types of actors involved in policy process Distribution of revenue flows across social groups Numbers of protest actions reported
Functional unit	A just food system transition	Change in dietary composition needs (%) when transitioning from current diet to a diet meeting dietary recommendations and reducing greenhouse gas emissions by one-third or half	Values presented per calories; person/calories; per unit of protein or other macronutrients.
Environmental dimensions	JRC Food System indicators JRC: Food System Sustainability Compass	Area of land cover categories; Areas Facing natural and other specific constraints; Natura 2000 area; Farmland birds index (FBI); Conservation status of agricultural habitats; Water abstraction in agriculture; Water quality; Soil organic matter in arable land; Soil erosion by water; Emissions from agriculture.	Includes at least: GHG emissions (and/or radiative forcing); N and P flows (and water quality and eutrophication); air pollution; indicators for biodiversity; land use and land use changes; waste generated (and in which stages of the value chain)
Waste generated	UN SDGs	Food loss index; food waste index	Waste generated (and in which stages of the value chain)
Social (and economic) dimensions	JRC: Food System Sustainability Compass	Safe diets; Protect the right to food; Increase food security and nutrition; Just working conditions; High animal welfare; Stable commodity prices	Cost of a (healthy/sustainable) diet (€/day) compared to purchase power; Percentage of population that cannot afford a healthy diet; retail value of ultraprocessed foods (€/year); Availability of fruits and vegetables (g/day); Nutritional level of the country's population, Prevalence of undernourishment (% of population); Evolution of

Evaluation criteria	The high-scoring framework	Examples of how these have been addressed by the indicator frameworks	Additional team proposition of indicators [(a)]
			diet-related diseases; Income to actors in the food chain; Percentage of population experiencing moderate or severe food security.
Weak and Strong Sustainability	JRC: Concepts for a sustainable EU Food System)	Practically all studied frameworks separate economic, social and environmental indicators	Separate indicators regarding economic, social and environmental issues
Environmental and social limits	DG Agri: Sustainability compass	Environmental limits only: Nitrates in groundwater; Pesticides: harmonised risk indicator 1 (index on 2011-2013 average); ammonia emissions (Mt NH_3); GHG emissions from agriculture (Mt + share of agriculture in total emissions).	Use of downscaled planetary boundaries for food systems; Considering biocapacity of countries or maximum sustainable yields of lands.

Notes: (a) These do not intend to be exhaustive.
References to the frameworks can be found in Table 4

4.3 Comparison of available indicators with transitions dimensions

We now summarise the indicators available and proposed in the table above in comparison to the transitions' dimensions shown in Table 2. The review of transitions' analyses in the food sector (see section 1.3) showed that the case studies of food systems in the transitions literature use a range of quantitative indicators. Our analysis has shown that there are a large number of quantitative indicators for the food systems that are available and relevant to transitions' analysis. The relevant indicators for any particular assessment are dependent on the particular food systems to be analysed and the context in which this system functions.

Two aspects that are important for an assessment of progress towards a transition to sustainability in food systems are, however, very limited to the indicator systems that have been identified in this project. First, there is little work on the governance structures and how the different levels of policymaking and regulation function in relation to sustainability policy for transitions. Second, there are no direct assessments of the overall progress with the (potential) sustainability transition dynamic. There are few indicators to measure the extent of (socio-political-economic) networks or their growth over time. Such indicators would address the growth of niches in the transitions theory. Measures of relations between the regime and niches, whether cooperative or competitive, are also required.

The relevant dimensions for governance in Table 2 are:

- Characteristics
    - Infrastructures: Physical, knowledge, financial
      Which physical, financial, and knowledge infrastuctures are involved?
    - Power structures
      What are existing power constellations (e.g. politically, financially, industrially, in civil

society) that hinder greater sustainability of the system?

- Governance structures
    - Degree of coordination
      Is a high or low degree of coordination amongst actors necessary for the transformation? How successful are actors in mobilizing and coordinating resources?

    - Nature of contestation
      What is the potential for social conflict (distribution, ethics, etc.)?

    - Degree of (national) autonomy
      To what extent is there a national degree of freedom to act on the technological, economic, and political sides?

- Dynamics (of the sustainability transition process)
    - Development over time
      Which transformative learning processes are needed by which actors? Which future windows of opportunity are possible and what is needed to take advantage of them?

    - Innovations
      Which innovations (e.g. technological, organisational, social) are necessary for the transformation?

We emphasise that the proposed indicator structure is not comprehensive and is derived from available indicator systems. The description and assessment of infrastructures (and the related concepts of capacity) could be addressed by separating infrastructure elements from food systems operations and outputs.

The dimensions with limited data and indicators mainly relate to social and policy processes of change, which determine the progress towards a sustainability transition (the dimensions of dynamics in Table 2). This reflects the requirement to provide scientifically valid measures of the food systems. However, the fundamental idea of the transitions' framework is that the technology and markets are only part of the system, and the policy processes and actor relations determine the progress or otherwise of a transition.

5 Conclusions and the path forward

This study aimed to provide a broad overview of food systems transitions by employing a scoping study approach that selected and compared diverse cases illustrating the use of indicators in food systems monitoring. Unlike systematic reviews or in-depth analyses of individual cases, it focused on mapping and evaluating 18 prominent examples to identify key elements, relationships, and sustainability considerations within food systems. Cases were selected based on their policy relevance, cross-country comparability, and data availability. Although the study is not exhaustive, it provides an overview on what indicators have been typically used to assess food systems' sustainability. We proposed practical indicators based on existing, reliable data while identifying gaps and development needs, offering insights for enhancing sustainability transition monitoring and informing future European environmental reporting.

In terms of the availability of quantitative data, numerous quantitative indicators for food systems exist with relative relevance for transitions' analysis. Existing sustainability and transition frameworks provide a strong knowledge base and address the most developed monitoring criteria. Many frameworks adopt a broad perspective, covering economic, social, and environmental aspects with multiple sub-themes and indicators. Significant overlap exists among frameworks, both due to reliance on common data sources and attempts to find synergies between different use contexts (such as the use of UN SDG indicators for the food sector reporting by the FAO).

Existing frameworks assessed fail to fully meet all the criteria, necessitating innovative approaches for comprehensive monitoring. Critical gaps exist in addressing feedback loop mechanisms, cross-systems interactions, and social contestation, with most frameworks scoring zero on these criteria. Other areas of concern include waste generation in the food chain and the number of actors per life cycle stage, where no framework achieved maximum scores. Variability and uncertainty are poorly addressed, with only two frameworks scoring highly in this criterion, reflecting a preference for conceptual approaches over data-driven methodologies. For criteria like feedback loops and social contestation, no suitable indicators were identified, requiring further research. Some of the evaluation criteria can be too ambitious and might require modeling. An example of such is cross-system indicators and feedback loops. Therefore, there might not be simple ways to respond to these needs. Regarding transitions: Indicators for governance structures and direct assessments of sustainability transition dynamics are notably limited. Existing indicators inadequately capture social and policy processes, which are crucial for understanding and advancing sustainability transitions. Additionally, indicator frameworks require better integration of policy and actor relations alongside technological and market considerations.

Significant gaps in the data exist, in particular with regards to the dynamic process of a transition to sustainability. While the assessed frameworks provide valuable insights, addressing data gaps and improving the treatment of variability and uncertainty are essential steps toward developing a more comprehensive monitoring framework for food systems transitions. The ETC ST work *"Cross-systems analysis and KPIs"* emerged as the highest-performing framework, excelling in seven criteria and demonstrating robust social and environmental coverage. This framework could serve as a foundation, with adjustments to incorporate additional elements and improve its scope.

Future research should focus on data availability and use across sectors, determining the optimal number of transition monitoring indicators, and refining the evaluative criteria. This includes integrating further assessments from transitions theory, examining power and policy dynamics, and drawing from political economy and sustainable finance perspectives.

6 List of abbreviations

Abbreviation	Name	Reference
EC	European Commission	
EEA	European Environment Agency	www.eea.europa.eu
ETC ST	European Topic Centre for Sustainability Transitions	
FAO	Food and Agricultura Organisation of the United Nations	
IF	Indicator Framework	
JRC	Joint Research Centre	
SDG	Sustainable Development Goals	
UN	United Nations	
WoS	Web of Science	

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