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EU food system monitoring framework. From concepts to indicators

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Contents

Abstract

The Joint Research Centre (JRC) – the European Commission service providing evidence-based science and knowledge to support EU policies – has set up its first monitoring framework to provide information on progress towards a fair, healthy and environmentally friendly food system, built on a set of environmental, economic and social (including health) indicators. More than 350 indicators on underpinning policies were screened and their suitability assessed for the intended objective. The selected indicators have been visualised in a monitoring dashboard, an information system and a communication tool created by the JRC.

This report summarises the main steps taken to develop the system, the principles governing the selection of the indicators and plans for further work. This EU monitoring framework does not constitute a final product. The various Commission services acknowledge data gaps and intend to address them to ensure a more comprehensive approach and reflect new policy priorities. The monitoring framework will provide policymakers, stakeholders and citizens with relevant information about the sustainability of the EU food system. Considering the significant impact of the food system on the EU's economy and citizens, the monitoring tool intends to assess the cumulative impact of all actions related to competitiveness, the environment and health in the EU.

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Executive summary

A sustainable food system delivers food security, nutrition and food safety for all without compromising economic, social and environmental sustainability to ensure food security, nutrition and food safety for future generations ([1]). In other words, food systems should contribute to the sustainable development goals, and, to achieve this, they have to operate within the planetary boundaries.

This report describes the scientific and technical work related to establishing a framework for monitoring the sustainability of the food system in the European Union. Key elements of this framework are indicators linked to the different elements of the conceptual model, including the components of the food supply chain and a system of sustainability criteria.

This framework builds, as much as possible, on existing data from various data sources in the EU and from international organisations. The Joint Research Centre (JRC) undertook a detailed quality assessment of relevant data based on original metadata. This process yielded an initial selection of existing indicators for immediate use in a monitoring framework for the EU food system. It also identified knowledge gaps related to the components of the food supply chain and sustainability criteria, which need further work in terms of developing the methodology and data collection.

In the course of the work, the JRC set up a comprehensive database documenting all indicators – including placeholder indicators – which were screened with a view to defining the knowledge gaps. The database is integrated with tools that enable stakeholders to interact with the data, including a dashboard for publishing data on the selected indicators.

Policy context

The European Green Deal aims to help the EU become climate neutral and resource-efficient, ensuring economic growth within the planetary boundaries. To meet this objective, it recognises the need for systemic changes in the key economic sectors, including those related to food. The farm-to-fork strategy communication (COM(2020) 381 final) recognises the inextricable links between healthy people, healthy societies and a healthy planet. It calls for reducing the environmental and climate footprint of the EU food system and monitoring the transition towards a sustainable food system to ensure that it operates within the planetary boundaries.

Key conclusions

Monitoring the sustainability of the EU food system is a complex task that requires a comprehensive understanding of environmental, economic and social aspects related to primary food production, processing, distribution and consumption. The monitoring framework has been developed primarily using official data sources in the EU and aims to be consistent with other existing monitoring frameworks. However, future work is needed to fill the current knowledge gaps, with the close involvement of experts from the policy, statistical and scientific communities, as well as from a wider group of stakeholders, in view of further developments in the years to come.

([1]) https://www.un.org/en/issues/food/taskforce/pdf/All%20food%20systems%20are%20sustainable.pdf.

Main findings

The sustainability of the EU food system can be monitored using indicators linked to the components of the food supply chain (i.e. pre-production, production, processing, distribution, consumption, disposal) and the various sustainability dimensions (i.e. economic, social, environmental). To better navigate the interlinked aspects, a conceptual model was developed containing 3 dimensions, 12 thematic areas and 38 domains. To improve their comparability, the indicators were documented based on standardised metadata and scored according to the criteria in a quality assessment framework. This procedure yielded an initial selection of indicators that covered all the thematic areas, the majority of the domains and the components of the food supply chain. However, gaps appeared in food processing and distribution, as well as in a few sustainability domains.

This report focuses on the gradual development of a database, a unique repository supporting the work of the experts in each thematic area, exchange with stakeholders, and the reporting and visualisation of the indicators in a dashboard. This database implements the conceptual framework for the monitoring system and stores the metadata on the indicators. The values of the indicators are not stored centrally but harvested from the original sources using machine-to-machine communication. This contributes to propagation of updates and overall consistency with the original sources.

Related and future JRC work

The monitoring framework will be a dynamic system incorporating new knowledge and new user requirements, including new policies. This process of evolutionary maintenance could also incorporate inputs from stakeholders and Member State experts.

In parallel with assessing existing indicators, knowledge gaps in food system sustainability were identified. One of the priorities for future work will be to explore new data sources and develop a methodology for establishing new indicators.

The harmonised presentation of indicators in the monitoring framework will offer new opportunities for analysing the state and progress of the EU food system, providing input to different stages of policymaking.

Quick guide

This report is structured as follows. Chapter 1 explains the importance of data on and monitoring of the transition to a sustainable food system in the EU. Chapter 2 describes the architecture of the monitoring system and its technical implementation. The conceptual model (data model, associated metadata schema and quality assessment framework) underlying the system is detailed in Chapter 3. The workflow for indicator selection is presented in Chapter 4, while the initial set of indicators proposed for the dashboard are provided in Chapter 5. The report concludes with a look at further work in Chapter 6 and general conclusions in Chapter 7.

1. Introduction

Food system sustainability in the global and EU political agenda

As recognised by the Food and Agriculture Organization of the United Nations (FAO) in 2014, 'a range of pressures, including rapid population growth, urbanisation, growing wealth and consequent changes in consumption patterns, are challenging our food systems' ability to provide nutritious food, and to contribute to enhanced livelihood opportunities in an environmentally sustainable way. Our food systems are contributing to, and affected by, extreme weather events as associated with climate change, land degradation and biodiversity loss. Responding to these challenges requires a systems-based approach that addresses the range and complexities in a holistic and sustainable manner' (FAO, 2014).

The European Green Deal (EGD) proposes a new and inclusive growth strategy that highlights the need for a holistic and cross-sectoral approach that includes climate, environment, agriculture and forestry, fisheries and aquaculture, energy, transport, industry and sustainable finance ([2]). The farm-to-fork (F2F) strategy is at the heart of the EGD. It addresses comprehensively the challenges of a sustainable food system and recognises the inextricable links between healthy people, healthy societies and a healthy planet (European Commission, 2020a). Food produced in and imported into the EU is already recognised as meeting the highest standards in food safety and food security. The challenge is now to accelerate the transition to sustainability, ensuring that the planetary boundaries and general welfare of society are respected.

A sustainable food system delivers food security, nutrition and food safety for all without compromising economic, social and environmental sustainability to ensure food security, nutrition and food safety for future generations (FAO, 2014). In the context of the EU, assuming that the goal of food safety has already been achieved, efforts to increase the sustainability of the food system should focus on the environmental, economic and social aspects in the context of common policies in all EU Member States. The common agricultural policy (CAP), the common fisheries policy (CFP), the zero-pollution action plan (ZPAP), the circular economy action plan (CEAP), the nature restoration law proposal and the biodiversity strategy – to mention just a few – include requirements and provisions that contribute to the sustainability of the EU food system in the short and medium terms. In addition, the EU food system should contribute to the commitments made under global initiatives such as the sustainable development goals (SDGs), the United Nations Framework Convention on Climate Change (UNFCCC) and the Global Biodiversity Framework (Borchardt et al., 2024).

In general, the scope of a monitoring system is reflected in its conceptual framework (Giuntoli et al., 2020). The developments of the EU food system should be monitored to address the question of whether it performs sufficiently well in terms of its environmental, economic and social impact and whether it stays within the planetary boundaries. Regularly updated, high-quality and policy-relevant indicators are needed for monitoring its current state and the distance to achieving the policy objectives, to provide information on the success of policy actions and indicate where additional measures are needed. Such a monitoring system should also provide information that enables further analysis by third parties, contributing to the involvement of, and dialogue and

([2]) https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en.

debate between, the European Commission, other EU institutions, stakeholders and citizens (Giuntoli et al., 2020).

Objectives of the monitoring framework

This study was carried out by the JRC at the request of the Directorate-General for Health and Food Safety, to provide a tool fit for monitoring the sustainability of the EU food system and developments in its sustainability. A monitoring framework (MF) presents trends, including past and recent performance, facilitates comparisons across countries/regions and tracks progress towards objectives (Fanzo et al., 2021). The first step was to define the scope of the EU food system monitoring framework (FSMF) and identify relevant indicators that could be regularly updated or further developed to inform users and ultimately guide policy choices on aspects related to sustainable food systems. An effective way to achieve this is to present policy-relevant indicators in a meaningful manner in a dashboard that is easy to navigate and help users to find answers to their own queries.

It should be noted that this initial MF will be further developed to monitor progress towards achieving the sustainability targets of EU legislation, including their environmental, economic and social dimensions. Sustainability must be monitored using indicators relevant to the associated policy targets and measures. It should also be noted that several relevant policy initiatives are in the process of being implemented or are under discussion by co-legislators, and their effects on sustainability might not be fully captured by the current system.

2. System design and architecture

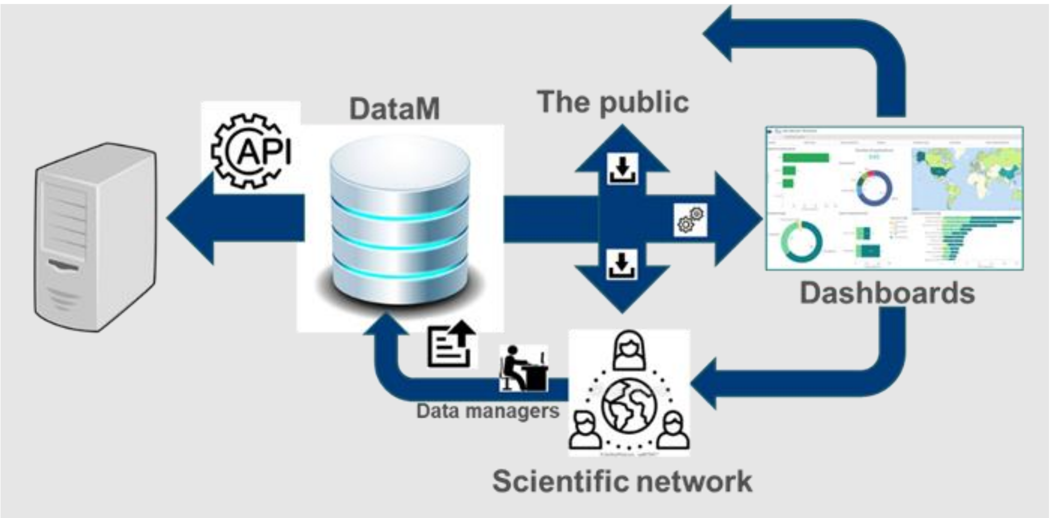
The design of the EU FSMF was driven by several key principles. First, we strived for an integrated system that would support all the phases of work – starting from data collection through to the publication of the results. All the data and metadata were thus inserted into a single database in the DataM platform (see description below), which ensures consistency and enables propagation of system updates at any point.

Second, we strictly followed the ‘reuse of existing’ principle (European Commission, 2019a), recommended by the Commission’s better regulation policy. By using this approach, we aimed to avoid placing an unnecessary burden on potential data providers in the Member States. This is a generally accepted good practice, also emphasised by the UN Sustainable Solutions Development Network in the context of SDGs monitoring: ‘Official statistics derived from surveys and other official administrative data will play a critical, preeminent role. They will be complemented by unofficial data, and other performance metrics including business metrics, polling data, and georeferenced information on government facilities, among others’ (UN SDSN, 2015). Given the role of the JRC, there was a particular opportunity here to integrate modelled data. In practice, data already available from the services and agencies of the EU are harvested through machine-to-machine communication using the application programming interfaces (APIs) developed for this purpose. This approach will be applied, whenever possible, to other data sources too.

Third, we also applied concepts and components of other existing monitoring systems. This contributes to semantic and technical interoperability. The DataM platform supports continuous technical maintenance, updates and automation of the indicator documentation, including generation of standard metadata (indicator fiches) for public users, in line with the guidance of Eurostat and the INSPIRE directive[3], to mention just a few examples. In addition, dedicated tools were created to engage with stakeholders, for example involving the partner Directorates-General in reviewing the prototype of the indicator dashboard. The architecture of the system is shown in Figure 1.

(3) https://knowledge-base.inspire.ec.europa.eu/index_en

Figure 1. Architecture of the monitoring system



Source: Own elaboration.

The EU FSMF and the associated dashboard are dynamic tools. In addition to the automatic indicator updates, periodic revisions are planned. Emerging requirements may result in introducing new indicators or replacing some of them with new ones. This will be implemented as part of 'evolutionary maintenance' that specifies the rules, actors and frequency of upgrades. Before releasing an upgrade, internal checks of the indicators will be performed in order to avoid redundancies and achieve a balanced coverage of indicators across the system.

DataM ([4]) is a versatile computer platform developed by the JRC specifically for the management of analytical data. DataM is tailored for managing the vast class of structured and consolidated data derived from analytical processes. This distinguishes DataM from 'big data' infrastructures designed for managing vast, rapidly changing and unstructured datasets.

DataM supports the entire life cycle of data of analytical origin. It provides a tool for customisable data entry with standardised forms and tailored web-scraping routines for gathering data from external sources, and connectors for uploading data from various file and database formats. It offers extracting, transforming and loading (ETL) scripting for data transformations, and tools for flexible definition of data warehouse schemas for data storage.

Metadata are definable in a standard format and are also used for automatic integration with open data portals. For data dissemination, DataM provides users with tools for bulk download and interactive queries, as well as advanced data analytics applications usable through a web browser, primarily based on Qlik Sense technology. As a development framework, DataM excels in the rapid construction of such interactive content. In the 'personal' area, accessible by logging in, special users can access restricted content and developers can access specific functionalities for data management and development.

([4]) https://datam.jrc.ec.europa.eu.

3. Conceptual framework

3.1. Overview and high-level concepts

Since the EU FSMF is an information system, we followed the standard development process that includes the following consecutive steps:

— identification of user requirements;

— development of the conceptual model;

— implementation of the conceptual model in a database.

The next phase is devoted to data, in particular to:

— identification of existing data sources;

— harmonised documentation of the indicators that have the potential to be included in our system;

— scrutiny of the quality of the indicators;

— selection of those indicators that are fit for monitoring the sustainability of the EU food system.

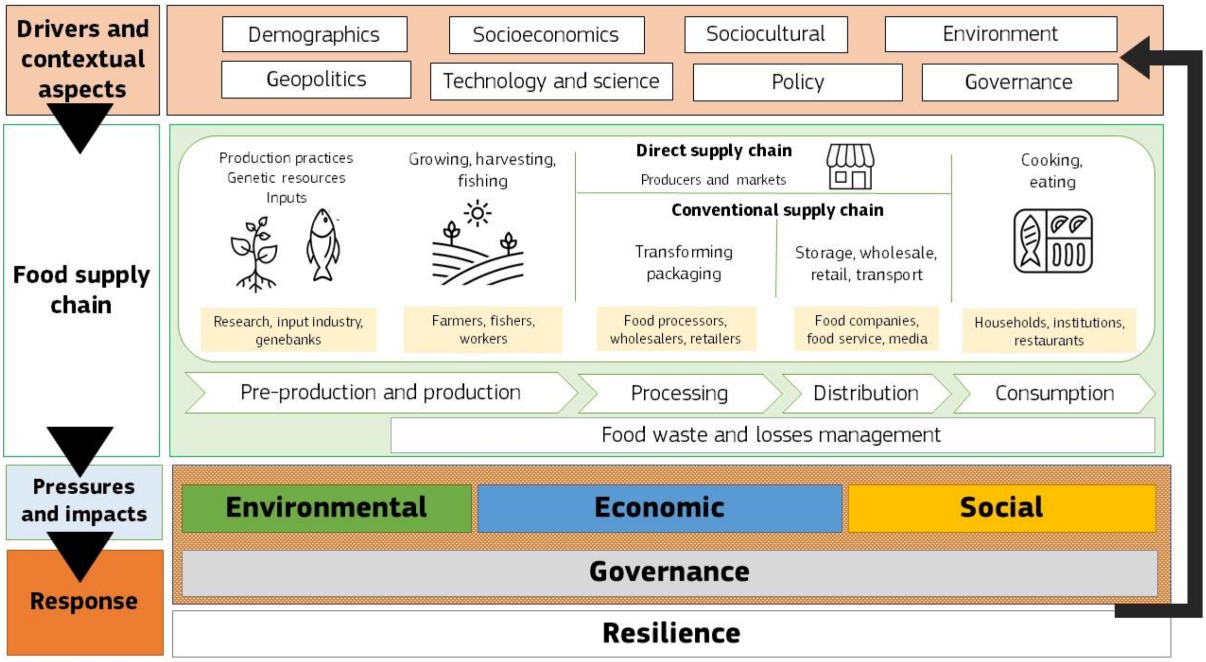
We populated the system with data from the original data sources using automatic harvesting. Finally, the indicators were visualised in the EU FSMF dashboard.

Before describing these steps from a thematic point of view, we would like to highlight some technical aspects of system development. Since food systems are complex and interdisciplinary, the implementation of a monitoring system requires the collaboration of experts from many different domains. Consequently, ensuring the interoperability of the information systems was key in the course of the implementation.

From a semantic point of view, it was very important to agree and document our key concepts. The integrated conceptual models for indicators, metadata and quality assessment served to harmonise semantics. Comparability of indicators and their assessment were further supported by standardised code lists, such as the list of policies, components of the food supply chain and levels of data granularity. For reasons of transparency and completeness of information, we provide the full conceptual model of the system, documented as a class diagram in Unified Modeling Language (UML), in Annex 1.

The heart of the conceptual foundation of the monitoring system is the food system model. This is our main knowledge management tool, which delineates the boundaries of our system and defines its elements and their interactions. It serves as a reference system for the indicators, as they are linked to the various elements of this model. This approach enables overlaps to be revealed, identifies gaps and subsequently guides the process of developing new indicators. The high-level representation of the main concepts of the food system is shown in Figure 2.

Figure 2. High-level representation of the food system conceptual model



Source: Own elaboration.

The food system model includes:

— the components of the food supply chain

— three dimensions of sustainability and two horizontal thematic areas

— a partial integration with a driver–pressure–state–impact–response (DPSIR) approach.

When discussing food systems, the first reference system is the food supply chain, the key parts of which include production, processing, distribution and consumption of food (European Commission Directorate-General for Research and Innovation, Group of Chief Scientific Advisors, 2020). This classification is fully in line with the horizontal topics proposed by DG Health and Food Safety ([5]). Primary production also includes pre-production, relying heavily on decisions on investments and research, as well as on other inputs, such as seeds, fertilisers, animal feed, fuel and veterinary services, which is often referred to as intermediate consumption.

Concerning pre-production, the EU agriculture, fisheries and aquaculture sectors are particularly dependent on energy and energy-intensive imports, as well as on feedstock, as demonstrated recently by the strong market reactions following Russia’s invasion of Ukraine. It is clear that increasing input costs in the food supply chain are driving up food prices further. In particular, the reliance on mineral fertiliser produced using fossil fuels (nitrogen fertiliser) and on imports of phosphate and potash have become a challenge for the EU (European Commission, 2022b).

The most important subcomponents of primary production are agriculture and fisheries, including aquaculture. Agriculture, as a dominant part of food production, plays a major role in the

([5]) https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy_en.

sustainability of the food system. Agricultural production relies directly on natural resources (e.g. soil and water) and input providers (e.g. energy, machinery, seeds and other planting material, fertilisers, pesticides and antimicrobials), which has significant implications for both human and environmental health (Halpern et al., 2022). For instance, agricultural practices can affect local biodiversity, not only on farmland but also in surrounding areas, through habitat alteration (Newbold et al., 2015) and the use of production inputs such as pesticides and fertilisers (Raven and Wagner, 2021). The environmental impacts of fisheries and aquaculture are multifaceted, ranging from biodiversity loss to water pollution.

Intensive farming practices often lead to soil degradation and erosion, further stressing the ecological balance (Panagos et al., 2016). The reliance of agriculture on synthetic fertilisers and pesticides contributes to environmental pollution, while the expansion of agricultural land leads to habitat destruction and ecosystem disruption. In addition, the livestock sector is a notable contributor to environmental concerns, particularly through greenhouse gas (GHG) emissions such as methane and nitrous oxide (Rojas-Downing et al., 2017), which are key factors in climate change. Furthermore, agriculture's water usage can strain local resources, exacerbating water scarcity issues (Gallardo, 2024).

On the other hand, there are some farming methods (e.g. extensive livestock grazing in mountain areas) that provide important environmental benefits (e.g. promoting biodiversity in soil and plants, reducing the risk of fires and providing nutrients to the soil) (EIP-AGRI, 2021; Leroy et al., 2024). These environmental impacts underscore the need for sustainable food production methods that harmonise agricultural productivity with environmental preservation. Sustainability principles should apply not only to domestic agriculture in the EU, but also to imported food and feed.

The sustainability of agricultural, aquaculture and fishery production cannot be separated from socioeconomic aspects either, as the presence of the workforce depends on the income of fishers and farmers, general living conditions (e.g. infrastructure, including the accessibility of broadband internet and digital services) and working conditions. The CAP (European Parliament and the Council of the European Union, 2021) and the CFP (European Parliament and the Council of the European Union, 2013a) have a fundamental impact on these conditions by providing direct support to producers and instruments for rural development. The new horizontal regulation of the CAP promotes environmental and climate-friendly practices, as well as social aspects, in its aim to align with the priorities and targets of the EGD and other relevant policies.

According to a recent report by the Intergovernmental Panel on Climate Change (IPCC) (Babiker et al., 2022), innovative food production systems such as controlled-environment agriculture (vertical farming), cellular agriculture and plant-based meat analogues may help to reduce agriculture's environmental footprint as well as improve the food environment (see Section 5.3.2) by widening the offer of sustainable and healthy dietary choices.

The EU is the eighth-largest producer of fishery and aquaculture products (behind China, Indonesia India, Vietnam, Peru, Russia and United States), accounting for around 4 % of global production. In 2021, EU fisheries captured about 4 million tonnes of seafood worth EUR 5.85 billion, while the aquaculture sector produced 1.1 million tonnes worth EUR 4.17 billion (EUMOFA, 2023). With only around 38 % of seafood products coming from its own waters, the EU is heavily dependent on imports.

The import and thus the processing and distribution of seafood products are also dependent on the supply of raw materials from non-EU countries. Therefore, policies for sustainable seafood production should not only help decrease imports by increasing EU production but also ensure that any remaining imports are sustainably produced. The main scope of the EU CFP is to bring fish stocks to sustainable levels, increase fishers' income, strengthen fisheries management and increase the sustainability of aquaculture production systems. The recently revised EU's fisheries control system will contribute to the fight against fraud through an enhanced traceability system and will explore its extension to processed fisheries products. The mandatory use of digitalised catch certificates will prevent illegal fish products from entering the EU market.

Food processing adds value to raw ingredients. With 70 % of agricultural production being processed, it is a key driver for the functioning of the food system. The food and drink industry is the largest manufacturing sector in terms of turnover in the EU (EUR 1.11 trillion in 2020) and the biggest industrial employer (4.6 million employees). It is important to note that 99 % of companies in the food processing industry and in the food retail sector are small and medium-sized enterprises, accounting for 39 % of the food and drink industry turnover and 41 % of the value added ([6]).

The trade of processed food products plays a key role in the single market and the competitiveness of the EU. Food processing supplies a variety of food products that are part of the EU diet, provides food security, food safety (including longer shelf life) and convenience, and ensures high-quality standards for food in Europe. However, a high proportion of processed and packaged products in the EU market have low nutritional value (e.g. high in calories, salt, sugars or fat, or low in wholegrains or fibre) and contribute to a poor diet (Moz-Christofoletti and Wollgast, 2021). The F2F strategy aims to shift consumption towards a healthy diet in line with dietary recommendations, including more transparent consumer information regarding the healthiness and sustainability of food product choices.

The concentration of actors in the food processing sector, as well as in the retail sector (related to the number of actors in the chain) creates conditions for economies of scale, thus allowing for more efficient food distribution. This is achieved through investments in logistics, mainly road transport. According to Eurostat ([7]), food products, beverages and tobacco had the highest share (17 %) transported by road in the EU in 2021 (in tonnes per kilometre) of all transported goods. Agriculture, hunting, forestry, aquaculture and fishing products account for another 11 % of the total. This generates an environmental burden in terms of air pollution, GHG emissions and noise. However, this burden must be seen in the context of the impracticality, inefficiency and cost of production, as not all climates, waters or soils are suited to all products (e.g. greenhouse heating cost and GHG emissions).

While intra-EU agricultural trade offers variety, availability and cost-efficiency to consumers with a limited transport-related environmental impact, agricultural products from global markets present specific concerns, especially when considering air cargo of off-season and specialty fruits. A longer period in transit can require more packaging, depending on the value chains (e.g. the transport of bananas is quite optimised), and producing and transporting such material to the place of utilisation creates emissions. According to Gerber et al. (2013), animal feed transport, together with production and processing, account for about 45 % of the overall environmental impact of the livestock sector.

([6]) https://www.fooddrinkeurope.eu/wp-content/uploads/2023/12/FoodDrinkEurope-Data-Trends-Report-2023-digital.pdf.

([7]) https://ec.europa.eu/eurostat/databrowser/view/road_go_ta_tg/default/table?lang=en.

However, food distribution and globalisation are important contributors to supporting access to diverse foods and food safety. In general, the use of smaller units of packaging, which is related to social changes in household structures, demands a higher volume of packaging and, consequently, generates more waste. Therefore, there is a demand for an overall reduction in the use of packaging and an increase in its reuse or recycling. Nevertheless, a more cross-sectoral approach is needed when considering the wider food system. Overall, there is strong evidence that any food saved by additional packaging (more packaging for smaller portions, special packaging for preservation, etc.) quickly offsets the impacts of that additional packaging (Wille, 2014).

By means of trade agreements, the EU is having an impact on socioeconomic conditions in producing countries outside the EU (e.g. on fairness), as well as an environmental impact, such as deforestation, changes in biodiversity, etc. The EU is a leading global actor in food trade, with exports reaching EUR 228.6 billion and imports amounting to EUR 158.6 billion in 2023 (European Commission, 2024a). Food imports and exports contributed to ensuring global food security, alongside domestic supply, while short supply chains also gained importance in this context.

The EU exports products from all parts of the food value chain, while imports are dominated by three key product groups (i.e. fruits and nuts, oilseed and protein crops, and coffee, tea, cocoa and spices). The EU also remains a net importer of seafood. Therefore, trade affects the sustainability of the EU food system through global trends and makes the EU vulnerable to external shocks, limiting its resilience. For example, increased demand for certain products (e.g. palm oil, soya) raises questions around sustainable land use, deforestation and local food security.

Food consumption is a result of broad and complex interactions, from individual aspects such as appetite and food preferences to the food environment (Bock et al., 2022). Commercial advertising, food marketing and promoting unhealthy food products have far-reaching consequences on the health of individuals and public spending. The F2F strategy highlights this interconnection and the importance of shaping the food environment as a necessary goal to facilitate healthier and more sustainable food choices to improve 'consumers' health and quality of life and reduce health-related costs for society'.

Assessing the sustainability of the food system requires a systematic and multidisciplinary approach with a capacity to provide metrics to measure the progress towards a 'fair, healthy and environmentally friendly food system' and a 'sustainable and inclusive growth strategy to boost the economy, improve people's health and quality of life, care for nature, and leave no one behind' (European Commission, 2020a). Considering these statements as well as the categorisation of Bock et al. (2022) and the European Commission Directorate-General for Research and Innovation, Group of Chief Scientific Advisors (2020), the following sustainability dimensions were agreed:

— environmental

— economic

— social, including health.

In addition to the three main dimensions, two thematic areas were identified as overarching aspects of sustainability, namely governance and resilience. These high-level components of the food system conceptual model are shown in Figure 2. More details of this model are given in Section 3.3.

The DPSIR framework (EEA, 2007) was initially used for environmental indicators. Later, aspects of economic and social dimensions were also included (Rodriguez-Labajos et al., 2009). This causal framework describes the interaction of society with the physical and social environment by classifying indicators in the categories included in Table 1. The structure of this framework links together various sustainability domains within the food system. This helps to create dedicated category views in the dashboard and enables selection of the corresponding normative criteria to monitor progress towards sustainability, including the planetary boundaries in the environmental dimension and targets of the EGD.

Table 1. The DPSIR framework

Category	Description
Driver	Social, demographic and economic developments in societies and the corresponding changes in lifestyles, overall levels of consumption and production patterns
Pressure	Developments in the release of substances (physical, chemical and biological agents), the use of resources and the use of land and water for human activities
State	Qualitative and quantitative characteristics of ecosystems, the quantity and quality of resources, living conditions of humans, exposure to the effects of pressures on humans
Impact	Changes in the functions of ecosystems, affecting social, economic and environmental dimensions
Response	Policy actions that are directly or indirectly triggered by the perception of impacts and that attempt to prevent, eliminate, compensate for or limit their consequences

Source: EEA (2007).

This classification was very useful in the course of assigning indicators to specific domains, especially to those of the horizontal thematic areas. Indicators in the 'response' category belong, in most cases, to governance. Indicators in the 'pressure' category provide input to 'resilience'.

3.2. Food system sustainability in the EU context

Although most EU policy instruments are inspired by sustainability principles (European Commission, 2022a; Galli et al., 2020), the requirements that are related to the sustainability of food system are scattered across different legal acts, addressing specific policy areas, such as those in the CAP, CFP, etc. (Barbero Vignola et al., 2024). Likewise, the EU monitoring systems in place (e.g. those monitoring the bioeconomy, the circular economy and the biodiversity strategy, and the soil health dashboard) provide specialist information on well-delimited segments of the food system. The F2F strategy calls for a more integrated EU food policy (Schebesta and Candel, 2020), which underlines the importance of developing an EU FSMF that is fit to measure the transition towards a more sustainable EU food system that operates within the planetary boundaries. As the F2F strategy has collected the relevant aspirational targets from policies underpinning the EGD, it was reasonable to start scoping the EU FSMF based on this document.

To assess the progress towards the targets and objectives listed in the F2F and the underpinning policies, we extracted them from the text of the communication (COM(2020) 381 final) and assessed their importance through semantic analysis using the SDG mapper tool in the Know SDGs platform ([8]). This platform was useful for identifying the sustainability areas most frequently referred to in the F2F strategy and checking the completeness of requirements. We also made sure to cover the entire food supply chain. The key topics identified in the exercise are included in Table 2. The topics listed in the table were also integrated into our DataM database and were used to anchor the indicators. In the first column of the table, we indicate the short names of the objectives as they appear in DataM, while the longer definitions in the second column are based on the wording of the F2F strategy. Even though a specific objective or target can have an impact in several sustainability dimensions, for the sake of simplicity of presentation we linked it to the most prominent one.

Table 2. Targets and high-level objectives of the F2F strategy

Key areas of F2F objectives and targets	Description
Environmental	
Tackle climate change	Ensure that agriculture, fisheries and aquaculture, and the food value chain, contribute to the target of reducing GHG emissions to at least 55 % below 1990 levels by 2030 and to achieving the objective of a climate-neutral EU by 2050.
Reduce environmental and climate footprint	Reduce the environmental and climate footprint of the EU food system, so that it operates within planetary boundaries.
Preserve biodiversity	Protect the environment and preserve biodiversity.
Sustainable fishing	Bring fish stocks to sustainable levels.
Energy efficiency	Adopt energy efficiency solutions in the agriculture and food sector by reducing energy consumption.
Reduce chemical pesticides (F2F target)	Reduce the overall use and risk of chemical pesticides by 50 % by 2030.
Reduce hazardous pesticides (F2F target)	Reduce the use of the more hazardous pesticides by 50 % by 2030.
Reduce nutrient losses (F2F target)	Reduce nutrient losses by at least 50 %, while ensuring that there is no deterioration in soil fertility.

([8]) https://knowsdgs.jrc.ec.europa.eu/.

Reduce fertiliser use (F2F target)	Reduce the use of fertilisers by at least 20 % by 2030.
Reduce antimicrobials (F2F target)	Reduce overall EU sales of antimicrobials for farmed animals and in aquaculture by 50 % by 2030.
Increase organic farming (F2F target)	Increase organic farming, with the aim of achieving at least 25 % of total farmland under organic farming by 2030.
Reduce food waste (F2F target)	Halve per capita food waste at retail and consumer levels by 2030. Prevent food loss and waste.
Economic	
Fair economic return in the food chain	Ensure fair economic return in the food chain. Ensure fair income and salaries. Improve the income of primary producers to ensure their sustainable livelihood.
Foster competitiveness	Foster the competitiveness of the EU supply sector.
Promote fair trade	Promote fair trade and ensure fair trade.
Digitalisation and knowledge transfer	Promote digitalisation and knowledge transfer for assisting food chain actors, especially farmers in the transition. Ensure access to fast broadband internet.
Social	
Food information*	Use food information and labelling to empower consumers to make informed, healthy and sustainable food choices.
Food reformulation*	Increase reformulation of food products in line with guidelines for healthy and sustainable diets.
Impact of unhealthy diet	Reverse the prevalence of overweight and diet-related diseases.
Move to healthier diet	Move to healthier and more sustainable diets in line with national dietary recommendations.
Sustainable food availability*	Improve the availability of sustainable food.

Sustainable food affordability*	Ensure access to sufficient, nutritious and sustainable food.
Food security	Ensure food security, making sure that everyone has access to sufficient, nutritious and sustainable food, while meeting daily dietary needs.
Resilient food system	Make the food system more resilient.
Animal welfare	Ensure better animal welfare to improve animal health and food quality.

*These key areas of the F2F objectives belong to the more overarching objective of the strategy on a healthy food environment: create a healthy food environment to ensure that the healthy and sustainable choice is always the easiest one.

Source: Own elaboration

To monitor whether the EU food system operates within the planetary boundaries in a systematic manner, the footprint approach was used. It evaluates the environmental impacts of the EU food system considering the entire supply chain and life cycle of products, from the extraction of raw materials to the management of food waste. The planetary boundaries framework provides a set of nine ecological processes that risk reaching tipping points towards drastic changes, potentially affecting humanity. This framework has been accepted by the scientific community as a set of ecological thresholds that can be employed to evaluate the environmental sustainability of systems from an absolute perspective. It has been adapted to the environmental footprint method using a two-step procedure: mapping between the boundaries and impact categories and adapting the metrics of the control variable of the boundary to the metrics of the impact category. This methodological adaptation is detailed in Sala et al. (2020).

3.3. Food system sustainability model

3.3.1. Overview

The functional requirements of the EU FSMF are already outlined in the targets and objectives included in the relevant EU legislation, especially those in the F2F strategy. To check the completeness of the requirements, we analysed the best practices detailed in the recent scientific literature, particularly Béné et al. (2019a), Bock et al. (2022), Fanzo et al. (2021), FAO (2014), Gustafson et al. (2016), and Hebinck et al. (2021a), which provided general frameworks for sustainability monitoring. Furthermore, we integrated the framework used in the concept paper of Bock et al. (2022) and the nomenclature applied by the FAO for food security assessment.

The content of these input models was extended to accommodate the economic dimension according to von Braun et al. (2021); Béné et al. (2019a); Bock et al. (2022); FAO (2014); and Hebinck et al. (2021a), but without significantly affecting the original structures. The analysis of the sustainability components in these works yielded a detailed food system sustainability model that we used as basis for our MF. We present this model in Table 3, together with references to the sources mentioned above.

Table 3. Structure of the model proposed for the EU FSMF

Thematic areas		Name of the corresponding domains/subdimensions	References
Environmental	Climate change	GHG emissions	B, F, H, G, FAO, FSFS
	Pollution and antimicrobials	Pollution	F, H, FAO, FSFS
		Antimicrobials	F, FSFS
	Sustainable use of resources	Land and soil	B, F, G, FAO, FSFS
		Water	B, F, H, G, FAO, FSFS
		Aquatic living resources	F, H, FSFS
		Energy	B, G, FSFS
	Biodiversity	Biodiversity conservation and restoration of natural ecosystems	B, F, H, G, FAO, FSFS
		Genetic biodiversity of food production systems	F, FAO, FSFS
	Cross-cutting areas	Food loss and waste	B, G, FAO, FSFS
		Circular economy	FSFS
		Consumption footprint	FSFS
Economic	Fair economic viability in food value chain	Sectorial growth	B, H, F, FSFS
		Market power and business structure	H, FAO, FSFS
		Income distribution	F, H, FAO, FSFS
		Price	B, H, FSFS
		Trade	H, FSFS

	Development and logistics	Technology and digitalisation	H, FSFS
		Transport, accessibility and infrastructure	FSFS
Social	Fair, inclusive and ethical food system	Employment	B, F, H, G, FAO, FSFS
		Social protection and poverty	F, H, G, FSFS
		Animal welfare	H, G, F, FSFS
	Food environment	Food affordability	F, G, FAO, FSFS
		Food availability	F, G, FAO, FSFS
		Food messaging	F, FSFS
		Properties of food	F, FSFS
		Food heritage	AGRI
	Nutrition and health	Nutrition and healthy, sustainable diets	B, F, H, G, FAO, FSFS
		Health impact from diet	B, H, FAO, FSFS
		Food security	F, FAO, FSFS
Horizontal thematic areas	Governance	Strategic planning and policies	F
		Effective implementation	F
		Accountability	F, FSFS
		Shared vision	F
	Resilience	Preparedness	JRC
		Shock resilience	JRC

		Adaptation	JRC
		Transformation	JRC

B – Béné et al. (2019b), F – Fanzo et al. (2021), H – Hebinck et al. (2021b), G – Gustafson et al. (2016), FSFS – Bock et al. (2022), FAO – FAO (2014), AGRI – proposal by the Directorate-General for Agriculture and Rural Development, JRC – own proposal.

Source: Own elaboration

3.3.2. Thematic areas and domains of the Environmental dimension

Food systems play a significant role in shaping the environment, and understanding their interactions with the environmental dimension is crucial for developing sustainable and resilient food systems. The following subsections define the thematic areas (in dedicated headings) and the domains (marked in bold within the subsections) of the environmental dimension of the food system.

3.3.2.1. Climate change

This thematic area aims to address climate change adaptation and mitigation, as well as reduce the environmental and climate footprint of the EU food system in order for it to operate within the planetary boundaries. By 2030, agriculture, fisheries and aquaculture, and food processing, distribution and consumption should contribute to the target of reducing GHG emissions to at least 55 % below 1990 levels and to achieving a climate-neutral EU by 2050 (Crippa et al., 2021).

Within that general context, here we underline the main EU regulatory framework linked to food system monitoring. First, Annex II(a) of Regulation (EU) 2018/841 (European Parliament and the Council of the European Union, 2018) specifies the national GHG reduction targets to be achieved by 2030, including those of the agriculture sector (e.g. related to livestock ([9]), enteric fermentation, managed cropland, grassland and wetland, manure management, fertilisers, ammonia and methane ([10])) and the land use and land use change and forestry (LULUCF) sector.

Under the LULUCF regulation, Member States will also need to upgrade their geographically explicit datasets relating to carbon baselines. These improvements will also firmly underpin the implementation of monitoring, reporting and verifying in carbon farming schemes ([11]) (European Commission Directorate-General for Climate Action, 2023). Second, taking into account the recommendation by the European Court of Auditors to assess the application of the polluter-pays

([9]) https://agriculture.ec.europa.eu/document/download/865f91a4-e7ea-45e0-a590-aed898226d5c_en?filename=cap-specific-objectives-brief-4-agriculture-and-climate-mitigation_en.pdf.

([10]) https://ec.europa.eu/commission/presscorner/detail/en/qanda_22_2239 and https://ec.europa.eu/environment/publications/proposal-revision-industrial-emissions-directive_en.

([11]) Carbon farming refers to farm management practices that aim to deliver climate mitigation in agriculture and to a green business model that rewards land managers for implementing climate-friendly farm management practices. The improved land management practices can result in the increase of carbon sequestration in living biomass, dead organic matter and soils by enhancing carbon capture and/or reducing the release of carbon to the atmosphere, in respect of ecological principles favourable to biodiversity and the overall natural capital.

principle in agriculture (ECA, 2021), the Commission has carried out a study on GHG emissions from agricultural activities (ECA, 2021; European Commission Directorate-General for Climate Action, 2023). Furthermore, the Commission will promote and pilot blue carbon ([12]) farming practices, in conjunction with the area of water and oceans, through some of the 'lighthouses' established as part of the mission 'Restore our ocean and waters'. For further technical details, please refer to the European Commission technical handbook (European Commission Directorate-General for Climate Action, 2023), which explored key issues, challenges, trade-offs, and design options of this business model for carbon farming.

3.3.2.2. Pollution and antimicrobials

Pollution. A recent assessment at the EU scale has estimated that pesticides affect more than 25 % of the stream network at a relatively high concern level and 4 % at a high concern level (Pistocchi et al., 2023). Similar results emerge from the monitoring of pesticides in soils (Vieira et al., 2023). In 2021, the ZPAP (COM(2021) 400 final) (European Commission, 2021a) announced the vision and actions for a healthy planet for all by 2050. The plan aims to achieve a situation where 'Air, water and soil pollution is reduced to levels no longer considered harmful to health and natural ecosystems and that respect the boundaries our planet can cope with, thus creating a toxic-free environment'. Among other objectives, the ZPAP aims to achieve a 50 % reduction in nutrient losses, the overall use and risk of chemical pesticides, in particular the use of the more hazardous ones, and sales of antimicrobials for farmed animals, including aquaculture.

Food production and consumption systems are large contributors to the pollution of air, water and soils. According to Sanye Mengual and Sala (2023), food consumption accounts for 48 % of the environmental impacts of an average EU citizen, calculated across 16 different environmental impact categories. Changes in the agricultural and fishing systems, aquaculture, food processing, consumption habits and dietary choices, as well as in waste production and management at all levels of the food chain, can contribute to the achievement of the zero pollution targets (Costa et al., 2022). For instance, reducing food waste in line with the food waste reduction targets set by the legislative proposal on the revision of the waste framework directive ([13]) (i.e. by 30 % at retail and consumption level and by 10 % at the processing and manufacturing stage) would lead to a reduction of up to 62 million tonnes of CO_2 equivalent yearly (De Jong et al., 2023).

Food processing has a significant environmental impact through food waste and emissions. It is estimated that about 14 % of food produced globally is lost between harvest and retail, and an additional 17 % is wasted at the consumer level (UNEP, 2021). In the EU, food waste is estimated to be responsible for 16 % of the total emissions of the food system, and for 12 % of the impacts that come from water use (Sala et al., 2023). In addition, processed food tends to have a higher environmental impact than non-processed or minimally processed food. Industrial processing hotspots are linked to ozone depletion potential and ionising radiation. Food processing is

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([12]) Blue carbon refers to carbon sequestration by the world's oceanic and coastal ecosystems, mostly by algae, seagrasses, macroalgae, mangroves, salt marshes and other plants and plant-like organisms (https://www.marineboard.eu/publications/blue-carbon).

([13]) https://eur-lex.europa.eu/resource.html?uri=cellar:05b634bd-1b4e-11ee-806b-01aa75ed71a1.0001.02/DOC_1&format=PDF.

responsible for about 10 % of the total ozone depletion potential and 5 % of the ionising radiation impact in the EU (Castellani et al., 2017).

Antimicrobials. While the use of antimicrobials in food production has decreased considerably over the years, overuse of antimicrobials by humans and for farmed animals (both in agri-food production and aquaculture) is a driver of antimicrobial resistance (AMR), leading to lower efficiency and the need to increase use (WHO, 2023). Between 2016 and 2020, there was a significant increase in the estimated number of deaths and disability-adjusted life years attributable to antibiotic-resistant bacteria in the EU/European Economic Area. It is estimated that AMR was responsible for more than 35 000 deaths and 1 million disability adjusted life years in 2020 (European Centre for Disease Prevention and Control, 2022). Minimisation of AMR is therefore a cross-cutting aspect and a priority of many EU strategies, including the Council Recommendation on stepping up EU actions to combat AMR in a 'one health' approach ([14]) and the EU one health action plan on AMR (European Commission, 2017). The yearly surveillance reports of the European Medicines Agency provide regular data on the sales of antimicrobials for food-producing animals.

3.3.2.3. Sustainable use of resources

Land and soil. In agricultural terms, land refers to the terrestrial surface used for farming, encompassing both its physical characteristics and how humans utilise these areas. This concept is known as land use. Land use involves not only the management and modification of land, including croplands, pastures and agroforestry areas, but also the maintenance of non-productive yet agro-ecologically important areas, known as landscape elements or landscape features.

The diversity of agricultural systems, including organic farming and agroforestry, along with practices such as crop diversification, crop rotation and precision farming, are integral to land use, contributing significantly to its complexity. In addition, agricultural land is used for the production of feed, raw materials for bio-based products and energy generation, which raises concerns about balancing these uses with food security (Muscat et al., 2020). Linked to this, agricultural land is also being removed in the increased urbanisation process ongoing in the EU and globally. These conflicting objectives have become important drivers of land use and, consequently, have a direct influence on the trade between EU and non-EU countries (Vera et al., 2022). Therefore, how land use is managed is key to successfully tackling sustainability challenges (Foley et al., 2005), including those related to climate change (Pongratz et al., 2021), biodiversity loss (Crenna et al., 2019), the spread of invasive alien species (Polce et al., 2023), soil productivity (Montanarella and Panagos, 2021) and even human health (Zaller et al., 2022).

The European Commission has set pivotal short-term actions promoting sustainable land use and management. Towards this objective, the F2F strategy has set a target to increase the share of agricultural land under organic farming to 25 % by 2030 (European Commission, 2020a). In addition, the biodiversity strategy aims for a minimum of 10 % of agricultural land to be devoted to landscape features or non-productive areas, such as hedgerows, trees, ponds and flower strips, by 2030. The main agricultural policy framework of the EU, the CAP, also plays a crucial role in influencing these sustainable farming systems and practices through compulsory conditionality criteria and voluntary agri-environment climate measures.

([14]) One health is defined by the One Health High-Level Expert Panel as an integrated, unifying approach that aims to sustainably balance and optimise the health of people, animals and ecosystems.

These targets are part of a broader effort to support and enhance biodiversity on farmland and contribute to the overall goal of promoting sustainable agriculture. Therefore, they help to create more diverse and resilient agricultural ecosystems, which are essential for sustainable food production and environmental conservation.

In July 2023, the European Commission proposed the Soil Monitoring Law (COM(2023) 416 final) ([15]) to ensure that all soils are in healthy condition by 2050. To achieve this, the law provides a harmonised definition of soil health, puts in place a comprehensive and coherent MF and lays down rules for sustainable soil management. Soil degradation processes, such as soil erosion (Panagos et al., 2018), soil organic matter decline (De Rosa et al., 2023) and soil biodiversity loss (Tibbett et al., 2020) contribute to loss of soil health and reduction in soil productivity and other ecosystem services that soils provide. In addition, soil diffuse pollution, such as high concentrations of heavy metals (Ballabio et al., 2018), excess nutrients, fertilisers and microplastics (Campanale et al., 2022), have negative impacts on both food production and ecosystem services (Hayes et al., 2018).

The Commission's sustainable carbon cycles communication (European Commission, 2021b) sets out short- to medium-term actions to support carbon farming and upscale this green business model to better reward land managers for carbon sequestration and biodiversity protection. Measures to achieve this goal include standardising the monitoring, reporting and verification methodologies needed to provide a clear and reliable certification framework. This framework enables the development of voluntary carbon markets and provides improved data management services to land managers.

Furthermore, an EU regulatory framework for the certification of carbon removals is currently being adopted by EU institutions. This framework is designed to contribute to the efforts of the Commission towards climate neutrality by 2050. It is based on robust and transparent carbon accounting rules to monitor and verify the authenticity and environmental integrity of high-quality sustainable carbon removals. Such rules will provide the necessary legal framework and may also support indicators to scale up carbon farming and industrial solutions for removing carbon from the atmosphere.

Water. Agriculture competes for the use of freshwater resources with other economic sectors such as drinking water supply, industry, tourism (landscape), fisheries and aquaculture and energy production, and also competes with ecological requirements (minimum flow in rivers). In Europe, over 50 % of drought-related economic losses occur in agriculture, rising to 60 % in the Mediterranean region (Rossi et al., 2023). Relevant initiatives are supported at the EU (e.g. through the CAP) and Member State levels to implement water-saving measures and reduce water withdrawals from groundwaters and surface waters. Various irrigation techniques can also help to reduce such withdrawals (De Roo et al., 2023).

Reuse of treated wastewater is a strategic action within the EGD and the CEAP (European Commission, 2020b), aimed at encouraging circular approaches to reusing water in agriculture, as well as in industrial processes (European Commission, 2020b). The water reuse regulation (Regulation (EU) 2020/741) (European Parliament and the Council of the European Union, 2020) sets minimum criteria and provisions for risk management to support appropriate and safe reuse of reclaimed water in agriculture, where the potential for reuse is estimated to be higher than actual reuse. Treated municipal wastewater is a reliable and continuous source of water in countries

([15]) eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52023PC0416.

affected by drought and water scarcity (De Roo et al., 2023; Maffettone and Gawlik, 2022; Pistocchi et al., 2022). Harmonised minimum requirements for the quality of reclaimed water ensure that crops within the EU market are irrigated under similar conditions, with safe practices for human and animal health (Alcalde-Sanz and Gawlik, 2017). Additional health and environmental risks are to be mitigated by establishing a risk management plan for water reuse systems in food production following EU established guidelines (Maffettone and Gawlik, 2022).

Appropriate planning of water resource allocation, including the establishment of environmental flows, is required in the river basin management plans prepared under the water framework directive (Directive 2000/60/EC). Planning should take into consideration the expected evolution of the water cycle and water demand, while also considering climate change. Under conditions of water scarcity, desalination is an increasingly relevant source of fresh water, which should ideally be used for multiple purposes and reused for irrigation (Pistocchi et al., 2020).

Aquatic living resources. Fish, shellfish, algae and other aquatic organisms cultivated and captured in all aquatic environments are highly diverse and rich in protein, essential micronutrients and fatty acids. They can offer sustainable alternatives to many terrestrial animal-source foods (Tigchelaar et al., 2022). In 2022, the EU's trade in fishery and aquaculture products – the sum of its imports from and exports to non-EU countries – reached 8.4 million tonnes, with a total value close to EUR 40 billion. This amount was second only to that of China (European Commission Directorate-General for Maritime Affairs and Fisheries, 2023). The EU is one of the biggest importers of seaweed products globally, and the demand is expected to reach EUR 9 billion in 2030, for use in food, cosmetics, pharmaceuticals and energy production in particular (Vincent et al., 2020).

Aquatic living resources plays a crucial role in global food security, providing a significant source of nutrition and livelihood for many communities worldwide. Seafood is essential in the culinary culture of some Member States (EUMOFA, 2023). Aquatic living resources (or "blue food") is also recognised for its potential in terms of sustainable and healthy diets (Tigchelaar et al., 2022), as well as for its contribution to the blue economy. Two-thirds of global aquatic living resources destined for human consumption are produced by small-scale fisheries and aquaculture (FAO, 2020). Strategic investments and policies that foster a thriving, regenerative blue food sector could help solve some of the most pressing challenges facing the world today (Tigchelaar et al., 2022).

The EU promotes the sustainable use of aquatic environments to ensure the long-term health and productivity of oceans, seas and freshwater ecosystems. It seeks to address challenges such as overfishing, habitat degradation and pollution, while promoting responsible practices in aquaculture and fisheries. The F2F strategy emphasises the need for sustainable fishing practices, reducing by-catch, protecting marine biodiversity and promoting sustainable aquaculture (e.g. organic and low-trophic ([16]) aquaculture). The strategy also aims to enhance consumer awareness and provide information on sustainable aquatic living resources choices through labelling and certification schemes. In summary, aquatic living resources within the context of the EU represent sustainable production and consumption and protection of aquatic environments, ensuring the long-term viability and health of ecosystems.

([16]) The trophic level of an organism represents the number of steps it is from the start of the food chain.

Although progress has been made, the sustainability objectives of EU fisheries have not been fully met yet. Currently, three criteria are recognised as central to the sustainability of both EU production and imported goods:

— proportion of overexploited stocks;

— impact on the seabed of specific fishing gear that affects benthic habitats;

— impact on biodiversity of by-catch.

In the North-East Atlantic, based on the 83 fully assessed stocks, the proportion of overexploitation decreased from 76 % in 2004 to 32 % in 2022 (STECF, 2024a). In the Mediterranean Sea and Black Sea, there are indications that fishing pressure has decreased since 2019 (based on 63 stocks), although no substantial increase in biomass (based on 64 stocks) has been observed since 2011 (STECF, 2024a). Sustainability of fisheries also depends on the use of fishing gear that impacts benthic habitats and the volume of by-catch, which affects the resilience of ecosystems (STECF, 2024b). To better inform consumers, labelling of fisheries products should also contain sustainability details (STECF, 2024b).

In 2021, the EU was the world's ninth largest aquaculture producer (freshwater and marine), accounting for 0.9 % of world production. The industry is dominated by carnivorous farmed fish and shellfish, while herbivorous farmed fish and algae remain marginal ([17]). Production systems based on different trophic levels have significantly different impacts on the environment. The risks range from fish escapees and excess nutrients (e.g. from uneaten feed) and medicines being released into the sea to pollution from animal wastes and feed production.

Currently, high-trophic-level (carnivorous) species are increasingly being farmed – the average trophic level at the scale of total aquaculture production rose by nearly one between 1950 and 2021 (Guillen et al., 2024). However, integrated multi-trophic aquaculture and low-trophic aquaculture (e.g. aquaculture of algae, molluscs) are recognised as substantially more sustainable (STECF, 2023), providing ecosystem services (e.g., direct and indirect removal of some pollutants and nutrients). Furthermore, the aquaculture of bivalves and algae, which have a lower carbon footprint than that of fish, is to become an important source of alternative protein for a sustainable food system and global food security. Depending on the species farmed and the feed used, the environmental impact, for example measured as the carbon footprint, can be relatively low compared with animal production on land (Bianchi et al., 2022; Gephart et al., 2021; Tsakiridis et al., 2020).

Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030 (European Commission, 2021c) stress the need to promote the farming of algae – both macroalgae (seaweed) and microalgae – and low-trophic levels in general as a way of contributing to achieving several objectives of the EGD. These include decarbonisation, zero pollution, circularity, the preservation and restoration of biodiversity, the protection of ecosystems and the increase of environmental services (European Commission, 2022b). The EU aquaculture sector still has great scope for further diversification, particularly the aquaculture of non-fed and low-trophic species, as well as freshwater aquaculture. Coordinated spatial planning with other types of land or marine area use is crucial.

([17]) https://eumofa.eu/documents/20124/35683/European+Union.pdf/f6357f0b-45c1-4f55-b08c-78ab773b9eae?t=1700837229916.

Current monitoring of the aquaculture production system sees a few mandatory pieces of information provided to consumers (e.g. species, country of production). In the case of EU products, the production system can be further identified using the EU Data Collection Framework and the related EU multiannual programme for data collection classification. However, to better inform consumers, details of the production system should also be made available for all imported aquaculture products.

Energy is a fundamental element for the sustainability goal, which can be achieved by coordinated and complementary efforts in two main directions, namely by:

— enhancing green energy production along the food chain;
— adopting energy-efficient solutions along the whole supply chain.

This domain is also significantly linked to other sustainability aspects such as reducing the environmental and climate footprint and combating climate change.

The EU has set targets for increasing the share of renewable energy in its total energy consumption. The production of renewable energy from agriculture and forestry is expected to play a significant role in meeting these targets. The EU has implemented policies and support measures to promote renewable energy from agriculture and forestry, including financial incentives, research and development programmes and regulatory frameworks (e.g. the bioeconomy strategy, CAP, sustainable use of plant protection products proposal and CEAP). Renewable energy from agriculture and forestry has great potential for the EU in terms of the following.

— Climate change mitigation. Agriculture and forestry can contribute to mitigating climate change by providing renewable energy sources that emit fewer GHGs than fossil fuels. This is crucial for the EU's efforts to meet its climate change mitigation targets under the Paris Agreement.
— Energy security. Renewable energy from agriculture, including photovoltaic production of electricity and biogas production from residues, as well as from forestry, can contribute to reducing the EU's dependency on fossil fuel imports, thus enhancing energy security.
— Rural development. The production of renewable energy from agriculture and forestry can provide economic opportunities for rural communities, creating jobs and generating income.
— Sustainable land use. The use of agricultural and forestry residues for energy production can contribute to the sustainable use of land, reducing waste and improving soil health.
— Biodiversity conservation. Sustainable agroforestry practices can help to conserve biodiversity, as well as providing a source of renewable energy.

As well as being strategic for environmental goals, this domain has important implications for economic and social dimensions, primarily in rural areas, but also for other sectors, such as industry and transport, along the food chain.

3.3.2.4. Biodiversity

The global food system is the primary driver of biodiversity loss (Benton et al., 2021). At the same time, however, food security is increasingly dependent on the ecosystem services that biodiversity provides to agricultural production (Tscharntke et al., 2012). In the F2F strategy, the EU recognises these two notions: the pressure the food system puts on biodiversity, and biodiversity loss as a threat to food security and livelihoods.

Biodiversity conservation and restoration of natural ecosystems. The EU biodiversity strategy (BDS) for 2030 ([18]) aims to put Europe's biodiversity on the path to recovery by 2030 for the benefit of people, the climate and the planet. A key element of the BDS is the Nature Restoration Law ([19]), which aims to put measures in place for improving the condition of ecosystems, including those of agricultural land, forests, marine, freshwater and urban ecosystems. The Nature Restoration Law calls for binding targets on specific objectives relating to various EU biodiversity components that contribute to the EU's environmental goals; the biodiversity of agricultural areas will be essential to achieving these goals (Geiger et al., 2010).

As previously mentioned in Section 3.3.2.3 on land use, the restoration of EU agro-ecosystems through the restitution and conservation of landscape elements is articulated in several European policy initiatives, such as the CAP and the BDS. These landscape elements are vital for the maintenance of biodiversity and ecosystem services in agro-ecosystems, and they make a fundamental contribution to the overall action for their conservation.

In addition, as part of the transition towards sustainability, the EU recognises the urgent need to revert the biodiversity decline caused by the food system. This includes measures to reduce pressures on biodiversity, for instance by reducing pesticide use and the risk of nutrient loss (European Commission, 2020a). To understand the effects of the food system on biodiversity, including not only the production phase but also subsequent phases, it is crucial to take a holistic approach. Through trade, EU food consumption extends beyond its territory. Consequently, the impact and pressures of the food system on biodiversity are a global concern (European Commission, 2020a).

Genetic biodiversity of food production systems. The definition of biodiversity includes not only the variability of species and ecosystems, but also diversity within species, or genetic biodiversity ([20]). In the provision of ecosystem services to and from agriculture, genetic diversity, as a vital component of food and agriculture, is of particular interest. Genetic variability of both the species used for food production and their relatives in the wild is crucial to ensure the resilience of the food system, as they provide the basis for new varieties and hybrids (Rawal et al., 2019). *In situ* (i.e. preservation in a natural environment) and *ex situ* (especially gene banks) conservation play a fundamental role in preserving ancient plant varieties and animal breeds that are highly resilient to different types of shocks (e.g. pests, drought, heatwaves, diseases) and thus useful for the sustainability of food systems.

Furthermore, crop diversity in agricultural landscapes favours habitat heterogeneity for the preservation of biodiversity (Benton et al., 2003) and benefits the provision of ecosystem services, such as pest regulation (Guinet et al., 2023) and food security (Massawe et al., 2016). For these reasons, crop diversity is undoubtedly considered a key biodiversity resource globally ([21]), and the importance of its conservation and sustainable use is recognised in various food system MFs and promoted under several policy initiatives, including the CAP.

([18]) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – EU biodiversity strategy for 2030: Bringing nature back into our lives (COM(2020) 380 final).

([19]) https://environment.ec.europa.eu/publications/nature-restoration-law_en.

([20]) https://www.cbd.int/convention/articles/?a=cbd-02.

([21]) https://www.fao.org/plant-treaty/en/.

3.3.2.5. *Cross-cutting areas*

Food loss and waste reduction has been gaining attention in recent years, leading to the development of policies aimed at achieving this objective. An important goal set to fight food loss and waste at the international level is SDG target 12.3: 'by 2030 halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses. The target was set under SDG 12 – responsible consumption and production. Besides committing to achieving SDG target 12.3, the European Commission has identified food loss and waste reduction as one of the priority areas in the F2F strategy.

The first challenge to address is the quantification of food waste. To this end, the 2018 amendment to Directive 2008/98/EC on waste (European Parliament and the Council of the European Union, 2008) mandates Member States to monitor the generation of food waste along the food supply chain and take measures to limit its generation. Delegated Decision (EU) 2019/1597 (European Commission, 2019b) harmonises the quantification of food waste in the EU, prescribing a common methodology and minimum quality requirements. Data should be reported according to Implementing Decision 2019/2000, which regulates data formats and the related quality checks. To date, Member States have reported food waste data relating to the years 2020 and 2021 ([22]). The Commission adopted a legislative proposal ([23]) (a revision of the waste framework directive) on 5 July 2023 setting the following mandatory targets for Member States:

- a 10 % reduction at the processing and manufacturing stage;
- a 30 % reduction at the retail and consumption stage.

These objectives must be achieved by 2030 against the baseline level of 2020.

In recent years, the JRC has developed a model (De Laurentiis et al., 2021) to estimate food loss and waste generation at each stage of the food supply chain (primary production, processing, distribution and consumption). The most recent results obtained with the up-to-date methodology are those between 2003 and 2021 (De Laurentiis et al., 2024a). For all countries, the consumption stage was identified as the major contributor to the total amount of food waste. The contribution of different food groups to the total food waste generated varies from country to country and from stage to stage. Data can be explored in the bioeconomy monitoring system dashboards ([24]).

In parallel, the JRC developed a framework to evaluate the performance of food waste prevention actions, in collaboration with the EU Platform on Food Losses and Food Waste, collecting information on prevention actions in the EU and assessing their effectiveness (Patinha Caldeira et al., 2019). This led to the development of key recommendations for action in food waste prevention ([25]), published by the platform. The evaluation framework is composed of several qualitative and quantitative indicators. The first group describes the quality of the action design and sustainability of the actions over time. The quantitative indicators provide information about environmental, economic and social efficiency, as well as the effectiveness of the actions. In an

([22]) https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Food_waste_and_food_waste_prevention_-_estimates.

([23]) https://eur-lex.europa.eu/resource.html?uri=cellar:05b634bd-1b4e-11ee-806b-01aa75ed71a1.0001.02/DOC_1&format=PDF.

([24]) https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en.

([25]) https://ec.europa.eu/food/system/files/2021-05/fs_eu-actions_action_platform_key-rcmnd_en.pdf.

evaluation of the environmental impacts of EU food consumption, a scenario analysing the effect of combined food waste prevention actions along the food supply chain was developed that estimated a reduction in environmental impacts of between 5 % and 12 %, depending on the impact category (Castellani et al., 2017).

In 2022/2023, the JRC supported an impact assessment of the legislative proposal to set legally binding food waste reduction targets for Member States, as mentioned above (European Commission, 2023). In the course of the assessment, different targets levels were tested. With the targets set in the proposal (a 10 % reduction at the processing and manufacturing stage and 30 % at the retail and consumption stage), the JRC estimated the associated savings in terms of GHG emissions at between 4 and 62 megatons of CO_2 equivalent (De Jong et al., 2023).

Circular economy. The CEAP (European Commission, 2020b) is one of the main building blocks of the EGD. Adopted in March 2020, it aims to pave the way for the EU's transition to a circular economy, targeting the reduction of pressure on natural resources and the creation of sustainable growth and jobs. It is also a prerequisite for achieving the EU's 2050 climate neutrality target and halting biodiversity loss.

In alignment with the SDGs, BDS and ZPAP, the CEAP focuses on key areas that use the most resources and where the potential for circularity is high, such as water, nutrients and processing waste within the EU food sector. Beyond food waste prevention (addressed in the previous thematic area), other flows of resources (e.g. by-products in food processing) and waste can be optimised through circular economy strategies, defining valorisation pathways.

Consumption footprint. Understanding the overall environmental impact of the EU food system is crucial in order to 'monitor the transition to a sustainable food system so that it operates within planetary boundaries, including progress on the targets and overall reduction of the environmental and climate footprint of the EU food system' (European Commission, 2020a).

Recently, the JRC has developed a series of Consumption Footprint indicators, consisting of 16 life cycle assessment (LCA)-based indicators and the aggregated environmental footprint, which is available as a single score. They quantify the environmental impacts of consumption at the EU and Member State levels, also considering the impacts embedded in traded goods. Their calculation is based on:

— emissions to air, soil and water, as well as the resources used along the life cycle of approximately 165 representative products belonging to five areas of consumption (food, mobility, housing, household goods and appliances);
— the consumption intensities of those products;
— the environmental footprint impact assessment method, which translates emissions and resource consumption into potential environmental impacts.

The consumption footprint, therefore, provides an integrated evaluation of the impact of the EU policy on the EU food system over time. The underlying impact assessment models integrate thousands of environmental pressures (e.g. resource use, emissions to the environment) into 16 environmental indicators at the impact level. This means that the different unitary impacts of environmental pressures on the same aspect are taken into account (e.g. the global warming potential of 1 kg of methane is 24 times that of 1 kg of carbon dioxide).

The assessment of food consumption within the Consumption Footprint mirrors the EU food system by representing around 89 % of overall food consumption through the modelling of the life cycle of 45 representative products (Sala et al., 2023). The Consumption Footprint has also been tested for the assessment of the social footprint (i.e. through the Product Social Impact Life Cycle Assessment database ([26]) and the biodiversity footprint (i.e. with multiple LCA methods) ([27]). Further improvements to the methodology are ongoing to enable the evaluation of positive externalities – for example those generated by agriculture (e.g. biodiversity, carbon sequestration).

The Consumption Footprint indicators are also used to monitor progress towards the 8th Environment Action Programme, the circular economy and the SDGs, as well as being included in the European Commission's resilience dashboards and listed in the modelling inventory and knowledge management system of the JRC for policy support (e.g. impact assessment).

3.3.3. Thematic areas and domains of the Economic dimension

The Economic dimension captures the economic health of the food system, including fairness in the distribution of returns to production and the economic sustainability of the supply chain. Each thematic area is listed in the headings below, with its constituent domains in bold.

3.3.3.1. Fair economic viability in the food value chain

Sectorial growth is best defined by the generated value added. The generation and distribution of added value at each step of the food chain is crucial for achieving and maintaining the economic viability of businesses in the various sectors involved in the food system. Traditionally, the number of businesses in the primary sectors is high compared with that in later stages in the food chain. However, the share of value added generated by each business in these primary sectors is comparatively smaller (Hebinck et al., 2021b). The importance of increasing the share of added value in agriculture, fisheries and aquaculture in the overall food supply chain is evident in terms of ensuring adequate distribution of profits.

Established food system frameworks also highlight the significance of having a fair distribution of added value along the food value chain for a sustainable food system (Bock et al., 2022; Hebinck et al., 2021b). The F2F strategy (European Parliament and the Council of the European Union, 2021), as well as the CFP (European Parliament and the Council of the European Union, 2013a) and the common market organisation for fishery and aquaculture products (European Parliament and the Council of the European Union, 2013b), highlights the aim to support farmers and fishers in strengthening their position in the supply chain and thus obtaining a fair share of the added value generated through sustainable production.

Market power and business structure. Concentration of market power and the competitiveness of the food sector are essential to ensure adequate distribution of profits and maintain an economically viable food system. Reinforcing the EU's competitiveness in the food supply sector, preventing unfair trading practices ([28]) and creating new business opportunities are among the main objectives of the F2F strategy. The importance of addressing imbalances in bargaining power within the food supply chain is also acknowledged in Hebinck et al. (2021b), as it can lead to unfair trading practices.

([26]) https://psilca.net/.

([27]) https://eplca.jrc.ec.europa.eu/ConsumptionFootprintPlatform.html.

([28]) https://agriculture.ec.europa.eu/common-agricultural-policy/agri-food-supply-chain/unfair-trading-practices_en.

Income distribution. One of the objectives of the F2F strategy, aligned with the new CAP, is to improve the incomes of primary producers to ensure sustainable livelihoods. The concept paper of Bock et al. (2022) covers income distribution, focusing on the profitability of sustainable primary producers as well as the income and added value distribution across the food chain. This domain falls within the broader thematic area of an economically viable food system. In addition, Fanzo et al. (2020) emphasise that livelihoods in the food system are often insecure and incomes insufficient to support a decent standard of living. Wages in the food system commonly fall below minimum standards set for other industries. Measuring incomes against the cost of living is an essential component of monitoring the progress of transformation in the food system.

Price is one of the key indicators of stability in the food chain, and preserving the affordability of food is one of the main objectives of many food system frameworks. To monitor food prices, it is also crucial to track agricultural input and commodity prices. The significance of food commodity price mechanisms in sustainable food system models is well recognised in Béné et al. (2019b), Bock et al. (2022) and Hebinck et al. (2021b). In addition to tracking food prices, it is important to monitor the share of household spending on food, which also helps to screen household income.

Trade. The EU food system exhibits strong integration with international trade. The EU is one of the world's largest exporters and importers of agri-food products (European Commission, 2024a), and is the second largest exporter and importer of seafood and aquaculture products, considering the combined total of exports and imports (EUMOFA, 2023). However, the levels of net trade, import dependency and diversification, as well as export specialisation, vary depending on the specific agri-food sector. While it is important to monitor trade as one of the indicators of the EU's competitiveness in the sector, a balance must be struck between trade openness in terms of a robust, open food system and, on the other hand, self-sufficiency and the impact of trade on local food security – which is recognised in several food system sustainability models (Bock et al., 2022; Hebinck et al., 2021b). The sustainability of trade is widely discussed in a concept paper on a sustainable EU food system by Bock et al. (2022). However, it remains challenging to measure due to its multifaceted nature, the complexity of global supply chains, difficulty in capturing indirect impacts and limited data availability.

3.3.3.2. Development and logistics

Technology and digitalisation. Research and innovation play a crucial role in expediting the transition towards a sustainable, healthy and inclusive food system across the entire food supply chain, from primary production to consumption. One of the most important prerequisites in terms of technology and digitalisation is providing fast and reliable internet access, through fast broadband connections, to all rural areas. This objective, which is also emphasised in the CAP, is crucial for enabling digitalisation and accelerating the use of precision farming and artificial intelligence. In addition, the significance of investments in agri-food research and development is emphasised in Hebinck et al. (2021b), particularly in relation to the overarching goal of fostering economically thriving and resilient food value chains. The framework proposed by Bock et al. (2022) also recognises the significance of innovation, training and ensuring broadband access in rural areas to create a fair business environment.

Transport, accessibility and infrastructure. Transport is one of the components of the food value chain. Creating shorter supply chains and reducing dependency on long-haul agri-food transport contribute to enhancing the resilience of regional and local food systems. In addition, the conceptual framework of Bock et al. (2022) considers sustainable transport and logistics crucial in improving environmental sustainability in the food value chain.

3.3.4. Thematic areas and domains of the social dimension

The social dimension of food systems defines how societies interact with food and how this impacts health. By addressing social factors, creating a supportive food environment, promoting a fair, inclusive and ethical food system and fostering balanced and varied diets, it is possible to create a healthier and more sustainable food system. In this subsection, thematic areas of the social dimension, listed by heading, and its constituent domains, in bold, are defined.

3.3.4.1. Fair, inclusive and ethical food system

Employment. Supporting the viability of livelihoods and fair, decent working conditions for all individuals involved in the food sector is a critical goal highlighted in the food system frameworks reviewed. The domains proposed for monitoring relate to factors that influence the lives of millions of people working in the EU food system and are therefore central to increasing social welfare in the region ([29]). The key principles for a more inclusive and fair EU society, as set in the European Pillar of Social Rights (EPSR), cover social protection and working conditions, which are inevitably connected to the transition towards a more sustainable food system (European Commission, 2020a, 2021d).

The F2F strategy also notes the importance of ensuring sustainable livelihoods and fair incomes for primary producers and protecting the most vulnerable, including people in precarious work and seasonal workers. Empowering women working in the food system is critical for ensuring a sustainable food system. Similarly, supporting and attracting young generations to work in the food system, especially in primary production, by increasing the uptake of sustainable practices and innovations is critical to accelerating the food system transformation (European Commission, 2020a).

Social protection and poverty. Social protection is central to making progress in reducing inequalities and ensuring that the most vulnerable and poor have access to healthy, nutritious food (Bock et al., 2022; FAO, 2018; Fanzo et al., 2020; Hebinck et al., 2021b; International Labour Organization, 2021). In the EU, the principles of social protection are covered under the EPSR. According to the F2F strategy, the consideration of workers' social protection, working and housing conditions as well as protecting their health and safety will play a major role in building a fair, strong and sustainable food system.

Animal welfare. The *Overview report on the use of indicators for animal welfare at farm level* (European Commission Directorate-General for Health and Food Safety, 2022) recommended the use of the five freedoms established by the British Farm Animal Welfare Council to assess animal welfare: (1) freedom from hunger and thirst, (2) freedom from discomfort, (3) freedom from pain, injury or disease, (4) freedom to express normal behaviour and (5) freedom from fear and distress. While freedom 1 is an absolute precondition for welfare, real progress on animal welfare can be measured in terms of improvements in the areas of freedoms 2–5.

The promotion of animal welfare in the EU is also an opportunity to mainstream the recognition that the health and well-being of animals, people, plants and the environment are deeply interconnected. The 'one health' initiative promoted by the FAO, United Nations Environment

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([29]) https://ec.europa.eu/social/main.jsp?catId=1606&langId=en.

Programme, World Health Organization (WHO) and World Organisation for Animal Health, as well as the European Commission and the competent EU agencies (the European Food Safety Agency (EFSA), European Medicines Agency, European Centre for Disease Prevention and Control, European Environment Agency and European Chemicals Agency), aims to unify and optimise the health of people, animals and ecosystems as part of an all-encompassing strategy.

3.3.4.2. Food environment

The creation of favourable food environments that make sustainable food choices easier for consumers is critical to achieving a sustainable food system, as highlighted in the recent recommendations of the Group of Chief Scientific Advisors (European Commission Directorate-General for Research and Innovation, Group of Chief Scientific Advisors, 2020). Food choices are shaped by the food environment, which encompasses the physical, economic, political and sociocultural context in which consumers make decisions on acquiring, preparing and consuming food (European Commission Secretary-General, 2023; HLPE, 2017). The food environment is thus a key interacting element in food systems and an important factor to consider in MFs (Fanzo et al., 2021).

The selection of domains for this thematic area is mainly based on Fanzo et al. (2021), which adapted the framework of the High-Level Panel of Experts. It is partially modified and enriched with additional elements in our food model to better reflect EU conditions. As a result, the food environment thematic area encompasses the following domains: food heritage, food affordability, food availability food messaging and properties of food.

Food heritage. The safeguarding and promotion of food heritage is often considered a possible way to achieve social and cultural sustainability objectives (Zocchi et al., 2021). However, there is a debate about what can be conceived as food heritage and how it contributes to the sustainability of food systems. In a broad sense, food heritage can be defined as an umbrella of tangible and intangible elements (Rahman et al., 2021) ranging from specific food products and production methods to culinary and gastronomic traditions that strengthen the identity of communities and improve the livelihood of people in the related, mostly rural, areas.

A widely accepted way of recognising and promoting food heritage is including their elements in certain lists, such as the FAO's register of globally important agricultural systems ([30]), the United Nations Educational, Scientific and Cultural Organization's list of food-related intangible cultural heritage ([31]) and the protected geographical indication (PGI), protected designation of origin (PDO) and geographical indication (GI) schemes established by the EU (European Union, 2012). These EU inventories are recognised contributors to the economic valorisation of food heritage.

While a meta-analysis (De Filippis et al., 2022) confirms that GIs lead to an increase in intra- and extra-EU trade, there is no evidence on the economic value of the intangible elements of food heritage. None of the reviewed food system frameworks (see Table 3) or monitoring systems (including the agri sustainability compass ([32]) singles out food heritage as a sustainability domain. Moreover, being listed in an inventory does not provide answers on environmental and social

([30]) https://www.fao.org/giahs/resources/publications/en/.

([31]) https://ich.unesco.org/en/lists.

([32]) https://agridata.ec.europa.eu/extensions/compass/compass.html.

sustainability either. Therefore, including food heritage as a specific sustainability domain in the food environment is controversial and needs further research. It has been retained in our model to satisfy emerging policy considerations.

Food affordability. Economic access can be measured in terms of the cost of food relative to a household's income and purchasing power (Herforth et al., 2020). Changes in food prices may affect household purchasing power, influencing food choices and compromising access to healthy diets and food security (HLPE, 2017). Monitoring the affordability of healthy diets can inform whether food environments provide affordable, healthy and adequate food for every individual and is tied to ensuring the right to food for everyone. Indicators to monitor food affordability are available globally from the FAO and published annually in *The state of food security and nutrition in the world* report (FAO et al., 2023). Nevertheless, a more context-specific indicator is probably needed to provide a better understanding of progress in this domain by considering actual household and non-food expenditures in the EU.

The related indicators provide evidence regarding people's economic access to the lowest-cost healthy diet in a given country, using locally available foods to meet nutritional requirements. In 2021, 3 billion people were unable to afford a healthy diet globally, reflecting an increase in the cost of a healthy diet, which increased by 4.3 % in comparison to 2020 (FAO et al., 2023). Access to a healthy diet is a more serious issue within developing countries. The cost of a healthy diet has been more stable recently in the EU region, with an increase of less than 1 %. It is estimated that in the EU 5 million people are unable to afford a healthy diet ([33]).

Food availability. Ensuring an adequate supply of food and the physical availability of healthier and sustainable products can influence consumer food choices. Food availability can be looked at from a national angle, by tracking changes in the food supply of key products and commodities, but also at the local level, by monitoring the availability of sustainable local food. For instance, the physical availability of sustainable and healthy food in supermarkets, restaurants, canteens and schools may influence and shape choices (European Commission Directorate-General for Research and Innovation, Group of Chief Scientific Advisors, 2023). In so-called food deserts the availability of healthy and sustainable food, especially to vulnerable individuals, is limited.

Actions targeting food availability, such as public procurement and food aid programmes, can increase the provision of sustainable food products and improve the quality of food environments. Data available from the FAO can help track changes in food supply over the time at the national level. However, accessible data on the physical availability of healthy, sustainable food products in local contexts are limited ([34]).

Food messaging. Consumer behaviour and food choices are influenced by various sources of food information, including messaging, promotion and advertising, in both the physical and the digital environment (HLPE, 2017). In particular, marketing ([35]) may compromise the quality of diets and health. Food labelling can also inform consumers and guide them towards healthier and sustainable food choices. The effective implementation of national food-based dietary guidelines (FBDGs) is also an opportunity to inform consumers about achieving healthy and sustainable diets in national

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([33]) https://www.fao.org/faostat/en/#data/CAHD.

([34]) https://www.fao.org/faostat/en/#data.

([35]) https://www.who.int/europe/activities/monitoring-and-restricting-digital-marketing-of-unhealthy-products-to-children-and-adolescents.

contexts (HLPE, 2017), considering local conditions and influencing community actions and educational programmes.

Overall, food information can play an important role in influencing consumers' knowledge and attitudes in many ways. Increasing consumer education and literacy is central to shaping the individual context in which consumers make their food choices. Strengthening educational messages on the importance of a healthy diet, sustainable food production and consumption, reducing food waste and the health and sustainability impact of diets is also emphasised in the F2F strategy. Monitoring food information remains a challenge, but a possible approach could involve looking at policies influencing food marketing (Fanzo et al., 2021). Other promising approaches have been developed in the context of EU joint actions, such as the recent EU–WHO monitoring protocol of marketing unhealthy food and non-alcoholic drinks to children (Boyland and Tatlow-Golden, 2017; Muc and Tatlow-Golden, 2023; Wyer et al., 2022).

Properties of food. Food properties relate to the many attributes of a food that influence its value and make it acceptable and desirable for consumers (HLPE, 2017). This may include physical properties (e.g. size and shape), flavour, convenience, food composition and how it has been produced or processed. Reformulating food products to reduce fat, salt or sugar and introducing healthier, plant-based alternatives, for instance, can shape the healthiness and sustainability value of the food environment (European Commission Directorate-General for Research and Innovation, Group of Chief Scientific Advisors, 2023).

While a complex interaction of food properties may influence consumers' choices, improving the nutritional and sustainability value of food is necessary to improve food environments. The sustainable properties of food products are not yet transparent to consumers. A possible approach to monitoring could be the use of sustainability labelling. In the context of the EU, joint action programmes such as the recently released food and beverages labels explorer ([36]) host the nutritional composition of processed foods and drinks and have the potential to be used as a tool to monitor food reformulation and the nutritional quality of processed food in the EU market.

3.3.4.3. Nutrition and health

Transforming the food system and promoting human health is not possible without diet change. The Nutrition and Health thematic area includes domains that provide information on the progress towards a healthier and sustainable diet and on diet-related health impacts.

Nutrition and a healthy, sustainable diet. A transition towards a diet with less red and processed meat and more fruit, vegetables, legumes and nuts is critical not only to promoting human health, but also reducing the environmental and climate impact of the food system. Reducing excessive consumption of sugar, salt and fats and increasing the consumption of wholegrain cereals remains an important goal to achieve a healthier diet in the EU (European Commission, 2020a). Adequate monitoring of diets remains a challenge, as it relies on r egular and updated food consumption estimates from national dietary surveys. Global efforts have seen the development of modelled estimates, such as those of the Global Dietary Database and the Global

([36]) https://food-labels-explorer.jrc.ec.europa.eu/en.

Burden of Disease (GBD) study (Afshin et al., 2019), but the differences observed highlight the importance of using these data with caution (Beal et al., 2021).

Health impacts of diet. Poor diet and excessive alcohol consumption are among the top contributors to the burden of disease in the EU. Low consumption of wholegrains, fruits and vegetables, legumes and nuts and high consumption of salt, sugar and red meat, as well as highly processed food, are some of the risk factors impacting the health of EU citizens. Linked to a poor and unhealthy diet, excess weight and obesity are major risk factors for many non-communicable diseases such as diabetes, cardiovascular disease and some types of cancer. In the EU, more than 50 % of the adult population is overweight or obese. Childhood obesity is also a concern for public health. The prevalence of excess weight among children is above 30 % in many countries ([37]).

Obesity and excess weight threaten the quality of life and well-being of many individuals, as well as the sustainability of healthcare systems (European Commission, 2020a). Monitoring these phenomena can provide information on the progress of the risk factors that are a major burden on public health in the EU. The WHO European Childhood Obesity Surveillance Initiative is a possible source of valuable information for monitoring the progression of childhood overweight and obesity (WHO, 2022a). Potentially, the burden attributable to dietary risk factors as quantified by the GBD study could also help track progress on the public health impact of diet in the EU.

Food security. Food insecurity has detrimental impacts on human health and well-being. It is strictly related to the limited availability and accessibility or inadequate utilisation of food. Food insecurity at a moderate level of severity is typically associated with the inability to regularly eat a balanced diet. High prevalence of food insecurity at a moderate level can be considered a predictor of various forms of diet-related health conditions in the population, associated with micronutrient deficiency and an unbalanced diet.

According to the 2023 edition of the United Nations' *State of food security and nutrition in the world* report, between 691 and 783 million people faced hunger in 2022, 2.4 billion people experienced moderate or severe food insecurity and over 3.1 billion people could not afford a healthy diet (FAO et al., 2023). The picture is quite different in the EU, where most households have sufficient access to food. Nevertheless, maintaining EU food security faces challenges. The FAO estimates that in 2022, 61 million people experienced moderate or severe food insecurity in Europe (FAO et al., 2023) and, according to Eurostat, 8.6 % of the EU population was unable to afford a meal with meat or fish, or a vegetarian equivalent, every second day in 2020 (Eurostat, 2022). The negative impacts of climate change, soil degradation and biodiversity loss on primary production systems are considered the greatest challenges for food availability in Europe (Meredith et al., 2019). In addition, the ongoing Russian military aggression against Ukraine has implications for food security in EU countries. Although food supply remains stable, high input costs and dependence on imports may impact food access and affordability in the region (Rabbi et al., 2023).

([37]) https://ec.europa.eu/eurostat/databrowser/view/sdg_02_10/default/table?lang=en.

3.3.5. Horizontal thematic areas

Horizontal thematic areas cut across different dimensions of food systems, bridge gaps between specialised areas and promote holistic approaches. The thematic areas included in our model are addressed below.

3.3.5.1. Governance

There is a growing awareness among policymakers that a food system that is developed from and shaped by the complex interactions between people, ecosystems and social forces necessitates more joined-up and integrated governance (Hammelman et al., 2020). One of the main constraints on governing an EU food system transformation is that current governance arrangements remain organised by sector (De Schutter et al., 2020; Fesenfeld et al., 2023; Schebesta and Candel, 2020). Our approach, simultaneously looking at the three sustainability dimensions, suggests that food system governance can become a game changer when it reflects all aspects in a coordinated way.

Governance measures intrinsically cover all the sustainability domains of the food system. This is the reason why governance indicators are directly included in the thematic dimensions in many food system frameworks. Such an approach, however, creates the risk of governance indicators masking the thematic gaps in the system; that is, the lack of indicators that measure sustainability in environmental, economic or social terms. We instead suggest separating governance as an overarching horizontal thematic area that mirrors the structure of the three main sustainability dimensions.

Governance refers to structures and processes that are designed to ensure accountability, transparency, responsiveness, rule of law, stability, equity and inclusiveness, empowerment and broad-based participation. Governance is fundamental to inclusive food system transformation, encompassing not only the political commitment to adopt supportive policies but also the promotion of participatory processes and accountability to ensure that policies have legitimacy and reach the intended target group (Schneider et al., 2023). The Food Systems Countdown Initiative ([38]) suggests the following domains for assessing the governance of the food system:

- Strategic planning and policies
- Effective implementation
- Accountability
- Shared vision.

Governance also concerns policy implications. When effectively implemented, governance can significantly influence management actions and represent a critical factor in achieving positive outcomes. Governance of the food system involves the design and review of mechanisms and processes related to the production, distribution and consumption of food, such as legislation, policies, finances, planning and monitoring, and coordinated implementation to ensure equitable, coherent and transparent management of the food system (Lasbennes et al., 2023; van Bers et al., 2016).

([38]) https://www.foodcountdown.org/.

It is widely recognised that effective governance should involve not only local governments, but also multiple stakeholders from the public and private sectors, such as health, agriculture, fisheries, environment and trade, as well as civil-society and non-governmental representatives (Canfield et al., 2021). Thus, due to the diversity of stakeholders involved, effective food governance is crucial for decision-making and accessing information across the food system (del Valle et al., 2022). Good food system governance requires a holistic approach, collaboration and adaptive policies that prioritise human well-being and planetary health.

3.3.5.2. Resilience

In the context of the food system, Exposure to shocks refers to the frequency of events that cause disruptions (Zurek et al., 2022). They can be environmental (e.g. extreme weather events) (Davis et al., 2021), socioeconomic (e.g. market volatility, conflicts and geopolitical crises) (Cottrell et al., 2019) or health-related (e.g. pandemics affecting food supply chains) (Meuwissen et al., 2021). Therefore, high exposure to shocks may lead to significant vulnerabilities in food supply chains, affecting food availability, access and nutrition (Cottrell et al., 2019).

Resilience capacity is defined as the capacity of these systems to absorb, adapt to and recover from these shocks, while maintaining their full functionality (Allen et al., 2019; Sundstrom et al., 2023). The resilience of the food system is deeply influenced by the management of agricultural systems, including the degree of dependence on imported inputs and the diversity of agricultural practices (Dardonville et al., 2020). It is also influenced by the ability to respond to various challenges (Ingram et al., 2023; Zurek et al., 2022) as well as the preparedness and educational level of management in the agricultural sector (Manyise and Dentoni, 2021). Food system stability is of the uttermost importance for food policy at the EU level (EC, 2023) ([39]) and forms the basis of food security (Tendall et al., 2015). A stable food system that is robust and therefore has a low supply variability ensures consistent availability of and access to nutritious food, which is vital for maintaining the overall health and well-being of populations (Seekell et al., 2017).

The EU's policy initiatives play a critical role in shaping this landscape, focusing on a sustainable, resilient and diversified food system that can withstand and adapt to various challenges ([40]), particularly the F2F strategy under the EGD (European Commission, 2020a; Guyomard et al., 2020). These policies were designed to promote sustainable practices and enhance biodiversity, thereby increasing the system's capacity to withstand and recover from disruptions. The strategy also emphasises the significance of training and knowledge in farm management, promoting sustainable land use and farming practices, and ensuring balanced production. Therefore, resilience is a key domain in ensuring food security, environmental sustainability and the well-being of populations, aligning with the broader goals of sustainable development and climate action (e.g. Huck, 2023; OECD, 2020; UNFCCC, 2015).

([39]) https://agridata.ec.europa.eu/extensions/dataportal/food-supply-security.html.

([40]) https://ec.europa.eu/commission/presscorner/detail/en/ip_20_884.

3.4. Processing the indicators

3.4.1. General requirements

Indicators are quantitative or qualitative measurements that provide a performance evaluation of the state of a concept or phenomenon of interest. Indicator selection depends on practical, statistical and conceptual criteria. For instance, the relevant, accepted, credible, easy to monitor and robust (RACER) ([41]) criteria state that indicators must be:

- relevant – linked to the objectives, goals and aims of the initiative;
- accepted – accepted by stakeholders as legitimate and informative;
- credible – unambiguous and interpretable for non-experts;
- easy to monitor – low cost and an acceptable administrative and technical burden;
- robust – cannot easily be manipulated by actors to improve their rating.

In addition, it is also desirable that indicators be (OECD and European Commission JRC, 2008):

- timely – data should be published and revised at regular intervals;
- accessible – in terms of data and metadata with user assistance;
- attributable – there should be clear causal link to the initiative.

Whenever a reliable direct measurement of an individual component in an MF is not available, a proxy variable can be used. Proxies are indicators that are closely related to a concept that they aim to capture, for example a by-product or consequence of the concept, and should lead to an assessment similar to the variable they mean to measure.

Indicators can be embedded in a structured dashboard and/or a composite indicator to aid their interpretation. Indicators are frequently categorised within a multidimensional and hierarchical system, such as the food system model described in this report. Such a structure contextualises the indicator and allows the user to unambiguously interpret it.

To allow meaningful interpretation and easy analysis of indicators by their users, they may undergo several statistical adjustments to make their performance metrics comparable across time and between countries (OECD and European Commission JRC, 2008).

First, the direction or 'polarity' of each indicator must be unequivocally assigned. This indicates whether positive or higher values represent a desired or undesirable state with regard to the overarching concept of the framework. When indicators of different polarities are included in a dashboard, we are able to improve readability by mathematically reversing some of the indicators and aligning the directions. Furthermore, if the final goal is to compute a composite indicator, before any aggregation, all the individual indicators must be adjusted so that they are pointing in the same direction with regard to the overarching concept.

Second, indicators must be denominated to make performance measurements comparable across countries of widely varying scale and size. The food system model includes two types of indicators:

([41]) https://commission.europa.eu/law/law-making-process/planning-and-proposing-law/better-regulation/better-regulation-guidelines-and-toolbox/better-regulation-toolbox_en.

— Extensive. The indicator is expressed in natural measurement units (kilograms, euro, etc.). These values are often dependent on other variables such as the area of a country or the size of its population or economy. Extensive indicators do not account for performance or efficiency, which are concepts where outputs are measured relative to inputs.

— Intensive. The indicator is expressed as a unit of natural measurement in relation to another internal property of the country (e.g. GDP (euro) per capita (population)). Intensive indicators are useful for comparing the performance of countries.

Each extensive indicator can be transformed into an intensive indicator by dividing it by a suitable denominator (e.g. food waste of a country in tonnes divided by its population = food waste per capita). This process is called denomination.

Third, the indicators are normalised to facilitate the comparison of performance across individual indicators. In practice, we normalise indicators by transforming them to a comparable scale of measurement. For example, we could translate all the measurements from each indicator onto a common normalised linear scale ranging from 0 to 100, where 0 would correspond to the bottom performer and 100 would be assigned to the top performer. Different normalisation methods can yield different results when computing a composite indicator; therefore, robustness tests should be conducted to assess the impact of the normalisation assumptions on the resulting scores and rankings (OECD and European Commission JRC, 2008).

The correlations between the elements in the framework are also relevant, since they uncover the strength of the statistical association between them. This helps assess the conceptual affinity between the individual components of the framework. The *Handbook on Constructing Composite Indicators* (OECD and European Commission JRC, 2008) recommends that pairwise correlations within each grouping of indicators should be between 0.3 and 0.9 to ensure that the constituent elements are conceptually coherent and interrelated. Very low – or negative – correlations should, in principle, be avoided, as they suggest that there may be a conceptual inconsistency and/or hidden trade-offs between the elements included in the grouping. Correlations of 0.9 and above would also be detrimental to the MF since they are interpreted as a sign of potential redundancy in the information provided by the indicators.

To achieve parsimony ([42])– a desirable feature of an MF – redundancy must be tackled by discarding the correlated indicators. An adequate correlation structure enables aggregates to present a reliable summary of the information contained in several indicators. It should be noted that ‘trend’ indicators are, in principle, not suitable for aggregation with ‘level’ indicators; that is, they should not be combined in composite indicators. Instead, they can be presented alongside each other in dashboards. In addition to using bivariate correlation matrices, the robustness and coherence of the correlation structure can be assessed using multivariate statistical methods such as factor or principal component analysis.

In the EU FSMF, every indicator is categorised within the food supply chain, the sustainability dimension, a thematic area and a domain, and is also characterised by several properties and metadata elements describing the steps above. These features ensure that the indicators meet the RACER criteria, enabling users to unambiguously interpret the indicators, facilitating technical

([42]) Representation or a model that uses relatively few independent variables to obtain a good fit to the data.

maintenance and providing methodological documentation, which, in turn, boosts the credibility and accessibility of the dashboard.

3.4.2. Metadata and documentation of indicators

As stated in Chapter 2, the EU FSMF plans to use, whenever possible, existing indicators. Therefore, the metadata provided at the source of the indicators play a key role in assessing their fitness for purpose. Furthermore, indicator data published in the food system dashboard should be accompanied by appropriate information that helps users to understand the data. Both tasks require harmonisation of the original metadata elements and presenting them according to an agreed metadata schema. The metadata schema is the basis of the standardised documentation of the indicators in the respective fiches, with an example provided in Annex 2.

To support the principle of reuse, it is important to ensure coherence with existing data policies and monitoring systems and build on current standards and best practices. To obtain an overview of how indicators (or datasets) are defined and documented, we compared the metadata profiles of several institutions and initiatives, such as the biodiversity strategy and dashboard, bioeconomy monitoring, the resilience dashboard, CAP indicators, Eurostat, INSPIRE and EU SDG indicators. We concluded that there is a wide overlap between the metadata elements used in these initiatives, even though the semantics (naming convention) may differ. Therefore, we applied the most commonly used naming and definitions.

To increase the comparability of the indicators based on their metadata, the project team agreed on using predefined data types (e.g. date in a fixed format) or values that are included in code lists. If standardised code lists were available in the public domain (e.g. a list of the Member States) we opted to reuse them. However, in the context of the EU FSMF we defined some specific code lists, for example a list of relevant policies and the objectives of relevant EU policies. These code lists can be extended if new indicators from other policy fields are identified or the objectives of the reviewed policies are revised. We also defined the mandatory multiplicity of every metadata element. The correctness of data types and the multiplicities were enforced by the application programming interface for entering the metadata of the indicators in DataM.

The EU FSMF harmonised metadata schema is presented in Table 4.

Table 4. Metadata schema of the EU FSMF

Metadata element	Sub-element	Multiplicity	Data type	Definition
Name		1	Free text	Denomination of the indicator.
F2F identifier		1	Character string	Identifier (code) used in the EU FSMF, assigned in DataM.
Definition		1	Free text	Concise text that provides the meaning of the identifier.
Description		0..1	Free text	Further, more detailed information about the indicator.

Domain		1..*	Code list	Topic category within a thematic field.
Link to F2F goals and targets		1..*	Code list	Reference to the objective or the target of the F2F strategy.
Support of other policies		1..*	Code list	Reference to the policies underlying the F2F strategy.
Supply chain component		1..*	Code list	Component(s) of the food supply chain that the indicator belongs to.
Spatial scope		1	Code list	Reference to the spatial unit that the indicator describes.
Level of detail		1	Code list	Granularity of data directly used for the calculation of the indicator.
Unit of measurement		1	Free text	Units in which the indicator is expressed.
Temporal characteristics	Timeliness	1	Date and time	Information about the delay between the data collection and publishing the data on indicator.
	Time coverage	1	Date and time	Period for which indicator values are available.
	Update frequency	1	Date and time	Time period between the regular updates of the indicator.
References		1..*		Citation of the publication that provides information about the indicator.
	Title	1	Free text	Name by which the reference is known.
	Date of publication	1	Date and time	Date of the publication.
	URL	0..1	URL	Unique resource locator.
Methodology				Documentation of the process of creation and maintenance of the indicator.
	Data sources	1..*	Free text	Description/reference to data sources used for calculating the indicator.

	Workflow	1	Free text	Description of the main processing steps in course of calculating the indicator.
	Formula	0..1	Free text	Mathematical expression of the calculation method.
	Link to calculation code	0..1	URL	URI/URL where machine-readable code of calculating the indicator is given.
	Quality control	1	Free text	Property of the indicator that informs about the quality control process of the indicator.
	Maintenan ce	1	Free text	Description of the (planned) maintenance process of the indicator.
	Uncertainty	1	Free text	Considerations for the use of the indicator in terms of thematic accuracy, soundness of the methodology, reliability of the input data, timeliness, conformance to the specifications of the dashboard, etc.
		1..*		Organisation involved in the management of the indicator.
Responsible party	Name	1	Free text	Name of the organisation.
	Role	1	Code list	Role played by the organisation in the management of the indicator.
	Contact	0..1	Free text	Functional mailbox of the responsible party.
	URL	0..1	URL	Website of the responsible party.
Coupled resource		0..1	URL	Link to web pages where information about the indicator (e.g. metadata) can be obtained
Data link		1	Code list	Link to a web service that the indicator can be downloaded from.
Conditions applying to use		1	Code list	Type of licences
Designation		0..1	Free text	Classification of indicators according to their designation in the dashboard.

Justification of designation		0..1	Free text	Succinct explanatory note on how and which aspects of food system sustainability can be measured by the indicator (if selected for the dashboard). If not selected, reasons for exclusion.
Comment		0..1	Free text	Any other important communication about the indicator, including on their eventual use in other MFs (e.g. SDGs, BDS, ZPAP)

NB: Notation: 0 – metadata element is not mandatory; 0..1 – metadata element is not mandatory and, when filled, can take one and only one value; 1 – metadata element is mandatory and can take one and only one value; 0..* – metadata element may take zero or more values; and 1..* – metadata element must take at least one value. URI – uniform resource identifier, URL – uniform resource locator.

Source: Own elaboration

Some of the indicator properties are published as accompanying information to the indicator dashboard as metadata for evaluation and use. They inform users whether an indicator responds to their queries. These metadata elements are complemented by the discovery metadata, which provide information about the data sources.

3.4.3. Quality assessment framework

The indicator properties and metadata are important inputs for assessing the fitness of an indicator for the purposes of the EU FSMF, which is assessed using standardised criteria and metrics. The need to assess the quality before reusing indicators has already been acknowledged in other Commission initiatives. For example, Eurostat reused indicators for SDG monitoring ([43]), selecting them according to the general principles of policy relevance, technical admissibility and data quality. In particular, the following aspects were taken into account.

— Indicators must be designed to monitor policy initiatives and must be relevant for measuring progress on the requirements of high-level EU policies. Only in areas where no such indicators exist are other indicators considered.

— Regular data production must be ensured. Indicators must have at least one data point ready to use and published by the producer. Data on indicators (metadata) must be accessible online and information on their data sources, methods of computation, etc. must be publicly available.

— Indicators and their underlying data must be produced according to a well-founded methodology and procedures. Indicators must comply with international or EU standards where such standards exist (i.e. agreed methodologies, definitions and classifications).

— Quality of indicators is based on a sound protocol that ensures regular monitoring and improvement of output quality.

We also considered the agriculture, environment, climate and health indicators reference quality framework, which is currently under development by the Commission and the European Environment Agency. It builds on the work of Eurostat but provides additional metrics for assessing

([43]) https://ec.europa.eu/eurostat/web/sdi/overview.

policy relevance and methodology, accepting that such indicators that do not fulfil all the requirements at the time of the assessment but could be still useful under certain conditions. This approach allows users to determine if such indicators are still fit for their specific purposes. We found this approach very useful for the 'pool' category of indicators, which does not fully correspond to the quality criteria (see Section 4.2) but may fulfil specific thematic requirements.

For the purposes of the EU FSMF, we merged the Eurostat and agriculture, environment, climate and health indicators systems, amending them to address aspects specific to the food system. As a result, we proposed assessing the quality of indicators based on policy relevance, methodology, geographical scope and temporal characteristics (timeliness, frequency of dissemination, time series duration). The assessment was carried out by assigning scores from 0 to 3 in each evaluation criterion. To reflect their relative importance, we assigned double the weight to relevance and methodology and developed detailed subcriteria for their evaluation. The quality assessment framework (QAF) of the EU FSMF is presented in Table 5.

Every criterion in the QAF is linked to one or more specific metadata element. Storing the QAF and the metadata schema in an integrated database enables automatization of the assessment, particularly when the metadata values come predefined by code list or are represented by specific data types. For example, the degree of geographical coverage can be easily determined from the list of Member States, and the temporal characteristics can be calculated from the standard representation of time values. In such cases, DataM calculated the score according to the rules specified in Table 5. Of course, metadata elements with free-text value (e.g. methodology) needed to be assessed by the thematic experts. The metadata revision by the experts was also an opportunity to check the results of automatic evaluations.

Table 5. Quality assessment framework of the EU FSMF

Weighting and points	High	Medium	Low	None (indicator is accepted)	Red line (indicator is not accepted)
	Criterion 1: Policy relevance – The indicator establishes a clear link between the EGD and the domains defined in the model, such as environment and climate and/or health. Indicators from existing MFs provide additional fitness for purpose. The indicator provides relevant information for policymaking and can be linked to either the goals or targets of the EGD and to the domains of the agreed food system model.				
Suggested criterion weight = 2 → maximum 6 points	**Scoring from 1 to 6 points in total** The indicator is relevant for monitoring: — a specific F2F objective/target (low, 1 p; moderate, 2 p; high, 3 p) — a specific domain of the food system model (low, 0 p; moderate, 1 p; high, 2 p). The indicator is used to monitor: — other EU policies underpinning F2F, EU or global policy MF (no, 0 p; yes, 1 p).				The indicator is not relevant to any of the domains in the food system model.
	Criterion 2: Sound methodology (including reliability) – The indicator has a sound and well-documented methodology.				
Suggested criterion weight = 2 → maximum 6 points	**Scoring from 0 to 6 points in total** The presented methods should be sufficiently transparent to enable replication of the indicator. A sound and detailed methodology is documented and available for consultation, and contains: — data sources (no, 0 p; yes, 1 p) — description of workflow (no, 0 p; yes, 1 p) — description of formula (even basic formulation) (no, 0 p; yes, 1 p) — type of quality control / validation (no, 0 p; yes, 1 p)				The indicator is not based on a sound methodology or its methodology is not documented at all.

Weighting and points	High	Medium	Low	None (indicator is accepted)	Red line (indicator is not accepted)
	— maintenance process (no, 0 p; yes, 1 p) — legal and/or peer-reviewed scientific references (no, 0 p; yes, 1 p) – a report without scientific review is 0 p.				
Suggested criterion weight = 1 → maximum 3 points	Criterion 3: Geographical scope – The data enable the development of an indicator with suitable geographical coverage.				
	(3 points) Data are available for 100 % of the relevant Member States at the level of aggregation preselected for the indicator (e.g. coastal Member State for marine-related indicators).	(2 points) Data are available for more than 75 % of relevant Member States at the level of aggregation preselected for the indicator. OR Data are available for 100 % of relevant Member States, but at a more aggregated level than preselected for the indicator.	(1 point) Data are available for 50–75 % of relevant Member States at the level of aggregation preselected for the indicator.	(0 points) Data are available for 50–75 % of the relevant Member States, but at a more aggregated level than preselected for the indicator.	Data are available for less than 50 % of the Member States.
Suggested criterion weight = 1 → maximum 3 points	Criterion 4: Timeliness – There is an acceptable gap between the last year of collected data (T_L) and the publication year of the indicator (T_P) (e.g. if $T_L = 2020$, $T_P = T_L + 1$ corresponds to publication before 31 December 2021) AND $T_L \geq$ NOW – 4 years (if NOW = 2022 then T_L must be ≥ 2018).				
	(3 points) $T_P = T_L$ +1 year AND	(2 points) $T_P = T_L$ +2 years AND	(1 point) $T_P = T_L$ +3 years AND	(0 points) TP is higher than T_L + 3 years or not	T_P is higher than T_L + 3 years or not specified and data have limited usefulness when published due to being outdated

Weighting and points	High	Medium	Low	None (indicator is accepted)	Red line (indicator is not accepted)
	TL ≥ NOW – 4 years	TL ≥ NOW – 4 years	TL ≥ NOW – 4 years	specified, but data are still useful when published OR T_L ≥ NOW – 4 years	OR T_L < NOW – 4 years
Suggested criterion weight = 1 → maximum 3 points	Criterion 5: Frequency of dissemination – The frequency of the data enables meaningful analysis of the evolution of the indicator.				
	(3 points) Data are available every year	(2 points) Data are available every 2 years	(1 point) Data are available every 3 years	(0 points) Data are available every 4–10 years	Data are available more than every 10 years or data availability not specified
Suggested criterion weight = 1 → maximum 3 points	Criterion 6: Time series duration near the reference year 2020 (as indicated by DG Health and Food Safety) – The period for which indicator values are available and useful for monitoring is T_L ≥ NOW – 4 years (if NOW = 2022 then T_L must be ≥ 2018).				
	(3 points) > 10 years AND T_L ≥ NOW – 4 years	(2 points) 5–10 years AND T_L ≥ NOW – 4 years	(1 point) < 5 years AND T_L ≥ NOW – 4 years	(0 points) New indicator in preparation or proposed	T_L < NOW – 4 years

NB: Temporal criteria (4, 5 and 6) are scored in relation to data of a given geographical coverage. If temporal criteria are inhomogeneous across areas / Member States, the lowest score is retained, as it probably affects the representativeness of the indicator.

Source: Own elaboration

3.4.4. Selection of indicators

The objective of the EU FSMF is to provide regular, accurate and up-to-date information about the state of the EU food system and measure its progress towards sustainability in the context of the EGD. According to previous research (Egenolf and Bringezu, 2019; Giuntoli et al., 2020), using a small number of indicators is appropriate for providing general overviews and statements, while using a large number of indicators is valuable for illustrating and highlighting detail. Data on the indicators must be published in a user-friendly way to inform policymakers, the general public and specialists in a structured manner. This implies an indicator selection process with a twofold objective.

— Identify indicators that are fit for including in the EU FSMF. These indicators must be policy-relevant and thematically informative while providing balanced coverage of all domains of the food system sustainability model. According to the UN Sustainable Solutions Development Network, the indicators need to be considered as an integrated package and must work in harmony with one another (UN SDSN, 2015).

— Select and highlight a limited number of 'headline' indicators that are essential for providing a quick and complete overview of sustainability.

The indicators must also be presented in such a way that enables them to be compared. Due to the heterogeneity of data sources, it is necessary to harmonise them. This work includes semantic harmonisation of terms and definitions, and denomination, normalisation and assessment of the quality of indicators based on the harmonised metadata elements.

During the development of the MF, two methods of measuring progress towards sustainability were considered: measurement in absolute terms or in relative terms. For the first method, absolute progress from a baseline value is considered. The reference (or baseline) values for indicators can be established based on expert opinion, political commitments or policy documents. Baseline values are indispensable for assessing explicit numerical targets. To remain consistent with the policies from which our indicators stem, we decided to adopt the baselines originally indicated in the existing relevant legal acts or monitoring initiatives. In other cases, we agreed to use 2020 as a baseline, as it is the year of publication of the F2F strategy.

To measure progress in relative terms, a comparison is made from one year to another to see whether an indicator value is improving, worsening or invariant. This kind of evaluation can give users a quick overview of trends. For this type of evaluation, the desired direction of the indicator must be clarified and recorded in the database.

3.4.4.1. Categories of indicators within the framework

Developing the EU FSMF required a multidisciplinary approach, where expertise in science and technology was coupled with policy advice. Given the high workload – during the project over 350 indicators and indicator concepts (placeholders) were collected, documented and assessed for quality and fitness for purpose – and the complexity of the food system (12 thematic areas with 38 domains), it was necessary to work in parallel in specialist thematic working groups (TWGs). Each TWG was responsible, depending on the number of indicators, for one or more thematic area of the food system.

The TWGs screened and compared the existing indicators within their thematic area(s) to propose a primary selection for the dashboard, as well as identify domains that were not sufficiently covered by indicators of acceptable quality. In addition to assessing the quality of the indicators using the

QAF, the TWGs paid special attention to selecting indicators directly related to the objectives and targets of the relevant policies. As an indicator can be linked to multiple domains, there were frequent exchanges between TWGs to agree on a primary domain for each indicator.

Indicators were processed according to their primary domains. The final objective of this exercise was to assign them to the dashboard as headline, secondary or placeholder indicators, remove duplicates and conceptually unsuitable indicators, and establish a pool of indicators with potential for future use, as defined below.

— Headline indicators measure the most important sustainability goals and targets related to the food system. They receive the highest visibility in the dashboard and are mostly policy driven.
— Secondary indicators provide further detail on headline indicators or additional, more specific, information. These indicators are selected for inclusion in the dashboard.
— Placeholder indicators are conceptually important indicators that might become part of the dashboard in the future. They also mark the gaps where data collection and/or conceptualisation of the indicator is needed.
— Pool indicators are indicators of insufficient quality and/or of lesser importance in the context of the EU FSMF. They can be activated when there is a new policy priority or used to replace similar indicators when their quality improves.
— Duplicate indicators are indicators with different names but build on the same methodology and report the same data.
— Unfit indicators are indicators that are not specific to or relevant for assessing the sustainability of the food system.

3.4.4.2. Selection workflow

To select the indicators, the workflow shown in Figure 3 was followed, which can be subdivided into three major phases:

— evaluating the scores and the domains of indicators;
— analysing indicators belonging to a specific domain;
— cross-checking the results of the domains and selecting headline indicators for the MF.

In the first phase, the results of quality assessment by different experts, represented as multiple scores of the same indicator, were analysed. The general aim of this step was to exclude outliers and increase general consistency of scores given by different experts to the same indicator.

In the domain analysis (the second phase), the starting point was the automatic ranking of the DataM system, based on the overall score. The most important step in this phase was to check, once again, to what extent the policy questions related to food system sustainability (e.g. F2F targets) have been met. This second phase also yielded a preliminary selection of headline indicators. Even though we did not define a priori a threshold, indicators with a score less than 17 were not selected as headline indicators.

In the third phase, a cross-domain check was carried out. First of all, an indicator should be included in the MF only once, as recommended by Eurostat. If the same indicator was selected in more than one domain, the experts working on each domain decided where it should be assigned. With these final steps, the preliminary proposal for the indicators to be included in the dashboard was concluded.

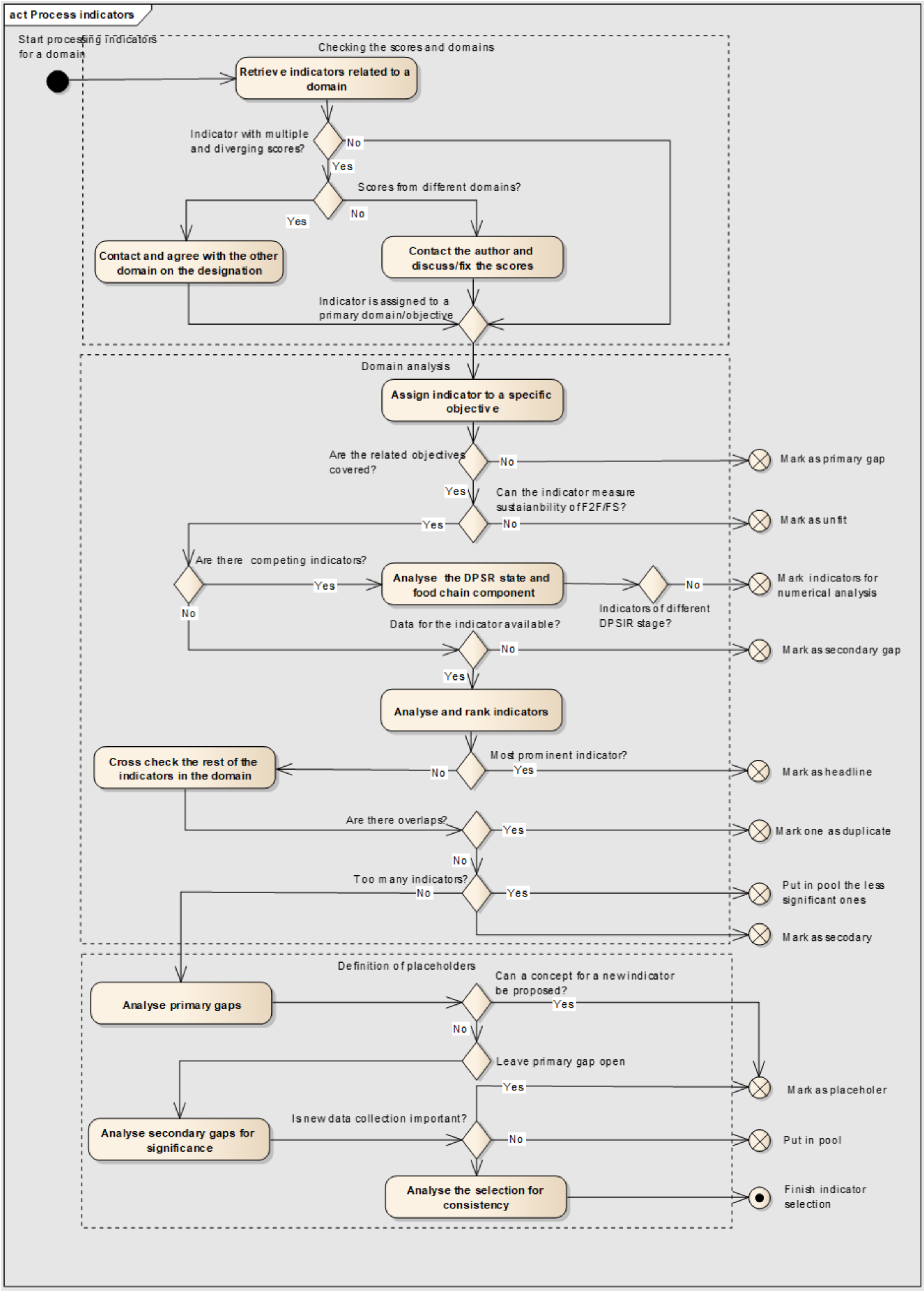
In the phase that followed, the proposed indicators were discussed with stakeholders – internally within the Commission and externally with the Advisory Group on Sustainability of Food Systems ([44]) and the Expert Group on General Food Law and Sustainability of Food Systems ([45]). The first external group is composed of representatives of various actors along the food supply chain and their associations, as well as non-governmental organisations. The second group consists of the experts delegated by the competent authorities of the Member State. The input from these groups helped to outline the direction of future work by identifying new placeholders for the system. The indicators presented in Chapter 4 also reflect the results of these consultations.

As indicated earlier in this report, the selected indicators are designated for the EU food system monitoring dashboard, a dynamic tool that will evolve together with our knowledge about the sustainability of the food system. Keeping all indicators in the master database of DataM enables regular revisions and rapid changes to keep the dashboard up to date.

([44]) https://food.ec.europa.eu/document/download/5819df4d-72ed-433d-83c1-5d41ada4f267_en?filename=adv-grp_ad-hoc_20230919_sum.pdf.

([45]) https://food.ec.europa.eu/document/download/1322c896-f1d0-4a24-83a6-08f9b790f594_en?filename=gfl_expg_20230919_min.pdf.

Figure 3. Indicator processing workflow



Source: Own elaboration

4. Indicators in the EU Food System Monitoring Framework

In this chapter we describe the two major components of the EU FSMF: the selected indicators and the dashboard designed for their visualisation. The first version of the dashboard, available as of the date of the present report, only covers the indicators classified as headline, and not the secondary or placeholder ones.

4.1. Overview of indicators selected for monitoring

After processing the indicators as described in Chapter 3, 236 indicators were retained in our database. Of these indicators, 44 were classified as headline, 31 as secondary, 25 as placeholder indicators and 136 as pool. The distribution of the selected indicators by thematic area is presented in Table 6.

Table 6. Distribution of indicators by thematic area and type of indicator

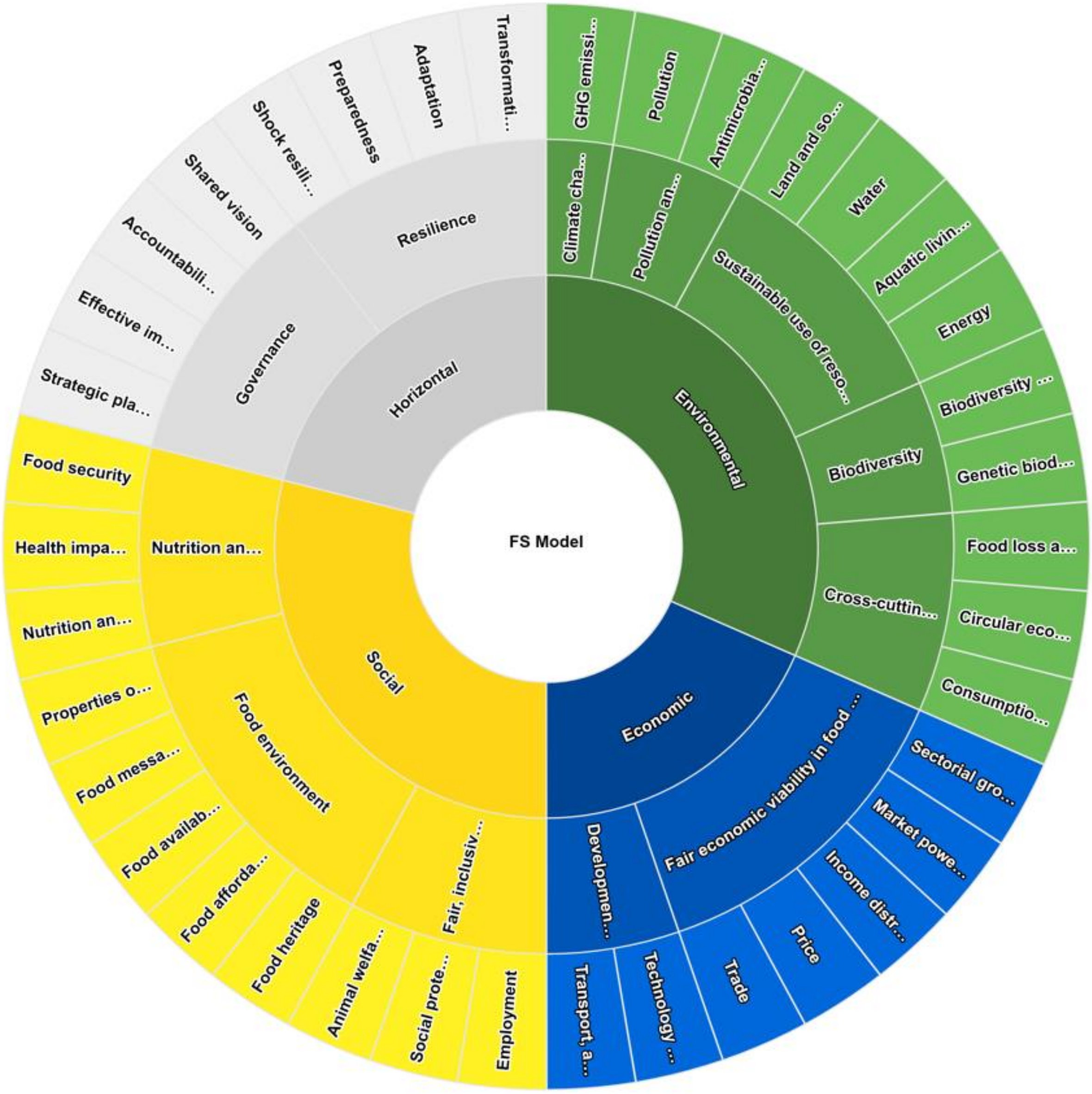
Thematic area	Total in the database	Headline	Secondary	Placeholder	Pool
Climate change	8	1	3	0	4
Pollution and antimicrobials	13	4	1	0	8
Sustainable use of resources	50	7	6	7	30
Biodiversity	13	3	1	2	7
Cross-cutting areas	24	2	17	1	4
Fair economic viability in the food value chain	30	9	1	7	13
Development and logistics	5	3	0	0	2
Fair, inclusive and ethical food system	21	6	1	3	11
Food environment	24	5	0	3	16
Nutrition and health	33	4	1	2	26
Governance	15	—	—	—	15
Resilience	—	—	—	—	—
Total	236	44	31	25	136

NB: For thematic areas, green shading denotes environmental, blue economic, yellow social and grey horizontal.

Source: Own elaboration

An overview of the distribution of indicators across sustainability dimensions, thematic areas and domains is provided in Figure 4.

Figure 4. Distribution overview of selected indicators



Source: Own elaboration

The proposed indicators could also be considered from the angle of supply chain components. The related statistics are included in Table 7.

Table 7. Distribution of indicators by food supply chain component

Supply chain component	Total in the database	Headline	Secondary	Placeholder
Primary production	176	34	30	18
Food processing	60	15	16	12
Food distribution	62	13	16	11
Food consumption	96	21	18	4

NB: The sum of the indicators does not coincide with the total figures in Table 6, as an indicator may include more than one component of the supply chain.

Source: Own elaboration

Concerning the components of the food supply chain, most of the selected indicators (82) are linked to primary production, 43 to food processing, 40 to food distribution and 43 to food consumption. These numbers suggest that the middle of the supply chain is underrepresented in our MF. This can be explained by the fact that our first efforts were focused on public data, while food processing and distribution are governed by private sector. However, according to a previous JRC study, the confidentiality of strategic business data and information is a major issue of concern (Bock et al., 2022).

In the following four sections we provide an overview of the headline, secondary and placeholder indicators for the domains categorised under the 12 thematic areas. Each indicator is presented in the context of the food supply chain component: primary production (PP), food processing (FP), food distribution (FD) and food consumption (FC). To enhance clarity, we applied the colour coding as included in Table 8. Please note that an example of an indicator fiche is provided in Annex 2.

Table 8. Colour coding and key properties of indicators

Colour	Indicator	Key properties
	Headline	Measures the most important goals and targets of the EGD/F2F and receives the highest visibility in the dashboard.
	Secondary	Provides further details on headline indicators or less prominent objectives of the EGD/F2F.
	Placeholder	Conceptually important indicators that will become secondary or headline indicators as soon as data are available.

Source: Own elaboration

4.2. Indicators proposed for the Environmental dimension

4.2.1. Climate change

After consultation with stakeholders and experts, the indicators included in Table 9 were proposed for the climate change thematic area. These indicators focus on GHG emissions.

Table 9. Indicators for climate change

Domain	Indicator	PP	FP	FD	FC
GHG emissions	GHG food system emissions				
	GHG emissions from agriculture				
	Net GHG emissions from LULUCF sector				
	Fishing-related CO_2 emissions related to fuel used per kilogram of landings (EU)				

PP-primary production, FP -Food processing, FD -Food distribution, FC -Food consumption; blue – headline, green– secondary.

Source: Own elaboration

The selected headline indicator, GHG food system emissions, was developed by the JRC (Crippa et al., 2021) and defines emissions associated with the production, distribution, consumption and disposal of food through the various stages and sectors of the global food system. These emissions include those related to agriculture, land use change, fisheries and aquaculture, as well as to energy demand and use at all stages of the food supply chain, covering all possible degrees of temporal and spatial granularity. An advantage of this indicator, when compared with other candidates, is that its modelling framework accounts for uncertainties in both the input data and the resulting outputs.

The secondary indicator GHG emissions from agriculture considers the following emission sources:

— enteric fermentation (CH_4)

— manure management (CH_4, N_2O)

— rice cultivation (CH_4)

— agricultural soil management (CH_4, N_2O, CO_2), including the burning of field residues, liming and the application of carbon-containing fertilisers.

Another secondary indicator, Net GHG emissions from the LULUCF sector, measures net carbon removals from the LULUCF sector, considering both emissions and removals from the sector.

We also identified a further secondary indicator, Fishing-related CO_2 emissions related to fuel used per kilogram of landings (EU), which tracks the efficiency of fuel use by marine capture fisheries expressed in terms of CO_2 equivalent emissions. This is calculated as the consumption of fuel divided by the total weight of landings, multiplied by a conversion constant factor of 2.64 to account for the carbon intensity of the fuel and the efficiency of the combustion process (Sala et al., 2022).

It should be noted that all four indicators are territorial indicators, which means that they account for food production in the EU territory only. To include the effect of food/feed imports, these indicators can be presented together with Consumption Footprint – GHG emission (see Section 4.2.5).

4.2.2. Pollution and antimicrobials

This thematic area comprises two domains: Pollution and Antimicrobials. In the first domain, the F2F strategy aims to reduce the overall use and risk of pesticides, as well as the utilisation of the more hazardous pesticides, by 50 %. In addition, the EU aims to reduce nutrient losses to the environment from both organic and mineral fertilisers by at least 50 %, while ensuring no deterioration in soil fertility. Regarding the second domain, the F2F strategy aspires to halve overall EU sales of antimicrobials for farmed animals and for use in aquaculture by 2030.

These targets are intrinsically related to primary production, with the consequent impacts on food consumption. For this reason, all the indicators within these two domains are associated with the cultivation of crops, the husbandry of livestock and aquaculture. To measure the progress towards these targets, the JRC proposed the indicators shown in Table 10.

Table 10. Indicators for pollution and antimicrobials

Domain	Indicator	PP	FP	FD	FC
Pollution	Use and risk of chemical pesticides (F2F pesticide reduction target 1)	[blue]			[blue]
	Use of the more hazardous pesticides (F2F pesticide reduction target 2)	[blue]			[blue]
	Water quality – nitrates in groundwater	[blue]	[blue]		[blue]
	Ammonia emissions from agriculture	[green]			
Antimicrobials	Sales of antimicrobials for food-producing animals	[blue]			[blue]

PP-primary production, FP -Food processing, FD -Food distribution, FC -Food consumption; blue– headline, green– secondary.

Source: Own elaboration

For this thematic area, we chose four headline indicators: Use and risk of chemical pesticides (F2F pesticide reduction target 1), Use of the more hazardous pesticides (F2F pesticide reduction target 2), Water quality – nitrates in groundwater and Sales of antimicrobials for food-producing animals. The first three indicators align with Target 7 of COP15 ([46]), which sets similar mitigation objectives concerning pollution risks and the negative impacts of pollution for achieving by 2030. These objectives include reducing excess nutrients lost to the environment by at least 50 % and halving the overall risk associated with pesticides and highly hazardous chemicals.

Risk from exposure to pesticides can be monitored using the harmonised risk indicators HRI1 and HRI2 under the sustainable use of pesticides directive (European Parliament and the Council of the European Union, 2009). An adapted version focusing only on chemical pesticides has been put forward under the May 2020 Farm to Fork and biodiversity strategies. These monitor reductions in the Use and risk of chemical pesticides using an indicator (F2F pesticide 50% reduction target 1) based on the quantities of active substances contained in the pesticides placed (sold) on the market, multiplied by relevant hazard weightings. The 50 % reduction in the Use of the more hazardous pesticides is measured using an indicator (F2F pesticide reduction target 2) that is based on sales data for the more hazardous pesticides, called 'candidates for substitution'.

It is clear that the current absence of EU data on the use of plant protection products (PPP) imposes a limitation on the design of harmonised indicators. The current shortcomings of the pesticide risk indicators have been stressed by some Member States, and by the European Court of Auditors (in its 2021 report on pesticide use) and by the citizens' initiative on pollinators. Some experts have argued that, due to shortfalls in the methodology, any trends reported by the indicators are misleading and do not sufficiently consider sustainability measures. As reducing pesticide usage and toxicity is essential for a more sustainable and healthier food system within the EU, further work on these indicators is expected that may lead to their substitution in our MF. New rules on the collection of agricultural statistics [Regulation (EU) 2022/2379 on Agricultural Inputs and Outputs], mean that farm level data on PPP use should become available from 2028. These new data could provide a basis for further improvement of HRIs or for the development of new indicators.

The third headline indicator, Water quality – nitrates in groundwater, addresses the EU's ambition of reducing nutrient losses to the environment from both organic and mineral fertilisers by at least 50 %. This indicator illustrates the potential threat to water quality of the presence of nitrates in groundwater on an annual basis. The protection of water resources, water ecosystems and drinking and bathing water is a cornerstone of the EU's environmental policy. This indicator is part of the performance monitoring and evaluation framework (PMEF) of the CAP (indicator C.39 I.15) and the EU's framework for the sustainable development goals (SDG_06_40), where it is used to monitor progress towards SDG 6 on clean water and sanitation and SDG 2 on ending hunger and malnutrition. The indicator can be calculated as average concentrations or as the number of monitoring stations exceeding the given thresholds.

While the use of both nitrogen and phosphorus greatly enhances crop production, their excessive utilisation can lead to nutrient losses and contribute to environmental pollution. Nutrient losses from fertiliser application and nitrates in groundwater are intrinsically linked, because their excessive application and improper management contributes to nutrient run-off and leaching into groundwater. Once nitrates enter groundwater, they can persist for long periods due to limited oxygen availability. Elevated nitrate concentrations in groundwater pose significant risks to both

([46]) https://www.cbd.int/article/cop15-cbd-press-release-final-19dec2022.

human and animal health, and to the environment, including eutrophication in surface water bodies, leading to harmful algal blooms and ecological imbalances.

Unfortunately, a lack of comprehensive data on fertiliser use hampers our ability to accurately assess associated emissions and pollution, thereby preventing rigorous evaluations of their potential environmental impacts.

This domain includes Ammonia emissions from agriculture as a secondary indicator, recognising ammonia (NH_3) as a key agricultural pollutant. Ammonia emissions are one of the main sources of atmospheric pollution from agriculture, arising primarily from manure management, inorganic nitrogen fertilisers and livestock waste (Van Damme et al., 2021). These emissions contribute to the formation of fine particulate matter (Wyer et al., 2022), adversely affecting air quality and public health, and leading to ecosystem acidification and eutrophication, which harm water bodies and soil fertility (Van Damme et al., 2018).

This indicator reflects the mitigation target expressed in the national emission ceilings directive (Directive (EU) 2016/2284) (European Parliament and the Council of the European Union, 2016), which sets national emission reduction commitments for Member States for five key air pollutants, including ammonia. Consequently, the EU closely monitors ammonia emissions under the CAP (indicator C.47 I.14), aligning with the European Environment Agency's inventory for the Long-range Transboundary Air Pollution Convention and sustainable development goals indicator SDG_02_60 (Pinterits et al., 2022).

The indicator Sales of antimicrobials for food-producing animals monitors progress towards a 50 % reduction in sales of antimicrobials for farmed animals by 2030. Reducing the use of antimicrobials in relation to food-producing animals is a response to societal demands regarding food and public health, including the fight against AMR, the promotion of safe, nutritious and sustainable food production, and the improvement of animal welfare. The indicator is also part of the PMEF of the CAP (indicator C.48 I.28).

4.2.3. Sustainable use of resources

This thematic area consists of four domains linked to the sustainable management and use of Land and soil, Water, Aquatic living resources and Energy, Table 11.

Table 11. Indicators for the sustainable use of resources

Domain	Indicator	PP	FP	FD	FC
Land and soil	Share of agricultural area under organic farming				
	Gross nutrient balance – nitrogen				
	Gross nutrient balance – phosphorus				
	Soil organic carbon in agricultural land				
	Consumption of inorganic fertilisers – nitrogen				

	Consumption of inorganic fertilisers – phosphorus				
	Share of the top three crops of total agricultural production				
	Agricultural land covered with landscape features				
	Drought impact on agriculture				
	Crop diversity				
	Global deforestation index due to EU food consumption (net imports)				
	Soil sealing in agricultural areas				
Water	Water exploitation index plus (WEI+)				
	Water use in food processing and distribution				
Aquatic living resources	Fishing pressure relative to maximum sustainable yield				
	Fish stock biomass relative to biomass in 2003				
	Proportion of assessed fish stocks for which fishing mortality (F) is above/below FMSY				
Energy	Final energy consumption in agriculture, forestry and the food industry				
	Production of renewable energy from agriculture and forestry				
	Fuel use of fisheries per kilogram of fish landed in ports				

PP-primary production, FP -Food processing, FD -Food distribution, FC -Food consumption; blue– headline, green– secondary, yellow– placeholder. NB: F – fish mortality by fishing FMSY – fishing mortality at maximum sustainable yield.

Source: Own elaboration

For the Land and soil domain, there are four headline indicators. The Share of agricultural area under organic farming directly monitors the F2F target of having at least 25 % of the EU's agricultural land under organic farming by 2030.

Two additional headline indicators are suggested to measure the Gross nutrient balance of nitrogen and phosphorus. The Gross nutrient balance of nitrogen presents a link between the agricultural activities responsible for high nitrogen loads and the environmental impact. The Gross nutrient balance of phosphorus provides an insight into the link between the use of agricultural nutrients, their losses to the environment and the sustainable use of soil nutrient resources.

Soil organic carbon in agricultural land estimates the total organic matter content in soils on agricultural land. Soil organic carbon, the major component of soil organic matter, is extremely important for all soil processes and the productivity of soils. Organic material in soil is essentially derived from residual plant and animal material, synthesised by microbes and decomposed under the influence of temperature, moisture and ambient soil conditions. Soil erosion and soil organic carbon are the two soil-relevant indicators used to monitor the impact of the CAP on soils.

The PMEF of the CAP includes the context indicator 'C.40 – Enhancing carbon sequestration', which is relevant to Soil organic carbon in agricultural land. The current total soil organic carbon content in arable lands is estimated using LUCAS topsoil ([47]) 2009, 2012 and 2018 surveys (De Rosa et al., 2023). In each of the three past LUCAS topsoil surveys, around 20 000 soil samples were collected and analysed for chemical, physical and biological attributes, including soil organic carbon (Orgiazzi et al., 2018).

In addition to the four headline indicators, there are three secondary indicators and five placeholders. The secondary indicators aim to address the F2F objective of preserving land, traditional land use and protecting the soil. Consumption of inorganic fertilisers – nitrogen and phosphorus measure the total amount (in tonnes) of inorganic fertilisers consumed by Member States. These were categorised as secondary indicators as they address a key secondary target (as a consequence of reducing nutrient losses by at least 50 %) of the F2F strategy: to reduce the use of fertilisers by at least 20 % by 2030. The indicators illustrate the total consumption of inorganic (or mineral) fertilisers in agriculture – in tonnes of nitrogen and phosphorus – reported by countries or estimated by Eurostat (data for some Member States were estimated up to 2018). To complete the picture, organic fertiliser use data would be necessary. Unfortunately, a lack of comprehensive data on organic fertiliser hampers the ability to accurately assess the overall quantity and distribution of fertiliser application, limiting comprehensive evaluations of their potential environmental impacts.

The Share of the top three crops of total agricultural production was chosen as a secondary indicator for the MF. A higher concentration of a few crops can reflect a lack of diversity in production systems, potentially increasing their vulnerability to various shocks (pest, extreme weather, shortage of seasonal workers, storage, etc.) and the risk to food security (The Economist Group, 2021). The necessary data can be obtained using remote sensing or from agricultural statistics.

Regarding the Agricultural land covered with landscape features indicator, the evaluation of landscape features is essential for monitoring biodiversity preservation and soil erosion mitigation measures. Preliminary data for certain categories of landscape features collected using remote sensing exist and are expected to be improved with reporting by Member States within the context of the PMEF of the CAP. Nevertheless, it has been classified as a placeholder due to the current difficulty in collecting numerical data.

The indicator Drought impact on agriculture provides important information about the resilience of the food system, as it is directly associated with vulnerability to environmental shocks,

([47]) LUCAS topsoil represents the largest harmonized open access dataset of topsoil properties available for the EU (Orgiazzi et al., 2018).

particularly in the context of drought situations. For the same reason than Agricultural land covered with landscape features indicator, it has been classified as a placeholder.

Crop Diversity, identified as C.22 I.22 in the CAP's PMEF, measures the number (and percentage) of farms classified by the number of crops that are grown in those farms, as well as the average number of crops grown on a holding at the regional level. Both measures can also be broken down by arable land size class. Overall, promoting crop diversity is essential for building resilience in agriculture and the food system, as it helps to mitigate risks, maintain soil health, ensure food security and support ecosystem services. It is currently classified as a placeholder, as it requires the use of confidential data from the Eurofarm database. A possible alternative for data acquisition is processing Earth observation data. Another option is to use the geospatial applications of CAP beneficiaries, which are increasingly being shared, linked to EU initiatives. These alternative sources of data will be explored in future releases.

Global deforestation index due to EU food consumption (net imports) measures the size of deforested area associated with the import of food products to the EU, expressed in hectares (De Laurentiis et al., 2024b). This indicator uses an estimation of the area needed to produce the food products imported by the EU and converts it into a potential deforested area (employing land use statistics). The indicator can measure how the EU reduces its contribution to global deforestation and forest degradation. Deforestation is also a focus of Regulation (EU) 2023/1115 ([48]) on deforestation-free products.

The indicator Soil sealing in agricultural areas provides information on the competition for land between agriculture, freshwater aquaculture and other sectors, such as transport, urbanisation, industry, energy and extraction of minerals and construction materials. This indicator is a placeholder and will be produced by the JRC in the future using remote sensing data.

A headline and placeholder indicator are proposed for the Water domain. The headline indicator monitors the Water exploitation index plus (WEI+) in general. The WEI+ provides an estimate of total water use as a percentage of renewable freshwater resources (groundwater and surface water) for a given territory and time period. The WEI+ accounts for water used in all economic sectors (households; service industries; mining and quarrying, and manufacturing and construction; electricity, gas, steam and air conditioning supply; and agriculture, forestry and fishing). Water use is estimated as the difference between the volume of water abstracted, and the volume of water returned to the environment in a specific sector (net water abstracted) (EEA, 2023).

Agriculture is the sector that puts the most pressure on renewable water resources. In the EU, only about 30 % of the total water abstracted for agricultural purposes returns to the environment (EEA, 2021). Water use in agriculture, forestry and fisheries accounted for 58.3 % of total water use in the EU in 2017 (EEA, 2021). With the implementation of the EU Water Reuse Regulation (Regulation (EU) 2020/741) and the obligation of Member States to report data on water reuse for agricultural irrigation, water use and, consequently, the WEI+ index will take into account the difference between the total freshwater withdrawn and the reclaimed water (reused treated wastewater) for agricultural irrigation.

([48]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R1115andqid=1687867231461.

A placeholder indicator on water use in other components of the food system is proposed: Water use in food processing and distribution. Agricultural activities do not include any subsequent processing of the agricultural products, which is therefore considered under the manufacture of food and beverage products sector (NACE division 10 and 12 ([49])). Data on water use in this sector are included in the data of water use in the economic sector 'mining and quarrying, manufacturing and construction', which overall accounted for 10.6 % of total water use in 2017 (EEA, 2022). Data on water use in food production are available in Eurostat databases (Eurostat, 2024).

In the Aquatic living resources domain, we propose one headline, one secondary and one placeholder indicators. In this domain we have focused on indicators related to sustainable fishing, (see the contribution of aquaculture to sustainability in the animal welfare section. with the indicator on the organic production of aquaculture products).

The Fishing pressure relative to maximum sustainable yield (trends in fishing mortality (F) / fishing mortality at maximum sustainable yield (FMSY)) indicator is currently the most relevant and the most inclusive for tracking fishing pressure and thus the decrease in overfishing in EU seas. This indicator shows the progress made towards the target of 1 (1.99 in 2004; 1.17 in 2020). However, it should be noted that a median of F/FMSY equal to 1 indicates that only 50 % of the included stocks are likely to be sustainably managed in terms of fishing effort.

The secondary indicator Fish stock biomass relative to biomass in 2003 charts the trend in the estimated fish stock biomass in the North-East Atlantic and in the Mediterranean Sea and Black Sea with reference to 2003 (trends in SSB/SSB2003). This indicator has comparatively higher uncertainty and is less influenced by human activity (e.g. it is also influenced by climate) than the fishing pressure relative to MSY indicator.

The indicator Proportion of assessed fish stocks for which fishing mortality (F) is above/below FMSY was proposed as an easy-to-understand placeholder indicator to assess the objective of the CFP to sustainably fish all fish stocks. In contrast, the headline indicator Fishing pressure relative to maximum sustainable yield provides the results of a complex statistical method enhancing the overall information of F/FMSY for the considered stocks. This placeholder indicator applied only to the North-East Atlantic area in 2023 but might also be developed for the Mediterranean Sea in 2024.

For the Energy domain, one headline and two secondary indicators are proposed. The F2F strategy is focused on increasing energy efficiency and renewable energy production in the food system. The headline indicator Final energy consumption in agriculture, forestry and the food industry provides valuable information for assessing energy efficiency, measuring the direct use of energy in primary production (agriculture and forestry) and food processing. It also contributes to the monitoring of other policies (forest strategy, CAP, SDGs) and, although it has some limitations due to the heterogeneous accuracy of national data sources, it is one of the few indicators within the Environmental dimension that crosses three thematic areas (Climate change, Pollution and antimicrobials, and Sustainable use of resources). It is currently the best available indicator that integrates data from the whole food chain for its purpose.

([49]) NACE is the general industrial classification of economic activities within the European Union(https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF).

The indicator Production of renewable energy from agriculture and forestry is defined as the installed capacity (thermal and electrical) of a specific renewable energy technology (hydropower, solid, liquid and gas biomass, biogas, wind, solar PV, solar thermal, geothermal and heat pumps), and was developed with CAP support. The indicator is maintained by Eurostat. Data are compiled under the standard collection cycles of the Energy Statistics Unit according to Regulation (EC) No 1099/2008 on energy statistics and its amendments. There is no target assigned to this indicator, although a higher value indicates a positive trend towards meeting the climate change mitigation objectives of the EU.

The Fuel use of fisheries per kilogram of fish landed in ports indicator estimates the energy demand of the wild-capture fisheries sector, calculated as gasoline consumed during its activities, which varies substantially depending on the types of fishing gear used. There is no target assigned to this indicator, although the lower the value the better.

4.2.4. Biodiversity

The Biodiversity conservation and restoration of natural ecosystems and the Genetic biodiversity of food production systems domains were included in the Biodiversity thematic area, where six indicators have been selected, as shown in Table 12.

Table 12. Indicators for Biodiversity

Domain	Indicator	PP	FP	FD	FC
Biodiversity conservation and restoration of natural ecosystems	Common farmland birds indicator	blue	blue	blue	blue
	Consumption Footprint - Food (biodiversity loss)	blue	blue	blue	blue
	Grassland butterfly index	blue			
	Impact of fisheries on marine biodiversity	yellow			
	Pressure of invasive alien species on ecosystems	yellow			
Genetic biodiversity of food production systems	Number of genetic resources for food production secured in either medium- or long-term conservation facilities	green			

PP-primary production, FP -Food processing, FD -Food distribution, FC -Food consumption; blue– headline, green– secondary, yellow– placeholder.

Source: Own elaboration

Three headline and two placeholder indicators are proposed for the domain of Biodiversity conservation and restoration of natural ecosystems. The headline indicators highlight the territorial (Common farmland birds indicator) and global (Consumption Footprint - Food (biodiversity loss)) aspects of biodiversity that are defined at the level of the whole food system.

The Common farmland birds indicator provides information on the impact of agricultural land use management on EU biodiversity. Considering birds as an indicator group for the status of other taxa, they are used as a proxy to assess EU agro-ecosystems' structure and function. The indicator is a composite index that measures the rate of change in the relative abundance of selected common bird species that are dependent on farmland. These population trends are derived from actual counts of individual bird species at selected census sites and modelled through time from a reference year. This indicator is widely used in several EU policies to assess the state of biodiversity associated with agricultural landscapes covering half of the EU's territory. It therefore has particularly high geographical and temporal coverage among the available biodiversity indicators. This indicator, with thematic identifier C.36 and I.19, is part of the PMEF of the CAP. It is also used in several other reporting frameworks, such as the agri-environmental indicators ('Population trends of farmland birds') and the SDGs indicators ('Common bird index by type of species – EU aggregate (sdg_15_60)').

The indicator Consumption Footprint – Food (biodiversity loss) was selected to provide a comprehensive assessment of the impacts on biodiversity of EU food consumption. A supply chain- and consumption-based approach enables assessment of the impacts occurring in both the EU and non-EU countries. This is an LCA-based indicator that evaluates biodiversity loss caused by the use of resources (e.g. including land occupation and transformation) and emissions to the environment (e.g. climate change, environmental pollution) along the entire supply chain of products (from the extraction from raw materials to the management of waste).

The third headline indicator, the Grassland butterfly index, is a good indicator of farmland biodiversity due to its sensitivity to habitat quality, which is intimately connected to agricultural management. It therefore offers a cost-effective method for monitoring biodiversity. Although it represents a group of pollinators, it is restricted to grasslands and is therefore considered to be a limited indicator for the whole domain.

The two placeholders we propose for this domain are indicators under development; when these indicators are able to be produced, they will be essential for understanding this thematic area. In particular, an indicator to measure the Impact of fisheries on marine biodiversity is needed to monitor the impacts of differences in selectivity and habitat alteration (pelagic versus seabed).

The proposed indicator Pressure of invasive alien species on ecosystems would be of value in the monitoring of both terrestrial and aquatic ecosystems, as the sustainability and stability of agriculture and fisheries production might be endangered by alien species. However, we currently have no direct access to a dataset with regular and accessible updates. Therefore, this indicator will remain a placeholder for the time being.

To conclude the definition of the indicators for Biodiversity thematic area, the Number of genetic resources for food production secured in either medium- or long-term conservation facilities is proposed as secondary indicator in the Genetic biodiversity of food production systems domain, and it is characterized by the two sub-indicators plant and animal. This indicator is derived from the global indicator framework for the sustainable development goals and targets of the 2030 Agenda for Sustainable Development and are listed under Goal 2: End hunger (target 2.5). It estimates the capacity to conserve *ex situ* different plant and animal varieties, which, by preserving the genetic diversity of organisms, is important for the food production system (van der Sluis et al., 2022). However, it should be noted that this indicator covers only some of the sustainability aspects in this domain (van der Sluis et al., 2022). The scarcity of data and the lack of a well-established framework for *in situ* conservation mean that additional study is required in this field.

4.2.5. Cross-cutting environmental areas

We have split the Cross-cutting environmental thematic area into three domains: Food loss and waste, Circular economy and Food Consumption footprint. An overview of the indicators for each of these domains is provided in Table 13.

Regarding the target on reducing food waste, we selected Food loss and waste as a headline indicator. The amount of food waste generated at any given stage of the food supply chain should be measured at least once every 4 years using 'in-depth measurement' (e.g. the methodologies of direct measurement, mass balances, surveys and diaries, as set out in Annex III of Delegated Decision (EU) 2019/1597) (European Commission, 2019b). Therefore, this indicator is based on official data reported by Member States to the European Commission (Eurostat). It is being used to draft food waste-related policies (e.g. as a baseline for setting targets) and is present in other MFs related to the EGD (e.g. the CEAP). This indicator is sufficient for assessing the achievement of the target, as it evaluates food waste generation as a whole.

Direct agricultural loss attributed to disasters is a secondary indicator and measures the economic impact of various disasters (e.g. floods, droughts and pests) on agriculture, directly indicating exposure to such shocks. These losses can affect the quantity and quality of food produced, which can ultimately lead to food shortages, price increases and reduced access to nutritious food.

Circular economy within the context of the food supply chain is an important domain that should be considered in any food system model. However, few indicators are available and those that exist are of insufficient quality. We plan to work on an indicator related to the circular material use rate, such as one that tracks the reuse of food processing by-products as feed, or the use of manure as fertiliser or material for energy production.

Consumption Footprint is a well-researched area that is a key focus of JRC research. Consequently, various available indicators have been proposed for the dashboard – the overall index as a headline indicator and its components as secondary indicators. The 16 impact categories of the Environmental Footprint method are recommended by the European Commission (European Commission, 2021e). As well as visualising these indicators together, each indicator can also be included in its corresponding domain (e.g. as indicated for water use). The Consumption Footprint – Food indicators can be assessed against the set of planetary boundaries adapted to the environmental footprint metrics (Sala et al., 2020), as is also done in the circular economy MF ([50]).

Table 13. Indicators for the cross-cutting environmental areas

Domain	Indicator	PP	FP	FD	FC
Food loss and waste	Food loss and waste	(blue)	(blue)	(blue)	(blue)
	Direct agricultural loss attributed to disasters	(green)			
Circular economy	Circular economy	(yellow)	(yellow)	(yellow)	(yellow)

([50]) https://ec.europa.eu/eurostat/web/circular-economy/monitoring-framework.

Consumption footprint	Consumption Footprint - Food				
Consumption footprint	Consumption Footprint - Food (acidification)				
Consumption footprint	Consumption Footprint - Food (climate change)				
Consumption footprint	Consumption Footprint - Food (eutrophication, freshwater)				
Consumption footprint	Consumption Footprint - Food (eutrophication, marine)				
Consumption footprint	Consumption Footprint - Food (eutrophication, terrestrial)				
Consumption footprint	Consumption Footprint - Food (freshwater ecotoxicity)				
Consumption footprint	Consumption Footprint - Food (human toxicity, cancer)				
Consumption footprint	Consumption Footprint - Food (human toxicity, non-cancer)				
Consumption footprint	Consumption Footprint - Food (ionising radiation)				
Consumption footprint	Consumption Footprint - Food (land use)				
Consumption footprint	Consumption Footprint - Food (ozone depletion)				
Consumption footprint	Consumption Footprint - Food (particulate matter)				
Consumption footprint	Consumption Footprint - Food (photochemical ozone formation)				
Consumption footprint	Consumption Footprint - Food (resource use, fossil)				
Consumption footprint	Consumption Footprint - Food (resource use, minerals and metals)				
Consumption footprint	Consumption Footprint - Food (water use)				

PP-primary production, FP -Food processing, FD -Food distribution, FC -Food consumption; blue– headline, green– secondary, yellow– placeholder.

Source: Own elaboration

4.3. Indicators proposed for the Economic dimension

4.3.1. Fair economic viability in the food value chain

The number of indicators initially identified for this thematic area was rather high. This was due to significant overlap with the Fair, inclusive and ethical food system of the Social dimension. Therefore, a comprehensive exchange took place, leading to the exclusive assignment of the shared concepts. As a result, 17 indicators were designated to this thematic area, with the selection of nine headline, one secondary indicators and seven placeholders distributed across five domains. An overview of the proposed indicators for this thematic area is presented in Table 14.

Table 14. Indicators for fair economic viability

Domain	Indicator	PP	FP	FD	FC
Sectorial growth	Value added along the food chain	blue	blue	blue	
	Labour productivity of the different sectors of the food chain	blue	blue	blue	
Market power and business structure	Gross fixed capital formation in agriculture	blue			
	Market concentration	yellow			
	Fish landings of EU small-scale fisheries (%)	green			
Income distribution	Farmers' income in agriculture compared with wages in the rest of the economy	blue			
	Average salary by sector	yellow	yellow	yellow	
	Employee earnings ratio	yellow	yellow	yellow	
	Employee remuneration as a share of value added, by sector	yellow	yellow	yellow	
Price	Consumer food inflation	blue	blue	blue	blue
	Price indices of agricultural inputs	blue			
	Share of household spending on food				blue
Trade	Trade balance	blue	blue	blue	
	Self-sufficiency rates – commodities	blue	blue	blue	blue
	Fertiliser self-sufficiency rate	yellow	yellow	yellow	
	Balassa index	yellow	yellow	yellow	
	Import dependency	yellow	yellow	yellow	

PP-primary production, FP -Food processing, FD -Food distribution, FC -Food consumption; blue– headline, green– secondary, yellow– placeholder.

Source: Own elaboration

The domain Sectorial growth is best defined by the generated value added. By monitoring this, we can identify which steps of the food chain generate the most value. Hence, we propose two headline indicators for this domain: Value added along the food chain and Labour productivity of the different sectors of the food chain.

With regard to the Market power and business structure domain, we focused on market concentration and competitiveness to monitor progress towards the EGD objective that 'No person is left behind'. This domain specifically targets producers. It includes indicators such as producers' investments, which gauge the economic well-being of the agriculture sector. This is best reflected in our headline indicator, Gross fixed capital formation in agriculture and the secondary indicator Fish landings of EU small-scale fisheries (%).

Small-scale fisheries (SSF) represent today a relatively marginal fraction of seafood products (8 % of gross tonnage) or even of capture fisheries (around 5 % of landings)' however, this sector has high social weight (SSF represents 50% of EU fishers, 76% of the total fleet in 2020) with high value-added to catches (high-quality).SSFs are defined as fishing vessels with a length of less than 12 m that use passive gear.

To complement that domain, we propose one additional indicator as placeholder: Market concentration The F2F strategy aims to improve the income of primary producers with the objective of ensuring the sustainability of their livelihood. Therefore, we compared Farmers' income in agriculture to the rest of the economy as the headline indicator for the Income distribution domain. This indicator gives an insight into the opportunity cost of working in agriculture relative to other sectors of the economy.

Finally, we added three placeholders to further monitor the income of food producers and processors (Average salary per sector and Employee earnings ratio) and the ability of farmers and other food chain employees to capture a fair share of the added value (Employee remuneration as a Share of value added, by sector). These are key indicators that should be promoted to headline indicators when data become available.

Price is one of the key indicators of stability in the food chain. After a long period of relative food price stability in Europe, food prices have been on the rise in the past few years, due mostly to increasing material and energy prices. We have included three headline indicators in this domain: Consumer food inflation by sector and agricultural input prices, Price indices of agricultural inputs and Share of household spending on food, including disaggregation by income group. However, the data for this indicator are currently reported only every 5 years; therefore, we can monitor this aspect using our framework only in the long term.

For the Trade domain, we selected Trade balance and Self-sufficiency rates – commodities, which measures the ability of the food system to sustain itself, as headline indicators. We also proposed Fertiliser self-sufficiency rate, the Balassa index and Import dependency as additional relevant placeholder indicators. While import dependency can show to what extent domestic consumption is covered by imports for selected commodities, the Balassa index measures the degree of specialisation of a country's export products. Including the fertiliser self-sufficiency rate recognises the important role of agricultural inputs in the resilience of the food chain, as it assesses the ability to maintain crop production with limited external inputs.

When considering this domain, we had extensive discussions on the sustainability of trade. Measuring the sustainability of trade is a real challenge, which makes it difficult to propose a suitable indicator for this purpose. It should be noted that the trade and sustainability chapters included in free trade agreements, which aim to address issues such as deforestation, do not contain sufficient detail to draw definite conclusions on trade sustainability. Consequently, we have chosen to approach the trade domain from a primarily economic perspective and not incorporate additional aspects of sustainability, as other thematic domains of our MF provide a thorough analysis of them.

4.3.2. Development and logistics

This thematic area is composed of two domains. Two headline indicators were selected for the technology and digitalisation domain and one indicator for the transport, accessibility and infrastructure domain, as shown in Table 15.

For the Technology and digitalisation domain, we selected broadband internet access by rural households (Rural Next Generation Access broadband coverage) as a headline indicator, as the importance of having reliable internet through fast broadband connections to all farmers and all rural areas is articulated in both the F2F strategy and the CAP. In addition, we selected Agricultural training of farm managers as a headline indicator to be used as a proxy for uptake of technologies, which can enhance farmers' ability to adapt and respond to agricultural challenges, contributing to resilience. Training, particularly in digitalisation and new technologies, can also lead to farm improvements and an increase in the productivity and value added of the food supply sector.

Table 15. Indicators for Development and logistics

Domain	Indicator	PP	FP	FD	FC
Technology and digitalisation	Rural Next Generation Access broadband coverage				
	Agricultural training of farm managers				
Transport, accessibility and infrastructure	Annual road freight transport by distance class				

PP-primary production, FP -Food processing, FD -Food distribution, FC -Food consumption; blue– headline.

Source: Own elaboration

Regarding the Transport, accessibility and infrastructure domain, we selected Annual road freight transport by distance class as a headline indicator. This indicator aligns with the F2F strategy's objective of reducing dependency on long-haul transport to enhance the resilience of regional and local food systems. It reports on the quantity of food products that are transported by road over different distance classes. While our current focus is on road transport, we plan to explore indicators for other forms of food transport as we gather relevant data.

4.4. Indicators proposed for the Social dimension

4.4.1. Fair, inclusive and ethical food system

For this thematic area, 34 indicators were analysed, out of which 10 were selected for the dashboard. Unfortunately, data for these indicators are scarce; only 7 can be immediately implemented as headline or secondary indicators, as shown in Table 16.

Table 16. Indicators for Fair, inclusive and ethical food system

Domain	Indicator	PP	FP	FD	FC
Employment	Employment by economic activity				
	Number of fishers in the EU small.-scale fisheries (passive gear)				
	Young farm managers in agriculture				
	Young fishers				
	Accidents at work				
	Gender employment gap in the food sector				
	Women employed in fisheries				

Social protection and poverty	Social protection and poverty				
Animal welfare	Share of laying hens by farming method				
	Organic production of aquaculture products				

PP-primary production, FP -Food processing, FD -Food distribution, FC -Food consumption; blue– headline, green– secondary, yellow– placeholder.

Source: Own elaboration

In the Employment domain, four headline, one secondary and two placeholder indicators are proposed. The headline indicator, Employment by economic activity, covers the entire food chain and reports on employment in agriculture and fisheries, the food industry and food services in absolute terms and as a share of total employment. It shows the importance of the food system in terms of jobs.

The Number of fishers in the EU small-scale fisheries is defined as the number of people employed on fishing vessels with a length of less than 12 m and using passive gear. SSFs have a high social weight (SSFs accounted for 50 % of crew in the EU and 76 % of active vessels in 2020) but also represents the regional and cultural importance of local fisheries Furthermore, the economic valorisation of the catch by EU SSFs (relative to total fisheries), although highly dependent on the targeted species, provides an indication of how the fish is caught to preserve its quality, and is perceived as responsible consumption (e.g. eat less animal protein, but of good quality). The social importance of SSFs justifies classifying this indicator as a headline in this dimension and domain (employment).

For this domain, another headline indicator, Young farm managers in agriculture, is proposed. Young farm managers are crucial for the continuation and sustainability of the agriculture sector. A similar indicator, Young fishers, is selected to illustrate the social sustainability of fisheries.

A secondary indicator on Accidents at work is proposed to monitor the F2F objective of improving working conditions and ensuring occupational health and safety. It considers only primary production (agriculture, forestry, fishing and aquaculture). We would like to extend this indicator to the other stages of the food supply chain; however, there are currently no available data.

The placeholder Gender employment gap in the food sector is proposed for monitoring gender equity in the employment domain. This indicator covers the entire food chain and looks at various economic activities, specifically crop and animal production; hunting and related service activities; fishing and aquaculture; manufacture of food products, beverages and tobacco products; and food and beverage service activities.

Data from the EPSR and the International Labour Organization's new database of labour statistics (ILOSTAT) could be also used to monitor employment, decent and safe working conditions, and social protection and poverty across EU countries; however, there is a lack of specific and adequate indicators related to food system activities.

It is worth noting that, regarding fisheries and aquaculture, the EU's annual economic report on the EU fishing fleet calls for the collection of data on the gender, age (groups), nationality (national, EU, European Economic Area, non-EU / European Economic Area), level of education (low, medium, high) and status (owner versus employee) of the workforce at the national level for future potential use. This is the reason why Women employed in fisheries was inserted as a placeholder indicator.

For the Social protection and poverty domain, no adequate indicator has yet been found. To assess poverty of workers in the food sector, we considered two indicators currently available in the Eurostat database. However, neither 'People at risk of poverty or social exclusion' nor 'In work at-risk-of-poverty rate' provide sectorial disaggregation. Therefore, they are not fit for the purpose of the FSMF. Regarding the first indicator, disaggregation by sector is not possible, because it includes all people at risk of poverty after social transfers, those severely materially and socially deprived, and people living in households with very low work intensity. These conditions are not related to specific job employment. The second indicator considers people who are employed and have an income below the risk-of-poverty threshold. Disaggregation by sector and a focus on the food sector would therefore be desirable in the future.

In the Animal welfare domain, the indicator Share of laying hens by farming method provides the percentage of laying hens that are kept in enhanced cages and barns, and those that are farmed using free range and organic farming methods. Data are available from 2011 (and in a few cases from 2014) at the Member State level, and an overall positive trend can be observed. Non-enriched cages have disappeared in the EU. Moreover, except for a few Member States, methods to ensure better welfare are increasingly being applied ([51]).

The level of uptake of organic standards could also be a proxy for monitoring progress towards animal welfare, as this is an important aspect of this production method (Hebinck et al., 2021b). In this respect, we propose two headline indicators to monitor the state of two groups of animals (organic production of aquaculture products and share of laying hens by farming method). For other animal production systems (e.g. meat and dairy bovine, pigs, broilers), no public datasets are available. We acknowledge the importance of monitoring stocking densities for other major livestock categories, which could be aggregated in an overall composite indicator describing animal welfare throughout their lifetime.

Another important potential indicator relates to the conditions of slaughter, linked to the food processing supply chain component. Animal welfare could be also approached from the point of view of the related legislation and financial funds directed to this area, but we consider that such an indicator is better suited to the Governance thematic area.

The relevance of Organic production of aquaculture products to this domain is still under discussion. We have included this indicator, as, according to the Scientific Technical and Economic Committee for Fisheries WG-2213 report on marketing standards (Ziegler et al., 2023), organic fish farmers must follow a special set of rules to obtain this certification. The feed provided must be organic, medicine treatment must be kept to a minimum, fingerlings used in grow-out farms must be organically produced, and there are rules for minimum water flows and maximum fish density. The related dataset 'organic production of aquaculture products in tonnes live weights (by country and year)' is available from Eurostat.

([51]) https://agriculture.ec.europa.eu/farming/animal-products/eggs_en.

4.4.2. Food environment

Five headline and three placeholder indicators were selected to monitor progress towards healthy and sustainable food environments, with 23 preselected indicators rejected. The source of the rejected indicators was the FAO, with many of the indicators (e.g. sanitation, access to drinking water) more relevant to developing countries. The indicators selected for our MF are included in Table 17.

Table 17. Indicators for the Food environment

Domain	Indicator	PP	FP	FD	FC
Food heritage	Number of products under a quality scheme per category and per scheme				
Food affordability	Percentage of the population who cannot afford a healthy diet				
	Affordability of a healthy diet: ratio of cost to total food expenditure				
Food availability	Ratio plant to total protein supply				
	Supply by food group				
Food messaging	Food labelling				
	Food promotion				
Properties of food	Nutritional quality of processed food offer				

PP-primary production, FP -Food processing, FD -Food distribution, FC -Food consumption; blue– headline, yellow– placeholder.

Source: Own elaboration

In the Food heritage domain, we included the headline indicator Number of products under a quality scheme per category and per scheme to account for the value of production under EU quality schemes. This indicator monitors the number of agri-food products categorised by type (e.g. wine, cheese and oils) and by quality scheme type (e.g. geographical indication and protected geographical indication).

In the Food affordability domain, we proposed two headline indicators. The Percentage of the population who cannot afford a healthy diet shows the proportion of the population who cannot afford the lowest cost selection of foods that would meet FBDG requirements, even when spending up to 52 % of their income on food (Penne and Goedemé, 2021). The indicator has been integrated into the FAO's *State of food security and nutrition in the world* annual report since 2020. Future work could possibly review the concept of affordability in the context of the EU. The other headline indicator, Affordability of a healthy diet: ratio of cost to total food expenditure, monitors the cost of the lowest cost selection of foods that would meet FBDG requirements (healthy diets) relative to households' total food budgets ([52]).

For the Food availability domain, two headline indicators were proposed: Ratio plant to total protein supply and Supply by food group. The Ratio of plant protein to total protein supply provides an overview of how food supply is evolving towards increased availability of plant-based food products. This indicator is derived from two variables from Faostat, the FAO's statistics database: 'average plant protein supply' and 'average animal protein supply'.

The domains Food messaging and Properties of food are not currently covered by adequate data; we therefore selected potential placeholders, as shown in Table 17.

4.4.3. Nutrition and health

Out of the 28 indicators screened, 4 headline, 1 secondary and 2 placeholder indicators were proposed for the 3 domains of this thematic area: Nutrition and healthy, sustainable diets, Health impact from diets and Food security (Table 18). The main reason for this restricted selection is the scarcity of available data.

Table 18. Indicators for Nutrition and health

Domain	Indicator	PP	FP	FD	FC
Nutrition and healthy, sustainable diets	Prevalence of exclusive breastfeeding among infants 0–5 months of age				
	Food consumption (food groups and other dietary factors)				
Health impact from diets	Prevalence of overweight and obesity among adults				
	Prevalence of overweight and obesity among children (aged 6 to 9 years)				
	Burden of disease attributable to dietary risk factors				
	Prevalence of overweight and obesity among children (< 5 years)				
Food security	Prevalence of moderate or severe food insecurity in the population				

PP-primary production, FP -Food processing, FD -Food distribution, FC -Food consumption; blue– headline, green– secondary, yellow– placeholder.

Source: Own elaboration

([52]) https://www.worldbank.org/en/programs/icp/brief/foodpricesfornutrition.

The Nutrition and healthy, sustainable diets domain is covered by two placeholder indicators. The Prevalence of exclusive breastfeeding among infants 0–5 months of age was included as WHO recognises that breastfeeding is essential for achieving optimal child growth, development and health (WHO, 2022b). While previous studies have been limited to low-income and middle-income countries, recent scientific literature, for example Neves et al. (2021) and Victora et al. (2016) indicate several national data sources for high-income countries, including EU Member States. We expect, therefore, that the geographical coverage of this indicator can be improved. However, temporal coverage, as well as semantic and methodological harmonisation, is lacking. That is the reason why this indicator is listed as a placeholder. We expect that this indicator can be populated with more recent data by contacting national statistical offices or by advanced searches on the web.

Regarding the Food consumption indicator, a healthy sustainable diet includes key food groups and nutritional aspects, as highlighted in national dietary guidelines and international recommendations (e.g. EFSA, WHO, FAO, EAT-Lancet, GBD study). The proportion of the population adhering to FBDGs could be a possible indicator for informing distance to target, but no data are available. Possible indicators can be identified in the definitions and principles of and recommendations for healthy and sustainable diets (Afshin et al., 2019; WHO and FAO, 2019), which include key food categories such as fruit, vegetables, legumes, nuts, and red and processed meat, and also dietary factors, including wholegrain, saturated fatty acids, free sugars, salt, added sugars and alcohol.

The EFSA's Comprehensive European Food Consumption Database is a source of information on food consumption, which is based on national dietary surveys. This database provides a good basis for exploring the development of adequate food consumption and nutritional factors. Where national food consumption surveys are too dated, food supply data trends (e.g. Faostat data or market research data) will be explored to extrapolate more recent information on Food consumption estimates. However, information on nutritional aspects is not readily available on the EFSA platform.

In the Health impact from diet domain, excess weight and obesity among adults and children are proposed as headline indicators, providing an indication on the progress towards reduction of excess weight among different age groups. Data on Prevalence of overweight and obesity among adults is provided by Eurostat. The WHO European Childhood Obesity Surveillance Initiative study provides data on the prevalence of overweight among children, providing standardised height and weight measurements every 3 years. As this dataset includes the data of more than 300 000 children in the WHO Europe region, it provides input to the headline indicator Prevalence of overweight and obesity among children (aged 6 to 9 years) and the secondary indicator Prevalence of overweight and obesity among children (< 5 years).

The other headline indicator, Burden of disease attributable to dietary risk factors, is estimated using the GBD study (Afshin et al., 2019).

In our model, the Food security domain is assessed using the Prevalence of moderate or severe food insecurity in the population indicator. This headline indicator provides information on people's access to adequate food at the level of the individual and household, as measured by the FAO's Food Insecurity Experience Scale survey module.

Several food insecurity indicators designed and used by international organisations such as the FAO, WHO and UN exist, but they are not able to be used for EU countries due to a lack of available data.

Food security in EU should be monitored using dedicated indicators. The lack of available data for the immediate and timely assessment of food security in EU is particularly noticeable currently, due to the recent economic crisis and the Russian war of aggression against Ukraine.

4.5. Indicators for the Horizontal thematic areas

4.5.1. Governance

In terms of the DPSIR framework, indicators on governance can be linked mainly to drivers and response, as measures and actions in this field are embedded in the wider political landscape with the participation of policymakers and civil society. From a technical point of view, governance indicators frequently use binary values (e.g. yes/no in the case of existence of legislation related to food system sustainability), and count measures or participating entities or the monetary values of resources spent on measures and actions.

As approaching governance in a horizontal and systematic manner is quite a novel approach, further work is needed to find the best balance between the indicators in this thematic area and select those that are the most informative in the context of food system sustainability. This is the reason why such indicators are not included in this report. The Commission plans to collaborate with Member States to learn from their good practices. Without pre-empting the future Governance thematic area, some potential domains for consideration when selecting future indicators are given below (indicated in bold in the subsequent paragraphs).

In the domain of Strategic planning and policy, an indicator could assess the existence of key policy measures in Member State legislation. Another key function of the MF might be to measure public and private funds directed to the research and development of food system sustainability.

The indicators in the domain of Effective implementation could look at concrete measures undertaken by the Member States to implement food system strategies and high-level objectives. In this respect, incentives, subsidies or taxation may play a fundamental role. The indicators linked to this domain are expected to provide further information on policy preferences within a Member State, rather than compare them.

Indicators in the domain of Accountability will describe how governments combat fraud and non-compliance with sustainability measures and what incentives they take to improve sustainability as a norm in both food production and consumption. Sustainable food procurement will be one of the priority areas of such assessment, but we will also address taxation measures, including taxes on unhealthy food (e.g. sugar taxes) or green taxation ([53]).

Strategies to influence food system governance are more effective when pursued through networks that include a broad range of actors (Hammelman et al., 2020). Indicators in the domain of Shared vision could deal with the participation of society in exchanging ideas to build up a fair, just and sustainable food system. An anchoring institution for the various actors could be food policy councils (European Economic and Social Committee, 2023). Furthermore, we may measure the number of companies that adhere to the codes of conduct on a sustainable food system and the

([53]) https://taxation-customs.ec.europa.eu/green-taxation-0_en.

existence or number of various fora that help food system actors (from producers to consumers) to communicate and exchange views with each other and the competent authorities.

Due to a lack of evidence on which governance measures influence the sustainability of the food system the most, we expect that selecting headline indicators and developing composite indices will be rather difficult. One of candidate headline indicators is the Healthy food environment policy index, which measures the extent to which governments have implemented healthy food environment policies compared with international best practices. The index includes the analysis of seven policy domains: food composition, food labelling, food promotion, food prices, food provision, food retail and food trade and investment.

Governance indicators that cover the whole food system are key to the faithful presentation of its sustainability perspectives. Visualising them together with the corresponding thematic indicators can be an important tool for informing the public and policymakers.

4.5.2. Resilience

Resilience, identified as a horizontal thematic area, represents a property that is cross-cutting within the food system, highlighting the system's capacity to adapt and respond differently across its diverse components (Seekell et al., 2017; Zurek et al., 2022). It includes inter- and transdisciplinary perspectives on emerging socioeconomic, environmental and governance challenges. This overarching concept characterises the capability of the food system, from primary production to consumption and food and nutrition security, to withstand and recover from shocks while maintaining its core structure, and to adapt during changes and pressures (Guyomard et al., 2020; Manca et al., 2017).

However, there is currently no clear consensus on how to measure resilience, as it is typically considered an abstract concept (Jones, 2019), There is also the question of whether resilience truly constitutes a dimension of (food system) sustainability (Béné et al., 2019a). Other food system frameworks consider resilience an important aspect for food system sustainability (Bock et al., 2022; Fanzo et al., 2021; Gustafson et al., 2016).

Despite commendable efforts to quantify resilience at the country level, these approaches tend to favour broad metrics, such as the economic impacts of disasters and infrastructure availability, which do not sufficiently address the EU's specific regulatory, social and environmental standards (CBD, 2023; Constas et al., 2021). This limitation highlights the insufficiency of a limited set of variables focusing on specific aspects of resilience for undertaking a comprehensive assessment within the EU context. Consequently, there is a need to develop a tailored methodology that more accurately reflects the complexities and unique characteristics of EU food system resilience.

To assess food system resilience, we have designed a framework that holistically integrates the key aspects of resilience (Davis et al., 2021; Zurek et al., 2022). The methodology that will be applied to calculate the final resilience index is as follows.

Step 1: Indicator selection and distribution

A suite of indicators that are reflective of food system resilience is selected. These indicators are then distributed into the following key resilience aspects or domains: preparedness, shock resistance, adaptation and transformation. Preparedness focuses on strategic planning for unforeseen events; Shock resistance is the system's ability to absorb sudden disruptions; Adaptation refers to adjusting to changing conditions; and Transformation involves making fundamental changes to respond to long-term shifts.

Step 2: Classification of indicators

Each indicator is then categorised according to its desired direction for resilience. Indicators for which the desired trend is positive – such as soil organic carbon, water quality and crop diversity – are classified as capacities. Indicators for which the desired trend is negative – such as soil erosion, pesticide sales and nitrogen surplus – are classified as vulnerabilities. The two resilience properties characterise the opposing factor that influences the food system's ability to cope with, adapt to and recover from stressors and shocks.

Step 3: Scoring against the EU median

For every Member State, each indicator is evaluated against the EU median. Scores for capacities are assigned as follows:

- '0' (zero) for values below the EU median minus the threshold;
- '0.5' (half) for values within the EU median plus or minus the threshold;
- '1' (one) for values exceeding the EU median plus the threshold.

For vulnerabilities, the scoring is inversed, as follows:

- '1' (one) for values below the EU median minus the threshold;
- '0.5' (half) for values within the EU median plus or minus the threshold;
- '0' (zero) for values exceeding the EU median plus the threshold.

Step 4: Summation and normalisation

Each Member State's score is summed up according to their original position within the environmental, social and economic dimensions, and governance thematic areas. To ensure comparability, these sums are normalised to range between 0 (zero) and 1 (one), providing an equivalent perspective of resilience across the board.

Step 5: Final score formulation

The normalised scores derived in step 4 are combined to form a composite score, which is then normalised again. The resultant final resilience score will range from 0 to 1.

The integration of resilience thinking into policy and into practice is a complex subject (Grafton et al., 2019). With this methodology, we are aiming for scientific precision, but also to develop a robust index that provides information to ensure a robust food system that promotes societal well-being and secures the prosperity of future generations. This requires recognising the potential trade-offs between the different dimensions. Therefore, we would like to stress that the methodology described here is an initial step, recognising that the final aggregation score is still subject to refinement.

4.6. Concept of the dashboard

4.6.1. Overview

The publicly accessible EU FSMF dashboard is the concrete outcome of the project. Concerted efforts to establish a suitable food system model, identify a comprehensive set of indicators, evaluate them, and select the most representative ones have culminated in this tool, conceived to offer a balanced representation across the sustainability domains and components of the food supply chain.

A structured dashboard can facilitate the monitoring and exploration of the complex, multidimensional reality of the food system in the EU. This involves breaking down this multidimensional system into hierarchical or cross-cutting subsystems, enabling users to navigate more effectively and find the specific details they seek. The dashboard is published as open data with persistent identifier https://data.europa.eu/89h/553a2cc8-2948-4d00-877e-f0b7b27e83c5, direct URL: https://datam.jrc.ec.europa.eu/datam/mashup/EU_FOOD_SYSTEM_MONITORING. DataM offers tools to rapidly develop two kinds of interactive pages for presenting data on the web, called interactive infographics and generic dashboards.

— Interactive infographics are the main method of presenting information in the MF dashboard. This solution enables the mixing of narratives and data visuals in a schema organised in horizontal tabs, with their subsections accessible using a lateral menu.
— Generic dashboards are obtainable from the infographics by zooming in on the data section in full-screen mode. This option is suitable for a technical audience, or when narrative is less important, or when users need to perform advanced self-analysis of data.

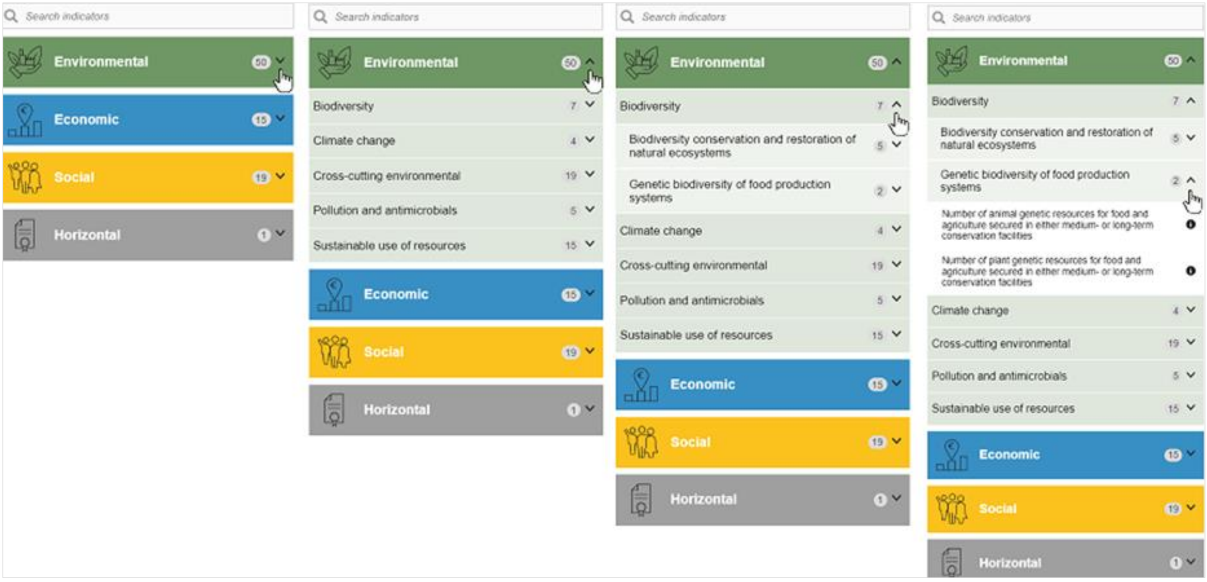
In the following subsections we describe the main functionalities of the dashboard.

4.6.2. Navigation

In the dashboard, users can approach the MF from different angles. In addition to searching for indicators by their names, users can also navigate according to the components of the food supply chain or the hierarchical food system model. While an indicator can be conceptually linked to more than one sustainability domain, for visualisation each indicator is assigned to a primary domain to integrate it into an overall hierarchical tree.

Such a structure can be used to present users with a drill-down menu along a multilevel navigation panel, where the main categories of the menu can be expanded or collapsed. The hierarchical navigation is illustrated in Error! Reference source not found.. Similar navigation trees are also available for the components of the food supply chain.

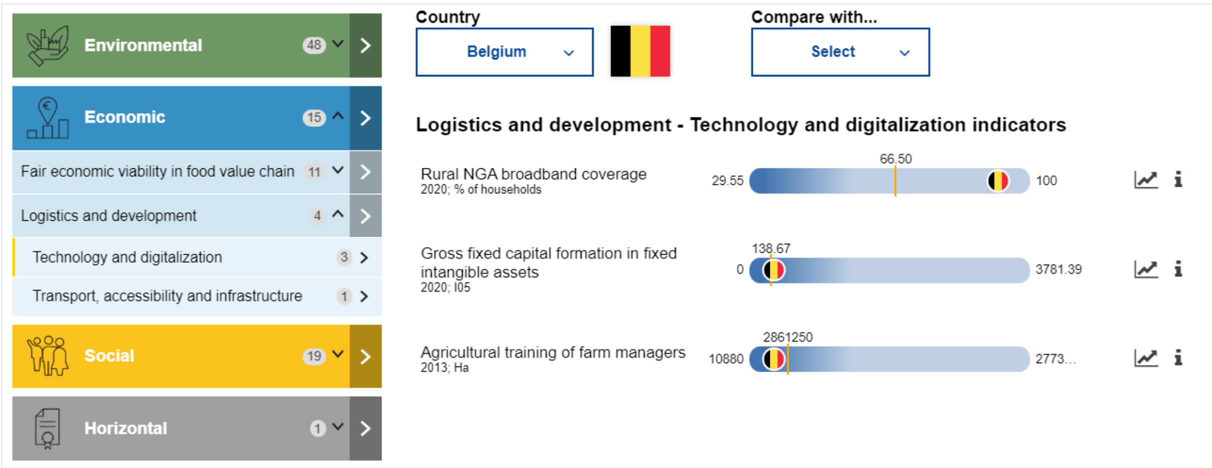
Figure°5. Hierarchical navigation in the EU FSMF dashboard



Source: Own elaboration.

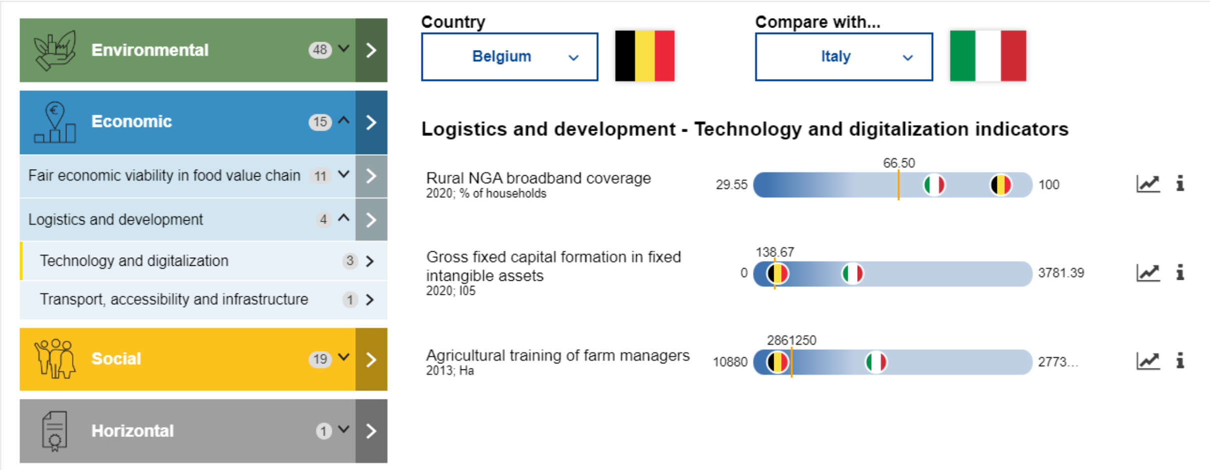
The top-down concept panel is easy to navigate due to its balanced structure, with a maximum of six children per parent node. Data can be classified according to other properties of the indicators, such as time and country. For example, selecting a country as an entry point in the country profile tab and then scrolling down within the food system model provides a comprehensive view of the selected domain, thematic area or dimension (Figure 6). Furthermore, this screen enables users to compare selected Member States (Figure 7).

Figure 6. Example of a country profile



Source: Own elaboration.

Figure 7. Example of a country comparison



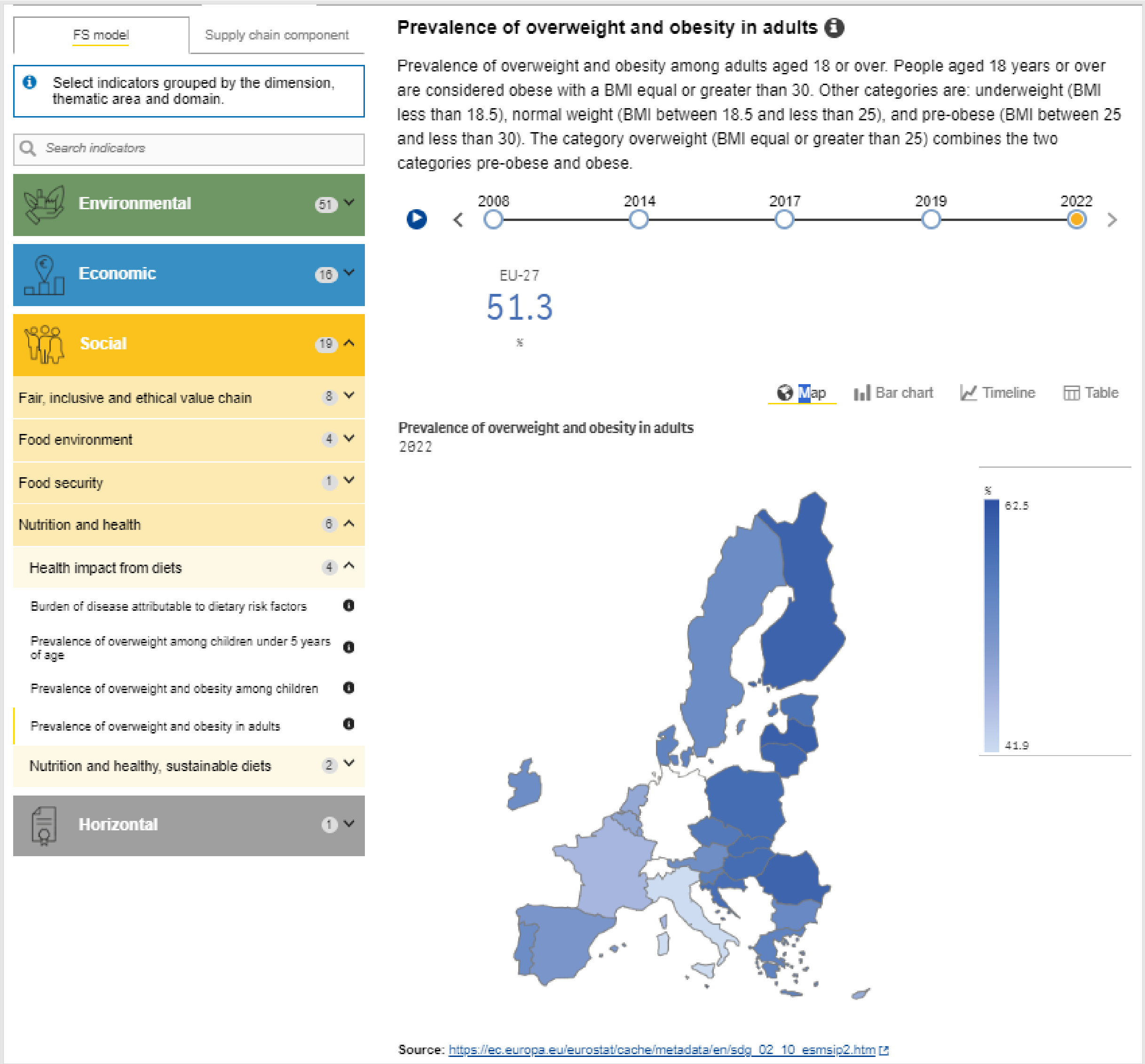
Source: Own elaboration.

4.6.3. Visualisation of indicators

The EU overview allows users to focus on one indicator at a time, with a view of the EU at a glance. The default view is the dynamic map (Figure 8), which enables users to see all Member States for a single indicator, for a specific year, and with an option to manually or automatically switch between the years. The bar chart option (Figure 9) is an equivalent alternative, which facilitates the ranking of countries.

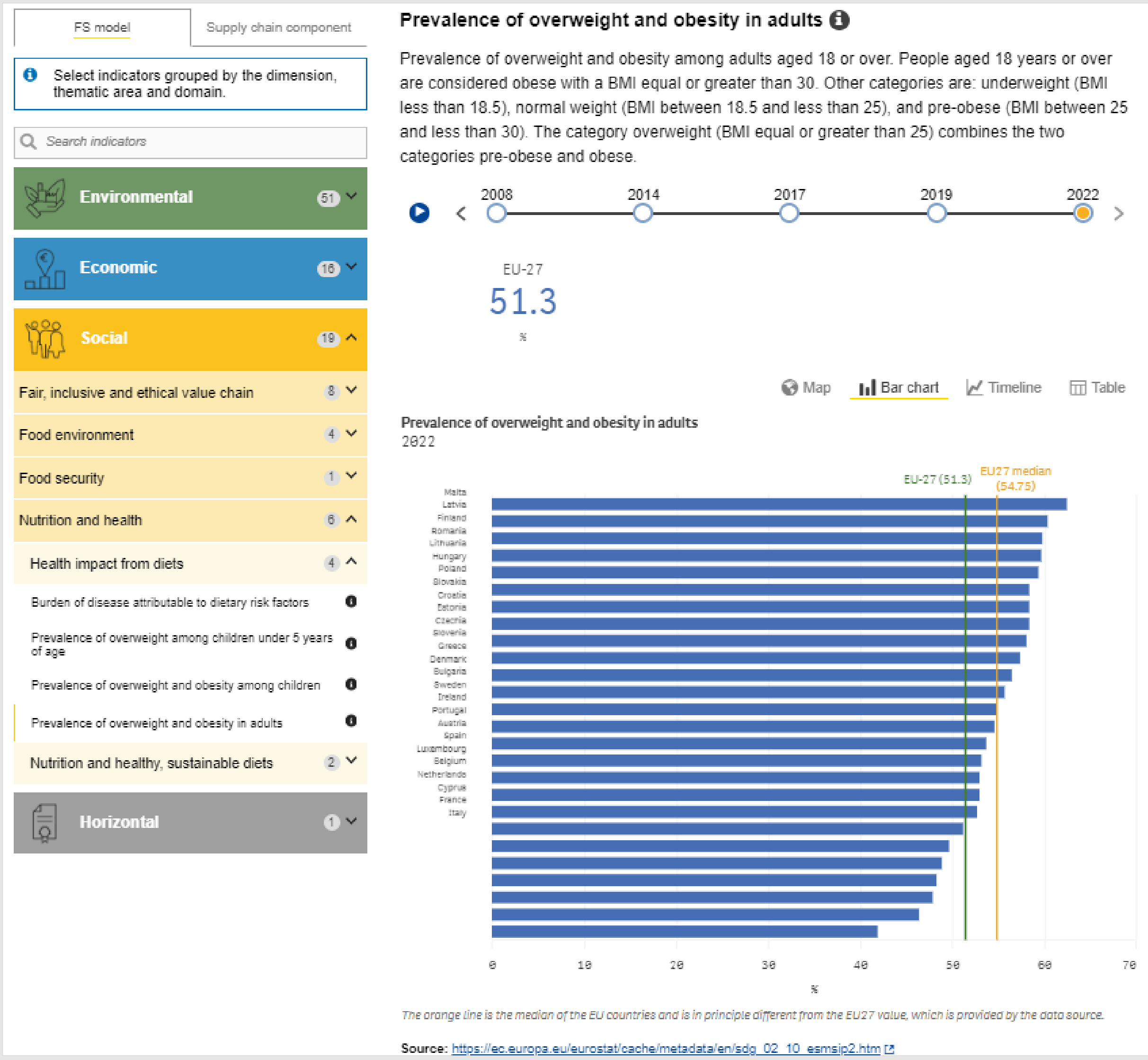
Alternatively, time series graphs (Figure 10) allow users to visualise the evolution of the indicator over time, but the effective display of multiple countries together is limited (e.g. showing more than five countries is not recommended).

Figure 8. Example of a map with autoplayer



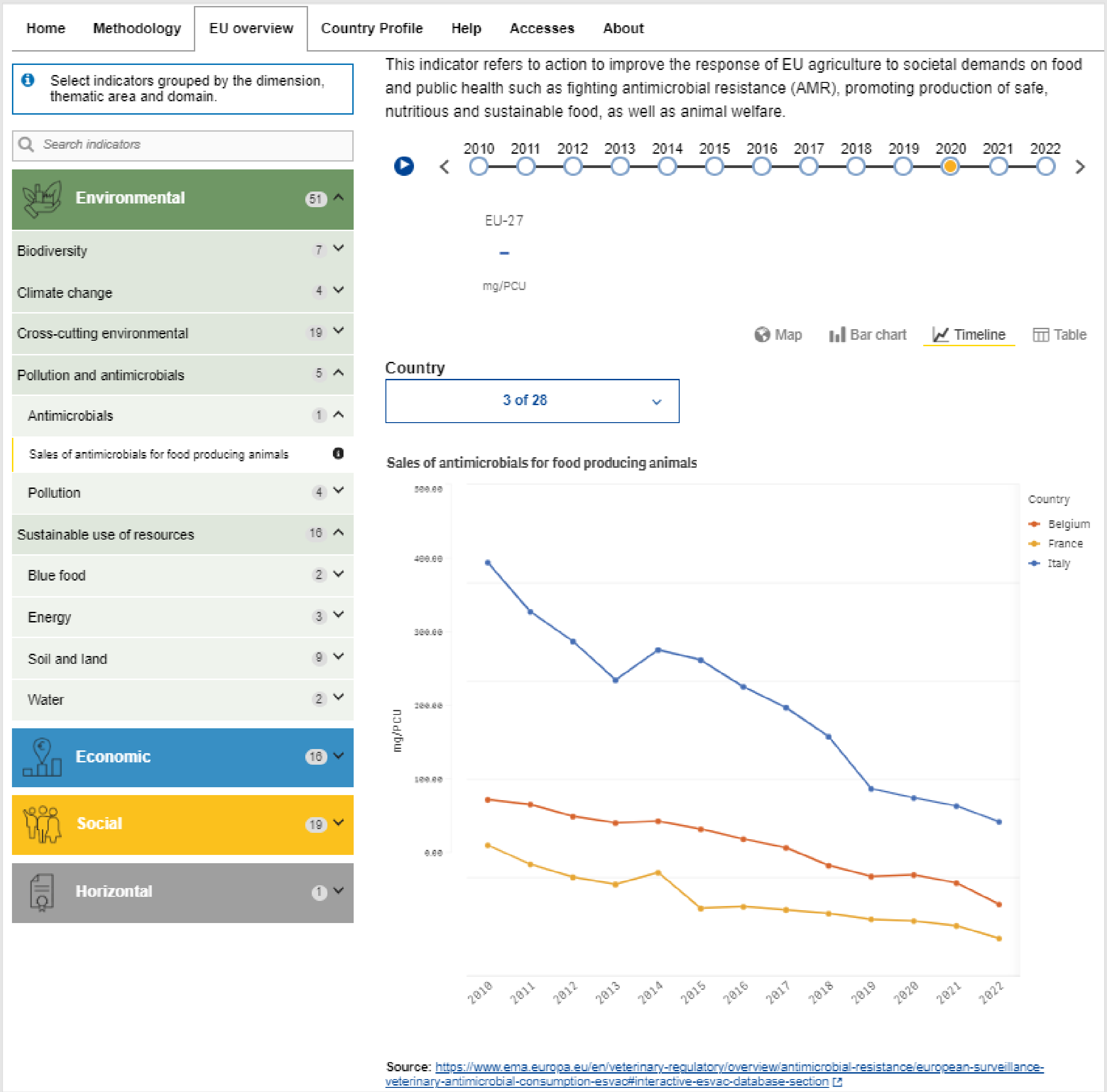
Source: Own elaboration.

Figure 9. Example of a time series in a bar chart



Source: Own elaboration.

Figure 10. Example of a timeline



Source: Own elaboration.

5. Further work

The set of selected indicators, as well as the dashboard, cannot be regarded as a final product. They will be continuously improved through evolutionary maintenance. As well as receiving technical support for continuous functioning, the framework will undergo periodic assessments and health checks.

One of the priorities for further work will be to develop the identified placeholders and designate them either headline or secondary indicators, depending on their importance. Work on the middle components of the food supply chain (food processing and distribution) will be a priority area, which may involve market intelligence data. Another opportunity would be to collaborate with DG Agriculture and Rural Development to process data from the Agriculture and Food Chain Observatory ([54]).

While some indicators require only some data transformation, in other cases development of the methodology is also needed. In both cases, the sequence of further indicator developments should be defined based on policy priorities and in agreement with a wider group of stakeholders, including Commission services and relevant EU agencies, as well as external experts and representatives. To facilitate this, emerging food system-related legislation and initiatives will be screened, with particular focus on acquiring timely information about new data collection and reporting. Establishing thematic working groups with the involvement of the widest range of experts may contribute to both defining the priorities and exploring new opportunities.

New indicators may also be proposed as additional elements in the dashboard or as replacements for any of the indicators previously selected. Our primary approach remains reusing existing data sources. However, when synergies between food system monitoring and the JRC research programme allow, we may set up or fine-tune scientific models to produce additional indicators.

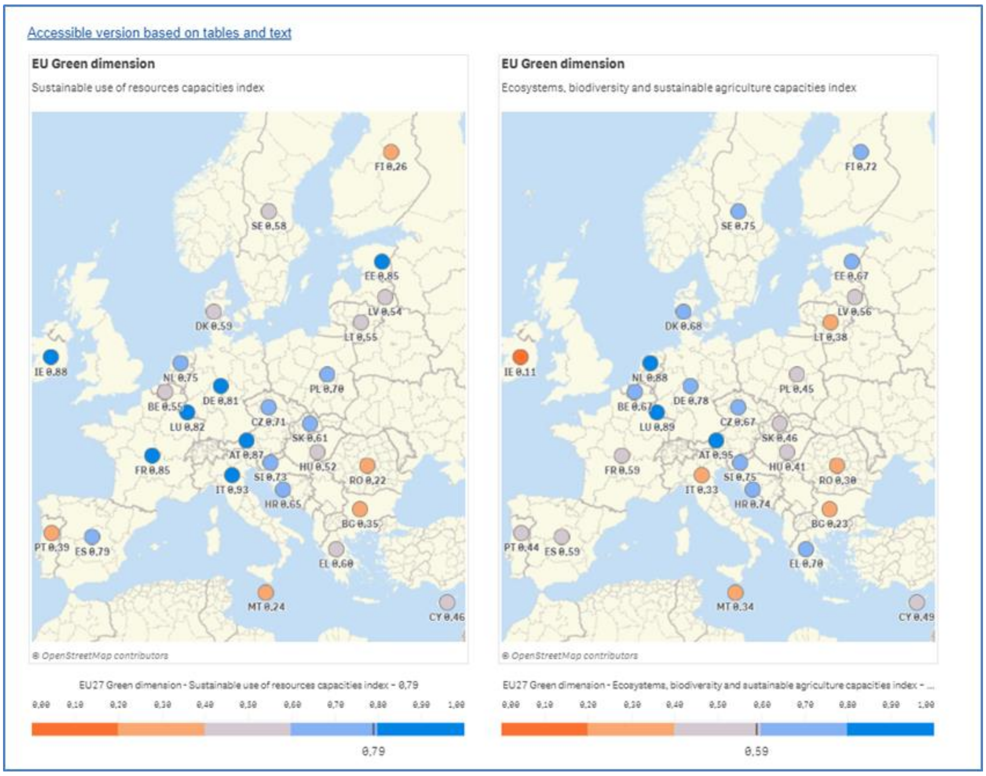
When new indicators are proposed for the dashboard, they should be scrutinised from two perspectives. First, the indicator should fulfil the requirements of our QAF; second, the new indicators should not disrupt the overall balance of the system. The prerequisite for the first task is the continuous updating of the indicator metadata. The second task requires periodic health checks, examining the distribution of the indicators across the domains and the components of the food supply chain. To avoid information overload, the number of indicators should be kept reasonably low.

We will use correlation analysis both to identify redundancies and to ensure the consistent messaging of the indicators. In addition, we will explore the use of composite indicators to provide information in a condensed way, from a broad perspective. Composite indicators, as statistical tools that summarise the information contained in different indicators into a general performance metric, may play an important role at this level, as they give a holistic but concise summary of the multidimensional concept. This representation is particularly useful to policymakers and the general population, who may seek only general information. Work on resilience indicators can be regarded as the development of composite indicators for the given domain.

([54]) https://agriculture.ec.europa.eu/news/commission-starts-setting-agriculture-and-food-chain-observatory-2024-04-09_en.

In addition to the developments and maintenance at the back end, we will gradually improve the front end, that is, the EU FSMF dashboard. We plan to introduce a few visuals that have proven to be useful in other MFs. For example, we plan to include visualisations of synthetic indices on maps, as shown in Figure 11.

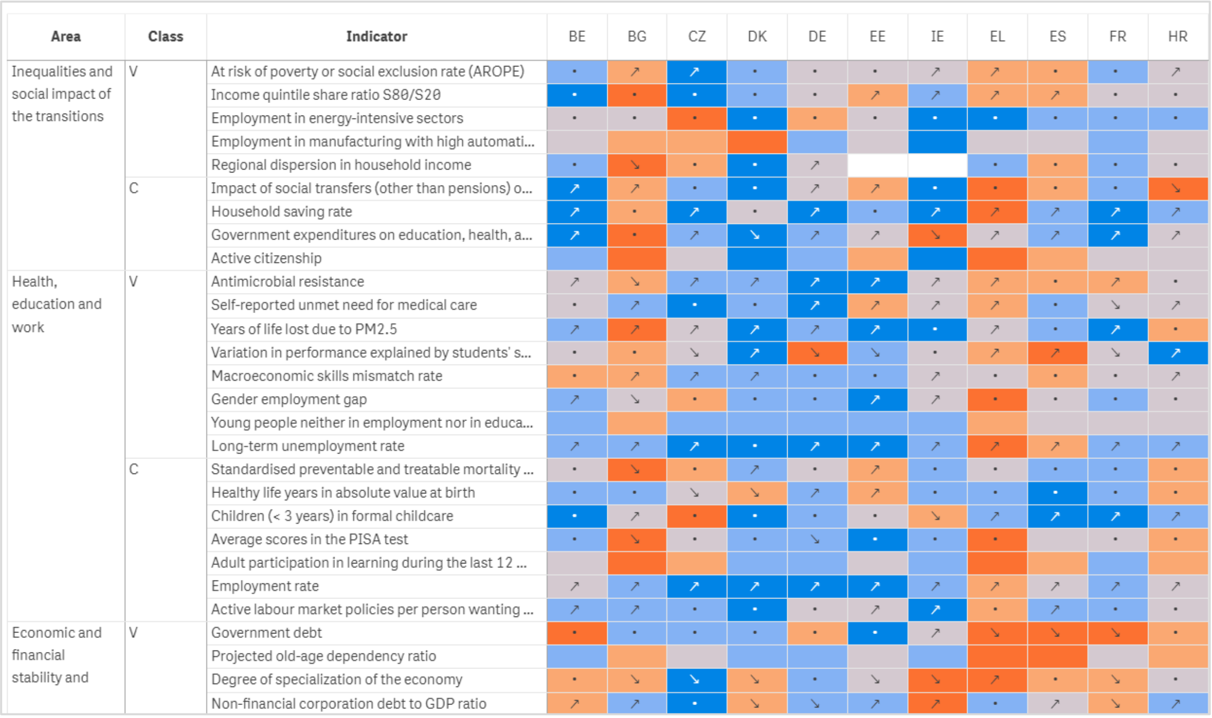
Figure 11. Example of visualisations of synthetic indices on maps



Source: European Commission Resilience dashboards, 2024.

Developing heat maps is also a possible direction, as they enable comparison of countries at a glance. Indicators are organised in a hierarchical manner, with different colours used to give a visual overview by area/dimension, as illustrated in Figure 12. Even though a prototype already exists, the intervals of different categories should still be discussed and agreed with the various stakeholder groups.

Figure 12. Example of a heat map



Source: European Commission Resilience dashboards, 2024.

Further developments in the monitoring system must also take into account the evolving context of the food system. As highlighted in the Communication 'Building the future with nature: Boosting biotechnology and biomanufacturing in the EU', these areas are among the EU's key priorities for 2024 and are expected to provide a new perspective on biotechnology, including in the context of the wider food system (European Commission, 2024b).

The strategic dialogue on the future of EU agriculture is another important initiative, bringing together farmers and other key stakeholders from across the agri-food chain, with the aim of finding common ground in terms of the future of the EU's agri-food sector. Eventually, the monitoring framework can encompass additional or modified indicators following the development of agri-food policies.

Taking a medium- to long-term perspective, given the envisaged enlargement of the EU to include western Balkan countries and Ukraine, we suggest that data on these countries should be incorporated as early as possible into a pilot version of an extended EU FSMF. The objective would be to identify and address data gaps in the pre-accession process.

6. Conclusions

The proposed framework for monitoring the sustainability of the EU food system provides the capability to measure the transition towards a competitive, sustainable, resilient and inclusive growth strategy, as indicated in the European Green Deal, and particularly the farm-to-fork strategy. Its conceptual model enables a holistic and cross-sectoral approach that addresses the environmental, economic and social dimensions of sustainability. Its implementation in an integrated database supports the entire cycle of data management, starting from the collection of indicators through to their publication in a dashboard. The architecture of the system follows the 'reuse of existing data' principle, in accordance with which data are harvested from the original sources, contributing to consistency with other monitoring systems and data sources. Using this approach helped collate information relevant to food system sustainability in a meaningful manner.

The conceptual model of the EU food system is based on a thorough review of the scientific literature and an analysis of the requirements of policies related to the European Green Deal. This model contains primary food production and food processing, distribution and consumption as components of the food supply chain. Sustainability aspects are presented in a hierarchical manner, categorised into 3 dimensions, 12 thematic areas and 38 domains. This structure enables indicators to be anchored to the elements of the model and gaps to be identified.

A condition for reusing indicators is that their suitability and quality for the intended purpose must be assessed. To achieve this, a quality assessment framework was established with a detailed workflow and a quality scoring system. To implement the framework, the identified indicators were documented according to a harmonised metadata schema. The quality scores and the harmonised metadata elements served as initial inputs for selecting headline and secondary indicators for the dashboard. To further refine the selection and gather input on data relevance and quality, consultations were conducted with the stakeholders, who ranged from Commission services to members of the Advisory Group on Sustainability of Food Systems and the Expert Group on General Food Law and Sustainability of Food Systems.

Through this participatory process, 44 headline indicators were identified and integrated into the first release, a user-friendly dashboard facilitating easy navigation and supporting users to find answers to their specific queries. The indicators will be continuously revised in the course of evolutionary maintenance. New indicators will be developed to fill the gaps and periodic health checks of the system will be carried out to ensure a balanced representation of the components of the supply chain and the sustainability domains. Currently, most of the gaps relate to food processing, distribution and consumption. These areas are mostly governed by the private sector, with limited publicly accessible data. Exploring alternative sources, such as big data, may be a way forward; however, special attention must be paid to ensuring data quality, including data supply at regular intervals with full geographical coverage.

The monitoring framework described in this report can be further developed to measure progress towards the targets and objectives of the European Green Deal. It can also serve to inform, and be tailored to, possible future EU policies or legislation. In this case, indicators on environmental, economic and social dimensions of sustainability will need to be aligned with the corresponding future policy targets and objectives, comparing them with the established baselines. The extensible conceptual framework, together with its flexible implementation in a database, provides a solid basis for this task.

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Abbreviations

AMR	antimicrobial resistance
BDS	biodiversity strategy
CAP	common agricultural policy
CEAP	circular economy action plan
CFP	common fisheries policy
DG	Directorate-General
DPSIR	driver–pressure–state–impact–response
EFSA	European Food Safety Agency
EGD	European Green Deal
EPSR	European Pillar of Social Rights
F2F	farm to fork
FAO	Food and Agriculture Organization of the United Nations
FBDGs	food-based dietary guidelines
FC	food consumption
FD	food distribution
FMSY	fishing mortality at maximum sustainable yield
FP	food processing
FSMF	food system monitoring framework
GBD	Global Burden of Disease
GHG	greenhouse gas
JRC	Joint Research Centre
LCA	life cycle assessment
LULUCF	land use, land use change and forestry
MF	monitoring framework
PMEF	performance monitoring and evaluation framework
PP	primary production
QAF	quality assessment framework
RACER	relevant, accepted, credible, easy to monitor and robust
SDG	sustainable development goal
SSB	spawning stock biomass
SSF	small-scale fisheries
TWG	thematic working group
WHO	World Health Organization
ZPAP	zero pollution action plan

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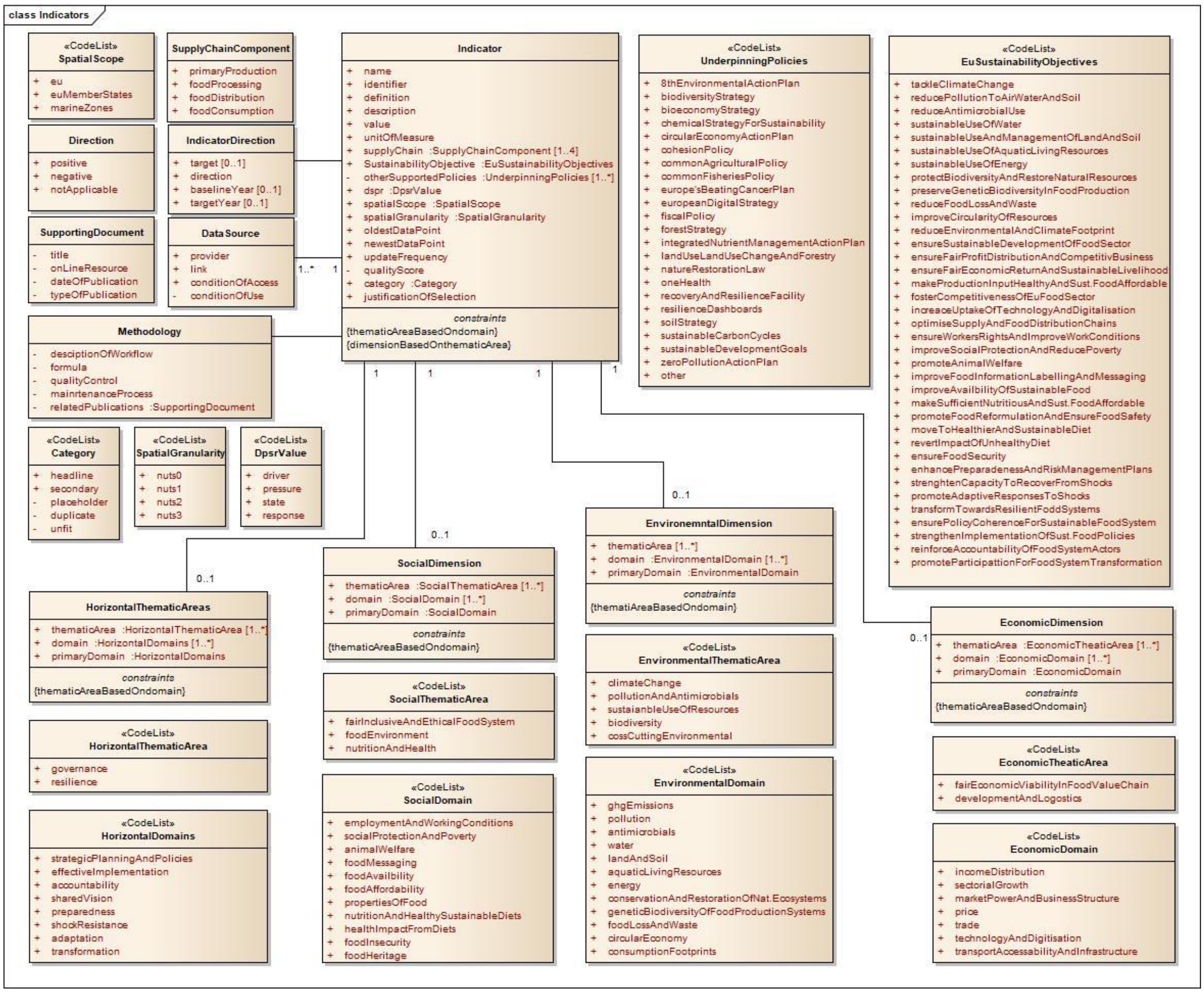
Annex 1. Unified Modeling Language model of the EU food system monitoring framework

Figure 13. Unified Modeling Language model of the EU FSMF information system



Source: Own elaboration.

Annex 2. Example of an indicator fiche

Table 19. Example of an indicator fiche applied in the EU FSMF

Indicator code	0004
Name	Common farmland birds indicator
Dimension(s)	Environmental
Area(s)	Biodiversity
Domain(s)	Biodiversity conservation and restoration of natural ecosystems
Definition	Modelled population trends of common bird species occurring in European farmland based on Europe-wide surveys
Description	The Farmland Birds index is a composite index that measures the rate of change in the relative abundance of common bird species that are dependent on farmland. It is used as a proxy to assess the biodiversity status of agricultural landscapes in Europe. Member States select their own species set, following guidelines from the European Bird Census Council, based on their distribution ranges and their relevance to different agricultural habitats in the EU. Population trends are derived from counts of individual bird species at census sites and are modelled through time.
Support other policies	• Biodiversity strategy • Common agricultural policy • Sustainable development goals
Supply chain component(s)	Primary food production
F2F goal(s)	
Spatial scope	EU
Granularity(ies)	Macro regions
Temporal characteristics	Information about the timeliness and time coverage of the indicator
— Oldest data point	1 January 1990
— Newest data point	1 January 2019
— Time granularity between the datapoints	Yearly
— Update frequency	Yearly
Unit of measurement	Index
Reference 1 (citation)	
— Title	Regulation (EU) 2021/2115 of the European Parliament and of the Council of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP strategic plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development

	(EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013
— URI/URL	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2021.435.01.0001.01.ENG
— Date of publication	2 December 2021
Reference 2 (citation)	
— Title	Context and impact indicators
— URI/URL	https://agriculture.ec.europa.eu/system/files/2023-02/pmef-context-impact-indicators_en.pdf
— Date of publication	7 March 2024
Responsible party	Organisation involved in the management of the indicator
— Name of data source	• DG Agriculture and Rural Development • Eurostat • PECBMS – Pan-European Common Bird Monitoring Scheme
Coupled resource	https://agridata.ec.europa.eu/extensions/DashboardIndicators/Biodiversity.html
Direct data link	https://ec.europa.eu/eurostat/databrowser/view/ENV_BIO2__custom_3626462/bookmark/table?lang=en&bookmarkId=6d4504fe-f5ae-452d-a60e-ab88335e3d10
Methodology	
— Workflow	For producing the EU aggregate index, a list of selected species is used (the so-called 'EU list of species', currently consisting of 39 species). The national indices for these species are combined into a European index by using a weighting factor accounting for the national proportion of the total European population. The methodology described below is followed for calculating the index. Methodology: The index for each Member State should be calculated based on the national species list. An index is first calculated for each species independently. The indices for the set of species are then combined on a geometric scale to create a multi-species aggregate index. National indices are compiled by each Member State using common software and methodology. A software modelling tool carries out the modelling work for estimating the index.
— Formula	
— Link to calculation code	https://pecbms.info/methods/software/
— Quality control	Validated
— Maintenance	
— Uncertainty	The amount of sampling plots/transects and the statistical representativeness of birdwatchers widely varies at the regional, national and EU levels. Ability to provide updates of indicators at the national level depends on the capacity of the national data providers. Small rises or falls in the indicator should be regarded as artefacts. It is best to look only at the trends from the defined baseline.

Conditions applying to access	Open source
Designation of the indicator	Headline
Justification of selection	Considering birds as an indicator group for the status of other taxa, they are used as a proxy to assess European agro-ecosystems' structure and function. This indicator is widely used in several European policies to assess the state of biodiversity associated with agricultural landscapes covering half of the EU's territory. It has a particularly high geographical and temporal coverage among the available biodiversity indicators. This indicator is part of the performance monitoring and evaluation framework of the CAP. An EU aggregated indicator is used in a number of reporting frameworks, for example agri-environmental indicator (AEI) 25 'Population trends of farmland birds' and the sustainable development goal indicator 'Common bird index by type of species – EU aggregate'. In the context of population trends of farmland birds, a positive direction is desirable.
Score (out of 24)	22 – from 3 evaluations (21; 22; 23)
Comment	This indicator is also used by the EU for reporting on the UN sustainable development goals (SDGs). For SDGs the first year in the time series with sufficient points has been established as the year 2000.

Source: Own eleboration.

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