



## Research Paper

# The FOODRUS index: Assessing suitability for effective food loss and waste prevention management under an integral perspective

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## ABSTRACT

The impact of food loss and waste (FLW) generation on food supply chains' (FSC) sustainability represents a challenge embodied in the Sustainable Development Goal (SDG) 12.3. This problem requires a methodology to measure such an impact in a rigorous, holistic, and standardized way that can be applied to any FSC. This paper aims to develop and validate a single index to assess the readiness of FSCs to implement FLW prevention strategies and measure their impact: the so-called FOODRUS index. The co-creation methodology followed incorporates experts and FSC stakeholders feedback. The index has been validated in 3 FSCs: The Slovak pilot scored 74.35%, the Spanish pilot reached 68.79%, and the Danish pilot was rated 61.14%. Its calculation, eased by the FOODRUS index self-assessment tool (described in the Appendix), allows quick diagnosis of the FSC capability to implement FLW prevention strategies considering both the knowledge provided by experts and the experience of the FSC stakeholders that participated in its co-creation process. In this way the FSC can assess its FLW prevention performance at a strategic and management level, with the aim of improving its sustainability impact.

## 1. Introduction

Food Loss and Waste (FLW) concern both the scientific community and the general public. The impact of this problem on the three sustainability pillars has been well documented in the literature (Alonso-Muñoz et al., 2022), becoming a specific target of the United Nations' Sustainable Development Goals (SDGs). Specifically, this target (number 12.3) aims to "halve per capita global food waste at the retail and consumer levels, and reduce food losses along production and supply chains by 2030" (United Nations, 2022). To achieve the target, a previous indispensable but controversial step due to discrepancies in the methodological procedure is the quantification of FLW, for which numerous efforts are being made. In 2011, FAO estimated that around one-third of the food produced for human consumption (i.e. 1.3 billion tons) is lost or wasted globally per year (Gustavsson et al., 2011). The FUSIONS project stated that this FLW generation amounted to 88 million tons in Europe during 2012 (Asa Stenmarck et al., 2016). In 2019, around 931 million tonnes of food waste (FW) (in retail, food service establishments, and

households) were generated on a global scale according to the Food Waste Index Report (Forbes et al., 2021). In the same year, considering the need to standardize quantification, the Commission Delegated Decision (EU) 2019/1597.

(European Commission, 2019a) was published. In annexes III and IV of that document, different methodologies to measure FLW are specified for each food supply chain (FSC) stage. Note that, in this article, the term FSC also encompasses all the actors participating in it. It also provides specifications on what must not be measured as FLW and how this quantification has to be carried out (European Commission, 2019a). In 2020, the European Union Member States were obliged for the first time to measure their FLW generation in accordance with the guidance that complements the delegated decision (European Commission, 2022). The results reported that 57 million tonnes of FLW were generated along the whole FSC at the EU level in 2020 (Eurostat, 2022). The delegated decision provided substantial insights regarding the FLW measurement unit generated and the FSC stages classification. Despite this and the proliferation of studies addressing FLW quantification, there is a

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challenge to establish a deeper standardization to make the studies comparable (Hoehn et al., 2023) since the delegated decision does not provide exhaustive descriptions of the FLW quantification methods and how practitioners should apply them depending on the context.

Moreover, measuring FLW is not enough, and other FLW-related indicators are necessary to holistically monitor the sustainability impact of prevention actions. A relevant study developed on this topic was the one conducted by Caldeira et al. (2019), who proposed indicators to measure the efficiency and effectiveness of the FLW prevention actions. They measure the efficiency of the resources invested and the degree to which the FLW prevention objectives are achieved, respectively. There is also noticeable work done in defining Key Performance Indicators (KPIs) for food systems, but not especially focused on the FLW, like the one performed by Yontar & Ersoz (2020). The proposal of this type of metrics is perfectly aligned with the Circular Economy action plan (European Commission, 2020a), which explicitly declares the need for indicators on resource use.

In parallel, the fourth industrial revolution is taking over. Digital technologies are being increasingly integrated into FSCs (Hassoun et al., 2023), which encounter various challenges, including that of reducing FLW (Jagtap et al., 2021a,b). Among them, Internet of Things (IoT)-based solutions are of major importance when it comes to data collection in FSCs, allowing the real-time measurement of parameters of interest (Bouzembrak et al., 2019; Hassoun et al., 2022; Marvin et al., 2022), which enhances the decision-making processes and therefore the organization performance (Qader et al., 2022). Given this context, considering the digitization feature when defining KPIs is of vital importance to prioritise the most digitizable KPIs and favour those processes. Indicators calculation is eased by this automation, which also allows a more updated and liable diagnosis of the FSC.

Some gaps were detected in the state of the art analysis presented in the next section by the authors of the present paper. Despite the efforts made to date, there is still a lack of efficient KPIs to measure the impact of FLW prevention actions that comply with the following requirements:

1. They are applicable to all the FSC stages and allow fair comparisons between FSC actors.
2. They allow for a holistic overview and not only at the level of individual actors.
3. They are in alignment with the current FLW regulatory framework.
4. They have gone through an evaluation process under the criteria of both experts (based on knowledge) and FSC stakeholders (based on practice).
5. They are easily calculable since digitization has been included as a key element during their definition.
6. They help estimate the fulfillment of the SDGs and specifically contribute to tackling SDG 12.3.

In this context, the present research article has three main objectives:

1. Creating a comprehensive list of sustainability KPIs to measure the impact of FLW prevention under a holistic perspective. It would encompass all the FSC stages and sustainability dimensions, would be in alignment with the FLW regulatory framework and would incorporate the calculation advantages provided by digital technologies.
2. Ensuring the KPIs' appropriateness and pragmatism through a participatory co-creation process relying on the knowledge of multidisciplinary experts in the FLW field (multidisciplinary approach) and the practical experience of FSC stakeholders (multi-actor approach).
3. Introducing a novel and easy way to compare the readiness of FSC actors to implement FLW prevention strategies by condensing all the information collected in the KPIs in a single index. Such an index does not aim to prevent FLW as such, but to serve as an initial step

prior to the implementation of the FLW prevention actions and the subsequent measurement of their impacts on sustainability.

## 2. State of the art

The process of identifying sustainability KPIs to monitor supply chains is widely explored in the literature. After a classification and unification procedure, Saeed & Kersten (2017) included standards and guidelines dealing with any sustainability aspect in its scope. They came up with a total of 70 sustainability KPIs. Undertaking a more empirical approach, Himanen & Martikainen (2019) conducted their research on finding out how organizations use KPIs to assess their supply chain sustainability performance. To that end, the list of KPIs was compiled by reviewing the literature, interviewing manufacturing companies, and checking their websites and annual reports. Another relevant contribution was made by Haddach et al. (2017), whose investigation aimed at tracking sustainability information of supply chains by means of developing a mathematical model to obtain a single score. AHP is also utilized in this study to weigh the KPIs. To establish a balanced set of KPIs covering the entire supply chain, Neri et al. (2021) performed a literature review taking into account the repetition of the KPIs in terms of number of appearances, the priority they were given by the authors, and the capability of the KPI to cover the gaps in the literature. Paying special attention to FSCs which is the topic the present study is framed in, Yontar & Ersoz (2020) sought to discover by which parameters the sustainability of an FSC is influenced. In that study, the KPIs were obtained through a literature review, interviews with experts, and questionnaires sent to producers and consumers. Later on, methods such as Confirmatory Factor Analysis, and AHP were used to assess the performance of such parameters. Finally, a single score was calculated to rate the sustainability performance of the FSC under study.

Moving to the specific domain of FLW, the Farm to Fork strategy (European Commission, 2020b) emerges as the guiding framework to build sustainable food systems. It is situated within the European Green Deal, an initiative that seeks to make Europe a more sustainable system by transforming its economy (European Commission, 2019b) and has served as the legal framework for sustainability KPIs since 2019. As a main building block of this pact, there is the Circular Economy Action Plan (European Commission, 2020a). This action plan promotes the development of indicators to monitor the use of resources in terms of consumption and materials footprint. They will serve as a way of quantifying the environmental impacts stemming from production and consumption patterns, which is directly related to SDG 12. Therefore, they will contribute to one of the key drivers of the CE: promoting economic growth without depleting resources. For that reason, the Horizon program is supporting the creation of these indicators while involving digitization due to its significance in fulfilling the CE goals (European Commission, 2020a). Hence, formulating indicators that can help achieve such SDG would mean a substantial contribution to the CE. Even if the advocated KPIs are introduced here as sustainability indicators, they contribute to constructing a CE as they aim for waste prevention. Waste prevention is explicitly mentioned in the CE action plan. Furthermore, waste generation and food waste specifically are 2 of the 10 indicators embraced by the European Commission to monitor the CE (Eurostat, 2022). The line separating sustainability and CE is not always clear in the related literature (Bianchi & Cordella, 2023) since they are two quite interrelated terms. Indeed, there is not a widely accepted CE definition as stated by Kirchherr et al. (2023), who found and analyzed more than 200 definitions. This is sometimes exploited to label sustainability practices or indicators as circular even though they are indistinguishable from sustainability ones.

This article includes several proposed KPIs that align with the Ellen MacArthur Foundation's CE vision, making them recognized as CE indicators. However, it is important to note that not all KPIs listed in the article fall under this category. Consequently, the entire set of KPIs and the final index cannot be labeled as "circular." As other authors have

already concluded, a higher level of circularity does not guarantee the most sustainable result (Bartie et al., 2023). Hence, the focus of this paper is on directly analyzing sustainability performance.

Another important part of the regulatory framework shaping this study is the Commission Delegated Decision (EU) 2019/1597, as already explained. The indicators mentioned in this delegated decision have been considered when conforming to the initial list of KPIs of the present study and as a cornerstone with the aim of standardizing the terminology and scope.

Significant work has been done in the field of FLW KPIs too. To accomplish the objective of preventing FLW generation, a series of

solutions are needed. In this regard, the most relevant contribution was brought by the Joint Research Centre (JRC) through the “Assessment of food waste prevention actions” technical report, which puts forward two groups of KPIs to evaluate the impact of such solutions. These groups of KPIs assess the effectiveness and efficiency of those preventive actions. These KPIs were also appraised to avoid overlooking those dimensions.

The literature exhibits robustness regarding the data sources where the KPIs were extracted from. Four main sources were identified: scientific bibliography, standards and guidelines, opinions from experts in the field, and insights from FSC stakeholders. The diversity of these sources of information provides these studies with a wide approach as

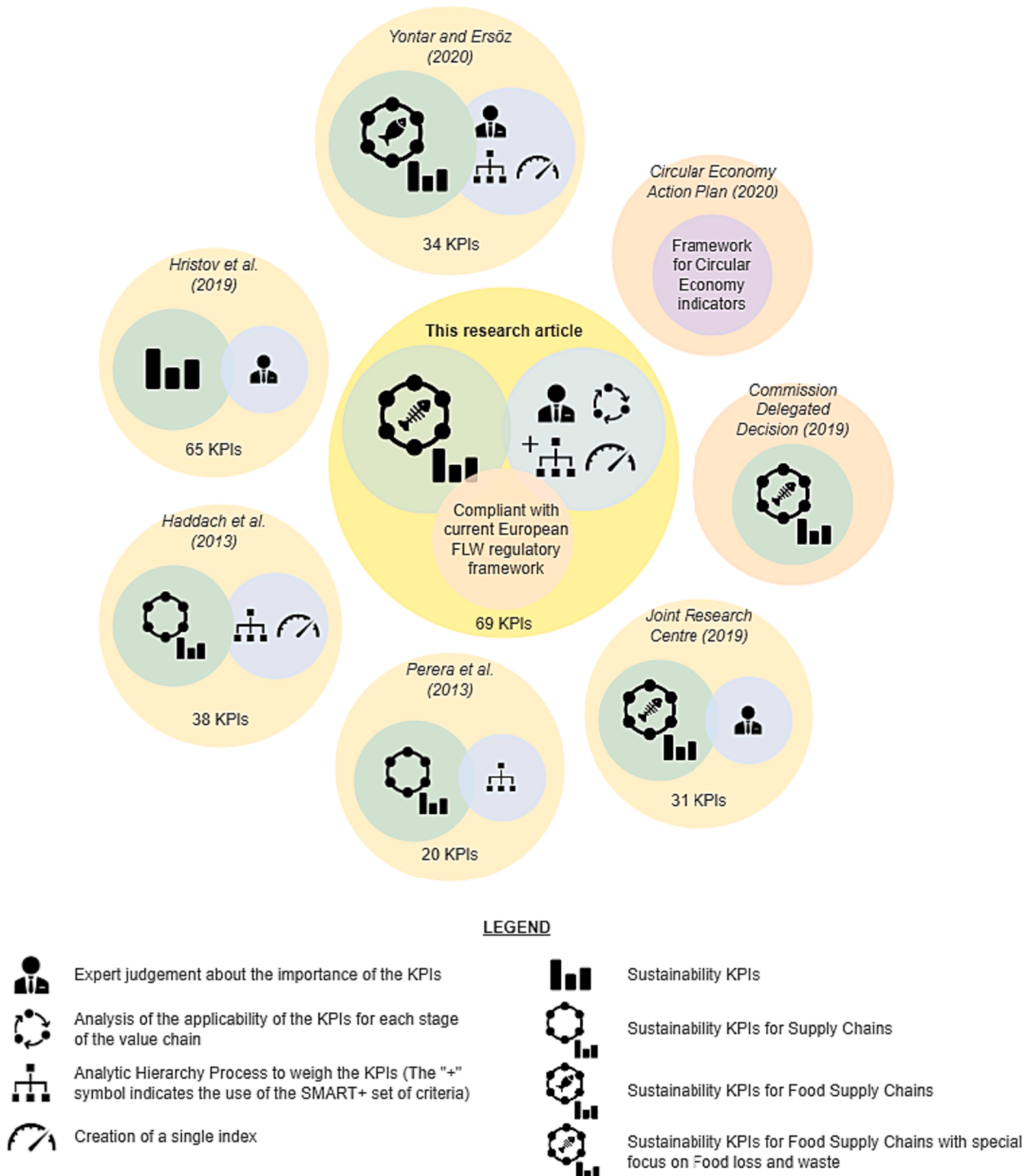


Fig. 1. Comparison of this research article with the related studies.

several perspectives were consulted. The literature also addresses the three sustainability pillars, which are clustered as three latent variables or divided into more specific ones. Most of the KPIs are pragmatic since they are easily adaptable to any scale level and do not entail complicated formulas. On the other hand, room for improvement was observed. While certain initial lists of KPIs may originate from reliable sources of information, they often lack an analysis to filter or relativize the KPIs, leading to potential concerns regarding redundancy and triviality. Even if some studies conducted statistical analysis, such as the AHP, they did not use any consolidated criteria to give such scores, as are the cases performed by Yontar & Ersoz (2020), which weighted latent variables and Haddach et al. (2017), which weighted KPIs. Furthermore, none of the retrieved studies encompass the entire supply chain as the unit of analysis. They usually focus on a particular point, leaving a gap in the rest of the stages. Regarding the topic in which the present article is framed, only one of the chosen studies examines FSCs in particular. However, it does not target FLW.

Consequently, the present investigation brings valuable contributions to fill the aforementioned gaps. Firstly, the background supporting the initial list of KPIs, from which the final group was derived, is comprehensive. It encompasses parameters collected from scientific literature, the insights of experts and FSC stakeholders, as well as relevant standards and guidelines. Secondly, the specifications stated in the Commission Delegated Decision (EU) 2019/1597 (European Commission, 2019a) to establish how FLW must be quantified have been added to that starting point, aligning the definitive list of KPIs with the Directive 2008/98/EC and thus leveraging standardization. To the best of the authors' knowledge, this is the first elaborated index that makes an initial diagnosis at strategic and management levels, which represents a preliminary step to assess how prepared a FSC is to implement FLW generation strategies and enhance its sustainability. Understanding preparedness or readiness as the capability of the FSC in terms of resources (such as cooperation and engagement with other stakeholders, process efficiency, means to quantify FLW...) to implement FLW prevention actions. A comparison of this article's contribution with that of similar work is showcased in Fig. 1. In addition to the filtering and weighing processes performed, in this study the set of SMART criteria was utilized, which is suggested to evaluate KPIs (Podgórski, 2015). Nevertheless, a new criteria was implemented to analyze the importance of the KPIs also under a digitization perspective. The so-called SMART + brings the digital dimension to the table in the KPIs domain. It is an

added value since industry 4.0 is taking over the business world (Hofmann & Rüsch, 2017; Kerdlap et al., 2019).

### 3. Methodology

The methodology followed in this scientific study to define the indicators consists of several stages as shown in Fig. 2.

The process is divided into 4 phases involving experts and FSC stakeholders with the goal of having a global vision from a knowledgeable and practical perspective: 1) literature review for KPIs preselection, 2) feedback from experts and practitioners by surveys, 3) multicriteria assessment by Analytic Hierarchy Process and, 4) creation of the unique Sustainability Index. Every phase is explained further in the subsections below.

#### 3.1. Phase 1: Literature review and preselection of KPIs

During this first phase, a systematic literature review on KPIs to measure sustainability in supply chains was carried out. The main goal was to obtain a comprehensive and robust list of KPIs to be employed as the starting point in the methodology. This review was performed by using Google Scholar, Scopus, and Web of Science search engines as sources of information. The chosen keywords to conduct the research are presented in a table as a supplementary material.

Only the scientific publications providing a detailed list of the proposed KPIs were selected as a baseline. Afterwards, the papers in which most of the indicators were perceived as latent variables instead and so were not specific enough to be faithfully interpreted and/or measured (e.g. "Environmental impact"), were ruled out. Priority was given to those papers that consulted the importance of the KPIs via expert knowledge, assessed the implementation of the KPIs in different stages of the supply chain, employed AHP (or similar approaches) to weigh the KPIs, or created a single index. Furthermore, indicators from other reference sources of information in FLW matter were added: The Commission Delegated Decision (EU) 2019/1597 of 3 May 2019 (European Commission, 2019a), the JRC technical report (Caldeira et al., 2019), and the KPIs pre-identified by experts of the FOODRUS project.

With the preliminary list obtained, a more organized list was prepared by grouping up the KPIs with similar significance. Then, the least specific indicators in each group were removed until having the most consistent one. To finish this first phase, some final adjustments were

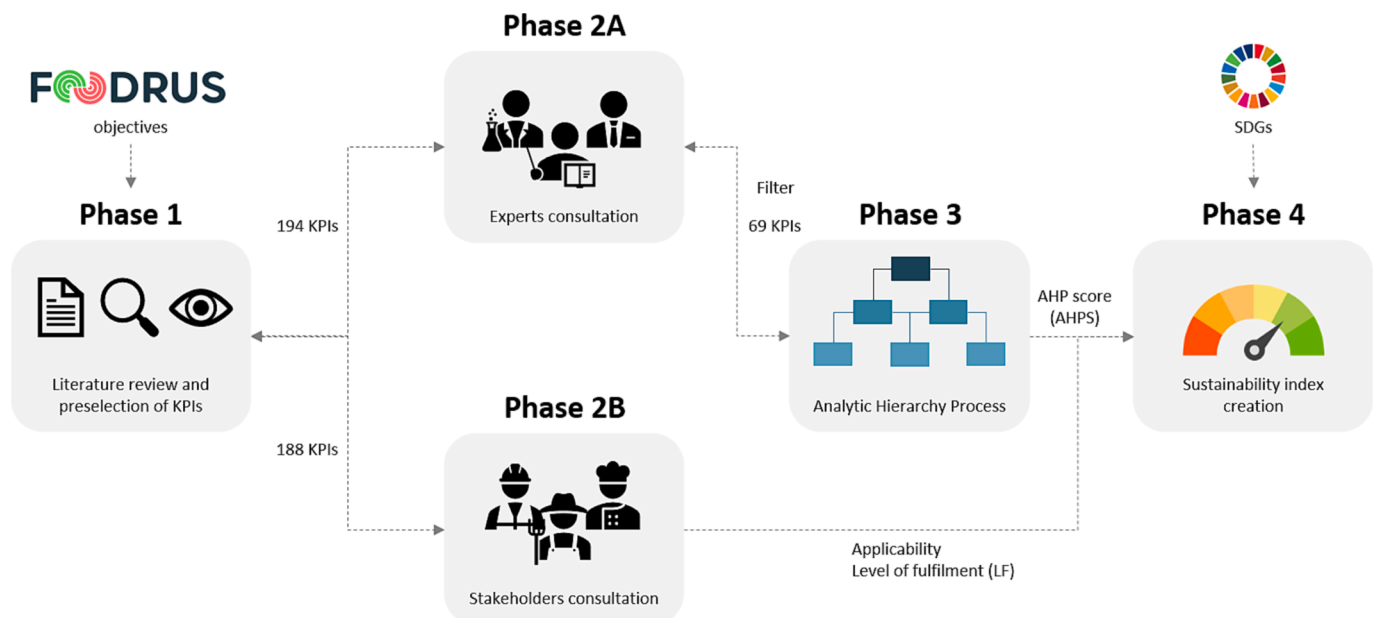


Fig. 2. KPIs definition methodology.

made. Firstly, the indicators were adapted to the FLW domain, and those that were not useful for FLW prevention objectives were excluded. The quantitative FLW objectives used for this are the ones delineated in FOODRUS, which are born out of the SDGs. Some KPIs were excluded since they were perceived as latent variables instead. Additionally, a concrete unit of measurement was defined for all of them. Next, the whole list was reviewed again to remove possible redundancies. To finalize Phase 1, latent variables were proposed to cluster the indicators in a more structured manner according to what they measure.

### 3.2. Phase 2A: Experts consultation

During this phase, experts in the field of FLW were consulted on the importance of the KPIs for the study: measuring the impact of FLW prevention strategies. The main goal was to reduce the number of KPIs in the list to enhance its usefulness and validity. An open call was held to recruit experts who wanted to participate in this KPIs definition process.

A survey to be filled out by experts was designed aiming to have an insight into the importance of the KPIs and to reduce the list. The KPIs were first clustered according to the latent variables proposed in Phase 1. Afterwards, the ones identified as compulsory in the context of the FOODRUS grant agreement were separated from the rest. The survey was provided with a Likert scale (with 7 levels of importance) so that experts could score the KPIs to evaluate their importance for the FLW prevention objectives. Experts were also allowed to add any comment or suggestion apart from proposing additional KPIs if appropriate.

A statistical analysis was conducted with the answers. The results of this phase 2A served to shorten the KPIs list. The short list's validity to measure the accomplishment of the FLW prevention objectives was verified: the KPIs were linked one by one to the pertinent FLW prevention objectives to guarantee that all of them were properly covered.

### 3.3. Phase 2B: Stakeholders consultation

During this phase, stakeholders from the 3 FSCs of FOODRUS were queried to appraise the measurement of the KPIs with a 7-level scale. This approach eliminates the necessity to measure the KPIs in their respective measurement units and mitigates data availability issues. The main goal was to determine the applicability of the KPIs to the different realities of the FSC stages with the added value of analyzing three completely different FSCs (meat and fish, bread, and prepared salads). This was done to evaluate the practical implementation potential of the list. To this end, a second survey was built, in this case intended for FSC stakeholders. To do so, the KPIs were reformulated as sentences to assess the level of fulfillment of the responding institution. Respondents could indicate those KPIs that were not applicable to them as they may be suitable for another FSC stage. They were also given the opportunity to provide feedback as comments and suggestions. The aim of this survey was twofold:

Assessing the level of applicability of the KPIs to every FSC stage in general and each of the three whole FSCs. This analysis was made for the long list of KPIs and for the short list of KPIs (i.e. before and after the screening process in Phase 2A). It was conducted by assessing the amount of KPIs that the respondents were able to measure and the stage of the FSC to which the respondents belonged. The applicability of each KPI to each FSC stage was determined by the percentage of respondents that were able to score that KPI.

Establishing an initial benchmark that may be used to compare the level of improvement of the FSCs after the implementation of FLW prevention actions (such as in FOODRUS project).

### 3.4. Phase 3: Analytic hierarchy process (AHP)

During this phase, an AHP was conducted with the help of both the experts and stakeholders involved in the previous phases. The main goal was to weigh the KPIs in terms of importance from both perspectives.

To develop a reliable AHP analysis, the first step was to research the criteria utilized in the bibliography to weigh the importance of KPIs in an AHP. To begin with, a maximum of 7 criteria was set as the upper limit to keep consistency (Saaty & Ozdemir, 2003). According to the literature, the SMART criteria was found to be the most suitable for this study (Carlucci, 2010; Podgórski, 2015; USA Bureau of Educational and Cultural Affairs, n.d.). This procedure is in concordance with Russo & Camanho (2015) findings, which indicate that when using AHP to rank indicators, the literature was used the most by the reviewed authors to define the criteria. To complement this with a digitization perspective, the SMART + criteria was proposed. To assess the capability of the KPI to be converted from analog into digital format, the definition of digitization given by Parviainen et al. (2017) was used as new criteria.

After that, an Excel file to carry out the AHP with the corresponding KPIs and criteria was created and an online workshop to instruct the AHP participants (experts and stakeholders) was held.

Next, the answers from experts and stakeholders were gathered and processed to:

1. Assign a relative weight to every criterion.
2. Assign a relative weight to every KPI within their corresponding latent variable.

### 3.5. Phase 4: Sustainability index creation

The main goal of Phase 4 was to create a single index capable of encompassing all the information collected in the KPIs in a coherent manner resulting in the FOODRUS index. The first step was the building of the index formula (Formula 1).

$$FOODRUS_{index} = \sum_{KPI_1}^{KPI_n} \left( \frac{LF - 1}{6} \right) \times KPI_w \times LV_w$$

Where:

1.  $LF$  is the level of fulfillment of the KPI obtained in Phase 2B by the survey delivered to FSC stakeholders. It ranges from 1 to 7.
2.  $KPI_w$  is the relative weight of the KPI obtained in Phase 3 by the AHP completed by experts and FSC stakeholders.
3.  $LV_w$  is the relative weight of the latent variable calculated in Phase 4.
4.  $n$  is the number of the KPI, going from 1 to 69. It is valid even if a KPI is not applicable to the case study, in which case its  $KPI_w$  will be zero.
5.  $m$  is the number of the latent variable, going from 1 to 15. It is valid even if a latent variable is not applicable to the case study, in which case its  $LV_w$  will be zero.

AHP data was collected from experts and FSC stakeholders to minimize knowledge bias. To address AHP's inherent bias,  $LV_w$  was used as a correction factor since the KPIs were evaluated taking into account only the other KPIs inside the same latent variable.

This responds to the infeasibility of carrying out the activity for the 69 KPIs altogether. Otherwise, the pairwise comparison matrices needed to be filled by the participants would have been too extensive, which reduces the quality of their judgments (Asadabadi et al., 2019; Miller, 1956). Hence, the KPIs were linked to those SDGs whose degree of achievement they would help measure, as done by Mancini et al. (2023). The linkage exercise was done not only with the SDG targets but with the specific SDG indicators inside each target. Each latent variable was then assigned a weight according to the percentage of KPIs inside the latent variable that contribute to the achievement of each SDG. This process was repeated for all the SDGs. Afterward, these weights were normalized so that for a given SDG, all the latent variables weights add up to 100%. And last,  $LV_w$  was calculated as the average weight for each latent variable considering all the SDGs. The SDGs were rated equally important here, following the same criteria as other related works like the SDG index for countries developed by Sachs et al. (2022).

## 4. Results and discussion

In this section, the results of the enumerated phases in [section 3](#) are presented and discussed.

### 4.1. Results of Phase 1

Along with the other resources pointed out in Phase 1 ([Caldeira et al., 2019](#); [European Commission, 2019a, 2020](#)), ten scientific publications constituted the backbone from where the final list was assembled. They are briefly examined hereunder:

1. [Yontar & Ersöz \(2020\)](#) studied the sustainability performance of the food sector in Turkey to find out which parameters were affecting the performance of those FSCs. A literature review, as well as insights from experts, academics, and people working in the food industry, was the first step to building their conceptual model. Then, 388 participants (FSC actors and consumers) were interviewed to define the latent variables and KPIs to be measured. Further on, they also performed an AHP consulting five experts to calculate the relative weight of each KPI. With the results they estimated a global score for the Turkish food sector.
2. [Al-Sheyadi et al. \(2019\)](#) addressed how the Green Supply Chain Management (GSCM) practices impact environmental performance taking an individual firm as their unit of analysis. The KPIs and latent variables were gathered from the literature.
3. [Cankaya & Sezen \(2018\)](#) researched the impact of GSCM on the overall sustainability performance in Turkey. They interviewed academics and supply chain stakeholders and employed a survey targeting manufacturers from the automotive, chemical, and electronics industry since each sector could offer different results.
4. [Perera et al. \(2013\)](#) aimed at measuring the environmental performance of a supply chain in a manufacturing company. They collected the data from the related literature as well as from reporting systems and certifications. To conclude, they deployed AHP to select the most ecological product from several alternatives, which also let decision-makers observe how those products' environmental performance was influenced by their choices.
5. [Li et al. \(2019\)](#) wanted to assess the impact of environmental issues on Chinese companies with a special focus on exports. They captured data from a questionnaire delivered to companies in the processing and manufacturing industry. It was validated with two case studies.
6. [Saeed & Kersten \(2017\)](#) studied related standards and guidelines to develop a procedure to analyze the sustainability performance of a supply chain. They were thoroughly read using sentences as the unit of analysis to identify KPIs. The so-called categories (latent variables) were shaped by consulting bibliography followed by classification, unification, and other processes focused on enhancing consistency, appropriateness, and understandability.
7. [Neri et al. \(2021\)](#) presented a set of KPIs to quantify the sustainability of supply chains. They based its structure on the BSC and SCOR models and selected the KPIs from the literature according to their frequency and priority. The KPIs covered the whole supply chain and the three pillars of sustainability, as well as different positions and company levels. The set was tested in three supply chains through interviews and a questionnaire.
8. [Haddach et al. \(2017\)](#) pursued the development of a mathematical model to measure the sustainability of a supply chain. KPIs from the literature entered the model seeking a single performance score. To do so, the KPIs passed through an AHP to be weighted first. After that, the KPIs comprising each sustainability pillar were treated, resulting in one score for each. Those three pillar scores led to a single score that indicated the supply chain's sustainability level.

9. [Himanen & Martikainen \(2019\)](#) examined the state of the art of the supply chains' sustainability KPIs via interviews in the field and information gathered from companies' websites and reports.
10. Lastly, [Hristov & Chirico \(2019\)](#) focused on identifying sustainability KPIs affecting businesses' performances and assisting companies to be sustainable with a new approach. The research methodology relied on a literature review and a survey. The survey was intended for managers who specialized in sustainability KPIs. The KPIs underwent a bibliometric analysis and were screened to ensure they represented the company's status and perspective.

After conducting the already outlined research, more than 450 KPIs were picked out.

A summary of the latent variables containing these KPIs is depicted in [Table 1](#).

### 4.2. Results of Phase 2A: Experts consultation

From the feedback provided by the experts, several analyzes were conducted. First, the definition of some KPIs was adapted to account for eight new KPIs proposed by the experts as they were partially considered in the initial list. No new indicators were included.

The results of the survey can be observed in [Fig. 3](#).

Each latent variable showcases the average value between its KPIs' scores. In this manner, Technical performance was the one regarded as the most important by the experts, reaching a score of 5.857. On the other hand, Employee management received the lowest score (3.433), therefore considered "slightly important" according to the Likert scale. The position in the ranking was not affected by the size of the latent variables (number of KPIs contained) since relatively small latent variables (like Technical performance with 4 KPIs) and quite comprehensive ones (like Environmental performance with 76 KPIs) can be found in adjacent positions.

No KPI was rated as "not important at all," "little important," or "slightly important" by the experts on average. This is a good indication of the KPIs quality. 44 % of the 158 KPIs under evaluation (not considering the compulsory ones) were situated at the second top level of the scale, constituting the biggest group. Moreover, 25 of them overcame the 6 Points (very important).

Regarding participation, 23 experts from 22 institutions provided their insights. These entities belong to a wide variety of sectors: Education and research (31.82 %), sectorial and civil associations (22.73 %), public administrations and governmental organizations (22.73 %), industry (13.64 %), finance (4.55 %). The multidisciplinary granted by such distinct professional perspectives strengthens and enriches the analysis. In fact, this multidisciplinary made it possible to achieve a high rate of responses: The results show that 60 % of the respondents fulfilled the questionnaire for all the KPIs, and the rest did it partially. That percentage rises to 95 % considering those participants that fulfilled at least 66 % of the questions. Analyzing the survey results per KPI, the maximum number of empty values is 7. And 95 % of the KPIs present less than 5 missing values. The analysis of the variation coefficients per KPI shows a high level of consensus among the participants regarding the importance of the KPI. The mean value for the variation coefficient is 0.327. For those KPIs with less than 5 empty values, the mean variation coefficient is 0.270, showing a higher level of consensus. There is a strong, positive and significant correlation at statistical confidence level of 95 % (0.858 with a p-value of 0.013) between the number of missing values and the variation coefficients.

As a screening step to shorten the list, aiming to achieve a balance between the number of compulsory KPIs and the efforts needed to complete them, the 25 % least important KPIs in the list were removed. The first quartile (Q1) setting the threshold from which this cut-off was done extends to 4.556 points. By applying this filter, all the KPIs regarded as "slightly important", and some of the "neutral" ones did not

**Table 1**  
Summary of the ten selected scientific publications.

Reference	Latent variables	No indicators
Yontar & Ersoz (2020)	Customer satisfaction (3 indicators) Resource utilization (7 indicators) Safety of products (4 indicators) Innovation (4 indicators) Reliability (6 indicators) Company information (4 indicators) Packaging (3 indicators) Waste management (3 indicators)	34
Al-Sheyadi et al. (2019)	Source-reduction (3 indicators) Ecodesign (3 indicators) Environmental management systems (5 indicators) External environmental management (6 indicators) Environmental impact (5 indicators) Environmental cost savings (4 indicators)	26
Cankaya & Sezen (2019)	Green purchasing (5 indicators) Green manufacturing (5 indicators) Green distribution and packaging (6 indicators) Internal environmental management (5 indicators) Green marketing (6 indicators) Environmental education (4 indicators) Investment recovery (2 indicators) Economic performance (7 indicators) Social performance (8 indicators) Environmental performance (5 indicators)	53
Perera et al. (2013)	Product and process design (9 indicators) Packaging (3 indicators) Transportation and collection (3 indicators) Recycling and disposal (5 indicators)	20
Li et al. (2020)	Green Supply Chain Management pressure (21 indicators) Green Supply Chain Management practices (25 indicators) Performance (26 indicators) Moderator (4 indicators)	76
Saeed & Kersten (2017)	Environmental sustainability dimension (34 indicators) Social sustainability dimension (26 indicators) Economic sustainability dimension (10 indicators)	70
Neri et al. (2021)	Financial perspective (6 indicators) Internal process perspective (6 indicators) Learning and growth perspective (5 indicators) Customer perspective (6 indicators) Environmental perspective (5 indicators) Social perspective (5 indicators)	33
Haddach et al. (2017)	Economic performance (9 indicators) Environmental performance (9 indicators) Social performance (20 indicators)	38
Martikainen & Himanen (2019)	Economic (22 indicators) Environmental (13 indicators) Social (8 indicators)	43
Hristov & Chirico (2019)	Environmental (24 indicators) Social (22 indicators) Economic (21 indicators)	67

continue in the process. As a result, the latent variables labeled as “Employee management” and “Customer satisfaction” lost all their KPIs.

After this step, the process continued with 11 latent variables and with a total of 155 KPIs. To move to the next step, an additional filter was required so that the KPIs could fit into the AHP. In that analysis, several matrices are built according to the number of items to be compared. The number of comparisons to be assessed by the

respondents is equal to  $(n^2 - n)/2$ , being “n” the number of KPIs inside a latent variable. Besides, this evaluation has to be repeated 6 times as that is the number of criteria that will be employed. Thus, it was concluded that the number of KPIs still had to be reduced to make the evaluation less demanding for the respondents. So for the second filter a maximum number of 8 KPIs per latent variable was allowed following the ranking obtained with the scores. However, some latent variables exceeded the limit because they held compulsory KPIs too, and so they were split. This division was done in such a way that the resulting latent variables gathered the most interrelated KPIs. The output of this second filter was a list of 69 KPIs in 15 latent variables, including compulsory (20) and non-compulsory KPIs (49).

#### 4.3. Results of Phase 2B: Stakeholders consultation

The measurement of the KPIs done by the stakeholders of the FOODRUS FSCs yielded interesting results from various perspectives. Given that the project counts on stakeholders from every stage of the FSC, a diagnosis of how many KPIs are applicable to each stage was conducted.

In some cases, one institution develops its activity in more than one stage (they have more than one economic activity according to the NACE codes). For those cases, the data corresponding to that institution was considered as input data for every of those stages. Therefore, the representativeness of the FSC stages was also different. The results are outlined in Table 2.

As can be noted in the table, the initial set of KPIs (before the screening steps) fits better with primary production, processing and manufacturing, and retail and distribution stakeholders. In restaurants, food services, and households, the applicability was under 50 %. The average applicability of the KPIs considering all the stages was 52.63 %. With the short list, this applicability increased for all the FSC stages and pilots, reaching 56.62 % on average. This means that the applicability (evaluated by the stakeholders) aligns with the experts’ criteria. The most favored FSC stages remained mostly the same.

The applicability of the KPIs turned out to be quite distinct among the pilots. The Spanish and Slovak pilots reached a very similar level (43.94 % and 42.42 % for the long list, respectively). The Spanish pilot covered the 5 FSC stages, but the Slovak pilot missed households. Meanwhile, the Danish pilot achieved the best performance (85.82 % for the long list), although it also missed the households stage. As for the FSC stages, the average applicability of the list to the pilots increased when the list was filtered according to the experts’ criteria (Phase 2A). It reached 57.39 % for the unfiltered list, while it reached 60.99 % for the already-filtered short list. Thus, the applicability has been validated with three real FSCs, ensuring that the index could be applied to other FSCs regardless of their structure or composition.

#### 4.4. Results of Phase 3: Analytic hierarchy process (AHP)

From the comparisons made by experts and stakeholders, relative weights were determined for each indicator within its latent variable, thus distributing 100 % of the weight of the latent variable among the KPIs belonging to it. These results are showcased in Table 3 along with the SDGs linked to each KPI in Phase 4.

It can be observed how KPIs that are part of smaller latent variables formed a higher score on average. As regards these scores, some interesting findings include:

1. Consumers’ environmental awareness was deemed as more important than that of FSC employees. The same view is showcased in Social performance, where the change in consumers’ behavior is the most valued KPI. It may respond to the heightened responsibility attributed to consumers since 53 % of the FLW is generated at households (Eurostat, 2022).

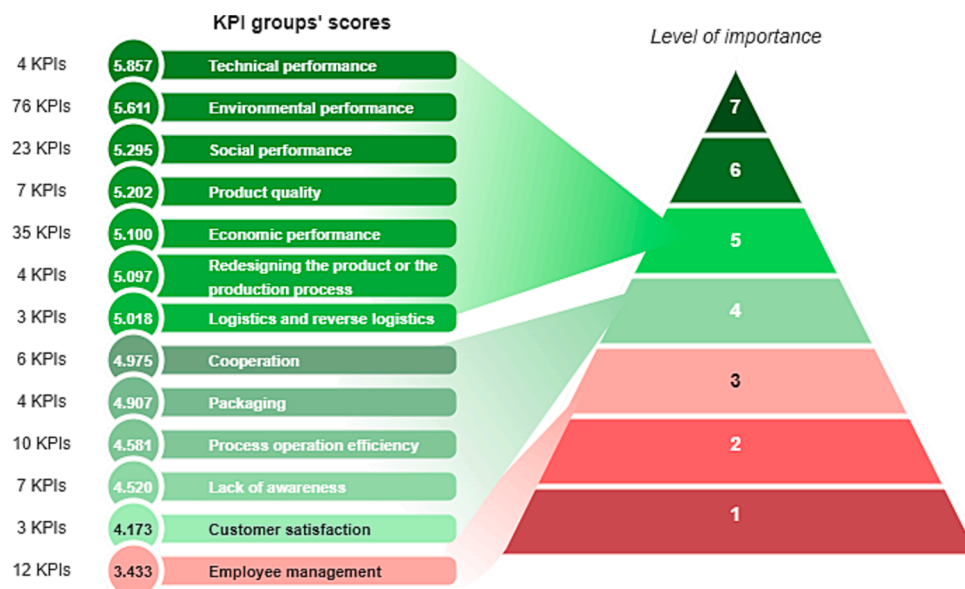


Fig. 3. Ranking of the latent variables according to the level of importance.

Table 2  
Average applicability of the KPIs before and after the filters.

FSC stage	Applicability (before filters)	Applicability (after filters)	No institutions	Representativeness
Primary production	67.02 %	72.10 %	4	17 %
Processing and manufacturing	67.02 %	72.10 %	4	17 %
Retail and other distribution of food	52.45 %	58.26 %	5	21 %
Restaurants and food services	44.75 %	47.28 %	8	33 %
Households	31.91 %	33.33 %	1	4 %
Average	52.63 %	56.62 %		

- The quantification of edible food loss and waste (FLW) is considered the most significant KPI. This choice is logical as edible food holds the greatest potential for avoidance, aligning with the FW hierarchy (Teigiserova et al., 2020).
- The emphasis on the number of events that lead to FLW generation outweighs the significance placed on improving demand forecasting or achieving a high inventory turnover rate. Therefore, experts consider reducing the number of incidents that may occur more important rather than actually making the industrial processes more efficient.
- Concerning Economic performance, the amount of FLW prevented per cost of the action is by far the most important KPI. Prioritizing the mass of FLW prevented over the costs, incomes, or FSC actors' parameters that form the other KPIs.
- The carbon footprint percentage avoided is preferred in the Environmental performance group. As it is well known, climate change is one of the most important environmental problems we face nowadays (Wu et al., 2023), which may explain this preference. Moreover, by expressing the KPI in percentage, the total carbon footprint generated is also taken into account. That could be the reason why the experts rated this KPI higher in comparison to the other carbon footprint KPIs in the group.

#### 4.5. Results of Phase 4: Sustainability index creation

The result of the process of linking the indicators to the SDGs, can be found in Table 3. Considering that the primary objective of the KPIs is to assess the sustainability of FLW prevention, SDG 12 exhibits the highest number of connections to them. All the KPIs from five latent variables are linked to SDG 12. This outcome was expected since the FOODRUS project aligns with SDG 12.3. However, it is worth noting that other

SDGs may also experience indirect positive effects.

The Environmental footprint group of KPIs turned out to be the one with the most related SDGs (6). Nevertheless, Involvement performance and Social outcomes were not regarded as being contributing to any SDG. Not all the SDGs showed a link with the proposed KPIs, which is why SDGs number 1, 3, 4, 5, 10, 11, 15, and 16 are not shown in the table.

Once the index was finished, it was calculated for 12 FSC stakeholders of the FOODRUS project, which were the ones answering the survey in Phase 2B. Some of these organizations are involved in several FSC stages (Table 4), which is an important remark because it hampers the comparison of these results per FSC stage.

Therefore, in order to make this comparison more reliably, some answers were omitted when spotted as an outlier in comparison with the rest of the answers from the organizations that were also involved in that particular FSC stage. By categorizing the organizations based on the three pilots of the project they belong to, Fig. 4 presents the index score achieved by each organization:

Keeping in mind that there are significant differences between the index scores of some organizations in the same pilot, on average:

- The Slovak pilot was the most sustainable, with a 74.35 % score.
- The Spanish pilot was in second position, with a 68.79 % score.
- The Danish pilot was in the last position, with a 61.14 % score.

These findings suggest that the Slovak pilot is the one that can implement the most effective FLW prevention measures, and consequently improve the sustainability of its FSC. Some KPIs in the survey primarily assess performance, while others analyse management. It was observed that when segregating the scores provided by the participants into these two categories, the ranking of the three FSCs remained

**Table 3**  
AHP scores and linkage between KPIs and SDGs.

Latent variable	KPI	AHP score	SDGs
Cooperation	Integration with Food Value Chain partners	0.239234132	17
	% purchasing budget spent in local providers	0.312379910	12
	Multifunctional cooperation between departments	0.199181583	–
Economic performance	Transport distance covered by third parties	0.249204376	–
	Total amount of FLW prevented/cost of the action implementation	0.205903436	12
	Net economic benefits/cost of the action implementation	0.120331115	8, 12
	Total number of businesses reporting a FLW reduction/cost of the action implementation	0.137575927	12
	Total number of businesses tracking FLW/cost of the action implementation	0.125323692	12
	Total number of people (end consumers) changing behaviour/cost of the action implementation	0.171134577	12
	% increase of sales of local/seasonal/organic/ugly food	0.129423854	8, 12
	% costs avoided	0.110307398	8, 12
	Total number of Regional Roadmaps	0.367726303	–
	Number of banks and public entities involved	0.309342206	–
Involvement performance	Number of certification entities and public administrations involved	0.322931491	–
	Total FLW generated per capita (end consumers)	0.164825157	12
	Total FLW generated (Per stage of the FSC)	0.211767019	12
	Total edible FLW generated (Per stage of the FSC)	0.222587001	12
	Total FLW avoided (Per stage of the FSC)	0.186266543	12
	Total edible FLW avoided (Per stage of the FSC)	0.214554280	2, 12
	% packaging saved	0.095438491	12
Environmental footprint	Water footprint of FLW avoided	0.129597153	2, 6, 12, 14
	Carbon footprint of FLW avoided	0.165565191	9, 13
	Carbon footprint of edible FLW avoided	0.148415033	9, 13
	% water footprint avoided	0.151105715	6, 12, 14
	% carbon footprint avoided	0.189032173	9, 13
	% recycling of FLW for biogas and biofertilizer production	0.120846244	7
	% actors of the entire FSC involved in each pilot tracking FLW	0.153846771	–
	% actors involved in each pilot reporting a FLW reduction	0.194768289	12
	New business models for FLW reduction and prevention	0.180882628	–
	Solutions developed	0.238500147	–
Implementation impact	New best practices adopted per pilot	0.232002165	12
	Environmental awareness of consumers	0.553740698	12, 13
	Environmental awareness of chain employees	0.446259302	12, 13
	Amount of returned products	0.443144265	12
	Adopting just-in-time logistics system	0.245875475	12

**Table 3 (continued)**

Latent variable	KPI	AHP score	SDGs
Packaging	Number of products recovered by reverse logistics	0.310980261	12
	Packaging reduction by eco-design	0.313441570	12
	Use of ecological, reusable, recyclable packaging	0.443210836	12
Process operation efficiency	Use of protective packaging	0.243347595	–
	Demand forecasting accuracy	0.184221536	8, 12
	Effective shipment consolidation and full vehicle loading	0.124598800	8, 12
	Number of events that cause FLW	0.251682662	9
Product quality	Production flexibility	0.150920443	–
	Inventory turnover rate	0.170254131	12
	Regular maintenance of the production equipment	0.118322427	9, 12
	Amount of ugly food, defective or expired food discharged	0.256594859	12
	Transport suitability according to the product	0.130057077	9, 12
	Food products traceability	0.140059646	17
	Supplier rejection rate	0.197769259	–
Redesigning the product or the production processes	Order tracking	0.134462700	–
	Number of food safety certifications	0.141056459	–
	Additional information in the product for consumers to avoid FLW and improve biowaste and packaging separation rates	0.351152863	–
	Research & Development investments in circular economy	0.347590106	9
	Investments in new technologies	0.301257032	9
	% people (end consumers) reporting a change in behaviour	0.169994831	13
	% staff reporting a change in behaviour	0.145576946	13
	% people (end consumers) aware of the FLW prevention campaign	0.106672622	–
	Number of people (end consumers) reached	0.114769014	13
	Outreach/behavioural change observed	0.112465010	13
Social performance	% people developing new skills	0.130933935	–
	Number of people in need with a better diet	0.093113583	2
	% nutritional value saved	0.126474058	12
	New social business models	0.372745118	–
	Maintenance and use of the platform beyond the duration of the project. Dissemination and exploitation of the results.	0.244939044	–
	Number of replicated cases	0.382315838	–
	New secondary products created	0.212054407	12
Social outcomes	% decrease of expired FLW	0.322605275	12
	Amount of FLW to landfill	0.249647220	12
	Amount of FLW to incineration	0.215693099	12
Technical performance			

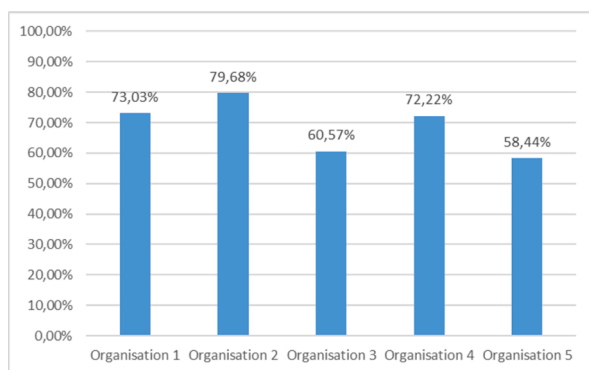
consistent.

### 5. Conclusions

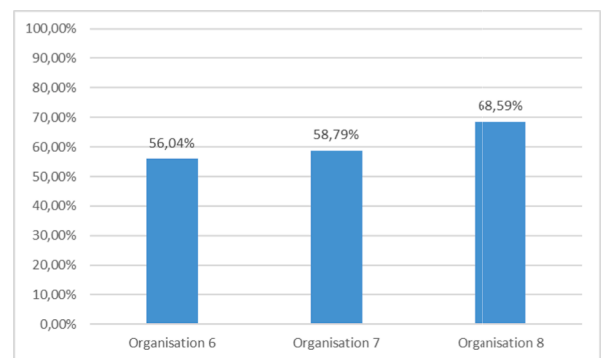
In this study, a single index has been created to measure the preparedness of 3 FSCs to deploy FLW prevention strategies with the aim of

**Table 4**  
Organizations analyzed and FSC stages.

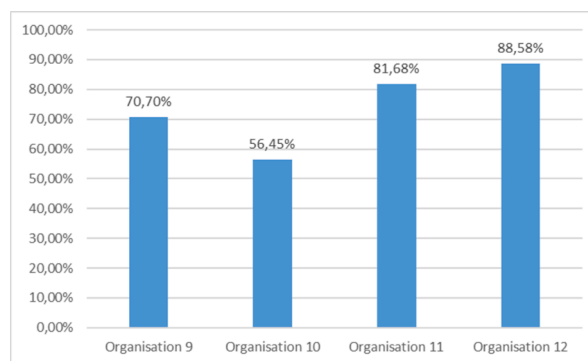
Organization	FSC stages				
	Primary production	Processing and manufacturing	Retail and other distribution of food	Restaurants and food services	Households
Organization 1	✓	✓			
Organization 2			✓		
Organization 3					✓
Organization 4				✓	
Organization 5				✓	
Organization 6	✓	✓			
Organization 7			✓		
Organization 8			✓	✓	
Organization 9	✓	✓		✓	
Organization 10	✓	✓	✓	✓	
Organization 11			✓	✓	
Organization 12				✓	



(a) Spanish pilot



(b) Danish pilot



(c) Slovak pilot

**Fig. 4.** Index score of the organizations in the three pilots.

enhancing their sustainability impact. The basis of this index is grounded in the related scientific and legal literature. It counts on the knowledge of experts in the field and on the experience of stakeholders from three FSCs in three different European countries. They allowed us to study the importance of the KPIs and their applicability to each FSC stage. The contribution of the KPIs to the fulfillment of the SDGs was integrated as well to finally develop the index. Once the entire process was completed, the index was calculated for the 12 stakeholders that participated as use cases.

In conclusion and in accordance with the objectives set:

1. The final list of KPIs proposed covers all sustainability dimensions and respects the FLW regulatory framework specifications. Both the scientific literature and the legislation served as a basis for building the list, and experts' feedback reaffirmed this. The list includes

digitization as a factor, considering the ease of digitizing each indicator to weigh them.

2. The opinion of experts in the area (theoretical vision) and FSC stakeholders (practical implementation) ensured the KPIs' appropriateness and pragmatism. Within the group of experts, there was a diversity of backgrounds which provided the analysis with multidisciplinarity when assessing the indicators' theoretical value. In the group of FSC stakeholders, professionals from all stages of an FSC belonging to three different countries and working on different food products were involved in the assessment. This guaranteed the KPIs capability to be applied generically (for all the FSC stages and different food products).
3. A sustainability index integrating all the 69 KPIs was created, which can be easily calculated by any interested party with the FOODRUS

index self-assessment tool (further explained in the Appendix). It was validated by the 12 case studies of the FOODRUS project.

However, some limitations inherent to any co-creation process were found. First of all, delivering and collecting such an amount of surveys and counting all the participants delayed the whole process. Every phase took more time than expected, leading to an extension of the period given to the participants to hand in the surveys in many cases.

And although in Phase 1, neither experts nor stakeholders were involved, it turned out to be a tedious process where detecting redundancies was not always easy. This was caused by the unclear or absent definition of many of the KPIs found in the literature.

The present FOODRUS index is aimed at having a vision for measuring these metrics at strategic and management levels. In other words, to see whether the KPIs are being considered in the enterprise policy. Which is a previous step in comparison with the other indexes found in the state of the art, which means a contribution. This index can be utilized for a subsequent measurement to assess improvements in the FSC at the strategic and management levels compared to the baseline. Going beyond, it would be interesting to explore the KPIs' thresholds issue so that an organization with the capacity and resources to measure the KPIs in their respective units of measurement could calculate a more ambitious sustainability index. For that purpose, more research is needed on the procedure for calculating the KPIs and setting upper and lower thresholds. As additional future work, the index could be applied to a higher number of FSCs followed by a statistical analysis order to provide it with specific readiness ranges. Lastly, the index could be replicated in other sectors by initiating the process from the point in Phase 1 where the KPIs were tailored to the FLW domain.

#### CRediT authorship contribution statement

**Manuel Amador-Cervera:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Juan S. Angarita-Zapata:** Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Alberto de la Calle Vicente:** Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization, Writing – review & editing. **Ainhoa Alonso-Vicario:** Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization, Writing – review & editing.

#### Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Manuel Amador Cervera, Juan Sebastián Angarita Zapata, Alberto de la Calle Vicente, and Ainhoa Alonso Vicario reports financial support was provided by the European Commission and the Basque Government.

#### Data availability

The data that has been used is confidential.

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#### Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.wasman.2024.02.050>.

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