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Methodology for the sustainability assessment of food loss and waste prevention actions

Ph.D. dissertation developed by

Manuel Amador Cervera

and supervised by

Ainhoa Alonso Vicario

within the doctoral programme of Engineering for the Information Society and Sustainable Development

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Agradecimientos

“¿Por qué nos caemos Bruce? Para aprender a levantarnos” – Thomas Wayne

En primer lugar, me gustaría expresar mi agradecimiento a mi directora de tesis Dra. Ainhoa Alonso Vicario por la dedicación, comprensión, y apoyo moral y profesional. Los conocimientos que me ha transmitido han sido fundamentales para poder llevar a cabo este trabajo, y me acompañarán más allá de este.

Además de a Ainhoa, agradecer también a otros compañeros y excompañeros de trabajo: Deitze, Bego, Armando, Aritz, Iván, Asier, Roberto, Ignacio, Naiara, Jon, Alcides, Oscar, Juan, Tony, Erick, Nekane, Alberto de la calle, Daniel, Dee, Maider, Ana, Alberto Lozano Carlos, y Maider, de los que también he aprendido mucho y a los que agradezco especialmente el hacer del lugar de trabajo un sitio mejor. El estar en un ambiente laboral tan agradable me ha facilitado enormemente el trabajo. Destacar especialmente los momentos de descanso para almorzar cada día, que han sido tan necesarios para relajarnos, compartir sobre cualquier tema y conocernos fuera del ámbito laboral.

También quiero expresar mi gratitud a mis compañeros del "Institute of Waste Management and Circularity" de la "University of Natural Resources and Life Sciences (BOKU)" en Viena, Austria, donde realicé mi estancia internacional. Aprendí mucho de ellos y facilitaron enormemente que disfrutase de cada momento de mi estancia en dicha ciudad.

Gracias a mis amigos, tanto a los que he hecho aquí en Bilbao como a los que sigo teniendo en otras partes de España y del mundo. En especial a mis amigos Manolito, Marco, Azman, Fran, Isaac, Álvaro, Gabriele, Luis, Cristina, Selu, y Marina.

Por último, agradecer por supuesto a mi familia: a mi madre Ángeles, a mi padre Manuel y a mi hermana Sonia. Sin su apoyo incondicional no hubiese sido posible el mudarme a Bilbao en primer lugar y el comenzar y seguir con este viaje profesional a día de hoy. A pesar de la distancia siempre he sentido que están conmigo, lo cual ha sido esencial para poder completar esta tesis doctoral con éxito.

Este trabajo de investigación ha sido posible gracias a la financiación proveída por los siguientes proyectos:

- Proyecto Horizon 2020 de la Unión Europea "FOODRUS".
- Proyecto estatal español de I+D+i Orientado a los Retos de la Sociedad "Blockchainfood".
- Proyecto regional con la Diputación Foral de Gipuzkoa "NEURTZEN".
- Proyecto Horizon 2020 de la Unión Europea "TONOWASTE".

Manuel Junio de 2024

Abstract

Food Loss and Waste (FLW) pose a significant global challenge, with approximately one-third of all food produced for human consumption lost or wasted annually, amounting to about 1.3 billion tons. This immense loss has profound environmental, economic, and social implications, contributing to environmental issues, economic inefficiencies, and food insecurity. In the European Union alone, an estimated 88 million tons of food are wasted annually, costing approximately €143 billion. For these reasons such a problem is embodied in Sustainable Development Goal (SDG) 12.3 aims to halve per capita global food waste by 2030, underscoring the urgency to understand FLW across the entire Food Supply Chain (FSC) and develop effective mitigation strategies.

In order to measure the effectiveness of FLW prevention actions, Key Performance Indicators (KPIs) are pivotal tools widely used in the literature, particularly those quantifying FLW generated and avoided. But despite a growing recognition of the FLW problem, current literature reveals fragmented methodologies for quantifying FLW and assessing the sustainability impacts of FLW prevention actions, resulting in inconsistencies and limited comparability. This includes FLW quantification, where while the European Union's standardised FLW quantification guidelines (Commission Delegated Decision 2019/1597) provide a foundational framework, variations persist in definitions, causes, and destinations across studies. On the other hand, Life Cycle Assessment (LCA) offers a standardised approach for assessing FLW's environmental impact, although its application to FLW prevention remains underexplored. Moreover, integrating sustainability KPIs with Information and Communication Technologies (ICT) shows promise in enhancing the standardisation of these assessments by advancing data reliability and transparency. Especially as regards LCA, a resource-intensive methodology that enormously benefits from this synergy.

To address these gaps, this dissertation develops a standardised methodology for evaluating the environmental, social, and economic impacts of FLW prevention actions across FSCs. With a holistic life cycle approach, the methodology aims to enable efficient and rigorous comparisons between different FSCs, considering the upstream and downstream consequences of FLW prevention efforts. Specific objectives include defining a taxonomy for FLW, establishing KPIs for sustainability impacts, refining FLW quantification and LCA methodologies, and leveraging digitisation for enhanced data reliability and transparency. Validation of this methodology involves analysing five circular economy scenarios in a real case study, encompassing various types of FLW prevention actions.

The research focuses on an entire FSC of prepared salads in Spain, adopting a cradle-to-grave approach to have a comprehensive vision of the case study. The data collected for this case study encompasses different temporal periods between 2021 and 2023. Through extensive literature review, and consultation to experts and stakeholders from 3 different FSCs, a robust set of 69 KPIs was defined, culminating in the creation of the FOODRUS index. This index integrates economic, environmental, and social dimensions, providing a comprehensive framework for evaluating FSC's preparedness to implement FLW prevention actions. The methodology adheres to Delegated Decision 2019/1597 guidelines to quantify FLW and expands its scope, refining definitions and methodologies to include preharvest losses and diverse waste fractions. It enhances FLW quantification by incorporating food characteristics, root causes, destinations, and standardised classifications using NACE codes for FSC stages, UNSPSC codes for food products, and EWC codes for FLW flows. This approach strengthens methodological reliability and exhaustiveness, crucial for monitoring progress towards SDG 12.3. LCA methodology was employed to evaluate the environmental impacts on climate change and water use of FLW prevention actions using the PEF v3.0 as impact assessment method. Digitisation was integrated in the methodology at different steps including the definition, calculation, and visualisation of KPIs. Validation through circular economy scenarios demonstrates the methodology's robustness, assessing a range of FLW prevention actions categorised by the Joint Research Centre (JRC). These scenarios integrate social actions and technological solutions aimed at reducing FLW, each evaluated based on identified causes and potential impacts. A decision tree aids in identifying optimal FLW prevention measures, particularly in Scenario 4.

Results include a standardised set of 69 KPIs to measure the sustainability impact of FLW prevention actions validated through expert knowledge and stakeholder consultations. The index, evaluated across five organisations within the case study, effectively measures readiness, coherent with subsequent KPI measurements. Detailed calculations for each KPI demonstrate considerable performance of the case study at the baseline, highlighting robust FLW prevention efforts such as food donations and animal feeding, notably from Processing and manufacturing (P&M) and Retail and other distribution of food (RDF) stages. FLW prevention action scenarios showcase diverse impacts within the FSC. Supply chain efficiency in Scenario 1 delivers significant economic benefits and reduces FLW to landfills. Redistribution efforts in Scenario 2 achieve moderate economic impact and FLW reduction. Consumer behaviour-focused Scenario 3 generates substantial social benefits despite targeting only the Household (HH) stage. Scenario 4, which incorporates FLW prevention governance, yields significant economic gains and nutritional value saved. Integrating all actions in Scenario 5 shows mixed economic performance but excels in social and technical KPIs, such as nutritional value saved. These scenarios underscore trade-offs and benefits of different FLW prevention actions across the FSC. As concerns FLW prevention, Scenario 5 showcases the best performance, followed closely by Scenario 4. Environmental assessments via LCA highlight significant impacts from Primary Production (PP), primarily contributing to carbon and water footprints. Even if this FSC stage is not where most FLW is generated, this result is due to the additional food production needed to fulfil the functional unit when FLW generation acts. Among FLW prevention actions, Scenario 4 demonstrates the best performance, significantly reducing carbon and water footprints through effective governance. Digitisation enhanced KPI visualisation, promoting transparency and aiding decision-making. Digital tools and data models supported rigorous sustainability assessments by standardising data and enhancing transparency and reliability.

In conclusion, this dissertation establishes a robust framework for assessing and enhancing sustainability within FSCs through 69 KPIs. Spanning economic, environmental, and social dimensions, these KPIs provide a comprehensive toolkit for measuring FLW prevention action impacts. The methodology integrates expert insights, stakeholder inputs, and regulatory guidelines, culminating in the FOODRUS index, a demonstrated useful tool to assess the readiness of FSCs to implement FLW prevention actions validated across 5 FSC stakeholders. The methodology provides a representative measure crucial for achieving SDG 12.3, enriched by food characteristics, root causes, destinations, and standardised classifications. LCA identifies effective solutions and underscores trade-offs, with governance actions showing the highest potential for environmental impact mitigation. Additionally, it is concluded that optimisation of FLW prevention actions' efficiency requires tailored approaches for each specific context. As regards digitisation, it streamlines the deployment of the methodology mainly by enhancing the KPI measurement practicality. Finally, prioritising critical KPIs results to be crucial for optimising FLW prevention actions combinations.

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Acronyms

AHP	Analytic Hierarchy Process
CE	Circular Economy
C&PS	Coefficients and production statistics
C/S	Counting/scanning
D	Diaries
DM (VA)	Direct measurement (Volumetric assessment)
DM (WA)	Direct measurement (Weighing assessment)
EMF	Ellen MacArthur Foundation
EPD	Environmental Product Declaration
EU	European Union
EWC	European Waste Codes
FAO	Food and Agriculture Organization
FL	Food Loss
FLW	Food Loss and Waste
FSC	Food Supply Chain
FVC	Food Value Chain
FW	Food Waste
FU	Functional Unit
GWP	Global Warming Potential
GHG	Greenhouse Gas
HORECA	Hotels, Restaurants, and Cafes
HH	Household
ICT	Information and Communication Technologies
ISO	International Organization for Standardization
IoT	Internet of things
JRC	Joint Research Centre
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LCI	Life Cycle Inventory
MB	Mass balance
NACE	Nomenclature of Economic Activities
PAYT	Pay As You Throw
PoG	Point of Generation

PP	Primary production
P&M	Processing and manufacturing
PCR	Product Category Rules
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
Q&I	Questionnaires and interviews
RFID	Radio-Frequency Identification
RFS	Restaurants and food services
RDF	Retail and other distribution of food
SMART	Specific, Measurable, Achievable, Relevant, Time-bound
SDG	Sustainable Development Goal
UNSPSC	United Nations Standard Products and Services Code
WRAP	Waste and Resources Action Programme
WCA	Waste composition analysis

1 Introduction

Food loss and waste (FLW) is a global-scale problem that entails various challenges, which act as barriers to make progress towards sustainable development, as indicated by Xue & Liu (2019). In other words, FLW generation has negative effects on sustainability. This negative effect has been documented to occur in the three pillars of sustainability: at environmental, economic, and social levels (Alonso-Muñoz et al., 2022). From an environmental perspective, the production of food and thus the generation of FLW contributes to several impact categories, such as: climate change (Nikravech et al., 2020), water use (García-Herrero et al., 2023), land use (Tonini et al., 2018), and resource use (Lopez Barrera & Hertel, 2021), for example. Enhancing the environmental performance of these food products would result in a significant improvement in the overall environmental impact of humanity. Specifically, the agriculture sector, which accounts for 86% of the total water footprint generated by humans (Hoekstra & Chapagain, 2008), and approximately 13.5% of the total anthropogenic greenhouse gas emissions (Pandey & Agrawal, 2014), plays a crucial role in this context. From an economic perspective, the management of the FLW generated represents a substantial financial loss, which subsequently translates into an increase in the prices of these products (Otles et al., 2015). From a social perspective, wasting food harms food security and exacerbates social inequalities (A. Chauhan et al., 2018).

Besides, the demand for food is still not satisfied and is expected to increase in the following years, intensifying the problem. First, food insecurity continues to escalate in the present day, affecting a significant portion of the global population. By 2020, approximately 2.37 billion people, accounting for nearly one-third of the world's population, were classified as food insecure (FAO et al., 2021). This alarming reality contradicts the considerable amount of food that is wasted due to inefficiencies within the food supply chain (FSC) (FAO et al., 2013). Specifically, an estimated 1.3 billion tons of food are lost or wasted annually according to FAO (2011). Although this estimation varies depending on the source. According to the FUSIONS project, the generation of FLW in Europe reached a total of 88 million tons in 2012 (Stenmarck et al., 2016). Later, the Food Waste Index Report in 2019 revealed that approximately 931 million tonnes of food waste (FW) were generated globally, encompassing retail, food service establishments, and households (Forbes et al., 2022). Apart from the amount of FLW generated, as the Food and Agriculture Organization (FAO) of the United Nations (UN) points out, it is projected that the global population will grow by approximately 2 billion individuals by the year 2050. Meeting the food needs of this expanding population, while dealing with the current agricultural land availability and depleting resources, will necessitate a 70% increase in food production (FAO, 2017; Kirova et al., 2019).

These figures provide compelling evidence highlighting the imperative to address this issue and establish a more sustainable and equitable food system in the pursuit of sustainable development. In fact, there is an SDG target especially dedicated to this problem: SDG 12.3. This target seeks 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, 2023b).

Some authors mention that Circular Economy (CE) would indirectly contribute to the fulfilment of such an SDG target by raising awareness, food sharing activities, acting on retail's food operations, composting, etc (Schroeder et al., 2018).

In order to reduce such FLW and address the issue, FLW quantification is needed first. So, in light of the requirement for harmonising measurement practices, the European Commission introduced the Commission Delegated Decision (EU) 2019/1597 in 2019 (European Commission, 2019), to establish standardisation in quantification methods. However, there remains a challenge in achieving a comprehensive standardisation that enables meaningful comparisons across studies (Hoehn et al., 2023), as the current delegated decision lacks the necessary level of specificity. Furthermore, simply measuring FLW is insufficient, and it is essential to incorporate additional FLW-related indicators to comprehensively monitor the sustainability impact of FLW prevention actions. The introduction of such metrics aligns perfectly with the Circular Economy action plan (European Commission, 2020a), which explicitly emphasises the importance of indicators related to resource utilisation as well as to address the problem from a holistic perspective. But no scientific consensus has been reached either in this matter, where the need for a standardised set of KPIs able to measure the impact of FLW prevention actions comprehensively and for any case study still persists.

1.1 Memory structure

This Ph.D. dissertation is divided into chapters, sections and subsections. The numbered chapters and the main content they comprise are briefly described hereunder.

Chapter 1 provides an overview of the topic, emphasising on the problems that FLW generation bring to the table and their sustainability impact. The motivation to carry out this research, along with the scope of the research and the memory structure are given as well.

Chapter 2 presents a review of the relevant scientific literature that deal with the topics of interest for this project. It begins with the most general topics, narrowing down the scope towards more specific ones. The main focus is on sustainability and circular economy, as well as new technologies and the synergies that result from their interactions in the FLW context.

Chapter 3 summarises the gaps and challenges identified in the state of the art. It sets the basis to define where the objectives will be oriented.

Chapter 4 indicates the main objective of the dissertation and the secondary objectives that stem from it.

Chapter 5 presents the methodological framework. It clearly defines what concepts and approaches were selected to form the theoretical background of the investigation. This framework conditions the rest of the methodology and therefore the results depend on it.

Chapter 6 explains the methodology followed to conduct the research activity. How the case study was defined, the whole definition process of the KPIs, the type of LCA that was conducted, the CE scenarios raised, and the digitisation of the KPIs are described in this chapter.

Chapter 7 discusses the results obtained from the case study after deploying the methodology. This chapter is structured in the same way as chapter 6, so that the results of each section can be unambiguously discerned.

Finally, Chapter 8 showcases the conclusions drawn in line with the previously established objectives. Additionally, in this chapter the implications and limitations of the work done as well as the future work that lie ahead in this research line are exposed.

The original contributions of this dissertation have resulted in the following publications and deliverables. Although the content is unique to the dissertation, it has been differently presented in these works to prevent self-plagiarism:

- Amador-Cervera, M., Angarita-Zapata, J. S., de la Calle Vicente, A., & Alonso-Vicario, A. (2024). The FOODRUS index: Assessing suitability for effective food loss and waste prevention management under an integral perspective. Waste Management, 179, 32–43. https://doi.org/10.1016/j.wasman.2024.02.050
- European H2020 FoodRUs project (2022). Deliverable D1.1 - Circular Food Strategies Documentation.
- European H2020 FoodRUs project (2022). Deliverable D1.3 – Preliminary Test Report
- European H2020 FoodRUs project (2024). Deliverable D1.4 – Full Test Report
- European H2020 FoodRUs project (2024). Deliverable D4.3 - Process-based life cycle sustainability assessment of FoodRUs food production and supply systems

2 State of the art

This section provides an overview of the current knowledge and research in the field of FLW, beginning with the most general topics and gradually narrowing down to the most specific ones. It aims to present a comprehensive understanding of the existing literature, theories, methodologies, and key findings related to the topic. By reviewing the most recent and relevant scholarly works, starting from broad concepts and progressively delving into more specialised areas, this section seeks to establish a foundation for the subsequent analysis and exploration of the research objectives. Through an examination of the advancements and gaps in the literature, this section will contribute to the identification of the research niche and the justification for the present study.

2.1 Sustainability and Circular Economy

First, the groundwork for the entire research will be laid by exploring the fundamental concept of sustainability. Sustainability serves as the overarching framework within which this Ph.D. dissertation is framed, encompassing environmental, social, and economic dimensions. Hence, providing an initial definition of "sustainability" is imperative for this dissertation.

Sustainability is defined as “an activity or action that is capable of being sustained” (Santillo, 2007). However, this is a general definition that does not match the sustainability concept that concerns this study’s approach. Instead, the term with a commonly recognised definition that is used to refer to such an idea is sustainable development. So, although sustainability and sustainable development are stated to be distinct and there is still debate on their definitions (Ruggerio, 2021), in the context of this dissertation they will be used interchangeably to avoid further complications. Sustainable development is understood as the progress of civilisation in parallel with a proper care for the environment so that the following generations' needs are not compromised (WCED, 1987). Indeed, the three pillars of sustainability, which are economy, society and environment, are seen by some authors as the goals of sustainable development (Purvis et al., 2019). In the same line of sight and in order to achieve this sustainable development, the Sustainable Development Goals (SDGs) were coined in 2012 at the United Nations Conference on Sustainable Development in Rio de Janeiro (United Nations, 2012). They were later approved in 2015, and finally became effective in January 2016. These SDGs work on different areas such as dignity, people, planet, justice and prosperity (Leal Filho et al., 2018). So, these 17 SDGs are listed in the 2030 Agenda for Sustainable Development, and are as follows (United Nations, 2023b):

1. No poverty.
2. Zero hunger.
3. Good health and well-being.
4. Quality education.
5. Gender equality.
6. Clean water and sanitation.

7. Affordable and clean energy.
8. Decent work and economic growth.
9. Industry, innovation and infrastructure.
10. Reduced inequalities.
11. Sustainable cities and communities.
12. Responsible consumption and production.
13. Climate action.
14. Life below water.
15. Life on land.
16. Peace, justice and strong institutions.
17. Partnership for the goals.

The fulfilment of these goals is up to the joint action of the different countries that form the United Nations. Although they are part of the same concept, further guidance is claimed concerning the priority that should be given to these goals (Kumar et al., 2018). This is necessary to prevent potential conflicts or trade-offs that may arise between different goals, as highlighted by Scherer et al. (2018).

But contrary to this, the economic system that is currently installed across the entire world is unsustainable. Today's linear vision of produce-consume-dispose products and materials is no longer a viable option (Sariatli, 2017). This prevailing system is a consequence of the uneven wealth distribution between developed and developing countries. Mostly, the materials flows come from different zones at a global level, but the consumers are mainly concentrated on developed countries. The effect of how expensive such materials are in comparison to human labour is the disregard of the adequate and ethical management of the waste. On top of that, legislation has allowed this since the organisations do not have any responsibility for the externalities. Which obviously causes producers to ignore the impacts of the previous stages of the supply chain (Sariatli, 2017).

According to Eurostat data (European Commission, 2023c), in the European economy 2.2 billion tons of material were dumped as waste. It is worth mentioning that this waste doesn’t fulfil its function and is a loss of energy as well. Only 39.2% of them were recycled.

The growth of the worldwide population along with the fast-paced development of China and India has enormously boosted the number of middle-class consumers. And the economic system we have at the present time, is unable to embrace the investment that will be necessary to meet their needs (for example regarding food) (Ellen MacArthur Foundation, 2013).

As an alternative to this situation, the Circular Economy (CE) comes up as a model that showcases hopeful characteristics. With a focus on the reduction of the resource use (greater than that of sustainable development) (Geissdoerfer et al., 2017), it is a concept that could leverage the implementation of sustainable development itself (Kirchherr et al., 2017). The concept was initially mentioned and established in 1990. Back then the definition of this idea alluded to the recycling of the wastes into resources, closing the loop with a natural or a technological procedure in such a way that the quantity of available resources keeps constant or is even increased (Ellen MacArthur Foundation, 2013; United Nations, 2023c). CE fosters the use of recycled, reused and repaired materials, together with investing in renewable energies (Andersen, 1999).

Nowadays, the most widely accepted view of this concept is the one provided by the Ellen MacArthur Foundation (EMF), which is one of the greatest references in this field. It states three principles that form the basis of the Circular Economy (Ellen MacArthur Foundation, 2023b):

- Designing out waste and pollution.
- Keeping products and materials in use for as long as possible.
- Regenerating natural ecosystems.

Designing out of waste and pollution is a manner of conducting ecodesign, which seeks to integrate the environmental considerations of the product into its design and development (ISO, 2002). Keeping materials in use (in contrast to planned obsolescence) aims at extending a product's useful life by means of design, maintenance and a wider use over time (Cooper, 2010). One of the most effective ways to fulfil this is by the servitisation of the product. With this approach the sale of the physical product is replaced by offering the service that was being satisfied by the mentioned product. It is also known as Product-Service systems (Tukker, 2015), which is indeed one of the keys of the so-called “Circular business models” (Bocken et al., 2016). Regenerating natural ecosystems consists of repairing the damage caused by human activities in the ecosystems by helping them recover their self-renewal capacity (Morseletto, 2020). Another dimension that provides an added value to CE is biomimicry. Biomimicry consists of observing the ways in which nature deals with the different problems it faces, with the purpose of learning from it. So that the solutions extracted from that experience can be successfully exploited to solve the issues that may arise in our lives (Sariatli, 2017).

The EMF presents CE as a win-win strategy for businesses and nature, serving as a way to generate economic and environmental benefits at the same time (Ellen MacArthur Foundation, 2013). CE can potentially take benefits from ecosystem cycles implementing them into its economic cycles and thereby permitting natural systems to regenerate at an acceptable rate. According to Korhonen et al. (2018), these benefits are:

- Environmental benefits:
    - Reduction of virgin material use and energy consumption.
    - Increase in the amount of renewable inputs.
    - Reduction of solid, liquid and gaseous wastes.
    - Extension of the resources' useful life.
    - Decarbonisation of fuels.
    - Regenerative outflows from which nature can take advantage of.
- Social benefits:
    - Creation of new jobs.
    - Enhancement of community relations.

    - Removal of the concept of ownership in favour of a services system.
- Economic benefits:
    - Reduction of materials and energy costs.
    - Increase of resources' profitability.
    - Reduction of legal and bureaucratic costs.
    - Improvement of company's image.
    - Reduction of waste costs.
    - Increase in incomes thanks to industrial symbiosis.

In recent years, CE has spread and institutions like the European Union (EU) are giving prominence to it through for example the publication of the "Circular Economy Action Plan" (European Commission, 2020a) included within the "European Green Deal" (European Commission, 2023a). One of the reasons why Circular Economy is being so actively promoted by institutions, may be its existent synergies with the SDGs. CE is strongly connected to SDG 12 (which is the one that concerns this study), although it isn't the only connection with SDGs. CE actions are highly linked to SDG 6 (Clear water and sanitation), SDG 7 (Affordable and clean energy), SDG 8 (Decent work and economic growth) and SDG 15 (Life on land) apart from the already mentioned SDG 12 (Responsible consumption and production) (Schroeder et al., 2018). Under the approach taken by (Schroeder et al., 2018), CE actions would directly help fulfil 21 targets (out of the 169 shaping the SDGs), and another 28 targets indirectly.

While it is true that circular economy (CE) appears to be a very promising idea and is gaining more and more relevance, there is no consensus on its definition (Kirchherr et al., 2017, 2023). That is one of the findings of Kirchherr et al. (2023), who found and analysed more than 200 definitions of CE. The EMF has its own perspective of what CE is, setting the next definition: "A circular economy is an industrial system that is restorative and regenerative by intention and design" (Ellen MacArthur Foundation, 2013). In another document published by the EMF, a slightly different definition is given: "A circular economy is one that is restorative by design, and which aims to keep products, components and materials at their highest utility and value, at all times" (Webster, 2017). Meanwhile, after conducting research and reviewing the aforementioned in addition to other definitions, Geissdoerfer et al. (2017) established the following concept as CE: "A regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling.". In these cases, as well as in other authors' perspectives like Bocken et al. (2016), Geng & Doberstein (2008), or Yuan et al. (2008), it can be observed that there are some ideas which are repeated in several of such definitions, such as "regenerative" and "closed-loops". This makes sense since that is the way nature works, and after all its designs are the most efficient structures (Aziz & El sherif, 2016). In fact, "circular" means "closed-loop" (Han et al., 2020), so it is part of the term itself. Therefore, it is considered by the author of this dissertation that those two ideas should be included in the final definition.

Differentiating between “circular economy” and “sustainability” has become a major issue of concern to use the language properly. Formerly called “sustainable” products, practices, services, etc, are now sold as “circular” without strong arguments to do it apart from marketing. So, to draw the line between the two terms is the first stone to start using the term CE and the adjective “circular” in a correct way. In this regard, the International Organization for Standardization (ISO) has recently published (in May 2024) a series of ISO norms for CE that must be considered. They are:

- ISO 59004: Circular Economy - Terminology, principles and guidance for implementation
- ISO 59010: Circular Economy - Guidance on the transition of business models and value networks
- ISO 59014: Environmental management and Circular Economy - Sustainability and traceability of secondary materials recovery - Principles and requirements
- ISO 59020: Circular Economy - Measuring and assessing circularity
- ISO 59031: Circular Economy - Performance based approaches
- ISO 59032: Circular Economy - Review of business model implementation
- ISO 59040: Circular Economy - Product circularity data sheet

These norms aim to standardise the concept and how circularity should be measured, among other aspects. ISO 59004 includes a definition of CE: *“Economic system that uses a systemic approach to maintain a circular flow of resources, by recovering, retaining or adding to their value, while contributing to sustainable development.”* (ISO, 2023b). Thus, in this dissertation, the definition provided by the ISO will be employed as it covers the same concepts found in the previously identified keywords, and it is also the definition most likely to be adopted by institutions.

There is a particular feature that is not explicitly mentioned in the CE definition but should not be overlooked. It is fair to say that as a consequence of human activity, there is always an impact (Groß et al., 2019; He et al., 2021). Aiming at no impact has to be the final goal, but it will not be fully achievable. Humans need food for eating, water for drinking, etc (Nayeri & Stothard, 2016; Sun et al., 2015). And that implies, inevitably, resource consumption. Not to produce any impact would be optimal, but in order for the CE to work out it must be assumed that our actions (among which are the economic activities) will have an impact and need to be profitable (otherwise they would not be sustainable). A CE definition that aims at achieving zero environmental impact is too utopic and may not be workable in practice due to thermodynamic limits among others (Korhonen et al., 2018; Quicker et al., 2020). For that reason, the author of this dissertation firmly believes that the economic system’s efficiency should be deemed in the definition. It should be established that CE must pursue solutions that are beneficial for both nature and economy. It is reasonable to assume that the word “value” in such a definition entails economic value as well.

As previously indicated, different principles of the CE are proposed in the literature. Apart from those of the EMF, there are others, such as those proposed by the institution Circle

Economy, that follow a similar approach. These principles serve as a basis for defining circular strategies and transitioning from theory to practice. Therefore, to put the concept into practice, it will be verified if this CE definition aligns with these principles. The Circle Economy has always proposed 4 different principles (also called strategies) to comply with their CE objectives. As repeated in the last edition of the Circularity Gap Report (Circle Economy, 2023), these are: Narrow flows - Use less, Slow flows - Use longer, Regenerate flows - Make clean, and Cycle flows - Use again. These 4 principles follow the same rationale as the ones stated by the EMF but portraying them as flows. From the accepted definition it must be possible to infer the CE principles, so that all the CE systems, activities, practices or processes are covered by the definition. A discussion about how it matches them takes place hereunder:

- Design out waste and pollution (Narrow flows - Use less): To contribute to sustainable development, it is reasonable to assert that the minimisation of resource consumption and waste/pollution generation is necessary. Thanks to evolution, life has been redesigning itself in such a way that no waste is produced and having a high efficiency in the management of resources (Benyus, 1997), that is why a CE draws inspiration from nature. First of all, definitions of waste and pollution are given so that it can be discussed if this principle matches the proposed definition of CE. “Waste” is defined by the Waste Framework Directive as “any substance or object which the holder discards or intends or is required to discard” (European Commission, 2008b). “Pollution” is defined by the European Environment Agency as “the introduction of substances or energy into the environment, resulting in deleterious effects of such a nature as to endanger human health, harm living resources and ecosystems, and impair or interfere with amenities and other legitimate uses of the environment” (European Environment Agency, 2022). In this definition of waste it is implicit that the product’s value has dropped for the holder. So, by retaining this value as the CE definition defends, this part of the principle could be inferred. Similarly, the definition of pollution implies environmental degradation, which is assumed to be contrary to the "maintenance of a circular flow of resources" described in the definition. So, the definition proposed by ISO is understood to be in line with this principle.
- Regenerate natural systems (Regenerate flows - Make clean): Regeneration is a key action line of the proposed definition of CE as a result of (1) maintaining the circular flow of resources and (2) recovering their value (assuming that value includes ecological value). According to Morseletto (2020), the regeneration of ecosystems consists of repairing the damage caused in ecological processes by human activity, leveraging ecosystems to recover their self-renewal capacity. By making resources recover their ecological value, ecosystems would be sent back to their natural states, letting them recover their properties and regenerate. Which on top of it, is key for maintaining the circular flow of resources. Consequently, this principle is considered to fit in with the proposed definition of CE.
- Keep products and materials in use (Cycle flows - Use again, and Slow flows - Use longer): To keep materials and products in use aims at expanding a product’s useful life via design, maintenance, and a long-time usage (Cooper, 2010). This principle is

also covered by the CE definition of ISO. Extending the lifespan of products/services is intrinsically linked to retaining or increasing their value. In this regard, servitisation has emerged as a successful solution thanks to reparation, remanufacturing and upgrading. It is one of the bases in circular business models, in which the internet of things (IoT) and network technologies play a key role (Han et al., 2020).

Therefore, taking into account the assumptions described above, the proposed definition is considered to align with the principles of both the EMF and Circle Economy. Figure 1 provides a schematic illustration of this alignment.

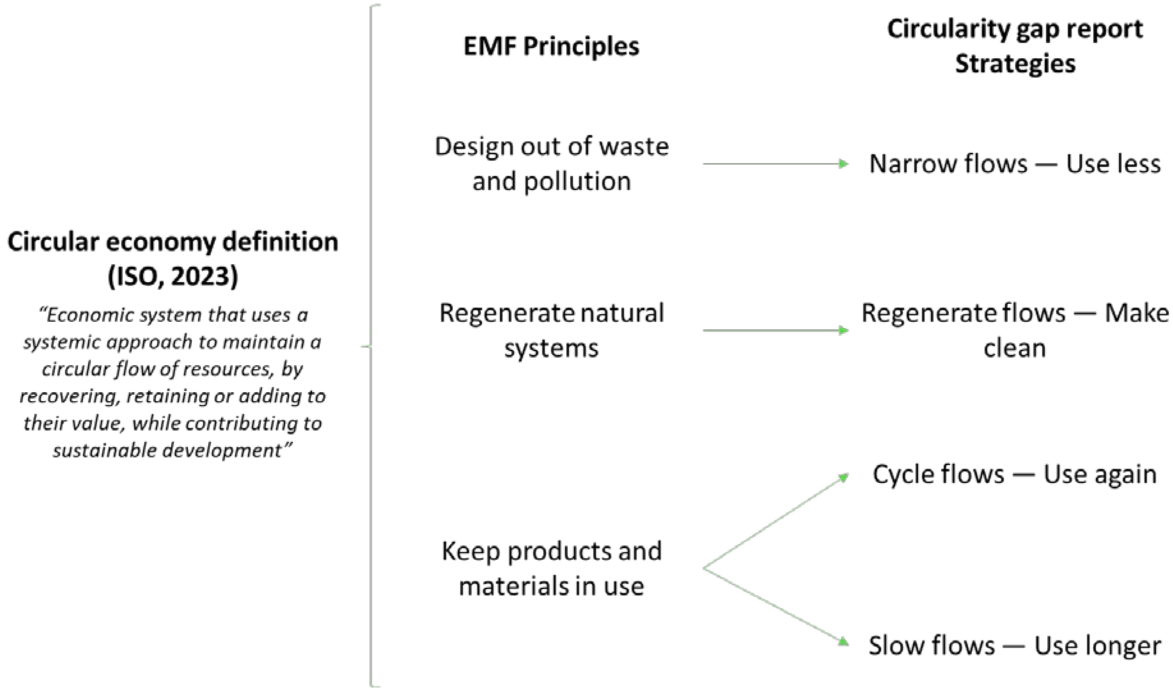


Figure 1. Circular economy definition and principles.

Once the definition to be followed and the principles derived from it are established, it is important to emphasise the differentiating characteristic that sets CE apart as not only a vehicle towards sustainable development but also something more ambitious. The principle of regeneration marks this distinction. While the other two principles of the EMF aim to reduce the environmental impact caused by human activities, that is, to be more sustainable, the principle of regeneration seeks to go beyond and have a positive impact on the environment. In Figure 2, the representation of the environmental impact and the appropriate terms for each type of action adjusted by Craft et al. (2017) is provided.

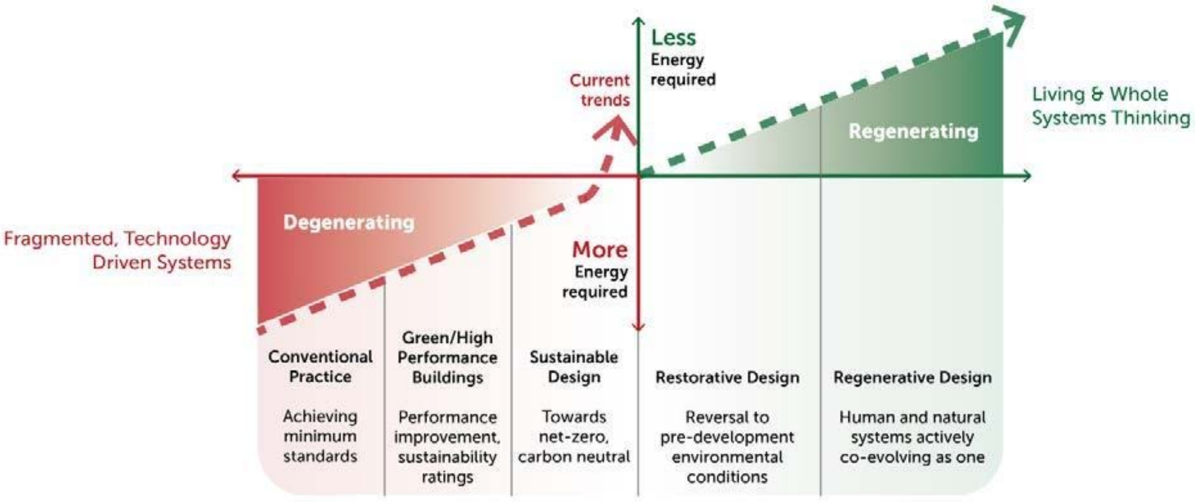


Figure 2. Environmental impact and types of actions. Source: Craft et al. (2017).

This scheme can be found in several different sources, but the main message is the same: current trends, aiming to promote sustainable development, would reduce the impact we already generate, but not improve the environmental conditions to their pre-development state. From the viewpoint of the author of this dissertation, this represents the utmost value proposition that the concept of CE offers: regeneration. Without such a factor, in terms of environmental impact circular products or services would not bring any improvement in comparison to sustainable ones. Indeed, that is the reason why in this dissertation the sustainability impact of a set of circular solutions is assessed. This nuance is crucial to emphasise since "circular", as presented, refers to the economic approach employed in the product design rather than its sustainability impact. Many companies are leveraging this aspect at marketing level, because as Boyer et al. (2021) concluded, consumers prefer products labelled as circular.

Regarding the methodology for assessing circularity, many indicators have been proposed. Apart from the academic literature, the EMF through the Circulytics indicators (Ellen MacArthur Foundation, 2023a), also Circle Economy (Circle Economy, 2023) put forward specific metrics to do so. However, there is currently no consensus on a standardised approach or framework to analyse the effectiveness of CE strategies in terms of impact reduction (Peña et al., 2021). This may lead to wrong conclusions if such a methodology is not having an overall picture of the system (Peña et al., 2021). For that reason, setting a common ground is needed so that the measurement of the circularity becomes comparable especially in practice (Peña et al., 2021). Although with the publication of the aforementioned ISO 59020 this situation is expected to change for the better. Nonetheless, as indicated by previous studies, achieving a higher level of circularity does not necessarily ensure the attainment of the most sustainable outcome (Bartie et al., 2023). Hence, this research work concentrates on conducting a direct analysis of sustainability performance, although the FLW prevention actions that will be assessed in this dissertation can be considered as circular solutions since they operate within the “Design out waste and pollution” principle.

2.2 Information and Communication Technologies (ICTs)

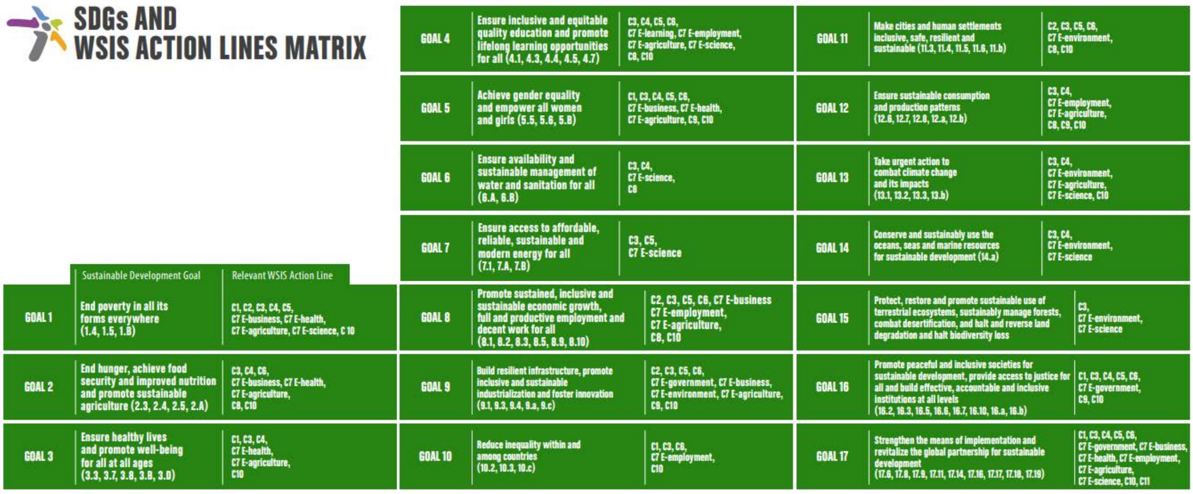
The subsequent focus turns towards exploring the crucial role of Information and Communication Technologies (ICTs) in achieving the SDGs. ICTs are those technological systems that enable people to control and manage different types of information (Carter & Grover, 2015). The development of these ICTs is leveraging what is known as Industry 4.0 (Peraković et al., 2020). This is an industrial revolution that integrates technologies such as the internet of things (IoT), big data analytics, artificial intelligence (AI), robotics, and cyber-physical systems (CPS) to create "smart factories" and enable intelligent decision-making across all aspects of production. These technologies allow for real-time data collection, analysis, and predictive maintenance, optimising manufacturing processes and improving efficiency (Jagatheesaperumal et al., 2022; Sniderman et al., 2016). According to small and mid-sized digital technologies users in manufacture, ICTs show advantages as concerns product quality, productivity, innovation and cost saving (Beaty & Quirk, 2018).

As recognised back in 2008 by the European Commission, ICTs have a high potential in terms of sustainability. They have the chance to make progress towards a more energy-efficient economy, which leads to a lower carbon system. Nevertheless, the European Commission also highlights that ICTs need to reduce their own energy use first (European Commission, 2008a). Even though it must be noted that ICTs imply environmental impacts too. Those impacts can be classified in: impacts coming from the ICTs life cycles (life-cycle impacts), impacts coming from implementation of new materials where there wasn't any before (enabling impacts) and impacts coming from economic structures and institutions that emerge from these ICT systems (structural impacts) (Hilty & Aebischer, 2015).

In this context, in 2016 The World Summit on the Information Society (WSIS) created a matrix in which the 17 SDGs are matched with 11 action lines for ICT. Those action lines are:

- C1. Role of Government and all Stakeholders in the Promotion of ICT for Development.
- C2. Information and communication infrastructure: an essential foundation for the Information Society.
- C3. Access to information knowledge.
- C4. Capacity building.
- C5. Building confidence and security in the use of ICTs.
- C6. Enabling environment.
- C7. ICT applications: benefits in all aspects of life.
- C8. Cultural diversity and identity, linguistic diversity and local content.
- C9. Media.
- C10. Ethical dimensions of the Information Society.
- C11. International and regional cooperation.

These proposed actions would operate in the SDGs as WSIS indicates in Figure 3:



SDGs AND WSIS ACTION LINES MATRIX

	Sustainable Development Goal	Relevant WSIS Action Line
GOAL 1	End poverty in all its forms everywhere (1.4, 1.5, 1.B)	C1, C2, C3, C4, C5, C7 E-business, C7 E-health, C7 E-agriculture, C7 E-science, C 10
GOAL 2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture (2.3, 2.4, 2.5, 2.A)	C3, C4, C6, C7 E-business, C7 E-health, C7 E-agriculture, C8, C10
GOAL 3	Ensure healthy lives and promote well-being for all at all ages (3.3, 3.7, 3.8, 3.B, 3.D)	C1, C3, C4, C7 E-health, C7 E-agriculture, C10
GOAL 4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all (4.1, 4.3, 4.4, 4.5, 4.7)	C3, C4, C5, C6, C7 E-learning, C7 E-employment, C7 E-agriculture, C7 E-science, C8, C10
GOAL 5	Achieve gender equality and empower all women and girls (5.5, 5.6, 5.B)	C1, C3, C4, C5, C6, C7 E-business, C7 E-health, C7 E-agriculture, C9, C10
GOAL 6	Ensure availability and sustainable management of water and sanitation for all (6.A, 6.B)	C3, C4, C7 E-science, C8
GOAL 7	Ensure access to affordable, reliable, sustainable and modern energy for all (7.1, 7.A, 7.B)	C3, C5, C7 E-science
GOAL 8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all (8.1, 8.2, 8.3, 8.5, 8.9, 8.10)	C2, C3, C5, C6, C7 E-business C7 E-employment, C7 E-agriculture, C8, C10
GOAL 9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation (9.1, 9.3, 9.4, 9.a, 9.c)	C2, C3, C5, C6, C7 E-government, C7 E-business, C7 E-environment, C7 E-agriculture, C9, C10
GOAL 10	Reduce inequality within and among countries (10.2, 10.3, 10.c)	C1, C3, C6, C7 E-employment, C10
GOAL 11	Make cities and human settlements inclusive, safe, resilient and sustainable (11.3, 11.4, 11.5, 11.6, 11.b)	C2, C3, C5, C6, C7 E-environment, C8, C10
GOAL 12	Ensure sustainable consumption and production patterns (12.6, 12.7, 12.8, 12.a, 12.b)	C3, C4, C7 E-employment, C7 E-agriculture, C8, C9, C10
GOAL 13	Take urgent action to combat climate change and its impacts (13.1, 13.2, 13.3, 13.b)	C3, C4, C7 E-environment, C7 E-agriculture, C7 E-science, C10
GOAL 14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development (14.a)	C3, C4, C7 E-environment, C7 E-science
GOAL 15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	C3, C7 E-environment, C7 E-science
GOAL 16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels (16.2, 16.3, 16.5, 16.6, 16.7, 16.10, 16.a, 16.b)	C1, C3, C4, C5, C6, C7 E-government, C9, C10
GOAL 17	Strengthen the means of implementation and revitalize the global partnership for sustainable development (17.6, 17.8, 17.9, 17.11, 17.14, 17.16, 17.17, 17.18, 17.19)	C1, C3, C4, C5, C6, C7 E-government, C7 E-business, C7 E-health, C7 E-employment, C7 E-agriculture, C7 E-science, C10, C11

Figure 3. SDGs and WSIS action lines matrix. Source: International Telecommunication Union et al. (2015).

A more detailed explanation about how they fit one another is given in the WSIS-SDG Matrix document (International Telecommunication Union et al., 2015).

Among new technologies, some of them like the IoT, cloud computing and big data are identified as crucial by 28 EU Member States (Peraković et al., 2020). A brief summary of them is given below.

Big data is defined as "Information assets characterised by such a high volume, velocity and variety to require specific technology and analytical methods for its transformation into Value" by De Mauro et al. (2014). Since nowadays digitisation is becoming a major subject, big data is gaining relevance because of the need to manage all that analogue information that is being digitised. Moreover, it has a heavy impact on both society and companies (De Mauro et al., 2014).

The cloud computing definition provided by the United States National Institute of Standards and Technology states that cloud computing is "a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" (Mell & Grance, 2011). Cloud computing includes five key features: On-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service (Dillon et al., 2010). In order to ensure the data integrity that cloud computing environments require, Blockchain has become an outstanding technology when building and deploying databases (Gaetani et al., 2017). Blockchain is a digital ledger capable of recording and storing information organised in a chronological order. It prevents manipulation by making that information permanent and immutable. Besides, it is decentralised and distributed, thereby resulting in a more reliable data management system

(Treiblmaier, 2018). Blockchain has remarkable applications in a broad range of areas, among which supply chain management is a prominent example (Kshetri, 2018).

And last but not least, a larger explanation of IoT will be given as it is an essential component of Industry 4.0 (Hofmann & Rüsch, 2017) and so more substantial within the framework of this dissertation. According to Vermesan & Friess (2013, 2014), IoT is a network conformed by a set of embedded devices. They can be integrated in a wide range of objects, such as vehicles, buildings, machines, instruments, etc. All of which are interconnected sending and receiving information with a defined objective. It shows improvement capacities and therefore has applications in tracing, safety, control, monitoring, administration, etc. An IoT system can share this information between people, between people and machines/things, and between machines/things. In systems such as these, the set of devices is even able to be ever-present through wireless and wired connections, interacting with each other in order to perform common tasks. Gathering data along the way and analysing it. They can run those tasks due to the intelligence they acquire, becoming capable of making decisions in accordance with the context. Thus, elaborating a complex service (Vermesan & Friess, 2013, 2014), the design of which can be constantly improved by them with the help of the primary data they are collecting (Manyika et al., 2015). According to Patel et al. (2016), the core characteristics of IoT are the following ones:

- Interconnectivity: IoT makes it possible to connect anything at different scales.
- Things-related service: IoT can provide services although it will be limited by the physical things themselves.
- Heterogeneity: IoT is a combination of different hardware structures.
- Dynamic changes: IoT devices' state can change continuously (location, speed, connected/disconnected, etc).
- Enormous scale: The IoT devices layer will always operate at a higher scale than the not IoT devices.
- Safety: An IoT system provides both data and physical safety.
- Connectivity: IoT connectivity abilities simplify accessibility and compatibility

As mentioned by Bouzembrak et al. (2019), IoT devices are conformed by 2 components:

- The sensor: Component that captures the information (temperature, humidity, light, movement...).
- The transmitter: Component that transfers the information. This encompasses Radio-frequency identification (RFID), bluetooth, Wi-Fi, etc.

The feasible advantages that IoT offers thanks to the measurement of parameters (that will be discussed later) creates an insightful opportunity within a CE context to perform looping/cascading processes, extend products lifetime and favour servitisation (Ellen MacArthur Foundation, 2016).

Once the high potential of IoT to enable circular strategies has been analysed, the associated environmental risks they entail also need to be accounted for. Their low durability alongside the toxic chemicals their waste may contain, could constitute a more significant impact on the environment in comparison with the ones their implementation is supposed to tackle (Ingemarsdotter, 2021).

Concerning terminology, the literature highlights a notable distinction between “digitisation” and “digitalisation” that necessitates clarification. These terms are frequently used as synonyms, but they are not. Gobble (2018) and Reis et al. (2020) affirm that numerous authors discuss the differentiation between digitisation and digitalisation. Digitisation refers to the conversion of analogue information into digital format, as stated by Parviainen et al. (2017): "the action or process of digitising; the conversion of analogue data (especially images, video, and text) into digital form." Conversely, digitalisation involves the transformation of business processes through the adoption of digital technologies. The literature review conducted by Reis et al. (2020) reveals that the definition of digitalisation can be ambiguous at times. Some definitions merge elements of both digitisation and digitalisation, while others align more closely with the definition of "digitisation", leading to potential misuse of the term and misleading conclusions.

2.3 IoT in the agroindustry

New technologies are transforming production lines. There is a growing trend by companies towards allocating investments to optimise operating systems. This is causing industry to be driven by the data provided by the aforementioned technologies, whose facilities are interconnected with each other (Bai et al., 2020; Dantas et al., 2021; Hatzivasilis et al., 2019; Manavalan & Jayakrishna, 2019). Thus, having every facility monitored and therefore the energy and resources waste generation are reduced (Andrews, 2015; Inoue et al., 2020). Agroindustry is at the forefront in the use of IoT. With its integration in the FSC several benefits can be achieved since the possibilities of encountering adverse circumstances are reduced due to a better control of the product (Cruz Introini et al., 2018; Misra et al., 2022). One of the drivers of this situation is the fact that companies whose environmental engagement is not up-to-date, are less preferable for investors since it is considered to be a business performance indicator (Morgan et al., 2015).

Particularly, integrated supply chain management is heading for IoT cloud distributed solutions and big data analysis of the captured information. Every object (physical layer) provides information to an ICT system (data exchange layer), which virtually creates a representation of every object (information integration layer). The physical layer updates constantly the information integration layer, which is then shared with the stakeholders (application service layer) (Ramundo et al., 2016).

When it comes to the agri-food sector, these new technologies track the food production in terms of provenance, processing factory, quality, fraud, impact on human health, etc. For instance, by using DNA barcoding, it is possible to identify whether food has been processed or not, as well as knowing the properties of its raw products (Ramundo et al., 2016). The environmental variations that may alter the quality of the product are measured with sensors (for example in vehicles during transport) and so the shelf life can be recalculated if necessary. Such data is uploaded to cloud systems, allowing supermarkets, consumers or other stakeholders to consult them with smartphones or tablets (Ramundo et al., 2016). There are already examples of this, such as the platform developed by Foodchain S.p.A., which generates a unique smart label for the product that the consumer can scan in order to obtain information about traceability (Grecuccio et al., 2020).

This food traceability is defined by the European Commission as “the ability to trade and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution.” (European Commission, 2002). Food traceability is a key factor in food safety, and so to prevent the FLW generation. This capability would be enhanced with the incorporation of more advanced systems. For example, the arrival of blockchain is affecting how food is being distributed globally. Its specific features are diffusing the limits between FSC actors, hence making food traceability even more important (Burke, 2019; Yu et al., 2020). The diversity showcased by the required data needs the use of new technologies so that data management can be efficient enough to localise the sources of food safety related problems and act accordingly. A smart food traceability system like that is able to gather information about location, ingredients, and packaging in every stage of the FSC. It uses IoT and cloud computing to collect and manage the food information improving food safety from farm to fork (Yu et al., 2020). Nevertheless, this ideal smart traceability system presents some drawbacks related to the complexity and diversity of the FSCs, the elevated cost of the equipment, and the difficulty of analysing the huge amount of data that is generated (Scholten et al., 2016). The traditional way to assess food safety in laboratories is expensive, slow, and requires a lot of work (Hameed et al., 2018). For that reason, several portable food safety detection technologies exist nowadays: portable spectroscopy, array sensors, microfluidic lab-on-a-chip, and smartphones.

Once food is packaged this traceability must be ensured as well. Smart packaging allows that tracking process either through the use of indicators that measure temperature, freshness, gas, or microbes in the food, or through the use of data carriers that provide data about previous FSC stages (Hameed et al., 2018). This smart packaging is defined by Hameed et al. (2018) as “any type of container that is capable of carrying out smart functions beyond a physical barrier between food and their surrounding environment.”

The data that such an IoT-blockchain based traceability system may collect, includes:

- Production stage: Planting date, temperature, humidity, soil and water quality, farming staff, time, origin, fertiliser and pesticides applications, water consumption (Bastas & Liyanage, 2018; Pincheira Caro et al., 2018), harvesting date, and weight (Feng et al., 2020).

- Processing stage: Time, processing equipment, batch modifications, information about packaging, cleaning process information, operators and information included in labels (Feng et al., 2019).
- Distribution stage: Time, temperature, relative humidity, gases, location and operator method (Feng et al., 2020; Galvez et al., 2018).
- Consumption stage: Name of the product, price, sale time and shelf life (Feng et al., 2020).

In the case of a plant food product, this information can also include seeding purchase and quality (Galvez et al., 2018). Meanwhile in a meat food product, animal health and breeding data are captured (Aung & Chang, 2014).

To gain a comprehensive understanding of the current state of digitalisation in FSCs, a literature review was conducted, incorporating a total of 89 scientific articles. These articles cover various types of supply chains, including a wide range of animal and crop products, and explore numerous parameters and ICTs. The examined parameters serve multiple purposes, such as enhancing productivity, promoting sustainability, ensuring food safety and quality, facilitating forecasting, enabling traceability, and addressing FLW. Each study identifies the specific stages of the FSC in which these parameters are considered. To organise and prioritise these parameters and ICTs, a classification was developed based on their frequency of occurrence in the reviewed literature. As a result of this analysis, the dynamic dashboard showcases in Figure 4 was created. This dashboard is freely accessible in Zenodo (doi: 10.5281/zenodo.8119271).

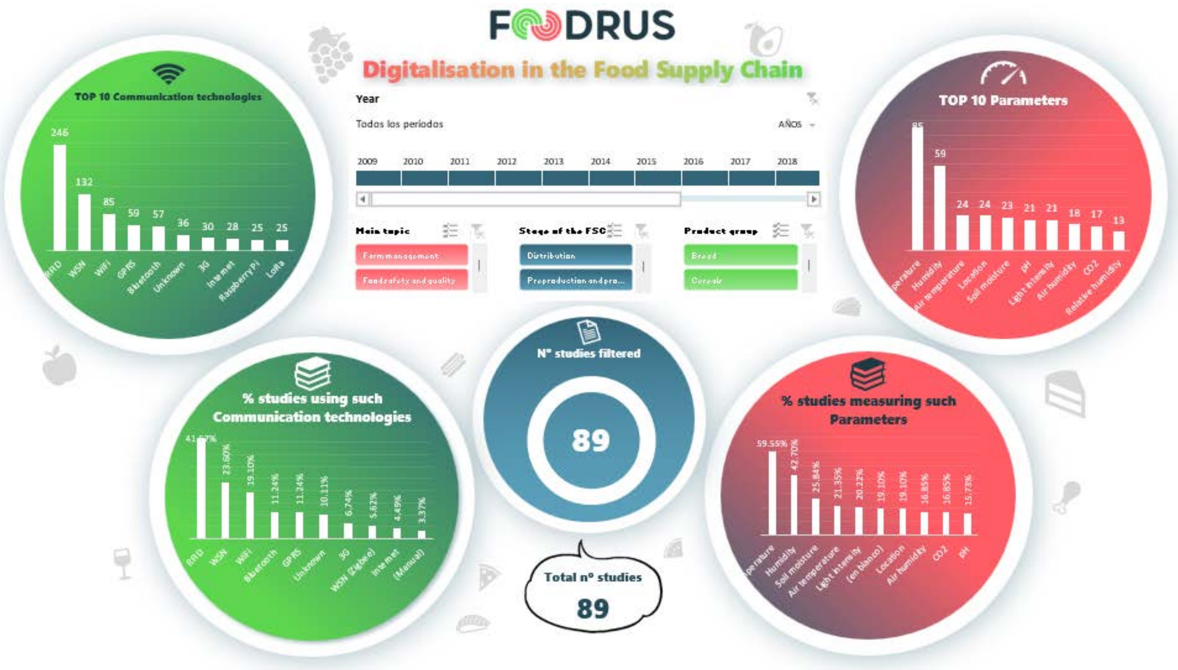


Figure 4. Dashboard with the results of the analysis of digitisation in FSCs.

The key findings derived from this review can be summarised as follows:

- Food safety and quality, FLW, sustainability, and traceability are interconnected topics, often mentioned together and driven by a shared objective of reducing FLW. Studies focused on productivity also tend to address prediction, while also addressing sustainability and food safety and quality concerns.
- There appears to be a lack of consensus regarding the terminology and division of the FSC. Various terms such as "production," "preproduction," "production in field," and "agricultural stage" are used interchangeably, highlighting the need for clarity and consistency. The processing stage is sometimes included in the production stage, leading to fewer studies specifically focused on this stage (only 26). It is important to note that not all food products require processing, which may explain those results. Similarly, the distribution stage may encompass the retail point, explaining the relatively smaller number of studies for this stage (28).
- In terms of the topics covered, the review reveals the following:
    - Food safety and quality is the most extensively studied topic (31 articles), particularly in the distribution stage (26) and retail stage (20). Temperature and humidity are the most frequently measured parameters, with RFID being the commonly used communication technology.
    - Sustainability is not a very explored topic (8 articles), especially in the retail stage and households, where no studies matching the requirements were found.
    - Studies specifically focused on FLW emerged in 2017, with the distribution stage being a significant focus in the majority of these studies (9 out of 11).
    - Traceability studies commonly measure temperature (in 13 studies), humidity (in 13 studies), and location (in 12 studies), given their close connection to food safety and quality.
- Examining the FSC stages, the following trends are observed:
    - Productivity is the predominant topic in the preproduction and production stage (31% of the studies).
    - Food safety and quality takes precedence in the processing (42%), distribution (54%), and retail stages (71%).

Since blockchain would leverage consumer confidence in food products and generate a traceability system such that it would enable it to recognise possible sources of contamination in real time (Tian, 2016), various studies are currently considering the possibility of applying blockchain to certification processes, especially in the agri-food industry. Besides, it would decrease operational costs in certification and verification processes (Ramakrishna et al., 2020). Both food safety and sustainability are significant topics to consider in order to prevent these FLW and quantify its impacts respectively. In these areas the new technologies are already spreading, setting up quite profitable applications like that of certification through blockchain.

2.4 Definitions, causes and destinations of FLW

Further elaborating on the topic of FLW, there are several aspects that must be clarified regarding terminology. Such a terminology lays the foundation for precise and unambiguous FLW quantification, which is crucial for rigorously measuring the impacts of FLW prevention actions. Defining each term properly, and identifying the root causes where the problem of FLW generation originates as well as the possible solutions (destinations) for such a problem are essential steps to standardise the methodology presented in this dissertation. For that purpose, a literature review was conducted to gain insights into the viewpoints of the scientific community and European legislation as concerns definitions. The focus was on understanding and establishing common terminology for the research, specifically examining terms such as food, edible food, inedible food, food loss (FL), and FW. During this review, inconsistencies and variations in definitions were observed across different sources. However, certain terms did exhibit widely accepted definitions that were consistently referenced in multiple sources. The definitions given in relevant sources of information for the terms “food”, “edible food” and “inedible food” are presented in Table 1, and for “food loss” and “food waste” in Table 2.

Table 1. Definitions in the literature for the terms “food”, “edible food” and “inedible food”.

Source	Definitions		
	Food	Edible food	Inedible food
(High Level Panel of Experts on Food Security and Nutrition et al., 2014)			"What WRAP calls “unavoidable waste”."
(Teuber & Jensen, 2016)			"The categories avoidable versus unavoidable and edible versus inedible are not clear-cut but depend on food safety considerations, available technologies and cultural factors."
(Hanson et al., 2016)	"Any substance—whether processed, semi-processed, or raw—that is intended for human consumption."		"Components associated with a food that, in a particular food supply chain, are not intended to be consumed by humans."
(Garcia-Garcia et al., 2017)		"It is or has been expected to be consumed by humans at any point during its life cycle, otherwise the product is inedible." It requires the product to be in demand, otherwise, it is considered inedible.	"Inedible food waste is thus considered unavoidable waste."
(Östergren et al., 2014)	"Any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be eaten by humans." It excludes inedible food.	It depends on "whether or not a substance or product is intended to be, or reasonably expected to be eaten by humans, which is determined by the person/company currently handling the raw material."	It depends on "whether or not a substance or product is intended to be, or reasonably expected to be eaten by humans, which is determined by the person/company currently handling the raw material."
(FAO, 2014)	"Any substance, whether processed, semi-processed or raw, which is intended for human consumption, and includes drinks, chewing gum and any substance which has been used in the manufacture, preparation or treatment of "food" but does not include cosmetics or tobacco or substances used only as drugs. (Codex Alimentarius Commission, Procedural Manual, 2013)		

Source	Definitions		
	Food	**Edible food**	**Inedible food**
(FAO, 2019)	"Any substance, whether processed, semi-processed or raw, intended for human consumption."		"Food components that, in a particular food supply chain, are not intended for human consumption (e.g. bones, rind)."
(WRAP, 2015)		Edible = Avoidable	Inedible = Unavoidable
(WRAP, 2020)	"Any substance that is – or was at some point – intended for human consumption."		"Components associated with a food that would never have been intended to be consumed by humans."
(WRAP, 2021)		"The parts which were intended for human consumption."	"Those parts associated with food that are not intended to be consumed (such as bones, egg shells)."
(European Commission, 2002)	"Any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans."		
(European Commission, 2021a)	"Any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans."	"Edible food parts are the components associated with a food, in its fresh mass status, that are usually consumed by humans, either as-is (raw consumption) or after processing or cooking. The definition of edible food parts might differ from country to country, or from region to region, according to local culture and habits."	"Food also includes inedible parts, where those were not separated as by products from the edible parts when the food was distributed or processed, such as bones attached to meat destined for human consumption, orange peels, seeds..."

Table 2. Definitions in the literature for the terms "food loss" and "food waste".

Source	**Definitions**	
	Food loss	**Food waste**
(High Level Panel of Experts on Food Security and Nutrition et al., 2014)	"Decrease, at all stages of the food chain prior to the consumer level, in mass, of food that was originally intended for human consumption, regardless of the cause." It does not include inedible food.	"Food appropriate for human consumption being discarded or left to spoil at the consumer level – regardless of the cause." It does not include inedible food.
(Teuber & Jensen, 2016)	It states that a general definition for food loss and food waste may not be feasible due to the complexities of FSCs. "It might be more realistic to work with different definitions according to the research objectives tackled."	
(Hanson et al., 2016)	"The FLW Standard is designed to allow for the fact that different organizations will have different reasons for quantifying food loss and waste. These different goals lead to (or government regulations may even explicitly state) different definitions of what constitutes food loss and waste."	
(Garcia-Garcia et al., 2017)		"Food materials (including drinks) originally intended to be used to feed humans and not ultimately sold for human consumption by the food business under study, and inedible parts of food." It includes donated food as food waste. Food wasted by consumers and managed at home (like home composting) is not considered.
(Teigiserova et al., 2019)	"The streams that are truly lost, i.e. inexplicable, whether because —not accounted for or disappearing from the accounting."	"Food that cannot be expected to be eaten by humans, due to either natural inedibility or inedibility due to the management of food, throughout the whole FSC."
(FUSIONS, 2016)	"Decrease in mass (dry matter) or nutritional value (quality) of food that was originally intended for human consumption." (FAO, 2013)	"Any food, and inedible parts of food, removed from the food supply chain to be recovered or disposed (including composted, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea)."
(FAO, 2014)	"The decrease in quantity or quality of food."	"Removal from the FSC of food which is fit for consumption, or which has spoiled or expired, mainly caused by economic behaviour, poor stock management or neglect." It states that it is different from food loss because "the underlying reasons, economic framework and motivation of the FSC actors for wasting food are very different from the unintended food loss, and subsequently the strategies on how to reduce food waste are conceived in a different, targeted manner."

Source	Definitions	
	Food loss	Food waste
(FAO, 2023)	"Decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retailers, food service providers and consumers."	"Decrease in the quantity or quality of food resulting from decisions and actions by retailers, food service providers and consumers."
(FAO, 2019)	"The decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retail, food service providers and consumers." It indicates that the Food Loss Index, which is part of SDG 12.3, includes the inedible parts in its quantification.	"The decrease in the quantity or quality of food resulting from decisions and actions by retailers, food services and consumers."
(WRAP, 2015)		"Any food that had the potential to be eaten, together with any unavoidable waste, which is lost from the human food supply chain, at any point along that chain." It includes edible and inedible. It includes only food produced for human consumption. It excludes food surplus heading animal feed.
(WRAP, 2020)	"Determining the difference between what may be defined as food loss versus food waste consistently can be difficult. The term 'food waste' as defined in this document is intended to cover all stages of the supply chain."	"Any food and inedible parts sent to any of the Food Waste Destinations listed below. This definition excludes any material that is sent for redistribution to people, animal feed or conversion into industrial products (collectively referred to as 'food surplus')."
(WRAP, 2021)		Total food waste = edible food + inedible parts.
(European Commission, 2021a)		"Any food that has become waste under these conditions: 1. it has entered the food supply chain, 2. it then has been removed or discarded from the food supply chain or at the final consumption stage, 3. it is finally destined to be processed as waste." It does not include losses at stages of the food supply chain where certain products have not yet become food as defined in Article 2 of Regulation (EC) No 178/2002, such as edible plants which have not been harvested. It does not include by-products from the production of food. It also excludes: straw and other natural non-hazardous agricultural or forestry material used in farming, forestry or for the production of energy from such biomass through processes or methods which do not harm the environment or endanger human health and animal by-products including processed products covered by Regulation (EC) No 1774/2002, except those which are destined for incineration, landfilling or use in a biogas or composting plant.

The review yielded several noteworthy findings:

- Consistently across the sources consulted, the requirement for a product to be intended for human consumption emerged as a defining characteristic of "food." This criterion also serves to distinguish between edible and inedible food.
- Edible and inedible food are often equated with avoidable and unavoidable FLW, respectively.
- As noted by FAO, FL is frequently associated with a decline in quality or quantity of food along the FSC.
- The influence of culture is a significant factor in determining the boundary between edible and inedible food in each region.

The final point merits special attention, as it implies that the quantification of FLW may not be possible to become completely standardised across regions. Consequently, the applicable solutions for managing potential FLW would also vary. In other words, the optimal approach to managing the same type of food surplus with the goal of minimising the environmental impact may differ between geographical areas.

The causes of FLW generation are also an important area to standardise. These determine the origin of the problem and serve as the first step in identifying potential solutions to prevent such FLW. In order to identify the underlying factors contributing to this generation of FLW, an extensive review of the literature was conducted, resulting in the identification of numerous causes. These causes have been categorised in 11 groups and are presented below:

- Stakeholders decisions: The attitudes of farmers, managers, and retailers play a crucial role in contributing to FLW generation. In some cases, farmers perceive FLW resulting from food overproduction as an acceptable deficiency, leading to a lack of preventive measures being taken. Additionally, the absence of standardised procedures to manage food surplus creates an environment that favours such situations (Beausang et al., 2017; Garrone et al., 2016; Peira et al., 2018; Pullman & Wikoff, 2017). Furthermore, the lack of awareness among consumers and other actors exacerbates this issue (Diaz-Ruiz et al., 2018).
- Transport related issues: Inappropriate food sourcing strategies for perishable goods and logistical challenges contribute to FLW (Rijpkema et al., 2014). Factors such as traffic issues and adverse weather conditions (Zhu, 2017), including temperature control and inadequate packaging, further exacerbate the problem (Arivazhagan et al., 2016; Diaz-Ruiz et al., 2018). Additionally, FLW occurs in international trade, primarily influenced by political changes (AL-Dalaeen et al., 2021).
- Food aspect and quality: Cosmetic and quality requirements contribute to the generation of FLW. These requirements are not only imposed by restrictive policies and standards but also arise from a self-imposed condition by stakeholders (de Hooge et al., 2018; Devin & Richards, 2018; Gillman et al., 2019). The behaviour of these actors is influenced by consumer demands, market competition, pricing, logistics, and production costs (de Hooge et al., 2018). The "one-third rule," an unspoken rule, leads

to the disposal of still edible food. It divides the shelf life or best before date of a product among the industry, supermarket, and consumption stages. If a product exceeds its designated time segment in the industry or supermarket stage, it is prematurely removed from the FSC (Diaz-Ruiz et al., 2018). Apart from FLW caused by adherence to aspect and quality standards, the uncertainty and misinterpretations surrounding them contribute to broader waste (Diaz-Ruiz et al., 2018). Last, adverse weather conditions also pose a threat to the integrity of food quality and shelf life (Mena et al., 2011).

- Business deals: One of the factors contributing to FLW in this context is the occurrence of returns and order cancellations between suppliers and retailers. This results in retailers increasing their economic gains while suppliers incur additional expenses and assume responsibility for the generation of FLW (Eriksson et al., 2017; Ghosh & Eriksson, 2018). Additionally, some retailers tend to order excessive quantities of products, resulting in waste, as their primary goal is to obtain discounts and better prices. Another driver of FLW is the limited flexibility that companies have in managing surplus food items under their own brand, which cannot be sold elsewhere (Barilla Center for Food and Nutrition, 2012; Gustavsson et al., 2011; Institution of Mechanical Engineers, 2013; Monier et al., 2011; Parfitt et al., 2010). The implementation of take-back agreements (TBAs) aggravates the problem by subjecting providers to the control of supermarkets, who are only obligated to pay for the products they manage to sell, leading to overordering and placing the burden of costs on the suppliers (Devin & Richards, 2018; Ghosh & Eriksson, 2018). Supermarkets further contribute to the generation of FLW by engaging in hoarding practices that restrict the opportunities for flexible buyers to store a variety of seasonal products in accordance with current availability (Feedback, 2018).
- Operational aspects of retailing: This encompasses various situations within the retail sector that contribute to the escalation of FLW. These include efforts to meet fluctuating consumer demand, the presence of perishable items with limited shelf life, excessive quantities of products acquired from suppliers or accumulated during promotional periods, the aim to provide a wide range of products for extended durations, and the obligation imposed on supermarkets to maintain full on-shelf availability of items (Diaz-Ruiz et al., 2018; Teller et al., 2018).
- Packaging-related challenges: Inappropriate packaging design and excessive packaging can inadvertently contribute to FLW instead of preventing it, as intended. In some cases, packaging design can make it difficult to access and retrieve the food, leading to unnecessary waste (Wohner et al., 2020). Additionally, certain packaging practices can inadvertently contribute to increased FLW. For instance, a study by Goossens et al. (2019) highlighted how a package of apples can result in complete waste if even one apple spoils. The negative environmental implications of this case are even greater, since packaging is unnecessary for certain food items like apples. In opposition, insufficient packaging can also contribute to FLW. During transportation, inadequate protection due to poor packaging can pose a threat to the integrity of the

products, especially when faced with challenging road conditions (Arivazhagan et al., 2016).

- Inadequate food management: FLW is also a result of improper practices during harvesting, cleaning, screening, and processing of food. The collection of products regardless of their maturity and the damage caused during harvesting and cleaning processes are identified as contributing factors. Additionally, the mishandling of food due to labour shortages further amplifies the issue (Arivazhagan et al., 2016). The lack of scientific methods undermines the efficiency of these activities (Balaji & Arshinder, 2016). Furthermore, consumers in supermarkets also contribute to FLW by mishandling fresh food (Diaz-Ruiz et al., 2018). And of course, cold chain breakages, which can lead to the occurrence of FLW (Diaz-Ruiz et al., 2018).
- Stakeholder network: The coordination and communication among stakeholders in the FSC are identified as additional factors that contribute to FLW (Balaji & Arshinder, 2016). When examining the FSC as a cohesive system, its effectiveness relies on the strength of its interconnections. Therefore, any lack of coordination or communication results in inefficiencies in the management of the product.
- Consumer behaviour: Within households, consumers contribute to FLW through misunderstandings or confusion regarding shelf life and best before dates, inadequate planning of purchases, and common cooking mistakes such as preparing more food than needed or neglecting to utilise leftovers due to a lack of knowledge (Diaz-Ruiz et al., 2018). Inadequate food preservation practices also play a role. Dietary choices may also contribute to FLW in a similar manner (Diaz-Ruiz et al., 2018). Additionally, limited cooking skills can hinder optimal utilisation of food resources. In certain retail settings like buffets, consumers may generate FLW by taking more food than necessary and failing to properly handle the excess elsewhere (Barilla Center for Food and Nutrition, 2012; Gustavsson et al., 2011; Institution of Mechanical Engineers, 2013; Monier et al., 2011; Parfitt et al., 2010). These behaviours can become even more challenging to anticipate during periods of significant weather fluctuations (Mena et al., 2011).
- Agricultural conditions: Similar to the challenges faced by retailers and stores, demand prediction at the farm level poses an obstacle to avoiding FLW. Moreover, farmers may prioritise the cultivation of crops based on profitability, considering previous season prices (Diaz-Ruiz et al., 2018). This approach can result in disproportionately high production during certain seasons, leading to food surplus that goes unconsumed. In the same way, farmers may choose not to harvest certain products when market prices decline and they are no longer economically viable (Muriana, 2017). Additionally, individualistic attitudes among farmers during trading can hinder the ability of farmers' cooperatives to effectively manage food surplus situations. Furthermore, certain policies, such as production subsidies, can promote overproduction of food (Bengtsson et al., 2018; Pritchard, 2012), contributing to FLW. Lastly, farmers' reliance on climatic conditions can be a driving factor for FLW, as favourable weather patterns may lead to excessive production (Diaz-Ruiz et al., 2018).
- Lack of financial resources to avoid FLW: Efforts and resources invested in preventing FLW are crucial for effective mitigation. Innovations and technical training targeted at

> reducing FLW play a significant role in this regard, yet their implementation and recognition are often insufficient (C. Chauhan et al., 2021).

As the last part of this section, a FLW hierarchy in which the destinations for FLW will be categorised is proposed. The hierarchy encompasses various levels, including prevention, recycling, recovery, and disposal. It is important to note that not all options within the prevention level are considered "destinations" per se, as they involve solutions implemented at the point of generation (PoG). The definitions of the four levels in the hierarchy are based on the Waste Framework Directive (European Commission, 2008b). It is worth mentioning that reuse is not included as an alternative within the FLW hierarchy, as its definition assumes that the product has already been consumed. This classification aligns with the FLW hierarchy established by the Waste and Resources Action Programme (WRAP), as depicted in Figure 5 (WRAP, 2018).

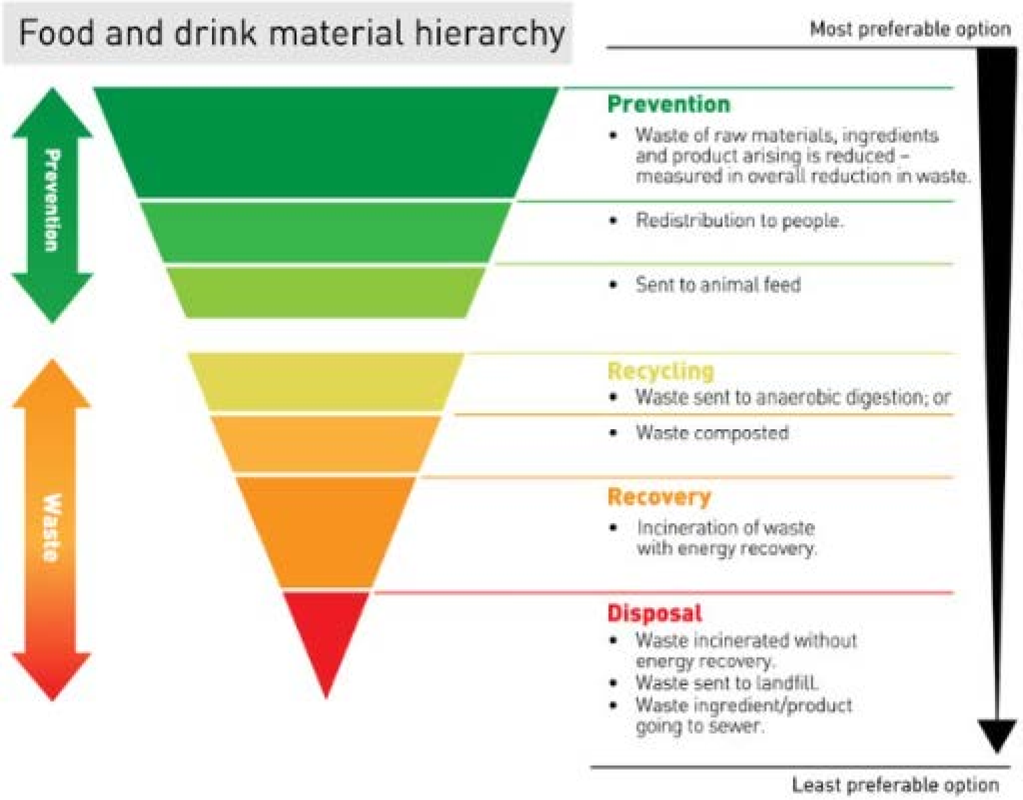


Figure 5. FLW hierarchy. Source: WRAP (2018).

Apart from this approach, other similar ones have been taken in the literature. In their study, Teigiserova et al. (2019) introduced a proposal that includes the distinction between food surplus and FLW depending on the destination. It considers reuse, however, to be a level of prevention.

The alternative waste hierarchy presented by the European Commission offers a different perspective, incorporating insights from Teigiserova et al. (2019) and other sources. While the first three levels remain similar, the fourth level is renamed as "Reuse by products/Recycle food waste." This revised version, developed by the Joint Research Centre (JRC), includes nutrient recovery as part of the recycling level and introduces a new option for disposal at the final level: discharging it through sewage.

Although the last 2 pyramids are more recent, because of the reasons exposed above the WRAP's approach was considered the most correct one. So, taking such a waste hierarchy as a model, a review was conducted to collect all possible destinations in the literature. Various scientific papers were identified as relevant sources, which provided valuable insights on the subject. These studies, conducted by Caldeira, De Laurentiis, & Sala (2019), Beausang et al. (2017), European Commission (2019), Filimonau & De Coteau (2019), Garcia-Garcia et al. (2017), Garrone et al. (2016), Girotto & Piazza (2022), Pinto et al. (2022), and Sánchez López et al. (2020) analysed the topic and alluded to a series of destinations to be considered. Hereunder the final list of destinations used in this dissertation is outlined, as well as a definition for each of them:

Prevention: The subsequent destinations/solutions represent those where the food has not yet reached the status of FLW, in accordance with the Waste Framework Directive (European Commission, 2008b). The following approaches are considered as preventive measures:

- Improvement of the supply chain efficiency: Strategies classified as supply chain efficiency strive to optimise the FSC (before consumption), thereby minimising FLW. This optimisation can be achieved through improvements in processes, products, or packaging (Caldeira, De Laurentiis, & Sala, 2019). In the context of this dissertation this category will include solutions such as: demand forecasting, cold chain traceability, quality forecasting, stocks optimisation, certifications on FLW prevention, or tools that help analyse data and identify patterns in order to enable the application of one of the aforementioned solutions.
- Consumer behaviour change: These actions are directed at inducing a shift in consumer behaviour patterns to reduce FLW (Caldeira, De Laurentiis, & Sala, 2019). They include programs that raise awareness among the public about the issue of FLW and its environmental impact (Filimonau & De Coteau, 2019), as well as digital tools to empower consumers with knowledge and resources that facilitate FLW prevention efforts.
- FLW prevention governance: This category encompasses all voluntary or mandatory initiatives designed to promote and facilitate the adoption of FLW prevention measures, such as: voluntary agreements, regulatory frameworks/policies, national FLW prevention programmes, or fiscal incentives (Caldeira, De Laurentiis, & Sala, 2019).
- Sales with promotions and discounts: This approach involves selling food in primary markets through promotional offers and discounts, which can help prevent wastage when there is a risk of expiry (Garrone et al., 2016). This also includes dynamic discount pricing, which is a pricing strategy that adjusts the price of a product based on its characteristics and condition changes, reducing wastage while offering

consumers the opportunity to purchase food according to its expiry date (Liu et al., 2008).
- Sales in secondary markets: When primary market options are not available, companies explore alternative sales channels such as specialised distributors or managed outlets known as secondary markets (Garrone et al., 2016).
- Internal distribution: This involves providing food to a company's own workers either for free or at reduced prices, typically when the product is no longer marketable but still edible (Garrone et al., 2016).
- Marketing actions and sponsorships: Organising events such as sports, charity, or tasting events can help prevent FLW by distributing food to participants and promoting specific brands (Garrone et al., 2016).
- Donation: This entails redistributing surplus food for human consumption to non-profit organisations such as soup kitchens, social supermarkets, and food banks, ensuring it reaches those in need (Garcia-Garcia et al., 2017; Garrone et al., 2016).
- Animal feed: This solution involves using surplus food as feed for animals when it is no longer suitable for human consumption, serving as an alternative to disposal (Garcia-Garcia et al., 2017).

It is important to distinguish between the first 3 prevention destinations outlined in this hierarchy and the subsequent ones. The initial 3 destinations refer to prevention at the PoG, and so address the root causes of FLW, representing more impactful solutions. Conversely, the remaining destinations target the management of already generated food surplus, as the root causes were not previously addressed. This distinction is crucial for understanding the effectiveness of prevention strategies. While the definitions for the first three destinations were adapted from Caldeira, De Laurentiis, & Sala (2019), a slight modification was made for the "Improvement of supply chain efficiency" destination. In the referenced report, this category appears to combine prevention at the PoG solutions with broader prevention measures. For instance, "price discounts" and "imperfect product sales" are included, which do not directly address the root causes of FLW (inaccurate demand forecasting and consumer perception on ugly food, respectively). To maintain consistency and ensure a comprehensive and rigorous classification system within this dissertation, these examples have been excluded from the "Improvement of supply chain efficiency" destination.

Recycling: Recycling, as defined by the Waste Framework Directive (European Commission, 2008b), involves the reprocessing of previously generated FLW into materials or substances. The following recycling destinations are considered:

- Remaking the same product: In cases of production errors or faults in labelling or packaging, companies may opt for remanufacturing or repackaging specific products, such as chocolate, pasta, or meat, depending on the nature of the product (Garrone et al., 2016).
- Revalorisation of FLW into new food products: This approach involves transforming FLW into new food items, such as making breadcrumbs from bread or recovering

nutrients to create a different food product, although the latter is a less preferred option (Girotto & Piazza, 2022).

- Revalorisation of FLW into value-added products: Processing FLW or food by-products can lead to the creation of different products with added value, while preserving the inherent molecular bonds in the material. This solution may involve collaborations with external companies, fostering industrial symbiosis (Pinto et al., 2022; Sánchez López et al., 2020).
- Left in the field: This process involves spreading food scraps on the ground to enrich the soil with nutrients (European Environment Agency, 2022; Garcia-Garcia et al., 2015).
- Ploughing back into the soil: Prior to spreading food scraps, the soil is ploughed as part of this management option.
- Composting: Composting is a biological decomposition process of organic matter, which can be conducted aerobically or anaerobically and results in the production of compost (Eurostat, 2015)
- Anaerobic digestion: Anaerobic digestion is a biological process that decomposes organic matter through the action of bacteria, generating biogas and digestate as by-products (United States Environmental Protection Agency, 2023).

Recovery: In the case of recovery three destinations were included, all of which refer to processes where the energy content of the FLW is harnessed. Which according to the Waste Framework Directive (European Commission, 2008b), correspond to recovery operations. They are:

- Gasification: Operation in which energy is extracted from the waste to obtain synthesis gas with the use of air below the stoichiometric level (Dong et al., 2019).
- Pyrolysis: Operation in which energy is extracted from the waste to obtain synthesis gas in the absence of oxygen (Dong et al., 2019).
- Incineration with energy recovery: Combustion process where the energy generated as a result of the exothermic reaction is harnessed (Eurostat, 2013).

Disposal: In accordance with the Waste Framework Directive (European Commission, 2008c), disposal destinations encompass processes that do not fall under the category of recovery. These options, considered the least preferred in the FLW hierarchy, include:

- Incineration without energy recovery: This involves a combustion process where the energy generated from the exothermic reaction is not utilised and is dissipated (Eurostat, 2013).
- Drained as or with wastewaters: This refers to disposing of the FLW by flushing it down the sink (European Commission, 2021a).
- Landfill: This involves the deposition of waste in designated land areas, either on the surface or underground (Eurostat, 2013b).

This section presents a comprehensive review of the terminology and approaches utilised in the existing literature regarding definitions, causes, and destinations related to the subject matter. Within Section 5 of this document, the chosen terms and approaches that form the foundational framework of this dissertation are documented.

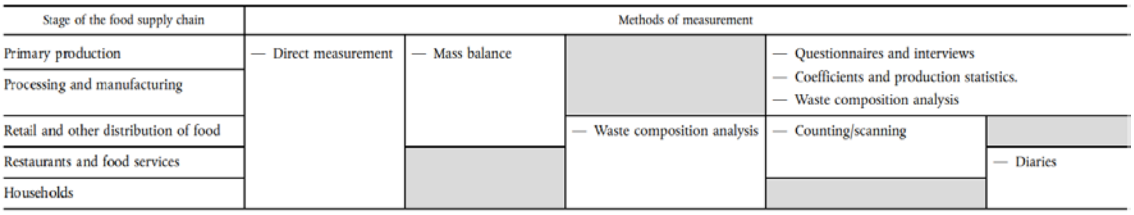
2.5 FLW quantification

To effectively address and mitigate the issue of FLW generation, it is imperative to establish a unified methodology that ensures consistent quantification of FLW. This methodology will encompass standardised specifications and considerations to ensure uniformity and comparability of FLW measurements.

Initially, the related literature provided various methodologies for FLW quantification. A highly cited standard that should be mentioned here is the FLW Standard (Hanson et al., 2016). This standard was developed by the FLW Protocol to provide requirements, guidance, and examples for quantifying and reporting on FLW. The standard aims to facilitate consistent and transparent quantification of FLW, supporting strategies for minimising FLW to achieve economic, food security, and environmental benefits. It is designed to be practical and voluntary, applicable to entities of all sizes and sectors worldwide. The FLW Standard allows users to develop inventories based on their specific goals, and it can be used for internal decision-making, compliance with FLW-reduction efforts, and informing policy or initiatives. The standard's flexibility allows users to choose the most appropriate scope for their FLW inventory. Additionally, it is worth mentioning the FLW protocol ranking tool. This tool facilitates the selection of appropriate methodologies for quantifying FLW in a specific context. This resource is accessible at the FLW protocol website: https://www.flwprotocol.org/flw-standard/.

Apart from this, in the academic literature the study conducted by Xue et al. (2017) stands out. They analysed 202 publications that reported on FLW, offering valuable insights in this domain.

In response to this need for standardised FLW quantification methods, the EU introduced the EU Delegated decision 2019/1597. This regulation establishes what should be measured and what should not be measured as FLW, as well as the quantification methodologies to be used at each FSC stage (Annexes III and IV). These methodologies can be seen in Figure 6. Priority order is established from left to right.



Stage of the food supply chain	Methods of measurement				
Primary production	— Direct measurement	— Mass balance	▨	— Questionnaires and interviews — Coefficients and production statistics. — Waste composition analysis	
Processing and manufacturing					
Retail and other distribution of food			— Waste composition analysis	— Counting/scanning	▨
Restaurants and food services		▨			— Diaries
Households				▨	

Figure 6. FLW quantification methodologies and FSC stages. Source: European Commission (2019).

Countries belonging to the EU are obliged to quantify their FLW generation in concordance with the requirements of the delegated decision. In 2022, the FLW generated by these countries in 2020 was reported for the first time following such a methodology. The results were published on the Eurostat website (Eurostat, 2023a). In addition, the delegated decision recommends the utilisation of Nomenclature of Economic Activities (NACE) codes for categorising the actors within the FSC (Annex I), and European Waste Codes (EWC) for grouping FLW (Annex II) depending on the FSC stage where it is generated.

In the particular case of Spain, in January 2024 the Spanish government approved the Food Loss and Waste Prevention Law project (Spanish government, 2022). This law points out that public administrations will promote the necessary means for the measurement of FLW in accordance with the Delegated Decision (EU) 2019/1597. The key points of the law include the obligation for all actors in the FSC, including primary sector operators, retail businesses, hospitality establishments, social entities, food banks, and public administrations, to comply with the provisions of the law. These entities are required to have FLW prevention plans and collaborate with other organisations to avoid FLW, with a priority given to human consumption through donation or redistribution. The project also emphasises the transformation of food surplus into products such as jams or animal feed, and the utilisation for composting, or biofuels production. Additionally, the law grants restaurant customers the right to take home leftover food and encourages the sale of imperfect or close-to-expiry-date products. Non-compliance with the law may result in fines ranging from minor to severe offences, with penalties reaching up to 500,000 euros. Amendments made during the legislative process include the entry into force of the law one month after its publication, exemptions for small supermarkets below a certain size, provisions for microenterprises and public procurement contracts, and limited liability for social entities involved in food donation.

After the publication of the delegated decision, relevant research articles dealing with the topic were identified, all of which are gathered in Table 3. The terminology used to allude to the FSC stages and the FLW quantification methods is the same as in the delegated decision.

Table 3. Methodologies employed for quantification of FLW in the recent literature.

Reference	Definitions	FSC stage(s)	FLW quantification method(s)	Geographical scale	Temporal scale
(Ioannou et al., 2022)	Not mentioned. It only refers to the Delegated decision. It is assumed they followed their definitions.	PP	Q&I CPS	Country level (Cyprus)	One calendar year (2018)
		P&M	Q&I CPS MB		
		RDF	Q&I CPS MB		
		RFS	Q&I MB		
		HH	D	68 households	2 weeks (then extrapolated to one calendar year)
(Thanomnim et al., 2022)	**Food loss:** "Any substance, drink that is intended for human consumption includes edible parts and inedible parts measures along production and supply chains, including post-harvest losses." **Food waste**: "Any substance, drink that is intended for human consumption includes edible parts and inedible parts measures at retail, food service, and households."	RDF RFS HH	WCA	Country level (Thailand)	One calendar year (2019)
(Fernandez-Zamudio et al., 2020)	**Food loss**: FUSIONS' concept.	PP	C/S Q&I	Regional level (Valencia, Spain): 12 parcels with 10 trees each	One month (From 12 Nov 2019 to 12 Dic 2019)
(Amicarelli et al., 2022)	**Food loss**: "Decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retailers, food service providers and consumers…" (FAO) **Food waste**: "Decrease in the quantity or quality of food resulting from decisions and actions by retailers, food service providers and consumers." (FAO)	PP P&M RDF HH	MB	Country level (Italy)	Before and during the COVID-19 lockdown

Reference	Definitions	FSC stage(s)	FLW quantification method(s)	Geographical scale	Temporal scale
(Afzal et al., 2022)	**Food waste**: "Decrease in the quantity or quality of food resulting from decisions and actions by retailers, food service providers and consumers." (FAO)	RFS	Q&I D	City level (Lahore, Pakistan): Questionnaire participants: 48 restaurants 11 hotels 15 wedding caterers Diary participants: 8 restaurants 1 hotel	Four months (From Nov 2020 to Feb 2021)
(Amicarelli et al., 2021)	**Food loss and waste**: "Intending food (including inedible parts) discharged, lost, degraded, consumed by pets or utilised in non-food or energy fields. Donation of food surpluses is not accounted for in the present paper."	PP P&M RDF RFS HH	MB	Country level (Italy)	One calendar year (2018)
(Herrera-Quinteros & Jara-Rojas, 2023)	**Food loss**: "A decrease in the mass of edible food originally intended for human consumption. Food losses occur at the production, postharvest, processing, and storage stages."	PP	Q&I	Regional level (Chile): 177 small-scale producers in 2 different regions	Two months (June and September 2020)
(Alshabanat et al., 2021)	Not clear.	PP P&M RDF RFS HH	MB Q&I	Country level (Arabia Saudi)	One calendar year (2016)
(Bedoya-Perales & Dal' Magro, 2021)	**Food loss**: "Decrease in the quantity or quality of food resulting from food suppliers' decisions and actions in the chain." **Food waste**: "Decreases the quantity or quality of food at the end of the food chain, resulting from decisions and actions by retailers, food services, and consumers."	PP P&M RDF RFS HH	MB	Peru	11 years (From 2007 until 2017, both included)
(Tóth et al., 2021)	**Food loss:** A reduction in the weight or quality of food at the beginning of the FSC (production, harvesting, processing). It is caused by logistical and infrastructural barriers.	P&M	DM (VA) DM (WA) MB CPS Q&I	Company level (Dairy Hungarian company)	Two months (January 2018 and January 2019)

Where:

- As FSC stages: PP = Primary production; P&M = Processing and manufacturing; RDF = Retail and other distribution of food; RFS = Restaurants and food services; HH = Household.
- As FLW quantification methods: MB = Mass balance; Q&I = Questionnaires and interviews; DM (VA) = Direct measurement (Volumetric assessment); DM (WA) = Direct measurement (Weighing assessment); C&PS = Coefficients and production statistics; WCA = Waste composition analysis; D = Diaries; C/S = Counting/scanning.

The main conclusions drawn from these scientific articles are:

- Definitions used, geographical and temporal scales, and FSC stages classifications are not always the same, which must be deemed when conducting comparative analyses. Moreover, sometimes it is not even stated which definitions are being used.
- All in all, the quantification methods can be classified according to those of the EU Delegated decision 2019/1597. So, such a list is comprehensive and seems to comprise all possibilities.
- Preharvest FL are excluded in some studies that cover PP, despite representing approximately 15% of the global FLW (WWF, 2021). Ignoring this aspect results in a significant gap in the data.
- Data accessibility and availability are usually an issue. Diverse assumptions are made to fill the gaps.

2.6 Sustainability in the field of FLW

To effectively measure and promote sustainability in the field of FLW, Key Performance Indicators (KPIs) are the most commonly used tools. KPIs provide a standardised and quantifiable method to assess environmental, economic, and social impacts. By utilising KPIs, stakeholders can systematically evaluate the efficiency and effectiveness of FLW prevention actions, ensuring that efforts are aligned with broader sustainability goals. The incorporation of sustainability KPIs in supply chains has gained significant attention in recent years. Sustainability KPIs provide a quantifiable means of assessing the progress made towards sustainable practices, enabling organisations to identify areas of improvement, set targets, and track their performance over time. So much so that the SDGs themselves establish a series of indicators within each target to measure progress towards the SDGs (United Nations, 2023a).

The literature extensively examines the process of identifying sustainability KPIs for monitoring supply chains. The sustainability KPIs found in these sources cover a wide range of issues, including reduction in GHG emissions, energy consumption, transport costs, customer satisfaction, demand forecasting accuracy, wastewater discharge, inventory turnover, number of employees, solid waste reduction, percentage of recycled water, and expenses in R&D, among others. To select them, authors employ different approaches and units of analysis. Perera et al. (2013) focused on a manufacturing company, using Analytic

Hierarchy Process (AHP) to quantify environmental performance with latent variables as criteria, KPIs as sub-criteria, and multiple product lines as alternatives. Saeed & Kersten (2017) expanded the scope by incorporating standards and guidelines, resulting in 70 sustainability KPIs. Himanen & Martikainen (2019) took an empirical approach, compiling KPIs through literature review, interviews, and analysis of company websites and reports. Haddach et al. (2017) developed a mathematical model and used AHP to obtain a single score for tracking sustainability information in supply chains. Neri et al. (2021) performed a literature review to establish a balanced set of KPIs considering their repetition, priority, and coverage of literature gaps. Yontar & Ersöz (2020) focused on FSCs and obtained KPIs through literature review, expert interviews, and questionnaires for FSC actors. Statistical techniques such as Confirmatory Factor Analysis and AHP were employed to evaluate parameter performance and calculate an overall sustainability score for the studied FSC.

To effectively address the challenge of FLW prevention, it is crucial to implement a range of targeted solutions. In this context, a significant contribution has been made by the JRC through their comprehensive report titled "Assessment of food waste prevention actions" (Caldeira, De Laurentiis, & Sala, 2019). This report introduces two distinct groups of KPIs that enable the evaluation of the impact of FLW prevention solutions. These KPIs focus on assessing the effectiveness and efficiency of various preventive actions and are tailored to different types of interventions. The identified categories include food redistribution, consumer behaviour, supply chain efficiency, and FLW prevention governance. By considering these dimensions, these KPIs aim to provide a holistic assessment framework that captures the multifaceted nature of FLW reduction efforts.

Recently the company Verra published a new methodology (Saez de Bikuña et al., 2023) to measure the GHG emissions that are avoided when conducting FLW prevention actions. The methodology is designed for project activities that aim to reduce FLW making more food available for consumption. It provides procedures to quantify the net GHG emission reductions resulting from keeping food in the FSC, diverting it from FLW destinations that are in lower levels than that of prevention (e.g., soil amendment production, energy recovery, landfill without biogas capture). To qualify, actions must reduce the amount of FLW compared to the baseline scenario, adhere to food health and safety legislation, and divert food away from specific FLW destinations. The methodology does not apply to actions that shift food from one destination to another that is not in the prevention level. In other words, the action must not just scale up in the FLW hierarchy but avoid FLW generation.

The literature on sustainability KPIs demonstrates robustness in terms of data sources, drawing from scientific publications, standards, expert opinions, and insights from stakeholders involved in FSCs. This diverse range of information sources enables a comprehensive and multidimensional approach in assessing sustainability. Moreover, sustainability KPIs commonly align with the three pillars of sustainability, either by clustering them under latent variables or by further subdividing them into more specific subjects within each pillar. These KPIs are predominantly pragmatic, as they are adaptable to different scales and do not rely on complex formulas. However, there is room for improvement, as certain lists of KPIs often lack critical analysis, leading to potential issues of redundancy and triviality.

While some studies employ statistical techniques like the AHP, the consolidation of criteria to assign scores is often missing. Notably, none of the reviewed studies encompass the entire supply chain as the unit of analysis, with most focusing on specific stages, leaving gaps in the overall understanding of FLW dynamics. In this context, which specifically examines FSCs, only one selected study delves into this area, but it does not provide a comprehensive set of KPIs targeting FLW.

2.7 LCA in the field of FLW

Life cycle assessment (LCA) is a standardised methodology defined by the ISO in ISO 14040 (ISO, 2006b) and ISO 14044 (ISO, 2006c). More specifically, ISO 14040 describes LCA principles and framework making the concept understandable for any reader interested in it. Meanwhile ISO 14044 is intended to assist LCA practitioners as a reference, outlining more technical information (Finkbeiner et al., 2006).

ISO 14040 (ISO, 2006b) states that “LCA deals with the environmental aspects and potential impacts throughout the whole life cycle of a product from the raw materials acquisition, production, use, final treatment, and recycling, to the final disposal (i.e. from cradle to grave)”.

In LCA there are 4 distinct stages according to ISO 14040 (ISO, 2006b):

- Goal and scope definition: The LCA goal will affect the thoroughness and breath of the study. Likewise, the LCA scope will depend on the goal and will establish the limits of the system as well as the processes included, the functional unit (FU), etc.
- Life cycle inventory (LCI) analysis: It contains an inventory of the system inputs and outputs. The data gathering is part of this phase.
- Impact assessment: In this step the results are analysed in order to understand and assign to every impact the importance it requires.
- Interpretation: In the interpretation phase a discussion takes place with the aim of coming to conclusions and making decisions in accordance with the goal and scope previously determined.

This scheme is depicted as follows in Figure 7:

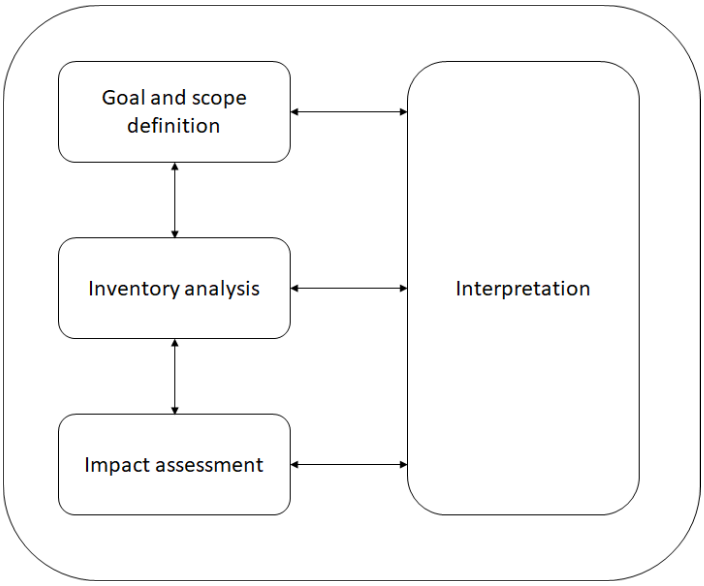


Figure 7. LCA stages. Source: International Organization for Standardization (2006b).

LCA offers a holistic and interdisciplinary approach that enables a better decision-making process by evaluating the environmental impacts of a product or a service (Zamagni et al., 2013). For instance, one of the aforementioned CE principles leans towards extending the useful life of the product for as long as possible. Which might be counterproductive on some occasions. This can be detected through the use of the LCA methodology (Peña et al., 2021). Actually, when it addresses those impacts taking into consideration the three pillars of sustainability (environment, society and economy), it is called Life cycle sustainability assessment (LCSA) (UNEP, 2011). Thus, being a helpful tool in order to achieve a CE. Moreover, LCA can bring interesting solutions since it is the most effective way to apply ecodesign (McAloone & Pigosso, 2018).

One of the benefits that LCA brings to the table is the avoidance of the trade-offs of impacts along the life cycle. It ensures that the processes involved in the upstream, core, and downstream stages of the life cycle are being considered. In other words, LCA helps in the evaluation of CE solutions making it easier to understand whether they can be achieved and to what extent. As well as in identifying the points of the life cycle where it is more important to act on (hotspots) (Peña et al., 2021). A practical example of this would be the replacement of an imported food product for a local one, which will require the impact assessment of the foreign supply chain (Peña et al., 2021). Even if LCA is standardised, there are still additional efforts needed to be made with the aim of facilitating the task of comparing LCA studies, and so CE strategies based on LCA (Peña et al., 2021). This includes the FU, system boundaries, cut-off rules, allocation criteria, assumptions, etc.

LCA in combination with the new technologies taking over and creating the industry 4.0 offers a great potential to address the environmental impacts of a product/service in real time. In a system like that, equipment and instruments would continuously record data of input and output flows. This new concept would even transform the way a FU is defined in conventional

LCA. The possibilities that smart manufacturing brings habilitates the calculation of the environmental impacts of a single process or of a region for instance. Under this framework no physical boundaries would be required as before, since IoT devices would allow this analysis to be conducted at an individual level. Many of the assumptions usually undertaken in an LCA would be softened or overcome by gathering specific identity data (Raihanian Mashhadi & Behdad, 2018). Such specific identity data is more pertinent for those products whose use stage stands a significant hotspot (Raihanian Mashhadi & Behdad, 2017a, 2017b). Which would vastly increase the credibility of the study, as average and steady data is substituted by a much more trustable and less biased one. As a consequence, the achievement of more ambitious economic, environmental, and social objectives would become an easier task coupling this system with optimisation techniques (Raihanian Mashhadi & Behdad, 2018).

LCA is also applied in the field of waste management, and consequently, in the field of FLW. In such a field, LCA is utilised for evaluating the environmental consequences of technologies and policies related to FLW management, as well as for identifying the most effective combinations of technologies and policies that reduce environmental impact the most (Lundie & Peters, 2005). In fact, LCA indicators should be included when measuring the environmental impact of waste prevention to obtain an objective view of the outcome (Nessi et al., 2013). Notable studies include the one conducted by Scherhaufer et al. (2018), which assessed the environmental impact of FLW at the European level, considering nine different products. The study conducted by Omolayo et al. (2021) is also noteworthy, as they conducted a comprehensive review of the state of the art in LCA applied to the FLW area focused on FLW management policies. Many gaps were identified in this study, ranging from the fact that the objectives of these LCAs should aim for the highest level of the waste hierarchy (prevention), to the need for improving data transparency. Specifically, in the evaluation of waste prevention performance (as it is the case of this dissertation), it is acknowledged in the literature that LCA has certain limitations (Bizcocho & Llatas, 2019; Nessi et al., 2013). These limitations primarily pertain to the determination of the FU and the establishment of system boundaries (Bizcocho & Llatas, 2019). Both of which are typically different and yet key to allow fair comparisons between LCA studies (Omolayo et al., 2021). The following table illustrates the FUs and system boundaries employed in different studies that deal with FLW prevention.

Table 4. Functional units and system boundaries in LCA studies that deal with FLW prevention.

Reference	Objective	Functional unit	System boundaries
(Albizzati et al., 2022)	To assess the sustainability of FLW prevention actions including the rebound effect caused by the monetary savings coming from that FLW avoided	Tonne of avoided FLW	Cradle-to-grave approach. They use system expansion to account for the consequences of avoiding FLW and thus saving money.
(Omolayo et al., 2021)	Defines the state of the art of LCA focused on FW.	- 14 articles used 1 tonne of FW. - 6 articles used 1 tonne of food consumed. - 2 articles used food products consumed by 1 individual.	The 22 reviewed studies utilised 10 different system boundaries.
(Cánovas Creus et al., 2018)	"Examine the FLW of a produce retailer and estimate the prevention potentials due to a prevention strategy".	"FSC with associated FLW related to 1 tonne of fresh produce delivered at the retailer gate."	Cradle-to-grave approach: It includes all the FSC stages, the waste treatments in each stage, and the prevention alternatives.
(Salemdeeb et al., 2017)	Present a model to evaluate FLW prevention.	Tonne of household FW	They exclude the upstream processes.
(Nessi et al., 2013)	To calculate the environmental impacts of municipal solid waste management systems including prevention actions.	Approach 1: Prevention is considered a waste management scenario. - "The integrated management of the waste potentially producible over a given period in a given geographical area (or by one of its inhabitants), in which waste prevention activities will be undertaken". Approach 2: Prevention is NOT considered a waste management scenario. - "The management of the waste produced over a given period in a given geographical area (or by one of its inhabitants)".	Approach 1: Prevention is considered a waste management scenario. - They don't include upstream processes in the baseline. Approach 2: Prevention is NOT considered a waste management scenario. - They don't include the avoided upstream processes in the waste prevention action scenario.
(Cleary, 2010)	Presents a methodology to address prevention in municipal solid waste LCAs.	- Primary FU: "Amount of material (mass or volume) addressed by the municipal solid waste management system on an annual basis". - Secondary FU: Only applicable when the prevention activity implies dematerialisation. It guarantees that municipal solid waste management scenarios are comparable, i.e. their product services are functionally equivalent.	They vary depending on the type of waste prevention action.

As can be observed, the related literature exhibits a lack of consensus when it comes to these aspects. As is well understood in LCA, this will also depend on the objective of the study, which is not always the same as indicated in the table. For instance, while some studies aim to evaluate the impact of waste prevention actions, others focus on assessing waste valorisation technologies. In the latter case, adopting 1 kg of waste as the FU is justified.

2.8 Certifications and environmental labelling

According to the ISO (2023a), a certification is “the provision by an independent body of written assurance (a certificate) that the product, service or system in question meets specific requirements.”. Namely, it is a procedure aimed at attesting that a product or service meets a standard’s requirements suitable for such product or service. Those standards assist companies with the traceability process throughout the supply chain (Verzijl et al., 2015). As stated by Purwandoko et al. (2018), the first step when developing a traceability system as the ones that are used for certification purposes, is to identify the information needed to be monitored. With that ultimate goal, surveys may be implemented to map stakeholders and their interconnections, have an outline of the supply chain and so determine the information that will be collected. In the same way, interviews and data from records are also relevant data sources to obtain more in-depth details. All that data will be stored and managed by the traceability system from a series of capture points along the supply chain (Purwandoko et al., 2018). A comprehensive example of which data is tracked in every capture point is given by Purwandoko et al. (2018) in the case of an organic rice certification.

Certification is closely linked to traceability. For example, to obtain a food safety certification the traceability of a series of parameters must be ensured. From the results of the dashboard presented in Figure 4, it is assumed that in food safety the most widely measured parameters comprise temperature, humidity and location. In addition to others like CO_2, SO_2, light, gas, ethylene, salinity, heavy metals, pressure, vibration, viscosity, wind, rain, microbial activity, etc. Likewise, the monitoring of specific parameters is also required for environmental certifications. These certifications, also called “ecolabels”, give insights into either the overall or specific environmental properties of a product or service. This information may serve to influence and guide consumers or users when making decisions in a purchasing situation. Which in turn can lead to an eco-innovation process, where the market is steered towards a vicious cycle that boosts ecolabelling due to business competition (ISO, 2022; Rennings, 2000).

Ecolabelling is governed by the Regulation (CE) n° 834/2007 (European Commission, 2007) about organic production and labelling of organic products. In this regulation organic production is defined as “an overall system of farm management and food production that combines best environmental practices, a high level of biodiversity, the preservation of natural resources, the application of high animal welfare standards and a production method in line with the preference of certain consumers for products produced using natural substances and processes”. It is worth highlighting that in the Spanish version, this regulation uses the equivalent term for “ecological” where the English version uses “organic”. This may lead to confusion since both terms do not share the exact same meaning.

The ISO standard 14020 which controls ecolabelling and environmental product declarations (EPD), distinguishes between 3 types of environmental labelling:

- Type I. Environmental labellings that certify the product is complying with specific environmental requirements. Validated by a third party (ISO, 2018).
- Type II. Self-declared environmental labels made by the manufacturing company (ISO, 2016).
- Type III. Environmental product declarations (EPD). They follow the LCA methodology and are validated by a third party (ISO, 2006a).

In these ecolabels the inclusion of all the life cycle of the product is required (ISO, 2022). For this reason, the traceability that new technologies offer fits perfectly with their requirements, adding a substantial added value.

In the particular case of type III ecolabels, IoT would revolutionise data collection, which is the toughest and the most cost and time-consuming part in the LCA (70%-80%) (Curran, 2012; Miah et al., 2018; Mieras et al., 2019). Data collection is part of the LCI analysis, a stage where all the material and energy inputs and outputs from the product system to the environment during the life cycle are measured (ISO, 2006b). Procedure that would be conducted in real time through the use of IoT, capturing on-site data instead of collecting statistical data (Mieras et al., 2019). Studies concerning this issue have already been carried out, showing how the introduction of these new technologies to collect data (using also a cloud platform to enable it) make more effective the use of LCA models, together with the later dissemination of results with a greater range than ever before (Mieras et al., 2019). Considering that data quality is one of the biggest challenges to deal with in the area of LCA (Djekic et al., 2019), IoT would be a major breakthrough in this regard as it allows to detect outliers by making the measurements on-site (Mieras et al., 2019). The integrity of the results that blockchain grants, offers an excellent solution to this problem as shown in the pioneer study performed by Zhang et al. (2020), which presented for the first time an LCA framework based on a blockchain system.

For type I and II ecolabels, IoT would also be used with the purpose of obtaining data of inputs and outputs in every stage of the life cycle (as ISO standards state), although it would need to adapt to the particular requirements of each. In the ISO 14020 it is specified that the utility and effectiveness of the ecolabels are based on the meaningfulness and reliability of the information they provide (ISO, 2022). And monitoring with IoT has demonstrated being capable of decreasing the mistake in comparison with that of the human being (Kishore Austeen et al., 2019; Saha et al., 2018), as well as managing data of high quality (Mieras et al., 2019).

Additionally, it is worth mentioning that ecolabels are being more and more ambitious with regard to the sustainability concept. So that health and social aspects are starting to be included as well (Asensi & Kaulins, 2019).

In this context, IoT would be applied in the form of surveys for workers, consumers, and other stakeholders throughout the FSC. Via IoT it would be much easier to standardise the data gathering, resulting in an improvement of the reliability and the rigour of these studies (Grubert, 2018; Mieras et al., 2019).

Once the data is collected by IoT devices, and stored in the blockchain cloud, by using smart contracts the compliance of the applicable standards or guidelines is ensured. Thereby promoting auditing and certification processes. This guarantee is due to the immutability that characterises the blockchain technology (Rejeb et al., 2019). What is more, since it is a decentralised technology and it does not need intermediaries (Mougayar & Buterin, 2016; Treiblmaier, 2018), these audit processes are conducted in a much faster way. Then the complementation between IoT and blockchain permits enhanced audit processes with a higher level of detail (Ma et al., 2019; Rejeb et al., 2019). Lastly, the information of the product can be delivered with smart labels, whose inks are even able to spot changes in environmental variables (Gligoric et al., 2019; Ramundo et al., 2016).

In summary, the application of IoT and big data will foster a huge progress in the agri-food sector in all the 3 pillars of sustainability: society (food safety, demand control, more product quality...), economy (more productivity, improvement of processes...) and environment (reduction of impacts, improvement of the resources use efficiency...) (Misra et al., 2022). Indeed, López-Morales et al. (2020) points out that the incorporation of IoT strengthens the agroindustry capabilities to minimise its environmental impact. By means of three use cases, this study demonstrated that the transformation of logistics processes that IoT entails, leads to an environmental footprint reduction along with other benefits. This progress is already a reality because of a rising interest registered as regards the implementation of the CE in this new industrial technology paradigm. Leveraging like this the fulfilment of the SDGs (Dantas et al., 2021). In the light of these results, it becomes a matter of scientific interest to research and analyse deeper the connection between these two branches of knowledge in the agri-food sector: sustainability and new technologies.

The indicators developed in this doctoral dissertation are intended to be integrated into a certification scheme. The inclusion of sustainability KPIs within certification processes proves to be highly valuable for several reasons. Firstly, sustainability KPIs provide a standardised and objective measure of an organisation's environmental, social, and economic performance, allowing for meaningful comparisons across different certified entities. By incorporating these indicators, certifications can effectively communicate the level of sustainability achieved by a certified organisation, promoting transparency and accountability. Additionally, sustainability KPIs enable continuous improvement by establishing clear targets and benchmarks, encouraging organisations to strive for higher levels of sustainability performance over time. Furthermore, the integration of KPIs within certification frameworks promotes the adoption of sustainable practices and encourages innovation by guiding organisations towards more sustainable strategies and operations. Ultimately, it enhances the credibility and relevance of certifications, empowering consumers, stakeholders, and decision-makers to make informed choices that contribute to a more sustainable future.

3 Motivation

The review of the state of the art served to identify several gaps and challenges. In the present chapter these identified gaps will be illustrated, serving as the motivation for the formulation of the research objectives. This approach ensures that the contributions of this study significantly enriches the knowledge domain in question.

Firstly, there is room for improvement in the existing FLW quantification methodologies, especially as concerns the lack of specificity in the EU Delegated Decision 2019/1597. These methodologies do not adequately capture the complexities of FLW across different stages of the FSC. This insufficiency poses a significant barrier for FSC actors striving to measure and reduce FLW effectively. A more comprehensive approach to quantify FLW is needed to facilitate this process for FSC actors.

Secondly, robust methodologies and sustainability indicators are necessary to track and evaluate the effectiveness of FLW prevention actions. There is not a widely accepted set of sustainability KPIs to measure such an impact. Challenges in this regard include ensuring that the KPIs: allow to measure sustainability performance; are applicable to all FSC stages; provide a holistic vision of the entire FSC; are aligned with current FLW regulatory frameworks; and are shaped by integrating input from experts and FSC stakeholders. It is also an added value to consider the digitisation capability of KPIs to guarantee the reliability of the data and their contribution to achieving the SDGs, particularly SDG 12.3. This set of metrics must be capable of allowing comparisons between different types of FLW prevention actions, deployed in different FSCs and contexts. This demands adequate criteria and factors to rigorously evaluate their overall impact on preventing FLW. In the particular case of environmental impact KPIs, robust methodologies such as LCA are essential for assessing the environmental impact of FLW prevention actions. However, the state of the art in this domain lacks a thorough LCA methodology to assess the net environmental impact of different FLW prevention strategies. This includes the definition of the FU and system boundaries. Besides, there is a notable lack of data transparency and insufficient emphasis on prevention at the PoG.

Thirdly, integrating ICTs in the agroindustry presents a significant opportunity to measure the sustainability of FSCs in a faster and more reliable manner. While the digitisation of FSCs has been growing in recent years, its application for sustainability purposes remains uncommon. This growth sets the stage to introduce sustainability performance KPIs, which can foster sustainable data-driven decisions. This is key to building more sustainable food systems based on real-time information on the impact of the implemented FLW prevention actions.

By addressing these gaps, this dissertation aims to develop a comprehensive and practical framework for evaluating the sustainability performance of FLW prevention actions ultimately contributing to the achievement of SDG 12.3.

4 Objectives

The main objective of this dissertation is to develop a standardised methodology capable of measuring the environmental, social, and economic impact of food loss and waste (FLW) prevention actions undertaking a holistic life cycle perspective. This methodology aims to be universally applicable across food supply chains (FSCs), irrespective of their composition or the type of food product under analysis. Moreover, it seeks to facilitate seamless comparisons between different FSCs, promoting ease and accuracy in evaluating their FLW prevention performance.

This goal can be reformulated in the following hypothesis:

If this standardised methodology is applied to assess FLW prevention actions in an FSC, then opportunities for FLW prevention and management can be identified, and their sustainability impacts can be evaluated from a holistic perspective.

For the achievement of this objective, a series of specific research goals are outlined below:

1. To define a taxonomy to address the FLW problem in the FSC.
2. To define the economic, social and environmental KPIs that enable the measurement of the sustainability of FLW prevention actions under a life cycle approach.
3. To develop a comprehensive methodology to quantify FLW, going beyond the specifications of the Delegated Decision 2019/1597, in order to identify solutions for moving up in the FLW hierarchy and their room for improvement.
4. To develop a thorough LCA methodology to assess the environmental impact of FLW prevention actions focusing on FLW prevention at the point of generation.
5. To analyse how digitisation assists in the measurement and analysis of the defined KPIs to enhance the standardisation, transparency and reliability of the data.
6. To validate the methodology through the assessment of circular economy scenarios that promote different types of FLW prevention actions covering every FSC stages in a real case study.

By achieving these objectives, this research aims to identify the optimal strategies for minimising FLW and advancing the fulfilment of SDG 12.3 without compromising other sustainability dimensions, ultimately paving the way for more sustainable food systems.

9 Bibliography

ADEME. (2023). *Agribalyse database*. https://doc.agribalyse.fr/documentation-en/agribalyse-data/data-access

Afzal, N., Basit, A., Daniel, A., Ilyas, N., Imran, A., Awan, Z. A., Papargyropoulou, E., Stringer, L. C., Hashem, M., Alamri, S., Bashir, M. A., Li, Y., & Roy, N. (2022). Quantifying Food Waste in the Hospitality Sector and Exploring Its Underlying Reasons—A Case Study of Lahore, Pakistan. *Sustainability (Basel, Switzerland)*, *14*(11), 6914. https://doi.org/10.3390/su14116914

Albizzati, P. F., Rocchi, P., Cai, M., Tonini, D., & Astrup, T. F. (2022). Rebound effects of food waste prevention: Environmental impacts. *Waste Management*, *153*, 138–146. https://doi.org/10.1016/j.wasman.2022.08.020

AL-Dalaeen, Q. R., Sivarajah, U., & Irani, Z. (2021). Determining sustainability key performance indicators for food loss reduction. *Journal of Enterprise Information Management*, *34*(3), 733–745. https://doi.org/10.1108/JEIM-04-2021-424

Alonso-Muñoz, S., García-Muiña, F. E., Medina-Salgado, M.-S., & González-Sánchez, R. (2022). Towards circular economy practices in food waste management: a retrospective overview and a research agenda. *British Food Journal (1966)*, *124*(13), 478–500. https://doi.org/10.1108/BFJ-01-2022-0072

Alshabanat, Z., Alkhorayef, A., Ben Haddad, H., Mezghani, I., Gouider, A., Tlili, A., Allouche, M. A., & Gannouni, K. A. (2021). Quantifying Food Loss and Waste in Saudi Arabia. *Sustainability (Basel, Switzerland)*, *13*(16), 9444. https://doi.org/10.3390/su13169444

Al-Sheyadi, A., Muyldermans, L., & Kauppi, K. (2019). The complementarity of green supply chain management practices and the impact on environmental performance. *Journal of Environmental Management*, *242*, 186–198. https://doi.org/10.1016/j.jenvman.2019.04.078

Amador-Cervera, M., Angarita-Zapata, J. S., de la Calle Vicente, A., & Alonso-Vicario, A. (2024). The FOODRUS index: Assessing suitability for effective food loss and waste prevention management under an integral perspective. *Waste Management*, *179*, 32–43. https://doi.org/10.1016/j.wasman.2024.02.050

Amicarelli, V., Rana, R., Lombardi, M., & Bux, C. (2021). Material flow analysis and sustainability of the Italian meat industry. *Journal of Cleaner Production*, *299*, 126902. https://doi.org/10.1016/j.jclepro.2021.126902

Amicarelli, V., Roe, B. E., & Bux, C. (2022). Measuring Food Loss and Waste Costs in the Italian Potato Chip Industry Using Material Flow Cost Accounting. *Agriculture (Basel)*, *12*(4), 523. https://doi.org/10.3390/agriculture12040523

Andersen, M. S. (1999). Governance by green taxes: implementing clean water policies in Europe 1970–1990. *Environmental Economics and Policy Studies*, *2*(1), 39–63. https://doi.org/10.1007/BF03353902

Andrews, D. (2015). The circular economy, design thinking and education for sustainability. *Local Economy*, *30*(3), 305–315. https://doi.org/10.1177/0269094215578226

Antonopoulos, I., Faraca, G., & Tonini, D. (2021). Recycling of post-consumer plastic packaging waste in the EU: Recovery rates, material flows, and barriers. *Waste Management*, *126*, 694–705. https://doi.org/10.1016/j.wasman.2021.04.002

Arivazhagan, R., Geetha, P., & Ravilochanan, P. (2016). Assessment of wastages in fruit supply chain with respect to fruit processing units in Tamilnadu, India. *International Food Research Journal*, *23*(2), 723. https://search.proquest.com/docview/1779957607

Asadabadi, M. R., Chang, E., & Saberi, M. (2019). Are MCDM methods useful? A critical review of Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP). *Cogent Engineering*, *6*(1), 1623153. https://doi.org/10.1080/23311916.2019.1623153

Asensi, E., & Kaulins, R. (2019). *Motivations and Barriers of using emerging technology in eco-label certification for sustainability, from the certification companies' perspective*.

Asselin, A., Popp, J., Henderson, A., Heller, M., Thoma, G., & Jolliet, O. (2013). Dairy farm greenhouse gas impacts: A parsimonious model for a farmer's decision support tool. *International Dairy Journal*, *31, Supplement 1*, S65–S77. https://doi.org/10.1016/j.idairyj.2012.09.004

Aung, M. M., & Chang, Y. S. (2014). Traceability in a food supply chain: Safety and quality perspectives. *Food Control*, *39*, 172–184. https://doi.org/10.1016/j.foodcont.2013.11.007

Aziz, M. S., & El sherif, A. Y. (2016). Biomimicry as an approach for bio-inspired structure with the aid of computation. *Alexandria Engineering Journal*, *55*(1), 707–714. https://doi.org/10.1016/j.aej.2015.10.015

Bai, C., Dallasega, P., Orzes, G., & Sarkis, J. (2020). Industry 4.0 technologies assessment: A sustainability perspective. *International Journal of Production Economics, 229*, 107776. https://doi.org/10.1016/j.ijpe.2020.107776

Balaji, M., & Arshinder, K. (2016). Modeling the causes of food wastage in Indian perishable food supply chain. *Resources, Conservation and Recycling, 114,* 153–167. https://doi.org/10.1016/j.resconrec.2016.07.016

Barilla Center for Food and Nutrition. (2012). *Food Waste: causes, impacts and proposals*. https://issuu.com/horticulturaposcosecha/docs/food_waste_barilla_center

Bartie, N., Cobos-Becerra, L., Mathies, F., Dagar, J., Unger, E., Fröhling, M., Reuter, M. A., & Schlatmann, R. (2023). Cost versus environment? Combined life cycle, techno-economic, and circularity assessment of silicon- and perovskite-based photovoltaic systems. *Journal of Industrial Ecology*, *27*(3), 993–1007. https://doi.org/10.1111/jiec.13389

Bartzas, G., Zaharaki, D., & Komnitsas, K. (2015). Life cycle assessment of open field and greenhouse cultivation of lettuce and barley. *Information Processing in Agriculture*, *2*(3), 191–207. https://doi.org/10.1016/j.inpa.2015.10.001

Bastas, A., & Liyanage, K. (2018). Sustainable supply chain quality management: A systematic review. *Journal of Cleaner Production*, *181*, 726–744. https://doi.org/10.1016/j.jclepro.2018.01.110

Beaty, D. L., & Quirk, D. (2018). Fog computing. *ASHRAE Journal*, *60*(1), 68–74.

Beausang, C., Hall, C., & Toma, L. (2017). Food waste and losses in primary production: Qualitative insights from horticulture. *Resources, Conservation and Recycling*, *126*, 177–185. https://doi.org/10.1016/j.resconrec.2017.07.042

Bedoya-Perales, N. S., & Dal' Magro, G. P. (2021). Quantification of Food Losses and Waste in Peru: A Mass Flow Analysis along the Food Supply Chain. *Sustainability (Basel, Switzerland)*, *13*(5), 2807. https://doi.org/10.3390/su13052807

Bengoa, X., Dubois, C., & Humbert, S. (2018). *Product Environmental Footprint Category Rules for Dairy Products Version 1.0*. http://eda.euromilk.org/uploads/media/PEFCR-DairyProducts_2018-04-25_V1.pdf

Bengtsson, M., Alfredsson, E., Cohen, M., Lorek, S., & Schroeder, P. (2018). Transforming systems of consumption and production for achieving the sustainable development goals: moving beyond efficiency. *Sustainability Science*, *13*(6), 1533–1547. https://doi.org/10.1007/s11625-018-0582-1

Benyus, J. M. (1997). *Biomimicry : innovation inspired by nature*. Morrow. https://ebookcentral.proquest.com/lib/[SITE_ID]/detail.action?docID=6931460

Bizcocho, N., & Llatas, C. (2019). Inclusion of prevention scenarios in LCA of construction waste management. *The International Journal of Life Cycle Assessment*, *24*. https://doi.org/10.1007/s11367-018-1462-8

Blandford, D., & Hassapoyannes, K. (2018). The role of agriculture in global GHG mitigation. In *Policy File*. Organization for Economic Cooperation and Development. https://search.proquest.com/docview/2187017992

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, *33*(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Bouzembrak, Y., Klüche, M., Gavai, A., & Marvin, H. J. P. (2019). Internet of Things in food safety: Literature review and a bibliometric analysis. *Trends in Food Science & Technology*, *94*, 54–64. https://doi.org/10.1016/j.tifs.2019.11.002

Boyer, R. H. W., Hunka, A. D., Linder, M., Whalen, K. A., & Habibi, S. (2021). Product Labels for the Circular Economy: Are Customers Willing to Pay for Circular? *Sustainable Production and Consumption*, *27*, 61–71. https://doi.org/10.1016/j.spc.2020.10.010

Burke, T. (2019). *Blockchain in Food Traceability* (pp. 133–143). https://doi.org/10.1007/978-3-030-10902-8_10

Caldeira, C., De Laurentiis, V., Corrado, S., van Holsteijn, F., & Sala, S. (2019). Quantification of food waste per product group along the food supply chain in the European Union: a mass flow analysis. *Resources, Conservation and Recycling*, *149*, 479–488. https://doi.org/10.1016/j.resconrec.2019.06.011

Caldeira, C., De Laurentiis, V., & Sala, S. (2019). *Assessment of food waste prevention actions*. https://doi.org/https://doi.org/10.2760/9773

Cánovas Creus, A., Bernstad Saraiva, A., & Arruda, E. F. (2018). Structured evaluation of food loss and waste prevention and avoidable impacts: A simplified method. *Waste Manag Res*, *36*(8), 698–707. https://doi.org/10.1177/0734242X18778779

Carlucci, D. (2010). Evaluating and selecting key performance indicators: an ANP-based model. *Measuring Business Excellence*, *14*(2), 66–76. https://doi.org/10.1108/13683041011047876

Carter, M., & Grover, V. (2015). Me, my self, and I(T). *Management Information Systems*, *39*(4), 931–957. http://www.econis.eu/PPNSET?PPN=84353088X

Castellani, V., Fusi, A., & Sala, S. (2017a). Consumer Footprint. Basket of Products indicator on Food. In *JRC technical reports*. https://publications.jrc.ec.europa.eu/repository/handle/JRC107959

Castellani, V., Fusi, A., & Sala, S. (2017b). *Consumer Footprint Basket of Products indicator on Food*. https://doi.org/10.2760/555836

Chauhan, A., Debnath, R. M., & Singh, S. P. (2018). Modelling the drivers for sustainable agri-food waste management. *Benchmarking: An International Journal*, *25*(3), 981–993. https://doi.org/10.1108/BIJ-07-2017-0196

Chauhan, C., Dhir, A., Akram, M. U., & Salo, J. (2021). Food loss and waste in food supply chains. A systematic literature review and framework development approach. *Journal of Cleaner Production*, *295,* 126438. https://doi.org/10.1016/j.jclepro.2021.126438

Cheng, K., Yan, M., Nayak, D., Pan, G. X., Smith, P., Zheng, J. F., & Zheng, J. W. (2015). Carbon footprint of crop production in China: an analysis of National Statistics data. *The Journal of Agricultural Science*, *153*(3), 422–431. https://doi.org/10.1017/S0021859614000665

Circle Economy. (2023). *The Circularity Gap Report 2023*. https://www.circularity-gap.world/2023#download

Cleary, J. (2010). The incorporation of waste prevention activities into life cycle assessments of municipal solid waste management systems: methodological issues. *The International Journal of Life Cycle Assessment*, *15*(6), 579–589. https://doi.org/10.1007/s11367-010-0186-1

Cooper, T. (2010). *Longer Lasting Products*. Routledge. https://doi.org/10.4324/9781315592930

Corbett, C. J. (2018). How Sustainable Is Big Data? *Production and Operations Management, 27*(9), 1685–1695. https://doi.org/10.1111/poms.12837

Craft, W., Ding, L., Prasad, D., Partridge, L., & Else, D. (2017). Development of a Regenerative Design Model for Building Retrofits. *Procedia Engineering*, *180*, 658–668. https://doi.org/10.1016/j.proeng.2017.04.225

Cruz Introini, S., Boza, A., & Alemany Díaz, M. D. M. (2018). *Traceability in the Food Supply Chain: Review of the literature from a technological perspective*. http://hdl.handle.net/10251/121089

Curran, M. A. (2012). *Life Cycle Assessment Handbook: A Guide for Environmentally Sustainable Products*. https://doi.org/10.1002/9781118528372

Dantas, T. E. T., de-Souza, E. D., Destro, I. R., Hammes, G., Rodriguez, C. M. T., & Soares, S. R. (2021). How the combination of Circular Economy and Industry 4.0 can contribute towards achieving the Sustainable Development Goals. *Sustainable Production and Consumption*, *26*, 213–227. https://doi.org/10.1016/j.spc.2020.10.005

Degieter, M., Gellynck, X., Goyal, S., Ott, D., & De Steur, H. (2022). Life cycle cost analysis of agri-food products: A systematic review. *Science of The Total Environment*, *850*, 158012. https://doi.org/10.1016/j.scitotenv.2022.158012

de Hooge, I. E., van Dulm, E., & van Trijp, H. C. M. (2018). Cosmetic specifications in the food waste issue: Supply chain considerations and practices concerning suboptimal food products. *Journal of Cleaner Production*, *183*, 698–709. https://doi.org/10.1016/j.jclepro.2018.02.132

De Mauro, A., Greco, M., & Grimaldi, M. (2014). *What is Big Data? A Consensual Definition and a Review of Key Research Topics*. https://doi.org/10.13140/2.1.2341.5048

Devin, B., & Richards, C. (2018). Food Waste, Power, and Corporate Social Responsibility in the Australian Food Supply Chain. *Journal of Business Ethics*, *150*(1), 199–210. https://doi.org/10.1007/s10551-016-3181-z

Diaz-Ruiz, R., Costa-Font, M., López-i-Gelats, F., & Gil, J. (2018). A Sum of Incidentals or a Structural Problem? The True Nature of Food Waste in the Metropolitan Region of Barcelona. *Sustainability*, *10*(10), 3730. https://doi.org/10.3390/su10103730

Dillon, T., wu, C., & Chang, E. (2010). *Cloud Computing: Issues and Challenges*.

Djekic, I., Pojić, M., Tonda, A., Putnik, P., Bursać Kovačević, D., Režek-Jambrak, A., & Tomasevic, I. (2019). Scientific Challenges in Performing Life-Cycle Assessment in the Food Supply Chain. *Foods*, *8*(8), 301. https://doi.org/10.3390/foods8080301

Dong, J., Tang, Y., Nzihou, A., & Chi, Y. (2019). Key factors influencing the environmental performance of pyrolysis, gasification and incineration Waste-to-Energy technologies. *Energy Conversion and Management*, *196*, 497–512. https://doi.org/10.1016/j.enconman.2019.06.016

Ecoinvent. (2023a). *Ecoinvent database*. https://ecoinvent.org/the-ecoinvent-database/

Ecoinvent. (2023b). *System models - Ecoinvent*. https://ecoinvent.org/the-ecoinvent-database/system-models/

Ellen MacArthur Foundation. (2013). *Towards the circular economy - Economic and business rationale for an accelerated transition*. https://ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an

Ellen MacArthur Foundation. (2016). *Intelligent assets: Unlocking the circular economy potential*. https://ellenmacarthurfoundation.org/intelligent-assets-unlocking-the-circular-economy-potential

Ellen MacArthur Foundation. (2023a). *Circulytics Resources*. https://ellenmacarthurfoundation.org/resources/circulytics/resources

Ellen MacArthur Foundation. (2023b). *What is a circular economy?* https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview#principles

Environdec. (2019). *Product category rules (PCR). Prepared and preserved vegetable and fruit products, including juice. Product category classification: UN CPC 213, 214. Version 1.01*. https://www.environdec.com/product-category-rules-pcr/find-your-pcr

Eriksson, M., Ghosh, R., Mattsson, L., & Ismatov, A. (2017). Take-back agreements in the perspective of food waste generation at the supplier-retailer interface. *Resources, Conservation and Recycling*, *122*, 83–93. https://doi.org/10.1016/j.resconrec.2017.02.006

European Commission. (2002). *Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety*. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32002R0178

European Commission. (2007). *Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32007R0834

European Commission. (2008a). *Addressing the challenge of energy efficiency through Information and Communication Technologies*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2008%3A0241%3AFIN

European Commission. (2008b). *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0098

European Commission. (2018). *Product Environmental Footprint Category Rules Guidance - Version 6.3.* https://eplca.jrc.ec.europa.eu/permalink/PEFCR_guidance_v6.3-2.pdf

European Commission. (2019). *Commission Delegated Decision (EU) 2019/1597 of 3 May 2019 supplementing Directive 2008/98/EC of the European Parliament and of the Council as regards a common methodology and minimum quality requirements for the uniform measurement of levels of food waste.* https://eur-lex.europa.eu/eli/dec_del/2019/1597/oj

European Commission. (2020a). *Circular Economy Action Plan - For a cleaner and more competitive Europe.* https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

European Commission. (2020b). *Farm to fork strategy - For a fair, healthy and environmentally-friendly food system.* https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy_en

European Commission. (2021a). *Guidance on reporting of data on food waste and food waste prevention according to Commission Implementing Decision (EU) 2019/2000.* https://ec.europa.eu/eurostat/documents/342366/351811/Guidance+on+food+waste+reporting/5581b0a2-b09e-adc0-4e0a-b20062dfe564

European Commission. (2021b). *Spain presents the latest data on food waste in households and out-of-home consumption.* Https://Ec.Europa.Eu/Newsroom/Sante/Items/716383/En#:~:Text=The%20latest%20results%20indicate%20that,The%20household%20bin%20in%202020.

European Commission. (2022). *European H2020 Waste4Think Project: Moving towards Life Cycle Thinking by integrating Advanced Waste Management Systems.*

European Commission. (2023a). *A European Green Deal.* https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

European Commission. (2023b). *NACE Rev. 2.1 classification is now official - Products Eurostat News - Eurostat.* https://ec.europa.eu/eurostat/web/products-eurostat-news/w/wdn-20230210-1

European Commission. (2023c). *Waste statistics.* https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics#Total_waste_generation

European Environment Agency. (2017). *Is Europe's freshwater use sustainable? — European Environment Agency*. https://www.eea.europa.eu/highlights/world-water-day-is-europe

European Environment Agency. (2022). *Pollution - European Environment Agency*. https://www.eea.europa.eu/archived/archived-content-water-topic/wise-help-centre/glossary-definitions/pollution#:~:text=Pollution%20is%20the%20introduction%20of,legitimate%20uses%20of%20the%20environment.

Eurostat. (2013a). *Glossary:Incineration - Statistics explained*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Incineration

Eurostat. (2013b). *Glossary:Landfill - Statistics explained*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Landfill

Eurostat. (2015). *Glossary:Composting - Statistics explained*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Composting

Eurostat. (2023a). *Food waste and food waste prevention - estimates - Statistics Explained*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Food_waste_and_food_waste_prevention_-_estimates#Amounts_of_food_waste_at_EU_level

Eurostat. (2023b). *Glossary:Statistical classification of products by activity (CPA) - Statistics Explained*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Statistical_classification_of_products_by_activity_(CPA)#:~:text=The%20Statistical%20classification%20of%20products,products%20that%20have%20common%20characteristics.

FAO. (2011). *Global food losses and food waste – Extent, causes and prevention*. https://www.fao.org/3/i2697e/i2697e.pdf

FAO. (2012). Coping with water scarcity: an action framework for agriculture and food security. In *FAO Water Reports (FAO)* (Issue 38). FAO. https://agris.fao.org/agris-search/search.do?recordID=XF2013001434

FAO. (2014). *SAVE FOOD: Global Initiative on Food Loss and Waste Reduction Definitional framework of food loss*. https://www.ipcinfo.org/fileadmin/user_upload/save-food/PDF/FLW_Definition_and_Scope_2014.pdf

FAO. (2017). The future of food and agriculture – Trends and challenges. In *1*. https://ageconsearch.umn.edu/record/319843/

FAO. (2019). *The state of food and agriculture. Moving forward on food loss and waste reduction*. https://www.fao.org/3/ca6030en/ca6030en.pdf

FAO. (2023). *Technical Platform on the Measurement and Reduction of Food Loss and Waste*. https://www.fao.org/platform-food-loss-waste/background/en

FAO, IFAD, UNICEF, WFP, & WHO. (2020). *The State of Food Security and Nutrition in the World 2020 Transforming food systems for affordable healthy diets*.

FAO, IFAD, UNICEF, WFP, & WHO. (2021). In brief to the state of food security and nutrition in the world 2021. In *FAO*. FAO. https://doi.org/10.4060/cb5409en

FAO, IFAD, & WFP. (2013). The State of Food Insecurity in the World - The multiple dimensions of food security. In *FAO*. FAO. https://www.fao.org/3/i3434e/i3434e.pdf

Feedback. (2018). *The food waste scorecard - An assessment of supermarket action to address food waste*. https://feedbackglobal.org/wp-content/uploads/2018/06/Supermarket-scorecard_136_fv-1.pdf

Feng, H., Chen, J., Zhou, W., Rungsardthong, V., & Zhang, X. (2019). Modeling and evaluation on WSN-enabled and knowledge-based HACCP quality control for frozen shellfish cold chain. *Food Control*, *98*, 348–358. https://doi.org/10.1016/j.foodcont.2018.11.050

Feng, H., Wang, X., Duan, Y., Zhang, J., & Zhang, X. (2020). Applying blockchain technology to improve agri-food traceability: A review of development methods, benefits and challenges. *Journal of Cleaner Production*, *260*, 121031. https://doi.org/10.1016/j.jclepro.2020.121031

Fernandez-Zamudio, M.-A., Barco, H., & Schneider, F. (2020). Direct Measurement of Mass and Economic Harvest and Post-Harvest Losses in Spanish Persimmon Primary Production. *Agriculture (Basel)*, *10*(12), 581. https://doi.org/10.3390/agriculture10120581

Filimonau, V., & De Coteau, D. A. (2019). Food waste management in hospitality operations: A critical review. *Tourism Management*, *71*, 234–245. https://doi.org/10.1016/j.tourman.2018.10.009

Finkbeiner, M., Inaba, A., Tan, R., Christiansen, K., & Klüppel, H.-J. (2006). The New International Standards for Life Cycle Assessment: ISO 14040 and ISO 14044. *The International Journal of Life Cycle Assessment*, *11*, 80–85. https://doi.org/10.1065/lca2006.02.002

Forbes, H., Quested, T., & O'Connor, C. (2022). *UNEP Food Waste Index Report 2021* (Vol. 73, Issue 7). UNEP. https://www.unep.org/resources/report/unep-food-waste-index-report-2021

Fusi, A., Castellani, V., Bacenetti, J., Cocetta, G., Fiala, M., & Guidetti, R. (2016). The environmental impact of the production of fresh cut salad: a case study in Italy. *The International Journal of Life Cycle Assessment*, *21*(2), 162–175. https://doi.org/10.1007/s11367-015-1019-z

FUSIONS. (2016). *Food waste definition*. https://www.eu-fusions.org/index.php/about-food-waste/280-food-waste-definition

Gaetani, E., Aniello, L., Lombardi, F., Margheri, A., & Sassone, V. (2017). *Blockchain-based database to ensure data integrity in cloud computing environments*.

Galli, F., Cavicchi, A., & Brunori, G. (2019). Food waste reduction and food poverty alleviation: a system dynamics conceptual model. *Agriculture and Human Values*, *36*(2), 289–300. https://doi.org/10.1007/s10460-019-09919-0

Galvez, J. F., Mejuto, J. C., & Simal-Gandara, J. (2018). Future challenges on the use of blockchain for food traceability analysis. *TrAC Trends in Analytical Chemistry*, *107*, 222–232. https://doi.org/10.1016/j.trac.2018.08.011

Garcia-Garcia, G., Woolley, E., & Rahimifard, S. (2015). A Framework for a More Efficient Approach to Food Waste Management. *ETP International Journal of Food Engineering*. https://doi.org/10.18178/ijfe.1.1.65-72

Garcia-Garcia, G., Woolley, E., Rahimifard, S., Colwill, J., White, R., & Needham, L. (2017). A Methodology for Sustainable Management of Food Waste. *Waste and Biomass Valorization*, *8*(6), 2209–2227. https://doi.org/10.1007/s12649-016-9720-0

García-Herrero, L., Gibin, D., Damiani, M., Sanyé-Mengual, E., & Sala, S. (2023). What is the water footprint of EU food consumption? A comparison of water footprint assessment methods. *Journal of Cleaner Production*, *415*, 137807. https://doi.org/10.1016/j.jclepro.2023.137807

Garrone, P., Melacini, M., Perego, A., & Sert, S. (2016). Reducing food waste in food manufacturing companies. *Journal of Cleaner Production*, *137*, 1076–1085. https://doi.org/10.1016/j.jclepro.2016.07.145

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Geng, Y., & Doberstein, B. (2008). Developing the circular economy in China: Challenges and opportunities for achieving “leapfrog development.” *International Journal of Sustainable Development & World Ecology*, *15*(3), 231–239. https://doi.org/10.3843/SusDev.15.3:6

Ghosh, R., & Eriksson, M. (2018). Food waste due to retail power in supply chains: Evidence from Sweden. *Global Food Security*, *20*, 1–8. https://doi.org/10.1016/j.gfs.2018.10.002

Gill, K. S., & Omokanye, A. T. (2018). Potential of Spring Barley, Oat and Triticale Intercrops with Field Peas for Forage Production, Nutrition Quality and Beef Cattle Diet. *Journal of Agricultural Science (Toronto)*, *10*(4), 1. https://doi.org/10.5539/jas.v10n4p1

Gillman, A., Campbell, D., & Spang, E. (2019). Does on-farm food loss prevent waste? Insights from California produce growers. *Resources Conservation and Recycling*, *150*. https://doi.org/10.1016/j.resconrec.2019.104408

Girotto, F., & Piazza, L. (2022). Food waste bioconversion into new food: A mini-review on nutrients circularity in the production of mushrooms, microalgae and insects. *Waste Manag Res*, *40*(1), 47–53. https://doi.org/10.1177/0734242X211038189

Gligoric, N., Krco, S., Hakola, L., Vehmas, K., De, S., Moessner, K., Jansson, K., Polenz, I., & Van Kranenburg, R. (2019). SmartTags: IoT Product Passport for Circular Economy Based on Printed Sensors and Unique Item-Level Identifiers. *Sensors (Basel, Switzerland)*, *19*(3), 586. https://doi.org/10.3390/s19030586

Gobble, M. M. (2018). Digitalization, Digitization, and Innovation. *Research-Technology Management*, *61*(4), 56–59. https://doi.org/10.1080/08956308.2018.1471280

Goossens, Y., Berrens, P., Custers, K., Hemelryck, S., Kellens, K., & Geeraerd, A. (2019). How origin, packaging and seasonality determine the environmental impact of apples, magnified by food waste and losses. *The International Journal of Life Cycle Assessment*, *24*. https://doi.org/10.1007/s11367-018-1522-0

Gorsuch, R. L. (1983). *Factor Analysis*. Psychology Press. https://doi.org/10.4324/9780203781098

Grecuccio, J., Giusto, E., Fiori, F., & Rebaudengo, M. (2020). Combining Blockchain and IoT: Food-Chain Traceability and Beyond. *Energies (Basel)*, *13*(15), 3820. https://doi.org/10.3390/en13153820

Groß, D., Piezonka, H., Corradini, E., Schmölcke, U., Zanon, M., Dörfler, W., Dreibrodt, S., Feeser, I., Krüger, S., Lübke, H., Panning, D., & Wilken, D. (2019). Adaptations and transformations of hunter-gatherers in forest environments: New archaeological and anthropological insights. *The Holocene*, *29*(10), 1531–1544. https://doi.org/10.1177/0959683619857231

Grubert, E. (2018). Rigor in social life cycle assessment: improving the scientific grounding of SLCA. *The International Journal of Life Cycle Assessment*, *23*(3), 481–491. https://doi.org/10.1007/s11367-016-1117-6

GS1 US. (2023). *Frequently Asked Questions*. https://www.unspsc.org/faqs#UNSPSC

Gustavsson, J., Cederberg, C., & Sonesson, U. (2011). *Global Food Losses and Food Waste - Save Food Congress*. https://www.madr.ro/docs/ind-alimentara/risipa_alimentara/presentation_food_waste.pdf

Guzzo, D., Walrave, B., & Pigosso, D. C. A. (2023). Unveiling the dynamic complexity of rebound effects in sustainability transitions: Towards a system's perspective. *Journal of Cleaner Production*, *405*, 137003. https://doi.org/10.1016/j.jclepro.2023.137003

Haddach, A., Ammari, M., Allal, L. Ben, AZAAR, K., & Laglaoui, A. (2017). HOW TO MEASURE SUSTAINABILITY OF SUPPLY CHAIN. *International Journal of Advanced Research (Indore)*, *5*(5), 401–418. https://doi.org/10.21474/IJAR01/4125

Hameed, S., Xie, L., & Ying, Y. (2018). Conventional and emerging detection techniques for pathogenic bacteria in food science: A review. *Trends in Food Science & Technology*, *81*, 61–73. https://doi.org/10.1016/j.tifs.2018.05.020

Han, J., Heshmati, A., & Rashidghalam, M. (2020). Circular Economy Business Models with a Focus on Servitization. *Sustainability*, *12*(21). https://doi.org/10.3390/su12218799

Hanson, C., Lipinski, B., Robertson, K., Dias, D., Gavilan, I., Greverath, P., Ritter, S., Fonseca, J., Van Otterdijk, R., Timmermans, T., Lomax, J., O'connor, C., Dawe, A., Swannell, R., Berger, V., Reddy, M., Somogyi, D., Tran, B., Leach, B., & Quested, T. (2016). Food Loss and Waste Accounting and Reporting Standard. In *Policy File*. https://flwprotocol.org/wp-content/uploads/2017/05/FLW_Standard_final_2016.pdf

Hartz, T. K., Johnstone, P. R., Williams, E., & Smith, R. F. (2007). Establishing Lettuce Leaf Nutrient Optimum Ranges Through DRIS Analysis. *HortScience Horts*, *42*(1), 143–146. https://doi.org/10.21273/HORTSCI.42.1.143

Hatzivasilis, G., Christodoulakis, N., Tzagkarakis, C., Ioannidis, S., Demetriou, G., Fysarakis, K., & Panayiotou, M. (2019). *The CE-IoT Framework for Green ICT*

Organizations The interplay of CE-IoT as an enabler for green innovation and e-waste management in ICT. https://doi.org/10.1109/DCOSS.2019.00088

Hauschild, M. Z., & Huijbregts, M. A. J. (2015). Introducing Life Cycle Impact Assessment. In M. Z. Hauschild & M. A. J. Huijbregts (Eds.), *Life Cycle Impact Assessment* (pp. 1–16). Springer Netherlands. https://doi.org/10.1007/978-94-017-9744-3_1

Hegwood, M., Burgess, M. G., Costigliolo, E. M., Smith, P., Bajželj, B., Saunders, H., & Davis, S. J. (2023). Rebound effects could offset more than half of avoided food loss and waste. *Nature Food*, *4*(7), 585–595. https://doi.org/10.1038/s43016-023-00792-z

He, M., Bu, F., Delang, C. O., Xie, J., Ye, Q., Zhao, H., He, Q., & He, W. (2021). Historical environmental changes in the Poyang Lake basin (Yangtze River, China) and impacts on agricultural activities. *The Holocene, 32*(1–2), 17–28. https://doi.org/10.1177/09596836211047777

Herrera-Quinteros, G., & Jara-Rojas, R. (2023). Food losses perceived by family farms: Challenges and policy implications from a micro-approach quantification. *Frontiers in Sustainable Food Systems, 6*. https://doi.org/10.3389/fsufs.2022.961120

Hidalgo-Carvajal, D., De Stefano, M. C., & Fernández Aguirre, R. (2023). *Social Life Cycle Analysis: An Overview of the Literature to Compare and Complement Current Methodologies* (pp. 462–467). https://doi.org/10.1007/978-3-031-27915-7_81

High Level Panel of Experts on Food Security and Nutrition, Pinstrup-Andersen, P., Rahmanian, M., Allahoury, A., Hendriks, S., Hewitt, J., Guillou, M., Iwanaga, M., Kalafatic, C., Kliksberg, B., Maluf, R., Murphy, S., Oniang'o, R., Pimbert, M., Sepulveda, M., Tang, H., Prakash, V., Ambuko, J., Belik, W., & Gitz, V. (2014). *Food losses and waste in the context of sustainable food systems.*

Hilty, L., & Aebischer, B. (2015). *ICT for Sustainability: An Emerging Research Field* (Vol. 310, pp. 3–36). https://doi.org/10.1007/978-3-319-09228-7_1

Himanen, L., & Martikainen, J. (2019). *Measuring Sustainability in Supply Chain with Key Performance Indicators.*

Hoehn, D., Vázquez-Rowe, I., Kahhat, R., Margallo, M., Laso, J., Fernández-Ríos, A., Ruiz-Salmón, I., & Aldaco, R. (2023). A critical review on food loss and waste quantification approaches: Is there a need to develop alternatives beyond the currently widespread pathways? *Resources, Conservation and Recycling, 188*, 106671. https://doi.org/10.1016/j.resconrec.2022.106671

Hoekstra, A., & Chapagain, A. (2008). *Globalization of Water: Sharing the Planet's Freshwater Resources* (Vol. 15). https://doi.org/10.1002/9780470696224.ch2

Hofmann, E., & Rüsch, M. (2017). Industry 4.0 and the current status as well as future prospects on logistics. *Computers in Industry*, *89*, 23–34. https://doi.org/10.1016/j.compind.2017.04.002

Hogeboom, R. J. (2020). The Water Footprint Concept and Water's Grand Environmental Challenges. *One Earth*, *2*(3), 218–222. https://doi.org/https://doi.org/10.1016/j.oneear.2020.02.010

Hoque, M. M., Ajwa, H., Othman, M., Smith, R., & Cahn, M. (2010). Yield and Postharvest Quality of Lettuce in Response to Nitrogen, Phosphorus, and Potassium Fertilizers. *HortScience Horts*, *45*(10), 1539–1544. https://doi.org/10.21273/HORTSCI.45.10.1539

Houghton, J. (2004). *Global warming - The complete briefing* (3. ed.). Cambridge Univ. Press. http://bvbr.bib-bvb.de:8991/F?func=service&doc_library=BVB01&local_base=BVB01&doc_number=012802333&sequence=000002&line_number=0001&func_code=DB_RECORDS&service_type=MEDIA

Hristov, I., & Chirico, A. (2019). The Role of Sustainability Key Performance Indicators (KPIs) in Implementing Sustainable Strategies. *Sustainability*, *11*, 5742. https://doi.org/10.3390/su11205742

Ingemarsdotter, E. K. (2021). *Circular Strategies Enabled by the Internet of Things: Opportunities, Implementation Challenges, and Environmental Impact*. https://doi.org/https://doi.org/10.4233/uuid:9ac826a1-2203-4f23-b074-3d765abd73e3

Inoue, M., Yamada, S., Miyajima, S., Ishii, K., Hasebe, R., Aoyama, K., Yamada, T., & Bracke, S. (2020). A modular design strategy considering sustainability and supplier selection. *Journal of Advanced Mechanical Design, Systems, and Manufacturing*, *14*(2), JAMDSM0023. https://doi.org/10.1299/jamdsm.2020jamdsm0023

Institution of Mechanical Engineers. (2013). *Global Food: Waste Not, Want Not.* https://www.imeche.org/policy-and-press/reports/detail/global-food-waste-not-want-not

International Telecommunication Union, UNESCO, UNCTAD, UNDP, UNDESA, FAO, WHO, Union Postale Universelle, UNEP, International Trade Centre, Organization, I. L., & O, W. M. (2015). *WSIS -SDG Matrix Linking WSIS Action Lines with Sustainable Development Goals*. www.wsis.org/sdg

Ioannou, A., Georgali, P.-Z., & Fokaides, P. A. (2022). Quantification of food waste in an insular island state for all stages of the food supply chain. *Resources, Conservation and Recycling*, *185*, 106486. https://doi.org/10.1016/j.resconrec.2022.106486

ISO. (2002). *PD ISO/TR 14062:2002: Environmental management. Integrating environmental aspects into product design and development*. International Organization for Standardization. https://www.iso.org/standard/33020.html

ISO. (2006a). *ISO 14025:2006 Environmental labels and declarations — Type III environmental declarations — Principles and procedures*. https://www.iso.org/standard/38131.html

ISO. (2006b). *ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework*. https://www.iso.org/standard/37456.html

ISO. (2006c). *ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines*. https://www.iso.org/standard/38498.html

ISO. (2016). *ISO 14021:2016 Environmental labels and declarations — Self-declared environmental claims (Type II environmental labelling)*. https://www.iso.org/standard/66652.html

ISO. (2018). *ISO 14024:2018 Environmental labels and declarations — Type I environmental labelling — Principles and procedures*. https://www.iso.org/standard/72458.html

ISO. (2022). *ISO 14020:2022 Environmental statements and programmes for products — Principles and general requirements*. https://www.iso.org/standard/79479.html

ISO. (2023a). *ISO - Certification*. https://www.iso.org/certification.html

ISO. (2023b). *ISO/DIS 59004: Circular Economy – Terminology, Principles and Guidance for Implementation*. https://www.iso.org/obp/ui/en/#iso:std:iso:59004:dis:ed-1:v1:en

Jagatheesaperumal, S. K., Rahouti, M., Ahmad, K., Al-Fuqaha, A., & Guizani, M. (2022). The Duo of Artificial Intelligence and Big Data for Industry 4.0: Applications, Techniques, Challenges, and Future Research Directions. *IEEE Internet of Things Journal*, *9*(15), 12861–12885. https://doi.org/10.1109/JIOT.2021.3139827

Jayathilake, N., Aheeyar, M., & Drechsel, P. (2022). Food Waste to Livestock Feed: Prospects and Challenges for Swine Farming in Peri-urban Sri Lanka. *Circular Economy and Sustainability*, *2*(4), 1301–1315. https://doi.org/10.1007/s43615-022-00168-8

Jevons, W. S. (1866). The Coal Question: an Enquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal-mines. In *The Economics of Population*.

Joint Research Centre. (2010a). *ILCD Handbook: International Reference Life Cycle Data System. Framework and requirements for Life Cycle Impact Assessment models and indicators*. https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-General-guide-for-LCA-DETAILED-GUIDANCE-12March2010-ISBN-fin-v1.0-EN.pdf

Joint Research Centre. (2010b). *ILCD Handbook: International Reference Life Cycle Data System. General guide for Life Cycle Assessment - Detailed guidance*. https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-General-guide-for-LCA-DETAILED-GUIDANCE-12March2010-ISBN-fin-v1.0-EN.pdf

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kirchherr, J., Yang, N.-H. N., Schulze-Spüntrup, F., Heerink, M. J., & Hartley, K. (2023). Conceptualizing the Circular Economy (Revisited): An Analysis of 221 Definitions. *Resources, Conservation and Recycling*, *194*, 107001. https://doi.org/10.1016/j.resconrec.2023.107001

Kirova, M., Montanari, F., Ferreira, I., Pesce, M., Albuquerque, J. D., Montfort, C., Neirynck, R., & Moroni, J. (2019). *Megatrends in the agri-food sector: global overview and possible policy response from an EU perspective*. https://www.europarl.europa.eu/RegData/etudes/STUD/2019/629205/IPOL_STU(2019)629205_EN.pdf

Kishore Austeen, X., Harish Kumar, V., Venkatesan, S., & Raghul, R. M. (2019). Design and implementation of aquaculture monitoring and controlling system using IoT. *International Research Journal of Engineering and Technology*, *6*(3). https://www.irjet.net/archives/V6/i3/IRJET-V6I3899.pdf

Kok, M. G., Castelein, R. B., Broeze, J., & Snels, J. C. M. A. (2021). *The EFFICIENT protocol : A pragmatic and integrated methodology for food loss and waste quantification, analysis of causes and intervention design*. https://doi.org/10.18174/556214

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular Economy: The Concept and its Limitations. *Ecological Economics*, *143*, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Kshetri, N. (2018). 1 Blockchain’s roles in meeting key supply chain management objectives. *International Journal of Information Management*, *39*, 80–89. https://doi.org/10.1016/j.ijinfomgt.2017.12.005

Kumar, P., Ahmed, F., Singh, R. K., & Sinha, P. (2018). Determination of hierarchical relationships among sustainable development goals using interpretive structural modeling. *Environment, Development and Sustainability*, *20*(5), 2119–2137. https://doi.org/10.1007/s10668-017-9981-1

Leal Filho, W., Azeiteiro, U., Alves, F., Pace, P., Mifsud, M., Brandli, L., Caeiro, S. S., & Disterheft, A. (2018). Reinvigorating the sustainable development research agenda: the role of the sustainable development goals (SDG). *International Journal of Sustainable Development & World Ecology*, *25*(2), 131–142. https://doi.org/10.1080/13504509.2017.1342103

Lekve Bjelle, E., Steen-Olsen, K., & Wood, R. (2018). Climate change mitigation potential of Norwegian households and the rebound effect. *Journal of Cleaner Production*, *172*, 208–217. https://doi.org/https://doi.org/10.1016/j.jclepro.2017.10.089

Lévesque, J., Perreault, V., & Mikhaylin, S. (2023). Food waste environmental impact assessment as leverage to better guide restaurants toward improving their sustainability. *International Journal of Gastronomy and Food Science*, *33*, 100742. https://doi.org/10.1016/j.ijgfs.2023.100742

Li, G., Li, L., Choi, T., & Sethi, S. P. (2019). Green supply chain management in Chinese firms: Innovative measures and the moderating role of quick response technology. *Journal of Operations Management*, *66*(7–8), 958–988. https://doi.org/10.1002/joom.1061

Liu, X., Tang, O., & Huang, P. (2008). Dynamic pricing and ordering decision for the perishable food of the supermarket using RFID technology. *Asia Pacific Journal of Marketing and Logistics*, *20*, 7–22. https://doi.org/10.1108/13555850810844841

Lopez Barrera, E., & Hertel, T. (2021). Global food waste across the income spectrum: Implications for food prices, production and resource use. *Food Policy*, *98*, 101874. https://doi.org/10.1016/j.foodpol.2020.101874

López-Morales, J. A., Martínez, J. A., & Skarmeta, A. F. (2020). Digital Transformation of Agriculture through the Use of an Interoperable Platform. *Sensors*, *20*(4), 1153. https://doi.org/10.3390/s20041153

Lundie, S., & Peters, G. M. (2005). Life cycle assessment of food waste management options. *Journal of Cleaner Production*, *13*(3), 275–286. https://doi.org/10.1016/j.jclepro.2004.02.020

Ma, M., Shi, G., & Li, F. (2019). Privacy-Oriented Blockchain-Based Distributed Key Management Architecture for Hierarchical Access Control in the IoT Scenario. *IEEE Access*, *7*, 34045–34059. https://doi.org/10.1109/ACCESS.2019.2904042

Manavalan, E., & Jayakrishna, K. (2019). A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements. *Computers & Industrial Engineering*, *127*, 925–953. https://doi.org/10.1016/j.cie.2018.11.030

Mancini, L., Valente, A., Barbero Vignola, G., Sanyé Mengual, E., & Sala, S. (2023). Social footprint of European food production and consumption. *Sustainable Production and Consumption*, *35*, 287–299. https://doi.org/10.1016/j.spc.2022.11.005

Manfredi, M., & Vignali, G. (2014). Life cycle assessment of a packaged tomato puree: a comparison of environmental impacts produced by different life cycle phases. *Journal of Cleaner Production*, *73*, 275–284. https://doi.org/10.1016/j.jclepro.2013.10.010

Manyika, J., Chui, M., Bisson, P., Woetzel, J., Dobbs, R., Bughin, J., & Aharon, D. (2015). *The internet of things: mapping the value beyond the hype*. McKinsey Global Institute. https://www.mckinsey.com/~/media/mckinsey/industries/technology%20media%20and%20telecommunications/high%20tech/our%20insights/the%20internet%20of%20things%20the%20value%20of%20digitizing%20the%20physical%20world/unlocking_the_potential_of_the_internet_of_things_executive_summary.pdf

McAloone, T., & Pigosso, D. (2018). *Ecodesign Implementation and LCA* (pp. 545–576). https://doi.org/10.1007/978-3-319-56475-3_23

McAvoy, S., Grant, T., Smith, C., & Bontinck, P. (2021). Combining Life Cycle Assessment and System Dynamics to improve impact assessment: A systematic review. *Journal of Cleaner Production*, *315*, 128060. https://doi.org/10.1016/j.jclepro.2021.128060

Meisterling, K., Samaras, C., & Schweizer, V. (2009). Decisions to reduce greenhouse gases from agriculture and product transport: LCA case study of organic and conventional wheat. *Journal of Cleaner Production*, *17*(2), 222–230. https://doi.org/10.1016/j.jclepro.2008.04.009

Mell, P., & Grance, T. (2011). *The NIST Definition of Cloud Computing*. https://csrc.nist.gov/pubs/sp/800/145/final

Mena, C., Adenso-Diaz, B., & Yurt, O. (2011). The causes of food waste in the supplier–retailer interface: Evidences from the UK and Spain. *Resources, Conservation and Recycling*, *55*(6), 648–658. https://doi.org/10.1016/j.resconrec.2010.09.006

Miah, J. H., Griffiths, A., McNeill, R., Halvorson, S., Schenker, U., Espinoza-Orias, N., Morse, S., Yang, A., & Sadhukhan, J. (2018). A framework for increasing the availability of life cycle inventory data based on the role of multinational companies. *The International Journal of Life Cycle Assessment*, *23*(9), 1744–1760. https://doi.org/10.1007/s11367-017-1391-y

Mieras, E., Gaasbeek, A., & Kan, D. (2019). How to Seize the Opportunities of New Technologies in Life Cycle Analysis Data Collection: A Case Study of the Dutch Dairy Farming Sector. *Challenges*, *10*(1), 8. https://doi.org/10.3390/challe10010008

Miller, G. A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological Review*, *63*(2), 81–97. https://doi.org/10.1037/h0043158

Ministerio de Agricultura Pesca y Ganadería. (2023). *Sistema de Información Agroclimática para el Regadío*. https://servicio.mapa.gob.es/websiar/

Ministerio para la transición ecológica y el reto demográfico. (2023). *Datos abiertos - Agencia Estatal de Meteorología - AEMET. Gobierno de España*. https://www.aemet.es/es/datos_abiertos

Misra, N. N., Dixit, Y., Al-Mallahi, A., Bhullar, M. S., Upadhyay, R., & Martynenko, A. (2022). IoT, Big Data, and Artificial Intelligence in Agriculture and Food Industry. *IEEE Internet of Things Journal*, *9*(9), 6305–6324. https://doi.org/10.1109/JIOT.2020.2998584

Monier, V., Mudgal, S., Escalon, V., O'Connor, C., Gibon, T., Anderson, G., Montoux, H., Dolley, P., Ogilvie, S., & Morton, G. (2011). *Preparatory study on food waste across EU 27*. https://library.wur.nl/WebQuery/groenekennis/1982421

Morgan, J., Levin, K., Song, J., & Osorino, J. (2015). Driving Transformative Change: The Role of the Private Sector in Advancing Short-term and Long-term Signals in the Paris Climate Agreement. In *Policy File*. World Resources Institute. https://www.wri.org/research/driving-transformative-change-role-private-sector-advancing-short-term-and-long-term

Morseletto, P. (2020). Restorative and regenerative: exploring the concepts in the circular economy. *Journal of Industrial Ecology*, *24*(4), 763–773. https://doi.org/10.1111/jiec.12987

Mougayar, W., & Buterin, V. (2016). *The business blockchain: promise, practice, and application of the next Internet technology*. John Wiley & Sons. http://cds.cern.ch/record/2222158

Muller, C., Brandenburger, M., Cachin, C., Felber, P., Gottel, C., & Schiavoni, V. (2020). TZ4Fabric: Executing Smart Contracts with ARM TrustZone : (Practical Experience

Report). *2020 International Symposium on Reliable Distributed Systems (SRDS)*, 31–40. https://doi.org/10.1109/SRDS51746.2020.00011

Muriana, C. (2017). A focus on the state of the art of food waste/losses issue and suggestions for future researches. *Waste Management*, *68*, 557–570. https://doi.org/10.1016/j.wasman.2017.06.047

Nayeri, S., & Stothard, P. (2016). Tissues, Metabolic Pathways and Genes of Key Importance in Lactating Dairy Cattle. *Springer Science Reviews*, *4*(2), 49–77. https://doi.org/10.1007/s40362-016-0040-3

Neri, A., Cagno, E., Lepri, M., & Trianni, A. (2021). A triple bottom line balanced set of key performance indicators to measure the sustainability performance of industrial supply chains. *Sustainable Production and Consumption*, *26*, 648–691. https://doi.org/10.1016/j.spc.2020.12.018

Nessi, S., Rigamonti, L., & Grosso, M. (2013). Discussion on methods to include prevention activities in waste management LCA. *The International Journal of Life Cycle Assessment*, *18*. https://doi.org/10.1007/s11367-013-0570-8

Nikravech, M., Kwan, V., Dobernig, K., Angelika, W.-R., & Langen, N. (2020). Limiting food waste via grassroots initiatives as a potential for climate change mitigation: a systematic review. *Environmental Research Letters*, *15*. https://doi.org/10.1088/1748-9326/aba2fe

Notarnicola, B., Tassielli, G., Renzulli, P. A., Castellani, V., & Sala, S. (2017). Environmental impacts of food consumption in Europe. *Journal of Cleaner Production*, *140*, 753–765. https://doi.org/10.1016/j.jclepro.2016.06.080

Omolayo, Y., Feingold, B., Neff, R., & Romeiko, X. (2021). Life cycle assessment of food loss and waste in the food supply chain. *Resources, Conservation and Recycling*, *164*, 105119. https://doi.org/10.1016/j.resconrec.2020.105119

Östergren, K., Gustavsson, J., Bos-Brouwers, H., Timmermans, T., Hansen, O.-J., Møller, H., Anderson, G., O'Connor, C., Soethoudt, H., Netherlands, T., Quested, T., Easteal, S., Politano, A., Bellettato, C., Canali, M., Falasconi, L., Gaiani, S., Vittuari, M., Schneider, F., & Redlingshöfer, B. (2014). *FUSIONS definitional framework for food waste. Full report*.

Otles, S., Despoudi, S., Bucatariu, C., & Kartal, C. (2015). Chapter 1 - Food waste management, valorization, and sustainability in the food industry. In C. M. Galanakis (Ed.), *Food Waste Recovery* (pp. 3–23). Academic Press. https://doi.org/10.1016/B978-0-12-800351-0.00001-8

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., Church, J. A., Clarke, L., Dahe, Q., Dasgupta, P., Dubash, N. K., Edenhofer, O., Elgizouli, I., Field, C. B., Forster, P., Friedlingstein, P., Fuglestvedt, J., Gomez-Echeverri, L., Hallegatte, S., … van Ypserle, J.-P. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC. http://epic.awi.de/37530/

Pandey, D., & Agrawal, M. (2014). Carbon Footprint Estimation in the Agriculture Sector. In S. S. Muthu (Ed.), *Assessment of Carbon Footprint in Different Industrial Sectors, Volume 1* (pp. 25–47). Springer Singapore. https://doi.org/10.1007/978-981-4560-41-2_2

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1554), 3065–3081. https://doi.org/10.1098/rstb.2010.0126

Parviainen, P., Tihinen, M., Kääriäinen, J., & Teppola, S. (2017). Tackling the digitalization challenge: how to benefit from digitalization in practice. *International Journal of Information Systems and Project Management*, *5*(1), 63–77. https://doi.org/10.12821/ijispm050104

Patel, K., Patel, S., Scholar, P., & Salazar, C. (2016). *Internet of Things-IOT: Definition, Characteristics, Architecture, Enabling Technologies, Application & Future Challenges*.

Peira, G., Bollani, L., Giachino, C., & Bonadonna, A. (2018). The Management of Unsold Food in Outdoor Market Areas: Food Operators' Behaviour and Attitudes. *Sustainability*, *10*(4), 1180. https://doi.org/10.3390/su10041180

Peña, C., Civit, B., Gallego-Schmid, A., Druckman, A., Pires, A. C.-, Weidema, B., Mieras, E., Wang, F., Fava, J., Canals, L. M. i., Cordella, M., Arbuckle, P., Valdivia, S., Fallaha, S., & Motta, W. (2021). Using life cycle assessment to achieve a circular economy. *The International Journal of Life Cycle Assessment*, *26*(2), 215–220. https://doi.org/10.1007/s11367-020-01856-z

Peraković, D., Periša, M., & Zorić, P. (2020). Challenges and Issues of ICT in Industry 4.0. In V. Ivanov, J. Trojanowska, J. Machado, O. Liaposhchenko, J. Zajac, I. Pavlenko, M. Edl, & D. Perakovic (Eds.), *Advances in Design, Simulation and Manufacturing* (pp. 259–269). Springer International Publishing.

Perera, P. S. T., Perera, H. S. C., & Wijesinghe, T. M. (2013). Environmental Performance Evaluation in Supply Chain. *Vision*, *17*(1), 53–61. https://doi.org/10.1177/0972262912469566

Pincheira Caro, M. R., Ali, M. S., Vecchio, M., & Giaffreda, R. (2018). *Blockchain-based traceability in Agri-Food supply chain management: A practical implementation*. https://doi.org/10.1109/IOT-TUSCANY.2018.8373021

Pinto, J., Boavida-Dias, R., Matos, H. A., & Azevedo, J. (2022). Analysis of the Food Loss and Waste Valorisation of Animal By-Products from the Retail Sector. *Sustainability (Basel, Switzerland)*, *14*(5), 2830. https://doi.org/10.3390/su14052830

Pizzol, M., Laurent, A., Sala, S., Weidema, B., Verones, F., & Koffler, C. (2017). Normalisation and weighting in life cycle assessment: quo vadis? *The International Journal of Life Cycle Assessment*, *22*(6), 853–866. https://doi.org/10.1007/s11367-016-1199-1

Podgórski, D. (2015). Measuring operational performance of OSH management system – A demonstration of AHP-based selection of leading key performance indicators. *Safety Science*, *73*, 146–166. https://doi.org/10.1016/j.ssci.2014.11.018

Pritchard, B. (2012). Trading into hunger? Trading out of hunger? In *Food Systems Failure - The Global Food Crisis and the Future of Agriculture*. https://doi.org/https://doi.org/10.4324/9781849776820

Pullman, M., & Wikoff, R. (2017). Institutional sustainable purchasing priorities. *International Journal of Operations & Production Management*, *37*(2), 162–181. https://doi.org/10.1108/IJOPM-07-2014-0348

Purvis, B., Mao, Y., & Robinson, D. (2019). Three pillars of sustainability: in search of conceptual origins. *Sustainability Science*, *14*(3), 681–695. https://doi.org/10.1007/s11625-018-0627-5

Purwandoko, P. B., Seminar, K. B., Sutrisno, & Sugiyanta. (2018). Framework for Design of Traceability System on Organic Rice Certification. *IOP Conference Series. Earth and Environmental Science*, *147*(1), 12044. https://doi.org/10.1088/1755-1315/147/1/012044

Quested, T. E., Palmer, G., Moreno, L. C., McDermott, C., & Schumacher, K. (2020). Comparing diaries and waste compositional analysis for measuring food waste in the home. *Journal of Cleaner Production*, *262*, 121263. https://doi.org/10.1016/j.jclepro.2020.121263

Quicker, P., Consonni, S., & Grosso, M. (2020). The Zero Waste utopia and the role of waste-to-energy. *Waste Manag Res*, *38*(5), 481–484. https://doi.org/10.1177/0734242X20918453

Raihanian Mashhadi, A., & Behdad, S. (2017a). *Demystifying the Relationship Between Use-Phase Attributes and Energy Consumption: A Case Study of Personal Computers*. https://doi.org/10.1115/DETC2017-67825

Raihanian Mashhadi, A., & Behdad, S. (2017b). Environmental Impact Assessment of the Heterogeneity in Consumers' Usage Behavior: An Agent-Based Modeling Approach. *Journal of Industrial Ecology*, *22*(4), 706–719. https://doi.org/https://doi.org/10.1111/jiec.12622

Raihanian Mashhadi, A., & Behdad, S. (2018). Ubiquitous Life Cycle Assessment (U-LCA): A Proposed Concept for Environmental and Social Impact Assessment of Industry 4.0. *Manufacturing Letters*, *15*, 93–96. https://doi.org/10.1016/j.mfglet.2017.12.012

Ramakrishna, S., Ngowi, A., Jager, H. De, & Awuzie, B. O. (2020). Emerging Industrial Revolution: Symbiosis of Industry 4.0 and Circular Economy: The Role of Universities. *Science, Technology and Society*, *25*(3), 505–525. https://doi.org/10.1177/0971721820912918

Ramundo, L., Taisch, M., & Terzi, S. (2016). *State of the art of technology in the food sector value chain towards the IoT*. https://doi.org/10.1109/RTSI.2016.7740612

Reis, J., Amorim, M., Melao, N., Cohen, Y., & Rodrigues, M. (2020). *Digitalization: A Literature Review and Research Agenda* (pp. 443–456). https://doi.org/10.1007/978-3-030-43616-2_47

Rejeb, A., Keogh, J. G., & Treiblmaier, H. (2019). Leveraging the Internet of Things and Blockchain Technology in Supply Chain Management. *Future Internet*, *11*(7), 161. https://doi.org/10.3390/fi11070161

Rennings, K. (2000). Redefining innovation — eco-innovation research and the contribution from ecological economics. *Ecological Economics*, *32*(2), 319–332. https://doi.org/10.1016/S0921-8009(99)00112-3

Rijpkema, W. A., Rossi, R., & van der Vorst, J. G. A. J. (2014). Effective sourcing strategies for perishable product supply chains. *International Journal of Physical Distribution & Logistics Management*, *44*(6), 494–510. https://doi.org/10.1108/IJPDLM-01-2013-0013

Ruggerio, C. A. (2021). Sustainability and sustainable development: A review of principles and definitions. *Science of The Total Environment*, *786*, 147481. https://doi.org/10.1016/j.scitotenv.2021.147481

Russo, R. de F. S. M., & Camanho, R. (2015). Criteria in AHP: A Systematic Review of Literature. *Procedia Computer Science*, *55*, 1123–1132. https://doi.org/10.1016/j.procs.2015.07.081

Ryu, J.-H., Kim, K.-H., So, K.-H., Lee, G.-Z., Kim, G.-Y., & Lee, D.-B. (2011). LCA on Lettuce Cropping System by Top-down Method in Protected Cultivation. *Korean Journal of Soil Science and Fertilizer*, *44*. https://doi.org/10.7745/KJSSF.2011.44.6.1185

Saaty, T. L., & Ozdemir, M. S. (2003). Why the magic number seven plus or minus two. *Mathematical and Computer Modelling*, *38*(3), 233–244. https://doi.org/10.1016/S0895-7177(03)90083-5

Sachs, J. D., Lafortune, G., Fuller, G., & Drumm, E. (2023). *Sustainable development report 2023 - Implementing the SDG Stimulus*. https://www.sdgindex.org/reports/sustainable-development-report-2023/

Saeed, M. A., & Kersten, W. (2017). Supply chain sustainability performance indicators: A content analysis based on published standards and guidelines. *Logistics Research*, *10*(12), 1–19. https://www.econstor.eu/handle/10419/182057

Saez de Bikuña, K., Robertson, K., & WRAP. (2023). *Methodology for reducing food loss and waste*. Verra. https://verra.org/verra-releases-food-loss-and-waste-methodology/

Saha, J., Saha, A., Chatterjee, A., Agrawal, S., Saha, A., Kar, A., & Saha, H. (2018). *Advanced IOT based combined remote health monitoring, home automation and alarm system*. https://doi.org/10.1109/CCWC.2018.8301659

Salemdeeb, R., Font Vivanco, D., Al-Tabbaa, A., & zu Ermgassen, E. K. H. J. (2017). A holistic approach to the environmental evaluation of food waste prevention. *Waste Management*, *59*, 442–450. https://doi.org/10.1016/j.wasman.2016.09.042

Sánchez López, J., Patinha Caldeira, C., De Laurentiis, V., Sala, S., & Avraamides, M. (2020). Brief on Food Waste in the European Union. In *Joint Research Centre*.

Santillo, D. (2007). Reclaiming the Definition of Sustainability (7 pp). *Environmental Science and Pollution Research - International*, *14*(1), 60–66. https://doi.org/10.1065/espr2007.01.375

Sariatli, F. (2017). Linear Economy Versus Circular Economy: A Comparative and Analyzer Study for Optimization of Economy for Sustainability. *Visegrad Journal on Bioeconomy and Sustainable Development*, *6*(1), 31–34. https://doi.org/10.1515/vjbsd-2017-0005

Schaubroeck, T., Gibon, T., Igos, E., & Benetto, E. (2021). Sustainability assessment of circular economy over time: Modelling of finite and variable loops & impact distribution among related products. *Resources, Conservation and Recycling*, *168*, 105319. https://doi.org/10.1016/j.resconrec.2020.105319

Scherer, L., Behrens, P., de Koning, A., Heijungs, R., Sprecher, B., & Tukker, A. (2018). Trade-offs between social and environmental Sustainable Development Goals. *Environmental Science & Policy*, *90*, 65–72. https://doi.org/10.1016/j.envsci.2018.10.002

Scherhaufer, S., Moates, G., Hartikainen, H., Waldron, K., & Obersteiner, G. (2018). Environmental impacts of food waste in Europe. *Waste Management*, *77*. https://doi.org/10.1016/j.wasman.2018.04.038

Scholten, H., Verdouw, C. N., Beulens, A., & van der Vorst, J. G. A. J. (2016). 2 - Defining and Analyzing Traceability Systems in Food Supply Chains. In M. Espiñeira & F. J. Santaclara (Eds.), *Advances in Food Traceability Techniques and Technologies* (pp. 9–33). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-100310-7.00002-8

Schroeder, P., Anggraeni, K., & Weber, U. (2018). The Relevance of Circular Economy Practices to the Sustainable Development Goals. *Journal of Industrial Ecology*, *23*(1), 77–95. https://doi.org/10.1111/jiec.12732

Sezen, B., & Çankaya, S. (2019). Effects of green supply chain management practices on sustainability performance. *Journal of Manufacturing Technology Management*, *30*, 98–121. https://doi.org/10.1108/JMTM-03-2018-0099

Sniderman, B., Mahto, M., & Cotteleer, M. J. (2016). *Industry 4.0 and manufacturing ecosystems - Exploring the world of connected enterprises*. Deloitte. https://www2.deloitte.com/content/dam/Deloitte/de/Documents/consumer-industrial-products/Deloitte-Industry-4-0-and-manufacturing-ecosystems.pdf

Spanish government. (2022). *Proyecto de Ley de prevención de las pérdidas y el desperdicio alimentario*. https://www.mapa.gob.es/es/prensa/anteproyectoleydesperdicio_tcm30-620834.pdf

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

Stenmarck, Å., Jensen, C., Quested, T., & Moates, G. (2016). *Estimates of European food waste levels*. https://doi.org/10.13140/RG.2.1.4658.4721

Sundin, N., Persson Osowski, C., Strid, I., & Eriksson, M. (2022). Surplus food donation: Effectiveness, carbon footprint, and rebound effect. *Resources, Conservation and Recycling*, *181*, 106271. https://doi.org/10.1016/j.resconrec.2022.106271

Sun, S., Wang, Y., Wang, F., Liu, J., Luan, X., Li, X., Zhou, T., & Wu, P. (2015). Alleviating Pressure on Water Resources: A new approach could be attempted. *Scientific Reports*, *5*(1), 14006. https://doi.org/10.1038/srep14006

Teigiserova, D., Hamelin, L., & Thomsen, M. (2019). Towards transparent valorization of food surplus, waste and loss: Clarifying definitions, food waste hierarchy, and role in the circular economy. *Science of The Total Environment*, *706*, 136033. https://doi.org/10.1016/j.scitotenv.2019.136033

Teller, C., Holweg, C., Reiner, G., & Kotzab, H. (2018). Retail store operations and food waste. *Journal of Cleaner Production*, *185*, 981–997. https://doi.org/10.1016/j.jclepro.2018.02.280

Teuber, R., & Jensen, J. (2016). *Food losses and food waste: Extent, underlying drivers and impact assessment of prevention approaches*.

Thanomnim, B., Papong, S., & Onbhuddha, R. (2022). The Methodology to Evaluate Food Waste Generation with Existing Data in Thailand. *Thai Environmental Engineering Journal*, *36*(1), 1–9.

Tian, F. (2016). An agri-food supply chain traceability system for China based on RFID & blockchain technology. *2016 13th International Conference on Service Systems and Service Management (ICSSSM)*, 1–6. https://doi.org/10.1109/ICSSSM.2016.7538424

TNO: Innovation for life. (2023). *Phyllis2 - Database for the physico-chemical composition of (treated) lignocellulosic biomass, micro- and macroalgae, various feedstocks for biogas production and biochar* . https://phyllis.nl/

Tonini, D., Albizzati, P. F., & Astrup, T. F. (2018). Environmental impacts of food waste: Learnings and challenges from a case study on UK. *Waste Management*, *76*, 744–766. https://doi.org/10.1016/j.wasman.2018.03.032

Tóth, K., Borbély, C., Nagy, B., Szabó-Szentgróti, G., & Szabó-Szentgróti, E. (2021). Measurement of Food Losses in a Hungarian Dairy Processing Plant. *Foods*, *10*(2), 229. https://doi.org/10.3390/foods10020229

Treiblmaier, H. (2018). The impact of the blockchain on the supply chain: a theory-based research framework and a call for action. *Supply Chain Management*, *23*(6), 545–559. https://doi.org/10.1108/SCM-01-2018-0029

Tukker, A. (2015). Product services for a resource-efficient and circular economy – a review. *Journal of Cleaner Production*, *97*, 76–91. https://doi.org/10.1016/j.jclepro.2013.11.049

Tzanakakis, V. A., Paranychianakis, N. V, & Angelakis, A. N. (2020). Water Supply and Water Scarcity. *Water (Basel), 12*(9), 2347. https://doi.org/10.3390/w12092347

UNEP. (2011). *Towards a Life Cycle Sustainability Assessment - Making informed choices on products*. https://www.lifecycleinitiative.org/wp-content/uploads/2012/12/2011%20-%20Towards%20LCSA.pdf

United Nations. (2012). *United Nations Conference on Sustainable Development, Rio+20*. https://sustainabledevelopment.un.org/rio20

United Nations. (2023a). *SDG Indicators - Metadata repository*. https://unstats.un.org/sdgs/metadata/

United Nations. (2023b). *THE 17 GOALS | Sustainable Development*. https://sdgs.un.org/es/goals

United Nations. (2023c). *Understanding circularity*. https://buildingcircularity.org/

United States Environmental Protection Agency. (2023). *How Does Anaerobic Digestion Work? | US EPA*. https://www.epa.gov/agstar/how-does-anaerobic-digestion-work

USA Bureau of Educational and Cultural Affairs. (n.d.). *A good start with S.M.A.R.T. (indicators)*. https://eca.state.gov/files/bureau/a_good_start_with_smart.pdf

van Herpen, E., van der Lans, I. A., Holthuysen, N., Nijenhuis-de Vries, M., & Quested, T. E. (2019). Comparing wasted apples and oranges: An assessment of methods to measure household food waste. *Waste Management, 88,* 71–84. https://doi.org/10.1016/j.wasman.2019.03.013

Vermesan, O., & Friess, P. (2013). Internet of Things: Converging Technologies for Smart Environments and Integrated Ecosystems. In *River Publishers Series in Communications* (1st ed.). Routledge. https://doi.org/10.1201/9781003338659

Vermesan, O., & Friess, P. (2014). *Internet of Things - From Research and Innovation to Market Deployment* (1st ed.). Routledge. https://doi.org/10.1201/9781003338628

Verzijl, D., Rouwmaat, E., Dervojeda, K., Probst, L., & Frideres, L. (2015). Traceability across the Value Chain - Standards, processes and traceability. In *European Commission*. https://single-market-economy.ec.europa.eu/system/files/2017-07/42-tvc-standards-processes-and-traceability_en_0.pdf

Wang, H., Yang, Y., Zhang, X., & Tian, G. (2015). Carbon Footprint Analysis for Mechanization of Maize Production Based on Life Cycle Assessment: A Case Study in Jilin Province, China. *Sustainability*, *7*(11), 15772–15784. https://doi.org/10.3390/su71115772

Watkins, M. W. (2018). Exploratory Factor Analysis: A Guide to Best Practice. *Journal of Black Psychology*, *44*(3), 219–246. https://doi.org/10.1177/0095798418771807

WCED. (1987). *Report of the World Commission on Environment and Development: Our Common Future*. https://digitallibrary.un.org/record/139811

Webster, K. (2017). *The circular economy* (2nd edition). Ellen MacArthur Foundation Publishing. http://www.econis.eu/PPNSET?PPN=883199688

Weidema, B. P., Pizzol, M., Schmidt, J., & Thoma, G. (2018). Attributional or consequential Life Cycle Assessment: A matter of social responsibility. *Journal of Cleaner Production*, *174*, 305–314. https://doi.org/10.1016/j.jclepro.2017.10.340

Williams, P. M. (2001). Techniques for Root Cause Analysis. *Baylor University Medical Center Proceedings*, *14*(2), 154–157. https://doi.org/10.1080/08998280.2001.11927753

Wohner, B., Gabriel, V. H., Krenn, B., Krauter, V., & Tacker, M. (2020). Environmental and economic assessment of food-packaging systems with a focus on food waste. Case study on tomato ketchup. *Science of The Total Environment*, *738*, 139846. https://doi.org/10.1016/j.scitotenv.2020.139846

World Resources Institute. (2020). *Aqueduct Country Rankings*. https://www.wri.org/applications/aqueduct/country-rankings/

WRAP. (2015). *Strategies to achieve economic and environmental gains by reducing food waste*. https://wrap.org.uk/resources/report/strategies-achieve-economic-and-environmental-gains-reducing-food-waste

WRAP. (2018). *Food waste measurement principles and resources guide*. https://food.ec.europa.eu/system/files/2018-04/fw_lib_fwp-guide_food-waste-measurement_wrap-2018.pdf

WRAP. (2020). *Food surplus and waste measurement and reporting. UK Guidelines*. https://wrap.org.uk/resources/guide/uk-food-surplus-and-waste-measurement-and-reporting-guidelines

WRAP. (2021). *Food surplus and waste in the UK – key facts*. https://wrap.org.uk/resources/report/food-surplus-and-waste-uk-key-facts

Wu, M., Long, R., Chen, F., Chen, H., Bai, Y., Cheng, K., & Huang, H. (2023). Spatio-temporal difference analysis in climate change topics and sentiment orientation:

Based on LDA and BiLSTM model. *Resources, Conservation and Recycling*, *188*, 106697. https://doi.org/10.1016/j.resconrec.2022.106697

Wunderlich, S. M., & Feldman, C. H. (2024). Challenges in the quantification of household food waste: the need for consistent methodologies. *British Food Journal*, *126*(6), 2539–2547. https://doi.org/10.1108/BFJ-10-2023-0940

WWF. (2021). *Driven to waste: The global impact of food loss and waste on farms*. https://wwfint.awsassets.panda.org/downloads/technical_report___wwf_farm_stage_food_loss_and_waste.pdf

Xue, L., & Liu, G. (2019). 1 - Introduction to global food losses and food waste. In C. M. Galanakis (Ed.), *Saving Food* (pp. 1–31). Academic Press. https://doi.org/10.1016/B978-0-12-815357-4.00001-8

Xue, L., Liu, G., Parfitt, J., Liu, X., Van Herpen, E., Stenmarck, Å., O'Connor, C., Östergren, K., & Cheng, S. (2017). Missing Food, Missing Data? A Critical Review of Global Food Losses and Food Waste Data. *Environmental Science & Technology*, *51*(12), 6618–6633. https://doi.org/10.1021/acs.est.7b00401

Yontar, E., & Ersöz, S. (2020). Investigation of Food Supply Chain Sustainability Performance for Turkey's Food Sector. *Frontiers in Sustainable Food Systems*, *4*. https://doi.org/10.3389/fsufs.2020.00068

Yuan, Z., Bi, J., & Moriguichi, Y. (2008). The Circular Economy: A New Development Strategy in China. *Journal of Industrial Ecology*, *10*(1–2), 4–8. https://doi.org/https://doi.org/10.1162/108819806775545321

Yu, Z., Jung, D., Park, S., Hu, Y., Huang, K., Rasco, B. A., Wang, S., Ronholm, J., Lu, X., & Chen, J. (2020). Smart traceability for food safety. *Critical Reviews in Food Science and Nutrition*, *62*(4), 905–916. https://doi.org/10.1080/10408398.2020.1830262

Zamagni, A., Pesonen, H.-L., & Swarr, T. (2013). From LCA to Life Cycle Sustainability Assessment: concept, practice and future directions. *The International Journal of Life Cycle Assessment*, *18*(9), 1637–1641. https://doi.org/10.1007/s11367-013-0648-3

Zhang, A., Zhong, R. Y., Farooque, M., Kang, K., & Venkatesh, V. G. (2020). Blockchain-based life cycle assessment: An implementation framework and system architecture. *Resources, Conservation and Recycling*, *152*, 104512. https://doi.org/10.1016/j.resconrec.2019.104512

Zhang, H., & Matsuto, T. (2010). Mass and element balance in food waste composting facilities. *Waste Management*, *30*(8), 1477–1485. https://doi.org/10.1016/j.wasman.2010.02.029

Zhu, L. (2017). Economic Analysis of a Traceability System for a Two-Level Perishable Food Supply Chain. *Sustainability*, *9*, 682. https://doi.org/10.3390/su9050682