energies

Review

Evaluating Environmental and Energy Performance Indicators of Food Systems, within Circular Economy and "Farm to Fork" Frameworks

Patrizia Ghisellini [1,*], Amos Ncube [2], Gloria Rotolo [3], Chiara Vassillo [1], Serena Kaiser [2], Renato Passaro [1] and Sergio Ulgiati [4,5]

1 Department of Engineering, University of Naples "Parthenope", 80143 Naples, Italy
2 International PhD Programme/UNESCO Chair "Environment, Resources and Sustainable Development" Department of Science and Technology, University of Naples "Parthenope", 80143 Naples, Italy
3 Oliveros Agricultural Experimental Station (EEA Oliveros), National Institute of Agricultural Technology (INTA), Oliveros 2206, Argentina
4 Department of Science and Technology, University of Naples "Parthenope", 80143 Naples, Italy
5 State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing 100875, China
* Correspondence: patrizia.ghisellini@uniparthenope.it

Abstract: This study proposes a framework of environmental and energy performance indicators identified and critically evaluated within the scientific literature and the Agricultural European Database for the monitoring and evaluation of the Common Agricultural Policy of the European Union. The identified set of performance indicators encompasses the whole life cycle of agri-food systems from primary production stage until end-of-life stage in agreement with the circular economy and EU "farm to fork strategy" frameworks. In particular, the practices/goals/targets suggested in the latter (e.g., organic farming goals, more relevance assigned to plant-based diets, support for the creation of short supply chains, and reduction in food losses and waste) have guided the search for the main topics of interest in our analysis and the associated environmental and energy indicators. The results of this study evidence a proposed set of performance indicators selected from the literature among LCA and non-LCA indicators (midpoint LCA impacts, cumulative energy use, emergy accounting, and material flow accounting, among others) that could be helpful in integrating the EU CAP indicators for monitoring and evaluating efforts and achieved results toward implementing and controlling the effectiveness of the adopted "farm to fork" policy and related legislative measures, as well as the application of the circular economy model.

Keywords: environmental indicators; energy indicators; circular economy; farm to fork strategy; common agricultural policy; food supply chain; Mediterranean diet; food waste valorisation

check for updates

Citation: Ghisellini, P.; Ncube, A.; Rotolo, G.; Vassillo, C.; Kaiser, S.; Passaro, R.; Ulgiati, S. Evaluating Environmental and Energy Performance Indicators of Food Systems, within Circular Economy and "Farm to Fork" Frameworks. *Energies* **2023**, *16*, 1671. https://doi.org/10.3390/en16041671

Academic Editor: Mark Laser

Received: 2 December 2022
Revised: 26 January 2023
Accepted: 29 January 2023
Published: 7 February 2023

1. Introduction

Climate change is currently one of the major challenges to global food production and security [1], negatively affecting the agricultural production in different ways [2,3]. The reported current negative effects on global food production are the reduced crop yields, reduced nutritional quality of most important cereals, and lower livestock productivity [3]. In this context, some European Union countries are presently experiencing the most severe drought of the last 500 years, due to the lack of rainfall and frequent heatwaves (recently monitored in May, June, and July).

Italy has been one of the most affected countries concerning this combined phenomenon, which caused a reduction by 10% in the summer agricultural production [4]. It is worth mentioning that the drought has had consequences not only in decreased food production but also in reduced hydro-electricity generation, e.g., in Italy and Norway, the latter relying on about 90% of its electricity from this source; the drought also caused problems for the cooling of nuclear reactors in France and for the coal transport in Germany, where coal was used to replace natural gas shortages due to lower imports from Russia [5].

Food production and manufacturing systems are deeply linked with the environmental crisis and worsening of climate change, as they significantly contribute to greenhouse gas emissions (GHGs) [6] and freshwater use [7,8]. It is then imperative to facilitate the shift toward a more environmentally sustainable food system [9–13] and to restore a better balance between human activities and the natural environment, in order to further prevent the worsening of climate change and the environmental degradation of the other environmental matrices such as soil and water. The role of natural environment is crucial for the existence of individuals [14].

The implementation of more sustainable agri-food systems based on a "circular economy" and the "food to fork strategy" (hereinafter, FF strategy) is considered by the EU a possible way to reconcile the society's needs for enough quality food while preventing the destruction of the natural capital [15,16]. These two approaches complement each other in such a challenge. The "FF strategy" is aimed toward fair, healthy and environmentally sustainable food systems with lower environmental impacts in the whole life cycle of food [17]. In that way, the FF strategy could potentially contribute to mitigate climate change, as well as to adapt to its environmental and economic contingences, thus tackling the increasing biodiversity loss [15].

Furthermore, the concept of circular economy (CE) draws attention to the strategies aimed at reducing and prolonging the use of natural resources (particularly finite resources), promoting their diversification with renewable ones, as well as the adoption of closed loops involving the valorization of waste [18], use of local resources, and the preservation of biodiversity [19]. Moreover, the CE involves socioeconomic innovation and the involvement and responsibility of all the actors to help them realize better living in the society [15,18]. Assessing the environmental and energy performances toward the desired goals of a more sustainable agri-food system and increasing their transparency are crucial.

In this paper, the goal is to provide a framework of environmental and energy indicators that could be helpful for decision makers in evaluating and monitoring the environmental and energy performances of agri-food systems throughout the life cycle of food. We identify and evaluate these indicators, taking into account the conceptual frameworks of a "circular economy" and the "FF strategy" of the European Union. The proposed framework includes environmental and energy indicators collected from the existing scientific literature as well as adopted by the European Union within the Common Agricultural Policy (CAP) monitoring framework [20].

The present study is organized as follows: Section 2 provides an overview of the concepts of the circular economy and "FF strategy" of the European Union, while Section 3 deals with the method adopted for the selection of the indicators (i.e., indicators and methods applied to CE and farm to fork strategy, as well as their comprehensiveness) for the purpose of this study. Section 4 presents the results in terms of the proposed framework of indicators, while Section 5 applies the latter to a case study of Italy considering the national and product scales. Section 6 summarizes the main results, the value added, and implications for both research and policy.

2. Background on the Circular Economy and Farm to Fork Strategy

This section focuses on the concept of CE and its application in the agri-food life cycle. The main aspects of the EU "FF strategy" are also summarized. This information provides an essential knowledge base for understanding the later sections, developed according to these two main conceptual frameworks.

2.1. The Circular Economy Framework in Agri-Food Life Cycle

The emerging concept of CE seeks to promote a more sustainable way of production, consumption, and living by using natural resources more efficiently, as well as maintaining their value in products, materials, and components as long as possible [21]. By means of appropriate use, reuse, and exchange of resources and "doing more with less" [22], the CE model aims to redesign the socioeconomic patterns of the current economies in agreement with the ecological limits of the planet. The circular economy is also receiving increased attention in the agri-food sector for its role in contributing to the bio-economy transition [18] and consequent reduction in fossil fuel dependence [23,24]. As evidenced by the Ellen MacArthur Foundation [25], the CE model aims to realize the energy transition to renewable energies as a way of reducing fossil fuel dependence and tackling climate change.

In the past years, the agricultural sector was based on a partially unaware circular model, where production and consumption were integrated with natural cycles. The byproducts originated in the production process of crops, vegetables, milk, or forestry were all reused again in further agricultural cycles [26]. With the development of industrial agriculture, the sector shifted toward a more linear model of production and consumption, separated from the natural cycles, relying on the increased use of raw materials (e.g., fertilizers and agrochemicals) produced outside of the agricultural system [27]. This also caused the production of vast amounts of residues not to be recycled within the system and disposed of outside the agricultural system itself [28]. Therefore, the current transition to the CE entails combined organizational and technological innovations for designing out waste and pollution, as well as achieving the most efficient use of agricultural waste and byproducts by means of their reuse/recycling into agricultural processes based on closed loops [18].

Circular models in agri-business involve the recovery of animal/vegetal coproducts and byproducts within the farm or among other farms or agricultural enterprises (e.g., for cycling into the soil and/or for the production of energy from biogas), as well as in companies operating in other sectors for the production of new materials and goods characterized by high value added (e.g., cosmetics, fabrics, and construction materials) [29]. Certified circular business models in the agri-food sector are also emerging within the adoption of the schemes BS 8001 guidelines and the XP X30-901 standard, as well as within the new ISO standard for circular economy (ISO/WD 59004) [29]. These latter authors investigated the bio-district concept by means of an Italian case study to understand the potential contribution of such a model to the implementation of the circular economy approach. The bio-district model, focusing on the whole chain of value, suggests that the application of CE to agricultural production should focus well beyond the currently adopted framework of efficient waste management, to embrace the different pillars of sustainability based on systems approach thinking and a more regenerative model, when especially referring to primary production. The recognition of these principles as key factors is central for circular coupling of agri-food systems and nature, as well as for facing the environmental and energy challenges ahead. Human and nature interact within agricultural systems [30] by cycling matter, energy, and information. Circular agriculture, or closed-loop agriculture, means farming with nature rather than against it [31]. Circular agriculture is mainly focused on restoring soil health, increasing biodiversity, and minimizing the use of inputs and wastes by mimicking nature, where nothing is wasted but everything becomes a resource for another step or process [32]. Technological, organizational, and social innovation are key factors for transitioning to a CE in agriculture. Political support for innovation in agri-food through different types of interventions (e.g., support to the use of new technologies and provision of incentives for their adoption) is one of the most relevant drivers for the take-up of CE in the agricultural sector and the creation of a favorable context to reduce the uncertainties embedded in innovations and the risks faced by the economic actors [33].

2.2. The EU "Farm to Fork Strategy": Main Goals/Areas of Intervention

The rationale underlying the adoption of the FF strategy is the need for supporting a radical innovation in the EU agri-food systems [15]. In order to accomplish to this purpose, the EU aims to put, at the basis of the strategy and food sustainability goals, the relationship with the health of people, health of societies, and health of the environment.

Obviously, the FF strategy should contribute to the achievement of the UN sustainable development goals that are also central goals in the current EU Commission agenda [15]. The goals and areas of intervention in the EU "FF strategy" are the following:

1. Ensuring sustainable food production;
2. Ensuring food security;
3. Stimulating sustainable food processing, wholesale, retail, hospitality, and food services practices;
4. Promoting sustainable food consumption and facilitating the shift to healthy, sustainable diets;
5. Reducing food losses and waste;
6. Fighting food fraud along the whole food supply chain.

These points are also depicted in Figure 1, following the conventional framework of a life cycle of a product; therefore, goals 2 and 6 of the FF strategy are not shown.

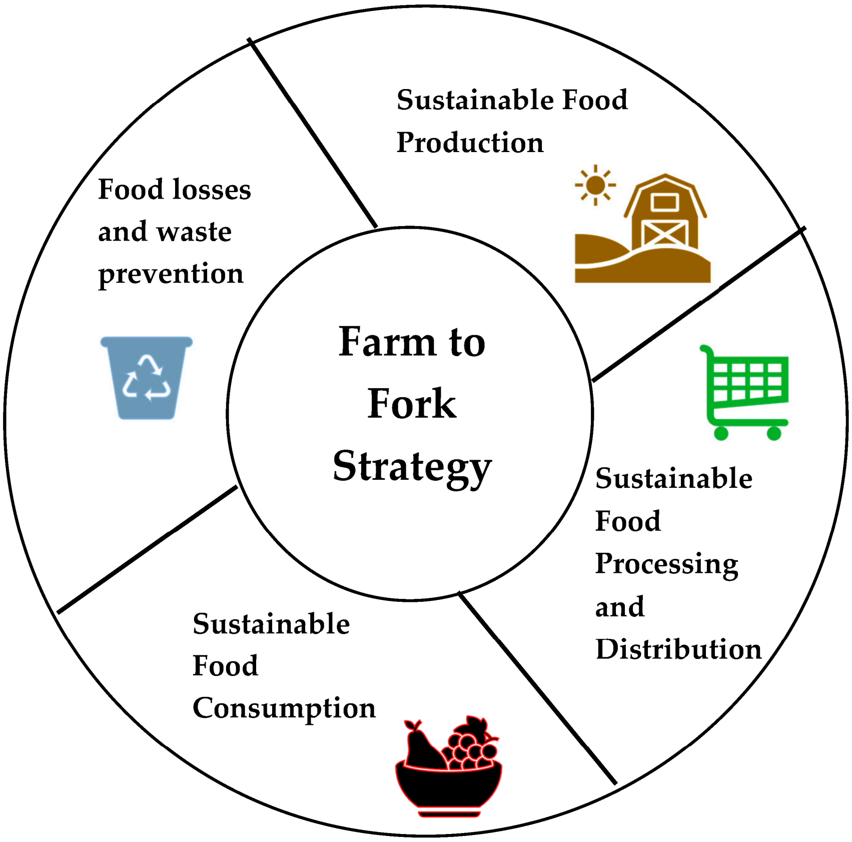

Figure 1. Farm to fork strategy (main goals/areas of intervention). Own elaboration from: "Farm to fork strategy" of the European Union [15].

Area 1 "ensuring sustainable food production" receives the highest attention in the FF strategy, developing over many subsectors of intervention (summarized in Appendix A), including (i) carbon sequestration activities performed by farmers and foresters, (ii) the development of circular biobased economy with the production of bioproducts and renewable energies (anaerobic digestion for biogas and solar panels), (iii) monitoring of the risks due to pesticide use, (iv) reduction in nutrient losses and the use of fertilizers, (v) support for the use of new feed additives to reduce the dependency on critical feed materials (e.g., soya grown on deforested land), (vi) reduction in the overall EU sales of antimicrobials for farmed animals and aquaculture by 50%, and (vii) development of organic agriculture and new eco-schemes to favor the adoption of more sustainable practices such as precision agriculture, agroecology (including organic farming), carbon farming, and agroforestry.

Each one of the above areas contains goals and proposals for action from the European Commission, by means of different available tools, both legislative and non-legislative. Economic instruments such as new eco-schemes are proposed to boost sustainable agricultural practices, along which tax incentives to support the shift toward sustainable and healthy diets by the consumers and, in turn, more sustainable agricultural practices with lower environmental externalities. With regard to legislation, the European Commission evidences, e.g., in area 3 (stimulating sustainable food processing, wholesale, retail, hospitality, and food services practices), plans to revise the food contact materials, legislation to ensure food safety and public health or to set legally binding targets to avoid food loss prevention, or the definition of minimum mandatory criteria for sustainable food procurement to support the provision of sustainable food for schools, hospitals, and public institutions.

The "FF strategy" suggests the transformation of current production methods in such a way that the agricultural stage could contribute to create a more environmentally sustainable food system [34,35]. Farmers should use the current available solutions (nature-based, technological, digital, and space-based) in order to reduce the contribution to climate change and other impact categories, as well as optimize the use of critical inputs such as pesticides and fertilizers. The "FF strategy" proposes both the adoption of more sustainable production methods, such as precision agriculture, agroecology (including organic farming), carbon farming, and agroforestry, and the reduction in the use of pesticides and fertilizers. In this vision, the role of organic farming in the EU should increase its share of total utilized agricultural area to at least 25% by 2030. With regard to livestock production, the areas addressed by the FF strategy regard the "circular biobased economy", "nutrient loss reduction and nutrient pollution management", and "better animal welfare".

An Important aspect is related to the aim of reducing the dependence on critical feed materials (e.g., soya grown on deforested land) by fostering EU-grown plant proteins, as well as alternative feed materials such as insects, marine feed stocks (e.g., algae), and byproducts from the bioeconomy (e.g., fish waste). Coupled to other measures, this should contribute to reduce the dependence of the EU and avoid or minimize the number of products in the EU market responsible of deforestation or forest degradation.

Several authors have analyzed the framework proposed by the "FF strategy", pointing out the importance of increasing the political efforts and addressing further aspects for supporting the transition toward more sustainable food systems. Mantanarella and Panagos [36] underlined the key role of soils, being the major carbon sink, in mitigating greenhouse gas emissions and then global warming, as well as the need for properly taking the soil into more account in the New Climate Law and the "FF strategy". Schebesta and Candel [35] stressed the importance of considering alternatives for those actors which could lose from the transition toward more sustainable food systems as proposed in the FF strategy. They also proposed the adoption of a more participative approach favoring the involvement of relevant actors such as food producers, processors, retailers, and consumers, while recognizing the goodness of some tools such as food policy councils or citizen summits. These proposals may help "making choices when values and interests come into conflict and when the consequences of decisions are uncertain". Such aspects were also shared in [34], emphasizing that the transformations required by the FF strategy, including the transition to a higher role of organic farming, require the responsibility of private and public actors in the value chain and a change in the attitudes of the society to support the required changes. These authors also suggested moving beyond the CAP perspective and adopting a comprehensive food policy to better address the goals advanced by the "FF strategy". Lastly, the authors of [37] evidenced the importance of combining the increased share of land devoted to organic agriculture with the use of modern biotechnologies and breeding techniques, in order to strengthen the capacities of both measures in contributing to the achievement of sustainable development goals.

3. Material and Methods

This section describes the types of data used in this study and the methods for their collection from the different sources, including the most common international bibliographic database for retrieving the scientific literature and the European Union database of performance indicators, adopted for the monitoring and evaluation the Common Agricultural Policy (CAP) [20].

3.1. Data Quality and Categories

Secondary data from the literature and databases have been mainly used in this study. Their identification, collection, and selection are driven by the main topics underlying this study, such as the EU "FF strategy" [15], the whole life cycle of the agri-food sector [17], the associated environmental and energy impacts and indicators, and the CE model and its relationship with the agri-food sector. In detail, we relied on the following types of secondary documents and sources:

1. Policy documents and other materials available from the websites of the European Union, including the data about performance indicators comprised in the monitoring and evaluation framework of the CAP [20];
2. Scientific literature available in the international database (such as Web of Science, Scopus, and Google Scholar), covering the topics investigated in this study.

3.2. Methods for Data Collection

Four sequential steps were followed for the selection of the international literature and the collection of the useful data:

(1) Identification of the keywords for searching the articles;
(2) Searching and retrieval of the articles;
(3) Verification of the relevance of the articles compared to the investigated topics mentioned above;
(4) Critical review of articles and synthesis of their results.

According to [38], the strength of literature analysis is largely related to the comprehensiveness of the underlying database. Clarivate's Web of Science®, Google Scholar, and Scopus were selected as appropriate databases. Boolean search techniques were used to retrieve the relevant literature, and a coding framework was adopted using the keywords summarized in Table 1.

Table 1. Keywords used for searching the literature (investigated time period: 1 January 2019–1 July 2022).

Keywords
• Organic agriculture AND environmental indicators AND European Union • Organic farming AND energy indicators AND European Union • Life cycle assessment of biogas AND manure AND European Union • Life cycle assessment of biogas AND rice husk
• Food supply chain AND environmental indicators • Food supply chain AND environmental indicators AND European Union
• Mediterranean diet AND environmental indicators AND European Union • Mediterranean diet AND energy indicators AND European Union
• Food waste prevention AND environmental indicators • Food waste prevention AND environmental indicators AND European Union • Food waste valorization AND environmental indicators • Food waste valorization AND environmental Indicators AND European Union • Food waste prevention AND energy indicators • Food waste prevention AND energy indicators AND European Union • Food waste valorization AND energy indicators • Food waste valorization AND energy indicators AND European Union

The identified literature was subjected to a critical review aiming to identify the main environmental and energy indicators available. The review considered articles published between 2019 and 2022 (1 July) as they are expected to provide the most current findings which align to the period in which major CE policies relating to the transition to a circular economy, including food waste prevention and valorization, were launched and started to be implemented (European Commission, 2020b; 2015). In the same period, the FF strategy was adopted along with the European Green Deal (European Commission, 2019). Therefore, to extract relevant information, published scholarly writings (research articles, literature reviews, and technical reports of the EU) in English were scrutinized. In order to prevent bias due to the selected time period, this study also included some articles (published before 2019) from the selected literature, which were considered relevant for the analysis [13,39–48].

3.3. Short Overview of the Accounting Methods Referred to in This Study

1. **Life cycle assessment (LCA)** is an internationally standardized methodology (ISO 14040/2006/Amd 1:2020) [49] that quantifies the environmental impacts associated with the life cycle of products, processes, or activities and the opportunities for the improvement of such impacts [50]. LCA midpoint indicators are summarized in Table 2.

Table 2. LCA midpoint indicators and related acronyms.

Impact Category	Unit	Abbreviation
Climate change potential	kg CO_2 eq	CCP
Stratospheric ozone depletion potential	kg CFC11 eq	SODP
Ionizing radiation potential	kBq Co-60 eq	IRP
Ozone formation, human health potential	kg NO_x eq	OFHP
Fine particulate matter formation potential	kg PM2.5 eq	PMFP
Ozone formation, terrestrial ecosystems potential	kg NO_x eq	OFEP
Terrestrial acidification potential	kg SO_2 eq	TAP
Freshwater eutrophication potential	kg P eq	FEP
Marine eutrophication potential	kg N eq	MEP
Terrestrial ecotoxicity potential	kg 1,4-DCB	TETP
Freshwater ecotoxicity potential	kg 1,4-DCB	FETP
Marine ecotoxicity potential	kg 1,4-DCB	METP
Human carcinogenic toxicity potential	kg 1,4-DCB	HCTP
Human noncarcinogenic toxicity potential	kg 1,4-DCB	HNCTP
Land use potential	m^2a crop eq	LUP
Mineral resource scarcity potential	kg Cu eq	MRSP
Fossil resource scarcity potential	kg oil eq	FRSP
Water consumption potential	m^3	WCP

2. **Material flow accounting (MFA)** assesses the flows of materials entering in a system (e.g., industrial) and the patterns in which such flows are used, reused, and lost in the form of waste in a given time [51]. The MFA takes into account physical and socioeconomic flows of an investigated system and the biotic or renewable resources, abiotic or nonrenewable raw materials, water, air, earth consumption, solid waste, emissions, and stocks [52].
3. **Emergy accounting (EA)** is a methodology that uses the thermodynamic basis of all forms of energy, materials and human services and converts them into equivalents of one form of available energy (exergy). Emergy is, by definition, the amount of available energy of one form (usually solar) needed to provide a given flow or storage of energy or matter [53]. Several performance indicators are calculated by means of the EA [54]:
   - Total emergy used in a process;
   - Emergy yield ratio (EYR), i.e., the emergy used per unit of emergy invested;

- Environmental loading ratio (ELR), i.e., the total nonrenewable and imported emergy released per unit of local renewable resources;
- Emergy sustainable index (ESI), i.e., the emergy yield per unit of environmental loading,
- Renewability (%REN), i.e., the percentage of renewable emergy used compared to the total emergy.

4. **Crop accounting method (CAM)** is a tool very suitable for agricultural enterprises that takes into account all the revenues and costs of growing crops until the time they are harvested. The nature of the costs considered by this method depend on the farming practice and varies e.g., from conventional to organic farming. In addition to the revenues and costs, the method calculates the gross income indicator as the difference between the revenues and costs [55].

4. Environmental and Energy Indicators in the Life Cycle of Food Systems: A Critical Description of Achieved Results

This section deals with the results of the analysis of environmental and energy indicators identified from the main sources, as described in Section 3: EU policy documents, CAP database [20], and the selected literature. The results are presented in four subsections following the framework of "FF strategy" of the EU (Section 2.2) and the four stages of the life cycle of a product (Figure 2). Each subsection briefly introduces the analyzed stage of the life cycle, before deepening the environmental and energy indicators and related topics.

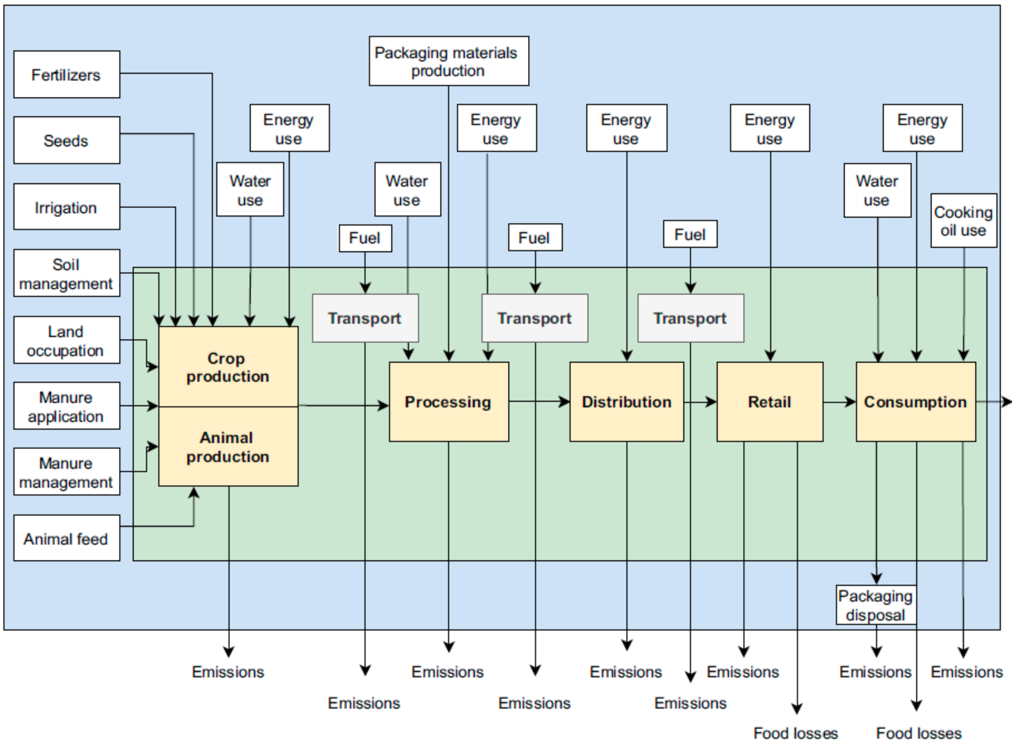

Figure 2. Stages of the life cycle of a product from FF and related sources of environmental and energy impacts. Source: [56]. Reprinted/adapted with permission from [56]. © 2021 The Authors [56].

4.1. *Ensuring Sustainable Food Production: Environmental and Energy Indicators at Production Stage*

4.1.1. Indicators of the Common Agricultural Policy

It is more than two decades since the Common Agricultural Policy (CAP) started to support the pursual of environmental sustainability in farming activities, in agreement with the goal of sustainable development declared in the Rio Earth Summit on 1992. Over time, the environmental goals have been further strengthened in the CAP until now when the adopted and reformed CAP for the period 2023–2027 also aligns with the "European Green Deal" and "FF strategy" by considering as key goals the tackling climate change, protecting natural resources, and enhancing biodiversity.

The Common Monitoring and Evaluation Framework (CMEF) for CAP was established within the CAP 2014–2020 frame and includes a set of performance indicators classified into four categories: context, output, result, and impact [20]. With regard in particular to the context indicators (whose information is particularly relevant for policy), they are further classified into socioeconomic indicators, sectoral indicators, and environmental indicators. Socioeconomic indicators allow the evaluation of the socioeconomic performances of the agricultural sector as a whole and include indicators about population, age structure, and employment and unemployment rate, whereas the sectorial indicators are more specific to each sector. Some of these sectorial indicators are, e.g., agricultural area under organic farming or labor productivity in agriculture, in forestry, and in the food industry. We focus on environmental indicators in great detail, given the goal of the present study.

Table 3 lists all the environmental indicators contained in the EU CAP database, adding a description of the information delivered by each indicator and the unit of measure [20]. The list provides indicators for monitoring environmental airborne, waterborne, and soil impacts. Moreover, the list also contains indicators of land use and others informing about the areas under Natura 2000, areas facing natural and other specific constraints, and the share of forest and other wooded land (FOWL) protected to conserve biodiversity, landscapes, and specific natural elements. Two energy indicators are considered: the production of renewable energy from agriculture and forestry residues and the energy use in agriculture, forestry, and the food industry.

Table 3. Environmental performance indicators of European Union Common Agricultural Policy (CAP). Source of the data: EU CAP indicators database [20].

Indicators	Description	Unit
Land cover	Distribution of land devoted to forests, water, desert, grassland, and other physical features of the land, including land created by human activities. The source of the data for the EU is Corinne land cover.	% of total area
Areas facing natural and other specific constraints	Measure of the share of agricultural area in different categories of areas facing natural or other specific constraints (ANCs) (ex-LFAs as they were defined in the period 2007–2013).	% of utilized agricultural area
Farming intensity	Defined as the level of inputs used by the farm per unit of production factor (in general land). Intensification is the increase in farm intensity, while extensification is the opposite, evidencing a reduction in farm intensity	ha and % of total utilized agricultural area
Natura 2000 areas	Information on the areas protected under Natura 2000 used for agriculture and/or forestry. Natura 2000 is a network of areas conserving natural habitats and species of wildlife which are rare, endangered, or vulnerable in the European Union. This indicator includes three sub-indicators: share of territory under Natura 2000 by categories; share of UAA (**utilized agricultural area** is the total area including arable land, permanent grassland, permanent crops, and kitchen gardens) under Natura 2000; share of forest area under Natura 2000.	% of area under Natura 2000
Farmland birds index	Composite index measuring the rate of change in the relative abundance of common bird species at selected sites. Birds are considered indicators in the evaluation of the state of biodiversity of European agricultural landscape.	Index (base year 2000 = 100)

Table 3. *Cont.*

Indicators	Description	Unit
Conservation status of agricultural habitats (grassland)	Conservation status of agricultural habitats (grassland)	% of total assessments of grassland (favorable, unfavorable/inadequate and unfavorable/bad conservation status)
High-nature-value farming	High-nature-value farmland areas are considered valuable assets of European agricultural landscapes, providing highly varied living conditions for a wide range of species contributing to biodiversity preservation.	
Protected Forests	Percentage of forests and other wooded land (FOWL) protected to conserve biodiversity, landscapes, and specific natural elements. This indicator has four sub-indicators based on different classes (1.1, 1.2, 1.3, and 2) of intervention and management.	% of FOWL area protected under each classes: 1.1, 1.2, 1.3, 2.
Water withdrawal in agriculture	Volume of water used for soils irrigation purposes. Data refer to water withdrawn from total surface and ground water.	m^3
Irrigated land	The indicator consists of two sub-indicators: (1) total irrigated area, i.e., the area which has actually been irrigated at least once during the 12 months prior to the reference day of the survey; (2) share of irrigated area in total UAA.	(ha) (%)
Water quality	Potential impact of agriculture activities on water quality due to pollution by nitrates and phosphates.	(Nitrates): kg N/ha/year (Phosphates): kg P/ha/year
Soil organic matter in arable land	Estimation of the content of soil organic matter in arable lands. The indicator contains two sub-indicators: (1) total estimate of organic carbon content in arable soils; (2) the mean organic carbon content.	(1) megaton (Mt) (2) g/kg
Soil erosion by water	Assessment of the soil loss due to water erosion including information of the areas affected by a certain rate of soil erosion (moderate to severe, i.e., >11 t/ha/year in the OECD definition). The indicator has two sub-indicators: (1) estimated rate of soil loss by water erosion; (2) estimated agricultural area affected by a certain rate of soil erosion by water (expressed as share of the total agricultural area).	(1) t/ha/year (2) ha and % of total agricultural area
Production of renewable energy from agriculture and forestry	Provides two sub-indicators: production of renewable energy from agriculture (biodiesel from biomass, ethanol from starch/sugar crops, energy from biogas with energy crops, and manure as the main feedstocks) and from forestry.	kt
Energy use in agriculture, forestry and food industry	Provides three sub-indicators measuring the direct energy use in the three sectors: (1) direct use of energy in agriculture and forestry; (2) direct use of energy in agriculture and forestry; (3) direct use of energy in food processing.	(1) total in kt (1000 t), ktoe (2) kg of oil equivalent, UAA + forest area in ha (3) total in kt (1000 t), ktoe
Emissions from agriculture (GHG per LSU and GHG per ha)	The indicator contains different sub-indicators of the greenhouse gas emissions and ammonia emissions released from agriculture.	(1) GHG emissions from agriculture: • Absolute net GHG emissions (t CO_2 equivalent) • Relative net emissions (percentage of the net emissions in the reference year 2005). (2) Ammonia emissions from agriculture (kt of NH_3)

Table 3. *Cont.*

Indicators	Description	Unit
Sales use of antimicrobials in food producing animals	Information on the actions aimed to improve the response of EU agriculture to the problems of antimicrobial resistance (AMR) and the need for promoting safe, nutritious and sustainable food, and a better animal welfare.	Sales of antimicrobial substances, (product package level), corrected by a population correction unit (PCU)
Sustainable and reduced use of pesticides: risk, use, and impact of pesticides	The indicator contains three specific sub-indicators: (1) sales of pesticides (sales as a proxy of the use of pesticides in agriculture); (2) the harmonized risk indicator 1 (related to risk of pesticides); (3) sales of the most hazardous pesticides (so-called "candidates for substitution" referring to active substances defined in Regulation (EC) No 1107/2009).	(1) kg (2) Index based on annual volumes of active substances placed on the market multiplied by the relevant weights (3) kg
Share of a member state organic farming area compared to total UAA	Area under organic farming compared to the total UAA excludes kitchen gardens and refers to organic crop area by agricultural production methods and crops.	(% of total UAA)
Organic area and organic producers	Indicators refer to the organically cropped area and the number of farmers involved.	ha Total amount
Share of organic area receiving CAP support	This indicator refers to the share in total organic area.	(%)

4.1.2. Environmental Indicators Evaluating the Effects of the EU Food System Outside the EU Area

The EU monitoring and evaluation framework of the CAP measures the environmental performances in the EU area and does not include, at the moment, indicators assessing the environmental and energy effects of the EU food system outside the EU area. The "FF strategy" underlines the willingness of the EU to contribute to the implementation of more sustainable agri-food systems at the global level. This goal will be pursued by means of both internal and external policies including, in this latter case, those related to international cooperation and trade. In particular, future trade policy aims to improve the cooperation with the third parties' countries in key areas such as animal welfare, the use of pesticides, and the fight against antimicrobial resistance. The international cooperation of the EU will aim to strengthen the food research and innovation in the area of climate change mitigation and adaptation, as well as in the following areas: "*agroecology; sustainable landscape management and land governance; conservation and sustainable use of biodiversity; inclusive and fair value chains; nutrition and healthy diets; prevention of and response to food crises, particularly in fragile contexts; resilience and risk preparedness; integrated pest management; plant and animal health and welfare; food safety standards; antimicrobial resistance; sustainability of its coordinated humanitarian and development interventions*".

Moreover, further actions are evidenced in the direction of reducing the EU's contribution to global deforestation and forest degradation. In that, future legislative proposals of the European Commission should aim to avoid or minimize the inclusion of products associated with deforestation or forest degradation within the EU market.

A previous report [57] evidenced other policies that could have an effect on the deforestation of third parties' countries, such climate and renewable energy policy, common agricultural policy, forestry strategy, biodiversity strategy, sustainable production and consumption policy, investment policy, development cooperation policy, and research and innovation policy. This report, even if not so recent, also identified the main drivers of deforestation such as agricultural expansion, logging (prior to agricultural expansion), urban areas expansion, and natural hazards (especially wildfire), and it adopted the concept of "embodied deforestation" to relate deforestation to food traded, produced, or consumed. In that, the deforestation embodied is the external cost associated with the trade, production, and consumption of a good, commodity, or a service. In all these cases, the deforestation embodied is measured in terms of land area. For example, millions of hectares of deforestation are embodied in crop and livestock products.

It has been calculated that, in the period 2005–2017, the EU imports caused the deforestation of 3–5 million of hectares and the release of 1.87 million tons of CO_2 emissions [58]. Other studies, in addition to the indicator of embodied deforestation, adopted an indicator of deforestation risk [59] and estimated that, in the period 2015–2017, the EU imports of commodities at forest risk were associated with an annual deforestation risk area of 190,000 ha. The imported products to the EU (in the period 2015–2017) characterized by the higher deforestation risk were palm oil (from Indonesia), soybeans (from Brazil and Paraguay), forest products such as wood pulp (from Brazil and Chile), cocoa (from Côte d'Ivoire, Liberia, and other countries), coffee (from Honduras and other countries), and beef (from Brazil and other countries) [59].

4.1.3. Brief Overview of Organic Farming

The "FF strategy" aims to promote a wider adoption of organic farming and achieve the target of having 25% of EU's agricultural land under organic conditions by the year 2030. Therefore, this subsection, after a brief presentation of the rationale for more sustainable models of agriculture and their features, focuses on the description of the key aspects of organic farming and its performances by means of the analysis of environmental and energy indicators collected from the literature related to such models.

The need for developing more sustainable models of agriculture has led to the proposal of different philosophical approaches to agricultural management and new agronomic techniques over time [13,60] such as agroecology [11,60]. circular agriculture [32], organic agriculture [61], regenerative agriculture [62], and biodynamic agriculture [63], as well as agricultural practices such as low-input agriculture [64] or sustainable intensification of agriculture [65]. Even though they have particularities, all of them share some practices and criteria such as product diversity, crop–animal rotation, the importance of having a healthy soil (since it is considered as a living organism), and biodiversity management according to the ecosystem involved. Moreover, a blend of organic and other farming alternatives used for getting close to sustainable agroecosystems, such as those mentioned above and other innovative ones able to appear in the near future, will be needed for a future global food and ecosystem security [11]. Therefore, carefully looking at one of those approaches such as organic agriculture or organic farming, we can also cover some common criteria of the others.

Karem et al. [61] defined organic farming as an agricultural system based on the use of green manure, biofertilizers, plant growth-promoting bacteria, integrated pest management, integrated nutrient management, zero or minimum tillage, mulching, and crop rotation. Moreover, as a practice, organic farming relies on routine plant cultivation and animal rearing [66]. For operation, organic fertilizers (such as manure and compost) are used along with biopesticides, while conventional inputs (e.g., synthetic chemicals) are avoided to maintain land biodiversity and ecosystem equilibrium and reduce the release of emissions and waste production [66,67]. Lastly, organic farming does not produce and use genetically modified organisms [61].

Environmental and Energy Indicators of Organic Farming

From the literature, a unique consensus does not emerge about the performances of organic farming, since some authors considered it as an inefficient method of food production [68], while other authors showed that some farming practices, such as the cultivation of old varieties and landraces in organic and low-input systems are not always fully organic [69]. Gomiero et al. [13] instead pointed out that organic farming has a higher energy efficiency (input/output) even if accompanied by lower yields and then reduced productivity than conventional agriculture [70]. However, organic farming is also claimed to be more profitable and environmentally friendly [68].

Several authors evaluated organic farming by comparing it with other systems and focusing on specific environmental and energy indicators. In this study, as an example of a set of indicators, olive production was selected, due to its health and economy importance for some EU countries such as Spain, Italy and Portugal which are world leading olive producing countries [71]. Programs have been raised (Life-EU, 2010), and authors have been making efforts in order to investigate the sustainable improvement of olive production by assessing environmental and biophysical indicators of different schemes of olive systems production (Table 4).

Table 4. Environmental and biophysical indicators of different schemes of olive systems production investigated by different authors.

Authors	Olives Production Systems	Environmental–Ecological Dimensions—Indicators		
		Environmental Impacts and Support	Soil	Biological
Lehmann et al. [72]	**Olives in Italy cultivated under:** a. Silvopastoral agroforestry b. Organic agroforestry c. Traditional agroforestry d. Conventional	* GWP * TAP * Eutrophication		
Guarino et al. [12]	**Olives in Italy cultivated under:** a. Conventional agriculture in plain areas b. Conventional agriculture on hill areas c. Organic agriculture in plain areas d. Organic agriculture on hill areas	CCP, SODP, IRP, OFHP, PMFP, TAP, FEP, TETP, FETP, METP, HCTP, HNCTP, LUP, MRSP, FRSP, WCP, primary energy		
Durán Zuazo et al. [73]	**Rainfed olives in Spain cultivated under:** a. Organic agricultural production b. Conservative agricultural production c. Integrated agricultural production d. Conventional agricultural production		**Soil physio-chemical parameters:** • Soil organic carbon • Total N • Extractable P (Olsen) • Available K • Cation exchange capacity (CEC) • pH • Soil matric potential (pF)	**Microbial activities:** • Microbial biomass—carbon • Microbial biomass—nitrogen) **Enzymatic activities:** • β-Glucosidase • Protease • Dehydrogenase • Phosphatase
Solomou and Sfougaris [74]	**Olives in Greece cultivated under:** a. Organic agriculture production b. Conventional agriculture production		Organic matter • Organic, potassium-rich fertilizer • Manure • Field size • Inorganic, nitrogen-rich fertilizer	• Earthworm density • Shannon plant diversity index

Indicators for Organic Olive Production

Lehmann et al. [72] investigated the airborne emissions of the olive grove cultivated under agroforestry with different management schemes (Table 4). Organic management involved sheep raising, natural grass pasture, and biological copper. The GWP of this system accounted for 0.266 kg CO_2 eq.$\cdot$kg$^{-1}\cdot$year^{-1}. This value is higher than olive trees cultivated under silvopastoral agroforestry and lower than those raised under traditional agroforestry. Acidifications and eutrophication accounted for 0.018 kgSO_2 eq.$\cdot$kg$^{-1}\cdot$year^{-1} and 0.005 kgPO_4 eq.$\cdot$kg$^{-1}\cdot$year^{-1} higher than traditional and conventional systems, respectively, but acidification was lower than silvopastoral ones. The values calculated for the environmental impact categories analyzed in the organic system were due mainly to the machinery use and the application of organic fertilizer from the animals (manure). Guarino et al. [12] assessed the life cycle of a glass bottle of 0.75 L of extra virgin olive oil from "cradle to gate". They considered four scenarios for the production of olives (two under conventional farming and two under organic farming). Their results showed that the agricultural stage has a relevant impact on the life cycle of olive oil. Scenarios under organic farming performed better than those under conventional farming with relevant differences in CC, PMFP, TAP, FEP, and FRSP.

Durán Zuazo et al. [73] and Solomou and Sfougaris [74] focused their analysis on biophysical parameters. The first team focused on the microbiochemical soil parameters, showing the potential environmental benefits of the organic system in controlling soil erosion and runoff and improving soil health restoration compared with a conventional system. They also found out that the integration of management practices between organic and conventional systems for preserving or enhancing soil health indices, while conserving yields, is a better approach than only limiting to organic practices. The second team focused on macrobio-physicochemical parameters, and one of their findings was that the use of manure and the increase in earthworm density increase the yields, being useful indicators for farmers, agronomists, land managers, and researchers to monitor the changes, hopefully toward an improved system, making it more resilient and sustainable.

In general, the improvement of soil structure and health, as well as the increase in biodiversity, helps slow down external inputs by changing the management practices and/or the design, thereby reducing emissions. In order to find evidence of the need for these changes, both biophysical and environmental evaluations need to be carried out as complementary studies. This reasoning is valid also in finding critical component/inputs of the agricultural system that cause high environmental emissions, whereby their decrease can promote changes in system management and potentially increase soil health and biodiversity. Farming systems have many edges to be integrally and interrelatedly addressed due to their multifunctional (producing commodities, while preserving health of ecosystems, consumers, and rural communities) and multiscale nature (complex networks of relations among ecosystems and socioeconomic systems) [11,29,60,68]. Therefore, the transition toward an environmentally sustainable agriculture by including organic practices principles, requires indicators that evaluate not only the system/processes emissions and environmental support, but also the physical and biological parameters as complementary indicators for studying, improving, and monitoring the system [68,69].

Indicators of Organic Durum Wheat Production

Studies analyzed the impacts of other relevant Mediterranean products such as durum wheat. Bux et al. [67] compared the environmental and economic performances of conventional and organic durum wheat production in the Apulia Region that accounts for 24% of total Italian production and 13% of EU production. The methods used for evaluation by the authors were material flow analysis and the crop accounting method. Organic durum wheat production resulted in lower environmental impacts compared to conventional production due to the reduction in the use of synthetic chemicals and phytosanitary products by up to 100%. Moreover, it reduced by 15% the fossil fuel use and related CO_2 emissions. Further environmental benefits provided by organic durum wheat production are the improvement of water retention due to the presence of roots and soil microfauna, but increases in exposure to fungal diseases, soil erosion, and production costs.

A further study by Iacola et al. [75] developed a sustainability assessment method named the Biodurum MCA tool to evaluate its effectiveness in addressing both the complexity and the need for a multidimensionality evaluation of sustainability performance related to the organic durum wheat production system in Italy, along with the reliability of the results in both ex ante and ex post stages. The tool was composed of 44% environmental indicators, 36% economic indicators, and 20% social indicators, and it was tested on field in organic farms in three Italian regions: Basilicata, Puglia, and Sicily. Their results highlighted that a very diverse cereal cropping system with agroecological service crops contributed most to enhance biodiversity, improve soil nitrogen fertility and better manage weed and disease. Canali [76] defined agroecological service crops as those "*sown in cropping systems to provide or promote agroecosystem services, independent of their position in the crop rotation and the method used to terminate them. This term includes catch crops, cover crops, and complementary crops. In vegetable systems, ASCs are usually grown during the cold rainy season. However, some authors have also highlighted the potential applicability of summer ASCs in southern Mediterranean regions of Europe, although their implementation is still limited*". Diversified systems are also able to ensure satisfactory and stable crop productivity that, coupled with processed products sold by means of short supply chains, achieve economic viability and an overall sustainability of the farm. Zingale et al. [69], reviewing the literature of LCA in the durum wheat sector, pointed out that durum wheat cultivation under organic farming seems achieving lower yields, as well as higher energy consumption and land use, but organic practices are recommended as they have mitigation potential in reducing TEP, FEP, and TETP while improving biodiversity. However, environmental benefits of the shift from conventional to organic depend on specific factors related to the site of production including the pedoclimatic conditions and organic farming practices adopted.

Miscellaneous Indicators of National, Regional, and Urban Organic Productions

Nitschelm et al. [77] used LCA to assess the environment impacts of a large sample of products coming from different organic French productive systems including cropping systems (annual crops, intercrops, and forages), grassland, wine grapes, cow milk, calves, beef cattle, sheep, pigs, broilers, and eggs. They considered as LCA indicators the cumulative energy demand, land competition (CML-IA non-baseline [78]), and biodiversity loss, and they provided both inventory data and environmental data.

Magrini [79] evaluated the sustainability in EU countries by measuring their performances with 12 indicators (five economic, four environmental, and three social). For the environmental dimension, he classified the environmental indicators depending on the positive or negative contribution due to agricultural practices. Production of renewable energy from agriculture and amount of area under organic cultivation were considered as indicators measuring a positive contribution from agricultural activities to the natural environment, while the pressure on the natural environment provided by agriculture was assessed by means of greenhouse gas emissions from the sector per hectare and gross nitrogen balance per hectare. The results showed three groups of countries with strong (good performances) and (worse performances) weak goals. Strong goals common to all groups included the growth of renewable energy production and organic farming, as well as a reduction in nitrogen balance. Instead, weak goals for all groups included the reduction in greenhouse gas emissions.

Beyond LCA indicators, other authors [80] considered the emergy accounting approach [53,54], as a method for the assessment of the socioecological impacts of the annual production of organic vegetables in Veneto Region (northeast Italy). They evaluated the performances of the system taking into account the emergy yield ratio (EYR), emergy investment ratio (EIR), environmental loading ratio (ELR), emergy sustainability index (ESI), percentage of renewable emergy use (%REN), and total emergy use (U). Their results showed that the ESI was very low (0.0017 sej/year), and the renewability of the organic production system was 0.16%. The emergy yield ratio was only 1.004.

Biernat et al. [81] evaluated if organic agriculture is aligned with the EU nitrate directive by considering the soil mineral nitrogen (N_{min}) status and N balance on field (kg N per hectare per year) of two organic crop rotations with different N inputs (organic low NL intensive, and organic semi-N-intensive) and one conventional crop rotation under farm-scale conditions over a 2 year period (October 2012 to October 2014).

Further studies investigated the environmental and energy impacts of organic farming in the context of urban regeneration projects. One of them started in the year 2018 in a peri-urban area in southeast Milan (Lombardy Region of Italy), which was evaluated by [82] by means of LCA and a geographic information system (GIS). The urban regeneration project consisted in the implementation of 26 food chains by five startups and two processed products (beer and bread) mainly based on sustainable farming practices ranging from intercropping/organic to organic and agroforestry. For each of the five startups and related food chains, they also evaluated five scenarios with three types organic farming scenarios and two conventional farming scenarios. They considered two functional units (FUs; mass based: kg or L and surface based: ha_{eq}) and three indicators (nonrenewable cumulative energy demand (MJ/FU), global warming potential (kg CO_2 equiv/FU), and PL (m^2/FU)) as the inverse of the crops' yields (m^2/FU). Their findings reported that scenarios with organic farming decreased on average the energy consumption by 55% and the contribution to global warming potential by 65% compared to the scenarios with conventional farming.

Lastly, some authors also evaluated the relationship between the local and regional environmental potential of EU member states (such as Poland) to implement organic farming and territorially targeted funds for supporting the development of organic farming. Wiśniewski et al. [83] investigated such a spatial match between targeted areas for organic farming and their environmental potential of implementing organic farming in terms of the following indicators: the indicator of environmental suitability of land for organic farming (IESAOF), the indicator of uptake of organic farming funds (IUOFF), and the indicator of spatial fit of organic farming support (ISFOFS). These authors found high spatial environmental differences in Poland and a weak relationship between the uptake of funds for organic farming and the environmental potential for pursuing it. There are areas in Poland with unexploited potential, suitable for the development of organic farming, and areas in which the environmental potential is not adequate to receive the funds. Therefore, the authors suggested the need for better targeting territorially the funds for organic farming and a change in the approach in the dedicated measures of EU agri-environmental policies for supporting the adoption of organic farming.

4.1.4. The Circular Biobased Economy at Agricultural Stage: Environmental and Energy Indicators

The FF strategy underlines the new potential opportunities for farmers deriving from the adoption of the circular economy model and related practices, including those contributing to the removal of CO_2 from the atmosphere and the participation in the carbon market, as well as the reuse/recycling of agricultural byproducts for the production of biofertilizers, protein feed, bioenergy, and biochemicals. The FF strategy encourages the production of renewable energy from biogas by utilizing manure (as it contributes to a reduction in the methane emissions from livestock while making farmers more self-sufficient for their consumption of energy) or using other sources such as sewage, wastewater, and treated municipal waste, and it highlights the importance of investing in solar energy and other energy-efficient solutions. The investments should also be supported in the future CAP strategic plans and, most importantly, be environmentally sustainable and not affect negatively food security or biodiversity [15]. In that, the FF strategy adds some criteria on how to assess CE practices for the production of energy at the farming stage, responding to the concerns around the first generation of biofuels produced using edible feedstocks such as maize and triticale in the case of Italy. These latter crops have been increasingly replaced by agri-food residues for the production of biofuels to avoid an excessive use of agricultural area for the production of energy crops or crops for energy purposes rather than for food consumption [84].

With regard to the use of manure, some literature reviews on biogas production cycle in the EU indicated that untreated manure has a low biogas production yield with less environmental impact than other substrates, while its co-digestion with other organic substrates is more energy efficient but has higher impacts, compared to the biogas only deriving from manure [85,86]. In any case, the contribution to GWP from the production of biogas energy (derived from manure or energy crops) is much lower than the energy from fossil fuels [86] but the contribution to AP and EP is similar in the case of biogas from manure and higher for biogas produced from energy crops. In other studies, the combination of the production of biogas only from manure and the production of electricity from solar PV increased the use of renewable resources from the farm, reducing the share of resources imported from outside the farm, the impacts on the local environment as measured by the emergy accounting indicators such as the percentage of renewables, ELR, ESI, and total emergy, as well as the LCA environmental impacts, GWP, AP, and EP [45].

Furthermore, "second-generation" feedstocks such as lignocellulosic crops ("Brassica carinata") were analyzed in [46], considering their cultivation on marginal lands of southern Italy for bioenergy and biochemical production. The authors applied SUMMA (Sustainability Multiscale Multimethod Approach), which integrates several methods and related indicators such as CED, midpoint LCA impact categories, material flow accounting, and emergy accounting. The study assessed the energy and environmental impacts of seeds, straw, seed oil, press cake, biodiesel, and glycerin. Their results showed, in particular, that the production and use of *Brassica carinata* crop for bioenergy provides a small net energy yield with no economic return, while the production of high-added-value biochemicals improves the process performance from environmental, energetic, and economic aspects [46]. In other areas outside the EU, the reuse of more common agricultural residues available in large quantities such as rice husk has been considered for the production of energy (heat) and its contribution to coal replacement [87]. The authors assessed by means of LCA the environmental impacts of the generation of 1 MJ of heat from rice husk and found that the GWP, AP, and EP impacts were lower than those of the generation of 1 MJ from coal, although water depletion (WD) would be higher. Despite the worse performance for WD, the results for the other indicators are important in light of the fact that, in developing countries, where there is a large production of rice, most of the rice husk (more than 90%) is currently burned in open air and/or disposed of in rivers or oceans [87]. The same issue is experienced in a particular area of northern Italy (Vercelli province) where there is an important production of rice. However, in one of these areas, rice byproducts are currently reused as an integrating building material [47]. Research on the reuse of rice husk for the production of bioplastics is also currently ongoing [88]. Other by-products such as hemp straw are reused for the production of concrete blocks with applications in non-load-bearing walls with particular thermal characteristics and environmental performance [48]. Concrete blocks made of hemp byproducts resulted in lower CED impacts compared to the conventional concrete and concrete made with recycled aggregates [24].

Lastly, with regard to the "third generation of substrates" such as microalgae, Catone et al. [89] analyzed the international literature in the last two decades, pointing out that algal substrates are mainly used for the generation of biodiesel, biogas, biohydrogen, and bioethanol, with a lower share of other bioproducts. Their interest was focused on evaluating the production of microalgae grown on wastewater. These microalgae are interesting for the opportunities from their treatment; in the case of microalgal production, the results highlighted that microalgae grown on wastewater are more economically advantageous compared to the production of microalgae grown on freshwater [89].

4.2. Stimulating EU Sustainable Food Processing, Wholesale, Retail, Hospitality, and Food Distribution Practices

This section looks at the environmental and energy indicators developed in order to evaluate the sustainability of food processors and distribution channels. The choices of these actors in terms of production methods and packaging, transport, merchandising, marketing practices, and distribution are relevant both for the environment and for society, as they influence consumers' dietary choices by means of the types and nutritional composition of produced food. The boundaries of both processing and distribution channels have a global scale since the EU is the biggest global food importer and exporter. As a result, an increased sustainability of this stage would also have the potential to contribute positively to the global environmental challenges, and to enhance the competitive advantage and reputation of involved companies, as well as the wellbeing of stakeholders, by means of the creation of products with a better value for consumers, workers, employees, other stakeholders, and communities.

4.2.1. Environmental and Energy Indicators of Food Supply Chain

The adoption of an integrated approach to the food supply chain (FSC) has been proposed to reach a simultaneous control of quality, safety, sustainability, and logistics efficiency of food products in a "from farm to fork approach". The global competition encourages companies to pursue these factors through collaborative relationships with suppliers and customers, in order to create a competitive advantage for the FSC as a whole [9].

The length of the FSC and the integration at various stages are among the factors influencing its environmental impacts, including GHG emissions and food waste generation. In general terms, in a shorter FSC, a reduction in food waste and losses would result due to fewer intermediaries and traders (with a direct responsibility of the producer for sales to consumers) and to a reduction in the distances between the location of these actors (also reducing the energy needed for transport). Moreover, intermediaries and traders tend to force overproduction to increase their sales and reject products that do not meet their standards, impacting food waste generation [90]. Thus, short food supply chains, more linked to local/regional communities, have emerged as a potential response to the demand of supply chain sustainability [91], while also proposing innovation-based solutions to enhance efficiency [9]. Nevertheless, researchers are skeptical about a generalized optimism toward the higher sustainability of local/short FSC, which can be more expensive and environmentally impactful than industrial/long FSC food when the volume of resources/products and the efficiency and specificity of logistic operations are considered [90]. In these cases, territorial specific factors (urban/rural areas, consumer preferences, and producer–consumer relationships) [90] or supply chain infrastructures [92] can play a relevant role. At the same time, it is worth mentioning that efficient solutions to reduce food losses and waste in a supply chain are keys to recognizing relationships (operational and strategic) among the different stages of the SC. Moreover, attention should be paid to the impact of technical innovation on socioeconomic and environmental contexts [9,93]. Recent contributions based on systematic literature reviews have highlighted that researchers recognize supply chain elements, namely, buyer–supplier agreements and supply chain interruptions, as being among the main factors impacting the emergence of food waste generation [94,95]. Furthermore, the need for an integrated set of environmental, social, and economic indicators to support an easier transition to sustainability in the food industry cannot be disregarded, to be operationalized in a toolbox supporting decision making in differentiated spatial areas [93].

Indicators of Short and Long Food Supply Chains

A study focusing on 208 food producers participating in 486 long and short chains in seven countries [96] developed nine indicators (economic dimension: three; social dimension: four; environmental dimension: two). By analyzing these indicators, interesting results emerged about the food supply chain investigated. Among others, a first result was the confirmation that producers benefit by taking part in a short FSC, since they increase their profit margin that is not absorbed by intermediaries. A second result, apparently unexpected, was that longer supply channels show lower environmental impacts when considering the volume of food transported. In fact, transporting large quantities of food for hypermarket chains translates into a lower value of food miles and carbon footprint per unit of product. This study adopted more indicators compared to previous ones. The two environmental indicators adopted were (1) food miles (measured as the km/kg ratio) aimed at reflecting the sum of the distance traveled by the product, from producers to markets and from markets to final consumption site, and (2) carbon footprint (measured as the product of fuel consumption times the carbon footprint coefficient) for all transportation vehicles used. The first indicator showed that, in short FSCs, the products are transported for three times the miles compared to a longer supply chain. Similarly, the second indicator highlighted that the carbon footprint per kg of product of short FSC is higher than that for longer supply chains. A reason of this result may be that the less concentrated transportation by means of small vehicles results in efficiency loss, and that specialized small shops are most often less environmentally effective than large stores, which supply consumers with a "one stop shop" service approach.

An analysis that specifically considers several environmental indicators in FSC was conducted by [39] with the aim of supporting the affirmation of a holistic approach to face the environmental emergence. This paper considered a set of 21 indicators grouped into management indicators (nine) and operational indicators (12) applied to five FSC stages (agriculture, processing, freight, consumer, and end-of-life). Four of the operational indicators were related to the impact of the energy consumption both in the processing stage (total energy consumption/production output) and in the consumption stage (renewable energy supplied/total energy provided to consumers; fridges sold with high-grade label/total sales; share of fridges produced in each grade) on the environmental performance of the FSC of tomato ketchup. By adopting an LCA framework, this research proposed a system of indicators that can be applied for the FSC as a whole or for single stages. It also highlighted the environmental problems that emerge with the growing international dimension of FSC, which require a holistic approach to face. The authors pointed out that environmental indicators are practical tools to be applied as policy tools in the frame of an integrated product (supply chain) policy. These indicators can also support the transparency and accountability of environmental FSC policy implementation by ensuring the monitoring, control, and evaluation of the measures adopted.

Similar characteristics were observed in [92], which also used an LCA approach to verify the environmental impacts of short and long FSCs. A large sample of different categories of FSC were analyzed in different European countries. The results revealed that longer FSCs have better environmental and energy performances (fossil fuel energy consumption, pollution, and GHG emissions) when the production volume is considered. The results vary according to the categories of supply chains and are influenced by the customer–supplier distance and by the characteristics of the supply chains.

Cold-based FSCs are among the production activities with the greatest environmental impact due to the enormous energy consumption for storage and handling of products. Diaz et al. [97] proposed a decision support system to improve the energy efficiency and reduce the environmental impact in different cold FSCs. Various methodologies have been adopted to propose a unique integrated toolbox (multicriteria decision analysis tool) which considers different indicators: environmental (GWP and water scarcity), energy (consumption and efficiency), and product losses. The toolbox was empirically tested on a sample of 122 participants of cold FSCs to assess potential improvement scenarios for the adoption of energy efficiency measures and food loss reduction. The complexity in dealing with many and different actors of a cold FSC as a whole and the need for a considerable number of input parameters were indicated as the main limits of the toolbox proposed [97].

Indicators of Specific Products: The Egg Supply Chain

Mitrovic et al. [98] analyzed the egg supply chain to comprehend the environmental impacts by observing a sample of three main categories of actors of the chain: farmers, retailers, and householders. The results revealed that the greatest environmental impacts came from the production of feed for laying hens and the use of natural resources. Moreover, differences among the different categories of actors emerged, related to strategies involving the entire egg supply chain and aimed at the optimization of animal feed, energy consumption, and household food waste management. Similarly, the different role of various actors in the FSC, namely, SMEs (small and medium sized enterprises) and large multinational companies (MNCs), in pursuing a sustainable FSC was underlined in [99]. Through a systematic review of the literature, this paper emphasized that greater knowledge of the differentiated role of the many SMEs operating in the FSC is needed, while

MNCs can provide guidance by supporting collaboration and making critical resources available for sustainability.

Consistently with the latter, more contributions have underlined the importance of providing indicators to analyze the sustainability performance of FSC, recognizing that an integrated vision of the food production along all the stages and the related actors (from farmers to waste food collectors and recyclers) is crucial to understand both the dimensions of the phenomenon and its causes, as well as to prepare viable solutions. A critical analysis of sustainability indicators was provided with reference to specific FSC categories (chicken and potato) in the UK [100]. Nine indicators were selected (three per each sustainability dimension). The environmental indicators adopted were (1) energy consumption (MJ), (2) water consumption (m^3), and (3) waste disposal (measured as currency needed to cover the disposal cost). Among the other results, it emerged that, to put these indicators into practice, relevant limits in the information availability exist. On one hand, the researchers underlined that the adoption of these indicators (for both companies and policies) is limited by the small amount of information available on the performance of growers and producers; on the other hand, an asymmetry emerges, since, while statistical information is available for agriculture and processing supply chain stages, final stages (wholesale, retailing, and food catering) show inadequate data availability. Moreover, these researchers revealed the difficulty in extracting values from aggregated data and assigning social and environmental impact values at the final stages [100].

Supply Chain Indicator Frameworks for Decision Making

Poponi et al. [93] also addressed the realization of a dashboard to support decision making in the FSC toward a circular economy and sustainability. Their systematic literature review provided an analysis of the indicators of the three sustainability pillars. A list of 102 indicators was generated and grouped according to eight categories (environment: air, water, soil, energy, waste; economy: cost, value and productivity; social: equality, knowledge and innovation). For each indicator, the authors provided a detailed description. Concerning the water category, they identified 17 indicators: green water footprint, blue water footprint, gray water footprint, total area equipped for irrigation, water withdrawal from agriculture, water use, water scarcity index, water exploitation index, water productivity, level of water stress, change in water use efficiency over time, degree of integrated water resource management implementation, EP, MEP, FEP, and conservation of fish genetic resources (in number: size of the stock). Concerning the energy category, they identified the energy use in agriculture and forestry as a share of total energy use, bioenergy production as a share of renewable energy, wood fuel production, energy self-sufficiency indicator, recovery of energy by using waste, energy required for waste recovery, CED and related indicators, energy productivity, and renewable energy share in the total final energy consumption [93].

The knowledge of these indicators represents a guide to orient the policy and entrepreneurial interventions on the three sustainability pillars and in relation to specific territorial and industrial contexts.

Four main considerations emerge from this brief analysis of the adoption of environmental indicators in the context of FSCs. The first addresses the need to work on the cultural and scientific development to affirm both the general adoption of a holistic (integrated) approach when analyzing the FSC and the awareness of always having to consider the action of specific factors (at the territory, product, or technology level). In both these circumstances, sustainability indicators become an indispensable tool for the purposes of implementing and controlling policy measures. The second consideration is aimed at stimulating the collection and processing of information by both companies at the different stages of the supply chain and external secondary sources to feed the proposed indicators. The third consideration is a confirmation of the skepticism of researchers toward the environmental superiority of short FSC when product volume is considered.

The last consideration promotes the need for developing more research and increasing the knowledge around the complexity of FSC, as well as around the factors influencing the environmental sustainability of the FSC, at the level of both the FSC and the specific actors. This is the key to avoid easy and short-lived solutions based on nonshared and nongeneralizable knowledge and values.

4.2.2. Promoting Sustainable Food Consumption and the Shift to Healthy and More Sustainable Diets

The "farm to fork strategy" suggests the move to more crop-based diets for their potential advantages for the natural environment and the decrease in life-threatening diseases, e.g., cardiovascular diseases and cancer [101]. As a result, this section focuses on the environmental and energy indicators of diets such as the Mediterranean diet (MD), where crops play a major role, compared with other dietary patterns mainly adopted in European countries. The MD is recognized as a more environmentally sustainable and important dietary pattern due to the socioeconomic benefits it delivers, including food security [102] and the achievement of UN sustainable development goals [103]. It is important to underline that the MD model has broader value (as already underlined by UNESCO) that goes beyond the concept of food, since the term "diet" itself derives from the ancient Greek to indicate the social and cultural value of adopted lifestyles [104]. Table 5 summarizes some of the main benefits of the MD retrieved from the selected literature.

Table 5. Environmental, social, and economic benefits of the MD.

Type of Benefits	Description
Environmental benefits	Lower use of natural resources (land, water, and resource use for production) and lower release of GHG emissions, compared to a diet mostly based on the consumption of meat and animal fats Higher seasonality as it encourages the consumption of season food. This translates into a reduction in greenhouse crops and related environmental impacts, as well as lower supply and transport costs from distant countries (food miles) Higher biodiversity, due to higher respect of each territory and its specific biodiversity, through different sowing in each area and crop rotation, in order to also guarantee food security Higher frugality as it considers moderate portions and consumption of whole and fresh, lightly processed foods. Both the quantities consumed and the minor transformations undergone by food contribute to reducing the environmental impacts of MD-based eating behaviors
Social benefits	Physical health: The MD, together with physical activity, helps prevent cardiovascular disease, diabetes, and some types of cancer (colorectal, breast, prostate, pancreas, and endometrial). In addition, the intake of fresh and whole foods allows greater availability and use of micronutrients and antioxidants Food awareness: The MD promotes greater food awareness and link with the territory and knowledge of seasonality, biodiversity, and naturalness of food Conviviality: The MD promotes social interaction; common meals are the cornerstone of the holidays and of social traditions Identity: The MD is an expression of the entire historical and cultural system of the Mediterranean area. It is a millenary food tradition that has been handed down from generation to generation, promoting not only the quality of foods and their territorial characterization, but also the dialogue between peoples
Economic benefits	Health expenditure: A greater adherence of eating habits to the MD would improve the general state of health of the population, which would translate into a decrease in national health expenditure Household spending: Adherence to the MD, favoring seasonal foods, mainly cereals and vegetables, would allow a decrease in household food spending Business enhancement: The spread of the MD would result in an increase in the commercial demand for natural products (fruit, vegetables, cereals, legumes, etc.) and their derivatives (oil, wine, pasta, bread, etc.), creating income and employment for companies in the Mediterranean regions Enhancement of territories: The spread of the MD would enhance the agro-eno-gastronomic offer of Mediterranean territories, contributing to the seasonal adjustment of the tourist offer

4.2.3. Energy, Water, and Carbon Footprints of Mediterranean Diet

In the EU, the average diet of people is largely based on the intake of red meat, sugars, salt, and animal fats, while the consumption of whole-grain cereals, fruits and vegetables, legumes, and nuts is still insufficient and sometimes declining [105].

Cambeses-Franco et al. [7] analyzed the environmental sustainability of the southern version of the New Nordic Diet (SNND) by means of LCA indicators and compared them with those of other recommended diets in Spain, such as the Southern European Atlantic Diet (SEAD) and the Mediterranean Diet (MD) relying on literature data [106]. The New Nordic Diet considers locally grown, seasonal, nutritious, and environmentally friendly foods mainly consumed in Denmark, Finland, Iceland, Sweden, and Norway [107] whereas the SEAD is the common dietary pattern followed in northwest of Spain, characterized by the consumption of fresh and seasonal foodstuffs, as well as freshly prepared and low-processed foods [108]. The results showed that the carbon footprint (CF) for the SNND was 3.58 kg CO_2eq·person^{-1}·day^{-1} while the CF reported by [106] for the MD was 2.79 kg CO_2eq·person^{-1}·day^{-1} and for the SEAD was 3.62 kg CO_2eq·person^{-1}·day^{-1}. The recommended daily intake of animal products is the main factor explaining the differences in the value of carbon footprint among the SNND, SEAD, and MD: 703 g·person^{-1}·day^{-1}, 677 g·person^{-1}·day^{-1}, and 390 g·person^{-1}·day^{-1}, respectively. In terms of water footprint, the SNND value was 3528 L·person^{-1}·day^{-1}, while the literature values were 3754 L·person^{-1}·day^{-1} and 3044 L·person^{-1}·day^{-1} for the SEAD and MD, respectively.

Hachem et al. [109] reviewed the international literature with the purpose of evaluating the contribution of the MD and New Nordic Diet (NND) to environmental, sociocultural, and economic sustainability. In this regard, they included a large list of environmental indicators through which it was possible to measure the environmental sustainability of diets/food systems. Their results showed that, in general, both MD and NND were associated with lower environmental impacts in relation to other healthy diets, but the impacts were higher when compared to pescetarian or vegetarian diets.

Belgacem et al. [110] estimated the environmental impacts of three dietary patterns (European, Western, and Mediterranean) on biodiversity by means of pressure indicators such as land use, water use, GHG emissions, and FEP. They highlighted that the northern European diet is based on a high content of proteins from meat and dairy products, while the dietary pattern in central Europe is based on the relevant role of pork meat, along with lard and butter. On the contrary, in southern Europe, dietary patterns are mainly based on fruits and vegetables (rich in vitamins, minerals, and fibers), while read meat and chicken are consumed to a lower extent. Lastly, the Western dietary patterns mainly adopted by developed countries consist of a high intake of red meat, processed meat, pre-packaged foods, refined grains, candy and sweets, butter, fried foods, eggs, high-fat dairy products, potatoes, corn, and high-sugar drinks. Their results revealed that the MD has lower environmental impacts in terms of all the above mentioned indicators. They, therefore, calculated that a shift to the MD in Europe and the USA would reduce land use by 41% in Europe and by 55% in the USA, as well as water use by 18% in Europe and by 2% in the USA. GHGs emissions would be lower by 36% in Europe and by 44% in the USA, while FEP would decrease by 36% in Europe and by 31% in the USA.

Vanham et al. [111] assessed and compared the water footprint (WF) of two diet scenarios, the EAT–Lancet Universal reference diet and the MD, in nine countries (Spain, France, Italy, Greece, Turkey, Egypt, Tunisia, Algeria, and Morocco). These two diets share a low consumption of animal products such as meat and milk, in favor of a higher intake of fruit, vegetables, pulses, nuts, and oilcrops. However, the results showed that the EAT–Lancet reference diet has a lower WF than the MD as it recommends a higher intake of cereals, pulses, nuts, and oilcrops. Furthermore, Paris et al. [56] assessed the sustainability of diets within a larger window of analysis and health issues for humans, animals, and the natural environment by means of an extended LCA incorporating the One Health framework. This extended LCA included environmental midpoint indicators (CC, PMFP, TAP, FEP, MEP, LUP, FRSP, and WCP) calculated by means of the impact assessment method

ReCiPe 2016 [112] and additional indicators related to animal welfare (animal life years suffered, loss of animal lives, and loss of morally adjusted animal lives) and human health (estimated on the basis of risk factors for noncommunicable diseases). The boundaries of the evaluation of the impacts were from farm to fork or from cradle to plate, taking into account men and women's reference diets of Germany in the North Rhine-Westphalia (NRW) state and three dietary scenarios under nutritional constraints such as the national dietary guidelines in Germany, a vegan diet (VD), and the MD. Their findings highlighted that greater impacts were caused by the men's reference diet compared to that of the women's due to the higher food consumption, particularly ready-to-eat meals, sausages, meat, and sweetened and alcoholic beverages. Instead, the comparison of the reference diet with the three scenarios revealed both benefits and tradeoffs. Shifting from a diet based on meat to VD plant-based proteins is likely to increase water scarcity. An increased consumption of fish, seafood, and honey has negative impacts on animal welfare. A larger share of crop-based foods such as fruits, vegetables, legumes, and grains in a diet leads to higher benefits for animal welfare and human health. Reducing the consumption of ready-to-eat foods and processed food improves human health, animal welfare, and environmental quality.

Lastly, a very recent scoping review by Harrison et al. [113] analyzed 103 empirical cases selected from the international literature, including indicators used to assess sustainable diets. With regard to environmental indicators, their findings revealed that the most used indicators were those associated with the concept category of GHG emissions, followed by water use, land use, toxicology, energy use (cumulative energy demand, energy consumption, fossil resource scarcity, and nonrenewable energy). These results aligned with a previous scoping review by Portugal-Nunes et al. [114] assessing the nutritional sustainability of the MD, where the most used indicators from the literature were GWP, WCP, LUP, and energy use.

4.3. Reducing Food Losses and Waste

Tackling food losses and waste is crucial for improving the sustainability of food systems. Where generation of food waste is unavoidable, valorization through recovery should be considered as a set of sustainable alternatives instead of linear disposal to landfills [115].

Recovery pathways including surplus food redistribution reduce the amount of food waste and may have important environmental and social impacts, providing benefits for consumers and operators, as well as creating connections with policies favoring the recovery of nutrients and secondary raw materials, improving the production of feed, assuring food safety, protecting biodiversity, and favoring the development of the bioeconomy and renewable energies [15,116].

The literature applies the concept of "food loss" to waste derived from agricultural stage and food processing, while the concept of "food waste" pertains to that from the retail and final consumption stages [115,117]. In some cases, the two terms are applied interchangeably, depending on the specific case [118]. This study adopted the first approach; hence, this section mainly deals with food waste from the final consumption stage issues and related indicators, although studies and indicators from the food waste processing stage are also presented [119,120].

Environmental and Energy Indicators of Food Waste Prevention and Valorization

Analyzing CE perspectives to mitigate environmental impacts from food systems requires the usage of available metrics and indicators that are capable of measuring important components of the CE concept [121]. In recent years, several authors have been involved in modeling environmental and energy indicators related to food waste prevention and valorization.

For example, the authors of [44] underlined the importance of applying the concept of "embodied energy" to food waste, pointing out that food waste can be considered as a double waste of energy due to the avoided energy intake of food not consumed and the energy input used for its production. Other authors [122] proposed a mathematical model aimed at developing an eco-inefficiency (EIy) formula to verify the economic-, environmental-, and social-related impacts of food services waste. The model entails six sequential stages: (i) identification of characteristic terms for food waste; (ii) definition of food waste constructs; (iii) identification of variables within each defined food waste construct; (iv) selection of indicators capable of measuring the impact generated by food waste; (v) definition of the mathematical formula; (vi) EIy pilot test in order to perform the analysis.

Three critical dimensions of sustainability were addressed (environmental, social, and economic) to define food waste constructs. Concerning the environmental impacts, water footprint (L/kg), cleaning material, food production waste (kg), amount of rest intake (% kg), and amount of distribution leftover (kg) were considered. Lastly, the energy consumption, raw material cost, and food handler's wages were accounted for in the economic dimension. The social dimension included the following issues: energy density (ED), rest intake (kcal/g), distribution of leftover ED (kcal/g), use of organic food, and food surplus donation. The scores in each dimension were then compiled using the EIy application. The authors posited that their eco-inefficiency formula was capable of identifying the critical points of food waste and enabling the development of strategies to reduce food waste. Banasik et al. [40] also developed a mathematical model based on multi-objective mixed integer linear programming to assess eco-efficiency by quantifying different production options associated with food waste handling alternatives such as prevention, recycling, and disposal. The authors used exergy-based (MJ) indicators to measure environmental performance as a single value, capturing similar and related indicators, such as energy consumption, fuel consumption, and waste generation. However, different mathematical models were applied at different scales and geographic settings, making comparisons on the outcomes more difficult.

Derqui and Fernandez [123] presented the case of tracking food waste in school canteens, with guidelines for self-assessment, using food waste destination as the main indicator. Here, the authors pointed out that major impacts occur in concentrated areas where many consumers get their food, such as school canteens and other institutional catering areas, e.g., hospitals and prisons. Such places host persons who have similar dining patterns, thus making it simultaneously easier to address both efficiency and waste amounts along the supply chain, by means of pre-consumer and post-consumer waste assessments.

As can be observed from Table 6, many studies have applied the predefined LCA methodology, employing a variety of indicators such as GWP, FRSP, OFEP, FEP, LUP, and TAP. However, other useful non-LCA indicators have been highlighted, allowing the integration of aspects for which LCA is not completely exhaustive. For instance, other important indicators at the household and supply chain levels are the redistribution of food for human consumption, food valorization (recovery of residues and transformation of waste into biofertilizer, bioenergy, and biobased materials), consumer behavior change, improvement of supply chain efficiency, and food waste prevention governance, which are often overlooked in LCA studies [94,95].

Furthermore, several authors [41–43] have recommended the appropriateness of including indicators other than those covered in LCA studies, such as avoidable food loss, unavoidable food loss, and total food loss (i.e., the sum of avoidable food loss and unavoidable food loss) [42]. The integration of various indicators is important for a much more extensive and thorough understanding and modeling of food waste prevention and valorization. Presently, a suitable evaluation framework capable of measuring and monitoring progress in prevention and valorization is still missing.

The European Platform on Food Loss and Waste (FLW) is currently developing a reporting framework to evaluate food waste management actions [90]. While LCA studies can provide environmental impact indicators from farm to fork, this EU platform strongly posits the need to apply a variety of evaluation methods, in order to ensure a more comprehensive understanding of the whole food supply chain [94,124]. This approach is capable of complementing efforts toward appropriate decision making on food waste and valorization policies, including incentives for food waste reduction and taxes on food production at all levels [94,95].

In the past years, two EU-funded H2020 projects, namely, ReTraCE (https://www.retrace-itn.eu/ (accessed on 25 January 2023)) and ProCeeds (http://proceeds-rise.eu/about/ (accessed on 25 January 2023)), have been actively involved in covering case studies on food systems in Europe with the application of two main methods for sustainability assessment: LCA and emergy accounting. Ncube et al. [119] and Oliveira et al. [120] presented results based on case studies in the agri-food sector to highlight the benefits of food waste valorization by comparing linear and circular scenarios. Several LCA and emergy accounting indicators, such as GWP, TAP, FEP, LUP, FSRP, WCP, %REN, EYR, ELR, and ESI were used to pinpoint the overall environmental costs and benefits. The case study on circular wineries covered in [119] exploited a microlevel case study approach in Italy to investigate the environmental implications of integrating circular patterns with linear chains within a biorefinery system relying on winery waste. In a similar manner, at the same microlevel scale (an average size dairy farm in Caserta, Italy), the authors of [120] investigated the feasibility of implementing multi-prospective sustainable solutions to produce buffalo milk and mozzarella cheese, supported by the reuse of coproducts such as whey and manure to improve environmental performance. In all of the above investigated case studies, circular economy alternatives were more environmentally favorable. The authors critically cautioned that, despite the appealing and achieved environmental benefits, the application of multioutput scenarios is recommended and ought to be carefully applied in order to prevent misleading results. Santagata et al. [115] took a broader approach by combining a review of the literature for more than 200 food waste conversion pathways, followed by the incorporation of LCA and emergy accounting, to assess food waste treatment options and enable the identification of drivers and constraints. Subramanian et al. [125] undertook a "nexus" approach, which integrated energy, water, and food to accelerate progress toward achieving sustainable development goals, focusing on food waste and related environmental issues, such as climate change and energy consumption. The latter issue considered the energy consumed within kitchen operations classified into two categories: direct and indirect energy use. The direct energy use in the case study's cafeteria operations was derived from the energy consumed to operate appliances in the kitchen and transportation from the distributor to the kitchen itself. Indirect energy was considered as the energy used to extract raw materials, along with their processing and transport from the farms to the local distributor. Cudoje et al. [126] explored the environmental and economic benefits for China derived from hydrogen production via steam reformation of biogas produced from food waste and found that it would be possible to produce 221.12 billion kg of hydrogen gas, generating ~661.97 TWh of electricity. The hydrogen production would reduce the amount of electricity from diesel fuel, thus avoiding a considerable amount of CO_2 emissions and contributing to a reduction in the impact on GWP.

Amicarelli et al. [118] applied the MFA to investigate the metabolism of the Italian meat industry, along with its consumption of resources and waste flows. The results of this MFA study showed that more than 2 Mt of edible meat is produced each year in Italy. This amount is about 40% of the total mass (4.9 Mt) entering the meat industry, while the remainder comprises food waste in the form of coproducts and byproducts. The material use efficiency of the recovery of food waste can be very high, achieving 96% at the slaughtering stage. However, it is important to promote the reduction in the amount of this type of food waste, as the efficiency of its recovery can be further reduced by considering the retail stage and the overall food waste in the meat industry.

Lastly, Wu et al. [127] integrated the anaerobic digestion process with bacterial cellulose production and vermicomposting to valorize the discharged residual solid fraction of kitchen waste. The LCA and economic analysis methods were adopted to investigate the environmental and economic sustainability of the new process. The results showed that the integrated process strongly reduced the contribution to GWP and AP while improving the net output of primary energy demand.

Table 6. Environmental Indicators identified from the reviewed literature.

Authors	Indicators	Method	Geographical Scale
Banasik et al. [40]	Exergy indicators (MJ)	Exergy analysis, mathematical modeling, and case study	The Netherlands
Bernstad et al. [41]	GHG emissions (kg CO_2 eq.)	Review on 28 LCA case studies and 2 review papers.	Worldwide
Corrado et al. [42]	Avoidable food loss Unavoidable food loss Total food loss (equal to avoidable food loss + unavoidable food loss)	Literature review on LCA studies.	Worldwide
De Menna et al. [43]	Net present value Internal rate of return Cost-to-benefit ratio Private cost/benefit to external cost/benefit	Literature review on LCA and LCC studies about food waste	Worldwide
Caldeira et al. [93]	Redistribution of food for human consumption Food valorization Transformation of waste Consumer behavior change Improvement of the supply chain efficiency Food waste prevention governance	Survey of members of the EU Platform on FLW and literature review	EU
Santagata et al. [115]	18 midpoint LCA indicators (ReCiPe 2016) and emergy accounting indicators (total emergy with/without L&S)	Literature review LCA and emergy accounting studies	Worldwide
Amicarelli et al. [118]	Domestic material input (Mt), domestic material output (Mt), and material use efficiency indicator (Mt and % of total DMI)	Material flow analysis	Italy
Lins et al. [122]	Water footprint (L/kg) Cleaning materials Food production waste (kg) Amount of rest intake (kg) Amount of distributed leftover (kg)	Mathematical formula: EIy pilot test based on eco-efficiency with focus on food waste	Brazil
Subramanian et al. [125]	Food waste, energy, water consumption, and emissions	LCA and survey	Hong Kong
Cudjoe et al. [126]	Amount of food waste (kg), hydrogen yield potential (TWh), return on investment (ROI), payback period (PBP), and global warming reduction potential (kt CO_2 eq.).	Energy analysis, cost–benefit analysis, and environmental analysis	China
Wu et al. [127]	GWP, AP, and primary energy demand	LCA and economic analysis	China

5. Discussion: Application of the Proposed Framework to Italy

The framework of indicators proposed in this study can be considered a useful tool to assess the environmental and energy performances of national agri-food systems and product systems. Both the CAP indicators of the EU and the indicators from the literature are already currently applied at the macro- and microscale.

5.1. Application of the Identified Indicators at the National Italian Scale

The data of the monitoring of the EU CAP indicators (included in this study) are available in the EU database [20], showing, for Italy, that, in the year 2018 as an example, the shares of agricultural area (52%) and forest and semi-natural area (42%) were most represented in total land cover, while water bodies only covered a 1% share.

A share of 34.2% of the total used agricultural area (UAA) of Italy in the year 2020 was subject to high faming intensity, achieving similar shares to France (35.9%), Sweden (34.6%), and Hungary (36.4%), while other countries had higher shares under high farming intensity such as Romania (80.6%) and Bulgaria (74.9%) and lower shares of UAA as in the case of Belgium, the latter resulting the member state with the lowest UAA share (15%) subjected to high farming intensity.

When it comes to the share of organic farming in total UAA, Italy was among the countries with the highest share (16%), together with Sweden (20.3%), Estonia (22.4%), and Latvia (14.8%). Overall, about 61.6% of the whole organic farming area in the EU received economic support. Further indicators showed that Italy had one of the highest fractions (20%) of irrigated area in total UAA of the member states, well above the average 6% share of EU (27 countries) UAA irrigated area.

Concerning water quality indicators, the data available for the period 2012–2015 evidence that, for Italy, the potential surplus of nitrogen was 70.4 kg N/ha. This value positions Italy more or less in the middle, compared to the values of the other countries. The highest potential surplus of nitrogen was found for Cyprus (187.8 kg N/ha) and the Netherlands (174.1 kg N/ha), while the lowest values was found for Romania (7.1 kg N/ha) and Bulgaria (23.9 kg N/ha).

With regard to energy, the direct energy use in agriculture and forestry (expressed as kg of oil equivalent per hectare of UAA and forest area in the year 2020) was 122 kg of oil equivalent, while the highest value was recorded in the Netherlands (1748 kg of oil equivalent per ha of UAA and forest area) and the lowest was recorded in Cyprus (11 kg of oil equivalent). In terms of energy use in agriculture and forestry as a share of total final energy consumption, in the year 2020, for Italy, it was 2.7% of the total, a value below the average 3.2% share of the EU-27. Lastly, considering GHG emissions from agriculture, their share (including soils) of total net emissions was 5.5% for Italy, while the average share of the EU-27 was 12.7%.

5.2. Application of the Identified Indicators at the Product Scale

For testing the microscale indicators, this study considered the analysis of the data of the most adopted product certification schemes, such as EPDs, to understand which of the proposed indicators are considered in the schemes for monitoring the environmental performances of certified Italian products and agri-food companies. Italy is one of the countries with the highest number of environmental product declarations [128]. This can also be ascertained from the international database of EPDs, which includes all products that have obtained an EPD, along with the various EPDs for the products [129]. An EPD provides transparent, verified, and comparable information about the life cycle environmental impacts of products and services (EPD International, available at https://www.environdec.com/library, accessed on 25 January 2023). It requires an LCA as a method for the assessment of environmental and energy performances of products across their whole life cycle [129].

Tables 7 and 8 show the LCA results included in the EPD of 1 kg of durum wheat produced by conventional and organic farming. The midpoint LCA indicators considered were GWP, AP, EP, POFP, ADP (kg Sb eq.), ADP (MJ), and water scarcity potential (m^3 eq.). For this product, the boundaries of the system were cradle to gate, including the production stage and the storage on site before distribution. The potential environmental impacts were higher for the organic cultivation of durum wheat than for conventional cultivation for most indicators, except for water scarcity potential. According to the Environmental Agency [130], "*water scarcity occurs where there are insufficient water resources to satisfy long-term average requirements. It refers to long-term water imbalances, combining low water availability with a level of water demand, exceeding the supply capacity of the natural system*" [130].

Further EPDs related to the environmental performance of products with midpoint LCA indicators, as proposed in this study, were found for a 0.5 L bottle of Olio Extra Vergine di Oliva Biologico (Table 9). The boundaries of the system were cradle to grave, considering upstream core processes and downstream processes. The EPD also contained interesting information about the organization and their efforts in improving the environmental performances of the company and of its products. This is evidenced by the company having installed two PV plants since the year 2010, allowing it to be energy self-sufficient while selling the surplus electricity to the national grid. Moreover, the internal pits of the olives are sold and recycled to obtain a biofuel, while the pomace pits are sold as a good alternative to pellets. A short supply chain and zero-km approach are adopted to reduce the environmental impacts and CO_2 emissions.

Table 7. Midpoint LCA indicators of 1 kg of durum wheat produced under conventional cultivation. Source of the data: EPD International [131].

Midpoint Impact Categories		Unit	Upstream	Core	Downstream	Total
Global Warming Potential	Fossil	kg CO_2 eq.	1.22×10^{-1}	2.24×10^{-1}	5.38×10^{-2}	4.00×10^{-1}
	Biogenic	kg CO_2 eq.	9.75×10^{-5}	4.07×10^{-4}	1.64×10^{-5}	5.21×10^{-4}
	Land use	kg CO_2 eq.	3.92×10^{-3}	1.72×10^{-4}	1.96×10^{-5}	4.11×10^{-3}
	Total	kg CO_2 eq.	1.26×10^{-1}	2.24×10^{-1}	5.39×10^{-2}	4.04×10^{-1}
Acidification potential		kg SO_2 eq.	1.20×10^{-3}	2.50×10^{-3}	2.46×10^{-4}	3.95×10^{-3}
Eutrophication potential		kg PO_4^{3-}eq.	6.92×10^{-4}	2.06×10^{-3}	4.90×10^{-5}	2.80×10^{-3}
Photochemical oxidant formation potential		kg NMVOC eq.	4.57×10^{-4}	1.72×10^{-3}	2.96×10^{-4}	2.47×10^{-3}
Abiotic Depletion potential (Elements)		kg Sb eq.	6.92×10^{-6}	9.37×10^{-6}	1.48×10^{-6}	1.78×10^{-5}
Abiotic Depletion potential (Fossil resources)		MJ, net calorific value	8.81×10^{-1}	2.57	8.10×10^{-1}	4.26
Water scarcity potential		m^3 eq.	7.85×10^{-1}	2.08×10^{-2}	2.34×10^{-3}	8.08×10^{-1}

Table 8. Midpoint LCA indicators of 1 kg of durum wheat produced under organic cultivation. Source of the data: EPD International [131].

Midpoint Impact Categories		Unit	Upstream	Core	Downstream	Total
Global Warming Potential	Fossil	kg CO_2 eq.	9.35×10^{-2}	2.73×10^{-1}	5.11×10^{-2}	4.17×10^{-1}
	Biogenic	kg CO_2 eq.	7.12×10^{-5}	4.31×10^{-4}	1.56×10^{-5}	5.18×10^{-4}
	Land use	kg CO_2 eq.	6.19×10^{-5}	2.04×10^{-4}	1.85×10^{-5}	2.85×10^{-4}
	Total	kg CO_2 eq.	9.37×10^{-2}	2.73×10^{-1}	5.11×10^{-2}	4.18×10^{-1}
Acidification potential		kg SO_2 eq.	1.93×10^{-3}	2.14×10^{-3}	2.33×10^{-4}	4.31×10^{-3}
Eutrophication potential		kg PO_4^{3-}eq.	1.42×10^{-3}	1.43×10^{-3}	4.64×10^{-5}	2.89×10^{-3}
Photochemical oxidant formation potential		kg NMVOC eq.	3.84×10^{-4}	2.03×10^{-3}	2.81×10^{-4}	2.70×10^{-3}
Abiotic Depletion potential (Elements)		kg Sb eq.	4.17×10^{-6}	1.21×10^{-5}	1.41×10^{-6}	1.77×10^{-5}
Abiotic Depletion potential (Fossil resources)		MJ, net calorific value	6.36×10^{-1}	3.38	7.68×10^{-1}	4.79
Water scarcity potential		m^3 eq.	1.97×10^{-1}	2.24×10^{-2}	2.21×10^{-3}	2.21×10^{-1}

Table 9. Midpoint LCA indicators of one bottle of organic olive oil (0.5 L). Source of the data: [132].

Midpoint Impact Categories		Unit	Upstream	Core	Downstream	Total
Global Warming Potential	Fossil	kg CO_2 eq.	1.97×10^0	4.21×10^{-1}	2.06×10^{-1}	2.60×10^0
	Biogenic	kg CO_2 eq.	7.12×10^{-3}	9.54×10^{-4}	2.30×10^{-5}	8.09×10^{-3}
	Land use	kg CO_2 eq.	9.72×10^{-4}	5.20×10^{-4}	2.07×10^{-5}	1.51×10^{-3}
	Total	kg CO_2 eq.	1.98×10^0	4.22×10^{-1}	2.06×10^{-1}	2.61×10^0
Acidification potential		kg SO_2 eq.	6.70×10^{-2}	1.84×10^{-3}	1.19×10^{-3}	7.00×10^{-2}
Eutrophication potential		kg PO_4^{3-}eq.	4.06×10^{-2}	6.99×10^{-4}	2.09×10^{-4}	4.15×10^{-2}
Photochemical oxidant formation potential		kg NMVOC eq.	8.98×10^{-3}	1.62×10^{-3}	2.04×10^{-3}	1.26×10^{-2}
Abiotic Depletion potential (Elements)		kg Sb eq.	5.15×10^{-5}	1.00×10^{-5}	1.28×10^{-6}	6.28×10^{-5}
Abiotic Depletion potential (Fossil resources)		MJ, net calorific value	1.57×10	7.24×10^0	2.85×10^0	2.58×10
Water scarcity potential		m^3 eq.	2.14×10^0	5.48×10^{-1}	2.69×10^{-3}	2.69×10^0

The Atlas of the Circular Economy [133] is another importance source for gathering data about Italian circular companies and the indicators that they adopt to measure their environmental and social performances, as well as the practices that they are implementing for transitioning to the CE. The agri-food sector is well represented in the Atlas, with 50 cases of profit and nonprofit companies out of a total of 376 [133].

Lastly, across the Italian regions, there are also education projects aimed at promoting the consumption of organic products in school canteens, the importance of the concept of zero food waste and when it is generated in the whole life cycle of agri-food products [134], as well as the importance of better animal welfare [135], short food chains, and the Mediterranean Diet. With regard to food waste, the project of the Emilia Romagna Region has revealed that the main indicators used are the amount of generated food waste, the related CO_2 emissions, and the economic value of food waste [136]. Another interesting project named "the Sun in the Plate" [137] is currently ongoing in Tuscany Region, financially promoted by a local bank. The project involves more than 20 farming companies producing the typical Tuscany products in partnership with the eco-dynamics group of the University of Siena. The project has adopted the emergy accounting method and its indicators (total emergy and others), with the aim of increasing the understanding of the importance of the environmental support provided by nature, for production of the food needed every day [138].

6. Concluding Remarks

In this work, our aim was to evaluate a set of environmental and energy performance indicators identified on the basis of their potential and useful inclusion in the frameworks of the circular economy and "farm to fork strategy" of the European Union. We considered LCA indicators integrated with other performance indicators capable of shedding light on environmental aspects not considered in the LCA approach but still important in evaluating the sustainability and current global challenges of agri-food systems. The indicators, which were selected, critically evaluated on the basis of the two frameworks (circular economy and farm-to-fork strategy), and applied to Italy, confirm that the EU strategy could be considered a good starting point toward more sustainable patterns in agri-food systems, from cradle to consumer, and that CE fully complements the perspective of the EU strategy to avoid food losses and waste while favoring a better valorization of unavoidable residues. The reviewed literature clearly indicates that environmental and energy performance indicators are mainly derived from LCA, although other indicators, e.g., derived from emergy accounting and material flow accounting, have also shown the capability to provide thorough information about the investigated systems.

The results of this study may have implications both for research, by suggesting a further exploration on the topics covered in this study, and for policy, by evidencing suitable performance indicators to monitor the achievement of targets and goals, as well as proposed legislative and policy measures, actions, and practices of the farm to fork strategy and CAP.

The proposed framework for Italian agriculture shows that the EU indicators provide important information for the environmental and energy performances of a national agriculture; however, in order to have a more comprehensive picture, the integration with other indicators, as well as a deeper analysis of the environmental and energy performances of farms and their products, is important and should not be disregarded.

This study still had some weaknesses, primarily due to the limited criteria for searching the literature related to the reference topic (CE and farm to fork strategy of the European Union), to the selected period (2019–2022), and to the geographical area (studies mainly in the European area). These criteria were consistent with the goals of the research; however, they may have limited the number and comprehensiveness of the articles evaluated, thus representing a source of possible bias concerning the results achieved. To partially overcome this issue, we slightly expanded our literature focus by including a number of papers dealing with specific topics (e.g., circular economy in the agri-food sector, indicators for sustainable healthy diets, and food waste recovery pathways) in previous years, to ensure the multidimensionality and comprehensiveness of the study.

Author Contributions: Conceptualization, P.G. and S.U.; methodology, P.G. and S.U.; writing—original draft preparation, P.G., A.N., G.R., C.V., S.K. and R.P.; writing—review and editing, P.G. and S.U.; visualization, P.G.; supervision, S.U.; project administration, R.P.; funding acquisition, R.P. All authors have read and agreed to the published version of the manuscript.

Funding: The research described in this article was funded by the following European Commission research programs: the H2020-SC5-2020-2 scheme, grant agreement 101003491 (JUST2CE project); the Horizon 2020–Marie Sklodowska-Curie Actions–Innovative Training Networks 2018 program (grant number: 814247) (Realizing the transition to circular economy"); the Horizon 2020-MSCA-RISE-2018 Program, under Project No. 823967 named "Promoting circular economy in the supply chain" (ProCEedS).

Data Availability Statement: Not applicable.

Acknowledgments: The authors greatly thank the three anonymous reviewers for their accurate revision of the manuscript and their valuable comments.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Summary of the framework proposed in the farm to fork strategy of the European Commission (2020).

Areas of Intervention (Food Life Cycle Stage and Goals)	Suggested Actions/Practices/Goals in the Farm to Fork Strategy
1. Ensuring sustainable food production systems	• Carbon sequestration activities carried out by farmers and foresters. The Commission proposed to reward such activities via CAP or via other private or public initiatives such as the carbon market, the new EU Carbon farming initiative under the Climate Pact, and the development of a new framework for certifying carbon removal • Circular bio-based economy based on, e.g., advanced biorefineries that produce biofertilizers, protein feed, bioenergy, and biochemicals. Reduction in methane emissions by investing in anaerobic digestion for production of biogas. Development of renewable energies in farms and support of the commission under the condition that their adoption is sustainable, taking into account food security and biodiversity • Evidenced by the adoption of harmonized risk indicator by the commission to monitor the evolution of the risk related to pesticides, along with actions to reduce the overall use and risk of chemical pesticides by 50% and the use of more hazardous pesticides by 50% by 2030. These include the revision of the Sustainable Use of Pesticides Directive, improvement of the provisions on integrated pest management, promotion of safer alternatives of protecting harvests, and the use of alternative control techniques to reduce the use of pesticides. Evidenced by the support of the commission for the market development of pesticides containing biological active substances • Proposed action by the commission for the reduction in nutrient losses by at least 50% while maintaining soil fertility. Reduction in the use of fertilizers by at least 20% by 2030 by enforcing the current relevant environmental and climate legislation. Development by the commission with member states of an integrated nutrient management action to address nutrient pollution at source and increase the sustainability of the livestock sector. Adoption of measures in hotspot areas of intensive livestock farming (e.g., recycling of organic waste into renewable fertilizers) • Facilitation by the commission of the use of sustainable and innovative feed additives to reduce the dependency on critical feed materials (e.g., soya grown on deforested land) by fostering EU-grown plant proteins, as well as alternative feed materials such as insects, marine feed stocks (e.g., algae), and byproducts from the bioeconomy (e.g., fish waste). Revision of the EU promotion program for agricultural products to contribute to sustainable production and consumption and diets. Support for more sustainable carbon-efficient methods of livestock production • Reduction in the overall EU sales of antimicrobials for farmed animals and aquaculture by 50% by 2030. Revision by the Commission of animal welfare legislation, including on animal transport and the slaughter of animals, to align it with the latest scientific evidence • Adoption by the commission of rules to strengthen the vigilance on plant imports and surveillance on EU territory, as well as of measures to improve the access of farmers to a range of quality seeds for plant varieties adapted to the pressures of climate change, easier registration of seed varieties, and market access to traditionally and locally adapted varieties • Organic farming (objective of at least 25% of the EU's agricultural land under organic farming by 2030) and organic aquaculture. Adoption by the commission of further measures such as the action plan on organic farming to existing ones (CAP measures, such as eco-schemes, investment and advisory services, and the Common Fisheries Policy (CFP) to stimulate both supply and demand for organic products • New eco-schemes to enhance sustainable practices, such as precision agriculture, agroecology (including organic farming), carbon farming, and agroforestry • Support for sustainable fish and seafood production by means of keeping fish stocks at sustainable levels via the Common Fisheries Policy • Support of the commission to strengthen the competition of farmers and fishers in the supply chain by clarifying the competition rules

Table A1. *Cont.*

Areas of Intervention (Food Life Cycle Stage and Goals)	Suggested Actions/Practices/Goals in the Farm to Fork Strategy
2. Ensuring food security	• Monitoring of food security and competitiveness of farmers and food operators by the commission • Mitigation of climate change and biodiversity loss, considered as imminent and lasting threats to food security and livelihoods • Increase in the sustainability of food producers to improve their resilience • Recognition by the commission of the importance of the value and role of agri-food workers. Compliance with the key principles of European Pillar of Social Rights for precarious workers. Improvement of workers' social protection, as well as working and housing conditions, and protection of health and safety as key factors in building fair, strong, and sustainable food systems • Assessment of the resilience of food system by the commission and contingency plan for ensuring food supply and food security in times of crisis
3. Stimulating sustainable food processing, wholesale, retail, hospitality, and food services practices	• Development of an EU code of conduct for responsible business and marketing practice (with a monitoring framework) by the commission to promote and increase the availability and affordability of healthy, environmentally sustainable food • Action of the commission with food companies and organization for the reformulation of food products in line with guidelines for healthy, sustainable diets, and lower environmental footprint and energy consumption • Adaptation of marketing and advertising strategies taking into account the needs of the most vulnerable • Ensuring that food price campaigns do not undermine citizens' perception of the value of food. Reducing packaging in line with the new CEAP • Improvement of the corporate governance framework to integrate sustainability into corporate strategies of food industry • Promotion of sustainable and socially responsible production methods and circular business models in food processing and retail • Improvement of legislation related to food contact materials to ensure food safety and public health (particularly in reducing the use of hazardous chemicals), support the use of innovative and sustainable packaging solutions using environmentally friendly, reusable and recyclable materials, and contribute to food waste reduction • Substitution of single-use food packaging and cutlery by reusable products • Revision of marketing standards for developing sustainable agricultural, fishery, and aquaculture products • Increasing of the resilience of regional and local food systems by means of creation of shorter supply chains to reduce the dependence on long-haul transportation
4. Promoting sustainable food consumption and facilitating the shift to healthy, sustainable diets	• Shift toward more plant-based diet with less red and processed meat and with more fruits and vegetables • Provision of clear information to consumers to enhance their choices in healthy and sustainable food; harmonization of mandatory front-of-pack nutrition labeling, along with extension of mandatory origin or provenance indications to certain products taking into account impacts on the single market. Harmonization of voluntary green claims and creation of a sustainable labeling framework based on the nutritional, climate, environmental, and social aspects of food products • Definition of minimum mandatory criteria for sustainable food procurement in order to support the provision of sustainable food for schools, hospitals, and public institutions, as well as development of sustainable farming systems, such as organic farming • Tax incentives to support the shift toward sustainable and healthy diets by the consumers and more sustainable production practices with lower environmental externalities
5. Reducing food loss and waste	• Food loss prevention by setting legally binding targets and integration of food loss avoidance in other EU policies • Quantification of food waste levels and further investigation of food losses at the production stage to prevent them

Table A1. *Cont.*

Areas of Intervention (Food Life Cycle Stage and Goals)	Suggested Actions/Practices/Goals in the Farm to Fork Strategy
6. Combating food fraud along the food supply chain	• Cooperation with member states, Europol, and other bodies to use EU data on traceability and alerts to improve coordination on food fraud • Proposals of stricter dissuasive measures, better import controls, and strengthened coordination and investigative capacities of the European Anti-Fraud Office (OLAF)

References

1. Arora, N.K. Impact of climate change on agriculture production and its sustainable solutions. *Environ. Sustain.* **2019**, *2*, 95–96. [CrossRef]
2. FAO (Food and Agriculture Organization of the United Nations). FAO's Work on Climate Change, United Nations Climate Change Conference 2019. 2019. Available online: https://www.fao.org/3/ca7126en/CA7126EN.pdf (accessed on 25 January 2023).
3. The World Bank, 2022, Climate Change. Available online: https://www.worldbank.org/en/topic/climatechange/overview (accessed on 2 December 2022).
4. Agrifood Tech. Available online: https://www.agrifood.tech/sostenibilita/agricoltura-6-miliardi-di-danni-nellestate-2022-la-peggiore-siccita-da-500-anni/ (accessed on 30 November 2022).
5. NY Times. Available online: https://www.nytimes.com/2022/08/18/world/europe/drought-heat-energy.html (accessed on 30 November 2022).
6. Esposito, B.; Sessa, M.R.; Sica, D.; Malandrino, O. Towards Circular Economy in the Agri-Food Sector. A Systematic Literature Review. *Sustainability* **2020**, *12*, 7401. [CrossRef]
7. Cambeses-Franco, C.; González-García, S.; Gumersindo, F.; Moreira, M.T. Encompassing health and nutrition with the adherence to the environmentally sustainable New Nordic Diet in Southern Europe. *J. Clean. Prod.* **2021**, *327*, 129470. [CrossRef]
8. Grosso, G.; Fresán, U.; Bes-Rastrollo, M.; Marventano, S.; Galvano, F. Environmental Impact of Dietary Choices: Role of the Mediterranean and other Dietary Patterns in an Italian Cohort. *Int. J. Environ. Res. Public Health* **2020**, *17*, 1468. [CrossRef] [PubMed]
9. Silvestri, C.; Silvestri, L.; Piccarozzi, M.; Ruggieri, A. Toward a framework for selecting indicators of measuring sustainability and circular economy in the agri-food sector: A systematic literature review. *Int. J. Life Cycle Assess.* **2022**. [CrossRef]
10. Xu, X.; Sharma, P.; Shu, S.; Lin, T.-S.; Ciais, P.; Tubiello, F.N.; Smith, P.; Campbell, N.; Jain, A.K. Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods. *Nat. Food* **2021**, *2*, 724–732. [CrossRef]
11. Rosati, A.; Borek, R.; Canali, S. Agroforestry and organic agriculture. *Agroforest Syst.* **2021**, *95*, 805–821. [CrossRef]
12. Guarino, F.; Falcone, G.; Stillitano, T.; De Luca, A.I.; Gulisano, G.; Mistretta, M.; Strano, A. Life cycle assessment of olive oil: A case study in southern Italy. *J. Environ. Manag. Acc.* **2019**, *238*, 396–407. [CrossRef]
13. Gomiero, T.; Pimentel, D.; Paoletti, M.G. Is there a need for a more sustainable agriculture? *Crit. Rev. Plant Sci.* **2011**, *30*, 6–23. [CrossRef]
14. Timmermans, F. Farm to Fork Strategy: Towards a More Healthy and Sustainable Food System. Available online: https://ec.europa.eu/newsroom/intpa/items/682193/en (accessed on 2 December 2022).
15. European Commission. Farm to Fork Strategy, For a Healthy and Environmentally-Friendly Food System. 2020. Available online: https://ec.europa.eu/food/system/files/2020-05/f2f_action-plan_2020_strategy-info_en.pdf#:~{}:text=The%20Farm%20to%20Fork%20Strategy%20is%20a%20new,should%20see%20this%20as%20their%20responsibility%20and%20opportunity (accessed on 29 November 2022).
16. European Commission. Communication from the Commission to the European Parliament, The Council, The European and Economic and Social Committee and the Committee of the Regions. A new Circular Economy Action Plan For a Cleaner and more Competitive Europe COM/2020/98 Final. 2022. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN (accessed on 4 October 2021).
17. Mason, R.E.; White, A.; Bucini, G.; Anderzén, J.; Méndez, V.E.; Merrill, S.C. The evolging landascape of agricultural research. *Agroecol. Food Syst.* **2020**, *45*, 551–591. [CrossRef]
18. Donner, M.; de Vries, H. How to innovate business models for a circular bio-economy? *Bus. Strat. Environ.* **2021**, *30*, 1932–1947. [CrossRef]
19. De Rosa, M.; Di Pasquale, J.; Adinolfi, F. The Root towards More Circularized Animal Production Systems: From Animal to Territorial Metabolism. *Animals* **2021**, *11*, 1540. [CrossRef] [PubMed]
20. European Commission. Common Monitoring and Evaluation Framework, CAP Indicators. 2022. Available online: https://agridata.ec.europa.eu/extensions/DataPortal/cmef_indicators.html (accessed on 29 November 2022).
21. Hahladakis, J.N.; Iacovidou, E.; Gerassimidou, S. Chapter 19—Plastic Waste in a Circular Economy. In *Plastic Waste and Recycling: Environmental Impact, Societal issues, Prevention and Solutions*; Elsevier: Oxford, UK, 2020; pp. 481–512.
22. Ghisellini, P.; Santagata, R.; Zucaro, A.; Ulgiati, S. Circular patterns of waste prevention and recovery. *E3S Web Conf.* **2019**, *119*, 00003. [CrossRef]

23. Popp, J.; Kovács, S.; Oláh, J.; Divéki, Z.; Balázs, E. Bioeconomy: Biomass and biomass-based energy supply and demand. *N. Technol.* **2021**, *60*, 76–84. [CrossRef] [PubMed]
24. Ghisellini, P.; Ncube, A.; D'Ambrosio, G.; Passaro, R.; Ulgiati, S. Potential Energy Savings from Circular Economy Scenarios Based on Construction and Agri-Food Waste in Italy. *Energies* **2021**, *14*, 8561. [CrossRef]
25. Ellen Mac Arthur Foundation. 2022. Available online: https://ellenmacarthurfoundation.org/articles/we-need-to-talk-about-renewables-part-2 (accessed on 30 November 2022).
26. Bouwman, L.; Goldewijk, K.K.; Van Der Hoek, K.W.; Stehfest, E. Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period. *PNAS* **2011**, *110*, 20882–20887. [CrossRef]
27. Barthel, S.; Isendhal, C. Urban gardens, agriculture and water management: Sources of resilience for long-term food security in cities. *Ecol. Econ.* **2013**, *86*, 224–234. [CrossRef]
28. Rete Rurale Nazionale. Ricognizione Preliminare sui Rifiuti Agricoli e sui Sottoprodotti Dell'agroindustria. 2016. Available online: https://www.reterurale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/16486 (accessed on 29 September 2021).
29. Poponi, S.; Arcese, G.; Mosconi, E.M.; Pacchera, F.; Martucci, O.; Elmo, G.C. Multi-Actor Governance for a Circular Economy in the Agri-Food Sector: Bio-Districts. *Sustainability* **2021**, *13*, 4718. [CrossRef]
30. Fassio, F.; Tecco, N. Circular Economy for Food: A Systemic Interpretation of 40 Case Histories in the Food System in Their Relationships with SDGs. *Systems* **2019**, *7*, 43. [CrossRef]
31. IFPRI. 2020. Available online: https://www.ifpri.org/blog/circular-agriculture-vision-sustainability (accessed on 30 November 2022).
32. De Boer, I.J.M.; van Ittersum, M.K. Circularity in Agricultural Production. Wageningen University & Research, Wageningen, Netherlands. 2018. Available online: https://www.wur.nl/upload_mm/7/5/5/14119893-7258-45e6-b4d0-e514a8b6316a_Circularity-in-agricultural-production-20122018.pdf (accessed on 1 December 2022).
33. Muscio, A.; Sisto, R. Are Agri-Food Systems Really Switching to a Circular Economy Model? Implications for European Research and Innovation Policy. *Sustainability* **2020**, *12*, 5554. [CrossRef]
34. Moschitz, H.; Muller, A.; Kretzschmar, U.; Haller, L.; de Porras, M.; Pfeifer, C.; Oehen, B.; Willer, H.; Stolz, H. How can the EU Farm to Fork strategy deliver on its organic promises? Some critical reflections. *Euro Choices* **2021**, *20*, 30–36. [CrossRef]
35. Schebesta, H.; Candel, J.J.L. Game-changing potential of the EU's Farm to Fork Strategy. *Nat. Food* **2020**, *1*, 586–588. [CrossRef]
36. Montanarella, L.; Panagos, P. The relevance of sustainable soil management within the European Green Deal. *Land Use Policy* **2021**, *100*, 104950. [CrossRef]
37. Purnhagen, K.P.; Clemens, S.; Eriksson, D.; Fresco, L.O.; Tosun, J.; Qaim, M.; Visser, R.G.; Weber, A.P.; Wesseler, J.H.; Zilberman, D. Europe's Farm to Fork Strategy and Its Commitment to Biotechnology and Organic Farming: Conflicting or Complementary Goals? *Trends Plant Sci.* **2021**, *26*, 6. [CrossRef]
38. Velasco-Munñoz, J.F.; Mendoza, J.M.F.; Aznar-Sánchez, J.A.; Gallego-Schmid, A. Circular economy implementation in the agricultural sector: Definition, strategies and indicators. *Resour Conserv. Recycl.* **2021**, *170*, 105618. [CrossRef]
39. Mintcheva, V. Indicators for environmental policy integration in the food supply chain (the case of the tomato ketchup supply chain and the integrated product policy). *J. Clean Prod* **2005**, *13*, 717–731. [CrossRef]
40. Banasik, A.; Kanellopoulos, A.; Claassen, G.D.H.; Bloemhof-Ruwaard, J.M.; Van Der Vorst, G.A.J.; Nl, O.B. Assessing alternative production options for eco-efficient food supply chains using multi-objective optimization. *Ann. Oper. Res.* **2017**, *250*, 341–362. [CrossRef]
41. Bernstad, A.K.; Cánovas, A.; Valle, R. Consideration of food wastage along the supply chain in lifecycle assessments: A mini-review based on the case of tomatoes. *Waste Manag. Res.* **2017**, *35*, 29–39. [CrossRef]
42. Corrado, S.; Ardente, F.; Sala, S.; Saouter, E. Modelling of food loss within life cycle assessment: From current practice towards a systematisation. *J. Clean. Prod.* **2017**, *140*, 847–859. [CrossRef]
43. De Menna, F.; Dietershagen, J.; Loubiere, M.; Vittuari, M. Life cycle costing of food waste: A review of methodological approaches. *Waste Manag.* **2018**, *73*, 1–13. [CrossRef]
44. Vittuari, M.; De Menna, F.; Pagani, M. The Hidden Burden of Food Waste: The Double Energy Waste in Italy. *Energies* **2016**, *9*, 660. [CrossRef]
45. Ghisellini, P.; Protano, G.; Viglia, S.; Gaworksi, M.; Setti, M.; Ulgiati, S. Integrated agricultural and dairy production within a circular economy framework. A comparison of Italian and Polish farming systems. *J. Environ. Account. Manag.* **2014**, *2*, 367–384. [CrossRef]
46. Fahd, S.; Firoentino, G.; Mellino, S.; Ulgiati, S. Cropping bioenergy and biomaterials in marginal land: The added value of the biorefinery concept. *Energy* **2012**, *37*, 79–93. [CrossRef]
47. Giordano, R.; Thiebat, F.; Serra, V.; Budau, E.M. Metodologie integrate di valutazione applicate ai materiali di un edificio ad alta quota. *TECHNE J. Technol. Archit. Environ.* **2018**, *16*, 207–217. [CrossRef]
48. Arrigoni, A.; Pelosato, R.; Melià, P.; Ruggieri, G.; Sabbadini, S.; Dotelli, G. Life cycle assessment of natural building materials: The role of carbonation, mixture components and transport in the environmental impacts of hempcrete blocks. *J. Clean. Prod.* **2017**, *149*, 1051–1061. [CrossRef]
49. *ISO 14040:2006*; Environmental Management—Life Cycle Assessment—Principles and Framework. ISO: Geneva, Switzerland. Available online: https://www.iso.org/standard/37456.html (accessed on 2 December 2022).

50. Notarnicola, B.; Tassielli, G.; Renzulli, P.A.; Castellani, V.; Sala, S. Environmental impacts of food consumption in Europe. *J. Clean. Prod.* **2017**, *140*, 753–765. [CrossRef]
51. Graedel, T.E. Material flow analysis from origin to evolution. *Environ. Sci. Technol.* **2019**, *53*, 12188–12196. [CrossRef]
52. Camana, D.; Manzardo, A.; Toniolo, S.; Gallo, F.; Scipioni, A. Assessing environmental sustainability of local waste management policies in Italy from a circular economy perspective. An overview of existing tools. *Sustain. Prod. Consum.* **2021**, *27*, 613–629. [CrossRef]
53. Odum, H.T. Environmental Accounting. In *Emergy and Environmental Decision-Making*; John Wiley and Sons: New York, NY, USA, 1996; p. 370.
54. Brown, M.; Ulgiati, S. Emergy evaluation of biosphere and natural capital. *AMBIO A J. Hum. Environ.* **1999**, *28*, 428–493.
55. Golova, E.E.; Baranova, I.V.; Gapon, M.N. Crop Production Cost Accounting Audit. In *Land Economy and Rural Studies Essentials*; Nardin, D.S., Stepanova, O.V., Kuznetsova, V.V., Eds.; European Publisher: London, UK, 2021; Volume 113, pp. 72–78.
56. Paris, J.M.G.; Falkenberg, T.; Nöthlings, U.; Heinzel, C.; Borgemeister, C.; Escobar, N. Changing dietary patterns is necessary to improve the sustainability of Western diets from a One Health perspective. *Sci. Total Environ.* **2022**, *811*, 151437. [CrossRef]
57. European Commission. The Impact of EU Consumption on Deforestation: Identification of Critical Areas Where Community Policies and Legislation Could be Reviewed. 2013. Available online: https://ec.europa.eu/environment/forests/pdf/1.%20Report%20analysis%20of%20impact.pdf (accessed on 1 December 2022).
58. WWF. Stepping Up? The Continuing Impact of EU Consumption on Nature Worldwide. 2021. Available online: https://wwfeu.awsassets.panda.org/downloads/stepping_up___the_continuing_impact_of_eu_consumption_on_nature_worldwide_execsummary.pdf (accessed on 1 December 2022).
59. Bager, S.L.; Persson, U.M.; dos Reis, T.N.P. Eighty-six EU policy options for reducing imported deforestation. *One Earth* **2021**, *4*, 289–306. [CrossRef]
60. Altieri, M.A. *The Science of Sustainable Agriculture, Second Edition, Boca Raton*; CRC Press: Boca Raton, FL, USA, 2019; p. 448.
61. Kareem, A.; Farooqi, Z.U.R.; Kalsom, A.; Mohy-Ud-Din, W.; Hussain, M.M.; Raza, M.; Khursheed, M.M. *Organic Farming for Sustainable Soil Use, Management, Food Production and Climate Change Mitigation*; Sustainable Agriculture; Bandh, S.A., Ed.; Springer: Cham, Switzerland, 2021; p. 39. [CrossRef]
62. Newton, P.; Civita, N.; Frankel-Goldwater, L.; Bartel, K.; Johns, C. What Is Regenerative Agriculture? A Review of Scholar and Practitioner Definitions Based on Processes and Outcomes. *Front. Sustain. Food Syst.* **2020**, *4*, 577723. [CrossRef]
63. Brock, C.; Geier, U.; Greiner, R.; Olbrich-Majer, M.; Fritz, J. Research in biodynamic food and farming—A review. *Open Agric.* **2019**, *4*, 743–757. [CrossRef]
64. Sarkar, D.; Kar, S.K.; Chattopadhyay, A.; Rakshit, A.; Tripathi, V.K.; Dubey, P.K.; Abhilash, P.C. Low input sustainable agriculture: A viable climate-smart option for boosting food production in a warming world. *Ecolog. Ind.* **2020**, *115*, 106412. [CrossRef]
65. Cassman, K.G.; Grassini, P. A global perspective on sustainable intensification research. *Nat. Sustain.* **2020**, *3*, 262–268. [CrossRef]
66. Silvestri, L.; Silvestri, C.; Forcina, A.; De Luca, C. A review of energy-based indicators for assessing sustainability and circular economy in the agri-food production. *Procedia Comput. Sci.* **2022**, *200*, 1756–1765. [CrossRef]
67. Bux, C.; Lombardi, M.; Varese, E.; Amicarelli, V. Economic and Environmental Assessment of Conventional versus Organic Durum Wheat Production in Southern Italy. *Sustainability* **2022**, *14*, 9143. [CrossRef]
68. Reganold, J.P.; Watcher, J.M. Agriculture. In *Terrestrial Ecosystem and Biodiversity Edited by Yeqiao Wang*; CRC Press: Boca Raton, FL, USA, 2020. [CrossRef]
69. Zingale, S.; Guarnaccia, P.; Matarazzo, A.; Lagioia, G.; Ingrao, C. A systematic literature review of life cycle assessments in the durum wheat sector. *Sci. Total Environ.* **2022**, *844*, 157230. [CrossRef]
70. Connor, D.J. Relative yield of food and efficiency of land-use in organic agriculture—A regional study. *Agric. Syst.* **2022**, *199*, 103404. [CrossRef]
71. FAOSTAT. Countries by Commodity, Top 10 Countries Production of Olives. Available online: https://www.fao.org/faostat/en/#rankings/countries_by_commodity (accessed on 25 January 2023).
72. Lehmann, L.M.; Borzecka, M.; Zylowska, K.; Pisanelli, A.; Russo, G.; Chaley, B.B. Environmental impact assessments of integrated food and non-food production systems in Italy and Denmark. *Energies* **2020**, *13*, 849. [CrossRef]
73. Durán Zuazo, V.H.; Cárceles Rodriguez, B.; García-Tejero, I.F.; Gálvez Ruiz, B.; Cuadros Tavira, S. Benefits of organic olive rainfed systems to control soil erosion and runoff and improve soil health restoration. *Agron. Sustain. Dev.* **2020**, *40*, 41. [CrossRef]
74. Solomou, A.D.; Sfougaris, A. Contribution of agro-environmental factors to yield and plant diversity of olive grove ecosystem (*Olea europea* L.) in the Mediterranean landscape. *Agronomy* **2021**, *11*, 161. [CrossRef]
75. Iacola, I.; Colombo, L.; Guccione, G.D.; De Vita, P.; Paumbo, M.; Rutinnano, V.; Sciacca, F.; Virzì, N.; Canali, S. A multi-criteria qualitative tool for the sustainability assessment of organic durum wheat-based farming systems designed through a participative process. *Ital. J. Agron.* **2021**, *16*, 1785. [CrossRef]
76. Canali, S.; Diacono, M.; Campanelli, G.; Montemurro, F. Organic no-till with roller crimpers: Agroecosystem servicesand applications in organic Mediterranean vegetable productions. *Sustain. Agric. Res.* **2015**, *4*, 70–79. [CrossRef]
77. Nitschelm, L.; Flipo, B.; Auberger, J.; Chambaut, H.; Dauguet, S.; Espagnol, S.; Gac, A.; Le Gall, C.; Malnoé, C.; Perrin, A.; et al. Life cycle assessment data of French organic agricultural products. *Data Brief* **2021**, *38*, 107356. [CrossRef] [PubMed]
78. Guinée, J. Handbook on Life Cycle Assessment. In *Operational Guide to the ISO Standards*; Springer: Berlin/Heidelberg, Germany, 2002.

79. Magrini, A. Assessment of agricultural sustainability in European Union countries: A group-based multivariate trajectory approach. *Asta-Adv. Stat. Anal.* **2022**, *106*, 673–703. [CrossRef]
80. Cristiano, S. Organic vegetables from community-supported agriculture in Italy: Emergy assessment and potential for sustainable, just, and resilient urban-rural local food production. *J. Clean. Prod.* **2021**, *292*, 126015. [CrossRef]
81. Biernat, L.; Taube, F.; Vogeler, I.; Reinsch, T.; Kluss, C.; Loges, R. Is organic agriculture in line with the EU-Nitrate directive? On-farm nitrate leaching from organic and conventional arable crop rotations. *Agric. Ecosyst. Environ.* **2021**, *298*, 106964. [CrossRef]
82. Caputo, P.; Zagarella, F.; Cusenza, M.A.; Mistretta, M.; Cellura, M. Energy-environmental assessment of the UIA-OpenAgri case study as urban regeneration project through agriculture. *Sci. Total Environ.* **2020**, *729*, 138819. [CrossRef]
83. Wiśniewski, L.; Biczkowski, M.; Rudnicki, R. Natural potential versus rationality of allocation of Common Agriculture Policy funds dedicated for supporting organic farming development—Assessment of spatial suitability: The case of Poland. *Ecol. Indic.* **2021**, *130*, 108039. [CrossRef]
84. Ingrao, C.; Bacenetti, I.; Adamczyk, J.; Ferrante, V.; Messineo, A.; Huisingh, D. Renew. *Energy* **2019**, *136*, 296–307.
85. Esteves, E.M.M.; Narajo Herrera, A.M.; Peçanha Esteves, V.P.; do Rosário Vaz Morgado, C. Life cycle assessment of manure biogas production: A review. *J. Clean. Prod.* **2019**, *219*, 411–423. [CrossRef]
86. Hijazi, O.; Munro, S.; Zerhusen, B.; Effenberger, M. Review of life cycle assessment for biogas production in Europe. *Renew. Sustain. Energy Rev.* **2016**, *54*, 1291–1300. [CrossRef]
87. Quispe, I.; Navia, R.; Kahhat, R. Life cycle assessment of rice husk as an energy source. A Peruvian case study. *J. Clean. Prod.* **2019**, *209*, 1235–1244. [CrossRef]
88. Ghisellini, P.; Ulgiati, S. Circular economy transition in Italy. Achievements, perspectives and constraints. *J. Clean. Prod.* **2020**, *243*, 118360. [CrossRef]
89. Catone, C.M.; Ripa, M.; Geremia, E.; Ulgiati, S. Bio-products from algae-based biorefinery on wastewater: A review. *J. Environ. Manag.* **2021**, *239*, 112792. [CrossRef] [PubMed]
90. Kiss, K.; Ruszkai, C.; Takács-György, K. Examination of Short Supply Chains Based on Circular Economy and Sustainability aspects. *Resources* **2019**, *8*, 161. [CrossRef]
91. Jarzębowski, S.; Bourlakis, M.; Bezat-Jarzębowska, A. Short food supply chains (SFSC) as local and sustainable systems. *Sustainability* **2020**, *12*, 4715. [CrossRef]
92. Majewski, E.; Komerska, A.; Kwiatkowski, J.; Malak-Rawlikowska, A.; Wąs, A.; Sulewski, P.; Gołaś, M.; Pogodzińska, K.; Lecoeur, J.-L.; Tocco, B.; et al. Are short food supply chains more environmentally sustainable than long chains? A life cycle assessment (LCA) of the Eco-Efficiency of Food Chains in Selected EU Countries. *Energies* **2020**, *13*, 4853. [CrossRef]
93. Poponi, S.; Arcese, G.; Pacchera, F.; Martucci, O. Evaluating the transition to the circular economy in the agri-food sector: Selection of indicators. *Resour. Conserv. Recycl.* **2022**, *176*, 105916. [CrossRef]
94. Caldeira, C.; De Laurentiis, V.; Sala, S. Assessment of Food Waste Prevention Actions. Development of an Evaluation Framework to Assess the Performance of Food Waste Prevention Actions. 2019, p. 204. Available online: https://publications.jrc.ec.europa.eu/repository/handle/JRC118276 (accessed on 25 January 2023).
95. Chauhan, C.; Dhir, A.; Ul Akram, M.U.; Salof, J. Food loss and waste in food supply chains. A systematic literature review and framework development approach. *J. Clean. Produc.* **2021**, *295*, 126438. [CrossRef]
96. Malak-Rawlikowska, A.; Majewski, E.; Was, A.; Borgen, S.O. Measuring the economic, environmental, and social sustainability of short food supply chains. *Sustainability* **2019**, *11*, 4004. [CrossRef]
97. Diaz, F.; Romagnoli, F.; Neusel, L.; Hirzel, S.; Paulus, J.; Marchi, B.; Zanoni, S. The ICCEE Toolbox. A Holistic Instrument Supporting Energy Efficiency of Cold Food and Beverage Supply Chains. *Environ. Clim. Technol.* **2022**, *26*, 428–440. [CrossRef]
98. Mitrovic, M.; Tomasevic, I.; Djekic, I. Assessment of Environmental Impacts from Different Perspectives—Case Study of Egg Value Chain System in Serbia. *Foods* **2022**, *11*, 1697. [CrossRef]
99. Adams, D.; Donovan, J.; Topple, C. Achieving sustainability in food manufacturing operations and their supply chains: Key insights from a systematic literature review. *Sustain. Prod. Consum.* **2021**, *28*, 1491–1499. [CrossRef]
100. Yakovleva, N. Measuring the Sustainability of the Food Supply Chain: A case study of the UK. *J. Environ. Policy Plan.* **2007**, *9*, 75–100. [CrossRef]
101. Biasini, B.; Rosi, A.; Menozzi, D.; Scazzina, F. Adherence to the Mediterranean Diet in Association with Self-Perception of Diet Sustainability, Anthropometric and Sociodemographic Factors: A Cross-Sectional Study in Italian Adults. *Nutrients* **2021**, *13*, 3282. [CrossRef] [PubMed]
102. Grammatikopoulou, M.G.; Gkiouas, K.; Tranidou, A.; Goulis, D.G. Chapter 8—Food security and Adherence to the Mediterranean Diet: An Interplay of Socio-Demographic Characteristics. In *the Mediterranean Diet*, 2nd ed.; Elsevier: Amsterdam, The Netherlands, 2020; pp. 79–87.
103. Serra-Majem, L.; Román-Viñas, B.; Sanchez-Villegas, A.; Guasch-Ferré, M.; Corella, D.; La Vecchia, C. Benefits of the Mediterranean diet: Epidemiological and molecular aspects. *Mol. Asp. Med.* **2019**, *67*, 1–55. [CrossRef]
104. Donini, L.M.; Serra-Majem, L.; Bulló, M.; Gil, Á.; Salas-Salvadó, J. The Mediterranean diet: Culture, health and science. *Br. J. Nutr.* **2015**, *113*, S1–S3. [CrossRef]

105. Willett, W.; Rockström, J.; Loken, B.; Springmann, M.; Lang, T.; Vermeulen, S.; Garnett, T.; Tilman, D.; Declerck, F.; Wood, A.; et al. Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems. *Lancet* **2019**, *393*, 447–492. [CrossRef] [PubMed]
106. González-García, S.; Green, R.F.; Scheelbeek, P.F.; Harris, F.; Dangour, A.D. Dietary recommendations in Spain –affordability and environmental sustainability? *J. Clean Prod.* **2020**, *254*, 120125. [CrossRef] [PubMed]
107. Meltzer, H.M.; Brantsæter, A.L.; Trolle, E.; Eneroth, H.; Fogelholm, M.; Ydersbond, T.A.; Birgisdottir, B.E. Environmental sustainability perspectives of the nordic diet. *Nutrients* **2019**, *11*, 2248. [CrossRef] [PubMed]
108. Esteve-Llorens, X.; Moreira, M.T.; Feijoo, G.; González-García, S. Linking environmental sustainability and nutritional quality of the Atlantic diet recommendations and real consumption habits in Galicia (NW Spain). *Sci. Total Environ.* **2019**, *683*, 71–79. [CrossRef] [PubMed]
109. Hachem, F.; Vanham, D.; Moreno, L.A. Territorial and Sustainable Diets. *Food Nutr. Bull.* **2020**, *41*, S87–S103. [CrossRef] [PubMed]
110. Belgacem, W.; Mattas, K.; Arampatzis, G.; Baourakis, G. Changing dietary behavior for better biodiversity preservation: A preliminary study. *Nutrients* **2021**, *13*, 2076. [CrossRef] [PubMed]
111. Vanham, D.; Del Pozo, S.; Pekcan, A.G.; Keinan-Boker, L.; Trichopoulou, A.; Gawlik, B.M. Water consumption related to different diets in Mediterranean cities. *Sci. Total Environ.* **2016**, *573*, 96–105. [CrossRef]
112. Huijbregts, M.A.; Steinmann, Z.J.; Elshout, P.M.; Stam, G.; Verones, F.; Vieira, M. ReCiPe2016: A harmonised life cycle impact assessment method at midpoint and endpoint level. *Int. J. Life Cycle Assess.* **2017**, *22*, 138–147. [CrossRef]
113. Harrison, M.R.; Palma, G.; Buendia, T.; Bueno-Tarodo, M.; Quell, D.; Hachem, F. A Scoping Review of Indicators for Sustainable Healthy Diets. *Front. Sustain. Food Syst.* **2022**, *5*, 822263. [CrossRef]
114. Portugal-Nunes, C.; Nunes, F.M.; Fraga, I.; Saraiva, C.; Gonçalves, C. Assessment of the Methodology That Is Used to Determine the Nutritional Sustainability of the Mediterranean Diet—A Scoping Review. *Front. Nutr.* **2020**, *8*, 772133. [CrossRef]
115. Santagata, R.; Ripa, M.; Genovese, A.; Ulgiati, S. Food waste recovery pathways: Challenges and opportunities for an emerging bio-based circular economy. A systematic review and an assessment. *J. Clean. Prod.* **2021**, *286*, 125490. [CrossRef]
116. Goossens, Y.; Wegner, A.; Schmidt, T. Sustainability Assessment of Food Waste Prevention Measures: Review of Existing Evaluation Practices. *Front. Sustain. Food Syst.* **2019**, *3*, 90. [CrossRef]
117. FAO. Food Loss and Waste. 2023. Available online: https://www.fao.org/nutrition/capacity-development/food-loss-and-waste/en/ (accessed on 25 January 2023).
118. Amicarelli, V.; Rana, R.; Lombardi, M.; Bux, C. Material flow analysis and sustainability of the Italian meat industry. *J. Clean. Prod.* **2021**, *299*, 126902. [CrossRef]
119. Ncube, A.; Fiorentino, G.; Colella, M.; Ulgiati, S. Upgrading wineries to biorefineries within a Circular Economy perspective: An Italian case study. *Sci. Total Environ.* **2021**, *775*, 145809. [CrossRef] [PubMed]
120. Oliveira, M.; Cocozza, A.; Zucaro, A.; Santagata, R.; Ulgiati, S. Circular economy in the agro-industry: Integrated environmental 1313 assessment of dairy products. *Renew. Sustain. Energy Rev.* **2021**, *148*, 111314. [CrossRef]
121. Rukundo, R.; Bergeron, S.; Bocoum, I.; Pelletier, N.; Doyon, M.; Rada, C.; Cioca, L.-I. A Methodological Approach to Designing 1289 Circular Economy Indicators for Agriculture: An Application to the Egg Sector. *Sustainability* **2021**, *13*, 8656. [CrossRef]
122. Lins, M.; Zandonadi, R.P.; Strasburg, V.J.; Nakano, E.Y.; Braz, R.; Botelho, A.; Raposo, A.; Ginani, V.C. Eco-Inefficiency Formula: A Method to Verify the Cost of the Economic, Environmental, and Social Impact of Waste in Food Services. *Foods* **2021**, *10*, 1369. [CrossRef]
123. Derqui, B.; Fernandez, V. The opportunity of tracking food waste in school canteens: Guidelines for self-assessment. *Waste Manag.* **2017**, *69*, 431–444. [CrossRef] [PubMed]
124. Oliveira, M.; Miguel, M.; Kevin Van Langen, S.; Ncube, A.; Zucaro, A.; Fiorentino, G.; Passaro, R.; Santagata, R.; Coleman, N.; Lowe, B.H.; et al. Circular Economy and the Transition to a Sustainable Society: Integrated Assessment Methods for a New Paradigm. *Circ. Econ. Sustain.* **2021**, *12*, 8990. [CrossRef]
125. Subramanian, K.; Chopra, S.S.; Wharton, C.M.; Yonge, W.; Allen, J.; Stevens, R.; Fahy, S.; Milindi, P.S. Mapping the food waste-energy-water-emissions nexus at commercial kitchens: A systems approach for a more sustainable food service sector. *J. Clean. Prod.* **2021**, *301*, 126856. [CrossRef]
126. Cudjoe, D.; Chen, W.; Zhu, B. Valorization of food waste into hydrogen: Energy potential, economic feasibility and environmental impact analysis. *Fuel* **2022**, *324*, 124476. [CrossRef]
127. Wu, M.; Hu, J.; Shen, F.; Huang, M.; Zhao, L.; Tian, D.; Zhang, Y.; Liu, Y.; Zeng, Y.; Deng, S. Conceptually integrating a multi-product strategy for the valorization of kitchen waste towards a more sustainable management. *J. Clean. Prod.* **2021**, *306*, 127292. [CrossRef]
128. Symbola, Cloros, Accredia. Certificare Per Competere. 2016. Available online: https://www.accredia.it/pubblicazione/certificare-per-competere-dalle-certificazioni-ambientali-nuova-forza-al-made-in-italy-rapporto-di-symbola-accredia-e-cloros-febbraio-2016/ (accessed on 25 January 2023).
129. EDP International, Library. Available online: https://www.environdec.com/library (accessed on 25 January 2023).
130. European Environment Agency. Water Scarcity. Available online: https://www.eea.europa.eu/archived/archived-content-water-topic/featured-articles/water-scarcity (accessed on 25 January 2023).
131. EPD International. Durum Wheat from Organic and Conventional Cultivation. Available online: https://epd-portal-api.azurewebsites.net/api/v1/EPDLibrary/Files/f4c3c242-f6b1-4ebf-1bc1-08da2ccce1bd/Data (accessed on 25 January 2023).

132. EPD International. Olio Extra Vergine Biologico. Available online: https://epd-portal-api.azurewebsites.net/api/v1/EPDLibrary/Files/93f87b3c-6645-4a9e-dd7a-08da1c754aa8/Data (accessed on 25 January 2023).
133. Atlas of the Circular Economy. Available online: https://economiacircolare.com/atlante/ (accessed on 25 January 2023).
134. Regione Emilia Romagna, Educazione Alimentare: Bio Nelle Mense Scolastiche, Spreco Alimentare km 0, Dieta Mediterranea. Available online: https://www.alimenti-salute.it/notizia/regione-emilia-romagna-educazione-alimentare-bio-mense-scolastiche-spreco-alimentare-km-0-e (accessed on 25 January 2023).
135. Regione Emilia Romagna, L'allevamento Della Gallina Ovaiola. Available online: https://www.alimenti-salute.it/infografica/benessere-animale-emilia-romagna-lallevamento-gallina-ovaiola (accessed on 25 January 2023).
136. Regione Emilia Romagna, Prevenire e Ridurre lo Spreco Alimenare. Available online: https://www.alimenti-salute.it/infografica/prevenire-e-ridurre-spreco-alimentare (accessed on 25 January 2023).
137. Ecodynamics, University of Siena, il sole nel Piatto. Available online: https://www.ecodynamics.unisi.it/il-sole-nel-piatto/ (accessed on 25 January 2023).
138. Pulselli, F.M.; Maccanti, M.; Esposito, G.; Niccolucci, V.; Kemda, M.M.; Marchettini, N. From Emergy Synthesis and UEVs of Agriproducts to Database, Labelling, and eco-Score. Emergy Conference 2023—Book of Abstract. Available online: https://www.emergysociety.com/emergy-synthesis-11/es11_book-of-abstracts/ (accessed on 25 January 2023).