Environmental Impact Assessment of Agricultural Production Using LCA: A Review

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Abstract: Life cycle impact assessment (LCA) provides a better understanding of the energy, water, and material input and evaluates any production system’s output impacts. LCA has been carried out on various crops and products across the world. Some countries, however, have none or only a few studies. Here, we present the results of a literature review, following the PRISMA protocol, of what has been done in LCA to help stakeholders in these regions to understand the environmental impact at different stages of a product. The published literature was examined using the Google Scholar database to synthesize LCA research on agricultural activities, and 74 studies were analyzed. The evaluated papers are extensively studied in order to comprehend the various impact categories involved in LCA. The study reveals that tomatoes and wheat were the major crops considered in LCA. The major environmental impacts, namely, human toxicity potential and terrestrial ecotoxicity potential, were the major focus. Furthermore, the most used impact methods were CML, ISO, and IPCC. It was also found that studies were most often conducted in the European sector since most models and databases are suited for European agri-food products. The literature review did not focus on a specific region or a crop. Consequently, many studies appeared while searching using the keywords. Notwithstanding such limitations, this review provides a valuable reference point for those practicing LCA.

Keywords: meta-analysis; GHG emission; ecotoxicity; agriculture; crop production; LCA

1. Introduction

Food supply chains (FSCs) are very complex. There are many components involved in FSCs that process, produce, package, store, transfer, distribute, and market food products to final consumers [1]. Each element in the FSC process is essential, as in any other supply chain; a change in one component affects the others. The relationship between the food system and the economy, environment, and society is mentioned by some organizations and agencies, such as the Food and Agricultural Organization (FAO), Institute of Medicine (IOM), and National Research Council (NRC), when they define the FSC [2]. Therefore, the most crucial question is as follows: Which food production system is more sustainable for the environment and communities?

There are many concerns about food resources and massive population growth, such as meeting the food demand for the world’s population, production, and food consumption [1]. The total crop production must double or increase by at least 70% to meet the increasing world population’s demand by 2050 [3]. Models have estimated that a 2.4% annual increase in crop yield is necessary to reach the 2050 demand [4]. The rise in food demand results in substantial energy and resource use by the food supply chain, leading to different environmental impacts. Many organizations have mentioned environmental impacts associated with food production, including the use of land, water, and climate
change. Significant environmental challenges that humans face are primarily due to climate change and the predicted future shortage of fossil fuels [5]. Farming methods, fertilizers, pesticides, water pumping, tractors to prepare the land, and transport of the crops or final food products via railroads, trucks, airplanes, or ships can all impact the environment. Lastly, food processing and food preservation methods such as refrigeration and packaging also contribute to environmental damages. There are many production sectors involved in environmental impacts, and one of them is the agricultural sector.

According to the Environmental Protection Agency (EPA), agricultural chemicals and pesticide manufacturing are two of the 68 area source groups that account for 90% of the overall emissions of the 30 urban air toxins. For example, in 2018, greenhouse gas (GHG) emissions from the agriculture economic sector accounted for 9.9% of total US greenhouse gas emissions. Furthermore, GHG from agriculture has increased by 10.1% since 1990 [6]. One of the direct greenhouse gases is nitrous oxide. Agricultural soil management operations such as synthetic and organic fertilizers and other cropping techniques, the management of manure, and the burning of agricultural wastes produce nitrous oxide. Agricultural soil management is the major source of \( \text{N}_2\text{O} \) emissions in the US, accounting for around 75% of total emissions [7]. Agricultural soils, for example, are a major source of \( \text{NO}_x \) pollution in California, with soil \( \text{NO}_x \) emissions in the state’s Central Valley region being particularly high. Therefore, it is necessary to quantify the impacts of agricultural products along the food supply chain for sustainable production and consumption systems.

Since the number of operations in the food system is large and complex, many studies have used the life cycle assessment (LCA) methodology as a tool to study the overall resources used and the environmental impact of food products over its entire life cycle [8]. It is best known for its qualitative and quantitative analysis of a product’s environmental aspects over its whole life cycle [9]. Products in this context include both goods and services [10]. Environmental impacts in the LCA context refer to the adverse effects on the areas of concern such as the ecosystem, human health, and natural resources. Due to the limitation of raw materials and energy resources, LCA has been used since the 1960s to find solutions for sustainable productions [11].

Such research on the crop supply chain provides helpful information from the economic, social, and environmental perspectives. Using the LCA offers a better understanding of the energy, water, and material input and evaluates the outputs’ impacts. Thus, decision-makers in various fields can regulate new policies and use modern practices to improve the production supply chains. As observed in previous studies [9,12], many authors have used LCA to address environmental impacts over the entire life cycle of crops. However, the world’s largest industrial sector, the food supply chain, involves various crops and products that still need to be addressed by the LCA.

Therefore, this study’s broad objective is to synthesize the LCA studies relating to different environmental impacts from agricultural production to support stakeholders with decision-making. Besides, an in-depth analysis of the various steps involved in LCA is provided.

2. Materials and Methods

A literature review of published articles in international journals was undertaken using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol to address the research aims.

2.1. Eligibility Criteria

The studies that applied the following selection criteria were chosen to reduce the number of articles: (i) using the LCA method, (ii) including GHG in their impact category and/or ecotoxicity, and (iii) researching agriculture products. A total of 36 research articles were eliminated because they were about FSCs and not GHG/ecotoxicity as an effect cate-
category, did not apply the LCA methodology, or utilized the LCA method for nonagricultural products. The LCA studies were analyzed extensively considering four phases of the LCA:

- Goal and scope definition,
- Life cycle inventory,
- Life cycle impact assessment,
- Life cycle interpretation/recommendation options.

2.2. Search Strategy

The literature review was done through the Google Scholar database. The keyword “LCA crop production” was used in the initial step, which yielded 59,100 studies as of July 2021. Later, more specific keywords were used, such as “agri-food supply chain and LCA” and “agri-food supply chain and GHG” combined with different fruit and vegetable products such as corn, peanuts, wheat, tomato, and apple. Nevertheless, the number of studies available remained enormous, the largest number of articles we got when we used the above key word with different crops was 7330, while the smallest number was 1820. A total of 110 articles were downloaded and analyzed. Twenty-nine studies were excluded because they were about FSCs and not about GHG/ecotoxicity as an effect category, or because they utilized the LCA method.

Furthermore, seven more were excluded because they used the LCA method for non-agricultural products. Accordingly, we ended up with 74 articles after applying the selection criteria. Figure 1 shows the steps used throughout the review and the inclusion criteria for the literature.

Figure 1. Steps followed for review and the inclusion/exclusion criteria.
2.3. Categorization

The data obtained from the reviewed articles included the year of study, the aim of the study, and the different steps involved in LCA assessment, which are discussed in the results section. The timeline, different components, the approach of the LCA, application of the LCA concept in the impact analysis, and suggestions for a sustainable food system are all covered.

2.4. Data Analysis

The analysis was carried out by obtaining the necessary information from the literature, as given in Tables A1 and A2 (Appendix A). Then, the information was visualized by means of collapsible trees, bar charts, doughnut figures, and word clouds after the information was classified into different result sections. Word clouds have evolved as a straightforward and visually appealing technique of text representation. They are used in a variety of contexts to offer an overview by reducing text down to the most frequently occurring terms. This is usually done statistically as a pure text summary [13,14]. Word clouds can be the initial step to refine the important concepts of results, which could save a great deal of time for other researchers since they already know where to start and the most common terms and ideas [15]. Pie and doughnut charts represent the relationship of parts with the whole [16,17]. Collapsible trees, bar charts, and doughnut figures are designed to provide greater numerical detail. Combining word clouds and bar charts allowed presenting both qualitative and quantitative information on LCA results.

The collapsible tree diagram was created with R software Version 3.6.1, and the bar and doughnut figures were created with Microsoft Excel. When making word cloud figures using the word cloud online website (https://www.jasondavies.com/wordcloud/ accessed on November 2021), each word must be typed correctly since the size and the color of the words in the figure are affected by the number of words entered. Therefore, it is essential to make sure that the number of entered words is accurate.

Lastly, the study was organized in IMRAD format, which is the most common format for scientific papers. The term represents the first letters of the words introduction, materials and methods, results, and discussion. IMRAD format facilitates knowledge acquisition and enables easy evaluation of an article [18]. Currently, IMRAD is used by the majority of academic publications. Before the IMRAD structure, all academic writing followed the IBC (introduction, body, and conclusion) pattern. The IMRAD format is only a more specified variant of the IBC format. [19]. It is important to keep in mind that no one journal follows a standard or consistent format. Each journal has its structure, yet they all have a guideline for authors [20].

3. Results

3.1. Snapshot of Selected Studies

The characteristics of publications during 1998–2021 are displayed in Figure 2 to obtain an overview of LCA research. The number of publications per year has increased steadily since 2008, following development of the ISO standard.

Critiques of the ISO 14040 series pre-2006 were that LCA is too nascent [21], and ISO 14040 does not address uncertainty, weighting, valuation, and allocation [22].

The release of the latest version of the ISO 14040 standard in 2006 explains why LCA research is attracting more attention. Moreover, some have recently gone so far as to state that the ISO 14040: 2006 series “has proven a suitable tool for sustainability assessment” [13,14]. Fava et al. (2009) claimed that ISO 14040 should be the basis for future LCA studies [23].
Figure 2. Frequency of studies related to LCA of agricultural production from 1998 to 2021 ($n = 74$).

Studies found that the most common tool to study the impact on the environment associated with a product over its life cycle in the agri-food sector was the LCA ISO 14040 standard [14,15]. LCA ISO 14040 has four main phases: (1) goal and scope, which is the essential component of the LCA, (2) qualitative and/or quantitative inventory analysis of the used resources and the emissions released from the life cycle of a product, (3) life cycle impact assessment, which can be divided into classification, characterization, and evaluation, and (4) the interpretation, involving the identification of key issues, evaluation (including checking completeness, sensitivity, and consistency), and development of conclusions together with recommendations, as defined by ISO 14043 (Figure 3). The details of each phase are discussed below.

Figure 3. Overview of life cycle assessment (LCA) phases.

3.2. Phase 1: Goal and Scope Definition
3.2.1. Goal

According to Lee and Inaba (2004), the following questions should be addressed to set up the goal: Why perform LCA, who is the target audience, and what is the product under the LCA study [10]? These were recognized from the reviewed articles while examining the first phase of the LCA, as given in Figure 4. Some of the studies stated the answers to these questions directly, whereas others addressed them indirectly. Figures 5–7 show the most common responses to each question.
Aims of LCA

As indicated in the literature, LCA studies can be partitioned into two major categories: descriptive and comparative. Descriptions aim to recognize the natural load of a chosen framework, while comparisons aim to differentiate between two frameworks. Among the discussed papers, 48 were descriptive, while 30 were comparative. As noted, the most common aim was to assess agricultural production, cultivation, processing, packaging, transport, and emission at all production stages to recognize the vast issues and to propose reasonable alternatives that decrease the environmental effects. The purpose of this review was to better understand how to use LCA to evaluate the environmental impact of agricultural production. The least common goal was to compare LCA to other methods, which may be due to the difficulty of making a fair comparison in terms of method performance.

Target Audience

The target audience defines who undertakes or commissions an LCA and for whom. It is critical to understand who will use the LCA results to provide them with helpful information. The majority of articles have multiple target audiences (TAs). Politicians working on climate change, decision-makers, and policymakers on global warming potential (GWP) footprints related to food and common agricultural policy (CAP) were the most common TAs, with 10 studies. Additionally, several studies targeted government sectors such as food sector policymakers, the country’s agriculture sector, and the fruit and vegetable sector. Following that, the producers, namely, the farmers and the producing industry, were targeted in eight studies, six of which provided information to the consumer on a local and international scale.

Agricultural

We divided the products into 11 categories: tomato, fruits, citrus, vegetable, fresh salad, grains, seeds, oil, sugar, flower, and trees, as shown in Figure 7. The most common product was tomato; 13 studies analyzed tomato production, including fresh tomato, canned tomato (whole peeled, paste, and diced), and ketchup. The second most common product was wheat with nine studies. Because some studies involved more than one crop,

Figure 4. Phase 1 (goal and scope definition) of life cycle assessment (LCA).

Figure 5. Quantitative and qualitative representation of the common aims of LCA from the literature.
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Figure 6. Target audiences in the literature represented as bars (quantitative) and a word cloud (qualitative).
that explains why the same reference was used for multiple crop groups and why the number of studies on the chart exceeds the number of studies covered. Tomato production was separated into three categories since three types of tomato products (fresh tomato, canned tomato, and tomato ketchup) were considered, as indicated in the diagram.

**Figure 7.** Common agricultural products used in LCA studies.
Agricultural

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3.2.2. Scope

The scope defines the product system boundaries that determine which unit processes should be included in the LCA analysis and which should be excluded. Table A2 (Appendix A) includes more information on all 74 studies, including their inputs and outputs inside and outside of the scope. Most studies (14) contained three to four phases in their boundaries, as shown in Figure 8A. There are two explanations for not including the eliminated phases in the majority of articles. The first is a lack of data and knowledge about individual inputs, making it difficult to get a decent overall view. Secondly, some authors excluded the minor influence stages because it was impossible to include all phases.

Since we are looking at the agri-food supply chain, most of the articles noticeably had similar steps when designing their boundaries. Depending on the selected crop and the target audience, there were slight differences in the scope’s starting point and
finishing point (Figure 8B). According to the review, 47 studies started their scope from the nursery stage (cradle), which involves preparing the raw materials, buildings, and field or land. Furthermore, 25 studies began their scope from the farming stage (farm gate). Considering our focus on agricultural production, only one study started their scope after the farming stage.

Similarly, the final stage differed from one study to another, ranging from the farming stage to the grave, including the product’s processing, packaging, storing, and transferring stages. Thirty-one studies in the literature review included steps until the crop harvesting stage, whereas 16 authors included some or all of the processing, packaging, and storing stages in the study’s scope. A number of reviewed studies reached the point of distribution and consumption in their analysis. Disposal and waste management were the final stages in some studies, with 10 articles including the end-of-life phase in their analysis (Figure 8B). One study did not specify boundaries; thus, the number in Figure 8B is less than the number of studies reviewed [24].

3.2.3. Functional Unit

Another step of the goal and scope phase is to choose a functional unit of the scope. A functional unit is the reference unit in which elementary flows from the inventory until the impact assessment stage are represented. Selecting the ideal functional unit is necessary during the boundary designation step. The functional unit is dependent on the type of input materials (raw material) and the final products. Accordingly, the input unit might be separate from the outputs. For example, the output such as GHG emissions could be in kg·ha\(^{-1}\) while the final product could be in tons or the input material could be in kWh for energy consumption and kg for fertilizers. Figure 9 shows the most common functional units used in previous studies.

![Figure 9. Functional units identified from the studies.](image)
3.2.4. Data Quality Requirement

The reliability of the results from LCA studies strongly depends on how data quality requirements are met. The following parameters should be considered: time-related coverage (selected year), geographical coverage (study area), and technology coverage (technology used in the processes stages). This paper examined the temporal and spatial data in detail and the used machinery in general.

It is understood from the literature review that most studies collected their data for a single year of cultivation (Figure 10B). The spatial scale of the analysis (global or regional) depends on the impact category. For example, global warming is a worldwide issue, whereas acidification is a regional issue. Furthermore, two countries were commonly represented in the evaluated research, Italy and the United States, with 17 and 14 studies, respectively (Figure 10A). When it comes to the technology used in each activity, the majority of the tools mentioned were agricultural equipment, which is to be expected given that we are investigating crop production.

![Figure 10. (A) Quantitative (bars) and qualitative (word cloud) representation of the geographic coverage considered in the reviewed studies; (B) donut chart depicting the temporal scales used in the literature.](image-url)
3.3. Phase 2: Life Cycle Inventory

The second step of the LCA is the life cycle inventory analysis (LCI). The product’s life cycle inventory results in an LCA study are obtained by summing up all fractional contributions of the input and output from each unit process in the product’s production system. Thus, LCI generates quantitative environmental information of a product throughout its entire life cycle.

Most studies at this stage specified the input material (water, fertilizer, pesticide, diesel, etc.) in each process of the production included in the scope, as well as the output (harvested crop, waste, emission to the air, soil, and water, etc.). Furthermore, they mentioned the sources of the inventory data (Figure 11), typically being from primary and/or secondary data sources. Primary data are obtained from specific processes throughout the life cycle of the researched product. Process activity data (physical measures of a process that results in GHG emissions or removal), direct emissions data (determined through direct monitoring, stoichiometry, mass balance, or similar methods) from a specific site, or data averaged across all sites containing the specific process are all examples of primary data [25]. Secondary data are collected from government departments, organizational records, and studies that previously gathered information from primary sources and made it available to other researchers.

![Figure 11. Phase 2 (inventory) of life cycle assessment (LCA).](image-url)
About 48% of the studies used secondary data, 13% used primary data, and 35% used both. One study collected data from a real farm experience. Three authors conducted interviews with owners to collect the data. Two studies used surveys with specific questions to collect the required information. One study mentioned that the source was primary, but the article did not specify their method. Seven studies utilized primary data, while the other nine used secondary data. The authors of the examined research utilized two types of secondary data methods: databases and previous studies. Eleven of the studies used databases, while five of them used previous studies. Five writers, on the other hand, gathered inventory data from databases and prior studies. Twenty-six studies utilized both primary and secondary approaches to reduce the uncertainty of their findings (Figure 12A,B).

Figure 12. (A) Data sources of the inventory stage rendered as a pie chart; (B) breakdown of primary and secondary data into various sources as obtained from the studies.
3.4. Phase 3: Life Cycle Impact Assessment

In life cycle impact assessment (LCIA), the significance of a product system’s potential environmental impacts, based on life cycle inventory results, is evaluated using LCIA. The LCIA consists of several elements: classification, characterization, normalization, and weighting. Of these four elements, normalization and weighting are considered optional, while the first two are mandatory elements in LCIA [10] (Figure 13). As shown in Figure 14, all 74 reviewed studies completed the classification and characterization phases, whereas 14 studies completed normalization and 10 completed weighting. Few studies included the waiting stage since it is optional and challenging.

The first step is classification, which involves identifying the impact assessment method. The most common standard method was the CML with various versions, such as CML 2 baseline 2000 V2/world, developed by the Center for Environmental Studies, and CML 2000 produced by the Center of Environmental Science of Leiden University. The second most common methods were ISO 14044 (2006), ISO (2000), and ISO 14040, followed by many other methods, such as IPCC 2001 GWP 100, proposed by the Intergovernmental Panel on Climate Change. For more information about the methods used in the studies, see Figure 15. The model used to calculate the impact is determined by the impact category the author intends to examine. As a result, LCA, ISO, and IPCC were the most commonly used impact methods since they provide categorization factors for ecotoxicity and climate change, which were among the criteria used to select articles for this review.

![Figure 13. Phase 3 (impact assessment) of life cycle assessment (LCA).](image-url)
Choosing the correct method for the LCA’s impact assessment stage depends on the impact category under investigation. Each method has categories; for example, CML 2000 has 10 environmental impact categories: abiotic depletion, global warming, ozone layer depletion, human toxicity, freshwater aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity, photochemical oxidation, acidification, and eutrophication.

In the process to quantify the impact of a procedure or material used, impact categories are first chosen, followed by quantifying environmental impact in each impact category using the equivalency approach. This process is termed “characterization” [10]. Characterization includes the emissions to air, soil, and water, as represented in Figure 16. The most prevalent impact categories in the 74 papers were human toxicity and ecotoxicity, with 48 and 41 studies, respectively. Moreover, 34 studies included global warming potential as an effect category, whereas marine pollution (26 articles), freshwater aquatic ecotoxicity
(23 articles), and acidification potential (22 articles) were topics of the remaining studies (Figure 16).

Figure 16. Illustration of LCIA impact categories from the literature (characterization).

3.5. Phase 4: Life Cycle Interpretation/Recommendation Options

The primary purpose of interpretation, which is the last phase of the LCA, is to use the inventory results and impact assessment analysis to evaluate the starting point for product improvement. The starting point is to understand the process tree and then identify the key issues, i.e., the key processes, materials, activities, components, or even
life cycle stages in developing a product. The primary purpose is followed up with improvement recommendations to find more environmentally friendly designs and/or process modification. Studies applied dominance analysis and marginal analysis to identify the key issues. The dominant aspects of the inventory table may be revealed by studying the environmental elements of a process matrix. An arbitrarily chosen criterion, such as “contribution greater than 1% of the total impact”, can be applied in identifying key issues from the matrix. Marginal analysis illustrates the changes in the process to which the intervention, effect, or index is most sensitive. In theory, marginal analysis is a powerful tool in determining product improvement options [8,26].

Many studies stated that, for a complete understanding of the significant driver of the impacts, it is necessary to include all stages and material used through a product’s life cycle, which is very challenging due to a lack of information and databases. However, depending on the aim of the LCA research, the literature review revealed a number of critical concerns, such as emissions from chemical and energy usage, the cultivation method used, land-use problems, and consumption waste.

Furthermore, studies in the literature proposed several recommendations for improving the agri-food system and reducing environmental consequences. One of them was adhering to the EPA and USDA pesticide and fertilizer guidelines. A frequent proposal was to use agricultural waste as animal feed. The most common request, however, was to enhance production without increasing inputs (Figure 17).

![Figure 17. Phase 4 (interpretation/recommendation) of life cycle assessment (LCA).](image)

4. Discussion

The present study reviewed articles related to the environmental impacts of agricultural production in LCA assessment. The main steps in conducting an LCA are defining the purpose of the study and boundary stages involved in the analysis, collecting the data of the inventory phase, estimating the impact of the involved process and used material, and then identifying the key issues, followed up with improvement recommendations. Most studies followed these steps, and some of them had common impact categories. However, implementing LCA is challenging and necessitates meticulous data collection.

4.1. Choice of Time, Spatial Domain, and Elementary Flows in LCA

Nearly 17% of studies did not mention the temporal scale of their analyses, depicting the inherent limitation of ISO 14040/ISO 14044 in considering the time period of evolution and process variations pertaining to diverse impact categories. The highest temporal resolution obtained from the literature was seasonal (4% of studies). The choice of time
in LCA depends on the spatial and temporal scale of the impact categories considered. For example, the temporal scale of ecotoxicity varies from hours to years. On the other hand, ecotoxicity impacts have multiple transport pathways such as air, water, and soil emissions with diverse temporal scales. Establishing a time frame for the evaluation in LCA is challenging, as both very lengthy and very short periods of assessment are not practicable depending on the topic of the LCA. Extremely short timescales violate the concept of intergenerational equality, whereas extremely long ones marginalize short-term actions, lowering the incentive to act [27]. Consequently, care should be taken when defining the temporal scale of inventory flows.

About half of the studies (49%) used secondary data collection for the LCA, acquiring data from websites and previous studies. The studies that constituted primary datasets were fewer due to the trouble of obtaining data at the desired spatial/temporal resolution for the inventory flows. The selection of impact categories and spatial domains (Figure 16) clearly reflects a preference for secondary datasets. The major categories studied were human toxicity potential and terrestrial ecotoxicity (the primary contributor being agricultural pesticide emissions). Studies used the approximated characterization factor from models for a particular spatial and temporal horizon to assess the potential impacts. Multimedia chemical exposure models such as CalTOX [28], USES-LCA [28,29], IMPACT 2002 [30], and USEtox [31] can provide the time-dependent concentrations of a chemical in the environmental compartments of air, soil, water, plants, and sediments. The potential impacts are characterized on the basis of the chemical’s fate in an environmental partition and its effect.

4.2. Impact Assessment

The quantity of the input material at each stage of the crop production chain can reduce GHG, as well as emissions, including energy use (diesel, fuel, electricity) both on farm (crop production, machinery use) and off farm (transportation, refrigeration). Additional emissions include fertilizer production and use (N, P₂O₅, K₂O), pesticide use (fungicide, herbicide, insecticide), raw material production and transportation, packaging production, and disposal (Table A2). These sources of emissions contribute to environmental impacts in various ways, including human toxicity, terrestrial toxicity, freshwater toxicity, aquatic toxicity, global warming, and acidification (Figure 16). It has been demonstrated that low-input crops have minimal impacts, but high-input crops have high impacts [32]. Furthermore, the type of input can affect the rate of the impacts. For example, replacing Thomas slag with triple superphosphate reduced the toxicity associated with the presence of heavy metals [33]. Simultaneously, replacing urea with ammonium nitrate reduced the influence of fertilization on eutrophication and acidity induced by ammonia volatilization [34].

4.3. LCA as a Tool in Environmental Policy Decisions

In order to achieve the population demand in the future, increasing food production is not the only pathway to increase food availability. Increased food production necessitates either more land or increased fertilizer and pesticide use on current arable land, with negative environmental consequences such as elevated GHG emissions, biodiversity loss, water contamination, and soil erosion [35]. That explains why, among the LCA papers, the most common target audiences were policymakers and producers, whereby policymakers regulate new policies for upcoming issues and producers follow these rules. The LCA methodology can be used to identify parameters and their variability in order to assist producers, wholesale and retail consumers, and policymakers in aligning their practices and purchasing decisions with low-carbon goals. LCA can also be used to analyze different production systems in order to quantify differences in input consumption and environmental consequences. The key parameters and their variability are then addressed to offer stakeholder metrics for evaluating and aligning their agricultural processes, purchasing decisions, and policies to optimize production supply chains.
4.4. Challenges in Collecting the Information and Limitations

Obtaining each LCA component from the reviewed studies is not simple for the reader due to the authors’ descriptive and nonexhaustive approach. Section 3 shows that diverse communities can benefit from this study on a local, international, and global scale. Hence, the author could have used a table or a flow chart to present the flow of components and stages to summarize the four phases and their components to enable the reader to focus on helpful information.

Another challenge is to identify what information needs to be included in the phases of the LCA. One of the essential characteristics of phase one of the LCA is using a functional unit; some authors mentioned it in the goal section while others mentioned it in the scope section. Noticeably, studies with an economic purpose often did not clearly report the functional unit. The necessity of incorporating all production processes and their input materials, analyzing all phases to understand the environmental effect, and obtaining an optimal outcome from the LCA analysis of food production systems was emphasized by researchers. However, that is neither possible nor practical because of data limitations and cost restrictions [10]. Accordingly, the minor influential stages were excluded. Hence, most studies focused on a single phase of the food production chain. For example, some studies focused on the cultivation phase because they considered that the food production system’s environmental impact mainly comes from farming activities.

The literature review did not focus on a specific region or a crop. Consequently, many studies appeared while searching using the keywords. Therefore, we included 74 articles related to LCA in agricultural production in general, as well as GHG emissions and ecotoxicity as an LCA impact category.

4.5. Assumptions Used, Benefits, and Recommendations

The LCA of crops along a food supply chain can provide helpful information from an economic, social, and environmental perspective. Using the LCA, stakeholders can better understand the energy, water, and material input and evaluate the outputs’ environmental impacts. Thus, they can regulate new policies and use modern practices to improve the production supply chains.

A substantial understanding of each phase of the LCA is required to present an accurate food product’s environmental impact. This paper clearly explains the LCA’s major components that can serve as a primer for the scientific community. Specifically, because LCA is a systematic tool that allows for analyzing a product throughout its life cycle, LCA is used to study the economic value and importance from the local and global perspectives.

If the final product’s functional unit is introduced at either the goal or the scope stage, the study results would be unaffected from our perspective. However, we recommend illustrating the input’s measurement unit and the outputs while illustrating the production scope, followed by a table of units to be more readable for the audience to understand at which stage the inputs are being used and to represent the elementary flows. Defining the system boundary determines the impact pathway for an impact category that links the elementary flows from inventory to the endpoint of analysis. It is clear that the system boundary processes need to be defined according to the study’s goal and the impact category. Furthermore, the functional unit must be clearly defined to explain the elementary flows from inventory to the endpoint. It is essential to know the impact category that the LCA aims to estimate, which processes are related to it, and their cause–effect relationships. The impact assessment studies were mostly conducted in the European sector since most models and databases are suited for European agri-food products.

4.6. Research Gaps

The information obtained from the literature sheds light on some of the future research needs: (a) the impact of land use on GHG emissions [36], (b) LCA applications based on irrigation techniques using solar energy dealing with waste streams [37], (c) LCA of processed and homegrown vegetables [38], (d) packaging of foods with eco-design
solutions [8], and (e) applications of LCA in organic agricultural practices, fertilization practices, mulching and milling techniques, and achievable production yields [39]. Some studies have called for more LCA applications in non-European and non-OECD countries to make their agri-food sector more environmentally friendly [40]. Therefore, it is understood that LCA can be used to make the agri-food supply chain more sustainable.

The inventory flows obtained from the present review point to the inter-dependency of three sectors in LCA: energy, food, and water. Consequently, policymakers can use LCA as a tool to spot the crucial areas that need improvisation within the framework of the food–energy–water nexus. Moreover, it is imperative to understand the drivers of environmental policy for selecting an environmentally friendly agri-food supply system. The regional variation of this nexus calls for more regional LCA assessments based on the allocation of resources. More research is needed to explore future scenarios [41] that drive resource consumption and policy design for long-term sustainability utilizing the LCA framework.

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### Appendix A

**Table A1.** Common aims in the selected studies.

| Aim                                      | Type of Aim | Studies                                      |
|------------------------------------------|-------------|----------------------------------------------|
| Evaluate the impact of all or most stages of FSC | Descriptive | [12,38,42–69]                               |
| Determine environmental differences of different cultivation options | Comparative | [24,36,39,70–77]                            |
| Estimate the impact of energy consumption | Descriptive | [42,43,48,50,78–80]                        |
| Investigate the impact of different fertilization rates and type | Comparative | [34,70,81–84]                               |
| Quantify impacts associated during cultivation cycle of a crop using life cycle analysis | Descriptive | [32,85–88]                                   |
| Investigate the impact of different pesticide rates and type | Comparative | [28,89–92]                                   |
| Evaluate the suitability of LCA          | Descriptive | [34,93,94]                                   |
| Compare the energy and GHG of regional and national scale | Comparative | [40,95,96]                                   |
| Compare the impact of the cultivation of different crops | Comparative | [97–99]                                      |
| Provide datasets on several agricultural products | Descriptive | [47,100]                                     |
| Compare two different methods            | Comparative | [101–103]                                    |
Table A2. Inventory data of the selected studies.

| #  | Reference | Data Source                  | Practice                                                                 | Input                                                                 | Unit          | Output                                                                 | Unit   |
|----|-----------|------------------------------|------------------------------------------------------------------------|----------------------------------------------------------------------|---------------|------------------------------------------------------------------------|--------|
| 1  | [42]      | Primary data                 | Field preparation, Seeding, Post seeding, weed control, Creation of irrigation ditches, Irrigation, Supporting with reeds, Fertilization, Plant protection, Harvest, Life cycle inventory data (per 1 t of beans produced) and (per 1 ha cultivated) | Diesel, Seeds, Manure, Water (electricity), Herbicides, insecticides, fungicides, N fertilizer, P₂O₅, K₂O, Manure cattle, sheep, Seaweeds, Land occupation | 60 kw tractor | Emissions to air, water, and soil) harvested beans                  | kg     |
| 2  | [43]      | Primary data (real farm)     | Cultivation and crop, Orange transport, Selection and washing, Primary extraction | Fertilizers: N, P₂O₅, K₂O, Water, Diesel, HDPE bins, Electric energy, Water, Recycled water | MJ            | Oranges                                                               | kg     |
|    | [43]      | Secondary data (previous studies) | Cultivation and crop, Orange transport, Selection and washing, Primary extraction | Fertilizers: N, P₂O₅, K₂O, Water, Diesel, HDPE bins, Electric energy, Water, Recycled water | MJ            | Oranges                                                               | kg     |
|    | [43]      | Secondary data (previous studies) | Cultivation and crop, Orange transport, Selection and washing, Primary extraction | Fertilizers: N, P₂O₅, K₂O, Water, Diesel, HDPE bins, Electric energy, Water, Recycled water | MJ            | Oranges                                                               | kg     |
Table A2. Cont.

| #  | Reference | Data Source          | Practice                                                | Input                  | Unit | Output                                        |
|----|-----------|----------------------|---------------------------------------------------------|------------------------|------|-----------------------------------------------|
| 3  | [44]      | Primary data (Interview) secondary data (Databases) | Crop management practices                                |                        |      | Excavation hydraulic digger                   |
|    |           |                      | Maintenance of watering canals                          |                        |      | Ploughing                                     |
|    |           |                      | Bank management                                         |                        |      | Tillage, plowing                              |
|    |           |                      | Flowing                                                  |                        |      | ha                                            |
|    |           |                      | Fertilizing                                              |                        |      | Tillage, by broadcaster                       |
|    |           |                      | Harrowing                                                |                        |      | ha                                            |
|    |           |                      | Sowing                                                   |                        |      | Sowing                                        |
|    |           |                      | Application of plant protection products                |                        |      | ha                                            |
|    |           |                      | Harvesting                                               |                        |      | Application of plant protection products, by | |
|    |           |                      |                                                         |                        |      | field sprayer                                 |
|    |           |                      |                                                         |                        |      | Combine harvesting                            |
|    |           |                      |                                                         |                        |      | 12% N, 46% N, 21% P₂O₅, 50% K₂O            |
|    |           |                      |                                                         |                        |      | Direct field emissions                        |
|    |           |                      |                                                         |                        |      | (CH₄, NH₃, etc.)                              |
|    |           |                      |                                                         |                        |      | Indirect emissions from combustion            |
|    |           |                      |                                                         |                        |      | delivered refined rice                        |
|    |           |                      |                                                         |                        |      | Rice byproducts                               |
|    |           |                      |                                                         |                        |      | husk, flour, broken grains                    |
|    |           |                      |                                                         |                        |      | green grains                                  |

Crop management practices
Maintenance of watering canals
Bank management
Flowing
Fertilizing
Harrowing
Sowing
Application of plant protection products
Harvesting
Fertilizers
Cuio torrefatto (12% N);
ORVET 8 (8% N);
Urea (46% N);
Calce Fosfopotassica (8% P₂O₅ – 22% K₂O – 20% CaO);
Complesso (18% N – 36% K₂O);
ORVET (10% N – 5% P₂O₅ – 15% K₂O);
Complesso (11% N – 12% P₂O₅ – 36% K₂O);
Pesticides
Gulliver
Londax 60 DF–Square 60 WDG
Pull 52 DF
Sunrice
Karmex
Buggy–Clinic 360
Stratos ultra
Aura
K-Othrine
Dipterex
Heteran
Nominee
Rift
Cannicid–Poladan

Excavation hydraulic digger
Ploughing
Tillage, plowing
Fertilizing, by broadcaster
Tillage, harrowing, by rotary harrow
Sowing
Application of plant protection products, by field sprayer
Combine harvesting
12% N, 46% N, 21% P₂O₅, 50% K₂O

Direct field emissions
Indirect emissions from combustion
delivered refined rice
Rice byproducts:
husk, flour, broken grains, green grains
| #  | Reference | Data Source (previous studies) | Practice | Input | Unit | Output | Unit |
|----|-----------|--------------------------------|----------|-------|------|--------|------|
| 4  | [104]     | Secondary data | Fertilizer production (process gas and fuel) | NA | NA | Fossil fuels (oil, natural gas, hard coal, lignite) | NA |
|    |           |                   | Arable farming | | | Minerals (phosphate rock, potash) | |
|    |           |                   | P fertilizer application | | | Land | |
|    |           |                   | Fertilizer production (effluents) | | | Cd | |
|    |           |                   | Arable farming (volatilization) | | | CH$_4$, CO$_2$, CO, NO$_x$, particles, SO$_2$, NMVOC | |
|    |           |                   | Fertilizer production (nitric acid production) | | | Ntot | |
|    |           |                   | Arable farming (denitrification/nitrification) | | | NH$_3$ | |
|    |           |                   | Arable farming (leaching) | | | N$_2$O | |
|    |           |                   | P fertilizer production (effluents) | | | NO$_x$-N | |
|    |           |                   | NA | | | Ptot | |
| 5  | [95]      | Secondary data (databases) | Field production | | | Field emissions of N$_2$O during tomato production | kg CO$_2$/mt km |
|    |           |                   | Diced tomato processing | | | GHG emissions associated with the production of seeds and transplants | |
|    |           |                   | Tomato paste processing | | | Emissions intensity | |
|    |           |                   | Diced tomato packaging | | | | |
|    |           |                   | Tomato paste consumer packaging | | | | |
|    |           |                   | Transport: long-haul truck, rail | | | | |
|    |           |                   | Fertilizers (synthetic/organic) | | | | |
|    |           |                   | Crop protection (chemical/organic) | | | | |
|    |           |                   | Energy (diesel, gas, electricity) | | | | |
|    |           |                   | Seeds/plants | | | | |
|    |           |                   | Water | | | | |
|    |           |                   | Energy | | | | |
|    |           |                   | Chemicals | | | | |
|    |           |                   | Packaging materials | | | | |
|    |           |                   | Fuel use efficiency | | | | |
| 6  | [78]      | Primary (survey and interview) data | Pesticides | | | Emission from direct energy consumption and field emission | 1 ton |
|    |           | (databases and previous studies) | Fertilizers | | | Harvested apple | |
|    |           |                   | Machinery | | | | |
|    |           |                   | Energy | | | | |
|    |           |                   | water | | | | |
| 7  | [8]       | Primary data (real farm) | Steel, aluminum, concrete, glass fiber resin, plastic | kg | | Organic waste | kg |
|    |           | (real farm) | Water | m$^3$ | | Construction waste | kg |
|    |           | Secondary data (databases) | Fertilizer, manure | kg | | Packaging | kg |
|    |           |                   | Pesticide | kg | | Plastics | kg |
|    |           |                   | Packaging | kg | | oils | kg |
|    |           |                   | Diesel | kg | | Hazardous waste | kg |
Table A2. Cont.

| #  | Reference | Data Source | Practice | Input | Unit | Output | Unit |
|----|-----------|-------------|----------|-------|------|--------|------|
| 8  | [45]      | Primary data (interview) Secondary data (databases) | Motion of tractors Conveying and unloading Optical selection Washing Peeling Crushing and pulping for the juice Sorting Can filling and pasteurization Water purification Palletizing Irrigation Tomato fertilization Plant protection Tomato fruit transport Packaging | Diesel Electricity Natural gas Water N, P₂O₅, K₂O Insecticide, fungicide Tin can, label, carton tray, plastic film, pallet, box for transport, plastic boxe | kg kWh/can kWh/can m³/Can kg L g/can | The resulting impact was provided as output. NA |
| 9  | [46]      | Primary data (Surveys) | Resources Raw materials and fossil fuels Electric and thermal energy | Occupation, permanent crop, fruit, extensive Transformation, to permanent crop, fruit, extensive Transformation, from pasture and meadow Water, process, unspecified natural origin Fertilizer N, P₂O₅, K₂O Pesticides Planting Irrigating Pesticide treatments Transport Power saw Petrol unleaded at a refinery Diesel at refinery Lubricating oil Sawmill Transport, lorry 16–32 ton, EURO Orchard end of life | ha-year ha ha m³ ton ton ton | Emission in water Nitrogen, total Phosphorus, total Potassium Waste treatments Disposal, hazardous waste, 25% water, to hazardous waste incineration | ton ton kg kg kg kg |
| #  | Reference | Data Source | Practice | Input | Unit | Output | Unit |
|----|-----------|-------------|----------|-------|------|--------|------|
| 10 | [47]      | Primary data (interview) Secondary data (databases) | Fuels, fertilizers, pesticides, water use, agricultural machinery models and use, yield, harvest schedule, distance and means of transport to the packing facility. | NA    | NA   | Air emission Water and soil waste | NA   |
|    |           |             |          | Machinery | Labor | kg |     |
|    |           |             |          | Diesel fuel | Electricity | h |   |
|    |           |             |          | Natural gas | Nitrogen | L |   |
|    |           |             |          | Phosphate | Potassium | kWh |   |
|    |           |             |          | Sul | Farm yard manure | m³ |   |
|    |           |             |          | Pesticides | Energy coefficients of different inputs and output used | kg |   |
|    |           |             |          | Water for irrigation | Plastic | kg |   |
|    |           |             |          | 1. Machinery | 1. Tractor, self-propelled equipment implemented, machinery | kg |   |
|    |           |             |          | 2. Human labor | Stationary | kg |   |
|    |           |             |          | 3. Natural gas | 4. Diesel fuel | m³ |   |
|    |           |             |          | 5. Biocide | Herbicide, fungicide, insecticide | L |   |
|    |           |             |          | 6. Fertilizers: N, P₂O₅, K₂O | Energy coefficients of different inputs and output used | kg |   |
|    |           |             |          | 7. Micro (M) | 8. Farmyard: manure | kg |   |
|    |           |             |          | 9. Water for Irrigation | 10. Electricity | kg |   |
|    |           |             |          | 11. Seeds | Tomato/cucumber | kg |   |

Life cycle inventory data for greenhouse tomato and cucumber (per 1 ton of produced crop).
Table A2. Cont.

| #  | Reference | Data Source | Practice | Input                                                                 | Unit | Output                                                                 | Unit |
|----|-----------|-------------|----------|----------------------------------------------------------------------|------|----------------------------------------------------------------------|------|
| 12 | [70]      | Primary data (real farm) Secondary data (databases) | 1- Preliminary considerations Doses of fertilizing products applied | Fertilizer application Compost HNO\textsubscript{3}, KNO\textsubscript{3}, KPO\textsubscript{4}, \textsubscript{2}SO\textsubscript{4} Nitrogen application organic, mineral | g m\textsuperscript{-2} | g m\textsuperscript{-2} | Outputs of the composting process in the industrial composting plant of Castelldefels | |
|    |           |             | 2- Stage of compost production (CP) Collection and transport of the organic waste Industrial composting process Biofilter characteristics and gaseous emissions | | | | Greenhouse gases | |
|    |           |             |          | 3- Stage of mineral fertilizer production (FP) | | | | |
|    |           |             |          | 4- Stage of compost transport | | | | |
|    |           |             |          | 5- Stage of mineral fertilizers transport (FT) | | | | |
|    |           |             |          | 6- Stage of cultivation (Cu) Fertigation infrastructure substage (CuF) Phytosanitary substances substage (CuP) Machinery and tools substage (CuM) Irrigation substage (CuI) Post-application emissions sub-stage (CuE) Nursery plants substage (CuN) Machinery and tools substage (CuM) Irrigation substage (CuI) Post-application emissions sub-stage (CuE) Nursery plants substage (CuN) Management of waste generated in the cultivation stage | | | | |
|    |           |             |          | 7- Greenhouse (G) Greenhouse structure substage (GS) Greenhouse management substage (GM) Avoided burdens of dumping OFMSW and BA in landfill | | | | |
|    |           |             |          | | | | | |


### Table A2. Cont.

| #  | Reference | Data Source          | Practice           | Input                                      | Unit          | Output                          | Unit |
|----|-----------|----------------------|--------------------|--------------------------------------------|---------------|---------------------------------|------|
| 13 | [71]      | Secondary data (both) | Wheat life cycle inputs Transport | N, P: conv Pesticide: conv Phosphate rock: org Manure: org Diesel (org and conv) Gasoline (org and conv) Truck, rail transport | kg, kg P kg kg of manure P L L t km | Baking, packaging, and sales Wheat Flour | kg  |

Average yield per cultural cycle
Specific area
Water
Organic fertilizers
Crop residues (durum wheat)
Manure
Foliar nitrogenous fertilizer t
Differentiated and prolonged release nitrogenous fertilizer m²
Mineral fertilizers t
Controlled release NPK fertilizer t (14–7–14)
NPK complex fertilizer kg
Total nutrient supply kg
N (organic fertilizers) kg
N (mineral fertilizers) kg
N (total) kg
P (total, as P₂O₅) kg
K (total, as K₂O) kg
Pesticides (active substances) kg
Benfluralin (herbicide) kg
Propyzamide (herbicide) kg
Boscalid (fungicide) kg
Pyraclostrobin (fungicide) kg
Cyprodinil (fungicide) kg
Fludioxonil (fungicide) kg
Deltamethrin (insecticide) kg
Spinosad (insecticide) kg
Black LDPE mulching film (35 mm; 28 g/m²) kg

To air: NH₃, NOₓ
Groundwater: NO₃⁻
Surface waters: (PO₄)
Soil
Heavy metals (Cd, Cr, Cu, Ni, Pb, Zn)
Pesticides (active substances)
| #  | Reference | Data Source | Practice | Input                                                                 | Unit                                      | Output                                                                                           | Unit |
|----|-----------|-------------|----------|----------------------------------------------------------------------|-------------------------------------------|--------------------------------------------------------------------------------------------------|------|
| 15 | [96]      | Secondary data (databases) | Fertilizer production Pesticide production Production of greenhouse infrastructure | Mineral fertilizer N Mineral fertilizer P Mineral fertilizer K Manure compost Organic fertilizer Steel Aluminum Glass Plexiglas Plastic Iron Concrete Rockwool | N kg ha\(^{-1}\) year\(^{-1}\) P kg ha\(^{-1}\) year\(^{-1}\) K kg ha\(^{-1}\) year\(^{-1}\) | Machine use Energy demand heating changes in soil organic carbon | h ha\(^{-1}\) GJ year\(^{-1}\) N\(_2\)O emissions direct N\(_2\)O emissions indirect Humus sequestration |
| 16 | [81]      | Primary data (real farm) | NA       | N min in the soil in spring Mineral N fertilizer rate Atmospheric N deposition Net N mineralization during vegetation Mineralization of N from sugar beet leaves (easily degradable part) Mineralization of N from sugar beet leaves (slowly degradable part) | NA | NH\(_3\) volatilization N\(_2\)O emission N removal with beets N content of leaves N uptake of winter wheat in autumn | One ton of grain |
| 17 | [49]      | Primary data (interview) | Greenhouse Training system Irrigation system | Low-density Polyethylene Sawn timber Steel Wire Polyethylene Sawn timber Wire Polyethylene Polyvinylchloride | k m\(^3\) kg kg kg m\(^3\) kg kg | Fresh tomato Air emissions NH\(_3\) N\(_2\)O N\(_2\)O-N NO\(_x\) N emissions Water emissions N-NO\(_3\) | t kg ha\(^{-1}\) kg ha\(^{-1}\) |
| #  | Reference | Data Source | Practice | Input                                    | Unit | Output | Unit |
|----|-----------|-------------|----------|------------------------------------------|------|--------|------|
| 18 | [50]      | Primary data (real farm) | Cultivation and crop Primary process (citrus selection and washing, extraction) Secondary process (refining; centrifugation) Secondary process (refining; pasteurization and cooling) Concentration and cooling Packaging and storage Transport of final products | Fertilizers Water Diesel Electric energy Water Recycled water Water-oil emulsion Electric energy Cooling water Raw juice Methane Electric energy Steam Electric energy Methane Steam Cooling water electric energy Essential oil Electric energy Natural juice Concentrated juice HFO, Diesel | NA   | Air emissions Amount of citrus fruit Wastes (scraps, leaves, rejected citrus) Wastewater to a purification plant Scraps to pressing process Essential oil to packaging and storage Wet wastes Wastewater to purification plant Natural and concentrated juice Concentrated juice | NA   |
| 19 | [40]      | Secondary data (previous studies) (larvae/fingerlings, fertilizers, and feeds). | NA | NA | nitrogen and phosphorus emissions | NA   | NA   |
Table A2. Cont.

| #  | Reference | Data Source | Practice | Input | Unit | Output | Unit |
|----|-----------|-------------|----------|-------|------|--------|------|
| 20 | [51]      | Primary data (reports) | Cane products | ha/year | Cane |
|    |           | Secondary data (databases) | Agr. Wastes | kg/ha-year | N<br>2O |
|    |           | Land use | | kg/ha-year | N<br>total to water |
|    |           | Pesticides | | kg/ha-year | Pesticides to water |
|    |           | Fertilizer use | | kg/ha-year | Pesticides to soil |
|    |           | Fuel use | | kg/ha-year | Sugar |
|    |           | Seed use | | kg/ha-year | kg/ha-day |
|    |           | Sun use | | kg/ha-year | kg/ha-day |
|    |           | Agr. operations | | kg/ha-year | kg/ha-day |
|    |           | Lime hydrated | | kg/ha-year | g/day |
|    |           | Cane | | g/day | g/day |
|    |           | Cane transport | | g/day | g/day |
|    |           | River water | | g/day | g/day |
|    |           | Air | | g/day | g/day |
|    |           | Softened water | | g/day | g/day |
|    |           | Ammonium sulfate | | g/day | g/day |
|    |           | Sulfuric acid | | g/day | g/day |
|    |           | Yeast | | g/day | g/day |
|    |           | Transport of filter cake | | g/day | g/day |
|    |           | Transport of ashes | | g/day | g/day |

| 21 | [52]      | Primary data (interview) | Seed production and transport | NA | NA | Emission to air and water | NA |
|    |           | Secondary data (databases) | Fertilizer protection and transport | NA | NA | Solid emission | NA |
| #  | Reference | Data Source                  | Practice                                                                 | Input                                                                 | Unit            | Output                                                                 | Unit          |
|----|-----------|------------------------------|--------------------------------------------------------------------------|----------------------------------------------------------------------|-----------------|------------------------------------------------------------------------|---------------|
| 22 | [53]      | Secondary data (databases)   | Cultivation: Plastic cover Greenhouse Transportation: small truck, truck, sea, pre-cooling, and storage | fuel consumption, refrigeration, driving                              | L/t km kWh/m²/year | Waste management (CO₂ emission, t/t) Paper, board, plastics            | kg/t kg/t km  |
|    |           |                              |                                                                          |                                                                      |                 | CO₂ emission from packaging, transportation, and storage               | kg/t          |
|    |           |                              |                                                                          |                                                                      |                 | Transportation Farm to packing house Packinghouse to wholesale         | kg/t          |
| 23 | [54]      | Secondary data (databases)   | Cattle manure Fuel use for various types of driving machinery and for different loads Low power Medium power High power Combine Willow harvester | N, P₂O₅, K₂O fertilizer Slurry Power | mg/kg mg/kg kw | Willow Straw Wheat                                                     | mg/kg mg/kg   |
|    |           |                              |                                                                          |                                                                      |                 |                                                                        |               |
| 24 | [82]      | Secondary data (both)        | Yields for main products Straw yields and crop residues Moisture content Quantity of seed Use of machinery (number of passes) Sowing and harvest date Quantity of fertilizers Types of fertilizers in integrated systems Types of fertilizers in organic systems Pesticide applications Chemical seed dressing Machinery classes Tractor harvester Trailer machinery, tillage Slurry tank | Steel, unalloyed Steel, alloyed Other metals Rubber Plastics Others (glass, paints, etc.) | NA             | Ammonia emissions Nitrate leaching P-emissions N₂O emissions Heavy-metal emissions Pesticide applications Tractor combustion emissions | NA            |
Table A2. Cont.

| #  | Reference | Data Source                  | Practice                                                                 | Input                                                                 | Unit         | Output                                                                 | Unit   |
|----|-----------|------------------------------|--------------------------------------------------------------------------|----------------------------------------------------------------------|--------------|------------------------------------------------------------------------|--------|
| 25 | [97]      | Secondary data (both)        | Inventory of agricultural inputs                                          | Fertilizers and lime                                                  | kg N         | Ammonia (NH₃)                                                          | kg/xkg |
|    |           |                              |                                                                          | Nitrogen fertilizer (urea and diammonium phosphate)                    | kg N₂O       | Nitrates (NO₃⁻)                                                        | kg/xkg |
|    |           |                              |                                                                          | Phosphate fertilizer (diammonium phosphate)                            | kg P₂O₅      | Nitrous oxide (N₂O)                                                    | kg/xkg |
|    |           |                              |                                                                          | Potassium fertilizer (potassium chloride)                              | kg K₂O       | Nitrogen oxides (NOx)                                                  | kg/xkg |
|    |           |                              |                                                                          | Agricultural lime (calcic carbonate)                                   | kg CaCO₃     | Phosphates (PO₄³⁻)                                                     | kg/xkg |
|    |           |                              |                                                                          | Pesticides: Clopyralid, Haloxyfop, Picoloram, Glyphosate, Linuron,     | kg            | Carbon dioxide (CO₂)                                                   | kg/xkg |
|    |           |                              |                                                                          | Thiophanate-methyl, Prochloraz Seed                                    | kg           | Glyphosate (main pesticide in rapeseed)                                | kg/xkg |
|    |           |                              |                                                                          | Seed                                                                   | kg           | Linuron (main pesticide in sunflower)                                  | kg/xkg |
|    |           |                              |                                                                          | Seed yield                                                             | t/ha         |                                                                        |        |
|    |           |                              |                                                                          | Fuel consumption in agricultural operations                            | kg           |                                                                        |        |
|    |           |                              |                                                                          | Seeding rate                                                           | m²           |                                                                        |        |
|    |           |                              |                                                                          | Irrigation water intake                                                | kg           |                                                                        |        |
|    |           |                              |                                                                          | Irrigation requirement                                                 | kg           |                                                                        |        |
|    |           |                              |                                                                          | Irrigation water intake                                                | kg           |                                                                        |        |
|    |           |                              |                                                                          | Diesel consumption: plowing, harrowing, crushing, sowing, spraying,   | kg           |                                                                        |        |
|    |           |                              |                                                                          | weeding, hilling/fertilizing harvest                                   | kg           |                                                                        |        |
|    |           |                              |                                                                          | Tractor for field operations                                            | kg           |                                                                        |        |
|    |           |                              |                                                                          | Tools and harvester                                                    | kg           |                                                                        |        |
|    |           |                              |                                                                          | Seed yield                                                             | t/ha         |                                                                        |        |
### Table A2. Cont.

| #  | Reference | Data Source                  | Practice                                                                 | Input                                                                 | Unit          | Output                   | Unit          |
|----|-----------|------------------------------|-------------------------------------------------------------------------|----------------------------------------------------------------------|---------------|--------------------------|---------------|
| 26 | [55]      | Secondary data (databases)   | Inventory data on wheat production (1995–2011, year⁻¹). Wheat grown in paddy fields and Wheat grown in upland fields | Production costs Seed Chemical fertilizers Purchased manure Pesticides 49858 Fossil fuels 14760 Electricity Land improvement and irrigation Agricultural services Buildings Agricultural machinery Fossil fuels Heavy oil Diesel oil Kerosene Gasoline Motor oil Premixed fuel Calcium carbonate fertilizer Nitrogen balance Chemical fertilizers Purchased manure Atmospheric deposition Wheat straw (incorporated) Wheat Wheat straw (total) Denitrification Ammonia volatilization Surplus | yen·ha⁻¹ L·ha⁻¹ kg·ha⁻¹ kg·N·ha⁻¹ | Wheat straw Wheat Air-emission sources included fossil fuel combustion, fertilizer application, and crop residue incorporation Emissions in fossil fuel combustion were calculated using the CO₂, CH₄, and N₂O emission factors and the NOₓ and SOₓ emission factors The CO₂ emission factor of calcium carbonate fertilizer on a weight the basis was 12% |
| #  | Reference | Data Source | Practice                                                                 | Input | Unit | Output                        | Unit |
|----|-----------|-------------|---------------------------------------------------------------------------|-------|------|-------------------------------|------|
| 27 | [105]     | Primary data (real farm) Secondary data (previous studies and databases) | Farming, Irrigation, Soil management, Pest treatment, Fertilization, Pruning, Harvesting, Olive oil mill, Washing, Milling, Pressing, Decantation, Oil pomace mill, Pitting, Drying, Solvent extraction, Dysventilation and condensation | Water | m³  | Olive mill                    | L    |
|     |           |             |                                                                           | Pesticides | kg  | Wastewater                    | L    |
|     |           |             |                                                                           | Fertilizers | kg  | Water from washing           | L    |
|     |           |             |                                                                           | Diesel | kg  | Virgin olive                  | kg   |
|     |           |             |                                                                           | Lubrification oil water | L | Exhausted pomace             | kg   |
|     |           |             |                                                                           | Electric energy | kWh | Pomace oil                    | kg   |
|     |           |             |                                                                           | Water | L   |                               |      |
|     |           |             |                                                                           | Electric energy | kWh |                               |      |
|     |           |             |                                                                           | Hexane | kg  |                               |      |
| 28 | [56]      | Primary data (interview) | Fertilization, Pesticides, Packaging, Transportation | N, P, K | kg | CH₄, N₂O, CO NMHC | kg per FU |
|     |           |             |                                                                           | Lubricating oils | kg | Biological oxygen demand (BOD) | kg per FU |
|     |           |             |                                                                           | Seeds | kg | NOₓ | g per FU |
|     |           |             |                                                                           | Tomatoes | kg | Other organic compounds | m³ per FU |
|     |           |             |                                                                           | Sugar beets | kg | Water emissions | kg |
|     |           |             |                                                                           | Tomato paste | kg | Soil emissions | kg |
|     |           |             |                                                                           | Raw sugar | kg |                               |      |
|     |           |             |                                                                           | Sugar solution | kg |                               |      |
|     |           |             |                                                                           | Vinegar | kg |                               |      |
|     |           |             |                                                                           | Spice emulsion | kg |                               |      |
|     |           |             |                                                                           | Salt | kg |                               |      |
|     |           |             |                                                                           | Tomato ketchup | kg |                               |      |
|     |           |             |                                                                           | Packaging system for tomato paste | kg |                               |      |
|     |           |             |                                                                           | Packaging system for ketchup | kg |                               |      |
|     |           |             |                                                                           | Transportation | kg |                               |      |
|     |           |             |                                                                           | Shopping | kg |                               |      |
|     |           |             |                                                                           | Household phase | kg |                               |      |
|     |           |             |                                                                           | Electricity production | kg |                               |      |
|     |           |             |                                                                           | Waste management | kg |                               |      |
Table A2. Cont.

| #  | Reference | Data Source (databases) | Practice | Input                                                                 | Unit | Output                                                                 | Unit |
|----|-----------|--------------------------|----------|-----------------------------------------------------------------------|------|-----------------------------------------------------------------------|------|
| 29 | [72]      | Secondary data           | Occupation, arable land | kg          | Soil emissions (literature)                                           | kg   | Crop                                                                 | kg   |
|    |           |                          | Plants (plugs)          | kg          | CO₂ from soil                                                         | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | CO₂ from air fixed in crop | kg          | CH₄ from soil                                                         | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Tractor use             | m²-year     | NH₃ from soil                                                         | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Diesel (for field operations) | kg          | NOₓ from soil                                                         | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Steel (spare parts replacement) | number     | N₂O from soil                                                        | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Labor (labor-intensive operations) | hours    | PO₄ from soil                                                        | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Diesel (for workers’ transport) | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Plastic (fleece, mulch . . . ) | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Pesticides (unspecified) | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Fertilizers: N, P, K   | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Manure/organic fertilizers | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Irrigation              | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Bluewater, surface water | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Bluewater, groundwater  | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Infrastructure (pipes, sprinklers . . . ) | m³ | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Electricity (pumps)     | m³         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Input packed broccoli to RDC | kg        | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Diesel for transport to RDC | kWh       | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | From Spain              | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | From the UK             | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Electricity RDC storage | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Input packed broccoli to retailer | MJ        | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Diesel for transport to retailer | kg        | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Electricity retailer storage and display | MJ       | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Solid waste from retailer to landfill | kg      | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Broccoli               | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | LDPE packaging          | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Diesel for solid waste transport | MJ        | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Input broccoli to household | MJ        | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Petrol for transport to household | MJ       | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Diesel for transport to household | L         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Electricity home storage | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Electricity cooking     | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Natural gas cooking     | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Tap water               | L          | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Solid waste from household to landfill | kg      | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Broccoli               | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | LDPE packaging          | kg         | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Diesel for solid waste transport | MJ        | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Cooking wastewater to WWTP | MJ       | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
|    |           |                          | Cooked broccoli (input to human excretion) | kg    | Change in soil organic carbon (SOC)                                   | kg   | Soil emissions (literature)                                           | kg   |
| #  | Reference                      | Data Source                  | Practice                                                                 | Input                  | Unit    | Output                  | Unit  |
|----|--------------------------------|------------------------------|--------------------------------------------------------------------------|------------------------|---------|-------------------------|-------|
| 30 | [38]                           | Secondary data (databases)   | Data inventory for the agricultural phase Data inventory for the processing phase (data refer to FU) | Seeds                  | Mg      | Emissions to air        |       |
|    |                                |                              |                                                                          | Compost from cow and horse manure | g       | Carbon dioxide          |       |
|    |                                |                              |                                                                          | Fosetyl-Al             | mg      | Carbon monoxide         |       |
|    |                                |                              |                                                                          | [Thio]carbamate-compounds | mg      | Nitrogen oxides         | g     |
|    |                                |                              |                                                                          | [Sulfonyl]urea-compounds | mg      | Particulate hydrocarbons | mg    |
|    |                                |                              |                                                                          | Diesel fuel            | g dm³   | Dinitrogen monoxide     | mg    |
|    |                                |                              |                                                                          | Water                  | kWh     | Ammonia                 | mg    |
|    |                                |                              |                                                                          | Electricity for irrigation | mg     | Benfluralin             | mg    |
|    |                                |                              |                                                                          | LDPE film (greenhouse) | m²      | Fosetyl-Al              | mg    |
|    |                                |                              |                                                                          | Land                   | g       | Propamocarb             | mg    |
|    |                                |                              |                                                                          | Salad (Valerianella locusta) | g       | Emissions to water      | mg    |
|    |                                |                              |                                                                          | Salad                  | g       | Benfluralin             | mg    |
|    |                                |                              |                                                                          | Electricity            | kWh     | Fosetyl-Al              | mg    |
|    |                                |                              |                                                                          | Water                  | dm³     | Propamocarb             | mg    |
|    |                                |                              |                                                                          | Sodium hypochlorite    | g       | Emissions to soil       | mg    |
|    |                                |                              |                                                                          | PP film                | g       | Benfluralin             | mg    |
|    |                                |                              |                                                                          |                        |         | Wastewater              |       |
| 31 | [98]                           | Secondary data (previous studies) | NA                                                                      | NA                     | NA      | NA                      | NA    |
|    |                                |                              |                                                                          | NA                     | NA      | NA                      | NA    |
| #  | Reference | Data Source | Practice                                                                 | Input                                                                 | Unit  | Output                                                                 | Unit    |
|----|-----------|-------------|----------------------------------------------------------------------------|----------------------------------------------------------------------|-------|------------------------------------------------------------------------|---------|
| 32 | [73]      | Primary data (interview) Secondary data (databases) | Main characteristics of the life cycle inventory of the studied conventional (Con) and organic (Org) groups of fruit tree orchards crops in Spain. Data refer to 1 ha and year unless otherwise stated | Drip irrigation Surface irrigation Water use Electricity Presence of cover crops Machinery use Fuel consumption Mulching plastic Mulching plastic Mineral nitrogen Mineral phosphorus Mineral potassium Manure Slurry Cover crop seeds Other organic fertilizers Total carbon inputs Total nitrogen inputs Synthetic pesticides Sulfur Copper Paraffin Natural pesticides Production Yield | % of cases % of cases m³ kWh % h L | Soil emissions Direct nitrous oxide Indirect nitrous oxide Methane Carbon | kg N kg P₂O₅ kg K₂O mg mg kg kg kg kg kg kg kg kg kg kg kg kg kg kg kg kg kg |
Table A2. Cont.

| #   | Reference | Data Source               | Practice                                                                 | Input                                    | Unit    | Output                                   | Unit     |
|-----|-----------|---------------------------|--------------------------------------------------------------------------|------------------------------------------|---------|------------------------------------------|----------|
| 33  | [57]      | Secondary data (previous studies) | LCI to produce a single oil palm seedling                              | Electricity                              | kWh     | Emissions to air                         |          |
|     |           |                            |                                                                          | Diesel                                   | L       | NH₃                                       |          |
|     |           |                            |                                                                          | Polybag                                  | kg      | N₂O                                       |          |
|     |           |                            |                                                                          | Water                                    | L       | NO                                        |          |
|     |           |                            |                                                                          | Fertilizer: N, P₂O₅, K₂O                 | kg      | N₂                                        |          |
|     |           |                            |                                                                          | Thiocarbamate                            | kg      | N₂O                                       |          |
|     |           |                            |                                                                          | Pyrethroid                               | kg      | NO                                        |          |
|     |           |                            |                                                                          | Organophosphate                          | kg      | NO₂                                        |          |
|     |           |                            |                                                                          | Dithiocarbamate                          | kg      | NO₂                                       |          |
|     |           |                            |                                                                          | Unspecified pesticide                    | kg      | Glufosinate ammonium                      |          |
|     |           |                            |                                                                          | Urea/sulfonylurea                        | kg      | Parquat                                   |          |
|     |           |                            |                                                                          | Glyphosate                               | kg      | Emissions to water                        | kg/t FFB |
|     |           |                            |                                                                          | Metsulfuron-methyl                       | kg      | Emissions to water                        | kg/t FFB |
|     |           |                            |                                                                          | Glufosinate ammonium                     | kg      | Leached out and runoff                    | g/t FFB  |
|     |           |                            |                                                                          | Carbofuran                               | kg      |                                            |          |
|     |           |                            |                                                                          | Glyphosate                               | kg      |                                            |          |
|     |           |                            |                                                                          | Metsulfuron-methyl                       | kg      |                                            |          |
|     |           |                            |                                                                          | Carbofuran                               | kg      |                                            |          |
|     |           |                            |                                                                          | Glyphosate                               | kg      |                                            |          |
|     |           |                            |                                                                          | Methamidophos                             | kg/t FFB|                                            |          |
| 34  | [58]      | Primary data (real farm)   | Fertilizer doses, application emissions, and irrigation water (per ha) for lettuce and escarole crops in the open field (OF), plastic mulch (PM), plastic mulch combined with fleece system (PM F), and greenhouse (GH) systems. Characteristics of materials and electricity and diesel consumption (per ha) included in the inventory. PY polyethylene, PP polypropylene. | Fertilizer doses                          |         | Air emissions                             |          |
|     |           | Secondary data (databases) |                                                                         | N optimum                                | kg      | NH₃-N                                     | kg       |
|     |           |                            |                                                                          | P₂O₅                                     | kg      | NO₂-N                                     | kg       |
|     |           |                            |                                                                          | K₂O                                      | kg      | NO₃-N                                     | kg       |
|     |           |                            |                                                                          | Mulch                                    | m²      |                                            | m²       |
|     |           |                            |                                                                          | Fleece                                   | m²      |                                            | m²       |
|     |           |                            |                                                                          | Main pipe 1                              | m       |                                            |          |
|     |           |                            |                                                                          | Main pipe 2                              | m       |                                            |          |
|     |           |                            |                                                                          | Main pipe 3                              | m       |                                            |          |
|     |           |                            |                                                                          | Secondary pipes                          | m       |                                            |          |
|     |           |                            |                                                                          | Drip irrigation pipes (lateralis)        | kg      |                                            |          |
|     |           |                            |                                                                          | Pumps                                    | MJ      |                                            |          |
|     |           |                            |                                                                          | Electricity (pumps)                      | MJ      |                                            |          |
|     |           |                            |                                                                          | Electricity (climate system)             | MJ      |                                            |          |
|     |           |                            |                                                                          | Diesel (crop management)                 | MJ      |                                            |          |
Table A2. Cont.

| #  | Reference | Data Source  | Practice | Input | Unit       | Output | Unit       |
|----|-----------|--------------|----------|-------|------------|--------|------------|
| 35 | [59]      | Primary data (interview) | Principal inputs involved in the analysis of the “Delizie di Bosco del Piemonte” production chain for raspberries and giant American blueberries | Substratum | L·ha\(^{-1}\) | GWP (global warming potential) | kg CO\(_2\) eq |
|    |           |              | Nursery  | Black PE | kg·ha\(^{-1}\) | IPCC 100a | MJ primary |
|    |           |              | Rooting  | White PE | kg·ha\(^{-1}\) |        |            |
|    |           |              | Mulching | Metal supports | kg·ha\(^{-1}\) |        |            |
|    |           |              | Covering | PVC piping | kg·ha\(^{-1}\) |        |            |
|    |           |              | Covering | PVC tubing | kg·ha\(^{-1}\) |        |            |
|    |           |              | Fertigation system Fertigation system Fertigation | Compost mix | kg·ha\(^{-1}\) |        |            |
|    |           |              | Fertigation | Water | m\(^3\)·ha\(^{-1}\) |        |            |
|    |           |              | Nozzles  | PVC | kg·ha\(^{-1}\) |        |            |
|    |           |              | Cold storage | Electrical energy | kWh·ha\(^{-1}\) |        |            |
|    |           |              | Field    | Plow or cultivator | h·ha\(^{-1}\) |        |            |
|    |           |              | Soil preparation | Harrow | h·ha\(^{-1}\) |        |            |
|    |           |              | Soil preparation | Bed-former | h·ha\(^{-1}\) |        |            |
|    |           |              | Soil preparation | Diesel consumption | m\(^3\)·ha\(^{-1}\) |        |            |
|    |           |              | Mulching | PE sheeting | kg·ha\(^{-1}\) |        |            |
|    |           |              | Total processes | PVC piping | kg·ha\(^{-1}\) |        |            |
|    |           |              | Mulching | PVC tubing | kg·ha\(^{-1}\) |        |            |
|    |           |              | Irrigation system | Water | m\(^3\)·ha\(^{-1}\) |        |            |
|    |           |              | Irrigation | Electrical energy for the well | kWh·ha\(^{-1}\) |        |            |
|    |           |              | Irrigation | Manure | t·ha\(^{-1}\) |        |           |
|    |           |              | Irrigation | Compost | t·ha\(^{-1}\) |        |            |
|    |           |              | Irrigation | White PE | kg·ha\(^{-1}\) |        |            |
|    |           |              | Irrigation | Metal supports | kg·ha\(^{-1}\) |        |            |
|    |           |              | Base fertilization | p.a. | kg·ha\(^{-1}\) |        |            |
|    |           |              | Total fertilization | Electrical energy | kWh·kg\(^{-1}\) |        |            |
|    |           |              | Covering | Electrical energy | kWh·kg\(^{-1}\) |        |            |
|    |           |              | Covering | PE tray | g·kg\(^{-1}\) |        |            |
|    |           |              | Covering | PE wrapping | g·kg\(^{-1}\) |        |            |
|    |           |              | Covering | Plant protection treatments |            |        |            |
|    |           |              | Covering | Post-harvesting |            |        |            |
|    |           |              | Covering | Refrigeration |            |        |            |
|    |           |              | Covering | Flow packaging |            |        |            |
|    |           |              | Covering | Flow packaging |            |        |            |
|    |           |              | Covering | Flow packaging |            |        |            |
### Table A2. Cont.

| #  | Reference | Data Source                                      | Practice                                      | Input                                      | Unit                                      | Output                                      | Unit                                      |
|----|-----------|--------------------------------------------------|-----------------------------------------------|--------------------------------------------|--------------------------------------------|--------------------------------------------|--------------------------------------------|
| 36 | [60]     | Secondary data (databases)                       | Rice production                               | Machines, materials                        |                                            | Rice field (emissions)                      |                                            |
|    |          |                                                  | tillage, growing, harvest                     |                                            |                                            | Product, byproduct                          |                                            |
|    |          |                                                  |                                               |                                            |                                            | ricefield product, byproduct,              |                                            |
|    |          |                                                  |                                               |                                            |                                            | pollution                                   |                                            |
| 37 | [36]     | Primary data (survey)                            |                                               |                                            |                                            | Methane emissions                           |                                            |
|    |          | Secondary data (previous studies and databases)  |                                               |                                            |                                            | Nitrous oxide emissions                     |                                            |
|    |          |                                                  |                                               |                                            |                                            | Electricity-based emissions from           |                                            |
|    |          |                                                  |                                               |                                            |                                            | irrigation                                  |                                            |
|    |          |                                                  |                                               |                                            |                                            | Embodied GHG emissions associated with     |                                            |
|    |          |                                                  |                                               |                                            |                                            | electricity                                  |                                            |
|    |          |                                                  |                                               |                                            |                                            | Harvest                                     |                                            |
|    |          |                                                  |                                               |                                            |                                            | Soil organic carbon                         |                                            |
| 38 | [61]     | Primary data (interview)                         | Primary production                            |                                            |                                            | Land-use change                             |                                            |
|    |          |                                                  | Grading and packing                            |                                            |                                            | Direct emission                             |                                            |
|    |          |                                                  | Regional distribution center                  |                                            |                                            | Nitrate                                     |                                            |
|    |          |                                                  | Supermarkets                                  |                                            |                                            | Nitrous oxide                               |                                            |
|    |          |                                                  |                                               |                                            |                                            | Ammonia                                     |                                            |
|    |          |                                                  |                                               |                                            |                                            | Waste                                       |                                            |
|    |          |                                                  |                                               |                                            |                                            | Waste                                       |                                            |
|    |          |                                                  |                                               |                                            |                                            | waste                                       |                                            |
| 39 | [62]     | Primary data (reports)                           | Orchard establishment inputs                 |                                            |                                            | Apple                                       |                                            |
|    |          |                                                  | Agricultural stage inputs                     |                                            |                                            | Peach                                       |                                            |
|    |          |                                                  | Retail stages inputs                          |                                            |                                            | (NPK) NO<sub>x</sub>                        |                                            |
|    |          |                                                  | Consumption stages inputs                     |                                            |                                            | N<sub>2</sub>O                                |                                            |
|    |          |                                                  |                                               |                                            |                                            | Machinery production emissions              |                                            |
|    |          |                                                  |                                               |                                            |                                            | and diesel                                  |                                            |
|    |          | Secondary data (previous studies)               |                                               |                                            |                                            | consumed for machinery operations           |                                            |
Table A2. Cont.

| #  | Reference | Data Source            | Practice                                                                 | Input                                      | Unit | Output                                      | Unit               |
|----|-----------|------------------------|--------------------------------------------------------------------------|--------------------------------------------|------|---------------------------------------------|--------------------|
| 40 | [74]      | Secondary data (both)  | Annual chemical inputs for managing a mature orange grove in Florida      | Roundup weather max                        | mL/ha| Emission from energy use                    | g CO₂ eq./FU       |
|    |           |                        |                                                                          | Solica 80 DF                               | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Karmex WP                                  | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Roundup weather max                        | mL/ha|                                             |                    |
|    |           |                        |                                                                          | Prowl H20                                  | mL/ha|                                             |                    |
|    |           |                        |                                                                          | Simazine 4L                                 | mL/ha|                                             |                    |
|    |           |                        |                                                                          | Roundup weather max                        | mL/ha|                                             |                    |
|    |           |                        |                                                                          | Mandate                                    | mL/ha|                                             |                    |
|    |           |                        |                                                                          | Direx 4L                                   | mL/ha|                                             |                    |
|    |           |                        |                                                                          | Spray oil                                  | mL/ha|                                             |                    |
|    |           |                        |                                                                          | Copper (Kocide 3000)                       | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Agrimek (if no mite resistance)            | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Zn, Mn, B                                  | mL/ha|                                             |                    |
|    |           |                        |                                                                          | Lorsban 4EC                                 | mL/ha|                                             |                    |
|    |           |                        |                                                                          | Copper (Kocide 3000)                       | mL/ha|                                             |                    |
|    |           |                        |                                                                          | Spray Oil                                  | mL/ha|                                             |                    |
|    |           |                        |                                                                          | MgO                                        | mL/ha|                                             |                    |
|    |           |                        |                                                                          | Dolomite                                   | mL/ha|                                             |                    |
|    |           |                        |                                                                          | Mowing (mechanical)                        | mL/ha|                                             |                    |
|    |           |                        |                                                                          | Mowing (chemical)                          | L/ha |                                             |                    |
|    |           |                        |                                                                          | Discing                                    | mg/ha|                                             |                    |
|    |           |                        |                                                                          | Soil shaping                               | mL/ha|                                             |                    |
|    |           |                        |                                                                          | Planting                                   | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Mowing (mechanical)                        | mL/ha|                                             |                    |
|    |           |                        |                                                                          | (chemical)                                 | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Fertilization (16–0–16–4 MgO)              | L/ha |                                             |                    |
|    |           |                        |                                                                          | Fertilization (lime)                       | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Herbicide                                  | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Pesticide                                  | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Conditioning                               | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Topping                                    | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Hedging                                    | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Brush removing                             | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Chopping brush                             | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Dead tree removal                          | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Irrigation                                 | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Fruit picking                              | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Transporting pickers                       | kg/ha|                                             |                    |
|    |           |                        |                                                                          | Roadsiding fruit                           | kg/ha|                                             |                    |
| #  | Reference | Data Source | Practice                                                                 | Input                  | Unit       | Output                                                                 |
|----|-----------|-------------|--------------------------------------------------------------------------|------------------------|------------|-------------------------------------------------------------------------|
| 41 | [75]      | Primary data (survey) Secondary data (databases) | Principal inputs involved in the production and distribution chain (scenarios 1 and 2) for strawberries | Substratum | L·ha⁻¹ | GWP (global warming potential)                                           |
|    |           |             | Nursery                                                                  | White PE              | kg·ha⁻¹   | kg CO₂ eq UF⁻¹                                                          |
|    |           |             | Rooting                                                                 | Metal supports        | kg·ha⁻¹   |                                                                         |
|    |           |             | Mulching                                                                | PVC piping            | kg·ha⁻¹   |                                                                         |
|    |           |             | Covering                                                                | PVC tubing            | kg·ha⁻¹   |                                                                         |
|    |           |             | Fertigation system                                                      | Compost mix           | kg·ha⁻¹   |                                                                         |
|    |           |             | Fertigation system                                                      | Water                 | m³·ha⁻¹   |                                                                         |
|    |           |             | Cold storage                                                            | Electrical energy     | kW·h⁻¹   |                                                                         |
|    |           |             | Field                                                                   | Plow or cultivator    | h·ha⁻¹   |                                                                         |
|    |           |             | Soil preparation                                                        | Harrow                | h·ha⁻¹   |                                                                         |
|    |           |             | Soil preparation                                                        | Bed-former            | h·ha⁻¹   |                                                                         |
|    |           |             | Mulching                                                                | Diesel consumption    | L·h⁻¹    |                                                                         |
|    |           |             | Mulching                                                                | PE sheeting           | kg·ha⁻¹   |                                                                         |
|    |           |             | Mulching                                                                | PVC piping            | kg·ha⁻¹   |                                                                         |
|    |           |             | Mulching                                                                | PVC tubing            | kg·ha⁻¹   |                                                                         |
|    |           |             | Mulching                                                                | Water                 | m³·ha⁻¹   |                                                                         |
|    |           |             | Field                                                                   | Electrical energy for the well | kWh·ha⁻¹ |                                                                         |
|    |           |             | Soil preparation                                                        | Manure                | t·ha⁻¹   |                                                                         |
|    |           |             | Soil preparation                                                        | Compost               | t·ha⁻¹   |                                                                         |
|    |           |             | Mulching                                                                | White PE              | kg·ha⁻¹   |                                                                         |
|    |           |             | Mulching                                                                | Metal supports        | kg·ha⁻¹   |                                                                         |
|    |           |             | Mulching                                                                | p.a.                  | kg·ha⁻¹   |                                                                         |
|    |           |             | Mulching                                                                | Electrical energy     | kWh·kg⁻¹ |                                                                         |
|    |           |             | Mulching                                                                | PE tray               | g·kg⁻¹   |                                                                         |
|    |           |             | Mulching                                                                | PE wrapping           | g·kg⁻¹   |                                                                         |
| # | Reference | Data Source                  | Practice                                                                 | Input                                                                 | Unit | Output       | Unit |
|---|-----------|------------------------------|--------------------------------------------------------------------------|----------------------------------------------------------------------|------|--------------|------|
| 42 | [93]      | Secondary data (databases)   | Life cycle inventory data for watermelon cultivation (per ha).           | 1. Human labor (man/woman)                                           |      | Watermelon   | kg   |
|    |           |                              |                                                                          | 2. Diesel fuel                                                        |      | On-farm emissions | kg   |
|    |           |                              |                                                                          | Flowing                                                              |      | N fertilizer  | MJ   |
|    |           |                              |                                                                          | Discing                                                              |      | Diesel fuel   | MJ   |
|    |           |                              |                                                                          | Ditcher                                                               |      |              |      |
|    |           |                              |                                                                          | 3. Machinery                                                          |      |              |      |
|    |           |                              |                                                                          | Tractor and self-propelled                                           |      |              |      |
|    |           |                              |                                                                          | Implement and machinery                                             |      |              |      |
|    |           |                              |                                                                          | 4. Fertilizers                                                       | b    |              |      |
|    |           |                              |                                                                          | Nitrogen (N)                                                         | L    |              |      |
|    |           |                              |                                                                          | Phosphate (P₂O₅)                                                     | kg   |              |      |
|    |           |                              |                                                                          | Potassium (K₂O)                                                     | kg   |              |      |
|    |           |                              |                                                                          | Microelements                                                       | kg   |              |      |
|    |           |                              |                                                                          | 5. Farmyard manure                                                  | kWh  |              |      |
|    |           |                              |                                                                          | 6. Electricity                                                      | kg   |              |      |
|    |           |                              |                                                                          | 7. Chemicals                                                        | kg   |              |      |
|    |           |                              |                                                                          | Fungicide                                                            | kg   |              |      |
|    |           |                              |                                                                          | Insecticide                                                         | kg   |              |      |
|    |           |                              |                                                                          | 8. Seeds                                                            | kg   |              |      |
|    |           |                              |                                                                          | Machinery                                                           | kg   |              |      |
|    |           |                              |                                                                          | Diesel fuel                                                        | kg   |              |      |
|    |           |                              |                                                                          | Chemical fertilizers                                               | kWh  |              |      |
|    |           |                              |                                                                          | (a) Urea                                                            | kg   |              |      |
|    |           |                              |                                                                          | (b) Phosphate (P₂O₅)                                                | kg   |              |      |
|    |           |                              |                                                                          | (c) Potassium (K₂O)                                                 | kg   |              |      |
|    |           |                              |                                                                          | Manure                                                              | kg   |              |      |
|    |           |                              |                                                                          | Pesticides                                                         | kg   |              |      |
|    |           |                              |                                                                          | Electricity                                                        | L    |              |      |
|    |           |                              |                                                                          | Plastics                                                            | kWh  |              |      |
|    |           |                              |                                                                          | Constanta                                                          | kg   |              |      |
|    |           |                              |                                                                          | N                                                                   | kg   |              |      |
|    |           |                              |                                                                          | K₂O                                                                 | kg   |              |      |
|    |           |                              |                                                                          | P₂O₅                                                                | kg   |              |      |
|    |           |                              |                                                                          | Manure                                                              | MJ   |              |      |
|    |           |                              |                                                                          | Diesel                                                              |      |              |      |
|    |           |                              |                                                                          | Electricity                                                        |      |              |      |
|    |           |                              |                                                                          | Seed                                                                 |      |              |      |
|    |           |                              |                                                                          | Chemicals                                                           |      |              |      |
|    |           |                              |                                                                          | Machinery                                                           |      |              |      |
|    |           |                              |                                                                          | Plastic                                                             |      |              |      |
|    |           |                              |                                                                          | Water                                                               |      |              |      |
| # | Reference | Data Source | Practice | Input                                                                 | Unit | Output | Unit |
|---|-----------|-------------|----------|-----------------------------------------------------------------------|------|---------|------|
| 43 | [76]      | Secondary data (databases) | NA       | Mulching film for pot production (PP)                                 | NA   | NA      | NA   |
|    |           |             |          | Wind-stopper (galvanized iron)                                         |      |         |      |
|    |           |             |          | Hydraulic pipe/micro pipe (PEHD/PELD/PVC)                              |      |         |      |
|    |           |             |          | Taps (PEHD/PVC)                                                       |      |         |      |
|    |           |             |          | Tunnel cover                                                          |      |         |      |
|    |           |             |          | Tunnel structure (galvanized iron)                                    |      |         |      |
|    |           |             |          | Poles (galvanized iron/wood)                                           |      |         |      |
|    |           |             |          | Sprinklers (galvanized iron)                                           |      |         |      |
|    |           |             |          | Hydraulic fittings (PE)                                               |      |         |      |
|    |           |             |          | Solenoid (PVC)                                                        |      |         |      |
|    |           |             |          | Support canes (bamboo)                                                |      |         |      |
|    |           |             |          | Black clip (PP)                                                       |      |         |      |
|    |           |             |          | Plates PP black wire (nylon)                                           |      |         |      |
|    |           |             |          | Green thread (PVC)                                                    |      |         |      |
|    |           |             |          | Iron wire (galvanized iron)                                            |      |         |      |
|    |           |             |          | Elastics/hooks/butterfly valve (PE)                                   |      |         |      |
|    |           |             |          | Irrigation bar (aluminum)                                              |      |         |      |
|    |           |             |          | Block (concrete)                                                      |      |         |      |
|    |           |             |          | Covering (gravel/volcanic stones)                                      |      |         |      |
|    |           |             |          | Raincoat towel (PVC/PP/PEHD)                                          |      |         |      |
|    |           |             |          | A chain-link fence (galvanized iron)                                  |      |         |      |
|    |           |             |          | Centrifugal/submersible pump (Cast iron/stainless steel)              |      |         |      |
|    |           |             |          | Electrical panel (PEHD/copper)                                        |      |         |      |
|    |           |             |          | Burlap (jute)                                                         |      |         |      |
|    |           |             |          | String (sisal)                                                        |      |         |      |
|    |           |             |          | Wire basket (iron)                                                    |      |         |      |
|    |           |             |          | Plastic net (PP)                                                      |      |         |      |
|    |           |             |          | Plastic box (PP)                                                      |      |         |      |

Total yearly GHG emissions are divided into different categories (kg CO$_2$ eq./m$^2$/year)

NFS $\frac{1}{2}$ nursery farm structure; AGS $\frac{1}{2}$ aboveground structures; IC $\frac{1}{4}$ inputs of cultivation; P $\frac{1}{4}$ packaging; EFS $\frac{1}{4}$ emissions from soil

| # | Reference | Data Source | Practice | Input                                | Unit | Output | Unit |
|---|-----------|-------------|----------|--------------------------------------|------|---------|------|
| 44 | [106]     | Secondary data (databases) | NA       | Strawberry (nursery field)            | NA   | Nonrenewable energy IPCC GWP 100a | MJ·UF$^{-1}$ |
|    |           |             |          | PE punnet                             |      |         |      |
|    |           |             |          | PE plastic film                       |      |         |      |
|    |           |             |          | End-of-life                           |      |         |      |
|    |           |             |          | Transport                             |      |         |      |
|    |           |             |          | Electricity                           |      |         |      |

Nonrenewable energy IPCC GWP 100a

MJ·UF$^{-1}$ kg CO$_2$ eq·UF$^{-1}$
| #  | Reference | Data Source          | Practice                                                                 |
|----|-----------|----------------------|--------------------------------------------------------------------------|
| 45 | [79]      | Primary data (surveys)| Gasoline at the refinery (US)                                            |
|    |           |                      | Diesel at the refinery (US)                                              |
|    |           |                      | Urea ammonium nitrate (UAN), (US)                                        |
|    |           |                      | Monoammonium phosphate (US)                                              |
|    |           |                      | Waxes/paraffin at the refinery (US)                                       |
|    |           |                      | Potassium sulfate, at regional storage (Europe)                          |
|    |           |                      | Mined from natural sources, only transport is modeled                    |
|    |           |                      | Fishmeal                                                                 |
|    |           |                      | Potassium carbonate, at the plant (Europe)                               |
|    |           |                      | Sulfur (elemental) at the refinery (US)                                  |
|    |           |                      | Yeast (surrogate data, yeast produced as a co-product)                   |
|    |           |                      | Serenade is a strain of *Bacillus subtilis* (Swiss)                      |
|    |           |                      | Glyphosate, at regional storehouse (Europe)                             |
|    |           |                      | Diphenyl-ether compounds at regional storehouse (Europe)                |
|    |           |                      | Phthalamide compounds at regional storehouse (Europe)                   |
|    |           |                      | Pesticide unspecified, at regional storehouse RER                       |
|    |           |                      | Developed based on Recycled Organics Unit (2006), updated with regionally appropriate LCI datasets |
|    |           |                      | Electricity grid mix (West US)                                           |
|    |           |                      | Modeled based on power rating and hours of operation (California model) |
|    |           |                      | and Diesel (US)                                                         |
|    |           |                      | Truck (combination)—diesel rail (US diesel)                            |
|    |           |                      | Gasoline                                                                 |
|    |           |                      | Diesel                                                                  |
|    |           |                      | Urea ammonium nitrate (UAN)                                              |
|    |           |                      | Monoammonium phosphate (MAP)                                             |
|    |           |                      | Adjuvant (stylet oil)                                                   |
|    |           |                      | Potassium sulfate                                                       |
|    |           |                      | Phytamin component: seabird guano                                        |
|    |           |                      | Phytamin component: fishmeal                                              |
|    |           |                      | Phytamin component: potassium carbonate                                  |
|    |           |                      | Sulfur dust                                                              |
|    |           |                      | Serenade                                                                |
|    |           |                      | Roundup Ultra Max                                                       |
|    |           |                      | Goal 2XL                                                                |
|    |           |                      | Chateau, Pristine (Boscalid and Pyraclostrobin)                         |
|    |           |                      | Compost production                                                      |
|    |           |                      | Electricity                                                              |
|    |           |                      | Equipment operation                                                      |
|    |           |                      | Truck, rail shipping                                                    |
|    |           |                      | International shipping                                                  |
|    |           |                      | IPCC Tier 2 emissions were used to calculate the field-based N₂O emissions from fertilizer and compost application and vineyard plant matter, including leaves, clippings, and cover crop residue following mowing (Intergovernmental Panel on Climate Change 2006; Point et al. 2012). |

**Note:** The table continues with additional entries not shown here.
Table A2. Cont.

| #   | Reference | Data Source                  | Practice                                                                 | Input                  | Unit       | Output                                                                 | Unit          |
|-----|-----------|------------------------------|--------------------------------------------------------------------------|------------------------|------------|------------------------------------------------------------------------|---------------|
| 46  | [63]      | Secondary data (databases)   | Fossil energy life cycle factors for agricultural inputs                 | Nitrogen               | MJ/kg      | Direct N₂O emissions from agricultural                                |               |
|     |           |                              |                                                                          | Phosphorous            | MJ/kg      | Emissions (e.g., volatile organic compound (VOC), carbon monoxide (CO), |               |
|     |           |                              |                                                                          | Potassium              | MJ/kg      | carbon dioxide (CO₂), nitrogen monoxide (NO), nitrogen dioxide (NO₂), |               |
|     |           |                              |                                                                          | Lime                   | MJ/kg      | nitrous oxide (N₂O), particulate matter (PM10), particulate matter (PM2.5), sulfur dioxide (SO₂), sulfur trioxide (SO₃), methane (CH₄)) |               |
|     |           |                              |                                                                          | Sulfur                 | MJ/kg      |                                                                        |               |
|     |           |                              |                                                                          | Micronutrients         | MJ/kg      |                                                                        |               |
|     |           |                              |                                                                          | Cover crop seed        | MJ/kg      |                                                                        |               |
|     |           |                              |                                                                          | Herbicide              | MJ/kg      |                                                                        |               |
|     |           |                              |                                                                          | Insecticide            | MJ/kg      |                                                                        |               |
|     |           |                              |                                                                          | Fungicide              | MJ/L       |                                                                        |               |
|     |           |                              |                                                                          | Gasoline               | MJ/L       |                                                                        |               |
|     |           |                              |                                                                          | Diesel                 | MJ/kg      |                                                                        |               |
|     |           |                              |                                                                          | Plastic                | MJ/h       | Emissions and energy use in transportation                             |               |
|     |           |                              |                                                                          | Agriculture machinery  | MJ/kWh     |                                                                        |               |
| 47  | [24]      | Secondary data (databases)   | Electric power production                                               | Electricity            | MJ         | CO₂                                                                    | kg            |
|     |           |                              |                                                                          | Oil                    | kg         | CH₄                                                                    | kg            |
|     |           |                              |                                                                          | Plastic P1             | kg         | N₂O                                                                    | kg            |
|     |           |                              |                                                                          | Produced A1            | 100 m      | NOₓ                                                                    | kg            |
|     |           |                              |                                                                          | Installed A1           | 100 m      | SO₂                                                                    | kg            |
|     |           |                              |                                                                          | Incinerated P1/A1      | kg         |                                                                        |               |
|     |           |                              |                                                                          | A1 in recycling        | kg         |                                                                        |               |
|     |           |                              |                                                                          | Avoided material B     | kg         |                                                                        |               |
|     |           |                              |                                                                          | Gutter A2 production   |            |                                                                        |               |
|     |           |                              |                                                                          | Gutter A2 use and demolition |          |                                                                        |               |
|     |           |                              |                                                                          | Incineration of P2/A2  |            |                                                                        |               |
|     |           |                              |                                                                          | Recycling process B     |            |                                                                        |               |
| #   | Reference | Data Source                      | Practice                          | Input                        | Unit          | Output          | Unit  |
|-----|-----------|----------------------------------|-----------------------------------|------------------------------|---------------|------------------|-------|
| 48  | [64]      | Secondary data (databases)       |                                   |                              |               |                  |       |
|     |           |                                   | Planting and maintenance          | Seed                         | kg·ha⁻¹       | Strawbale        | kg    |
|     |           |                                   | Harvesting and baling             | Fertilizer                   |               |                  |       |
|     |           |                                   | Receiving/storage                 | Pesticide/herbicide          | kg·ha⁻¹       |                  |       |
|     |           |                                   | Drying and chopping               | Land use                      | ha            |                  |       |
|     |           |                                   | Pelletizing/cooling/screening     | Machinery                    | ha            |                  |       |
|     |           |                                   | Packing and storage               | Fuel                         | MJ            |                  |       |
|     |           |                                   |                                   | Machinery                    | kWh           | Pellet           | kg    |
|     |           |                                   |                                   | Fuel                         | g CO₂ eq      |                  |       |
|     |           |                                   |                                   | Electricity                  | g CO₂ eq      |                  |       |
|     |           |                                   |                                   | Air                          | g SO₂ eq      |                  |       |
|     |           |                                   |                                   | Plastic bag                  | g PO₄ eq      |                  |       |
|     |           |                                   |                                   |                              |               |                  |       |
| 49  | [65]      | Primary data (real farm)          |                                   |                              |               |                  |       |
|     |           | Secondary data (database and previous studies) |                       |                              |               |                  |       |
|     |           |                                   | Production characteristics        |                              |               | Roses            | g     |
|     |           |                                   | Greenhouse plastic                |                              |               |                  |       |
|     |           |                                   | Water consumption                 |                              |               |                  |       |
|     |           |                                   | Growing media                     |                              |               |                  |       |
|     |           |                                   | Fertilizer                        |                              |               |                  |       |
|     |           |                                   | Pesticide                         |                              |               |                  |       |
|     |           |                                   | Electric power                    |                              |               |                  |       |
|     |           |                                   | Diesel and petrol                 |                              |               |                  |       |
|     |           |                                   | Post-harvest chemicals            |                              |               |                  |       |
|     |           |                                   |                                   |                              |               |                  |       |
|     |           |                                   |                                   | Plastic consumption          | g             |                  |       |
|     |           |                                   |                                   | Rejected steams              | #             |                  |       |
|     |           |                                   |                                   | Power consumption            | kWh           |                  |       |
|     |           |                                   |                                   | Diesel                       | g             |                  |       |
|     |           |                                   |                                   | Petrol                       | g             |                  |       |
|     |           |                                   |                                   | Cardboard box                | g             |                  |       |
|     |           |                                   |                                   | Bunching paper               | g             |                  |       |
|     |           |                                   |                                   | Rubber band                  | g             |                  |       |
|     |           |                                   |                                   | Strapping roll               | g             |                  |       |
|     |           |                                   |                                   | Water                        | L             |                  |       |
|     |           |                                   |                                   | Substrate (red ash)          | g             |                  |       |
|     |           |                                   |                                   | Pesticide                    | g             |                  |       |
|     |           |                                   |                                   | Pesticide empty containers    | g             |                  |       |
|     |           |                                   |                                   | Calcium nitrate              | g             |                  |       |
|     |           |                                   |                                   | Other fertilizers             | g             |                  |       |
|     |           |                                   |                                   | Acids                        | g             |                  |       |
|     |           |                                   |                                   | Post-harvest chemicals       | g             |                  |       |
|     |           |                                   |                                   | Post-harvest water use       | L             |                  |       |
| #  | Reference | Data Source | Practice | Input | Unit | Output | Unit |
|----|-----------|-------------|----------|-------|------|--------|------|
| 50 | [32]     | Secondary data (database and previous studies) | Production of crop inputs, production and use of diesel, and field emissions | N (ammonium nitrate) kg/ha | Hemp ha | |
|    |          |            |          | P<sub>2</sub>O<sub>5</sub> (triple superphosphate) kg/ha | Sunflower ha | |
|    |          |            |          | K<sub>2</sub>O (potassium chloride) kg/ha | Rapeseed ha | |
|    |          |            |          | CaO kg/ha | Pea ha | |
|    |          |            |          | Seed for sowing kg/ha | Wheat ha | |
|    |          |            |          | Pesticide (active ingredient) kg/ha | Maize ha | |
|    |          |            |          | Diesel kg/ha | Potato ha | |
|    |          |            |          | Natural gas (for grain drying) kg/ha | Sugar beet ha | |
|    |          |            |          | Agricultural machinery kg/ha | NH₃-N emissions/kg | |
|    |          |            |          | Grain dry matter yield kg/ha | NO₃-N emissions/kg | |
|    |          |            |          | Stem/straw dry matter yield kg/ha | N₂O-N emissions/kg | |
|    |          |            |          | Sugar/tuber dry matter yield kg/ha | PO₄-P emissions/kg | |
|    |          |            |          | Followed bycatch crop (%) kg/ha | |
|    |          |            |          | Succeeding crop NO₃-N emitted kg/ha | |
| 51 | [100]    | Secondary data (database and previous studies) | Infrastructure: | Mineral fertilizers kg | Potatoes organic, at the farm kg | |
|    |          |            |          | Organic fertilizers kg | Rapeseed extensive, at the farm kg | |
|    |          |            |          | Pesticides kg | Wheat grains conventional, Barrois, at the farm kg | |
|    |          |            |          | Seed kg | Carbon dioxide CO₂ g/kg | |
|    |          |            |          | Feed kg | Sulfur dioxide SO₂ g/kg | |
|    |          |            |          | Soil cultivation | Lead Pb g/kg | |
|    |          |            |          | Fertilization | Methane CH₄ g/kg | |
|    |          |            |          | Sowing | Benzene C₆H₆ g/kg | |
|    |          |            |          | Chemical plant protection | Particulate Matter PM g/kg | |
|    |          |            |          | Mechanical treatment | Cadmium Cd g/kg | |
|    |          |            |          | Harvest | Chromium Cr g/kg | |
|    |          |            |          | Transport | Copper Cu g/kg | |
|    |          |            |          |          | Monoxide N₂O g/kg | |
|    |          |            |          |          | Nickel Ni | |
Table A2. Cont.

| #  | Reference | Data Source     | Practice                                                                 | Input                                                                                      | Unit | Output                      | Unit          |
|----|-----------|-----------------|--------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|------|-----------------------------|---------------|
| 52 | [85]      | Primary data (survey) | Tractors and equipment                                                   | Pesticides                                                                                 |      | kg active matter            | USD-ha^{-1}   |
|    |           |                  | Buildings required energy                                               | Fungicide                                                                                  |      | kg N                        |
|    |           |                  |                                                                          | Insecticide                                                                                 |      | kg K2O                      |
|    |           |                  |                                                                          | Herbicide                                                                                   |      | kg P2O5                     |
|    |           |                  |                                                                          | Other plants treatment products                                                            |      | kg                           |
|    |           |                  |                                                                          | Fertilizers                                                                                 |      | kg Ca, Mg                   |
|    |           |                  |                                                                          | N-fertilizer                                                                                |      | kg                           |
|    |           |                  |                                                                          | Ca- and Mg-fertilizer                                                                       |      | kg                           |
|    |           |                  |                                                                          | (kg Ca, Mg)                                                                                 |      | kg                           |
|    |           |                  |                                                                          | K-fertilizer                                                                                |      | kg                           |
|    |           |                  |                                                                          | P-fertilizer                                                                                |      | kg                           |
|    |           |                  |                                                                          | Machinery                                                                                  |      | m²                          |
|    |           |                  |                                                                          | Machinery Dieisel                                                                           |      | Total receipts              |
|    |           |                  |                                                                          | Machinery Tractor                                                                          |      | USD            |
|    |           |                  |                                                                          | Machinery Equipment                                                                        |      |                            |
|    |           |                  |                                                                          | Buildings                                    Ft CO2                                      |      | t CO2                      |
| 53 | [89]      | Secondary data (databases) | Pesticide                                                               |                                                                                           |      | eq-ha^{-1}.year^{-1}       |
|    |           |                  | Seeds                                                                    |                                                                                           |      | kg                           |
|    |           |                  | PK fertilizer                                                            |                                                                                           |      | eq-ha^{-1}.year^{-1}       |
|    |           |                  | N fertilizer                                                             |                                                                                           |      | t CO2                       |
|    |           |                  | Machinery mulching                                                       |                                                                                           |      | eq-ha^{-1}.year^{-1}       |
|    |           |                  | Machinery irrigation                                                     |                                                                                           |      | kg                           |
|    |           |                  | Machinery pesticide                                                     |                                                                                           |      | eq-ha^{-1}.year^{-1}       |
|    |           |                  | Machinery fertilization                                                  |                                                                                           |      | kg                           |
|    |           |                  | Machinery weeding                                                        |                                                                                           |      | eq-ha^{-1}.year^{-1}       |
|    |           |                  | Machinery soil tillage                                                   |                                                                                           |      | kg                           |
|    |           |                  | Machinery harvest                                                        |                                                                                           |      | eq-ha^{-1}.year^{-1}       |
|    |           |                  | Machinery sowing                                                         |                                                                                           |      | kg                           |
|    |           |                  |                                                                          | Energy input                                                                                | MJ   | eq-ha^{-1}.year^{-1}       |
|    |           |                  |                                                                          |                                                                                           |      | kg                           |
|    |           |                  |                                                                          |                                                                                           |      | eq-ha^{-1}.year^{-1}       |
|    |           |                  |                                                                          |                                                                                           |      | kg                           |
# Reference Data Source Practice Input Unit Output Unit

| # | Reference | Data Source | Practice | Input | Unit | Output | Unit |
|---|-----------|-------------|----------|-------|------|--------|------|
| 54 | [77] | Primary data (farmers) Secondary data (databases and references) | Transportation Fertilization Pesticides Irrigation | | | | Grape |
|   |          |             |          |       |      | Ammonia (NH$_3$) | kg |
|   |          |             |          |       |      | Ammonia (NH$_3$) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Benzene | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Benzo (a) pyrene | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Cadmium (Cd) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Carbon dioxide (CO$_2$) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Carbon dioxide (CO$_2$) from urea. | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Carbon monoxide (CO) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Chromium (Cr) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Copper (Cu) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Dazinon | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Dinitrogen monoxide (N$_2$O) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Dinitrogen monoxide (N$_2$O) from atmospheric deposition | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Hydrocarbons (HC, as NMVOC) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Methane (CH$_4$) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Nickel (Ni) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Nitrate (NO$_3$) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Nitrogen oxide (NO$_x$) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Nitrogen oxides (NO$_x$) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | PAH (polycyclic hydrocarbons) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Particulates (b2.5 mm) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Phosphorus emissions from fertilizers application emitted into groundwater. | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Selenium (Se) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Sulfur dioxide (SO$_2$) | kg·ha$^{-1}$ |
|   |          |             |          |       |      | Zinc (Zn) | kg·ha$^{-1}$ |

Inputs
1. Diesel fuel
2. Transportation
3. Human labor
4. Chemical fertilizers
   (a) Nitrogen
   (b) Phosphate
   (c) Potassium
   (d) Sulfur
5. Manure
6. Chemical pesticides
   (a) Fungicide
   (b) Insecticide
7. Irrigation water
The total energy input
Table A2. Cont.

| #  | Reference | Data Source | Practice | Input | Unit | Output | Unit |
|----|-----------|-------------|----------|-------|------|--------|------|
| 55 | [83]      | Primary data (field experiment) Secondary data (database) | Fertilization Cutting preparation Spraying Ploughing Disking Harrowing Marking Spraying Mechanical weeding Fertilizing Lignin production and application Harvest Transport Liquidation | Tractor/harvester Machinery Diesel fuel | kg·ha⁻¹ | CO₂, PM, SO₂, p | kg Mg⁻¹ CO₂ eq kg MP 10 eq kg SO₂ eq kg p eq |
| 56 | [90]      | Secondary data (databases and previous studies) | Pesticide application | Active ingredients of the pesticide | t | Active ingredients emissions | Unitless |
| 57 | [66]      | Primary (survey) Secondary data (database and previous studies) | Nursery Tomato cultivation Packaging Transportation | Reporting period Country (Production site) Growing period Greenhouse structure Substrate Greenhouse heating CO₂ enrichment Yield Fertilization Irrigation Energy consumption | ton·ha⁻¹ kg N·ha⁻¹, kg P₂O₅·ha⁻¹, kg K₂O·ha⁻¹ water m³·ha⁻¹ kWh·ha⁻¹ | Nitrogen oxides, phosphates, and pesticides emissions nitrous oxide, and ammonia | g N eq g P eq |
Table A2. Cont.

| #  | Reference | Data Source | Practice | Input | Unit | Output | Unit |
|----|-----------|-------------|----------|-------|------|--------|------|
| 58 | [86] | Secondary data (databases) | Applying farmyard manure | N-based fertilizers | kg | Carbon dioxide (CO₂) | kg |
|    |          |             | Land preparation | P-based fertilizers | kg | Sulfur dioxide (SO₂) | kg |
|    |          |             | Planting | K-based fertilizers | kg | Methane (CH₄) | kg |
|    |          |             | Fertilizing | Pesticides | kg | Benzene | kg |
|    |          |             | Harvesting | Farmyard manure | kg | Cadmium (Cd) | kg |
|    |          |             |         | Microelements | t | Chromium (Cr) | kg |
|    |          |             |         | Diesel fuel | kg | Copper (Cu) | kg |
|    |          |             |         | Water | m³ | Dinitrogen monoxide (N₂O) | kg |
| 59 | [67] | Secondary data (databases) | Fertilization, split fertilization, chemical fallow, liming, sowing and spraying at the farm | NPK-fertilizer | kg·ha⁻¹ | Nickel (Ni) | kg |
|    |          |             |         | N-fertilizer | kg·ha⁻¹ | Zinc (Zn) | kg |
|    |          |             |         | Roundup (glyphosate) | kg·ha⁻¹ | Benzo(a)pyrene | kg |
|    |          |             |         | Dolomite (CaO) | kg·ha⁻¹ | Ammonia (NH₃) | kg |
|    |          |             |         | Celest Formula M (fludioxonil) | kg·ha⁻¹ | Selenium (Se) | kg |
|    |          |             |         | Starane XL (fluroxypyr/florasulam) | kg·ha⁻¹ | PAH (polycyclic hydrocarbons) | kg |
|    |          |             |         | Fastac 50 (alpha-ceypermethrin) | kg·ha⁻¹ | Hydrocarbons (HC, as NMVOC) | kg |
|    |          |             |         |         | kg·ha⁻¹ | Nitrogen oxides (NOₓ) | kg |
|    |          |             |         |         | kg·ha⁻¹ | Carbon monoxide (CO) | kg |
|    |          |             |         |         | kg·ha⁻¹ | Particulates (<2.5 µm) | kg |
| 60 | [103] | Primary data (real farm) Secondary data (databases) | production, transport to the farm and use on the farm | Fertilizers, pesticides, field materials, pesticide spray equipment, irrigation system and packaging manufacturing | NA | Pesticide emission | NA |
Table A2. Cont.

| #   | Reference | Data Source                                                                 | Practice                                                                 | Input                                | Unit                     | Output                                           | Unit |
|-----|-----------|----------------------------------------------------------------------------|-------------------------------------------------------------------------|--------------------------------------|--------------------------|--------------------------------------------------|------|
| 61  | [87]      | Secondary data (databases and previous studies)                             | • Production of nitrogenous mineral fertilizer                          | Fertilizer N, P, K                   | NA                       | Agricultural engine emissions (CO, HC, NOx, SO2, PM, CO2) (EPA 2004) | NA   |
|     |           |                                                                            | • Transportation of organic fertilizer                                  | Lime                                 | NA                       | Direct field emission from fertilization (NO3, NH4, N2O, NOx, CO2, PO4) |      |
|     |           |                                                                            | • Production of phosphorus mineral fertilizer                           | Fuel                                 | NA                       | Hemp straws and seeds                             |      |
|     |           |                                                                            | • Production of potassium mineral fertilizer                            | Seeds                                | NA                       |                                                  |      |
|     |           |                                                                            | • Production of agricultural equipment                                  | Agricultural equipment               | NA                       |                                                  |      |
|     |           |                                                                            | • Production of seeds for sowing/default seeds harvested crop scenario  | Production of diesel                |                          |                                                  |      |
| 62  | [91]      | Secondary data (databases)                                                 | Pesticide application                                                   | S-Metolachlor (H)                    | kg/kg corn               | Pesticide emission to air, surface water, and groundwater | %    |
|     |           |                                                                            |                                                                        | Simazine (H)                         | kg/kg corn               |                                                  |      |
|     |           |                                                                            |                                                                        | Glyphosate (H)                       | kg/kg corn               |                                                  |      |
|     |           |                                                                            |                                                                        | Glufosinate ammonium (H)            | kg/kg corn               |                                                  |      |
|     |           |                                                                            |                                                                        | Dimethenamid-P (H)                  | kg/kg corn               |                                                  |      |
|     |           |                                                                            |                                                                        | Atrazine (H)                        | kg/kg corn               |                                                  |      |
|     |           |                                                                            |                                                                        | Alachlor (H)                        | kg/kg corn               |                                                  |      |
|     |           |                                                                            |                                                                        | Acetochlor (H)                      | kg/kg corn               |                                                  |      |
|     |           |                                                                            |                                                                        | 2,4,6-trimethylammonium…            | kg/kg corn               |                                                  |      |
|     |           |                                                                            |                                                                        | 2,4,6-2-ethylhexyl ester (H)        | kg/kg corn               |                                                  |      |
|     |           |                                                                            |                                                                        | Fipronil (I)                        | kg/kg corn               |                                                  |      |
|     |           |                                                                            |                                                                        | Chlorpyrifos (I)                    | kg/kg corn               |                                                  |      |
Table A2. Cont.

| #  | Reference | Data Source                        | Practice                                                                 | Input                                                                 | Unit       | Output              | Unit  |
|----|-----------|-----------------------------------|--------------------------------------------------------------------------|----------------------------------------------------------------------|------------|---------------------|-------|
| 63 | [101]     | Primary data (real farm)           | Manufacture of greenhouse components, substrate, fertilizers, and pesticides. the electricity production mix; and transport and disposal of materials | greenhouse components, Water consumption and fertilizer and pesticide doses applied | kg, m², m³ | N₂O, NOₓ, NH₃ | kg    |
|    |           | Secondary data (databases)        |                                                                          |                                                                      | kg, L      | Azoxystrobin, Chlorothalonil, Clofentezine, Fenbutatin oxide, Mancozeb, Spinosad, Copper chloride oxide, hydrate, Concrete, Plastics, Substrate | kg, kg, kg |
|    |           |                                   |                                                                          |                                                                      | kg         | Fertilizers’ emissions | kg/ha |
|    |           |                                   |                                                                          |                                                                      | kg N/ha    | NH₃, N₂O, PO₄ | kg/ha |
|    |           |                                   |                                                                          |                                                                      | kg N/ha    | Fertilizers’ emissions | kg/ha |
|    |           |                                   |                                                                          |                                                                      | kg N/ha    | Fertilizers’ emissions | kg/ha |
|    |           |                                   |                                                                          |                                                                      | kg N/ha    | Fertilizers’ emissions | kg/ha |
|    |           |                                   |                                                                          |                                                                      | kg N/ha    | Fertilizers’ emissions | kg/ha |
|    |           |                                   |                                                                          |                                                                      | kg N/ha    | Fertilizers’ emissions | kg/ha |
| 64 | [94]      | Primary data (survey)              |                                                                          |                                                                      | t/ha       | Yield               | t/ha  |
|    |           | Secondary data (databases and previous studies) |                                                                          |                                                                      | reps       | Grain field operations | t/ha  |
|    |           |                                   |                                                                          |                                                                      | reps       | Fertilizers’ emissions | kg/ha |
|    |           |                                   |                                                                          |                                                                      | reps       | Fertilizers’ emissions | kg/ha |
|    |           |                                   |                                                                          |                                                                      | reps       | Fertilizers’ emissions | kg/ha |
|    |           |                                   |                                                                          |                                                                      | reps       | Fertilizers’ emissions | kg/ha |
|    |           |                                   |                                                                          |                                                                      | reps       | Fertilizers’ emissions | kg/ha |
|    |           |                                   |                                                                          |                                                                      | reps       | Fertilizers’ emissions | kg/ha |
|    |           |                                   |                                                                          |                                                                      | reps       | Fertilizers’ emissions | kg/ha |
|    |           |                                   |                                                                          |                                                                      | reps       | Fertilizers’ emissions | kg/ha |

- Agricultural field operations (including plowing, harrowing, sowing, chemical weed control, harvesting, straw baling);
- Seeds, fertilizers, and pesticides production.
- Grain drying.
- Nitrogen and phosphate (fertilizers’) emissions; and
- Pesticide’s emissions.
### Table A2. Cont.

| #  | Reference | Data Source | Practice                                                                 | Input                      | Unit                  | Output                                                                 | Unit         |
|----|-----------|-------------|---------------------------------------------------------------------------|----------------------------|-----------------------|----------------------------------------------------------------------|--------------|
| 65 | [80]      | Secondary data (databases) | Slurry tanker and spreading device production  
Tractor production  
Diesel production | Raw materials  
Energy | Field emissions NH₃, N₂O, NOₓ, PO₄  
Other emissions to air, soil, water | kg N | |
| 66 | [84]      | Secondary data (databases) | Transportation of raw materials  
Production of technical oxide  
Transportation of technical oxide  
Production of fertilizer  
Transportation of fertilizer Spreading | Zinc ashes  
Every three years | Zn  
ZnCl₂  
ZnO | kg  
kg  
kg | |
| 67 | [68]      | Primary data (interview)   | Desiccation  
Liming  
Soybean and sunflower seeds treatment  
Sowing and fertilization  
Topdressing fertilization  
Pesticide and herbicide application  
Soybean and sunflower harvesting | Product  
Resources  
Occupation, arable, non-irrigated  
Materials/fuels  
Seeds  
Limestone  
Urea, as N  
Potassium chloride, as K₂O  
Herbicides  
Insecticides  
Fungicides  
Mineral oil  
Boric acid  
Liming  
Pesticide application  
Sowing and fertilization  
Pesticide application  
Harvesting | Emissions to air  
Ammonia  
Dinitrogen monoxide  
Nitrogen oxides  
CO₂, fossil  
CO₂, land transformation  
Emissions to water  
Nitrate  
Cadmium 2  
Copper  
Nickel  
Chromium  
Emissions to soil  
Cadmium  
Copper  
Zinc  
Zinc  
Lead  
Nickel  
Chromium  
Herbicides  
Insecticides  
Fungicides | kg  
kg  
kg  
kg  
kg  
kg  
kg  
kg  
kg  
kg  
kg  
kg  
kg  
kg  
kg  
kg  
kg  
kg  
kg  
kg  
kg  |
Table A2. Cont.

| #  | Reference | Data Source                     | Practice                                                                 | Input                                                                                                                                                                                                 | Unit                   | Output                           | Unit              |
|----|-----------|---------------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|-----------------------------------------------------------------------------|-------------------|
| 68 | [99]      | Primary data (survey)           | Direct agricultural inputs Production of the different agricultural inputs, | Information about tractors and implements, labor hours, and input rates such as agrochemicals and water use) nitrogen (urea and ammonium nitrate), phosphorous or potassium-based fertilizers and herbicides (terbutilazine, alachlor, lumax, and S-metolachlor | NH₃, N₂O, NO₃         | kg N₂O-N·ha⁻¹·kg⁻¹            |                   |
| 69 | [92]      | Secondary data (databases and previous studies) | Pesticide application | Abamectin, Azadirachtin, Chlorpyrifos, Clofentezine, Copper oxychloride, Fenazaquin, Fenbutatin-oxyde, Fluroxypyr, Fosetyl-Al, Glufosinate-ammonium, Glyphosate, Hexythiazox, Imazalil, Imidacloprid Insecticide, Lambda-cyhalothrin, Mancozeb, MCPA, Parquat, Propargite, Pyridaben, Pyriproxyfen, Spinosad, Tebufenpyrad, Thiadendazole, White mineral oil (paraffin oil) | kg·m⁻²                  |                                                                                   |                   |
### Table A2. Cont.

| #  | Reference | Data Source | Practice | Input | Unit | Output | Unit |
|----|-----------|-------------|----------|-------|------|--------|------|
| 70 | [88]      | Primary data (survey and interview) Secondary data (Databases and previous studies) | NA | Cut flowers Carnation support net Plastic cover material Putty for sun protection Water for the putty used for sun protection Transporting of cut flowers to Athens (2 times per week) Electricity consumption for refrigeration of the cut flowers, water pumping Fertilizers Water for plant protection Fungicides, Pesticides Soil disinfection (once every three years) Water for soil disinfection, plant watering (3 times per week) Humidification | Stems/year kg/year kg/year kg/year m²/year km/year kWh/year kg N/year, kg P/year, kg K/year m³/year | N₂O, NOₓ, and ammonia | NA |
| 71 | [28]      | Secondary data (databases and previous studies) | Pesticide application | Abamectine Azoxystrobin Benomyl Bromopropylate Captan Cyromazine Deltametrin Fenamidol Iprodione Kresoxim-metil Mancozeb Pimetrozine | kgai-FU⁻¹ kgai-FU⁻¹ kgai-FU⁻¹ kgai-FU⁻¹ kgai-FU⁻¹ kgai-FU⁻¹ kgai-FU⁻¹ kgai-FU⁻¹ kgai-FU⁻¹ kgai-FU⁻¹ kgai-FU⁻¹ kgai-FU⁻¹ kgai-FU⁻¹ kgai-FU⁻¹ kgai-FU⁻¹ | Pesticide emission to air, soil, and water | NA |
| #  | Reference | Data Source | Practice | Input | Unit | Output | Unit |
|----|-----------|-------------|----------|-------|------|--------|------|
| 72 | [12]      | Secondary data (databases) | Fertilizer application<br>Seeds use<br>Plant protection production<br>application<br>Agriculture activity | N, P, K fertilizer | NA | NH₃, NOₓ, N₂O, NO₃, PO₄⁻³, P | NA |
|    |           |             |          |       |      | HM, Heavy metal<br>Active ingredients<br>CO₂<br>NMVO, PM |     |
| 73 | [102]     | Secondary data (databases) | NA |       |       | N₂O, air emission<br>P, water<br>Emission<br>NO⁻³, water<br>Emission<br>Pesticides, water<br>emission | NA |
| 74 | [69]      | Primary data (surveys)<br>Secondary data (databases) | Soil tillage<br>Seedbed preparation<br>Owing<br>Fertilization<br>Plant protection<br>Harvest<br>Stubble cultivation<br>Transport to the farm and grain drying<br>Fertilizer use<br>Number of passes for fertilizer spreading<br>Pesticide use (active ingredients)<br>Herbicides<br>Fungicides<br>Insecticides<br>Other pesticides<br>Total pesticides<br>Number of passes for pesticide spraying | kg<br>N-ha⁻¹-year⁻¹<br>kg<br>P₂O₅-ha⁻¹-year⁻¹<br>kg<br>K₂O-ha⁻¹-year⁻¹<br>kg<br>ha⁻¹-year⁻¹<br>kg<br>ha⁻¹-year⁻¹<br>kg<br>ha⁻¹-year⁻¹<br>ha⁻¹-year⁻¹<br>Yields<br>Gross energy yield<br>Raw protein yield<br>Gross margin | kg DM-ha⁻¹-year⁻¹<br>GJ ha⁻¹-year⁻¹<br>kg ha⁻¹-year⁻¹<br>D ha⁻¹-year⁻¹ |     |
References

1. Kucukvar, M.; Ismaen, R.; Onat, N.C.; Al-Hajri, A.; Al-Yafay, H.; Al-Darwish, A. Exploring the Social, Economic and Environmental Footprint of Food Consumption: A Supply Chain-Linked Sustainability Assessment. In Proceedings of the 2019 IEEE 6th International Conference on Industrial Engineering and Applications (ICIEA), Tokyo, Japan, 12–15 April 2019; IEEE: Piscataway, NJ, USA; pp. 733–742.

2. Institute of Medicine and National Research Council. 2 Overview of the U.S. Food System. In A Framework for Assessing Effects of the Food System; The National Academies Press: Washington, DC, USA, 2015. Available online: https://www.nap.edu/read/18846/chapter/5 (accessed on 28 September 2021). [CrossRef]

3. Tilman, D.; Balzer, C.; Hill, J.; Befort, B.L. Global Food Demand and the Sustainable Intensification of Agriculture. Proc. Natl Acad. Sci. USA 2011, 108, 20260–20264. [CrossRef] [PubMed]

4. Brandt, K.; Barrangou, R. Applications of CRISPR Technologies Across the Food Supply Chain. Annu. Rev. Food Sci. Technol. 2019, 10, 133–150. [CrossRef] [PubMed]

5. FAO; WFP; IFAD. The State of Food Insecurity in the World 2012. Economic Growth Is Necessary but Not Sufficient to Accelerate Reduction of Hunger and Malnutrition; FAO: Rome, Italy, 2012; p. 5. Available online: https://www.fao.org/3/i3027e/i3027e00.pdf (accessed on 28 September 2021).

6. Sources of Greenhouse Gas Emissions. US EPA. Available online: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions (accessed on 28 July 2021).

7. US EPA. Overview of Greenhouse Gases. Available online: https://www.epa.gov/ghgemissions/overview-greenhouse-gases (accessed on 28 July 2021).

8. Cellura, M.; Longo, S.; Mistretta, M. Life Cycle Assessment (LCA) of Protected Crops: An Italian Case Study. J. Clean. Prod. 2012, 28, 56–62. [CrossRef]

9. Von Blottnitz, H.; Curran, M.A. A Review of Assessments Conducted on Bio-Ethanol as a Transportation Fuel from a Net Energy, Greenhouse Gas, and Environmental Life Cycle Perspective. J. Clean. Prod. 2007, 15, 607–619. [CrossRef]

10. Lee, K.-M.; Inaba, A. Life Cycle Assessment Best Practices of ISO 14040 Series; Center for Ecodesign and LCA (CEL), Ajou University: Suwon, Korea, 2004; p. 96.

11. Buyle, M.; Braet, J.; Audenaert, A. Life Cycle Assessment in the Construction Sector: A Review. Renew. Sustain. Energy Rev. 2013, 26, 379–388. [CrossRef]

12. Corrado, S.; Castellani, V.; Zampori, L.; Sala, S. Systematic Analysis of Secondary Life Cycle Inventories When Modelling Agricultural Production: A Case Study for Arable Crops. J. Clean. Prod. 2018, 172, 3990–4000. [CrossRef] [PubMed]

13. Atenstaedt, R. Word Cloud Analysis of the BJGP. Br. J. Gen. Pract. 2012, 62, 148. [CrossRef] [PubMed]

14. Heimerl, F.; Lohmann, S.; Lange, S.; Ertl, T. Word Cloud Explorer: Text Analytics Based on Word Clouds. In Proceedings of the 2014 47th Hawaii International Conference on System Sciences, Waikoloa, HI, USA, 6–9 January 2014; pp. 1833–1842.

15. DePaolo, C.A.; Wilkinson, K. Get Your Head into the Clouds: Using Word Clouds for Analyzing Qualitative Assessment Data. TechTrends 2014, 58, 38–44. [CrossRef]

16. Present Your Data in A Doughnut Chart. Available online: https://support.microsoft.com/en-us/office/present-your-data-in-a-doughnut-chart-0ac0efde-34e2-4d6c-9b7f-ac93d1783353 (accessed on 4 October 2021).

17. What Is A Pie Chart and When to Use It. Available online: https://www.storytellingwithdata.com/blog/2020/5/14/what-is-a-pie-chart (accessed on 4 October 2021).

18. Wu, J. Improving the Writing of Research Papers: IMRAD and Beyond. J. Clean. Prod. 2016, 1345–1349. [CrossRef]

19. Vyas, V.d.H.a. Tantraguna—The Ancient Criteria for Scientific Writing. Ayu, J.B. (Eds.) Environmental Life Cycle Assessment of Products; Centre of Environmental Science: Leiden, The Netherlands, 1992.

20. Hertwich, E.G.; Pease, W.S. ISO 14042 Restricts Use and Development of Impact Assessment. Int. J. Life Cycle Assess. 1998, 3, 180–181. [CrossRef]

21. Prystialakivsky, J.; Searcy, C. Fifteen Years of ISO 14040: A Review. J. Clean. Prod. 2013, 57, 115–123. [CrossRef]

22. Fava, J.; Baer, S.; Cooper, J. Increasing Demands for Life Cycle Assessments in North America. J. Ind. Ecol. 2009, 13, 491–494. [CrossRef]

23. Huijbregts, M. Uncertainty and Variability in Environmental Life-Cycle Assessment. Int. J. Life Cycle Assess. 2002, 7, 173. [CrossRef]

24. Bhatia, P.; Cummins, C.; Draucker, L.; Rich, D.; Labd, H.; Brown (WBCSD), A. Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting Standard; World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD): Washington, DC, USA, 2011.

25. Bhatia, P.; Cummins, C.; Draucker, L.; Rich, D.; Labd, H.; Brown (WBCSD). A Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting Standard; World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD): Washington, DC, USA, 2011.
28. Antón, A.; Castells, F.; Montero, J.I.; Huijbregts, M. Comparison of Toxicological Impacts of Integrated and Chemical Pest Management in Mediterranean Greenhouses. *Chemosphere* 2004, 54, 1225–1235. [CrossRef] [PubMed]

29. Huijbregts, M.A.J.; Striejs, J.; Goedkoop, M.; Heijungs, R.; Jan Hendriks, A.; van de Meent, D. Human Population Intake Fractions and Environmental Fate Factors of Toxic Pollutants in Life Cycle Impact Assessment. *Chemosphere* 2005, 61, 1495–1504. [CrossRef] [PubMed]

30. Jollivet, O.; Margni, M.; Charles, R.; Humbert, S.; Payet, J.; Rebitzer, G.; Rosenbaum, R. IMPACT 2002+: A New Life Cycle Impact Assessment Methodology. *Int. J. Life Cycle Assess.* 2003, 8, 324. [CrossRef]

31. de García, S.O.; García-Encina, P.A.; Irusta-Mata, R. The Potential Ecotoxicological Impact of Pharmaceutical and Personal Care Products on Humans and Freshwater, Based on USEtox™ Characterization Factors. A Spanish Case Study of Toxicity Impact Scores. *Sci. Total Environ.* 2017, 609, 429–445. [CrossRef]

32. Van Der Werf, H.M.G. Life Cycle Analysis of Field Production of Fibre Hemp, the Effect of Production Practices on Environmental Impacts. *Euphytica* 2004, 140, 13–23. [CrossRef]

33. Charles, R.; Jollivet, O.; Gaillard, G.; Pellet, D. Environmental Analysis of Intensity Level in Wheat Crop Production Using Life Cycle Assessment. *Agric. Ecosyst. Environ.* 2006, 113, 216–225. [CrossRef]

34. Brentrup, F.; Küsters, J.; Lammel, J.; Barraclough, P.; Kuhlmann, H. Environmental Impact Assessment of Agricultural Production Systems Using the Life Cycle Assessment (LCA) Methodology II. The Application to N Fertilizer Use in Winter Wheat Production Systems. *Eur. J. Agron.* 2004, 20, 265–279. [CrossRef]

35. Nesheim, M.C.; Oria, M.; Yih, P.T.; Committee on a Framework for Assessing the Health, Environmental, and Social Effects of the Food System; Food and Nutrition Board; Board on Agriculture and Natural Resources; Institute of Medicine; National Research Council. *Environmental Effects of the U.S. Food System:* National Academies Press: Washington, DC, USA, 2015.

36. Gathorne-Hardy, A. A life cycle assessment (LCA) of greenhouse gas emissions from SRI and flooded rice production in SE India. *Tiwai Water Conserv.* J. 2013, 61, 111–125.

37. Hanieh, A.A.; Hasan, A.; Assi, M. Date Palm Trees Supply Chain and Sustainable Model. *J. Clean. Prod.* 2020, 258, 120951. [CrossRef]

38. Fusi, A.; Castellani, V.; Bacenetti, J.; Cocetta, G.; Fiala, M.; Guidetti, R. The Environmental Impact of the Production of Fresh Cut Salad: A Case Study in Italy. *Int. J. Life Cycle Assess.* 2016, 21, 162–175. [CrossRef]

39. Tasca, A.L.; Nessi, S.; Rigamonti, L. Environmental Sustainability of Agri-Food Supply Chains: An LCA Comparison between Two Alternative Forms of Production and Distribution of Endive in Northern Italy. *J. Clean. Prod.* 2017, 140, 725–741. [CrossRef]

40. Keckenholz-Tänikon, A. Towards a Sustainable Management of the Food Chain. In Proceedings of the Research Station ART 6th International Conference on Life Cycle Assessment in the Agri-Food Sector, Zurich, Switzerland, 12–14 November 2008.

41. O’Neill, B.C.; Kriegler, E.; Ebi, K.L.; Kemp-Benedict, E.; Riahi, K.; Rothman, D.S.; van Ruijven, B.J.; van Vuuren, D.P.; Birkmann, J.; Kok, K. The Roads Ahead: Narratives for Shared Socioeconomic Pathways Describing World Futures in the 21st Century. *Glob. Environ. Chang.* 2017, 42, 169–180. [CrossRef]

42. Abeliotis, K.; Detsis, V.; Pappia, C. Life Cycle Assessment of Bean Production in the Prespa National Park, Greece. *J. Clean. Prod.* 2013, 41, 89–96. [CrossRef]

43. Beccali, M.; Cellura, M.; Iudicello, M.; Mistretta, M. Resource Consumption and Environmental Impacts of the Agrofood Sector: Life Cycle Assessment of Italian Citrus-Based Products. *Environ. Manag.* 2009, 43, 707–724. [CrossRef] [PubMed]

44. Blengini, G.A.; Busto, M. The Life Cycle of Rice: LCA of Alternative Agri-Food Chain Management Systems in Vercelli (Italy). *J. Environ. Manag.* 2009, 90, 1512–1522. [CrossRef] [PubMed]

45. Garofalo, P.; D’Andrea, L.; Tomaiuolo, M.; Venezia, A.; Castrignanò, A. Environmental Sustainability of Agri-Food Supply Chains in Italy: The Case of the Whole-Peeled Tomato Production under Life Cycle Assessment Methodology. *J. Food Eng.* 2017, 200, 1–12. [CrossRef]

46. Radzyminska, M.; Garbowska, B.; Jakubowska, D. Health Quality and Nutritional Value of Rye Bread Produced on a Small and Large Scale in Poland. *Int. J. Food Sci.* 2013, 25, 126.

47. Ingwersen, W.W. Life Cycle Assessment of Fresh Pineapple from Costa Rica. *J. Clean. Prod.* 2012, 35, 152–163. [CrossRef]

48. Khoshnevisan, B.; Rafiee, S.; Omid, M.; Mousazadeh, H.; Clark, S. Environmental Impact Assessment of Tomato and Cucumber Cultivation in Greenhouses Using Life Cycle Assessment and Adaptive Neuro-Fuzzy Inference System. *J. Clean. Prod.* 2014, 73, 183–192. [CrossRef]

49. Bojadac, C.R.; Wyckhuys, K.A.; Schrevens, E. Life Cycle Assessment of Colombian Greenhouse Tomato Production Based on Farmer-Level Survey Data. *J. Clean. Prod.* 2014, 69, 26–33. [CrossRef]

50. Beccali, M.; Cellura, M.; Iudicello, M.; Mistretta, M. Life Cycle Assessment of Italian Citrus-Based Products. Sensitivity Analysis and Improvement Scenarios. *J. Environ. Manag.* 2010, 91, 1415–1428. [CrossRef]

51. Contreras, A.M.; Rosa, E.; Pérez, M.; Van Langenhove, H.; Dewulf, J. Comparative Life Cycle Assessment of Four Alternatives for Using By-Products of Cane Sugar Production. *J. Clean. Prod.* 2009, 17, 772–779. [CrossRef]

52. Hospido, A.; Miñá i Canals, L.; McLaren, S.; Truninger, M.; Edwards-Jones, G.; Clift, R. The Role of Seasonality in Lettuce Consumption: A Case Study of Environmental and Social Aspects. *Int. J. Life Cycle Assess.* 2009, 14, 381–391. [CrossRef]

53. Roy, P.; Nei, D.; Okadome, H.; Nakamura, N.; Orikasa, T.; Shiina, T. Life Cycle Inventory Analysis of Fresh Tomato Distribution Systems in Japan Considering the Quality Aspect. *J. Food Eng.* 2008, 86, 225–233. [CrossRef]
54. Broek, R.; Treffers, D-J.; Meeusen, M.; Wijk, A.; Nieuwlaar, E.; Turkenburg, W. Green Energy or Organic Food? A Life-Cycle Assessment Comparing Two Uses of Set-Aside Land. *J. Ind. Ecol.* 2001, 5, 65–87. [CrossRef]

55. Masuda, K. Measuring Eco-Efficiency of Wheat Production in Japan: A Combined Application of Life Cycle Assessment and Data Envelopment Analysis. *J. Clean. Prod.* 2016, 126, 373–381. [CrossRef]

56. Andersson, K.; Ohlsson, T.; Olsson, P. Screening Life Cycle Assessment (LCA) of Tomato Ketchup: A Case Study. *J. Clean. Prod.* 1998, 6, 277–288. [CrossRef]

57. Choo, Y.M.; Muhamad, H.; Hashim, Z.; Subramaniam, V.; Puah, C.W.; Tan, Y. Determination of GHG Contributions by Subsystems in the Oil Palm Supply Chain Using the LCA Approach. *Int. J. Life Cycle Assess.* 2011, 16, 669–681. [CrossRef]

58. Romero-Gámez, M.; Audsley, E.; Suárez-Rey, E.M. Life Cycle Assessment of Cultivating Lettuce and Escarole in Spain. *J. Clean. Prod.* 2014, 73, 193–203. [CrossRef]

59. Girgenti, V.; Peano, C.; Bounous, M.; Baudino, C. A Life Cycle Assessment of Non-Renewable Energy Use and Greenhouse Gas Emissions Associated with Blueberry and Raspberry Production in Northern Italy. *Sci. Total Environ.* 2013, 458, 414–418. [CrossRef][PubMed]

60. Breiling, M.; Hoshino, T.; Matsushashi, R. *Contributions of Rice Production to Japanese Greenhouse Gas Emissions Applying Life Cycle Assessment as a Methodology;* The University of Tokyo: Tokyo, Japan, 1999; p. 32.

61. Kulak, M.; Graves, A.; Chatterton, J. Reducing Greenhouse Gas Emissions with Urban Agriculture: A Life Cycle Assessment Perspective. *Landscape Urban Plan.* 2013, 111, 68–78. [CrossRef]

62. Vinyes, E.; Asin, L.; Alegre, S.; Muñoz, P.; Boschmonart, J.; Gasol, C.M. Life Cycle Assessment of Apple and Peach Production, Distribution and Consumption in Mediterranean Fruit Sector. *J. Clean. Prod.* 2017, 149, 313–320. [CrossRef]

63. Tabatabae, S.M.H.; Murthy, G.S. Cradle to Farm Gate Life Cycle Assessment of Strawberry Production in the United States. *J. Clean. Prod.* 2016, 127, 548–554. [CrossRef]

64. Li, X.; Mupondwa, E.; Panigrahi, S.; Tabil, L.; Adapa, P. Life Cycle Assessment of Densified Wheat Straw Pellets in the Canadian Prairies. *Int. J. Life Cycle Assess.* 2012, 17, 420–431. [CrossRef]

65. Sahle, A.; Potting, J. Environmental Life Cycle Assessment of Ethiopian Rose Cultivation. *Sci. Total Environ.* 2013, 443, 163–172. [CrossRef]

66. Payen, S.; Basset-Mens, C.; Perret, S. LCA of Local and Imported Tomato: An Energy and Water Trade-Off. *J. Clean. Prod.* 2015, 87, 139–148. [CrossRef]

67. Roer, A.-G.; Korsaeth, A.; Henriksen, T.M.; Olsson, P. Screening Life Cycle Assessment (LCA): Case Study in New Zealand. *Agric. Ecosyst. Environ.* 2001, 81, 277–288. [CrossRef]

68. Matsuura, M.I.S.F.; Dias, F.R.T.D.; Picoli, J.F.; Lucas, K.R.G.; de Castro, C.; Hirakuri, M.H. Life-Cycle Assessment of the Soybean-Sunflower Production System in the Brazilian Cerrado. *Int. J. Life Cycle Assess.* 2017, 22, 492–501. [CrossRef]

69. Nemeczek, T.; Von Richthofen, J.-S.; Dubois, G.; Casta, P.; Charles, R.; Pahl, H. Environmental Impacts of Introducing Grain Legumes into European Crop Rotations. *Eur. J. Agron.* 2008, 28, 380–393. [CrossRef]

70. Martinez-Blanco, J.; Muñoz, P.; Antón, A.; Rieradevall, J. Assessment of Tomato Mediterranean Production in Open-Field and Standard Multi-Tunnel Greenhouse, with Compost or Mineral Fertilizers, from an Agricultural and Environmental Standpoint. *J. Clean. Prod.* 2011, 19, 985–997. [CrossRef]

71. Meisterling, K.; Samaras, C.; Schweizer, V. Decisions to Reduce Greenhouse Gases from Agriculture and Product Transport: LCA Case Study of Organic and Conventional Wheat. *Agric. Syst.* 2009, 17, 222–230. [CrossRef]

72. Canals, L.M.I.; Muñoz, I.; Hospido, A.; Plassmann, K.; McLaren, S.; Edwards-Jones, G.; Hansons, B. Life cycle assessment (LCA) of domestic vs. imported vegetables. In *RELU Project REW-224-25-0044;* Centre for Environmental Strategy, University of Surrey: Guildford, UK, 2008.

73. Aguilera, E.; Guzmán, G.; Alonso, A. Greenhouse Gas Emissions from Conventional and Organic Cropping Systems in Spain. II. Fruit Tree Orchards. *Agron. Sustain. Dev.* 2015, 35, 725–737. [CrossRef]

74. Dwivedi, P.; Sreen, T.; Goodrich-Schneider, R. Global Warming Impact of Florida’s Not-From-Concentrate (NFC) Orange Juice. *Agric. Syst.* 2012, 108, 104–111. [CrossRef]

75. Girgenti, V.; Peano, C.; Baudino, C.; Tecco, N. From “Farm to Fork” Strawberry System: Current Realities and Potential Innovative Scenarios from Life Cycle Assessment of Non-Renewable Energy Use and Green House Gas Emissions. *Sci. Total Environ.* 2014, 473, 48–53. [CrossRef][PubMed]

76. Lazzerini, G.; Lucchetti, S.; Nice, F.P. Green House Gases(GHG) Emissions from the Ornamental Plant Nursery Industry: A Life Cycle Assessment(LCA) Approach in a Nursery District in Central Italy. *J. Clean. Prod.* 2016, 112, 4022–4030. [CrossRef]

77. Mohseni, P.; Borganh, A.M.; Haniali, M. Coupled Life Cycle Assessment and Data Envelopment Analysis for Mitigation of Environmental Impacts and Enhancement of Energy Efficiency in Grape Production. *J. Clean. Prod.* 2018, 197, 937–947. [CrossRef]

78. Milá Canals, L.; Burnip, G.M.; Cowell, S.J. Evaluation of the Environmental Impacts of Apple Production Using Life Cycle Assessment Comparing Two Uses of Set-Aside Land. *Int. J. Ind. Ecol.* 2001, 5, 226–238. [CrossRef]

79. Steenwerth, K.L.; Strong, E.B.; Greenhut, R.F.; Williams, L.; Kendall, A. Life Cycle Greenhouse Gas, Energy, and Water Assessment of Wine Grape Production in California. *Int. J. Life Cycle Assess.* 2015, 20, 1243–1253. [CrossRef]

80. Langen, B.; Basset-Mens, C.; Lardon, L. Inclusion of the Variability of Diffuse Pollutions in LCA for Agriculture: The Case of Slurry Application Techniques. *J. Clean. Prod.* 2010, 18, 747–755. [CrossRef]
