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REVIEW **Open Access**

Ecosystem services and biodiversity appraisals by means of life cycle tools: state-of-art in agri-food and forestry field

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Abstract

Background In recent years, the importance of ecosystem services (ESs) has been significantly recognized in policy-making processes. The choice of life cycle (LC) methodologies to measure potential impacts, also relative to the changes in the levels of ecosystem services provided by nature, is increasing, but the implementation of ESs in LC approaches does not seem to be widespread, just as there is no comprehensive and exhaustive framework of the directions taken by scientific research in this regard. To explore the state of the art and try to overcome this gap a systematic and critical literature search was conducted for application case studies that evaluate ESs by means of LC tools (Life Cycle Assessment, Life Cycle Costing, and Social Life Cycle Assessment). Using Scopus and WoS databases and PRISMA model, a selection and skimming of the resulting records were carried out based on several criteria such as general criteria, specific criteria related to ESs, and LC methodological criteria.

Results In general, the analysis of results showed as ESs uses typical methodological aspects such as the use of the functional unit related and the use of secondary data. Regarding impact categories, the LCIA methods are used also for the assessment of ESs due to the implementation through LCA software such as Simapro or GaBi, to analyse different pressure caused, for example, by land use and land-use change and the assessment of "regulating" ESs.

Conclusions Future research advancements should focus on the assessment of cultural and supporting services because, at the actual state, they are very neglected in the literature. Similarly, the implementation of ESs in LC methodologies should provide the inclusion of cause-and-effect relationships that go beyond the environmental services or disservices to understand how and how much the alterations of ESs impact also from an economic and social point of view.

Keywords Agriculture, Ecosystem services, Forestry, Life cycle methodologies, Prisma, Review

Introduction

Ecosystem services: classification and importance in policy-making

Ecosystem services (ESs) are benefits that communities obtain from ecosystems and are closely related to human well-being, but they have been damaged in recent years. Examples of this impairments are the degradation of 20% of the total land area between 2000 and 2015 [1] and 59% of the oceans suffering cumulative impacts related to climate change, overexploitation of resources, pollution and maritime transport [2]. These phenomena indicate a degradation of terrestrial and aquatic ecosystems that can threaten the well-being of 3.2 billion people because of the [1]. To face these

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phenomena and their impacts, an assessment of ESs in both environmental and economic terms is increasingly needed to help policy-makers. A demonstration of how this assessment is important in decision-making processes can be found in the European Taxonomy [3], which outlines a common classification for green public procurement based on six objectives: the sixth objective concerns "the protection and restoration of biodiversity and ecosystems." Another important example is the European Biodiversity Strategy 2030 [4], which includes important targets for biodiversity conservation, such as planting 3 billion trees and restoring degraded ecosystems by reducing pesticides. These important policy decisions have the aim of protecting ESs guaranteeing human well-being. However, the need to protect human well-being through correctly using ESs and preventing their degradation is related to the need to measure their impacts [5].

To guarantee a better evaluation of ESs, in the last 20 years, several initiatives for classification have been proposed. The first proposal for ESs classification was made by Millennium Ecosystem Assessment [6] and aimed to assess how ESs changes modify human well-being and how they can be enhanced through their conservation and use for human well-being. MA classification divides ESs into four groups:

- Provisioning services, i.e., products that can be obtained from ecosystems such as food and water;
- Regulating services, i.e., benefits that can be obtained from the regulation of ecosystem processes such as air quality regulation or climate regulation;
- Cultural services, i.e., non-material benefits that communities can obtain from ecosystems such as education values or social relations;
- Supporting services, i.e., ESs that support ESs previously defined, such as photosynthesis or soil formation.

The MA work has been criticized because the relationship between ESs and human well-being is not very clear and very complex, regarding, for example, the definition of human well-being itself or what competes it. The ESs provide benefits to communities but are not exclusive of human well-being improvement [7].

An improvement of MA's classification is the work realized by The Economic of Ecosystem and Biodiversity [8], which tried to better explain the linkage between ESs and human well-being by adopting the following four definitions:

- Structures (and processes) are the base for the functions of the ecosystem (e.g., primary production);
- Functions are the potential that an ecosystem needs for producing and delivering an ES (e.g., a viable fish population);
- Benefits are the fraction of ecosystem services that communities use (e.g., contribution to human health);
- Values can be from an economic, social or health point of view, and they are intrinsic to benefits (e.g., willingness to pay for protection).

TEEB classification divides ESs mainly following MA classification but with some differences. Unlike MA classification, TEEB classification does not consider supporting services but considers them in the ecosystem processes. To better understand the importance of ESs in providing habitat for migratory species and protecting the variability of the gene pool, TEEB considers Habitat services a separate group of ESs.

A further improvement of the TEEB classification is represented by the work realized by the Common International Classification of Ecosystem Services (CICES) [9]. This classification presents a hierarchy structure that becomes more and more detailed, progressively going down a level. The CICES classification has a hierarchy structure in five levels, i.e.: Section, Division; Group; Class; Class type. The first one represents the most general level in the CICES hierarchy, and is based on three ESs types: Provisioning, Regulating and maintenance, and Cultural. The CICES classification tries to overcome double counting problems that can be generated by the other two classifications, especially for the water compartment. For example, surface water flow, water quality improvement by infiltration through the soil and potable water supply are, respectively, regulation, supporting and provisioning services. However, water regulation and water infiltration through soil contribute to the potable water supply.

Theoretical background: ESs in LCA

Due to their importance in policy making and considering all initiatives to try, it is necessary to find methodologies to evaluate ESs. Among the best-known methodologies to assess impacts and help, policymakers are Life Cycle (LC) Methodologies, in particular Life Cycle Assessment (LCA). The LCA is a methodology created to analyse environmental impacts throughout the entire life cycle, from cradle to grave, of a product, a service, or a process. The first studies of LCA date back to the late '60 s and '70 s, but it is only in the '90 s that the methodology was standardized through specific norms and guidelines to guide its application [10]. The use of LCA to evaluate ESs is not common nor easy. In the last 10 years, several studies have been published, such as the

UNEP-SETAC Initiative [11], which proposed the creation of five new LCA impact categories for ESs evaluation and two new LCA impact categories for biodiversity assessment. Another significant action is UNEP-SETAC task force, started in 2015 [12] whose main goals were the improvement and harmonization of the Life Cycle Impact Assessment (LCIA) characterization framework, improving the consensus on normalization and weighting, spatial differentiation, uncertainty assessment, endpoint indicators for human health, ecosystem quality, and natural resources, as well as the identification of representative reference states. However, the assessment of ESs using LCA is not widespread, and some methodological problems persist, e.g., the relationship in the cause-effect chain or the harmonization between Life Cycle Inventory (LCI) and LCIA is not always clear. Currently, in LCA, ESs are considered through the EPS 2015 (Environmental Priority Strategy in product design) method impact assessment [13], the successor of EPS 2000, which considers five types of ESs as reported in Table 1.

No regulating services nor supporting is considered in this method, while biodiversity is considered through the extinction of species expressed in Normalized Extinction species (NEX). In this case, biodiversity focuses mainly on species diversity, which is one of three biodiversity groups. Biodiversity is defined by the Conventional on Biological Diversity (CBD) as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems" [14]:3). Species diversity and ecosystem diversity are the most investigated areas in LCA [15]. Most of the time, species richness is used to measure species diversity. However, in the course of time, some attempts have been made to add measures and information that species richness doesn't measure. These attempts include the use of indicators of vulnerability and scarcity [16–18] or the investigation of other aspects of biodiversity, like functional diversity [19, 20]. Ecosystem diversity is based on several LCA categories such as acidification or eutrophication and they represent the condition of living organisms. Species diversity and ecosystem diversity are jointly considered in the Area of Protection (AoP Ecosystem Quality, the most units of measure used for valuing this end-point category are the Potentially Disappearing Fraction (PDF or PDF m^2 yr (terrestrial ecosystem) or PDF m^3 yr (freshwater and marine ecosystem) or species yr (species density) or m^2 yr. Furthermore, to model species diversity were developed: the "classical" species-area relationship (SAR), matrix-calibrated species-area relationship (matrix SAR) and countryside species-area relationship (countryside SAR). The classical SAR model [21] is the most widely used relationship for calculating biodiversity. It is based on the following function:

Table 1 ESs in EPS 2015

Type of ESs	ESs description	Unit of measure
Provisioning	Crop growth capacity	kg
Provisioning	Production capacity of fruits and vegetables	kg
Provisioning	Wood growth capacity	kg
Provisioning	Fish and meat production capacity	kg
Cultural	Quality time	Person·years

$$S = cA^z$$

where S is the number of species, A is the area and c and z are parameters that depend on several variables (taxonomic group, study region, sampling scale and regime) [22]. The assumption underlying this model is based on the fact that habitat changes caused by human activities are adverse to hosting any type of species [23] and this can lead to an overestimation of the extinction risk [24].

The matrix-calibrated SAR [25] is the first correction to the SAR model and is based on the same power function that also considers the sensibility of taxa for each land use in a heterogeneous landscape. However, this model predicts a high level of extinction for a reduction in the natural area, disregarding the species' ability to adapt to the anthropogenic area. Countryside SAR [26] is another correction of the SAR model and predicts an adaptation of species to the anthropized area. This model is more realistic than the others, as pointed out in the case of bird protection, because it is based on the affinity of species to habitat: in other words, the modification of habitats from natural to modified by human activities does not involve the extinction of species [27]. Two recent reviews have analyzed the implementation of LCA for ESs evaluation. VanderWilde and Newell [28] used a bibliometric analysis for the assessment of ESs with LCA, and found that these two topics have evolved into two fields with little correlation in recent decades. De Luca Peña et al. [29] analyzed the degree to which ES assessment is integrated with other methodologies such as LCA and Risk Assessment.

This review aims to analyze, from a methodological point of view, how LCA practitioners have implemented ESs assessment in their studies and identify possible areas of research due to critical issues. In particular, the research questions this study seeks to answer are:

1. How much is widespread ESs evaluation in LCA?
2. Which types of ESs are the most evaluated?

3. Which methods are used to assess ESs?

The analysis was restricted to the agri-food and forestry sectors because of their importance in different economic activities and human well-being, as strategic sectors because they ensure the provision of food, fibres and fuels and affect the regulation of various natural processes, like biogeochemical cycles, the nitrogen cycle, or the phosphorus cycle (Table 2). However, they can lead to some "ecosystem dis-services" such as loss of habitat, competition for pollination, and poisoning of non-target species caused by pesticides [30]. Another aspect to consider in agriculture is the type of practices because they influence a group of ESs: conventional agriculture has the aim of providing food, fuel and fibres, and it allows the use of chemical fertilizers, synthetic pesticides, and other external inputs to maximize the production of food, fibres, and fuel. On the other side, organic agriculture aims to produce primary products without compromising the environment, biodiversity and therefore the ESs, using, for example, a reduced amount of pesticides [31].

Material and methods

Articles selection and screening

The Scopus and Web of Science (WoS) databases were used to search for relevant articles in June 2022. The syntax used for the relevant literature consisted of three parts: "ecosystem services" which are the subject of this review, the applied methodology, e.g., "life cycle assessment" and the field of application "agr*" which includes words like agriculture, agroforestry, agroecosystem, etc. Each part of the syntax is connected through Boolean operators, e.g., AND/OR. The complete query strings used for the research were the following:

- (TITLE-ABS-KEY (ecosystem AND services) AND TITLE-ABS-KEY (life AND cycle AND assessment) AND TITLE-ABS-KEY (agr*);
- (TITLE-ABS-KEY (ecosystem AND services) AND TITLE-ABS-KEY (life AND cycle AND costing) AND TITLE-ABS-KEY (agr*);
- (TITLE-ABS-KEY (ecosystem AND services) AND TITLE-ABS-KEY (social AND life AND cycle AND assessment) AND TITLE-ABS-KEY (agr*).

The search in the Scopus and WOS databases yielded 77 and 142 articles, respectively, for a total of 219 papers. Subsequently, several articles were selected through the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [32], a formal guidelines for systematic reviews. This standard is a peer-accepted methodology that contributes to the quality of the revision process and its replicability. Duplicate papers were excluded, resulting in 155 documents, which underwent a screening process. An initial selection was made using the "Refine Results" tool of the databases used to exclude reviews and editorial material and include only English-language articles. Thus, only indexed references to applied case studies were considered. A second screening was carried out through a thorough reading of the full text. Studies that did not directly focus on measuring ecosystem services through LC Methodologies were discarded. From the initial searches, 35 articles were found that adhered to the aim of the current review, so they were analyzed in depth according to review parameters. The final screening produced a matrix with all information deemed relevant to answer the questions of this review. Figure 1 illustrates the complete selection of the literature search using the PRISMA model.

Data extraction

The matrix consists of four parts: the first concerns general information about the articles, i.e., authors, title, year of publication, journal, and country. The second part concerns ecosystem services and biodiversity and which methods and units were used to assess them. The third part focuses on methodological aspects of LCA, considering e.g., reasons for carrying out the study, the functional unit (FU), the scale of analysis, etc. There is also another section on the methodological aspects of LCC, covering the type of approach used, type of data and type of costs. Table 3 below provides a complete overview of all information sought in all documents.

Table 2 ESs of agri-food and forestry production systems (rework based on Swinton et al. [80])

Ecosystem services typology	Examples
Provisioning services	Food and fibres
Regulating services	Climate and air regulation, pollination, and pest regulation
Cultural services	Aesthetic and recreation
Supporting services	Water provisioning, soil provisioning, genetic diversity, and biodiversity conservation

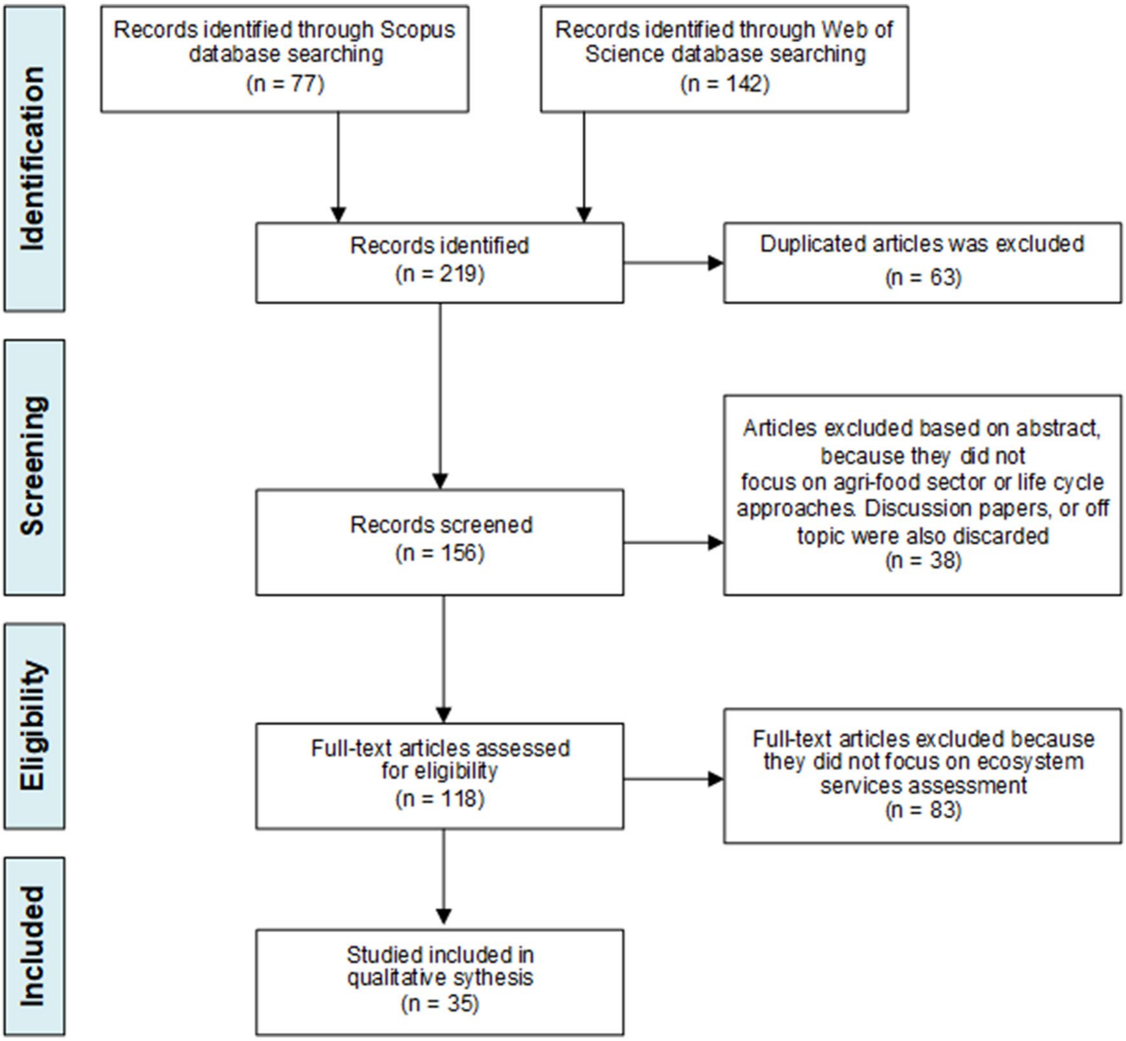

Fig. 1 Methodological steps of the literature search process using PRISMA flow diagram (rework based on Moher et al. [32])

Table 3 Matrix criteria for the critical review of the selected papers

Section	Criteria
General information	Authors, Year, Title, Source, Place, Data duration gathering, Field of application, Main reference products
Ecosystem Services (ESs) information	Provisioning services, Regulating services, Cultural services, Supporting services and Biodiversity, Method and unit used for the analysis
LCA details	Reasons for carrying out the study, Functional units, System boundaries, Scale of analysis, Data source, Allocation procedures, Impact categories selected, Methodology of impact assessment
LCC details	Approach used, Type of cost, Data

The section "General information" considers all information related to the publication of a paper such as titles, authors, year of publication and journal. This section also includes information on the field of application and products discussed in the article.

Information on ESs provides information related to classification groups, ESs evaluated, and their units of measure. In this review, all ESs have been classified according to the MA classification because it is the most established, and some impact categories that will be discussed below are based on it. In relation to this classification, biodiversity assessment is considered separately because it cuts across all groups of ESs. Each ES column also considers the method and the unit of measurement of the ES group.

In the section on LCA details, all methodological aspects are discussed. The reasons for carrying out the study are grouped into similar objectives. The functional unit was classified into four groups, based on the object of the FU. Thus, FUs have been classified into "mass-related", "land-related", "energy-related" and "economic value-related". Similarly, system boundaries have been classified into three groups: "cradle to gate", "cradle to grave" and "gate to gate". The "well to tank" system boundary considered in some papers, was interpreted as a "cradle to gate" system boundary.

Regarding the scale of analysis, it concerns the spatial scale on which the study was conducted. Four levels were detected: local level (for studies that involve a farm/company or a small group of them), regional level (for studies that involve a part of a country or a large group of farms or companies), national level (for studies that involve a country) and continental level (for studies that involve a whole continent).

Also, the approaches used in the LCA applications were analysed. A typical LCA study can be performed following two main approaches: attributional and consequential. Attributional LCA (ALCA) represent the potential environmental impacts that can be retrieved from a system product throughout its life cycle. To model LCA following an attributional approach, average or generic data can be used when the system product comes from several producers or technologies. Consequential LCA (CLCA) studies how a decision in foreground processes influence the other process or the economy. To model LCA following a consequential approach, marginal data can be used that allow evaluation of the consequences of a decision or a series of decisions [33].

Data sources are classified according to their gathering modality: if data are collected for a specific site using interviews, questionnaires, or direct measurements, they are classified as primary data. Secondary data have been classified according to three subcategories: secondary data from databases (e.g., Ecoinvent), secondary data from the literature (e.g., from previous scientific studies in the same field), and secondary data from other bibliography sources (grey literature such as reports, statistics, theses, non-indexed journals, etc.). The remaining types of data, e.g., calculated data, are classified as tertiary data.

For the allocation procedures, some specific criteria were identified and classified, but not the approach applied. The term "criteria" refers to how the allocation was made, e.g., through physical criteria (e.g., mass or energy) or economic criteria. The term "approach" refers to how the environmental load is allocated in the study, e.g., the cut-off approach (100:0 approach). Moreover, for the purpose of this review, a specific selection of terms and definitions was proposed (Table 4), to describe ESs, and inspect their use and life cycle inclusion in the articles examined.

Results

General information

As shown in Fig. 2a, countries are divided into groups by macro-areas. The category "Others" includes comparisons between different countries or missing information. Most of the studies took place in Europe, followed by North America. According to D'Amato et al. [34] the reason why Europe and North America have, in general, the largest number of case studies, is related to the history of LCA [35]. Moreover, as it will see later, most of the methods used for analysis in papers were developed in Europe and North America.

Interest in LCA of ESs increased in 2013 and subsequent years as shown in Fig. 2b. This may be related to the publication of UNEP-SETAC guidelines [11] that create five new categories to assess ESs and two new categories to assess biodiversity. Indeed, several papers have applied these categories, and Lathuillière et al. [36] assessed the robustness of these guidelines. The results have made it possible to highlight some criticism in the area of study due to ESs problems, e.g., climate sequestration and soil mechanical filtration. To explain the reason for the critical issues, it is necessary to have knowledge of biophysics processes and the uncertainty due to the regionalization of characterization factors.

Most of the articles are published in the Journal of Cleaner Production with eight case studies. This may be related to its multidisciplinary nature, as the topics cover environmental science, economics, engineering, and energy. The same number of articles were published in the International Journal of Life Cycle Assessment and Agricultural Systems (Fig. 2c).

According to the search syntax, most of the papers concern agriculture, with thirteen articles (Fig. 2d). Other important fields of application are Bioenergy/Biofuels with nine papers, and livestock with eight papers. Sectors less explored are agroforestry with three papers, food production with two papers, and orchard and biomass production with one paper each. Only two papers explored two fields jointly: agriculture and livestock [37] and agriculture and agroforestry [38].

Table 4 Definition used in this review

Term	Definition	References
Biotic Production Potential (BPP)	BPP is the condition of the land to support biomass production in the short, medium, and long term. Given the definition, BPP is considered a supporting service in this revision. In the LCA, BPP is a mid-point category, and the unit of measurement is kg C yr/FU	Brandão and Milà i Canals [81]
Climate Regulation Potential (CRP)	CRP is the lack of carbon sequestration due to land use, i.e., non-stored carbon, compared to a reference land use. Given the definition, CRP is considered a regulating service in this revision. In the LCA, CRP is a mid-point category, and the unit of measurement is kg C transferred to air/FU	Müller-Wenk and Brandão [82]
Erosion Regulation Potential (ERP)	ERP is the capacity of a terrestrial ecosystem to resist soil loss through erosion. Given the definition, ERP is considered a regulating service in this revision. In the LCA, ERP is a mid-point category, and the unit of measurement is kg of soil potentially eroded/FU	Saad et al. [83]
Water Purification Potential related to physicochemical filtration (WPP-PCF)	WPP-PCF is the ability of soil to act as an absorption matrix and adsorb dissolved substances. Given the definition, WPP-PCF is considered a regulating service in this revision. In the LCA, WPP-PCF is a mid-point category, and the unit of measurement is centimoles of cation fixed per kilogram of soil per kg of soil ($cmol_c/kg_{soil}$/FU)	Saad et al. [83]
Water Purification Potential related to mechanical filtration (WPP-MF)	WPP-MF is the ability of soil to mechanically clarify a suspension through soil infiltration and provide a cleaning action to ensure groundwater protection. Given the definition, WPP-MF is considered a regulating service in this revision. In the LCA, WPP-MF is a mid-point category, and the unit of measurement is centimetre per day (cm/day/FU)	Saad et al. [83]
Net primary production (NPP)	NPP is the quantity of carbon assimilated through photosynthesis by vegetation in a certain period. In LCA, NPP can be both a mid-point category and an end-point category for ecosystem quality. The unit of measure of NPP is MJ_{se} and when it is used as an end-point category, it can be converted into the most common unit of ecosystem quality, PDF	Taelman et al. [84]
Human appropriation net primary production (HANPP)	HANPP is an indicator that measures the difference between NPP of potential vegetation without any human intervention and NPP remaining due to human intervention. In LCA, it can be considered a mid-point category	Haberl et al. [85] and Mattila et al. [86]
Emergy	Emergy is the quantity of direct and indirect solar energy used for delivering a product or a service. The common unit of measure is Solar Equivalent Joule (J_{se}). In LCA, it can be a proxy to consider and measure ESs for example for the measuring of soil erosion [41]	Perrotti [87]
Land use	Land use is the change in the use or management of land by humans, which can lead to a change in land cover. It is part of the driver "habitat change", one of the five drivers of ESs and biodiversity loss. In the LCA, land use is a mid-point category, and the units of measure are m^2 yr or PDF m^2 yr	MA [6] and Mattila et al. [86]
Land occupation	Land occupation is the continuous use of an area for a certain purpose controlled by humans, e.g., agriculture, forestry, or construction. It is part of the driver "habitat change", one of the five drivers of ESs and biodiversity loss. In the LCA, land occupation is a mid-point category, and the unit of measure is m^2 yr	MA [6] and Mattila et al. [86]

Table 4 (continued)

Term	Definition	References
Climate change	Climate change is the change in climate induced by increasing temperature and CO_2 concentration. It is one of the five factors driving the loss of ESs and biodiversity. In LCA this can be both a mid-point category and an end-point category	MA [6]
Overexploitation	Overexploitation is the exploitation of natural resources and wildlife for human activities. It is one of the five drivers of ESs and biodiversity loss. In LCA does not exist counterpart in the mid-category, so this should be a new category for impact for ESs and biodiversity assessment	MA [6]
Exotic species	Exotic species are indigenous species that can disturb the ecological functions of a natural ecosystem. It is one of the five factors that determine the loss of ESs and biodiversity. In LCA does not exist counterpart in the mid-category, so this should be a new category for impact for ESs and biodiversity assessment	MA [6]
Pollution	Pollution is a change in the composition of soil, atmosphere and water caused by chemicals. It is one of the five drivers of ESs and biodiversity loss. This driver is represented by several categories, e.g., acidification or eutrophication. However other impact categories can be added, e.g., emission of noise or emission of light	MA [6]

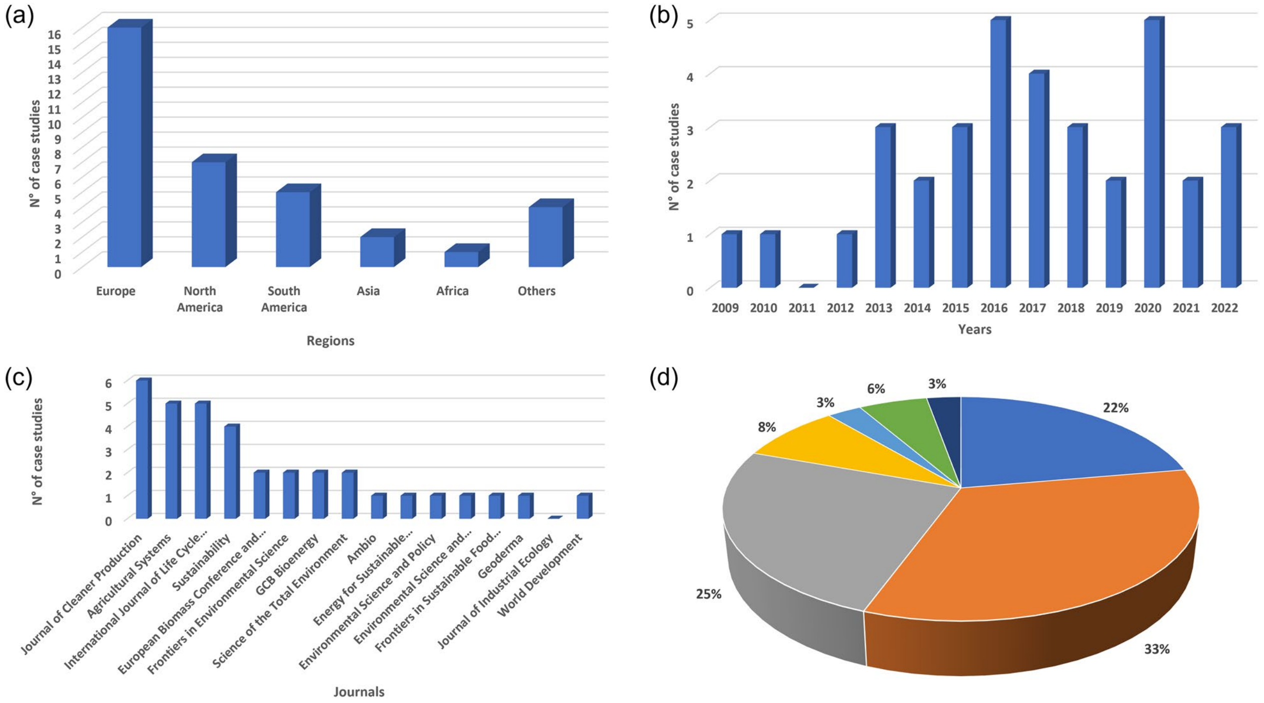

Fig. 2 Graphs related to country (**a**), years of publication (**b**) journal of publication (**c**) and field of application (**d**). In graph (**d**): livestock (blue), agriculture (orange), bioenergy/biofuels (grey), agroforestry (yellow), orchard (light blue), food product (green), biomass production (dark blue) and aquaculture (brown)

Ecosystem services information

In this section, the information on ESs, as well as how they are considered, was interpreted, and the respective unit of measure considered in the articles was discussed. As mentioned above, this information was classified according to the MA classification. In addition, biodiversity was analyzed as an independent category because it cuts across all categories.

Provisioning services

Since each article reviewed focuses on food or crops for fuel/energy production, these have been considered as provisioning services. To take these services into account, if the method and unit of measurement were not expressed, they were considered within the LCA methodology itself and the unit of measurement was considered to be the functional unit of the LCA. Most of the articles (26) analyze food supply, followed by biomass production for energy (7), biomass for fuel production (5) and water (4). The category "Other" considers the supply of other materials, e.g., lithological material [39] or genetic resources [40] (Fig. 3). For further information concerning methods or units of measure of provisioning services, please refer to Additional file 1: SM1 - Review's Records Matrix.

Regulating services

Regulatory services are all those services that allow part of ecosystems to be regulated. This category includes, for example, pollination or erosion regulation. Regulating services consider many categories, as can be seen from the Fig. 4. The category "Others" considers regulating services that are not considered more than once, such as Hazard regulation [40] and Nitrogen mineralisation [39]. The most analyzed regulating services are climate regulation (10), followed by erosion (9) where both wind-caused and water-caused erosion are jointly considered, carbon sequestration (8) and water purification (6) where both mechanical and physical–chemical purification are jointly considered. The category "N/A" (8) means that in this case, the paper does not analyse any regulating services (Fig. 4). For regulating services that are taken from UNEP-SETAC Guidelines [11] the unit of measure is the same as Table 3, e.g., CRP or ERP. Other units of measure are MJ_{SE} with emergy modelling [41] or t ha^{-1} y^{-1} with RUSLE equation [42] for the measuring of soil erosion or t ha^{-1} for soil carbon sequestration through SOC quantification [43]. For further details concerning methods and units of measure related to regulating services, please refer to the Additional file 1: SM1- Review's Records Matrix.

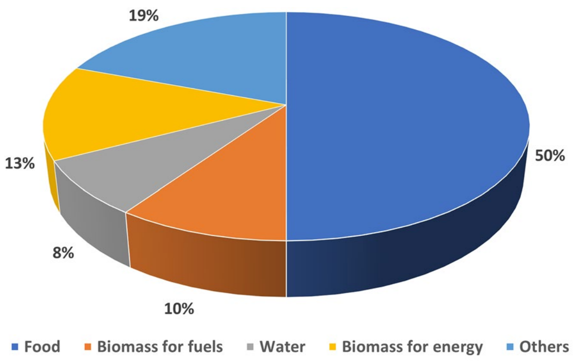

Fig. 3 Provisioning ESs in reviewed papers

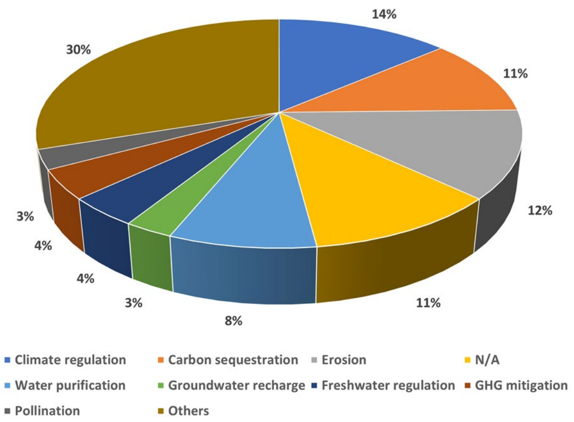

Fig. 4 Regulating ESs in reviewed papers

Cultural services

Cultural services are the least treated category for the evaluation of ESs. Few articles consider them, and the methods for calculating them are too weak compared to methods for calculating other services. Of the five articles that consider this type of ESs, the most reliable is probably the application of an economic value because cultural services are based on the intrinsic value that people attach to, for example, a landscape (aesthetic, social or cultural). Furthermore, Zhang et al. [30] assert that economic valuation "is the most appropriate way to account for cultural services since these services are truly anthropocentric in nature".

Supporting services

Supporting services are a particular category because they are the only category that is in a double relationship with the others. Due to this peculiarity, this category is not often considered in papers. Supporting services are services that guarantee the functionalities of the other services, e.g., without good soil quality, it would be impossible to guarantee food, fibres, nitrogen cycle, etc. Other services of this category can reflect the propriety of a system,

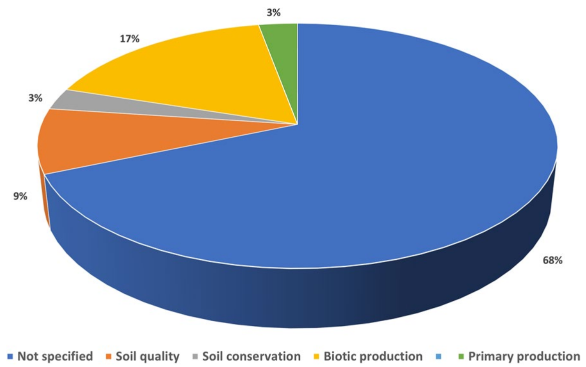

Fig. 5 Supporting ESs in reviewed papers

e.g., soil quality does not consider other proprieties of the supporting system except for the quality. Other services in this category are biotic production (6), whose definition is reported in Table 3, primary production (1), soil conservation (1) and soil quality (3) (Fig. 5). For supporting services that are taken from UNEP-SETAC Guidelines [11], e.g., BPP, the units of measure are the same as in Table 3. Other units of measure are, for example, kg C per year using the LANCA method [44] or t C ha^{-1} y^{-1} for measuring soil quality using SOC quantification [42]. For further details concerning methods and units of measure related to regulating services, please refer to the Additional file 1: SM1 - Review's Records Matrix.

Biodiversity

Biodiversity is a special category for ESs assessment because it can influence all ESs categories. Almost 50% (17) of papers analysed biodiversity with different methods: a paper [45] used a ranking system to classify, for example biodiversity conservation, while other papers used Biodiversity Damage Potential (BDP) as proposed in UNEP-SETAC guidelines [11]. One paper [44] used the LANCA model [46] and in this case, it specified the type of relationship to calculated biodiversity through countryside SAR.

LCA details

The following section scrutinizes the specific characteristics of the methodology as used by the authors' articles examined.

Reasons for carrying out the study, functional unit, system boundaries and scale of analysis

All the reasons for carrying out the study were classified into the following six categories, grouping them for the same objective (Fig. 6a):

- comparison between two or more products/supply chains, which concerns 13 papers and is the second most common category in this review;
- trade-off assessment, which concerns only one paper;
- environmental, economic and/or social assessment, which concerns 20 papers, and is the most common category in this review;
- comparison of different management practices, which concerns 4 papers;
- develop and/or test a methodology, which concerns 5 papers;
- identify environmental, economic and/or social hotspots, which contain 3 papers.

As already mentioned, FUs were classified into four categories, as shown in Fig. 6b:

- mass-based: this first category is the most used FU in papers reviewed with 18 articles. In general, environmental impacts are related to 1 kg of product or 1 tonne of production. However, there are several cases which use several mass-based FUs, i.e., the annual production or human food intake;
- land based: this category is the second more use in papers reviewed used by 16 papers. This type of FU is the second more use of FUs in this review;
- energy based: this type of FU is used by 5 papers and is used when the focus of the paper is on biomass production for energy or fuels;
- economic value based: this type of FU is used in only one case and for a comparison to a land-based FU.

According to Kim and Dale [47], LCA outcomes can have a strong influence on the final results, generating very different or conflicting upshots for what concerning impact assessment, and, consequently, also for impacts on ESs. Seda et al. [48] suggest working with multiple FUs to ensure a complete overview of a product system analyzed from different points of view. In this review, only six papers operate using double FUs. As reported in "Material and methods" section, the system boundaries were classified into three categories (Fig. 6c). The most commonly used system boundaries are cradle-to-gate (27 papers), followed by gate-to-gate (7) and cradle-to-grave (2). In cradle-to-gate, both well-to-tank system boundaries and papers that consider the distribution of a product are considered. The gate-to-gate system boundaries focus on a single phase: in this review, the phase analyzed is the agricultural phase because of the initial research setting and because it is assumed that the agricultural phase is the one that can generate the greatest impacts for ESs and biodiversity.

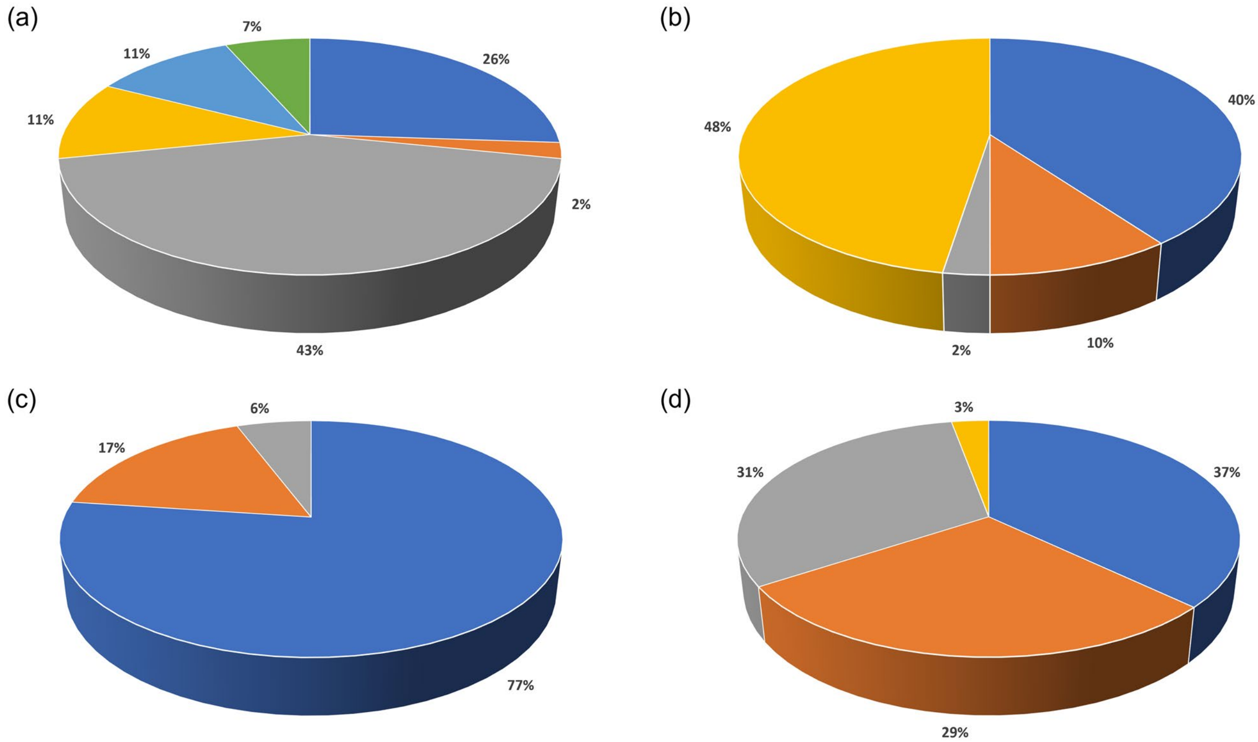

Fig. 6 Graphs related to goals (**a**) FUs (**b**), system boundaries (**c**) and scale of analysis (**d**). In graph (**a**): comparison of two or more products/supply chains (blue), assessment of trade-offs (orange), environmental, economic, and social assessment (grey), comparison of different management practices (yellow), development and/or testing a methodology (light blue) and identification of environmental, economic and/or social hotspots (green). In graph (**b**): mass-based FU (yellow), land-based FU (blue), energy-based FU (orange) and economic value-based (grey). In graph (**c**): cradle-to-gate (blue), cradle-to-grave (grey) and gate-to-gate (orange). In graph (**d**): local level (blue), regional level (orange), national level (grey and continental level (yellow)

The scale of analysis was evaluated considering the spatial scale of the evaluation. In this review, scales of analysis were classified into four categories (Fig. 6d):

- the local level is where the focus of assessment is a specific farm or a company. This assessment is quite common in literature, with 14 papers that used this scale;
- the regional level is where the focus of assessment is an area of a country or a group of farms or companies in a different part. This assessment is applied to 9 papers;
- the national level is where the focus of assessment is the whole country, i.e., the whole United Kingdom. This assessment is performed by 12 papers and is the second most used scale of analysis.
- the continental level is where the focus of assessment is a continent. There is only a single paper in which the assessment was performed, considering the whole of Europe.

Data source and allocation procedures

The most frequently used approach is ALCA, applied in 34 papers. Two papers [40, 49] applied both ALCA and CLCA approaches to assess the difference between their applications. This approach is not widely applied: it requires the estimation of consequences through market data or economic models, and this can produce high uncertainty. Styles et al. [40] used both ALCA and CLCA to assess eight possible bioenergy scenarios. The results showed how to manage a scenario to pursue a purpose, e.g., maintain the production for food crops instead of energetic crops, while also considering ESs from a qualitative point of view, i.e., an increasing or decreasing trend.

Styles et al. [49] analyzed three scenarios for assessing three ESs. CLCA allows capturing some negative effects related to the expansion or intensification of agricultural production to compensate for the food loss.

Most of the studies are considered secondary data, and as mentioned before, they are classified according to their source. Secondary data from the literature (34) is more widely used than secondary data from databases

(22). Some papers use secondary data from other literature sources, i.e., statistics or almanacks (grey literature). Fifteen of the reviewed studies analyzed primary data obtained from interviews or questionnaires. The last category considered in this review is tertiary data: in this category were grouped data obtained from experts' judgement, data obtained from simulations, and data obtained from calculations and assumptions (Fig. 7a).

A multifunctionality problem, and thus of allocation, occurs when a system produces two or more products or services. In this review, no paper has been found that has applied system boundaries expansion. The economic allocation is the most applied method with nine papers, followed by physical allocation (e.g., mass and energy criteria) with seven papers and biophysical allocation with one paper. There are also four papers where multifunctionality does not need to be applied, 19 papers where it is not specified which application of allocation is performed, nor whether it is avoided and why, and two papers that consider the allocation approach, allocating a single product (Fig. 7b).

Impact categories selected and methodology of impact assessment

The most investigated category was found to be Global Warming Potential (GWP) which represents certainly the most important topic in LCA of agriculture systems because the impacts in these systems can lead to up to 24% of Greenhouse gases (GHG).

End-point categories are not widely assessed, with only three papers considering them. Lathuillière et al. [36] considered a generic endpoint with an economic value to consider the effect of mid-point analysis. Golkowska et al. [50] used the "classical" end-point categories present in the ReCiPe method: Natural Resources, Ecosystem Quality and Human Health. Núñez et al. [41] analyzed the end-point impact way for soil erosion, considering human health and ecosystem quality. Finally, it can be found that only one paper considers all ESs, and this supports the idea that a new area of protection related to ESs analysis should be developed in the future to include the potential damages. There is a diversity of impact assessment methods used to assess ESs in LCA. Two methods are more widely used than others, e.g., Recipe with six papers and CML with seven papers. Three papers apply the TRACI method and consider Recipe and CML as well, sixteen papers used a method developed in Europe or North America. As previously mentioned, this can be traced back to the origin of LCA, which started to develop in Europe and North America. There is also an application for a single ecosystem service, i.e., RUSLE for erosion or IPCC for climate mitigation. UNEP-SETAC was applied by five papers, but this method is innovative for the creation of seven specific categories for ESs and biodiversity assessment. Eight papers did not specify the method used while twelve papers used other methods.

The software to perform an LCA can be very different: nineteen papers used a software LCA (e.g., Simapro, GaBi, OpenLCA, etc.), fourteen papers did not specify the software, and eleven papers used other types of software. Furthermore, the most widely used LCA software is Simapro, with ten papers having used it.

LCC details

Life Cycle Costing (LCC) was applied only in two papers. Brandão et al. [38] used a conventional LCC to explore complementary fields to the environmental aspect. The system boundary covered is cradle to gate and includes all costs supported by the land manager related to the specific cultures (wheat, oilseed rape, Scots Pine, willow

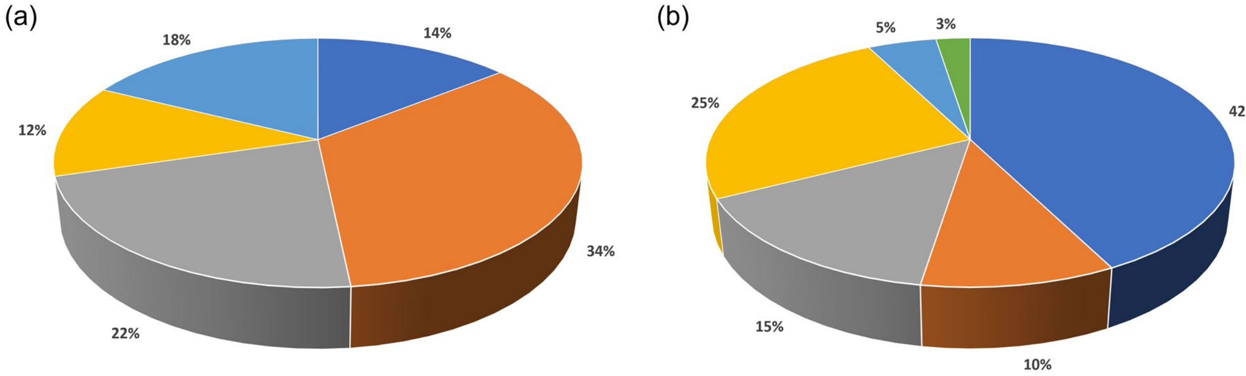

Fig. 7 Graphs related to data type (**a**) and allocation performed (**b**). In graph (**a**): primary data (blue), secondary data from the literature (orange), secondary data from databases (grey), secondary data from other literature sources (yellow) and tertiary data (light blue). For graph (**b**): allocation not specified (blue), no allocation performed (orange), physical allocation (grey), economical allocation (yellow), allocation to a single product (light blue) and biophysical allocation (green)

and Miscanthus) for each land use (production of food, energy, or timber). Consequently, costs related to end-of-life and use costs are not considered because they are supported by non-land managers and are outside system boundaries. The assessment of LCC was performed in parallel to LCA starting from LCA's steps and considering the corruptive steps of LCC. The data type was secondary data, mainly from literature, considering the equivalent economic data from the environmental data of LCA.

Fan et al. [51] did not specify the type of LCC, but they used this methodology to assess land use capitalization resources. The costs considered in the study are related to materials, energy, labour and mechanical equipment during the whole life cycle. They considered primary data, obtained through field research and interviews, for the economic value of materials, energy, labour, mechanicals and fee and tertiary data to establish the economic value of ESs through the calculation of their economic values. Formulas to obtain the values of ESs were obtained from different papers and allow the calculation of different ESs values, e.g., the food production value or the value of biodiversity, but they also allow the calculation of negative services, e.g., economic loss due to cadmium pollution or pesticide pollution.

Discussion

Main findings from articles reviewed

The overall objective of all the articles examined was the integration of ESs into the LCA. As shown in the results section, this integration is very different article-to-article, because it changes depending on the purpose of the study and the method of evaluation of ESs.

The use of LCA and LCC has only been applied in two papers [38, 51] with different methods and, consequently, different results. The first articles compared different land uses, different crops, and different land management to assess ESs and biodiversity impacts and thus establish which have the greatest benefits and impacts. The second article analyzed "land tickets" in China, i.e., a system to incentive farmers to recover abandoned lands by agriculture and their connected, by also considering ESs, as for example, climate regulation for regulating services and soil conservation for supporting services, and some dis-services, like pollution by pesticides and pollution by fertilizers and found that the positive benefits from ESs in this system are greater than the negative impacts. Different methodologies were applied in some papers, as described below. Baral et al. [39] used a hybrid Eco-LCA model that combines the Input–Output life-cycle economic inventory with the process-based inventory to evaluate different energy raw materials while also considering thermodynamic indicators. Glendining et al. [37] combined the LCA with the economic Total Factor Productivity (TFP) index using land-use assessment for the ESs analysis to estimate the optimal level of all inputs to reduce pollution with a minimum number of resources and maintain agricultural income at the highest possible level. Núñez et al. [41] developed their specific methodology to study the regulatory service "soil erosion", and the analyzed end-point category has considered natural resources and ecosystem quality by emphasising the importance of a regionalized assessment for soil erosion due to its variability. Liu et al. [52] observed rice cultivation in the United States, China and India through the application of the cascade model developed by Rugani et al. [53], analyzing four ESs, namely water supply, carbon sequestration and air/water quality regulation and identifying some critical issues in integrating ES-LCA framework, e.g., the generic nature of this methodology to analyse other products and sectors in which human activity have an important contribution for the delivering of ESs or the lacking of data or the complexity to run this method. Finally, Wang et al. [54] used an energy-based LCA framework to assess the ecosystem services and disservices of six crops.

The methodology of the UNEP-SETAC guidelines [11] has been applied by Milà i Canals et al. [55], Muñoz et al. [56], Helin et al. [57], Piastrellini et al. [58] and Lathuillière et al. [36], in different fields and products: in agriculture for the evaluation of margarine and soya, in bioenergy sector for the comparison between bio-based and fossil-based ethanol production, and in forestry through the assessment of the energy produced from wood, agro-biomass and peat.

All outcomes have found that the main critical issue concerns land occupation, which results in being the main driver of impacts instead of land transformation, and the importance of the development of characterisation factors specifying also soil management (e.g., conventional vs. biological).

The assessment of ESs can also be carried out on a continental scale, as demonstrated by Jeswani et al. [44] who applied the LANCA model [46].

A further possibility for the study of ESs and biodiversity is the coupling of ALCA and CLCA, as carried out by Styles et al. [40, 49] in the field of bioenergy, the assessment can be carried out in both quantitative and qualitative terms, considering, for example, an increase or decrease in ESs compared to a baseline.

The application of allocation methods for the comparison of different land use management practices does not seem to influence the results of impacts if the assessment is carried out on a local scale and under similar conditions, as highlighted by Salvador et al. [59].

However, when ESs are not considered in the analysis and they need to be allocated, GHG emissions decrease by increasing the intensification from a pasture-based system (lowest intensity), to a zero-grazing system (highest intensity) otherwise, GHG emissions decrease by decreasing the intensification, from a zero-grazing system to a pasture-based system, as reported by Ripoll-Bosch et al. [60].

A similar outcome can be found in Bragaglio et al. [61]. They assessed four livestock systems ("traditional" Podolian system, Specialized extensive system, Cow-calf intensive system and Fattening system) at the beginning without considering ESs, e.g., the co-production of milk as a provisioning service or the presence of a festival as a cultural service, and after considering them.

When the assessment field is bioenergy, the most studied ESs are those related to carbon sequestration and soil organic carbon, as reported, for example, by Tichenor et al. [62], Baumert et al. [63] and Nguyen et al. [43]. However, these are not the only cases where the study focuses on GHG emissions. Agriculture is another sector where the assessment of GHG emissions is on the rise because, as mentioned above, this sector produces up to 24% of GHGs, and for example, Fiore et al. [64], Bais-Moleman et al. [65], Martinelli et al. [66], Bessou et al. [67] and Rowntree et al. [68].

Some works used comparisons between different land management practices to understand how outcomes are affected, such as Jarchow et al. [69] and Berti et al. [70, 71]. Similarly, other studies consider different crops or scenarios for agricultural and livestock systems to observe how the results will change, as in Marton et al. [72], Golkowska et al. [50], Hessle et al. [73], Cecchin et al. [42] and Dick et al. [45].

To conclude, Souza et al. [74] evaluated the production of electricity from sugarcane biomass, making it possible to identify the most promising scenario concerning, for example, bioenergy production or water recycling, with, moreover, spatial planning for energy production, not limiting the analysis of impacts to LCA results alone, but expanding this assessment to ESs.

Analysis of the use of ESs' classification

As mentioned at the beginning of this document, several approaches are available for ESs classification, but the most important are MA, TEEB and CICES. Despite their widespread use in the assessment of ESs, as already mentioned, they are not widely used in LCA. The MA classification was used as the basis for the creation of the UNEP-SETAC guidelines with seven new categories in LCA and it is used in some documents [36, 55–58]. The TEEB classification is not used in any documents retrieved from this review, and the CICES classification is used in only one document [52]. This article explicitly reported the type of classification instead of the articles that adopted the MA classification. Furthermore, it is easy to establish a single ES due to the hierarchy structure of the CICES classification.

The use of classification can be helpful to understand the areas where actions are needed to improve the ESs group. It can also be applied to understand which area of investigation should be taken into account for future research: cultural services, for example, are important services for human cultural heritage but are not much included in the LCA.

Methodological aspects

The methodological aspects used to analyse ESs are similar to those of other LCA studies: e.g., the FU is based on mass, land, energy or economical value. These types of FUs focus on a product or a group of products and not on ecosystem services. A single article [66] used a particular land-based FU, namely one hectare of an agroforestry system which also includes ecosystem functions.

Data availability is another important aspect to consider when analyzing ESs. Europe and North America are two macro-areas with a substantial amount of data from databases, statistics, scientific literature, and other sources. In other areas, this can be very difficult. As an example, Lathuillière et al. [36] and Dick et al. [45] point out the lack of data in Brazil to differentiate the different factors influencing biodiversity and ecosystem services. In addition to the above, it is important to use spatial differentiation of information to ensure a more accurate result. A solution can be found in the use of ecoregions, which are "relatively large units of land containing a distinct assemblage of natural communities and species, with boundaries that approximate the original extent of natural communities prior to major land-use change" [75, 933].

Managing multifunctionality can be a real problem when it is necessary to allocate flows to each output, including ESs; because LCA can be applied to products and services, ESs are, thus, an outcome that must be allocated for its production. This can completely change the results as reported by Ripoll-Bosch et al. [60] and Bragaglio et al. [61] in which the impacts of the systems analyzed can change from the choice of an industrial system to a local or extensive system. Another example of multifunctionality management is given using economic allocation to distribute environmental impacts to honey and pollination service [76]. Regarding environmental categories, some mid-point categories can assess some ESs, e.g., BPP, CRP, etc. Areas of protection (AoP) cover only human health, ecosystem quality and resource, but there is also the possibility to develop other AoP represented by the different typologies of ESs.

Drivers or ESs?

It is important to differentiate ESs and biodiversity from the drivers that affect them. Drivers produce negative consequences, e.g., reduction or loss in biodiversity and ESs. According to MA, these causes are the following: Habitat change (due to land use and land occupation); Pollution; Overexploitation; Exotic species; Climate change. Measuring one of them, it is evaluated the contribution of a driver to the loss of biodiversity and ESs. The measurement of ESs and biodiversity should be conducted using specific categories for what concerns the first topic and using different indicators, e.g., the functional diversity index [19] or types of relationships (e.g., SAR, matrix-calibrated SAR, countryside SAR) for the last one.

Reference situation

Reference situation is a "standard" condition for assessing environmental impacts related to biodiversity and ESs. According to Koellner et al. [11], three options are available from the literature:

- Applying "Potential Natural Vegetation (PNV)": "which describes the expected state of mature vegetation in the absence of human intervention" [77, 1172],
- Considering natural or semi-natural land cover as a reference status for each region/biome;
- Using the actual mix of land use in Europe [78],

It is very important to consider a reference situation to understand the extent of impact or how much a driver affects ESs or biodiversity. The UNEP-SETAC Guidelines [11] and Milà i Canals et al. [79] suggested using the second option, considering the quantity and quality of data available and the impracticality of land use.

Conclusions

This review represents, to the authors' knowledge, the first overview of LC methodologies applied to ESs studies in the agricultural and forestry sectors. The topic of ESs in LCA in these two fields was increased after the publication of UNEP-SETAC guidelines and is evaluated, more or less, constantly, even though there is no uniform framework to implement these two topics efficiently. The ESs most analyzed were "provisioning" and "regulating" services, even though there is an interest in "cultural" and "supporting" services. Identifying from the studies analyzed the relationships between indicators and ecosystem services was a difficult task because ESs are connected one to the other. More detailed classifications, such as the Common International Classification of Ecosystem Services (CICES) can help to overcome this problem by identifying more precisely the ecosystem services through coding; it would allow the double-counting problem, which could occur, for example, in the evaluation of soil quality that can be considered "regulating" and "supporting" service.

In general, LC approaches are applied following current advice about the functional unit, system boundaries, and life cycle inventory. Regarding impact categories, the common LCIA methods are also used for the assessment of ESs thanks to their easy estimation through LCA software. They can analyze different pressures on ESs caused mainly by land use and land-use change. Of particular interest is the UNEP-SETAC methodology [11] because it allows for the assessment of different aspects of ESs, in particular, "regulating" services such as Biotic Primary Production (BPP), Climate Regulation Potential (CRP), Erosion Regulation Potential (ERP), Biodiversity Damage Potential (BDP).

Future research should focus on the assessment of cultural and supporting services because, at the moment, they are neglected in a few studies. Similarly, it could also be desirable to implement economic and social aspects for the same reason abovementioned: there are only a few studies that use these methodologies. These new inclusions can be useful to understand how alterations to ecosystem services impact not only the environmental terms but also economic and social terms.

Abbreviations

ESs	Ecosystem services
LC	Life cycle
LCA	Life cycle assessment
LCC	Life cycle costing
SLCA	Social life cycle assessment
MA	Millennium ecosystem assessment
TEEB	The Economics of Ecosystems and Biodiversity
CICES	Common International Classification of Ecosystem Services
PDF	Potentially disappearing fraction
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
WoS	Web of science
BPP	Biotic production potential
CRP	Climate regulation potential
ERP	Erosion regulation potential
WPP-PCF	Water purification potential related to physicochemical filtration
WPP-MF	Water purification potential related to mechanical filtration
NPP	Net primary production
HANPP	Human appropriation net primary production
ALCA	Attributional life cycle assessment
CLCA	Consequential life cycle assessment
SAR	Species-area relationship

Supplementary Information

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Additional file 1. Table S1: Overview of the general information's and specific criteria in Review's Records Matrix

Author contributions

Conceptualization: AIDL, GF, and NI contributed to the conception and design of the study; AIDL, CS, GF, and NI carried out the setting up of the methodology; CS conducted the literature search; data analysis was performed by CS, and ES. The first draft of the manuscript was written by CS; the writing-review and editing was conducted by AIDL, GF, and NI; AIDL and GG conducted the supervision of the study; funding acquisition: AIDL, CS. All authors commented on previous versions of the manuscript, read, and approved the final manuscript.

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Availability of data and materials

The authors declare that the data generated or analyzed in this study are included in this published article and its Additional file 1: SM1.

Code availability

Not applicable.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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