Review (Revisión)

CHALLENGES AND TRENDS IN THE VALUATION OF ECOSYSTEM SERVICES IN AGRO-ECOSYSTEMS: A SYSTEMATIC REVISION †

[DESAFÍOS Y TENDENCIAS EN LA VALORACIÓN DE SERVICIOS ECOSISTÉMICOS EN AGROECOSISTEMAS: UNA REVISIÓN SISTEMÁTICA]

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SUMMARY

Background. Climate change, the loss of ecosystems, the increase of poverty, the rise of marginality within rural communities and the decrease of food security, are global concerns in need of urgent attention. In this regard, an important number of studies focus on studying the way agro-ecosystems may face such challenges, as they provide ecosystem services (ES), which generate higher levels of resilience, adaptability, productivity and self-sufficiency. Hence, the valuation of ecosystem services plays a relevant role in the decision-making process toward the design and management of agro-ecosystems. Nevertheless, the assignment of value to these ES is usually done exclusively under the economic-monetary dimension, thus leaving other dimensions of value aside. **Objective.** To propose a hierarchical structure of Ecosystem Services assessment that integrates the value dimensions principles and criteria. **Methodology**. The method employed to define the hierarchical structure was a comprehensive literature review the fields of Agroecology and Ecological Economics, based on information search strategy and classification. 182 scientific publications were full paper screened within the period between 2000 and 2017. **Implications.** Outcomes of this work provide a foundation for further discussion of ES assessments and its potential application in agro-ecosystem and specific contexts. **Conclusion.** There is an important number of studies identifying the significance of ES in agroecosystems from different dimensions. Nevertheless, such works do not associate their importance with the value of such services. Therefore, it remains a challenge for research projects to achieve relating their contributions to their multidimensional valuation.
Keywords: Ecological Economics; Agroecology; complex systems.

RESUMEN

Antecedentes. El cambio climático, la pérdida de ecosistemas, el aumento de la pobreza, el aumento de la marginalidad en las comunidades rurales y la disminución de la seguridad alimentaria son preocupaciones mundiales que requieren atención urgente. A este respecto, un número importante de trabajos se centran en el estudio de la forma en que los agroecosistemas pueden hacer frente a estos desafíos, ya que proporcionan servicios ecosistémicos (SE) que generan mayores niveles de resiliencia, adaptabilidad, productividad y autosuficiencia. Por lo tanto, la valoración de los servicios de los ecosistemas juega un papel relevante en el proceso de toma de decisiones hacia el diseño y manejo de los agroecosistemas. Sin embargo, la asignación de valor a estos SE suele hacerse exclusivamente bajo la dimensión económico-monetaria, dejando así de lado otras dimensiones del valor. **Objetivo**. Proponer una estructura jerárquica de valoración de los SE que integre las dimensiones del valor con principios y criterios de valoración. **Metodología.** El método empleado para definir la estructura jerárquica fue una revisión exhaustiva de la literatura en los campos de la Agroecología y la Economía Ecológica, basada en una estrategia de búsqueda y clasificación de la información. Se examinaron 182 publicaciones científicas en su totalidad, en el período comprendido entre 2000 y 2017. **Implicaciones.** Este trabajo proporciona una base para fortalecer la discusión sobre la valoración de SE y su posible aplicación en contextos específicos asociados a agroecosistemas. **Conclusión.** Existe una cantidad importante de estudios que identifican la importancia de los SE en los agroecosistemas de diferentes dimensiones. Sin embargo, tales

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trabajos no asocian su importancia con el valor de dichos servicios. Por lo tanto, sigue siendo un desafío para los proyectos de investigación lograr relacionar sus contribuciones a su valoración multidimensional.
Palabras clave: Economía Ecológica; Agroecología; sistemas complejos

INTRODUCTION

The development of interdisciplinary strategies in the design and management of agro-ecosystems, which may face the current climate, ecological and cultural challenges and issues, is a relevant area in agroecological research (Altieri and Nicholls 2009; Nicholls, Henao, and Altieri 2017). In this sense, when incorporating features such as productivity, stability, viability, resilience, adaptability, equity and self-sufficiency, the ecosystem is afforded with the conditions to achieve dynamic balance and the maintenance of its functions (Gliessman 2002). When aspects such as biodiversity, agroecological strategies, culture, local technology and the reduction of environmental effects are included in the design of agro-ecosystems, the generation of ecosystem services (ES) is thus promoted (Altieri, Koohafkan, and Holt Gimenez 2012). ES are defined as either, the direct or indirect benefits received by humanity through biodiversity (Millennium Ecosystem Assessment 2003).

The generation of ES must be guaranteed in the design and management of agro-ecosystems, through the integration of key conditions such as ecological interactions, the function of regulation, habitat, production and information (Millennium Ecosystem Assessment 2003), and synergies among the livestock, agricultural, forest and water components (Barrezueta 2015). Such conditions are influenced by the importance or value given to ES. Valuation is a highly complex process, which cannot be approached through either simple or linear heuristics, from unidimensional perspectives, nor from one single discipline (Gómez-Baggethun and Martín-López 2015; Martínez-Alier 2006).

Notwithstanding the fact that the value of ES has had broad research development, it is not generally related to ES in agro-ecosystems. To give a first overview, only 76 documents were retrieved through a quick search in Scopus (March 2018); by using the keywords “ecosystem services”, “agroecosystem”, and “value”. Whereas, when only the keywords “ecosystem services” and “value” were used, 7839 documents were identified. These searches included articles and reviews without any time restrictions. This implies that only 0.97% of published studies focus on the value of ES in agro-ecosystems. Nevertheless, an increase has been observed in the number of articles published since 2012, thus reflecting the interest in this issue within the scientific community (Belem and Saqalli 2017; Bernués et al. 2014, 2015; Ma, Eneji, and Liu 2015; Swagemakers et al. 2017; Villegas-Palacio et al. 2016).

In view of the results mentioned above, a more detailed and systematic revision strategy of literature was developed, including both databases in English and in Spanish (Science Direct, Springer, Scopus, Scielo y Proquest). Also, the search was extended to included articles, doctoral dissertations and books published between 2000 and 2017. As a result, 182 publications were identified (details of this set of documents are shown in Appendix 1). The present work proposes five dimensions of value based on 65 documents reviewed: ecological, sociocultural, economic, technological and political. Dimensions of value are implemented through a series of premises approached by the scientific community, which in the present paper are referred to as valuation principles. A series of measurable conditions were determined for each principle, called criteria, which allow the establishment of the level of value in need of quantification. 108 documents were used as a basis in the identification of principles and criteria valuation. Additionally, methods, tools and models based on Ecological Economics were identified in 63 documents. Summarizing, the present work contributes to the valuation of ES in agro-ecosystems, poses methodological challenges, and suggests research approaches.

The remainder of this paper is structured as follows. Section 2, presents the methods used to establish, which valuation dimensions, principles, criteria and methods are provided by Ecological Economics and Agroecology for the valuation of ES in agro-ecosystems. Then, Section 3 shows outcomes and discussions about valuation approaches based on Agroecology and Ecological Economics (section 3.1), from agro-ecosystems to sustainable agro-ecosystems (section 3.2), the dimensions of ES valuation identified (section 3.3), the principles and criteria linked to dimension of ES valuation (section 3.4). Section 3.5 presents the valuation methods based on Ecological Economics. Finally, Section 3.6 shows an ES valuation framework proposed in agro-ecosystems, in this section displays a discussion about topics such as the framework implementation requires, and identification of research needs.

METHOD

The establishment of dimensions, principles and criteria for the valuation and identification of methodologies based on Ecological Economics, is founded on the analysis of literature. By means of a systematic revision which is structured as follows (Table 1): (I) definition of the research question, (II) the description of the parameters for the revision of literature, and (III) the selection and analysis of documents; the search strategy is specified in Table 1.

RESULTS AND DISCUSSION

The search strings indicated in Table 1 were applied to paper titles, abstracts and keywords for the revision process. The search within the databases led to overall 215 items. In a first step, the authors performed a title and abstract analysis, filtering duplicate articles and articles with a different focus from this of the research question. As a result, 182 items remained for a full paper screening. In a second step, a document classification was done related to the topics considered in the research question, as shown in Appendix 1. In a third and final step, based on full-paper reviews, a set of outcomes and discussion was proposed about the concept of sustainable agro-ecosystem, the definition of dimensions, principles and criteria of ES valuation, the identification of valuation methods of ES from Ecological Economics and a proposal of valuation framework.

Valuation approaches based on Agroecology and Ecological Economics

Within the group of papers that analyzes the processes of ES valuation in agro-ecosystems, a set of approaches was addressed to achieve greater understanding and a holistic view of the valuation. The approaches are: transdisciplinary, systemic approach, ecological approach, multidimensionality, and participatory approach. These focuses have not been treated together, and their connection to valuation processes is not yet clearly established. This is the reason why the integration of the five approaches is proposed in this work. First, this integration enables the conceptual construction of sustainable agroecosystems (section 3.2). Second, in order to identify dimensions, principles and criteria that will constitute the valuation system (sections 3.3 and 3.4). And third, in order to identify the valuation methodologies based on Ecological Economics (section 3.5). Figure 1, shows the approaches integration in the valuation process.

Transdisciplinary approach: It integrates diverse disciplines such as agricultural sciences, ecology, sociology, anthropology, geography, peasants and rural development studies, with social aspects, equity, distribution, ethics, culture and economics, as well as knowledge on local agricultural communities; in order to grant value to ES, through participation and dialogue (Altieri and Nicholls 2010; Castiblanco 2007; Gliessman et al. 2007; Perfecto, Vandermeer, and Wright 2009).

Systemic approach: an Agro-ecosystem is considered as a complex system, consisting of a structure or the subsystems and interrelations conforming it (agricultural, livestock, forest, soil, water and among others subsystems), anthropocentric components (machinery, fertilizers, seeds, irrigation water, labor), and natural components (solar radiation, rain, wind, sediments, nutrients and energy) (Gliessman 2002). Processes of matter and energy transfer, the nutrient cycle, and regulation mechanisms take place within the agro-ecosystem, which interacts so that emerging behaviors and synergies contribute to fertility, productivity and crop protection (Altieri 2002).

Ecological approach: in this approach, the agro-ecosystem’s ecological dimension sets productive, economic and biophysical boundaries thus conditioning the development of the other dimensions (Altieri 2002; Gonzáles de Molina and Caporal 2013; Leon 2009; Machado et al. 2015). The ecological approach proposes the design of agro-ecosystems imitating the local ecosystems in their structure, processes and functions. This, in order to generate ES which minimize dependence from external energy flows, promote diversity of species and habitats, originate higher resilience, stability and productivity (Gliessman 2002). The ecological approach acknowledges limits and biophysical laws circumscribing the economic process that takes place in the agro-ecosystem, thus becoming an approach which integrates interactions between the economy and its context.

Multidimensional approach: the multidimensional concept arises from strong sustainability theory as the goals of the ecological, sociocultural, economic, technological and political dimensions, cannot replace each other. In Ecological Economy, the theory of value claims ecosystem services has a multidimensional nature, as they consider both different kinds of value and the interrelations amongst them. Therefore, when the multidimensional approach is employed, the agro-ecosystem is analyzed in a holistic way, and the importance of ES is comprehensively valuated (Gómez-Baggethun et al. 2014; Gómez-Baggethun and De Groot 2007; Martínez-Alier 2006; Rótolo and Francis 2008).

Table 1. Search strategy.

Stage	Description
(I) definition of the research question:	Which valuation dimensions, principles, criteria and methods are provided by Ecological Economics and Agroecology for the valuation of ES in agro-ecosystems?
(II) parameters for revision of literature	**a. Kinds of documents which should be included:** Research reports, books, articles in indexed journals, memoirs of doctoral and master's dissertations related to the research question.
	b. Keywords and Boolean expressions: • (Title ("Ecosystem Services")) And (Title ("Valorization and Methodology")) or (All ("Agroecosystem")) And (Title-Abs-Key ("Principle or criteria or indicator")) • (Title-Abs-Key ("Agroecosystem") And Title-Abs-Key ("Ecosystem and Services") And Title-Abs-Key ("Valuation")) • (Title-Abs-Key ("Agroecosystem") And Title-Abs-Key ("Ecosystem and Services") And Title-Abs-Key ("Value"))
	c. Sources of information: Science Direct, Springer, Scopus, Scielo y Proquest.
	d. The period when the search was made: 2000 -2017.
(III) document selection and analysis	**Deductive analysis:** • Degree of contribution of the document to the research question. • Incorporation of approaches on valuation based on EE.

Source: Authors (2018) based on (A Espinoza et al. 2017).

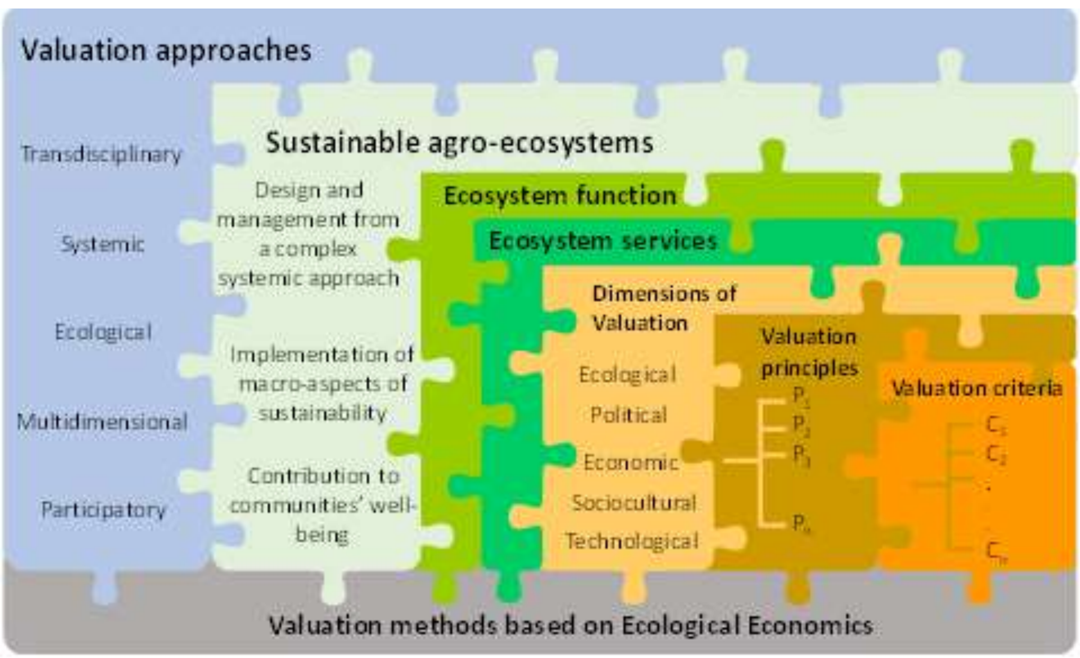

Figure 1. Relations between approaches, sustainable agro-ecosystem, dimensions, principles, criteria and valuation methods.

Participatory approach: it highlights the importance of the knowledge, experiences and practices of both communities and scientists in the valuation of ecosystem services, thus allowing the integration of diverse actors with the agro-ecosystem's complexity (Berbés-Blázquez 2011). Such knowledge, ancient wisdom, and traditional practices allow the increase of both individual and collective understanding of the agro-ecosystem's processes and functions, manage to show the importance or value of ES for communities' well-being. Through the participatory approach, the decisions made by the actors over the ES within the agro-ecosystem, will be mediated by their valuation (Dougill, Fraser, and Reed 2010; Louah et al. 2017; Minga 2017; Nicholls et al. 2017; Turrent-Fernández et al. 2016).

From agro-ecosystems to sustainable agro-ecosystems

An agro-ecosystem is regarded as a productive ecosystem of human origin, linked to specific social systems and cultural contexts, of complex nature and dependent on time-space alterations, where ecological, social, economic and technological factors interact (Caro-Caro and Torres-Mora 2015; Sarandón and Flores 2014). The decision-making involved in the agro-ecosystem's design and management is influenced by differences of perception, symbolic relations and interests between the actors and the different local technological forms (Caro-Caro and Torres-Mora 2015; Leon 2009).

The concept of agro-ecosystem is so broad that it may include both an indigenous "chagra" in the Amazon jungle, and a cattle hacienda in the Colombian plains. The complex social and ecological relations may be observed in both systems, and both would be Agroecology's objects of study (León 2014). Notwithstanding the multiple publications referring to the concept of sustainable agro-ecosystem, its definition still not clear. Therefore, it is relevant to make a difference between the concept of agro-ecosystem and that of sustainable agro-ecosystem.

In this sense, a sustainable agro-ecosystem incorporates three fundamental features; the first one is its design and management from a complex systemic approach (Altieri 2002; Blanco et al. 2013; León 2014). The second one is its implementation of macro-aspects of sustainability such as the promotion of biodiversity, the implementation of agroecological strategies, the decrease of undesirable environmental effects, and the incorporation of ancient and local knowledge, practices and other sociocultural aspects (Altieri 2002; Altieri et al. 2012; Altieri and Nicholls 2007). The third feature is its contribution to communities' well-being, by generating and maintaining attributes such as productivity, stability, viability, resilience, adaptability, equity and self-sufficiency (Astier, Masera, and Galván-Miyoshi 2008; Bastida, Alonso, and González 2013; López-Ridaura, Masera, and Astier 2002). After claiming that a sustainable agro-ecosystem provides adequate conditions for the generation of ES, its concept needs to be established; it is defined in the present work as follows:

A sustainable agro-ecosystem is an agro-ecosystem which has been modified for the production of goods and services, and generates well-being for communities. It is approached as a complex system, including ecological, sociocultural, economic, technological, and political variables and relations. It is designed and managed to imitate the structure and function of local ecosystems, thus involving traditional and scientific knowledge. So that ecological interactions and synergies among its components, generate ecosystem functions and services (ES), which may guarantee productivity in time, as well as the protection of the system from external variables (Author, 2018) based on (Altieri 2002, 2013; Altieri et al. 2012; Altieri and Nicholls 2000, 2007; Gliessman 2002; Sarandón and Flores 2014).

According to the proposed concept, in order to imitate the structure and functions of local ecosystems in sustainable agro-ecosystems, it is necessary to have high biodiversity involved in its design and management, which allows the production of ES. When polyculture, agroforestry systems and cover crops are used, habitats are provided for hibernation and feeding of a variety of fauna and insects, thus generating the service of biological plague control in crops (Daniels et al. 2017; Nicholls et al. 2017). ES such as pollination, the increase of biological activity, nutrient cycling, and nitrogen fixation are observed, which improve the soil's physical, chemical and biological conditions (Beer et al. 2003). ES such as water balance regulation and micro-climate generation bring benefits including the stability of harvests and the increase of food security (Altieri et al. 2012; Altieri and Nicholls 2004; Gutiérrez González, Luisa Suárez Alonso, and Rosario Vidal-Abarca Gutiérrez 2016; Martín and Osorio 2012).

The inclusion of high biodiversity provides products such as timber, firewood, resins, fruits, medicinal plants (Moonen and Bàrberi 2008). It participates as shelter and habitat for many species and contributes to the maintenance of both biological and genetic information (Sayago Ortega 2016). It improves the ecological carrying capacity (Machado et al., 2015), and provides cultural services such as science, education, aesthetical beauty and recreation (rural tourism) (Rositano and Ferraro 2014).

In a sustainable agro-ecosystem, ecological interactions and synergies among its components allow the reduction of dependence form external energy inputs, derived from fossil resources (fuels, agrochemicals), the minimization of carbon dioxide emissions and the production of food which is free from harmful elements. Additionally, when agroforestry systems are implemented, higher amounts of bio mass are incorporated into the soil and the ES of capture of carbon is generated (Hossain et al. 2017; Lal 2009; Tsonkova et al. 2014).

Dimensions of ES Valuation in sustainable agroecosystems

A community assigns value to ES the same way they assign importance to them, such conceptual approximation is derived from literature where ecology, economics and culture are linked (Gómez-Baggethun et al. 2014; Gómez-Baggethun and De Groot 2007; Rótolo and Francis 2008). The assignment of value becomes a process depending on the understanding of a particular human group, of the meaning or importance of ecosystem services in a particular biophysical, sociopolitical and time context (Dendoncker et al. 2013).

Understanding the importance of ES, and therefore their valuation, is intrinsically complex, as they influence both tangible and intangible dimensions of human well-being. They are valuable because of their contribution to the maintenance of life, production and culture, that is, their value goes beyond their level of usefulness, their sole existence gives them value by itself. Other aspects making their valuation complex are the features of eco-systems providing ES, such as irreversible thresholds of change and emerging behaviors, which are hard to model and predict (Aguilera, 2006; Wegner and Pascual, 2011).

There is a great number of authors who are interested in research on valuation, languages of value, plurality of value or dimensions of value of ES (Aguilar González and Segura Bonilla 2016; Dendoncker et al. 2013; Gómez-Baggethun et al. 2014; Gómez-Baggethun and De Groot 2007; Gómez-Baggethun and Martín-López 2015; De Groot, Wilson, and Boumans 2002; Jax et al. 2013; Kumar 2010; Martínez-Alier 2006). In this sense, the present work proposes five dimensions of value: ecological, sociocultural, economic, technological and political. Where the structure, processes and functions of local ecosystems are the base for the development of agro-ecosystems; thus generating the functions of regulation, habitat, production and information that become ES, which are valuated multi-dimensionally, thus contributing in decision-making.

Dimension of ecological value: ecological value underlies agro-biodiversity, in biological interactions, in the synergies which are likely to emerge amidst the variety of species (both grown and wild) and the animal component, incorporating arrangements and forms of management which are consequent with local biophysical restrictions, which increases the productive potential of the agro-ecosystem. Together with agro-biodiversity, a valuation is made on the agro-ecosystem’s connectivity with the habitats of the ecosystems where it is immersed, thus making interchange and the movement of species easier (Aguilar-Jiménez, Tolón-Becerra, and Lastra-Bravo 2011; Altieri 2002; Altieri and Nicholls 2009; Díaz-Manrique 2014; Gliessman, Engles, and Krieger 1998; Güldner and Krausmann 2017; Harris 2003; León 2014; Nicholls, Altieri, and Vázquez 2015; Nicholls et al. 2017; Paleologos et al. 2017; Vargas and León 2013).

Ecological value is also related to regulation functions, such as the regulation of gases contributing to the ES of climate change mitigation and carbon storage, water regulation generated by the ES of prevention of alterations in water supply and flood control. Other regulation functions are valuated which provide ES such as biological control, soil formation and retention, and waste assimilation (Altieri et al. 2012; Altieri and Nicholls 2004, 2010; Barrezueta Unda 2015a; Daniels et al. 2017; Garbach and Morgan 2017; Gliessman 2002; Martín and Osorio 2012; Nodari and Guerra 2015; Ratnadass et al. 2012; Rositano and Ferraro 2014; Sarandón and Flores 2014; Silva-Santamaría and Ramírez-Hernández 2017).

The agro-ecosystem’s ecological sustainability is related to ecological value when the arrangements, practices and management consider the reduction of negative environmental effects. As well as the decrease of the consumption of external inputs, either agro-chemicals or fuels, thus assigning value to the agro-ecosystem’s capability to generate ES which promote higher levels of autonomy (Dale and Polasky 2007; Nicholls et al. 2017; Sarandón and Flores 2014; Swagemakers et al. 2017).

Dimension of sociocultural value: in the context of agro-ecosystems, sociocultural value is assigned to ES participating in food security, related to availability and equitable access to varied, nutritious, and harmless food, notwithstanding disturbances and extreme climatic, political or economic events. Additionally, valuation is made of the ES contributing to food sovereignty and the development of production, distribution and consumption networks at different geographic levels (Altieri 2002; Altieri et al. 2012; Bastida et al. 2013; Céspedes, Arboleda, and Morales-Pinzón 2010; Dale and Polasky 2007; Lescourret et al. 2015; Nicholls et al. 2017; Nodari and Tomás 2016; Sarandón and Flores 2014; De Schutter 2014; Zuluaga Sánchez and Ramírez Villegas 2015).

The sociocultural value of ES in agro-ecosystems is also associated to their level of support to the so-called resilient social infrastructure, based on local organizations’ collective action, networks among communities, social cohesion, inclusiveness and sense of belonging. Thus increasing governance over ES, as substantial elements in the maintenance and resilience of such systems (Altieri 2013; Altieri et al. 2012; Balvanera et al. 2011; Díaz-Manrique 2014; Louah et al. 2017; Machado et al. 2015; Nicholls et al. 2017; Vázquez and Martínez 2015).

Dimension of economic value: the proposal of the present study is to incorporate a broader concept of economics, based on Ecological Economics. If economics may be understood as the general compliance with human needs, the economic value of ES would be linked to their importance in communities’ well-being (Gómez-Baggethun et al. 2014). According to Ecological Economics, the maintenance and preservation of ecosystem functions and services are not conditioned by their monetary valuation.

Economic value is assigned to ES contributing to the agro-ecosystem's viability, taken as a rise in productivity throughout time, the promotion of positive energy balances, the stability of food production and product diversification. Diverse units associated to the measuring of efficiency and productivity are incorporated into economic value, for instance, the relation between energy invested and energy produced is defined through energy balance, thus establishing the agro-ecosystem's energy efficiency (Altieri 2002; Bastida et al. 2013; Bautista et al. 2016b; Gliessman et al. 2007; Gonzáles de Molina and Caporal 2013; De Groot et al. 2002; Sarandón and Flores 2014).

After claiming that agro-ecosystems are not restricted to a plantation or a farm, and that their physical, biological, social, economic and political limits are blurry (Leon 2009), consideration is given to the assessment of the agro-ecosystem's level of contribution to rural well-being (Altieri et al. 2012). In this regard, economic value is assigned to ES contributing to income diversification and reduction of poverty, to good health, recreation and spiritual benefit (Abaunza, Arango, and Olaya 2011; Figueroa 2016; Gonzáles de Molina and Caporal 2013; Machado Vargas and Ríos Osorio 2016; Sámano 2013).

Dimension of political value: agro-ecosystems' ES are influenced by a political context, which is able to affect them to a greater or lesser extent than ecologic determiners. An agro-ecosystem reacts actively when it is faced with such influences, by promoting cultural, social and economic changes, which influence political decisions on the management of ES (Leon 2009).

The political value of ES is assigned by the level to which it is protected, or its rational use promoted through political instruments, which could be either taxing instruments, compensations, definition of protected areas, or the restriction of zones for certain uses. Political value may reflect upon the implementation of sustainable agro-ecosystems, for the use and conservation of processes, functions and ES (Altieri et al. 2012; Altieri and Nicholls 2012; Daniels et al. 2017; Gonzáles de Molina and Caporal 2013; Millennium Ecosystem Assessment 2003; Sabourin et al. 2017).

The political value of ES is also assigned by the level where resources are assigned for the support of research and extension of agroecological studies, the promotion of local knowledge, and the training of human capital, aimed at understanding the functions and ES at local, regional and national levels (Altieri et al. 2012; Altieri and Nicholls 2012; Cesano and Obermaier 2014; Daniels et al. 2017; Fonseca, J. Jarma and Cleves 2014; Garbach and Morgan 2017; Gonzáles de Molina and Caporal 2013; Nodari and Tomás 2016; Turrent-Fernández et al. 2016; Vázquez and Martínez 2015).

Dimension of technological value: technology is one element of culture which gathers the complexity of human thought and action, and becomes tools, instruments, equipment or systems (León, Mendoza, and Córdoba 2014). The value of ES when they become part of culture, and traditional and scientific knowledge is called technological value, which later transforms into practices, habits, costumes and traditions applied onto the design and management of agro-ecosystems (Altieri et al. 2012; Casanova-Pérez et al. 2015; Cesano and Obermaier 2014; Foyer et al. 2014; Gliessman et al. 2007; Lescourret et al. 2015; Louah et al. 2017; Nicholls et al. 2017; Sarandón and Flores 2014; Swagemakers et al. 2017; Zuluaga Sánchez and Ramírez Villegas 2015).

The technological value assigned to local and scientific knowledge of ecosystem functions and services favors the subordination and adaptation of practices to the biophysical and sociocultural conditions of each agro-ecosystem. Thus valuating the promotion of local autonomy, technological sovereignty and energy sovereignty based on renewable sources (Altieri et al. 2012; Bautista et al. 2016a; Dai et al. 2015; Figueroa 2016; Garbach and Morgan 2017; Nodari and Tomás 2016; Salembier, Elverdin, and Meynard 2016).

Valuation principles and criteria

Dimensions of value are implemented through a series of premises approached by the scientific community, which in the present paper are referred to as valuation principles. A series of measurable conditions was determined for each principle, called criteria, which allow the establishment of the level of value in need of quantification; a similar structure is proposed in Batista's research (2015). The principles and criteria identified are described in Table 2. The definitions adopted for principles and criteria in the present work are as follows:

- Valuation principles of ES: these are universal premises or bases included in the design and management of sustainable agro-ecosystems, whose level of compliance shows the value assigned to such ES in the agro-ecosystem's operation. Therefore, as long as ES contribute to the agro-system's productivity, stability, reliability, resilience, equity and self-management, its valuation increases in terms of its ecological, sociocultural, economic, technological and political dimensions.

- Valuation criteria of ES: these are measurable conditions (either quantitatively or qualitatively) which establish the level of implementation of each valuation principle.

Valuation methods of Ecological Economics

In the valuation of ES, it is required to identify methods based on Ecological Economics with the potential to integrate the proposed dimensions, principles and criteria. For this, the 63 documents resulting from the systematic literature review were considered, enabling us analyze functions, ES and dimensions of value. The strategy for the analysis of methodologies was based on work reported by Espinoza et al. (2017). A detailed description of each publication is introduced in Table 3, the document is cited in the first column, functions are established and ES valuated in the second column, they can be either regulation (Re), habitat (Ha), production (Pr) or information (In) (Millennium Ecosystem Assessment 2003).

The tools and models employed were identified in the third column. In the fourth one, mention is made of the dimensions of value considered in the publication, which are either ecological (Ec), economic (En), sociocultural (Sc), technological (Tc) or political (Po). Finally, the employed valuation methods are identified, which could be multi-criteria (A), deliberative – consulting (B), based on system dynamics modelling (C), energy or biophysical balances (D), fuzzy logic modelling, (E) or agent-based modelling (F).

Table 2. Valuation dimensions, principles and criteria of ES in agro-ecosystems.

	Principles	Criteria	References
Ecological Dimension of valuation	Principle 1: Increase of biodiversity within the sustainable agro-ecosystem, so that ecosystem processes and functions are generated (Altieri 2002, 2013; Altieri et al. 2012; Altieri and Nicholls 2000, 2005, 2007, 2009; Barrezueta Unda 2015b; Caro-Caro and Torres-Mora 2015; CIFOR 2000; Daniels et al. 2017; Gliessman et al. 1998; Güldner and Krausmann 2017; Harris 2003; Leyva Galan and Pohlan 2005; Lores, Leyva, and Tejeda 2008; Martín and Osorio 2012; Mateos-Maces et al. 2016; Nicholls et al. 2017; Nodari and Guerra 2015; Nodari and Tomás 2016; Paleologos et al. 2015, 2017; Salembier et al. 2016; Sarandón and Flores 2014; Stupino et al. 2014; Turrent-Fernández et al. 2016; Vargas and León 2013; Yong 2010; Zuluaga Sánchez and Ramírez Villegas 2015).	Criterion 1: Increase of biodiversity, biological interactions and synergies amidst the species present in the agro-ecosystem.	(Abaunza et al. 2011; Aguilar-Jiménez et al. 2011; Altieri 2002, 2013; Altieri and Nicholls 2009, 2012; Barrezueta Unda 2015b; Daniels et al. 2017; Díaz-Manrique 2014; Güldner and Krausmann 2017; Harris 2003; León 2014; Martín and Osorio 2012; Mateos-Maces et al. 2016; Nicholls et al. 2015, 2017; Nodari and Guerra 2015; Nodari and Tomás 2016; Paleologos et al. 2015, 2017; Stupino et al. 2014; Turrent-Fernández et al. 2016; Vargas and León 2013; Vázquez and Martínez 2015; Wu et al. 2015; Zuluaga Sánchez and Ramírez Villegas 2015).
		Criterion 2: Increase of the agro-ecosystem's connectivity with the surrounding habitats, thus allowing the movement and interchange of different species.	
	Principle 2: Improvement of the sustainable agro-ecosystem's ecological resilience, by imitating the structure, processes and functions of local ecosystems (Altieri 2002; Altieri and Nicholls 2009; Barrezueta Unda 2015b; Gliessman et al. 1998; Martín and Osorio 2012; Nicholls et al. 2015, 2017; Nodari and Guerra 2015; Osorio González 2015; Paleologos et al. 2017; Sarandón and Flores 2014; Zuluaga Sánchez and Ramírez Villegas 2015).	Criterion 3: Increase of processes of transference of energy, matter, and of functions of regulation, production and habitat.	(Altieri 2002; Altieri et al. 2012; Altieri and Nicholls 2004, 2009, 2010; Barrezueta Unda 2015b; Brunett Pérez, González Esquivel, and García Hernández 2005; Daniels et al. 2017; Garbach and Morgan 2017; Gliessman 2002; Güldner and Krausmann 2017; Martín and Osorio 2012; Nodari and Guerra 2015; Osorio González 2015; Paleologos et al. 2017; Ratnadass et al. 2012; Rositano and Ferraro 2014; Sarandón and Flores 2014; Silva-Santamaría and Ramírez-Hernández 2017).
		Criterion 4: Increase of the agro-ecosystem's productive potential, considering both the biophysical restrictions and local potentials.	(Altieri 2002, 2013; Álvarez Uribe, Mancilla López, and Cortés Torres 2007; Barrezueta Unda 2015b; Cesano and Obermaier 2014; Martín and Osorio 2012; Nicholls et al. 2017;

	Principles	Criteria	References
			Nodari and Guerra 2015; Nodari and Tomás 2016; Osorio González 2015).
	Principle 3: Reduction of negative environmental effects in the sustainable agro-ecosystem, able to impact the ecosystem structure, processes and functions (Altieri et al. 2012; Altieri and Nicholls 2013; Avellaneda-Torres, Torres, and León-Sicard 2014; Barrezueta Unda 2015b; Dale and Polasky 2007; Guzmán Vargas and Palacios Lozano 2009; López Báez et al. 2016; Nicholls et al. 2017; Sarandón and Flores 2014; Swagemakers et al. 2017; Vázquez and Martínez 2015).	Criterion 5: Reduction of agrochemicals and fossil fuel consumption.	(Altieri 2002; Altieri et al. 2012; Altieri and Nicholls 2004, 2009, 2010; Barrezueta Unda 2015b; Bonaudo et al. 2014; Güldner and Krausmann 2017; Martín and Osorio 2012; Nicholls et al. 2017, 2015; Ratnadass et al. 2012; Rositano and Ferraro 2014; Swagemakers et al. 2017; Vargas and León 2013; Vázquez and Martínez 2015).
		Criterion 6: Generation of micro-climates decreasing the loss of water and soil, due to solar radiation and the dragging of the wind.	(Altieri 2002; Altieri and Nicholls 2000, 2009, 2010, 2013; Barrezueta Unda 2015b; León 2014; Miccolis et al. 2016; Nicholls et al. 2015, 2017; Sarandón and Flores 2014).
		Criterion 7: Conservation, management and rational use of water.	(Altieri et al. 2015; Altieri and Nicholls 2013; Angel Sanchez 2016; Barrezueta Unda 2015b; Cesano and Obermaier 2014; Infante and Infante 2013; Nicholls et al. 2017; Turrent-Fernández et al. 2016; Varela Pérez 2010; Vargas and León 2013; Vázquez and Martínez 2015; Wu et al. 2015).
		Criterion 8: Decrease of soil degradation and loss, conservation and increase of its physical, chemical and biological properties.	(Altieri 2002; Altieri et al. 2012; Barrezueta Unda 2015b; Bonaudo et al. 2014; Brunett Pérez et al. 2005; Iermanó et al. 2015; Leon 2009; Machado et al. 2015; Martín and Osorio 2012; Nicholls et al. 2017; Peyraud, Taboada, and Delaby 2014; Vargas and León 2013; Vázquez and Martínez 2015).
		Criterion 9: Decrease of emission of greenhouse gases and increase of their capture and storage, thus generating either a positive or a neutral balance of gases such as CO_2, CH_4, NO_2, HFC, among others.	(Altieri et al. 2012; Altieri and Nicholls 2010; Angel Sanchez 2016; Bautista et al. 2016a; A. Espinoza et al. 2017; Montagnini et al. 2015; Nicholls et al. 2017; Vargas and León 2013; Zuluaga Sánchez and Ramírez Villegas 2015).
Sociocultural Dimension of valuation	Principle 4: Generation of goods and services within the sustainable agro-ecosystem, contributing to the population's food security, under changing conditions derived from disturbances and extreme events (Altieri 2002; Altieri et al. 2012; Altieri and Toledo 2011; Bastida et al. 2013; Burbano-Orjuela 2016; Céspedes et al. 2010; Dale and Polasky 2007; Lescourret et al. 2015; Nicholls et al. 2017; Nodari and Tomás 2016; Rivas and Condón 2016; Sarandón and Flores 2014; De Schutter 2014; UN FAO 2011; Zuluaga Sánchez and Ramírez Villegas 2015).	Criterion 10: Decrease of the agro-ecosystem's vulnerability to climate change and climate variability.	(Acevedo-Osorio et al. 2017; Altieri et al. 2012; Altieri and Nicholls 2008, 2013; Álvarez Uribe et al. 2007; Angel Sanchez 2016; Barrezueta Unda 2015a; Bastida et al. 2013; Bautista et al. 2016a; Brunett Pérez et al. 2005; Céspedes et al. 2010; Dale and Polasky 2007; Díaz-Manrique 2014; Infante and Infante 2013; Nicholls et al. 2015, 2017; Nodari and Tomás 2016; De Schutter 2014; Turrent-Fernández et al. 2016; Vargas and León 2013; Vázquez 2011; Vázquez and Martínez 2015; Zuluaga Sánchez and Ramírez Villegas 2015).
		Criterion 11: Maintenance of food availability under changing conditions.	
		Criterion 12: Maintenance of access to food and promotion of its equitable distribution under changing conditions.	(Altieri and Nicholls 2012; Bastida et al. 2013; Céspedes et al. 2010; Lope-Alzina 2014; Nicholls et al. 2017; De Schutter 2014; Zuluaga Sánchez and Ramírez Villegas 2015).
		Criterion 13: Improvement of quality and harmlessness of the	(Altieri and Nicholls 2012; Céspedes et al. 2010; Nodari and Tomás 2016;

	Principles	Criteria	References
		population's food and nutrition, by incorporating local species.	De Schutter 2014; Swagemakers et al. 2017; Zuluaga Sánchez and Ramírez Villegas 2015).
		Criterion 14: Increase of food sovereignty so that healthy food production, distribution and consumption networks may be sustainable at both local and regional levels.	(Altieri 2002; Altieri and Nicholls 2012; Casanova-Pérez et al. 2015; Gonzáles de Molina and Caporal 2013; Nicholls et al. 2017; Nodari and Tomás 2016; De Schutter 2014).
	Principle 5: Generation of resilient social infrastructure within the sustainable agro-ecosystem, by keeping ecosystem processes and functions (Altieri 2013; Altieri et al. 2012; Altieri and Nicholls 2013; Díaz-Manrique 2014; Louah et al. 2017; Machado et al. 2015; Moyano Estrada, Garrido, and Costabeber 2000; Nicholls et al. 2017; Vázquez and Martínez 2015).	Criterion 15: Maintenance and promotion of collective action among peasant organizations.	(Altieri et al. 2012; Altieri and Nicholls 2012; Cesano and Obermaier 2014; Garbach and Morgan 2017; Gonzáles de Molina and Caporal 2013; Güldner and Krausmann 2017; Lin 2011; Machado et al. 2015; Moyano Estrada et al. 2000; Nicholls et al. 2017; Vázquez and Martínez 2015).
		Criterion 16: Increase of social capital, networks and bonds between communities, aimed at facing the changing conditions.	(Altieri et al. 2012; Cesano and Obermaier 2014; Díaz-Manrique 2014; Figueroa 2016; Garbach and Morgan 2017; Gonzáles de Molina and Caporal 2013; Lope-Alzina 2014; Louah et al. 2017; Machado et al. 2015; Nicholls et al. 2017; Russi, Gómez-Perazzolli, and Andreoni 2015; Vázquez and Martínez 2015).
		Criterion 17: Increase of governance over local ES and decrease of conflicts over the use of and access to such services.	(Bravo-medina et al. 2017; Foyer et al. 2014; Iniesta Arandia 2015; Nicholls et al. 2017; Ruíz-Echavarría 2017; Villegas-Palacio et al. 2016).
	Principle 6: Distribution, access and equitable use of productive resources in the sustainable agro-ecosystem, by keeping ecosystem processes and functions (Altieri et al. 2012; Cesano and Obermaier 2014; Gliessman et al. 2007; Gonzáles de Molina and Caporal 2013; Nicholls et al. 2015, 2017; Sarandón and Flores 2014).	Criterion 18: Maintenance of Access to and use of productive resources (land, seeds, water, agricultural biodiversity, agroecological technologies, production networks, credit and local markets).	(Altieri et al. 2012; Cesano and Obermaier 2014; Gliessman et al. 2007; Gonzáles de Molina and Caporal 2013; Nicholls et al. 2017; Sarandón and Flores 2014).
		Criterion 19: Improvement of equitable distribution of productive resources (land, seeds, water, agricultural biodiversity, agroecological technologies, production networks, credit and local markets).	
	Principle 7: Maintenance and improvement of social cohesion of the sustainable agro-ecosystem, so that ecosystem processes and functions may be kept (Altieri et al. 2012; Altieri and Nicholls 2013; CEPAL and FAO 2007; Fajardo Gómez 2016; Fonseca, J. Jarma and Cleves 2014; Nicholls et al. 2017; Swagemakers et al. 2017).	Criterion 20: Increase of social inclusiveness of minorities and vulnerable groups in the management of agro-ecosystems and the distribution of their benefits.	(Altieri 2002; Altieri et al. 2012; Altieri and Nicholls 2013; CEPAL and FAO 2007; Díaz-Manrique 2014; Vázquez and Martínez 2015).
		Criterion 21: Increase of sense of belonging by contributing to social adhesion, cultural diversity, and prosocial values (solidarity, respect for regulations, tolerance, security).	(Altieri et al. 2012; Altieri and Nicholls 2013; Casanova-Pérez et al. 2015; CEPAL and FAO 2007; Díaz-Manrique 2014; Fajardo Gómez 2016; Figueroa 2016; Fonseca, J. Jarma and Cleves 2014).
Techno logical dimensi	Principle 8: Inclusion of traditional and scientific knowledge, increasing the technological sovereignty in the sustainable agro-ecosystem, by keeping	Criterion 22: Generation and use of innovative technologies subordinated to local ecosystem functions and adapted to	(Altieri 2002, 2009; Altieri and Nicholls 2012; Casanova-Pérez et al. 2015; Cesano and Obermaier 2014; Figueroa 2016; Garbach and Morgan

	Principles	Criteria	References
	ecosystem processes and functions. (Altieri et al. 2012; Altieri and Toledo 2011; Casanova-Pérez et al. 2015; Cesano and Obermaier 2014; Foyer et al. 2014; Gliessman et al. 2007; Leon 2009; Lescourret et al. 2015; Louah et al. 2017; Nicholls et al. 2017; Purroy-Vásquez et al. 2016; Red PP-AL 2017; Sarandón and Flores 2014; Swagemakers et al. 2017; Vázquez and Martínez 2015; Zuluaga Sánchez and Ramírez Villegas 2015).	communities' needs and resources.	2017; Louah et al. 2017; Nicholls et al. 2017; Nodari and Tomás 2016; Salembier et al. 2016; Sarandón and Flores 2014; Swagemakers et al. 2017; Vázquez and Martínez 2015; Zuluaga Sánchez and Ramírez Villegas 2015).
		Criterion 23: Inclusion of local knowledge and practices in the design and management of sustainable agro-ecosystems, by acknowledging and keeping heritage agricultural systems.	
		Criterion 24: Increase of energy security and sovereignty through the use of renewable energy sources.	
Economic Dimension of valuation	Principle 9: Increase of productivity, by improving the economic viability of a sustainable agro-ecosystem, by keeping ecosystem processes and functions (Altieri 2002; Bastida et al. 2013; Bautista et al. 2016a; Gliessman et al. 2007; Gonzáles de Molina and Caporal 2013; De Groot et al. 2002; Sarandón and Flores 2014; Wu et al. 2015).	Criterion 25: Increase of the agro-system's energy efficiency by generating a positive energy balance.	(Altieri 2002; Bastida et al. 2013; Daniels et al. 2017; Gliessman et al. 2007; De Groot et al. 2002; Güldner and Krausmann 2017; Mateos-Maces et al. 2016; Nicholls et al. 2015, 2017; Nodari and Tomás 2016; Paleologos et al. 2017; Sarandón and Flores 2014; Turrent-Fernández et al. 2016; Vázquez and Martínez 2015; Wu et al. 2015).
		Criterion 26: Maintenance of stability in food production either under changing or stressful conditions, generated by disturbances or extreme events.	(Altieri et al. 2012; Bastida et al. 2013; Nicholls et al. 2017; Zuluaga Sánchez and Ramírez Villegas 2015).
		Criterion 27: Increase of income diversification, generation of secondary products and alternatives linked to farming activity.	(Abaunza et al. 2011; Bastida et al. 2013; Beer et al. 2003; Brunett Pérez et al. 2005; Cesano and Obermaier 2014; Moonen and Bàrberi 2008; Sayago Ortega 2016; Sosa-Fernández et al. 2017; Swagemakers et al. 2017; Vázquez and Martínez 2015).
		Criterion 28: Increase of crop diversity, by adapting production to market changes and local needs.	
		Criterion 29: Increase of local input use contributing to the economic viability of agro-ecosystem.	(Altieri et al. 2012; Bastida et al. 2013; Bonaudo et al. 2014; Brunett Pérez et al. 2005; Casanova-Pérez et al. 2015; Cesano and Obermaier 2014; Iermanó et al. 2015; Swagemakers et al. 2017; Vázquez and Martínez 2015).
	Principle 10: Reduction of poverty and improvement of human well-being within the sustainable agro-ecosystem, by preserving ecosystem processes and functions (Abaunza et al. 2011; Balvanera et al. 2011; Figueroa 2016; Fisher et al. 2014; Gonzáles de Molina and Caporal 2013; Hossain et al. 2017; Laterra, Jobbágy, and Paruelo 2011; Machado Vargas and Ríos Osorio 2016; Sámano 2013; Suich, Howe, and Mace 2015; Tamayo 2014).	Criterion 30: Increase of job opportunities and better income by communities benefitting from agro-ecosystems.	(Abaunza et al. 2011; Altieri et al. 2012; Cesano and Obermaier 2014; Fisher et al. 2014; Gonzáles de Molina and Caporal 2013; Machado Vargas and Ríos Osorio 2016; Sámano 2013).
		Criterion 31: Increase of good living, good human health, recreation and spiritual benefit of local communities.	(Bastida et al. 2013; Casanova-Pérez et al. 2015; Gasparatos, Stromberg, and Takeuchi 2011; Hossain et al. 2017; Millennium Ecosystem Assessment 2003; Minga 2017; Nieto Rodríguez 2017; Rótolo and Francis 2008; Sámano 2013).
Political dimension of valuation	Principle 11: Generation of national policies promoting the implementation of sustainable agro-ecosystems, thus keeping ecosystem processes and functions (Altieri et al. 2012; Altieri and Nicholls 2012; Cesano and Obermaier	Criterion 32: Generation and implementation of incentives for the re-conversion of agricultural systems in sustainable agro-ecosystems.	(Altieri et al. 2012; Altieri and Nicholls 2012; Cesano and Obermaier 2014; Daniels et al. 2017; Dennis et al. 2013; Fonseca, J. Jarma and Cleves 2014; Gonzáles de Molina and Caporal 2013; Millennium Ecosystem

Principles	Criteria	References
2014; Daniels et al. 2017; Dennis, Agraria, and Norte 2013; Fonseca, J. Jarma and Cleves 2014; Gonzáles de Molina and Caporal 2013; Millennium Ecosystem Assessment 2003; Nicholls et al. 2017; Sabourin et al. 2017; Swagemakers et al. 2017; Turrent-Fernández et al. 2016; Vázquez and Martínez 2015).	Criterion 33: Support to commodification of products and services derived from sustainable agro-ecosystems.	Assessment 2003; Nicholls et al. 2017; Sabourin et al. 2017; Swagemakers et al. 2017; Turrent-Fernández et al. 2016; Vázquez and Martínez 2015).
	Criterion 34: Implementation of policies promoting access to and the adoption of low-cost technologies suited for local conditions.	(Altieri and Nicholls 2012; Bautista et al. 2016a; Cesano and Obermaier 2014; Nodari and Tomás 2016; Sabourin et al. 2017; Turrent-Fernández et al. 2016; Vázquez and Martínez 2015).
Principle 12: Increase of agroecological research and extension within sustainable agro-ecosystems, thus promoting local knowledge and the preservation of ecosystem processes and functions (Altieri et al. 2012; Altieri and Nicholls 2012; Cesano and Obermaier 2014; Daniels et al. 2017; Fonseca, J. Jarma and Cleves 2014; Garbach and Morgan 2017; Gonzáles de Molina and Caporal 2013; Nodari and Tomás 2016; Turrent-Fernández et al. 2016; Vázquez and Martínez 2015).	Criterion 35: Promotion of transdisciplinary and participatory research, based on local knowledge.	(Altieri and Nicholls 2012; Casanova et al. 2016; Cesano and Obermaier 2014; Gonzáles de Molina and Caporal 2013; Guzmán Vargas and Palacios Lozano 2009; Lescourret et al. 2015; Louah et al. 2017; Minga 2017; Nicholls et al. 2017; Nodari and Tomás 2016; Turrent-Fernández et al. 2016).
	Criterion 36: Support of human capital and agroecological extension, adapted to the needs of communities, associations and networks.	(Altieri and Nicholls 2012; Cesano and Obermaier 2014; Dennis et al. 2013; Figueroa 2016; Garbach and Morgan 2017; Gonzáles de Molina and Caporal 2013; Lescourret et al. 2015; Louah et al. 2017; Nicholls et al. 2017; Turrent-Fernández et al. 2016; Vázquez and Martínez 2015).

Table 3. Valuation methods of ES in agro-ecosystems based on Ecological Economics.

Publication	Valuated functions and ES	Tools/models	Dimensions	Valuation Methods					
				(A)	(B)	(C)	(D)	(E)	(F)
(Fu et al. 2000)	Re	Stella	Ec			x			
(Panzieri, Marchettini, and Hallam 2000)	Re	Emergy Analysis	Ec+ En				x		
(Seppelt 2000)	Re	SIG, Stella, scenarios	Ec+ Sc			x			
(Zoebl 2000)	Re, Ha	Inputs and outputs balance	Ec+ En+ Tc				x		
(Grouzis and Milleville 2001)	Re, In	Conceptual model	Ec+ Sc+ Tc			x			
(Portela and Rademacher 2001)	Re, Ha	Stella	Ec+ En+ Sc+ Tc			x			
(Tripathi and Sah 2001)	Pr	Inputs and outputs balance	Ec+ En				x		
(Musacchio and Grant 2002)	Ha, Pr, In	Stella, scenarios	Ec+ En+ Sc+ Tc+ Po			x			
(Belcher, Boehm, and Fulton 2004)	Re	Stella, SAM[1]	Ec+ En+ Tc			x			
(Shi and Gill 2005)	Pr, Re	Stella	Ec+ En+ Sc+ Tc+ Po			x			
(Tscharntke et al. 2005)	Ha, In	SIG	Ec+ Tc	x					
(Chen et al. 2006)	Re, Pr	Emergy Analysis	Ec+ En				x		
(Kirsta 2006)	Re	SAnM[2]	Ec+ En+ Sc			x	x		
(Ferraro 2008)	Re, Pr	Exergy Analysis	Ec				x		
(Pizzigallo, Granai, and Borsa 2008)	Re	Life cycle analysis, emergy analysis	Ec+ En				x		
(Zhang et al. 2008)	Re	Statistical analysis	Ec+ Tc						x

Publication	Valuated functions and ES	Tools/models	Dimensions	Valuation Methods					
				(A)	(B)	(C)	(D)	(E)	(F)
(Ferraro 2009)	Re, In	System based on knowledge, hierarchical organization of indicators	Ec+ Sc		x			x	
(Zuo-fang et al. 2009)	Re	Emergy Analysis	Ec+ En				x		
(Cao, Xie, and Zhen 2010)	Pr	Total required contents of energy, input-output analysis	Ec+ Tc+ Po				x		
(Dougill et al. 2010)	Re, In	Scenarios, Vensim	Ec+ En+ Sc+ Tc+ Po			x			
(Jogo and Hassan 2010)	Re	Stella	Ec+ En+ Po			x			
(Speelman and García-Barrios 2010)	Ha, Pr	Netlogo 3.1.5	Ec+ Sc						x
(Abaunza et al. 2011)	Pr, Re	Stella	En+ Sc+ Tc			x			
(Chandra et al. 2011)	Ha, Pr	Energy balance, input/output balance	Ec+ En+ Tc				x		
(Limin, Jia, and Xueping 2011)	Re	Emergy analysis, yield ratio	Ec+ En				x		
(Berbés-Blázquez 2011)	Re	Photo-voice	Ec+ Sc		x				
(Calvet-Mir, Gómez-Baggethun, and Reyes-García 2012)	Re, Pr, In	Interviews, participatory observation	Ec+ Sc		x				
(Dana, Kapuscinski, and Donaldson 2012)	Ha	Ecological risk analysis, biodiversity assessment, workshop, consultation with experts	Ec+ Sc	x	x				
(Nainggolan et al. 2012)	Re	Scenarios, multi-time maps	Ec+ Sc+ Po Regional						x
(Manes et al. 2012)	Re	Stella	Ec			x			
(Mialhe, Becu, and Gunnell 2012)	Re, Ha	Algorithms, dynamic systems	Ec+ En+ Po						x
(Willaarts, Volk, and Aguilera 2012)	Re	BalanceMED[3], consultation with experts, AHP[4]	Ec+ Sc	x	x				
(Blanco et al. 2013)	Ha	Biodiversity assessment, SIG	Ec+ Tc	x			x		
(Sijtsma, Van der Heide, and Van Hinsberg 2013)	Ha, In	Multi-criteria analysis	Ec+ En+ Sc	x					
(Velu 2013)	Re	Statistical analysis, physico-chemical and biological methods	Ec+ Tc	x					
(Vidal-Legaz et al. 2013)	In, Re	Stella	Ec+ En+ Sc			x			
(Díaz-Manrique 2014)	Pr, Re, In	Stella	Ec+ Sc+ En+ Tc+ Po			x			
(Oteros-Rozas et al. 2014)	Re, In, Pr	Interviews, multivaried statistical analysis	Ec+ Sc	x	x				
(Ricou et al. 2014)	Re, Ha	Decision trees	Ec		x			x	
(Rositano and Ferraro 2014)	Pr, Re, Ha	Conceptual network, Ucinet6[5], panel of experts, Bayes' theorem	Ec+ Sc+ Tc		x				
(Zwickle, Wilson, and Doohan 2014)	Re	Mental models, Heuristic analysis, Consultation with experts	Ec + Sc+ En+ Tc		x				
(Bautista 2015)	Pr, Re, Ha	Stella, Multi-criteria analysis	Ec+ Sc+ En+ Tc+ Po	x		x			
(Dai et al. 2015)	Re, Pr	Exergy analysis, ACV[6]	Ec+ En				x		
(Gómez, Andrade, and Vásquez 2015)	Pr	AgroDiSi	Ec			x			
(Ma et al. 2015)	Re	Emergy Analysis	Ec+ Sc				x		
(Wu et al. 2015)	Pr	Emergy Analysis	Ec+En				x		
(Bravo-Monroy, Potts, and Tzanopoulos 2016)	In	Etnography, non-parametric methods	Sc+ Po+Tc		x				

Publication	Valuated functions and ES	Tools/models	Dimensions	Valuation Methods					
				(A)	(B)	(C)	(D)	(E)	(F)
(Ferreira, Sánchez-Román, and Orellana 2016)	Re	Stella	Ec+ En +Tc			x			
(Hanna et al. 2016)	Pr	Ecological footprint, Stella	Ec+ En+ Sc			x			
(Morales et al. 2016)	Pr	Mental models	Ec+ Sc + Po+ Tc		x				
(Rodríguez, Peche, and Garbisu 2016)	Re	Consultation with experts, Fuzzy logic, linguistic variables, multi-attribute analysis	Ec		x			x	
(Villegas-Palacio et al. 2016)	In, Re, Ha	Workshops, focus groups, photo-language, brainstorming, scenarios	Ec+ En+ Sc+ Po	x	x				
(Saarikoski et al. 2016)	In, Re	ACB[7], MCDA[8], SMCE[9], AHP	Ec+ En+ Sc+ Po+ Tc	x					
(Winkler and Nicholas 2016)	Ha, In	Q-methodology, ACP[10]	Ec+ Sc		x				
(Belem and Saqalli 2017)	Re, Pr,	Scenario analysis	Ec+ En+ Sc+ Po						x
(Daniels et al. 2017)	Re, Ha	Stella, scenarios, VUI[11]	Ec+ En			x			
(Were et al. 2017)	Re	Optimization (genetic evolutionary algorithm) and SIG	Ec					x	
(Garbach and Morgan 2017)	Re, In	Network analysis	Ec+ Sc+ Tc		x				
(Güldner and Krausmann 2017)	Re	Biophysical flows, inputs – outputs balance	Ec				x		
(Lecq et al. 2017)	Ha	Biodiversity assessment	Ec				x		
(Liu et al. 2017)	Re	Exergy analysis	Ec				x		
(Louah et al. 2017)	Pr, In	Q-methodology, ACP	Sc		x				
(Swagemakers et al. 2017)	Ha	Q-methodology	Sc+ Po+ Tc		x				

Function and ES: regulation (Re), habitat (Ha), production (Pr) or information (In)
Dimensions of valuation: ecological (Ec), economic (En), sociocultural (Sc), technological (Tc) or political (Po).
Methods: multi-criteria (A), deliberative – consulting (B), based on system dynamics modelling (C), energy or biophysical balances (D), fuzzy logic modelling, (E) or agent-based modelling (F).
[1] Sustainable agro-ecosystem model
[2] System-analytical modelling, is based on an information-hierarchical approach, as well as on numerical experiments with the use of vast experimental data on system dynamics
[3] Specific software for hydrological models
[4] Analytic hierarchy process
[5] Social media analysis software
[6] Life cycle analysis
[7] Cost-Benefit Assessment
[8] Multi-criteria decision analysis
[9] Multi-criteria social assessment
[10] Main component analysis
[11] Indirect use value

After considering the analysis of information done in Table 3, it becomes apparent that the same publication could cover two or more functions and ES. The ES of Regulation were considered in 54 documents, such as cycles of nutrients, soil formation, hydrological cycle, gas regulation aimed at climate change mitigation, carbon sequestration, energy cycle, waste assimilation, plague control, prevention of disturbances, and water and soil quality. Services such as food production, raw materials, bio-energy, and ornamental and medicinal resources were analyzed in 25 documents. Information services such as maintenance of traditions and costumes, cultural enrichment, traditional knowledge, cognitive development, research, recreation, tourism and landscape were valuated in 16 documents. In spite of biodiversity's being the main base in the provision of ecosystem services, only 7 of such studies valuate habitat and biodiversity protection services.

In regard to the valuation dimensions, 11 documents considered one single dimension, 23 studies coped with two dimensions, 17 publications analyzed three dimensions, 6 publications bore four dimensions in mind, and 6 works included all five dimensions of valuation, 5 studies out of the latter used the system dynamics modelling. The distribution of the number of articles related to the dimensions of valuation and the methods are introduced in Figure 2.

In regard to the integration of methods, two studies applying systems dynamics modelling also integrated multi-criteria valuation, as well as energy or biophysical balances. In the case of publications using deliberative – consulting methods, three works included fuzzy logic modelling and multi-criteria valuation. Methods such as the deliberative – consulting ones, based on social sciences, are hardly ever integrated with natural science methods such as energy and biophysical balances.

The relations between the identified methods, functions, ES, and the tools and models applied in the analyzed publications, are introduced in Figure 3. Regulation and production systems are specially approached from valuation based on system dynamics modelling, and on energy or biophysical balances. The ES associated to habitat and information are treated by techniques based on deliberative –consulting, multi-criteria, and valuation on agent-based modelling as well as on and fuzzy logic modelling.

Analysis of publications on the employed methods shows that in 34 out of the 63 articles, one or two dimensions of value are considered, generally either economic or ecological, only 6 works included all 5 dimensions. This shows that a reduced number of studies include the complexity of valuation, thus leaving aside socio-cultural, technological and political values.

Given the increasing importance of ES in the design and management of sustainable agro-ecosystems, it is necessary to implement integrating frameworks, which support the decision-making process. In Table 4, the main findings of the document revision are described, thus identifying both the current conditions and the ideal conditions for ES valuation methods.

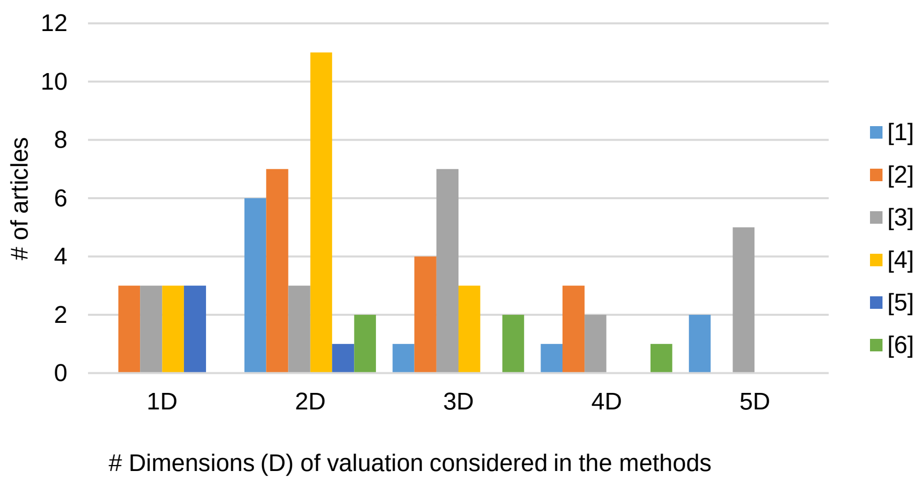

Figure 2. Relations between dimensions and methods of valuation
Methods: Multi-criteria valuation (1), Deliberative – Consulting Valuation (2) Valuation based on system dynamics modelling (3) Valuation through energy or bio-physical balances (4), Valuation through fuzzy logic modelling (5) Valuation based on Agent based modelling (6).

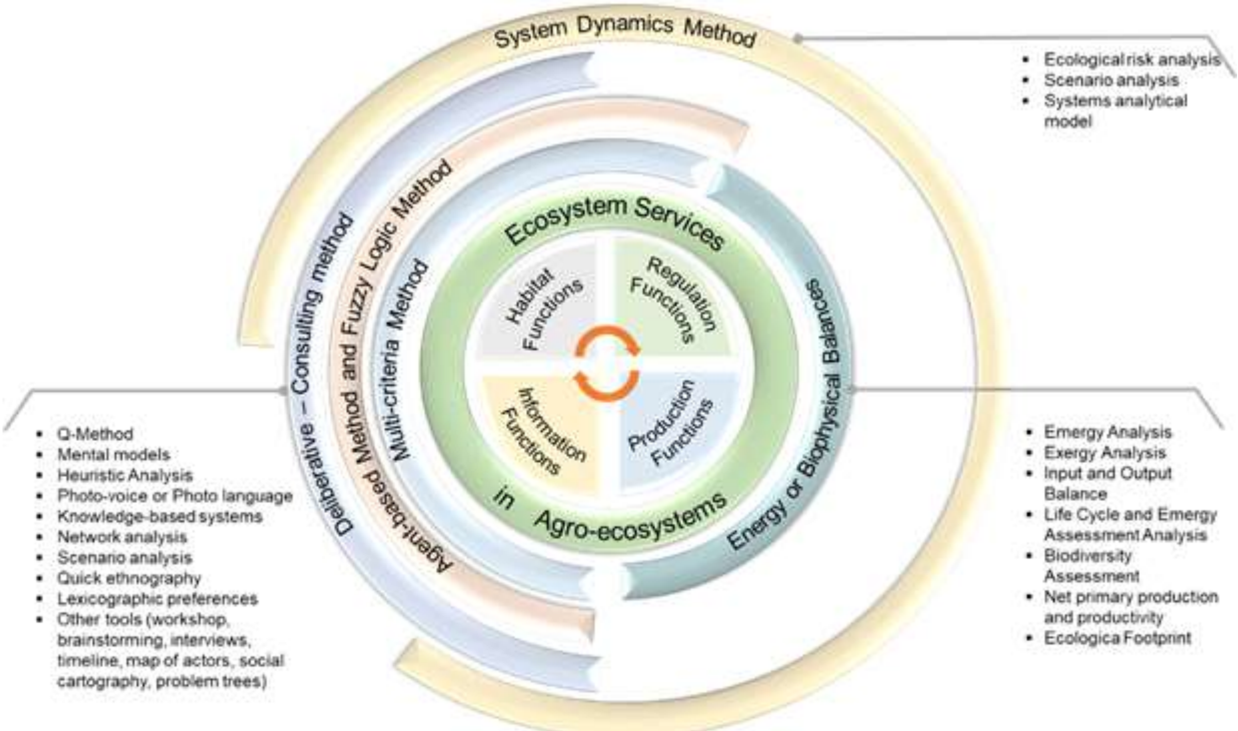

Figure 3. Relations between the identified methods, functions, ES, and either tools or models.
Source: Authors (2018) based on bibliography cited on Table 3.

Table 4. Characteristics of valuation methods of ES in agro-ecosystems.

Valuation approaches	Current Features	Ideal Features
Interdisciplinary	Disciplinary approaches, energy analyses, input and output balances, scenario analyses, mental models, ethnography, and lexicographic preferences were used, among others.	Integration of methods and tools of complex system modeling. It performs sensibility analysis.
Systemic	Partial approaches to subsystems, components and processes within the agro-ecosystem.	It analyzes the agro-ecosystem as a complex system. It shows and models synergies and emerging behaviors associated to the provision of ES.
Ecological	Some ES are valuated, mostly the ones of production and regulation.	Capability to value ecosystem services derived from the functions of habitat, regulation, production and information.
Multidimensional	Low integration of the five dimensions of value.	It integrates the ecological, sociocultural, economic, technological and political dimensions. It incorporates qualitative and quantitative indicators associated to valuation principles and criteria.
Participatory	Reduced integration of the communities' knowledge with scientific knowledge in ES valuation. Low understanding of the relations between ES and the communities' well-being.	It includes both communities' knowledge, experiences and practices, and scientific knowledge in valuation processes. It shows the importance or value of ES for the communities' well-being.

Source: Authors (2018)

ES valuation framework in agro-ecosystems

After considering the need of establishing tools which may support decision-making processes, the present work proposes a valuation framework based on Agroecology and Ecological Economics, as well as on valuation approaches, the concept of sustainable agro-ecosystem and multidimensional value.

Sustainable agro-ecosystems have the potential to generate ES as they are designed and managed from a systemic view, thus implementing macro aspects of sustainability and contributing to communities' well-being. By generating ES, valuation approaches and dimensions of value allow the identification of their importance. ES value is used in decision-making processes over the management of agro-ecosystems, thus guaranteeing their provision. The valuation framework is introduced in Figure 4, it consists of ecological, sociocultural, economic, political and technological dimensions of value. Each dimension is articulated through a series of principles and criteria described in Table 2.

Implementing the valuation framework requires methods allowing the integration of approaches with multidimensional value. This poses important methodological challenges which should be coped with by Agroecology and Ecological Economics, where non-linearity, synergies, emerging behaviors, interrelations, causality and hierarchies, and self-organization should be included, as well as any other aspects which may only be analyzed by modeling the agro-ecosystem as a complex system. Therefore, the identified methods were muticriteria valuation, deliberative – consulting valuation, valuation based on system dynamics modelling, valuation through energy or biophysical balances, valuation through fuzzy logic modelling and valuation on agent-based modelling.

After considering the valuation methods of ES in agro-ecosystems, described in Table 4, methods based on system dynamics modelling seems to have better potential to implement the valuation framework, given that, first of all, it allows involving multi-criteria analysis, and both energy and biophysical balances. Second, such method allows, as claimed by Kirsta (2006), to analyze emerging properties, relations and connections between ecosystem services, agro-ecosystems and their environments. Third, it models the non-linear behaviors that are characteristic of agro-ecosystems, establishes levels of sensitivity to external changes, identifies thresholds of change within the flow of ecosystem services and analyzes scenarios (Díaz-Manrique 2014). Fourth, it integrates the five valuation dimensions proposed in the present research.

CONCLUSIONS

The integration of the transdisciplinary, systemic, multi-dimensional and participatory approaches in the valuation of ecosystem services contributes to decision-making in the management of agro-ecosystems. This way, the distinctive features of a sustainable agro-ecosystem are incorporated, such as being designed and managed from a complex systemic approach, implementing macro-aspects of sustainability, and contributing to the well-being of communities.

The value of ecosystem services derives from both individual and collective acknowledgement of its importance for well-being, without being limited to monetary valuation. Therefore, other languages of value are required, associated to ecological, sociocultural, economic, technological and political dimensions. Dimensions are implemented through principles; whose level of accomplishment shows the value of a given service has for the operation of the agro-ecosystem. The principles are measured through the criteria established by their degree of implementation. The criteria may be taken as a base for future research, aimed at establishing quantitative indicators associated to local contexts.

The valuation framework consisting of dimensions, principles and criteria may be implemented through the methods and models identified: multi-criteria, deliberative – consulting, based on system dynamics, energy or biophysical balances, fuzzy logic and agent based. Such methods and models allow approaching the research of agro-ecosystems as complex systems. System dynamics modelling approach has a high potential of development in valuation processes, due to its capability to integrate other methods, especially multi-criteria valuation and energy and biophysical balances, to describe through causal cycles the interrelations between ecosystem services, dimensions of value and macro-aspects of agro-ecosystems' sustainability, thus showing the relations between the value of ES and communities' well-being.

There is an important number of studies identifying the significance of ES in agro-ecosystems from different dimensions. Nevertheless, such works do not associate their importance with the value of such services. Therefore, it remains a challenge for research projects to achieve relating their contributions to their multidimensional valuation.

In regard to methodological challenges, it is relevant to achieve the integration of tools and models provided by different methods, to incorporate the characteristics of a complex system such as the agro-ecosystem, which allows reducing the limitations in ES valuation processes.

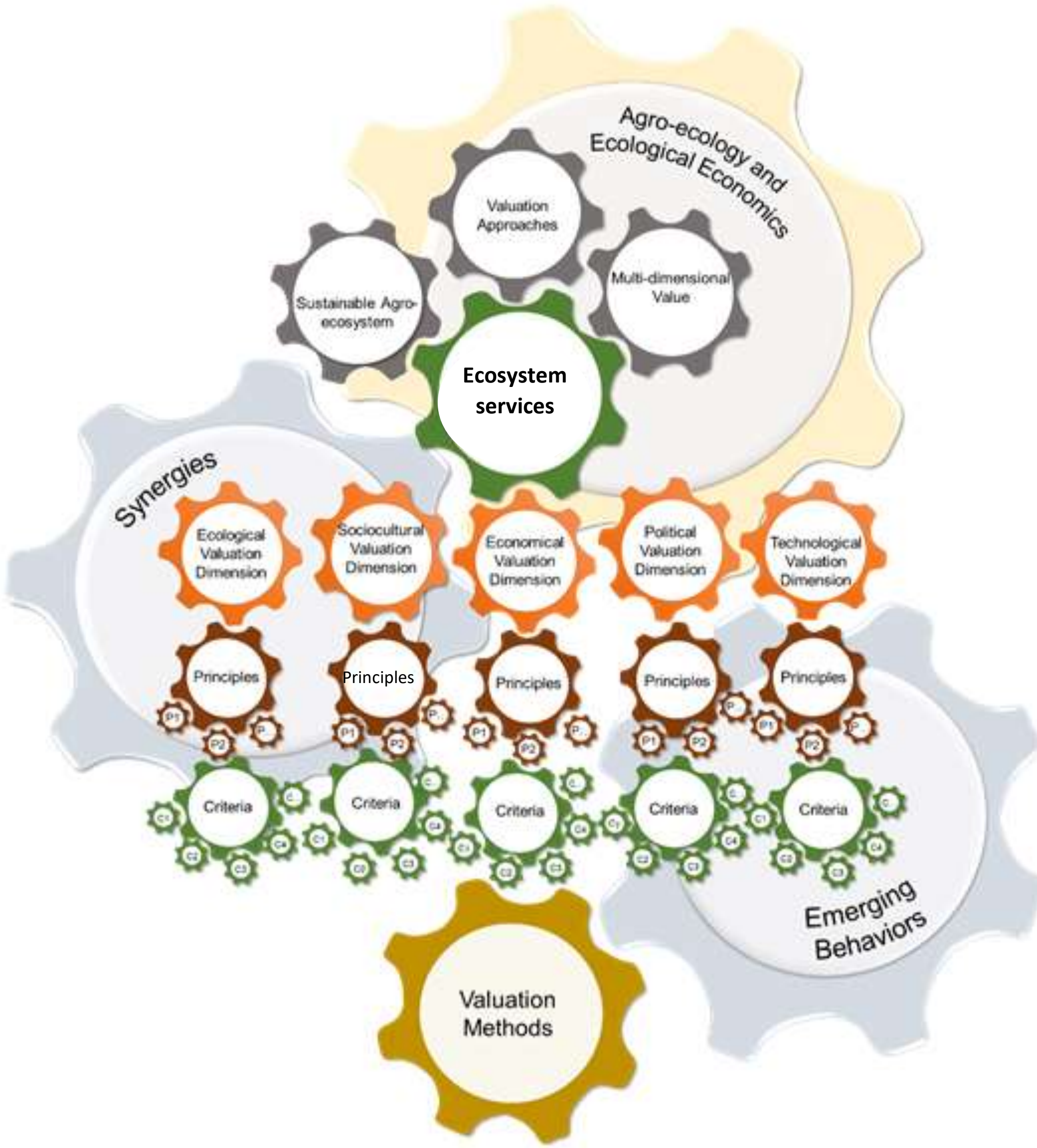

Figure 4. Valuation framework
Source: Authors (2018)

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Appendix 1. Documents classification related to the topics considering in the research question

		Topics considering in the research question				
#	**Documents**	**Valuation approach**	**Sustainable agro-ecosystems**	**Dimensions of ES valuation**	**Principles and criteria**	**Valuation methods**
1	Altieri and Nicholls, 2000		x		x	
2	CIFOR, 2000				x	
3	Fu et al., 2000					x
4	Moyano Estrada et al., 2000				x	
5	Panzieri et al., 2000					x
6	Seppelt, 2000					x
7	Zoebl, 2000					x
8	Grouzis and Milleville, 2001					x
9	Portela and Rademacher, 2001					x
10	Tripathi and Sah, 2001					x
11	Altieri, 2002	x	x	x	x	
12	De Groot et al., 2002			x	x	
13	Gliessman, 2002	x	x	x	x	
14	López-Ridaura et al., 2002		x			
15	Musacchio and Grant, 2002					x
16	Beer et al., 2003		x			
17	Harris, 2003			x	x	
18	Millennium Ecosystem Assessment, 2003			x	x	
19	Altieri and Nicholls, 2004		x	x	x	
20	Belcher et al., 2004					x
21	Altieri and Nicholls, 2005				x	
22	Brunett Pérez et al., 2005				x	
23	Shi and Gill, 2005					x
24	Leyva Galan and Pohlan, 2005				x	
25	Tscharntke et al., 2005					
26	Aguilera, 2006			x		
27	Chen et al., 2006					x
28	Martínez-Alier, 2006	x		x		
29	Kirsta, 2006					x
30	Altieri and Nicholls, 2007		x			
31	Álvarez Uribe et al., 2007				x	
32	Castiblanco, 2007	x				
33	CEPAL and FAO, 2007				x	
34	Dale and Polasky, 2007			x	x	
35	Gliessman et al., 2007	x		x	x	
36	Gómez-Baggethun and De Groot, 2007	x		x		
37	Astier et al., 2008		x			
38	Ferraro, 2008					x
39	Lores, Leyva and Tejeda, 2008				x	
40	Moonen and Bàrberi, 2008		x		x	
41	Pizzigallo et al., 2008					x
42	Rótolo and Francis, 2008	x		x	x	
43	Zhang et al., 2008					x
44	Altieri and Nicholls, 2009			x	x	
45	Ferraro, 2009					x
46	Guzmán Vargas and Palacios Lozano, 2009				x	
47	Lal, 2009					

#	Documents	Topics considering in the research question				
		Valuation approach	Sustainable agro-ecosystems	Dimensions of ES valuation	Principles and criteria	Valuation methods
48	Leon, 2009	x	x	x	x	
49	Perfecto et al., 2009	x				
50	Zuo-fang et al., 2009					x
51	Altieri and Nicholls, 2010	x		x	x	
52	Cao et al., 2010					x
53	Céspedes et al., 2010			x	x	
54	Dougill et al., 2010	x				x
55	Jogo and Hassan, 2010					x
56	Kumar, 2010			x		
57	Speelman and García-Barrios, 2010					x
58	Varela Pérez, 2010				x	
59	Yong, 2010				x	
60	Abaunza et al., 2011			x	x	x
61	Aguilar-Jiménez et al., 2011			x	x	
62	Altieri and Toledo, 2011				x	
63	Balvanera et al., 2011			x	x	
64	Berbés-Blázquez, 2011	x				x
65	Chandra et al., 2011					x
66	Gasparatos et al., 2011				x	
67	Laterra et al., 2011				x	
68	Limin et al., 2011					x
69	Lin, 2011				x	
70	UN FAO, 2011				x	
71	Vázquez, 2011				x	
72	Wagner and Pacual, 2011			x		
73	Altieri et al., 2012		x	x	x	
74	Calvet-Mir et al., 2012					x
75	Dana et al., 2012					x
76	Manes et al., 2012					x
77	Martín and Osorio, 2012			x	x	
78	Mialhe et al., 2012					x
79	Nainggolan et al., 2012					x
80	Ratnadass et al., 2012			x	x	
81	Willaarts et al., 2012					x
82	Altieri, 2013		x	x	x	
83	Bastida et al., 2013		x	x	x	
84	Blanco et al., 2013		x			x
85	Dennis et al., 2013				x	
86	Gonzáles de Molina and Caporal, 2013	x		x	x	
87	Infante and Infante, 2013				x	
88	Jax et al., 2013			x		
89	Sámano, 2013			x	x	
90	Sijtsma et al., 2013					x
91	Vargas and León, 2013			x	x	
92	Velu, 2013					x
93	Vidal-Legaz et al., 2013					x
94	Bonaudo et al., 2014				x	
95	Cesano and Obermaier, 2014			x	x	
96	Dendoncker et al., 2014			x		
97	De Schutter, 2014			x	x	
98	Díaz-Manrique, 2014			x	x	x
99	Fisher et al., 2014				x	
100	Fonseca, J. Jarma and Cleves, 2014			x	x	
101	Foyer et al., 2014			x	x	
102	Gómez-Baggethun et al., 2014	x		x		
103	León, 2014		x	x	x	

#	Documents	Topics considering in the research question				
		Valuation approach	Sustainable agro-ecosystems	Dimensions of ES valuation	Principles and criteria	Valuation methods
104	Lope-Alzina, 2014				x	
105	Oteros-Rozas et al., 2014					x
106	Peyraud et al., 2014				x	
107	Ricou et al., 2014					x
108	Rositano and Ferraro, 2014		x	x	x	x
109	Sarandón and Flores, 2014		x	x	x	
110	Stupino et al., 2014				x	
111	Tamayo, 2014				x	
112	Tsonkova et al., 2014		x			
113	Zwickle et al., 2014					x
114	Bautista, 2015					x
115	Barrezueta Unda, 2015a			x	x	
116	Casanova-Pérez et al., 2015			x	x	
117	Caro-Caro and Torres-Mora, 2015		x		x	
118	Dai et al., 2015			x		x
119	Gómez-Baggethun and Martín-López, 2015			x		x
120	Iermanó et al., 2015				x	
121	Iniesta Arandia, 2015				x	
122	Lescourret et al., 2015			x	x	
123	Ma et al., 2015					x
124	Machado et al., 2015	x	x	x	x	
125	Montagnini et al., 2015				x	
126	Nodari and Guerra, 2015			x	x	
127	Nicholls et al., 2015			x	x	
128	Osorio González, 2015				x	
129	Paleologos et al., 2015				x	
130	Russi et al., 2015				x	
131	Suich et al., 2015				x	
132	Vázquez and Martínez, 2015			x	x	
133	Wu et al., 2015				x	x
134	Zuluaga Sánchez and Ramírez Villegas, 2015			x	x	
135	Angel Sanchez, 2016				x	
136	Aguilar González and Segura Bonilla, 2016			x		
137	Bautista et al., 2016a			x		
138	Bravo-Monroy et al., 2016					x
139	Burbano-Orjuela, 2016				x	
140	Fajardo Gómez, 2016				x	
141	Ferreira et al., 2016					x
142	Figueroa, 2016			x	x	
143	Gutiérrez González et al., 2016		x			
144	Hanna et al., 2016					x
145	López Báez et al., 2016				x	
146	Machado Vargas and Ríos Osorio, 2016			x		
147	Martín and Osorio, 2016		x			
148	Mateos-Maces et al., 2016				x	
149	Miccolis et al., 2016				x	
150	Morales et al., 2016					x
151	Nodari and Tomás, 2016			x	x	
152	Purroy-Vásquez et al., 2016				x	
153	Rivas and Condón, 2016				x	
154	Rodríguez et al., 2016					x
155	Salembier et al., 2016			x	x	
156	Sayago Ortega, 2016		x		x	
157	Villegas-Palacio et al., 2016				x	x
158	Saarikoski et al., 2016					x
159	Turrent-Fernández et al., 2016	x		x	x	

		Topics considering in the research question				
#	Documents	Valuation approach	Sustainable agro-ecosystems	Dimensions of ES valuation	Principles and criteria	Valuation methods
160	Winkler and Nicholas, 2016					x
161	Belem and Saqalli, 2017					x
162	Bravo-medina et al., 2017				x	
163	Daniels et al., 2017		x	x	x	x
164	Espinoza et al., 2017				x	
165	Garbach and Morgan, 2017			x	x	x
166	Güldner and Krausmann, 2017			x	x	x
167	Hossain et al., 2017		x		x	
168	Lecq et al., 2017					x
169	Acevedo-Osorio et al., 2017				x	
170	Liu et al., 2017					x
171	Louah et al., 2017	x		x	x	x
172	Minga, 2017	x			x	
173	Nicholls et al., 2017	x	x	x	x	
174	Nieto Rodríguez, 2017				x	
175	Paleologos et al., 2017				x	
176	Red PP-AL, 2017				x	
177	Ruíz, 2017				x	
178	Sabourin et al., 2017			x	x	
179	Silva-Santamaría and Ramírez-Hernández, 2017			x	x	
180	Sosa-Fernández et al., 2017				x	
181	Swagemakers et al., 2017			x	x	x
182	Were et al., 2017					x
		19	26	65	108	63