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Article

Rethinking Study and Management of Agricultural Systems for Policy Design

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Abstract: There is a concern that agriculture will no longer be able to meet, on a global scale, the growing demand for food. Facing such a challenge requires new patterns of thinking in the context of complexity and sustainability sciences. This paper, focused on the social dimension of the study and management of agricultural systems, suggests that rethinking the study of agricultural systems entails analyzing them as complex socio-ecological systems, as well as considering the differing thinking patterns of diverse stakeholders. The intersubjective nature of knowledge, as studied by different philosophical schools, needs to be better integrated into the study and management of agricultural systems than it is done so far, forcing us to accept that there are no simplistic solutions, and to seek a better understanding of the social dimension of agriculture. Different agriculture related problems require different policy and institutional approaches. Finally, the intersubjective nature of knowledge asks for the visualization of different framings and the power relations taking place in the decision-making process. Rethinking management of agricultural systems implies that policy making should be shaped by different principles: learning, flexibility, adaptation, scale-matching, participation, diversity

enhancement and precaution hold the promise to significantly improve current standard management procedures.

Keywords: Complex Socio-ecological Systems; constructivism; realism; pragmatism; food security

1. Introduction

Agriculture is primary to food security and sustainable livelihoods. Since its early beginnings, the advance of technology and knowledge to produce food has been adapted to human needs and accompanied human development ever since [1]. During the latter half of the previous century, it successfully met, on a global scale, the growing demand for food [2]. However, the current concern is that this will be no longer possible, because the system of global food production is in the process of undercutting the very foundations on which it was built [2]. Issues as diverse as climate change [3], the massive use of unsustainable energy sources in a context of limited availability and fluctuating prices, water scarcity, biodiversity loss, change on habitats, urban-rural population structural changes, land-grabbing, new human health challenges, changes in global markets, *etc*., together with the important bearing that poverty has on these issues, are all related to agriculture, and they are eroding its capabilities to ensure food security and sustainable livelihoods. Furthermore, agriculture is no longer an isolated activity in the provision of food. Food provisioning involves many other activities beyond production, affecting the sustainable future of food, such as transport, retail and packaging, being all activities included in what is known as the agri-food system. Some figures can illustrate the enormous challenge that needs to be addressed: the number of undernourished people is close to 1,000 million [4], with an additional billion suffering nutrient and vitamin deficiencies [5], while the number of overweight people is approximately 1,500 million [6], at the same time the contribution of food production to global warming ranges between 10%–12% for agriculture only [7] and up to 44%–57%, adding deforestation, transport, processing, marketing, consumption and waste [8]. These numbers suggest that current agri-food policies are not enough to properly address some of the fundamental socio-environmental problems and that major improvements are required, agriculture still being the most important agri-food activity worldwide, as well as the most analyzed, and thus, the focus of this paper.

Traditionally, agriculture was understood as the science or practice of farming, including cultivation of the soil for the growing of crops and the rearing of animals to provide food, wool and other products. However, today agricultural systems are no longer evaluated solely on the basis of production, but on the basis of services and disservices that they provide to humans and services that they receive from natural ecosystem systems [9]. Regarding services, humans may not only benefit from production services, but also from regulation and the cultural service of ecosystems managed by farmers [10]. Agriculture becomes multifunctional when re-oriented towards ecosystem services provision [11]. Furthermore, farmers are no longer seen as external managers of an ecological system; they become part of the system. The role of agriculture as a contributor to development has been contrasted to a role that recognizes the peasants' livelihoods in sustainable development and promotes

community-based approaches to food production [12]. According to the EU, agriculture is at a crossroads, and challenges, impacts and solutions worldwide vary. However, a common theme is also emerging: sustainability is at the core of solutions [12].

Policies for sustainable agricultural systems should aim at developing rules to guide decisions for meeting today's needs and challenges regarding the production and provision of safe and nutritious food, without compromising the ability of future generations to meet their own needs. In general, the design of any agricultural policy is enhanced by consideration of three tiers [13]: (I) assessment (scientists and generation of knowledge, composed by the study of systems, as well as the reviewing, monitoring and evaluation of management options and strategies); (II) management by policy-makers (e.g., institutions/governance, social systems and legislation); and (III) strategies and practices related to food production (e.g., technology selection and implementation). These tiers are interconnected: assessments generally evaluate and are conditioned by agricultural practices to provide information to management, which, in turn, affects agricultural strategies and practices. If it is considered that new policies are required to favor sustainable agricultural systems, assessment, management and practices may also need to fit into different frameworks. Experience indicates that traditional approaches to agricultural system development bring in incremental gains in knowledge, but appear unable to produce the leaps required to overcome such fundamental problems [14]. In this context, if traditional approaches are insufficient, the patterns of thinking may need to be revised. Thinking about thinking and the exploring of new approaches regarding beliefs and claims fall into the realm of philosophy [15]. The revision of thinking patterns may result into a shift of paradigms [16] that replaces the traditional thought patterns in agriculture with a concept simultaneously tackling several features of complex agricultural systems, including its strong social component, and that profoundly affects agricultural policies, strategies and tactics dealing with complex adaptive systems and their sustainability [17]. Some key elements on this revision may be obtained from sustainability science, a discipline that is focused in the advances of the basic understanding of the dynamics of human-environment (socio-ecological) systems to facilitate the design, implementation and evaluation of practical interventions that promote sustainability in particular places and contexts and to improve linkages between relevant research and innovation communities, on the one hand, and policy and management communities, on the other [18–20]. Creating sustainable agricultural policies will require a debate about the role of agriculture in society in different contexts and the development of new principles and rules. The question is: what principles should guide the design of agricultural systems to make them more robust to external (e.g., market, climate) shocks?

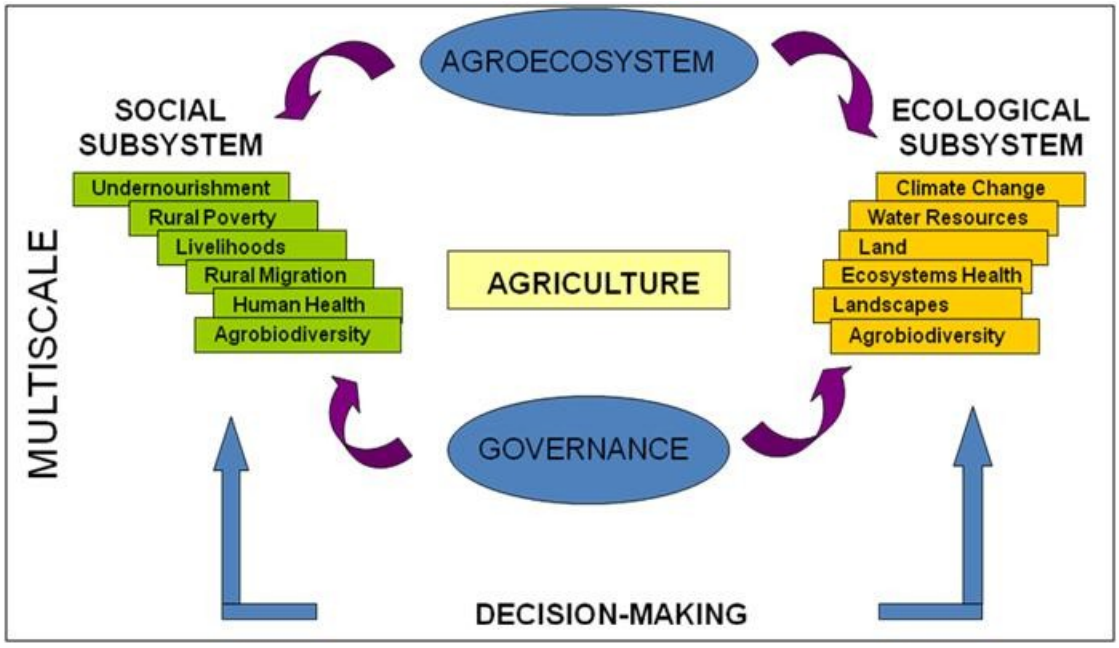
This paper attempts to overcome the fundamental limitations of traditional approaches by discussing an open proposal of new patterns of thinking into agricultural system study and management (S&M). For the sake of simplicity, the paper emphasizes agricultural systems (in the state of agri-food systems) and does not cover the entire geographical scales, timespan and institutional diversity relevant for S&M of agricultural systems. To meet the objectives, first, the paper summarizes important elements for rethinking the study of agricultural systems, including the need to define the role of agriculture in society, and identifies, thereafter, design principles for managing sustainable agricultural systems. By focusing on the policy level, the paper largely neglects the tactical and strategic aspects [21] of a system analysis.

2. Rethinking the Study of Agricultural Systems

Although progress has been made during the last few decades to integrate complex features into agricultural studies, policy-makers may still have to face many challenges when promoting sustainability. Their task is impeded by the different patterns of thinking underlying agricultural studies. Hence, policy makers may find the following short summary of agricultural system qualities and some comments on constructivist and realist views shaping agricultural studies useful.

(a) Agriculture can be characterized as a complex socio-ecological system (SES, Figure 1). SESs are qualified with far-from equilibrium states, co-evolution of system components, self-organizing properties, non-linear dynamics, multivariable structure, high levels of uncertainty, control of limited factors and cross-scale relationships in time and space. As a complex system, agriculture is an expression of certain human-environment interactions in a dynamic process shaped by uncertainty, errors, learning and adaptation. The need to rely on a systems approach was formulated decades ago, both in agriculture and ecology [22–24]. However, in the agricultural sciences, the perception of humans as decoupled from, and in control of, nature still remains, which, in turn, is an underlying cause of society's vulnerability [25]. In analogy to physics, agricultural sciences may also suffer from a predominant reliance on logical positivism and instrumentalism [26,27]. Logical positivism can be made responsible for atomistic or sectorial thinking dominating over holistic thinking and for preferring experimental approaches over abstract laws and fundamental principles for supporting scientific claims [15]. This pattern of thinking is also a hindrance for overcoming the limitations of linear cause and effect chain analyses. The limitations are further aggravated by the narrow methodology applied to support scientific claims. Namely, agronomy's focus on the state of systems relies heavily on controlled field trials for hypotheses testing and favors frequentist approaches for data analysis. Thereby, it overlooks the advantages of process analyses for explaining the state of systems and disregards powerful analytic tools provided by information theory-based methods; for example, [28]. The predominant instrumentalism in agricultural sciences also motivates agronomists to disregard the dynamics of agricultural systems (of ecological processes and social value systems) and to focus instead on technologies and futile efforts to make long-term predictions on agricultural productivity and profitability. As a consequence, agronomists overlook that complex structures, nonlinear behaviors and uncertainties seriously restrict the predictability of system dynamics [29,30]. Importantly, in agricultural systems, the uncertainty arising from human interventions is often higher than uncertainty derived from nature [31]. Distracted by instrumentalism, agronomists may also fail to see the limitations of technology-centered approaches that are a barrier for addressing new challenges, such as climate change, food security or emerging diseases with scientific methods [32,33], being also a motivation to neglect the dynamics of agricultural development and to strive for idealized states, such as organic and integrated systems. The limitations of logical positivism and the disadvantages of instrumentalism are further aggravated by decisions and actions based on a utilitarian value system, disregarding deontological and virtue ethics [32].

Figure 1. Agriculture as a complex socio-ecological system.



Additionally, multiple causes may underlie the dynamics of agriculture related problems, which may require diverse and context-specific solutions, *i.e.*, panaceas do not exist [34]. Nevertheless, most studies still focus on short-term optimization and gains in efficiency, rather than on the capacity to foster long-term social-ecological resilience [35]. Usually, these studies only consider some parts of the system and, frequently, the natural subsystem and tend to define agricultural problems as technical, relying mostly on technical solutions. However, in systems theory, it is widely accepted that if each part of a system, considered separately, is made to operate as efficiently as possible (as actors strive to do under the economic narrative), then the system as a whole will not operate as effectively as possible [36]. Approaches centered on the natural, ecological or social aspects only cannot provide the kind of knowledge that is required by socio-ecological systems. Synthetic analysis has been proposed to address complexity [37] through the connection of different perspectives that favors the notion of emergent properties as a step forward in the creation of knowledge. In this sense, the connection of macro- and micro-explanations, combining both holistic and reductionist approaches, expands the theoretical framework to accommodate more perspectives, more postulates and more theoretical tools [37]. Soft system approaches in science emphasize subjective perceptions and the role of the analyst as a participant in a process of social learning in which models serve to structure the debate are also designed to tackle complexity [38]. In the assessment of complex systems, it is common to adopt multiple perspectives and to see things at different levels of organization, and thus, different scales. This requires inter- and trans-disciplinary collaboration and openness to realistic positions when working with different types of knowledge, including local and traditional knowledge [24,29].

(b) The intersubjective nature of knowledge has important consequences in the study of agricultural systems [13]. Philosophical relativists assert that statements cannot be objectively true or false, only legitimized or delegitimized by a particular culture [15]. Social constructivists assert that knowledge is social in origin, knowledge formation and the development of knowledge structures take place within a socio-cultural context and individuals live in a world that is physically, socially and subjectively

constructed [39]. This implies that science is a social construction, and reconsidering the notion that natural sciences are objective and value-free is needed [26,40,41]. Some physicists also believe that the concept of reality is never independent of the theory used to explain it [42]. Realists, however, argue against the denial of realism [27]. Realism states that our reality, or some aspect of it, is ontologically independent of our conceptual schemes and linguistic practices. When differentiating between realism and anti-realism, philosophers refer to directions rather than positions. To assert that something is somehow mind-independent is to move into the realist direction; to deny it is to move into the opposite direction. No sane position is reached at either extremes [15]. In agriculture, many ecologists tend to or express an awareness of things as they really are, while social constructivists defend that knowledge, and identities are constructed in discourses that categorize the world and bring phenomena into view [39]. The separation of realistic and anti-realistic directions taken by constructivists and realists is helpful for structuring explanations, but disregards that a constructivist may consider both directions.

The intersubjective nature of knowledge moves the study into the constructivist direction and has strong methodological implications. Major agriculture related problems, e.g., food security, are "wicked problems", with no definitive formulation, no stopping rule and no test for a solution. However, the technical solutions proposed to increase sustainability of agriculture treat the issue more as a tame problem [43]. Wicked problems require framing as an essential step to derive assessment and management options [13]. In that manner, socio-ecological systems are entities constructed for analysis [33], with realistic and mental models describing specific representations of information about reality and frames referring to the context into which such models are embedded and give sense to it [38]. Framing involves not just choices about which elements to highlight, but also subjective perspectives and value judgments [44]; that is, the study of agricultural systems depends on our understanding of the system and the narratives used. For instance, different framings co-exist in the study of agricultural production (production-innovation, growth, agroecological, participatory) [45], obesity (individual/societal, physiological/psychological, economic/cultural, short-/long-termism) [46], or vulnerability to climate change (end point/starting point) [47], resulting in different theories, options and policies for addressing the problem. In science, this is called post-normal, characterized by "radical uncertainty" and "plurality of legitimate perspectives" [48]. In agriculture, dominant narratives have evolved from studies by deterministic models that utilize equilibrium conditions, to improved methods that incorporate risks and uncertainty. However, these approaches fail to address major agriculture related problems, because they do not properly analyze all relevant types of uncertainty associated with complex SES, including ignorance [29]. This failure has major consequences for agricultural governance and the type of scientific tools used; particularly, it relocates the role of modelling, recognizing more clearly its limits, and increases the importance of developing scenarios and interactive simulation modelling [49]. Thus, the evaluation of social and ecological implications of political decisions and the development of scenarios introducing different perceptions of reality by different stakeholders should be included in the core of any agricultural study. Furthermore, the intersubjectivity of knowledge poses several ethical constraints to both the S&M processes of policy-making and may also lead to misinformation, since the way we approach a problem leads researchers to search for specific types of information, neglecting other sources that might be relevant. For this reason, it is common that rigorous scientific assessments (e.g.,

Intergovernmental Panel of Climate Change, International Assessment of Agriculture Science and Technology for Development) have among their objectives to illustrate the different analyses carried out by the scientific community of one set of data that leads to different conclusions. This may result in a lack of consensus on different matters, increasing the complexity of the policy-making process [50]. In this context, and given the complexity of agricultural systems, it may be useful to adopt a pragmatic position [51] when working on the basis of constructivists views [24]. That is, we may adopt a model-dependent, constructivist realism: our image of the world consists of a model and a group of rules that connect the elements of the model with the observed reality. However, at the same time, reality may also depend on the observer.

Finally, the results derived from on-going discourses between and among realists and constructivists may produce different power, governance and governing structures. In environmental policy, for example, it is well accepted that the power of different actors can facilitate the adoption of one or another type of policy, as shown in the occasional confrontation among environmental and economic policies [44], both based on scientific knowledge developed under uncertainty or ignorance conditions. The same conflict may occur in agricultural systems, where some decisions based on scientific studies can distribute or concentrate power among different actors or shift discourses; or where the chances of particular options to be adopted are determined by the extent to which powerful actors see them as meeting their interests and/or values better than others [52]. The distribution of this power in decision-making can affect the scale at which decisions are taken and, thus, the institutional arrangements required. For instance, in terms of management, this can be reflected in the option of governing structures that favor top-down or bottom-up control of decisions. Studies and assessments can reinforce or dilute this trend, depending on the results, which, as has been said, are closely related to worldviews and narratives.

Defining the Role of Agriculture in Society

A clear example of the importance of worldviews and narratives in the process of designing agricultural policies for sustainability is the definition of the role of agriculture in society. This is important, since this affects both the assessment and management tiers of policy-making, and a lack of clarity during this process facilitates rambling on about important issues and, even, the suggestion of contradictory policies. The existence of different narratives or worldviews that impose themselves favors a lack of consensus in the policy outcomes [29]. Despite a risk of oversimplification and with the objective to exemplify how narratives determine agricultural systems S&M and, thus, decision-making, only the economic and the human rights narratives [13], as two distinct and opposed narratives about the role of agriculture in society, are considered here. In reality, a range of different narratives co-exist in different contexts.

The economic narrative suggests that the main role of agriculture is to contribute to development through economic growth, which will finally lead to an increase in social welfare (including improving nutrition), while negative ecological impacts associated with agriculture are minimized through the development and spread of new technologies. This narrative is mainly supported by major governments; for example, in Ethiopia [53], some actors in the private sector (agribusiness, large farmers) and some multilateral institutions. For instance, the Food and Agriculture Organization of the

United Nations (FAO), states that international agricultural policies should aim at raising levels of nutrition, increasing agricultural productivity, improving the lives of rural people and contributing to the growth of the world economy [54]. In this narrative, problems related to agriculture are very often driven by an inappropriate or insufficient use of technology (e.g., low agricultural productivity). Technology innovations, usually from top-down initiatives, are seen as key elements to achieve sustainability. Policies are market-centered, and inefficient farmers (in terms of agricultural productivity) are prone to disappear, unless they modernize and enter into regional or international markets.

The human-rights narrative is promoted by some parts of civil society, small peasants' organizations and other multilateral institutions (e.g., United Nations Special Rapporteur on the Right to Food). According to them, the main goal of agriculture is to provide a healthy and culturally adequate food, through a democratization of the food system, the recognition of the role of peasants' livelihoods in sustainable development, the recognition of other forms of knowledge and the promotion of community-based approaches. This is based on participation and enhances access rights, equity and social responsibility [55–57]. In this narrative, only people-centered policies can overcome the problems related to food. They recognize the important role of technology and innovations developed through bottom-up approaches and suggest that problems related to agriculture are more political than technical.

Before defining the role of agriculture in different contexts, it is important to consider the initial state of agricultural systems and to promote the participation of actors and society, in the way it is suggested later in the article, since different contexts and situations may result in different narratives. Policy makers also need to ponder that technical solutions are important, but unless political issues are considered, they will only produce partial and incomplete successes [13]. Traits in which initial short-term success lead to unsustainability and vulnerability in the long run [35] should be avoided, too.

3. Rethinking Agricultural Systems Management

The study of agricultural systems need to fit into a management structure that properly addresses stakeholders' demands and people's needs, as well as the preservation of agricultural ecosystems [58]. They need to integrate knowledge of human-ecological relationships into a complex sociopolitical and value-laden framework towards the general goal of long-term producing and provisioning safe and nutritious food for all. That is, management of agricultural systems needs to consider concept, such as resilience and socio-ecological justice.

Policy options have been proposed to manage complex SES [59], which, at the same time, integrate different perspectives into management. The literature refers to adaptive management, ecosystem-based management, ecological public health, integrated environmental management, polycentric approach or pragmatism, among others, without being able to satisfactorily consider them in agricultural management. In light of the diversity of management options, policy makers may look for principles or practices that they may include in agricultural systems management to create new management options. Of particular interest are learning, flexibility, adaptation, scale-matching, participation, diversity and precaution. These principles are mutually dependent; hence, problems or limitations in one aspect cannot be resolved or minimized without taking into account the reaction of

others and the response of institutions. Some of these principles are increasingly adopted in fisheries management [60,61]. In this section, we discuss how each principle may tackle the characteristics of studying agricultural systems (SES and intersubjective nature of knowledge) and present existing examples showing that it is possible to implement them in practice.

(a) *Learning, flexibility and adaptation*: Sustainability science considers adaptation as a key element for sustainable development [62]. Adaptation is the result of reflexibility, learning and flexibility. Learning is acquiring new or modifying existing knowledge, behaviors, skills, values or preferences and may involve synthesizing different types of information. Reflexibility is a prerequisite for learning; but learning is possible without adaptation, and learning alone does not guarantee successful governance of SES [34]. Building flexibility into management processes can accommodate both endogenous and exogenous technical, political and environmental changes [63] typical of complex systems. In that manner, all three elements are closely linked to building resilience. Evidence suggests that the impact of learning is greater when learning processes are devolved and dispersed among citizens, rather than confined to experts, officials or other interest groups [49].

The most widely known management strategy based on learning and adaptation is Adaptive Management, whose objective is to increase the adaptive capacity of the system. Adaptive Management acknowledges the uncertainty and complexity of systems [30] and the gaps in a manager's knowledge of a system. Policy makers adopt a learning process, institutional learning also being important. Since efforts to impose a standard solution can be worse than inaction, continuous policy modification through learning is critical for management of SES under persistent uncertainty [64]. The strong emphasis of Adaptive Management into learning and adaptation processes suggests that this approach has major advantages for agricultural systems management, heavily influenced by social aspects. When the social component becomes more important, Adaptive Management is extended to Adaptive Governance [59], as in the management of common-pool resources, e.g., mountainous agropastoral systems [65].

In Adaptive Management, scenarios of different policy alternatives and potential outcomes in alternative futures and actions are continuously evaluated to facilitate decision-making. Scientists provide user-friendly models and visual interfaces to communicate dynamic interactions across scales and support social learning processes [35,66,67]. However, care must be taken to not be trapped into models and scenarios [49]. Some limitations of Adaptive Management include the feasibility of large-scale concerted action (requiring of *participation* and *scale-matching* principles); and the boundary problem (requiring of *participation* and *diversity*).

(b) *Scale-matching*: it has been suggested that successes or failures in science and policy for human well-being are context-specific [68,69], based in understandings of both ecological dimensions and governance settings. However, the present complexity of agricultural systems and our societies shows that many linkages exist at different levels. Incongruence between spatial (local, regional, global) and temporal (present, future generations) scales and their interactions is an important source of surprise [70]. For instance, global (or present) decisions can have local (or future) impacts, respectively. Thus, decision-makers have to find the types of policies and management strategies for which scale-specific, adequate information exists in terms of social and natural processes, both in time and space [63]. In agricultural systems, scale governance is also important, because institutions and actors are embedded in time and space [70], and a scale-mismatch between agriculture-related

problems and the institutional scale may create issues for policy makers. Scale-matching can also refer to the combination of different knowledge systems developed at different temporal and spatial scales, such as indigenous and scientific knowledge [14]. In that manner, scale-matching allows one to integrate both the complexity of agricultural systems, as well as different framings of knowledge creation. Scale matching in decision-making has important trade-offs, exemplified by the tension between short-term efficiency and long-term adaptability [35]. A balance may be found by adopting participation and diversity principles.

Several management initiatives address the scale-mismatch. From an economic perspective, we refer to the use of Full Cost Allocation to address the distribution of burdens and benefits of activities between the origin of the benefits of agriculture and the location where the costs are born [71] in the global agri-food system. The understanding of non-marketed regulation and cultural agro-ecosystem services depends on how these services are used by different stakeholders, and this valuation requires participation [10]. Even if future tendencies lead to a boost of regional or local markets, it is important to consider all the costs and benefits (internal-external; social-ecological) of rules in the decision-making process. An interesting relevant case is the EU Water framework directive (2000/60/EC) [72]. From an ecological perspective, we refer to the concept of Environmental Sustainability, which aims at keeping the scale of the human economic system within the biophysical limits of the ecosystem. This means *inter alia* holding waste emissions within the assimilation capacity of the system on the sink side and keeping harvest traits of renewable resources within the regeneration rate on the source side [73]. From an institutional perspective, the Polycentric Approach, recently suggested to address climate change policies [74,75], is also promising for agricultural policies. For instance, the definition of a common pool regime at a global level, coordinated and managed with other more local institutional levels, might be needed to address global agriculture-related problems, including food security and climate change.

(c) *Participation*: the participation of policy-makers, stakeholders, scientists and society in general [48] is essential at different stages in the decision-making process. It is an element crucial to scale-matching and is linked to adaptive management [76], favoring self-organization, a characteristic of SES rarely considered in agricultural policies. Self-enforcing networks have the capacity for establishing flexible, collaborative and learning-based processes [77]. In this sense, close connections between social learning processes and adaptive management exist [49]. Participation is also important to transform conflicting interests into effective and sustained collective action, which are central in crises. Crises often lead to adjustments in SES, and the new state will be determined by human impacts on the system, which, ultimately, is determined by values and narratives, addressing also the intersubjective nature of knowledge. As stated, participation is required to bridge the gaps between narratives in order to meet long-term objectives and to yield more practical arrangements. Learning and participation are essential for changing mental models that apply to norms, values and framings. Participation also allows considering place-based cultural identity, including both practices and institutions and, thus, facilitating scale-matching processes. Farming system researchers, however, call attention to the difficulties of implementing participation [24] and how different qualities of participation may exist, ranging from the manipulation of local actors to self-mobilization of communities [26]. Furthermore, important in the process is the power of different actors in the participation process. In that manner, different stakeholders involved need to reach agreement on the

best course of action in the context of open-ended uncertainty and post-normal science. A process of negotiation is needed to define the rights, roles and responsibilities of different stakeholders/actors, as well as to collectively agree on the best way forward in a particular context and at a particular time. Learning by doing and Adaptive Management, as well as deciding "*whose knowledge counts*" in assessments depend on this negotiated political process and the agreements co-developed by different actors in agricultural systems and food providing landscapes [78].

A promising approach to recognize the existence of conflicting views regarding the role of agriculture in society is Ecological Pragmatism, developed by Bryan Norton for ecological discussions [51]. For example, Pragmatism may translate small policy changes into substantial steps forward at different spatial scales, even if seen globally in a different way, and the leading principles/values of different groups differ. Ecological Pragmatism would enable policy makers to overcome the limitations of philosophical relativism and refrain from a denial of philosophical realism. Nevertheless, Pragmatism should not lead to disregarding principles underlying ecological and social processes in decision-making. Namely, the foundations of population dynamics and ecosystem theories [79,80] should be taken into account in the same way as eco-social principles, as exemplified by Pawłosky [81], who assigned a fundamental role in sustainable development to ethics, because moral convictions determine human activities. Limited knowledge of these fundamental principles among stakeholders is often a cause for superficial sustainability assessments.

(d) *Diversity*: Social and ecological diversity are basic elements to build resilience. For example, it is recognized that diverse perennial agricultural systems produce certain services more efficiently than systems based on annual crops [82,83]. Furthermore, the diversity of human opportunities, cultures and economic options facilitates buffering and reorganization after disturbance and change [84]. Finally, diversity of adaptive institutions is particularly important to foster sustainable development [85]. Diversity of institutions also requires the recognition of boundaries different to those given by countries (e.g., pastoralism [86]). Diversity also includes variety of plausible hypothesis about the world and possible strategies [40], an essential basis for building agricultural governance approaches that contribute to equity and social justice [77]. Furthermore, diversity in assessments offers different sources of information and, hence, helps to reduce uncertainty and to manage complexity [50]. The diversity principle often requires *participation* and *scale-matching* principles. Diversity enhancement is a central principle for raising sustainability in any of the tiers of the policy-making process. Thus, it is not surprising that most of the management strategies mentioned in this article put strong emphasis on diversity as a leading principle. This is the case in Adaptive Management, Ecosystem-based Management, Polycentrism, Pragmatism, Integrated Environmental Management and Ecological Public Health.

(e) *Precaution*: Precaution implies that under uncertainty, common in agricultural systems, both ecological and social decisions should opt for caution, and the burden of proof should devolve upon those whose activities potentially damage the environment or have negative social consequences. Risk is a social construct, and the limits to precaution are given by the risk that society finds acceptable (participation and adaptation principles). Precaution is not new in agriculture, although it has been mostly suggested for novel technology adoptions. Recently, it has also been suggested to guide climate change policies [87]. Precaution provides a normative guide for policy-making in states of ignorance

and allows the use of an array of analytical methods, as well as recognizing that different and contextual findings might result in different assessments of the same issue [29,50].

Thus, existing management options rely on some or all of the principles outlined above (Table 1), and different agriculture-related problems require different policy and institutional approaches. For instance, Ecosystems-based Management or an Ecosystem Approach to planning and management has been extensively used for the management of marine resources [88]. It is a holistic, interdisciplinary, goal-oriented and participatory approach [89] that can be adopted at different large and small scales. It recognizes the role of the human dimension, which also reflects the properties of complex adaptive systems, in shaping ecosystem processes and dynamics [59]. An Ecosystem-based Management program must develop a new institutional arrangement capable of integrating environment and development considerations in a manner acceptable to society [90] and, thus, requires adoption of precaution. For climate change, the definition of global common pool regime embedded in a Polycentric approach is a promising suggestion. For food security concerns, a Pragmatism approach embedded in a Polycentric approach with a strong emphasis on adaptation can suggest the emergent properties of food systems.

In sum, management based on an SES perspective should recognize the need to move into realist and constructivist directions. Importantly, the latter dealing with the intersubjectivity of knowledge provides us with indications and tools that have concrete applications for agricultural systems management. Furthermore, elements introduced in adopting a SES approach, such as resilience, adaptation and vulnerability, gives the flexibility to use frameworks developed for vulnerability situations [68,91]. Agricultural systems probably require new and diverse management approaches that combine different existing strategies or develop new ones for different contexts and specific problems. As said, an intrinsic characteristic of agricultural systems is the importance and predominant role of the social subsystem, which current management strategies, designed with a strong focus on ecological subsystems, do not properly address. Thus, different agriculture-related problems require different policy and institutional approaches, but common principles based on resilience and social-ecological justice are needed for the design of sustainable agricultural systems.

Table 1. Principles guiding different types of management (A: adaptation; F: flexibility; L: learning; S-M: scale-matching; P: participation; D: diversity; Pr: precaution).

	A	F	L	S-M	P	D	Pr
Adaptive Management	■	■	■	■	■	■	■
Ecosystem-based Management		■		■	■	■	■
Polycentric approach		■		■	■	■	
Full cost allocation			■	■	■		
Pragmatism				■	■	■	
Ecological public health				■	■	■	■
Integrated environmental			■	■	■	■	
Management			■	■	■	■	
Social-institutional learning	■	■	■		■	■	

This paper states that a revision of thinking patterns is necessary for overcoming the difficulties of modern agriculture. The rethinking of the S&M of agricultural systems may only scratch the surface, but, nevertheless, indicates that there is an unexploited potential in a revision of philosophies underlying knowledge acquisition and rationalization of management procedures. In our view, the realization of this potential holds the promise to improve agricultural policies in leaps rather than in incremental gains. Above, we consider this to be a prerequisite for meeting the challenges that agriculture is facing today. Hence, the rethinking undertaken here may contribute to on-going assessments for policy design by international institutions (e.g., FAO [92] and European Commission [12]) and point to opportunities for further developing the ideas. Though the paper put emphasis on the policy level of food production systems, the rethinking also points to a potential for improving strategic and tactic levels in food production-oriented and multifunctional agriculture.

4. Conclusions

Rethinking how current agricultural policies are designed is needed. From this paper, we can conclude that the intersubjective nature of knowledge needs to be better integrated into the study and management of agricultural systems than has been done so far. This forces us to develop new modeling tools and scenario analysis; it also requires recognizing the nonexistence of panaceas and demands for more and better understanding of the social dimension of agriculture, including its role in society in different contexts. Finally, it asks for the recognition and visualization of the different framings and narratives on the S&M processes and the power relations taking place in the decision-making process. In terms of management, the adoption of some basic principles, such as learning, flexibility, adaptation, scale-matching, participation, diversity and precaution, may significantly improve the current standard procedures.

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Conflicts of Interest

The authors declare no conflict of interest.

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