

Review

Environmental Scenario Analysis on Natural and Social-Ecological Systems: A Review of Methods, Approaches and Applications

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Abstract: Scenario analysis is a useful tool to facilitate discussions about the main trends of future change and to promote the understanding of global environmental changes implications on relevant aspects of sustainability. In this paper, we reviewed 294 articles published between 1995–2019, to evaluate the state of the art use of models and scenarios to investigate the effects of land use change and climate change on natural and social-ecological systems. Our review focuses on three issues. The first explores the extent to which the environmental dynamics of land use and climate change were jointly analyzed and the spatial scales associated with such integrated studies. The second explores the modelling methodologies and approaches used in the scenario analysis. The third explores the methods for developing or building scenarios. Results show that in most predictions there is little integration of key drivers of change. We find most forecasting studies use a sectoral modelling approach through dynamic spatially distributed models. Most articles do not apply a participatory approach in the development of scenarios. Based on this review, we conclude that there are some gaps in how scenario analysis on natural and social-ecological systems are conducted. These gaps pose a challenge for the use of models and scenarios as predictive tools in decision-making processes in the context of global change.

Keywords: climate change; land use change; models; scenarios; sustainability; watersheds

1. Introduction

In recent decades, changes in land use and climate have had major impacts on the environment at local, regional and global scales [1–5]. The high rate of land use change and climate change are now one of the most important environmental problems on regional to global scales [2,6–8]. Both processes operate simultaneously, with feedbacks at varying spatial and temporal scales.

Given this significant and accelerated process of global change, the need arises to analyze and understand the interactions between human activities and natural resources [2], which leads to the definition of social-ecological systems as a unit of analysis and management. Berkes and Folke (1998) [9] point out that social systems and natural systems are linked at a multi-scale level and that the exclusive delimitation of an ecosystem or the resulting social system is arbitrary and artificial. Janssen and Ostrom (2006) [10] define social-ecological systems as complex adaptive systems in which social and bio-geophysical agents are interacting through multiple spatial-temporal scales. This approach from social-ecological systems will allow to build alternative ways of interaction between society and ecosystems towards sustainability.

Case studies of these types of systems, such as watersheds, are key to understand their functionality and to address the specific problems that threaten them, such as land use change and climate change. This requires a thorough understanding of the causes that determine land use and climate change and the use of simulation tools capable of taking into account the interactions among key factors of socioeconomic and environmental subsystems. This will allow us to explore the consequences in the medium and long-term in aspects relevant to sustainability such as water resources, biodiversity or nature conservation policies. However, the effects of land use change on water resources may not be as obvious, depending on the spatial scale of analysis.

In recent years, advances in research and understanding have led to increased attention to the importance of future scenarios of land use change [11–13], with simulation models [14–17] helping in the analysis of environmental responses.

Scenarios of land use change make possible to explore potential futures and their environmental consequences, as well as potential solutions to environmental problems and thus support decision-making [18]. A scenario is a creative, visionary tool that can support planning for a desired future as well as the preparation for possible undesirable events [19]. Scenarios are best developed not by researchers alone but with stakeholder participation. However, there are many successful and high-profile scenarios that have been developed with little participation from stakeholders [20,21]. Participatory approaches offer a chance to discuss, negotiate, and reach agreement [22,23].

The involvement of stakeholders in designing land use scenarios helps to identify acceptable land use alternatives by reflecting local preferences in land use decisions [24]. It facilitates the understanding of the multifaceted nature of land use issues from the perspective of stakeholders who are directly affected by land use decisions, but with usually limited participation in science and policy discourses [25]. However, development of land use change scenarios which are spatially explicit and detailed remains a complex challenge. In this regard, we ask the extent to which the literature has progressed in emphasizing these topics, and the extent to which there appear to be demonstrable advances in the understanding of the importance of interactions of changes in land use and climate.

We made a review of the recent scientific literature to address the following questions related to our understanding of socio-ecological responses to future scenarios of land use change:

- (1) In the evaluations of socio-ecological responses, to what extent were the environmental dynamics of land use change and climate change analyzed jointly in each study, and generally what were the spatial scales associated with such integrated studies? To what extent was a direct or implied synergistic effect considered between both of these two environmental dynamics in those studies?
- (2) What were the modelling methodologies and approaches used in the scenario analysis?
- (3) What were the methods used for developing or building scenarios?

2. Materials and Methods

This review used international publications that were included in the Web of Knowledge encompassing the 25 years period, from 1995–2019. The type of publications includes articles in journals that are published by a publishing company or organization and have undergone peer-review.

The search, through the Web of Science database integrated into the source Web of Knowledge, has been conducted through a first search based on the following key words: “Land use model” ($n = 423$), “Land use change model” ($n = 168$), “Land use simulation model” ($n = 23$). This search identified a total of 614 articles, which were successively screened based on their titles, keywords, and abstracts. In order to select the articles according with the aim of this review, we adopted an additional filter for each key word based on the topic “scenarios”, which reduced the list of articles to 231, the rest of articles were excluded because they were considered out of the scope of this review.

We did a second search based on the following key words: “Land use change scenarios” ($n = 273$) and “Land use and climate change scenarios” ($n = 32$) that give access to all publications containing those words in their title, abstract and/or keywords in the article. That search identified a total of

305 publications. Duplicated publications were removed and a total of 294 peer review journals were screened as a result of the combination of the two searches.

Most peer review were published in the categories of environmental sciences, ecology and water resources.

For the data analysis based on the aims of the paper, a publication summary was elaborated including the following attributes:

1. Year of publication.
2. Classification of study areas by country.
3. Spatial scale of analysis. We classified the publications according to two different spatial scales of analysis: watersheds and other spatial scales. The publications defined as watersheds were those whose areas of study referred to a region of land within which water flows down into a specified body such as a river, lake, sea or ocean. We included in the classification of watersheds areas of study such as a basin, river basin, watershed, river catchment and catchment. The publications defined as other spatial scales were those whose areas of study referred from local to global levels (e.g., cities, islands, countries, states, earth system).
4. If land use change and climate change are both jointly analyzed.
5. If the possible synergistic effect between land use change and climate change is analyzed.
6. Methodologies applied to analyze climate change scenarios. The applied methodology has been classified into two groups: global climate models (GCM) and regional climate models (RCM), which increase the resolution of the GCM in a small or limited area of interest.
7. Methodologies applied to analyze land-use change scenarios. The applied methodology has been classified into four groups of models: (1) non-spatial statistical models, (2) spatial statistical models (e.g., Geographic Information System (GIS)), (3) aggregated dynamic models and (4) dynamic spatially distributed models.
8. If the methodologies applied to analyze land use change scenarios do or do not analyze effects on hydrological dynamics.
9. If the methodologies applied to analyze land use change scenarios do or do not analyze effects on nutrient dynamics.
10. If the methodologies applied to analyze land use change scenarios do or do not analyze other environmental effects different to the effects on hydrological dynamics and nutrient dynamics, such as effects on the biodiversity and in the ecosystem services.
11. Land use change scenarios methods. We classified the articles according to two approaches [26,27]: researcher-driven processes and participatory processes. Researcher-driven approaches are experts-driven scenario development. A participatory approach in the scenario development is a process in which stakeholders, frequently guided by researchers, are engaged in a highly collaborative process and develop a leadership role within some or all stages of a scenario development process to investigate alternative futures.

The analysis and assessment of this review focused on a comparative study of all these attributes in articles using the social-ecological system of watershed as spatial scale, versus articles using other different spatial scales of analysis.

3. Results

Of the 294 articles that were found to include scenario analysis of land use change, nearly half (49%) analyzed the changes at watershed scale. These articles focusing on watersheds are relatively recent, especially when considering the joint study of land use change with climate change and/or analysis of the synergistic effect of both processes (Figure 1). In the last decade of the analyzed period, 79% of the articles on land use change scenarios in watersheds were published. More than half of the publications also discussed the climate change (72%). The synergistic effect of both processes (80%) were published in the last six years (2014–2019). The data indicate that recent advances in research

and/or changing research priorities may provide more complete knowledge about the likely trajectories of land use change under different scenarios and their synergistic effect with climate change at a watershed scale.

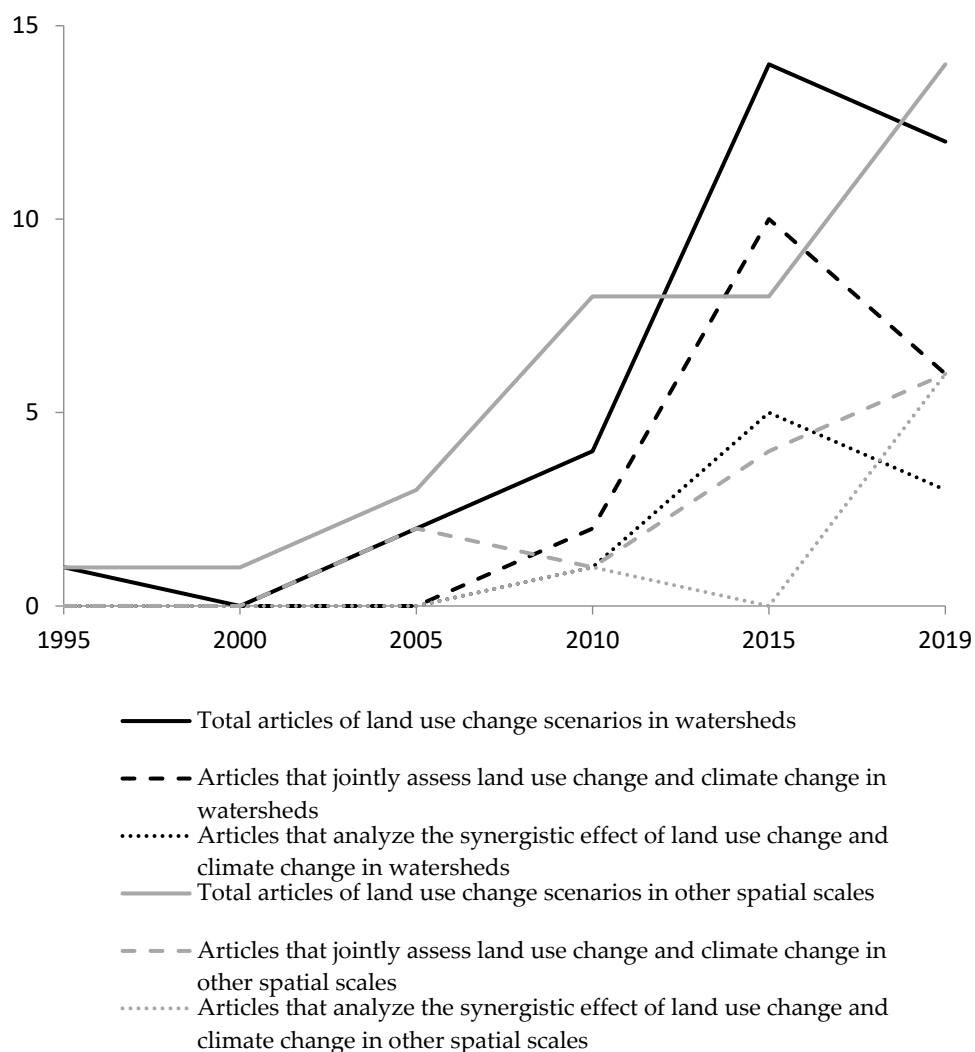


Figure 1. Number of publications in the analysis of land use change scenarios. 1995–2019.

Only 47% of these articles of land use change at the watershed scale also analyzed the process of climate change. In this group, most cases applied regionalized climate change scenarios (68%) compared to global scenarios (32%), possibly due to the increasing availability of regionalized scenarios. Of articles at the watershed scale that also address climate change, more than half (52%) analyzed the synergistic effect between the two processes of global change. Moreover, the evolution over time of these group of articles is rising, although there is a small recession in the last two years (2018 and 2019) (Figure 1).

As for the methodology applied to analyze scenarios of land use changes in watersheds, dynamic spatially distributed models were used more often than spatial statistical models (Table 1). Among the dynamic spatially distributed models the most used were the hydrological models (83%). Specifically, the SWAT model was used in 28% of the reviewed articles. The consideration or lack thereof of climate change did not significantly alter the overall distribution of applied methodological approaches (Table 1).

Table 1. Models classification applied in the analysis of land use change scenarios in watersheds.

Models Classification	Number of Total Articles in Watersheds	Number of Articles of Land Use Change and Climate Change Jointly Analyzed in Watersheds	Number of Articles of Synergistic Effects of Land Use Change and Climate Change in Watersheds
Non-spatial statistical model	4	0	0
Spatial statistical model (e.g., GIS)	14	5	5
Aggregated dynamic model	0	0	0
Dynamic spatially distributed model	119	59	30
Other methodologies	6	3	0
Total	143	67	35

Moreover, in order to know the methodological approach of the models (sectoral or integrated approach), we identified what kind of land use change effects were considered in the reviewed papers, including effects on hydrological dynamics, nutrient dynamics and other different potential environmental effects that may affect the sustainability of the watershed socio-ecological system. Most papers evaluated the hydrological dynamics effects (75%), and there was less frequent analysis of the effects on the dynamics of nutrients (26%) and other environmental attributes (28%), mainly the loss of biodiversity and ecosystem services. Again, the consideration or lack thereof of climate change did not substantially alter the type of analyzed effects.

Most of these publications (86%) evaluated these impacts in the watershed with a sectoral (hydro-ecological discipline) approach. The percentage of articles analyzing the hydrological dynamics effects without considering other possible effects in the watershed were 67%, although the analysis of the effects on the dynamics of the nutrients in the watershed was accompanied by the study of the hydrological dynamics effects in most cases (65%), especially when taking into account the synergistic effect of climate change (91%). Moreover, the study of other environmental effects was accompanied by the study of the hydrological dynamic effects in the 35% of the articles. The analysis of hydrological and nutrient dynamics effects along with other different environmental effects in the watershed was studied in just 2% of the publications, where the watershed was analyzed as a social-ecological system.

These results indicated that there were few integrated approaches, and the analyses were focused primarily on the hydrological dynamics effects of the watershed, versus an integrated and more interdisciplinary approach.

The articles that have analyzed land use changes scenarios in other spatial scales were placed together on a percentage slightly higher to that of watershed (51% of the 294 reviewed publications). More than 50% (specifically, 53%) of these articles were also published in the period 2014–2019 (Figure 1).

Notably, only 28% of these articles analyzed the process of climate change, a much lower percentage than in the case of watersheds (47%). Moreover, only 48% of these cases used regionalized climate change scenarios. Just as in watersheds, 67% of the publications that took into account both processes of global change, were published in the last six years, from 2014 to 2019 (Figure 1). The study of the synergistic effect of land use change and climate change was discussed only in seventeen studies (39%) and 81% of these studies were published in the last four years (2016–2019) (Figure 1).

In relation to the methodology used in the analysis of scenarios in other spatial scales, it is noteworthy that although the dynamic spatially-distributed models remained the most common method, their use was not as major as in the case of the analysis of land use change scenarios in

watersheds (Table 1). The spatial statistical models rose to 59% in the articles analyzing the synergistic effects of land use change and climate change (Table 2).

Table 2. Models classification applied in the analysis of land use change scenarios in other spatial scales to watershed.

Models Classification	Number of Total Articles in Other Spatial Scales to Watershed	Number of Articles of Land Use Change and Climate Change Jointly Analyzed in Other Spatial Scales to Watershed	Number of Articles of Synergistic Effects of Land Use Change and Climate Change in Other Spatial Scales to Watershed
Non-spatial statistical model	26	4	0
Spatial statistical model (e.g., GIS)	26	11	10
Aggregated dynamic model	1	0	0
Dynamic spatially distributed model	72	24	7
Other methodologies	26	4	0
Total	151	43	17

Unlike the analysis of land use change scenarios in watersheds, most of these publications in other spatial scales assessed other environmental effects (87%) compared to the effects of hydrological dynamics (9%) and nutrients (3%). The consideration or lack thereof of climate change did not substantially alter the type of effects analyzed. The approach for the analysis of scenarios in other spatial scales was totally sectorial and cases studies were not analyzed within the social-ecological framework. Overall, 95% of articles studying other environmental effects on scenario analysis did not take into account the effects on the hydrological dynamics and nutrients.

The participation of stakeholders in the process of building land use change scenarios was only collected in twelve articles (Table 3) and 50% of these articles have been published recently—in the last four years (2016–2019). Most of the articles (95%) developed land use scenarios with researcher-driven approaches [4,28–33], where the experts drove scenario development with an objective of providing rigorous descriptions of plausible futures, including details that are well supported by available science.

Table 3. Articles with a participatory approach in the land use change scenarios development.

References	Spatial Scale	Land Use Change and Climate Change Jointly Analyzed	Synergistic Effect of Land Use Change and Climate Change	Methodology to Study LUC	Effects on Hydrological Dynamic	Effects on Nutrients Dynamic	Other Environmental Effects
Mancosu, E. et al. 2014 [34]	Catchment	YES	NO	Dynamic spatially distributed models	YES	NO	NO
Harmáčková, Z.V. and Vacka, D. 2015 [18]	Basin	NO	NO	Dynamic spatially distributed models	NO	YES	YES
Ronfort, C. et al. 2011 [35]	Watershed	NO	NO	Dynamic spatially distributed models	YES	NO	NO
Rickebusch, S. et al. 2011 [36]	Regional	NO	NO	Spatial statistical model	NO	NO	YES
Castella, J.C., Verburg, P.H. 2007 [37]	Local	NO	NO	Dynamic spatially distributed models	NO	NO	YES
van Noordwijk, M. et al. 2001 [38]	Local	NO	NO	Dynamic spatially distributed models	NO	NO	YES
Kim, Y.S. et al. 2018 [39]	Local	NO	NO	Dynamic spatially distributed models	YES	NO	YES
Lippe, M. et al. 2017 [40]	Local	NO	NO	Dynamic spatially distributed models	NO	NO	YES
Sherrouse, B.C. et al. 2017 [41]	Local	NO	NO	Spatial statistical model	NO	NO	YES
Benini, L. et al. 2016 [42]	Basin	YES	YES	Dynamic spatially distributed models	YES	NO	NO
Trisurat, Y. et al. 2016 [43]	Watershed	YES	NO	Dynamic spatially distributed models	YES	NO	NO
Min, F. et al. 2016 [44]	Watershed	YES	NO	Dynamic spatially distributed models	YES	YES	NO

4. Discussion

The interest of current studies of land use change, beyond a mere descriptive representation in form of maps analysis, focuses on a more dynamic modeling for understanding the past, monitoring the current situation, and predicting future trajectories [45,46]. The review conducted confirms this and shows that there are numerous models of land use that allow us to explore the dynamics of changes and analyze future scenarios that may be useful to support land use planning and policy development [15,47,48]. In the following subsections, we return to the questions posed in the Introduction.

4.1. Extent to Which the Environmental Dynamics of Land Use and Climate Change Were Analyzed Jointly and Spatial Scales Associated with Such Integrated Studies

The results of the review show that although many papers have analyzed the dynamics and influence of land use change, e.g., [34,49–51] or climate change, e.g., [52–55] on a particular natural or social-ecological system, the papers that jointly assess both environmental processes are less frequent and very recent (past decade, Figure 1), particularly those that analyze its synergistic effect, e.g., [4,33,56–58]. The evolution of the number of articles on land use change over time has had an upward trend in the past two decades (Figure 1) and more than half of the articles that also take into account climate change analysis have been published in just the last six years of the analyzed period (Figure 1) [33,59]. Therefore, this joint assessment is still fairly recent in spite of scientific reports, such as the Science plan of the Global Land Project [60], which in 2005 highlighted its importance for the sustainable management of social-ecological systems. The scientific literature in this review has demonstrated that the combined effect is much greater than the individual effects, with examples in water resources and the hydrological dynamics. Publications such as Chung, E.S. et al. 2011 [61]; Lopez-Moreno, L.I. et al. 2013 [62] and Mehdi, B. et al. 2015 [3] made the case that the environmental synergistic impact of both environmental processes is much greater than the sum of individual impacts.

The joint study of land use change and climate change varies according to the spatial scale of analysis. In watersheds, it has been taken into account in almost half of the reviewed articles (Figure 1), and half of these also assess the synergistic effect of both environmental processes, especially on the hydrological dynamics and water resources of the watershed [3,29,33,63,64]. When analysis is made in other spatial scales, the analysis with climate change only constitutes a quarter of the reviewed articles. Of those articles, the interaction and the synergistic effect of both environmental processes is evaluated in 39% of the articles [32,33,65–67]. As already noted in [68], the synergies between land use change and climate change are insufficiently addressed. Moreover, recent publications emphasize the importance of assessing the synergistic effect of both, climate and land use change processes at sub-global scales [4,32,33,62].

On the other hand, watersheds are a perfect example of a socio-ecological system [69,70]—dynamic, open and complex, in which its biophysical components are combined with the characteristics of economic systems, and the demographic patterns and sociocultural dynamics of the population that inhabits them. To address the inherent complexity of SES, an integral approach is required [71]. However, despite the increasing acknowledgment of the need for holistic approaches, the results in this review point out that their application in real socio-ecological systems is less frequent than would be desirable.

In relation to the scale of analysis, land use changes have direct effects on important components of sustainability, such as the connectivity of natural areas or biodiversity within the territory/landscape, attributes which can be studied at multiple spatial scales [66,67]. However, relative to a territorial analysis using administrative boundaries as study unit, the application of ecological and other functional criteria as units of analysis, within watersheds, promotes the integration of goods and services produced by ecosystems [72–74]. Apparently for this general reason, watersheds were the dominant spatial scale of analysis, used in nearly half of the reviewed articles (Figure 1). Although in the last two years (2018 and 2019) the analysis of watersheds decreased lightly, we can point out that

the watershed is considered the most successful spatial scale for integrated management of natural resources, especially water [75]. In this regard, it should be noted that only a small percentage of reviewed publications in other spatial scales analyze the effects of land use changes on water resources, corresponding, in some cases, with islands [76,77], possibly because the islands are also units with well-defined natural limits and where land use change effects can be easily recognized in the whole system, including water resources [78,79].

However, using the watershed as a spatial scale and as a social-ecological system not only allows addressing resources such as water and land within an optimum geographical context, but also provides a spatial framework for the integration of relevant biophysical aspects with socio-economic aspects [18,80]. In fact, the analysis of land use change and all the direct and indirect effects that result may not be so obvious depending on the spatial scale of the analysis.

There are indirect effects of land use change that are only disclosed at a watershed scale [81]. Indeed, among the direct effects of land use change are included the alteration of water flows, alteration which in turn results in indirect effects on other components such as aquatic ecosystems, natural spaces, maintaining wetlands or biodiversity. For example, cases studies such as the Mar Menor social-ecological system (SE, Spain) show how land use changes, particularly the increased irrigation in the watershed, have increased water and nutrient flows into the Mar Menor lagoon and its wetlands. This high input of nutrients into the lagoon has caused serious ecological impacts on the species and habitats, the loss of the traditional transparency of the waters, and important damages to the tourist quality and other ecosystem services [81–84].

These indirect effects are barely addressed by our reviewed scientific literature, although we can highlight the work of Santos, R.M.B. et al. 2015 [57], which uses a range of scenarios to evaluate the impact of land use and change and climate change on the conservation of a species, the mollusc *Margaritifera margaritifera*, which depends on specific river flows and depth conditions. Instead, most of the case studies of our reviewed scientific literature analyze the direct effects, such as the hydrological ones, but not the indirect effects that these hydrological effects cause on other components such as the biodiversity. Therefore, the indirect impacts remain underestimated or not considered.

Furthermore, the analysis of watersheds as a social-ecological system implies having an integrated knowledge of the relationships between its natural and social components. Farhad, 2012 [85] points out that only a multidisciplinary analysis can jointly conceive these different natural and social aspects, focusing not only on the components of the system, but also on their relationships, interactions and feedbacks, thus having a deeper understanding of the system. Interactions in social-ecological systems are continuously changing due to feedbacks and internal or external factors (e.g., land use change and climate change), taking place across different temporal and spatial scales, making social-ecological systems highly dynamic systems [10]. The approach of the analysis of watershed in this review confirms that the holistic approach and its application in social-ecological systems has not been applied in most cases. Among the difficulties behind this, the need for a new conceptual perspective concerning the relationships between science and the management of real social-ecological systems, as well as the lack of tools to manage the inherent complexity of such systems, should be emphasized. However, to manage complex socio-ecological systems using partial approaches or linear causal thinking may provide unrealistic or, at least, questionable results [86].

4.2. Modeling Methodologies and Approaches Used in the Scenario Analysis

In relation to the methodology, there are differences depending on the spatial scale of analysis. The analysis of land use change scenarios at the watershed scale is made with dynamic spatially distributed modeling in more than 80% of the articles (Table 1). Among these models, hydrological models are the most used, particularly the SWAT model (Soil and Water Assessment Tools), because of the wide variety of environmental conditions that may be applied [64,68]. In other spatial scales, dynamic spatially distributed models remain the most common, but not as common as watersheds, also spatial statistical models (e.g., GIS) are often applied (Table 2). The approach of dynamic spatially

distributed models is generally sectoral (discipline-specific) in any of the spatial scales, especially in the different spatial scales to watersheds. In watersheds, this approach focuses on the effects that land use change has on the hydrological functioning of the watershed, such as water flows [45,87,88] and nutrients [89,90], which in turn translate into changes on different subsystems of the watershed (drainage, aquifers, wetlands, river, lake or final receiving system of water flows).

In publications focusing on different spatial scales to the watershed, the sectoral approach focuses on other environmental effects such as loss of biodiversity and ecosystem services [51,91,92]. The trend in the use of dynamic spatially distributed models has been rising throughout the analyzed period, principally within the last decade. The use of dynamic spatially-distributed models that integrate across disciplines is increasingly recognized to be an informative approach to best understand and evaluate trends of socio-ecological dynamics under a range of future scenarios, with examples of such research/modeling goals in the Everglades, USA, watershed [93], and more broadly with respect to the integration of social and ecological processes across a range of scales to better simulate land use changes in general [94]. While NRC 2014 [94] provides a comprehensive suite of recommendations, we note that their review did not explicitly address the range of uncertainties and complexities associated with climate change.

Dynamic models, unlike statistical models, can conceptualize the complex interrelationships that characterize social-ecological systems and to facilitate their understanding and monitoring [95,96]. Furthermore, dynamic spatially distributed models with integrated approaches have the advantage of being able to integrate different processes, scales, variables, and the possibility of generating configurations with stakeholders within the framework of participatory modeling processes [88]. This becomes a potential for interdisciplinary planning and management processes in SES, particularly for the support decision-making processes at the local level. However, in this review, we can highlight few cases using dynamic spatially distributed models for integrated approaches [57,97–100].

4.3. Methods for Developing or Building Scenarios

Regarding the development of land use change scenarios, some studies [23,101,102] point out that scenario planning in environmental research and the management of natural resources has become more participatory. However, in this review, just 4% of the articles apply a participatory approach in the development of land use scenarios [18,43].

In many articles of this review, scenario creation is expert- and/or model-driven, and researchers make the case for their utility to end users [33,45]. This is problematic in a case with high stakes and high uncertainty, as with land use [24]. Westervelt, J. et al. 2011 [103] point out that decision makers often prefer their own judgment to model results, highlighting the need for a model to be transparent and simple. However, using a participatory approach can partly relieve this issue. Stakeholder and public participation legitimize the process and justifies the use of the outcomes for planning and decision-making [23]. Reed et al. 2013 [104] point out that participatory scenario development has the potential to make scenarios more relevant to stakeholder needs and priorities, extend the range of scenarios developed, develop more detailed and precise scenarios through the integration of local and scientific knowledge and move beyond scenario development to facilitate adaptation to future change.

A key issue in scenario-building methods is the integration of stakeholder-derived qualitative data (typically in the form of a storyline) into models that require quantitative data to produce the final output [105]. Still, these participatory approaches are rarely spatially explicit, making them difficult to apply. Walz et al. 2007 [106] point out several drawbacks and limitations of stakeholder participation in scenario development. For example, local knowledge is not always sufficiently robust or detailed enough to provide information about relationships between system components, necessary for scenario quantification. Reed et al. 2013 [104] highlight that effective stakeholder participation in scenario development is likely to take extra time and resources, requiring integrating diverse types of knowledge, and the success of this participation is likely to depend on the quality of the process design and effective representation of stakeholder interests.

All these limitations could explain the low percentage of land use scenarios with participatory approach in this review. Therefore, Booth et al. 2016 [107] and Mallampalli et al. 2016 [108] highlight that applications of land-use scenario processes are still in the early stages of learning how to effectively combine stakeholder and scientific (model-based) inputs. Participatory scenario development still requires greater systematic monitoring and evaluation to assess its impact on the promotion of collective action for transitions to sustainability and the adaptation to global environmental change and its challenges [101]. However, involving stakeholders in scenario development can bring significant benefits to both stakeholders and researchers, leading to the development of more consistent and robust scenarios.

4.4. Recommendations for the Future

Based on results from this review we identify the following issues that we think need to be addressed in the study of land use change scenarios on natural and social-ecological systems: (1) to work in the complex interface of ecological and social systems, which is where policies concerning land use are developed. In turn, this involves integrating the social and natural sciences, and there is a growing agreement that transdisciplinary research is a key approach in facing environmental challenges. Hence, there is a need to expand the boundaries of the studied cases towards the social-ecological systems, (2) to integrate multiple processes and driving forces such as climate change, operating at different spatio-temporal scales, (3) to develop models to apply integrated approaches incorporating biophysical and socioeconomic factors and (4) to promote participatory approaches in the scenario development, integrating both types of knowledge, scientific and local. Progress in these deficiencies could improve the use of predictive tools in decision-making processes to contribute to sustainability goals.

5. Conclusions

In recent decades, there has been a breakthrough in the development of models to simulate land use change at different spatial scales and under different future scenarios, covering issues such as the expansion of agriculture, abandonment of farmland, deforestation, as well as growth and urban sprawl, among others. However, the papers that assess land use change jointly with climate change are less frequent and very recent, particularly those that analyze their synergistic effect.

Land use change and climate change are two main components of global environmental change that must be analyzed jointly. Recent research confirms and emphasizes the importance of assessing the synergistic effect of both processes, since it has been demonstrated that the combined effect is much greater than the individual effects. This issue is still insufficiently addressed by the reviewed scientific literature, although an upward trend has recently been observed in the number of publications, with some variation depending on the spatial scale of analysis.

The results presented also confirm that the analysis of land use change and its direct and indirect resulting effects may not be as obvious, depending on the spatial scale of analysis. The direct effects of the connectivity of protected natural areas and biodiversity within the territory/landscape can be analyzed at a variety of spatial scales, whereas the direct effect on water resources and the indirect effects they generate on other important components of sustainability, such as aquatic ecosystems, natural areas, maintenance of wetlands, biodiversity and ecosystem services, are only revealed at the watershed scale. In addition, watersheds are social-ecological systems that offer two other advantages: they favor the integration of goods and services produced by ecosystems and provide a spatial framework for the integration of relevant biophysical aspects with socio-economic aspects.

From our review, we saw that a common methodology used to analyze land use change scenarios and their impacts on different territorial units is that of dynamic spatially distributed models.

Overall, the models use a sectoral approach, focusing primarily on the study of hydrological dynamics, in the case of watersheds, and other possible environmental effects, such as loss of biodiversity, in the case of other different spatial scales. In this regard, it is necessary to promote more integrated approaches through models incorporating biophysical and socioeconomic factors

and also to take into account land use change, climate change and their synergies. The development and application of methodologies for integrated modeling will certainly help develop such a systemic integrated knowledge of the territory. This will facilitate the understanding of the implications of land use changes not only in the functionality of the watershed, but also in other aspects of sustainability.

Finally, in spite of the fact that the literature reviewed does not show many articles with a participatory approach in land use change scenario development, this approach can be a useful and powerful tool to facilitate the sustainable management, because such approaches draw on multiple sources of knowledge to accurately describe complex social-ecological processes and because stakeholder participation can yield more effective and resilient decisions. Active involvement of the wider stakeholder community can play a crucial function in the better consideration of problems by identifying different stakeholder perspectives, provide an active learning arena for all those involved, and offer the interactive basis necessary for generating joined-up thinking.

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