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ORIGINAL ARTICLE

ScenaLand: a simple methodology for developing land use and management scenarios

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Abstract
Scenarios serve science by testing the sensitivity of a system and/or society to adapt to the future. In this study, we present a new land use scenario methodology called ScenaLand. This methodology aims to develop plausible and contrasting land use and management (LUM) scenarios, useful to explore how LUM (e.g. soil and water conservation techniques) may affect ecosystem services under global change in a wide range of environments. ScenaLand is a method for constructing narrative and spatially explicit land use scenarios that are useful for end-users and impact modellers. This method is innovative because it merges literature and expert knowledge, and its low data requirement makes it easy to be implemented in the context of inter-site comparison, including global change projections. ScenaLand was developed and tested on six different Mediterranean agroecological and socioeconomic contexts during the MASCC research project (Mediterranean agricultural soil conservation under global change). The method first highlights the socioeconomic trends of each study site including emerging trends such as new government laws, LUM techniques through a qualitative survey addressed to local experts. Then, the method includes a ranking of driving factors, a matrix about land use evolution, and soil and water conservation techniques. ScenaLand also includes a framework to develop narratives along with two priority axes (contextualized to environmental protection vs. land productivity in this study). In the context of this research project, four contrasting scenarios are proposed: S1 (business-as-usual), S2 (market-oriented), S3 (environmental protection), and S4 (sustainable). Land use maps are then built with the creation of LUM allocation rules based on agroecological zoning. ScenaLand resulted in a robust and easy method to apply with the creation of 24 contrasted scenarios. These scenarios come not only with narratives but also with spatially explicit maps that are potentially used by impact modellers and other end-users. The last part of our study discusses the way the method can be implemented including a comparison between sites and the possibilities to implement ScenaLand in other contexts.

Keywords Land degradation · Land use and management scenarios · Narrative · Experts · Soil and water conservation techniques

1 Introduction

Land degradation (LD) is recognized as a global environmental problem (Lal 1995, 2003). It is defined as a natural or human-induced process that negatively affects the land to function effectively within an environmental system and can be defined as a process of degrading land from a former state (Zorn and Komac 2013). Recent studies also show that earth-tipping points are closer to their limits and LD has accelerated due to anthropogenic pressures on natural resources including soil and water (Rockström et al. 2009; Steffen et al. 2015; Olsson et al. 2019; Gerten et al. 2020). Recently, LD was made a priority by the United Nations (UN) with the Sustainable Development Goal 15 "Life on land", the Land Degradation Neutrality (LDN) program (Gilbey et al. 2019), and the UN decade on ecosystem restoration program (2021–2030) (Dubey et al. 2021). In the Mediterranean region, severe LD can impede productive agriculture development (Borrelli et al. 2016; Panagos et al. 2015; Raclot et al. 2018) which is likely to be exacerbated by climate change (Lagacherie et al. 2018; Borrelli et al. 2020). Traditionally, farmers used soil and water conservation (SWC) techniques for land and soil preservation (Bocco 1991; Gessesse et al. 2009; Sartori et al. 2019) commonly known as "indigenous knowledge" of soil management (Critchley et al. 1994; Makondo and Thomas 2018). Besides, SWC techniques were proven to help mitigate and adapt ecosystems and related ecosystem services to climate change (Delgado et al. 2011; Lal 2014). As shown by Rattan Lal (2014), maintaining fertile soils and/or restoring eroded soils through soil conservation measures have multiple benefits on ecosystem services such as increasing water, carbon, and nutrient storage in the soil, increasing soil biodiversity, and contributing to climate change mitigation. For instance, Panagos et al. (2015) show that SWC techniques such as cover crops, crop residue restitution, and reduced-tillage practices can decrease soil erosion by 19% in the Mediterranean context. However, with the intensification of agriculture, these techniques have been often neglected despite their proven efficiency in soil conservation (Prosdocimi et al. 2016).

Sustainable soil management requires understanding the biophysical and socioeconomic drivers of LD, and better forecasting approaches for land use/management changes (Kok et al. 2006; Terranova et al. 2009; Cerdan et al. 2010; Raclot et al. 2018). Environmental impact studies were developed to assess the impact of anthropogenic practices on the Earth system and the resilience of a system and/or restore this system to "acceptable" and/or better conditions (Jay et al. 2007). For that, scenarios are a useful way to evaluate potential future developments and/or assess potential risks and catastrophic events at different spatial and temporal scales (Kriegler et al. 2012). Additionally, they form an innovative basis to help scientists and policymakers to prepare long-term planning strategies under a wide range of plausible futures. Scenarios were initially used in military planning and gaming and were then taken over by business and environmental planners (Moss et al. 2010). In the 1960s, businesses and organizations used scenarios to explore windows of opportunity and plan long-term investments. Then, scientists started to use scenarios for impact studies. For instance, "A socioeconomic scenario is a combination of quantitative projections and qualitative information such as narratives that jointly characterize a plausible future" (Kriegler et al. 2012). Kok et al. (2006) showed that the involvement of stakeholders improves the quality of developed scenarios, especially in the design of narrative scenarios and in the tasks of identifying past and future socioeconomic trends. Besides, land use and management techniques are often site-specific and depend on pedological and climatic conditions;

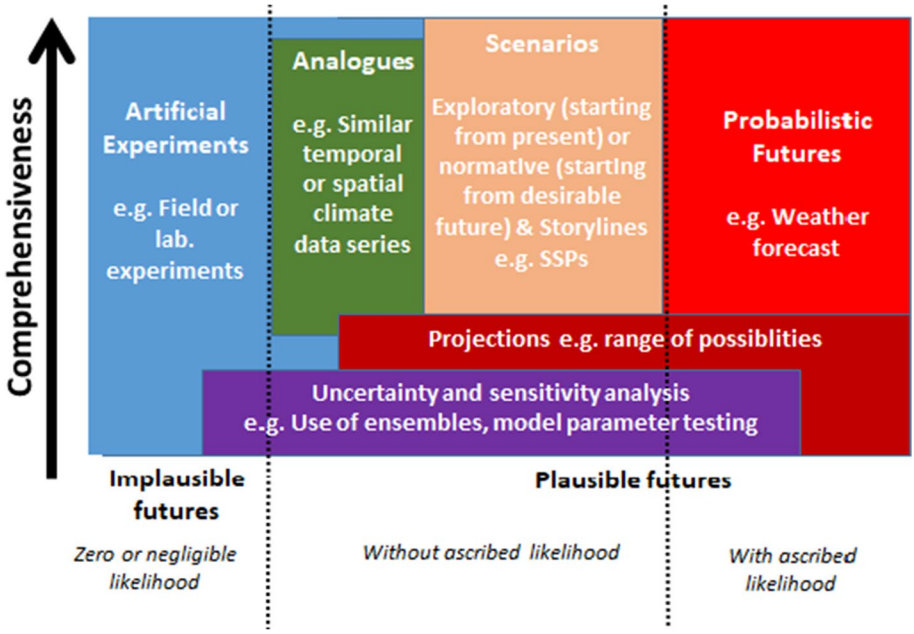

Fig. 1 Characterization of the level of comprehensiveness of implausible and plausible futures (Adapted from Parry et al., 2007)

thus, it is important to involve stakeholders to achieve a satisfactory scenario design and implementation (Keizer and Hessel 2019).

Scenarios are described as plausible futures with a high level of comprehensiveness and without an ascribed likelihood (Fig. 1). Comprehensiveness represents the level of understanding of the biophysical and socioeconomic system, while likelihood represents the probability of occurrence (Parry 2007). Figure 1 shows that scenarios are set with a high level of comprehensiveness and within the scope of plausible futures without ascribed likelihood. Scenarios are different from probabilistic futures, which are based on ascribed likelihood. Narratives are useful for designing scenarios because they allow stakeholders to contextualize a plausible future with a high level of comprehensiveness of the future environmental and socioeconomic characteristics. According to Fauré et al. (2017), three types of scenarios exist: predictive ("what will happen?", "how specific drivers develop, extrapolation of future, business-as-usual (BAU)), explorative[1] ("what can happen?", identify qualitative drivers, strategic scenarios, forecasting), and normative[2] ("what should happen?", how a specific end-point and/or desirable future can be reached, backcasting). Many environmental impact studies use a mix of these types of scenarios to explore desirable and undesirable futures under global change (Kok et al. 2007, 2018; Kok and van Delden 2009).

[1] Normative scenario = organized attempts at evaluating the feasibility and consequences of trying to achieve certain desires or risks to avoid.

[2] Exploratory scenario = "what if" theory is explored.

On a global scale, climatic and socioeconomic scenarios are usually designed with the Representative Concentration Pathways (RCPs) for plausible greenhouse gases emissions and the Socioeconomic Shared Pathways (SSPs) for exploring socioeconomic global trends such as population rise, gross domestic product (GD) evolution, and consumer preferences (van Vuuren et al. 2011; O'Neill et al. 2015). Each of the SSPs contains a storyline or a narrative (Van Vuuren et al. 2011) and their combination has been set with the recent accomplishment of CMIP6 climate and SSP datasets (O'Neill et al. 2016; Hurtt et al. 2020). At the regional scale, SSPs can be downscaled and contextualized according to the local socioeconomic context, and climate change scenarios can be downscaled with various statistical and numerical methods from global climate models (GCMs) to regional climate models (RCMs) and validated with local climate measurements (Maraun 2016). For example, the European scale project IMPRESSIONS (Impacts and Risks from high-end scenarios: Strategies for innovative solutions) has been successful to design regional-scale scenarios and to involve stakeholders from more than four European countries (Kok et al. 2019).

While climate scenarios are often used in a wide range of environmental projects, SSPs require some regional hypothesis to address a specific environmental problem at a local scale. For example, exploring different agricultural management and soil conservation techniques might be out of the scope of the SSPs. If SSPs were used to test land management techniques, it would require organizing stakeholder workshops to build a hypothesis of land management behind each SSPs, which could be time- and resource-consuming at an early stage of exploration. Moreover, in regions where stakeholders have been overstretched, there might be a "stakeholder fatigue" that leads potentially to the failure of the project (Gramberger et al. 2015). Therefore, impact studies can create their own land use scenarios to explore in a short time the possible landscape evolution (Bracken et al. 2015). Scenarios are often used to feed impact assessment models, integrated assessment models (IAMs), and climate change impacts, adaptation, and vulnerabilities (IAVs) frameworks (Swart et al. 2004). Thus, while scenarios of climate change and socioeconomics are harmonized on the global scale (Hurtt et al. 2020), regional scenarios are difficult to downscale and often need bottom-up readjustments with statistical downscaling techniques (e.g. climate downscaling) and/or by organizing stakeholder workshops to gain knowledge and expertise on a specific site. However, there is a lack of methods and studies allowing the creation of robust local and regional scenarios with low data and input resources (Goodspeed and DeBoskey 2020). Therefore, there is a need for a simple and robust approach that can help scientists design plausible land use scenarios, including improved land use management in a systematic way.

This study aims at developing "plausible" scenarios based on expert knowledge within realistic socioeconomic contexts within the frame of the Mediterranean agricultural soil conservation under global change (MASCC)[3] project. The narrative scenarios and related quantitative inputs created with the method developed in this study named "ScenaLand" provide input for subsequent modelling works such as in the study of Pastor et al. (2019) with the use of an impact erosion model "LandSoil" (Ciampalini et al. 2012, 2017). The specific research question was: "How to create plausible scenarios within a multi-site context to explore future impacts of global change on ecosystem services including soil and water conservation within constrained time and resources?" A comparison between

[3] Mediterranean agricultural soil conservation under global change: https://mascc-project.org/

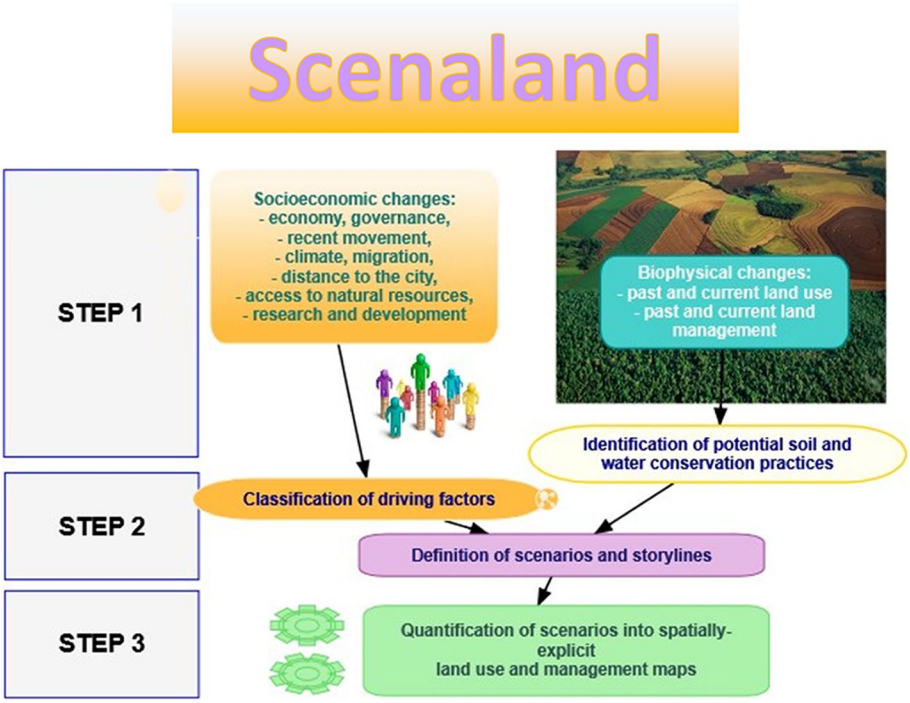

Fig. 2 Methodological flowchart of ScenaLand

different Mediterranean agroecosystems with contrasted socioeconomic contexts was carried out, and future impacts of climate change, LUM change, and soil conservation techniques were explored. The aim was to produce four land use narratives and scenarios in six study sites using the ScenaLand methodology. Finally, with the outcome of the ScenaLand method, an inter-site comparison of the evolution of LUM has been conducted. The novelty of the ScenaLand method is that (i) it provides qualitative information (narratives) based on expert knowledge and literature review, (ii) it comes up with explicit quantitative inputs for LUM for impact modellers (end-users), and (iii) it provides a common framework to takes into account site-specific characteristics to facilitate the inter-site comparison of similar SSPs (or trajectories).

2 Materials and methods

2.1 Description of ScenaLand methodology

ScenaLand is a methodology that provides contrasted scenarios to evaluate the impact of global change. ScenaLand is applied using the following steps: the first step allowed identifying the socioeconomic and biophysical drivers of change; the second step consists on developing a narrative per scenario and per site with the experts; and the last step comprises the construction of LUM maps for each study site based on spatial

Table 1 Description and ranking variables of socioeconomic trends (survey 1)

Driving factors	Description
Economy	Influence of international market on local production
Access to natural resources	Soil, water for irrigation, energy constraints, topography
Governance	National and local policies, subsidies, etc
Recent movement	Any recent economic or social activity that changed the dynamic of the region
Climate	Temperature, rainfall constraints
Migration/distance to the city	Is the distance to the city a limitation to local economic development?
Research and development	University and NGOs promoting, transferring and collecting knowledge on-site

allocation rules (Fig. 2). Land use and management practices have been incorporated in the scenarios in steps 2 and 3. The common framework is based on two (or more) axes such as environmental protection and/or socioeconomic dimensions to explore a specific research question. To achieve that, each step is addressed by a questionnaire that should be answered by a minimum of three local experts either individually or in groups. Experts are represented by local scientists and/or representatives of local public and/or private institutions. Additionally, a facilitator is designated to moderate the debate and take notes. At the beginning of the exercise, the group agrees on the facilitator who will complete the questionnaire. This method is illustrated in Fig. 2 and in the 3 section and Appendix A-B-C.

2.1.1 Step 1: Socioeconomic context and biophysical changes

Step 1.1. Identification of socioeconomic and biophysical key drivers This step draws on socioeconomic analysis for each study site in the last 50 years to identify socioeconomic trends and biophysical changes (Kriegler et al. 2012). Then, a description and ranking of seven driving factors is conducted with the local experts (Fig. 2, Table 1). This classification allows for an in-depth discussion of the socioeconomic context and an inventory of the emergent facts and plausible futures.

Concerning the reference to the ranking, each stakeholder has to classify the different categories to answer the question: "What are the dominant/slowing factors driving your CS?" This ranking is not necessarily important in the quantitative answer but rather to start a discussion on the socioeconomics drivers of the region with the stakeholders.

Step 1.2. Land use and management evolution In this step, an analysis of the land use evolution is carried out including abandoned and emergent LUM from past and actual decades and their possible impacts on economic profit, food self-sufficiency, environmental impact and erosion, rate of abandonment, and a possible shift to another land use based on its biophysical tolerance (slope, soil type, etc.). Then, an analysis of the current and potential water and soil conservation practices is carried out for the rating of environmental benefits, the impact on erosion, and social acceptance. In this step, a weighing sign

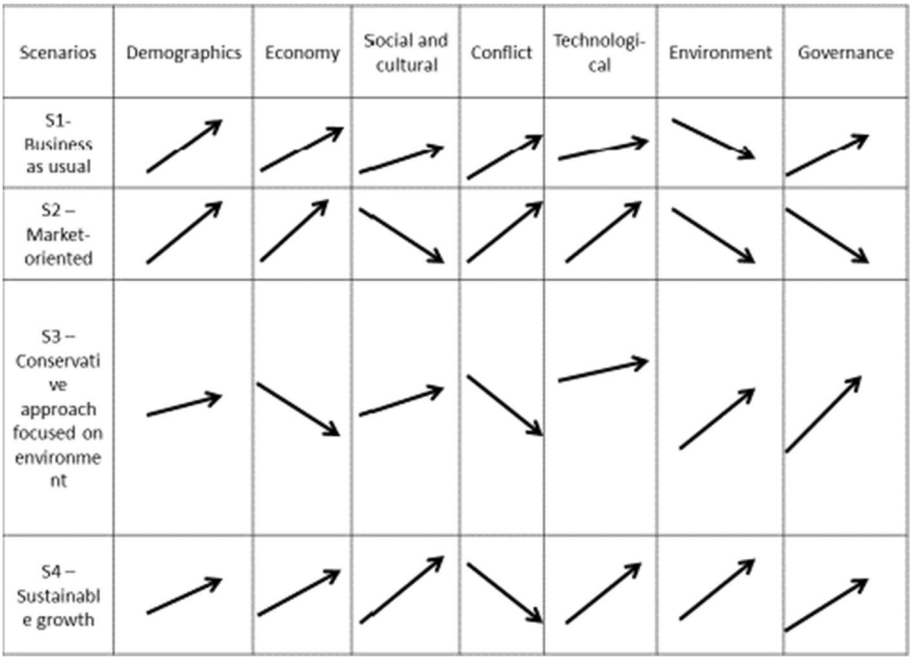

Fig. 3 Likely trends of development of indicators for each scenario ; TERI 2009 (Adapted from Kriegler et al. 2012

(–,-,=,+,++) was used to describe the evolution of one category over time (past (1990–2010)–present (2010–2020)–future (2020–2050)).

2.1.2 Step 2: Definition of four scenarios and narratives

This step consists of developing narratives and land use scenarios based on step 1.

Step 2.1. Construction of trends The driving factors of the current landscape are defined in this step to develop the business-as-usual (BAU) scenario based on historical and current trends and to create three other revolving contrasted narratives. The shift in socioeconomic and biophysical variables (demography, economy, social and cultural, technological, environment, and governance) is also described for each scenario (Fig. 3). Note that when the study is developed in multiple sites, the four scenarios must be replicated for each site.

Step 2.2. Construction of narratives This step consists of developing the four scenarios based on Kriegler et al.'s approach (2012; Fig. 3). Based on the trends developed in step 2.1, a concise narrative (within 300 words) is created for each of the four scenarios: S1 (business-as-usual), S2 (market-oriented), S3 (environmental protection), and S4 (sustainable). According to each local context, trends can be adapted after agreements between experts. In this step, the results of steps 2.1 and 2.2 are sent to local experts, so that the synthesis of the local trends and narrative scenarios can be validated.

2.1.3 Step 3. Land use maps creation

The last step consists of translating the narrative scenarios into spatially explicit land use maps including land management practices (tillage, SWC, etc.).

Step 3.1. Quantification of land use and management changes for each scenario and site In this step, based on the baseline land use map (S0), a trend evolution is defined for each land use (expressed as a percentage of surface area) corresponding to the narrative as well as to the degree of implementation of each SWC technique chosen by scenario.

Step 3.2. Creation of topographic zones Land use and management allocation rules and biophysical constraints based on soil type, slope, and field size are defined with a GIS-based system. Based on these constraints, allocation rules are created to optimize the allocation of land use and SWC techniques.

Step 3.3. Spatialization of land use maps for each scenario in each study site" In this last step, a consensus on the final land use surface and the implemented SWC is discussed and agreed upon with the local experts.

2.2 Implementation of the ScenaLand method to six case studies

The ScenaLand methodology was developed and applied in the framework of the MASCC (Mediterranean Agricultural Soils Conservation under global Change) project. This research project was developed to address soil erosion and degradation mitigation and adaptation strategies to global change in the Mediterranean region. This project is based on the study of six sites across six Mediterranean countries with different agroecosystems and socioeconomic contexts (Table 2 and Appendix A-B). Some sites can show similarities, for example, half of these sites are characterized by abandoned rural areas (Can Vila, Macieira, and Cannata), while the other half of the sites is having agricultural activity and urbanization pressure on agricultural land (Roujan, Kamech, and Tleta). More details on the MASCC project and related site descriptions can be found at https://mascc-project.org/study-sites and in Appendix A-B-C.

The aim of the MASCC project was to determine how LUM can be adapted to mitigate soil erosion in six study sites of the Mediterranean region, given the local constraints and the different levels of land profitability and environmental protection. The ScenaLand methodology was implemented in all MASCC sites except for the Tleta where step 3 was developed with a different methodology (Hérivaux et al. 2021). The scenarios were elaborated based on two axes: "socioeconomic development" and "environmental protection" to answer the research question of this study: "How to create plausible scenarios within a multi-site context to explore future impacts of global change on ecosystem services including soil and water conservation within constrained time and resources?" (Fig. 4).

In the frame of the MASCC project, Scenaland was applied with a participatory approach known as 'consultation approach' (De Vente et al. 2016). We have adapted the way the questionnaires was performed for each location, depending on the number of people available, and on the available time and resources. Each survey was performed in one of the official languages of the country in consultation with local experts and inhabitants. The surveys were sent in advance so that the local team had enough time to gather the

Table 2 Study sites description

	Roujan, France	Can Vila, Spain	Cannata, Italy	Macieira, Portugal	Kamech, Tunisia	Tleta, Morocco
Area (km^2)	0.92	4.17	1.3	0.94	2.63	178
Outlet coordinates (lat; lon)	43.5; 3.3	42.2; 1.8	37.7; 15.1	41.3; − 8.3	36.8; 10.9	35.9, − 5.4
Altitude (m)	300–400	1100–1650	903–1270	441–620	80–190	80–650
Climate (Koppen classification)	Mediterranean semi-arid (Csa – Mediterranean)	Mediterranean subhumid (Cfb – Oceanic)	Mediterranean semi-arid (Csa – Mediterranean)	Mediterranean humid (Cfb – Oceanic)	Between Mediterranean semiarid and sub-humid (Csa – Mediterranean)	Between Mediterranean semiarid and sub-humid (Csa – Mediterranean)
Mean annual precipitation (mm)	628	850	715	1300	645	690
Aridity index (FAO classification)[a]	Dry subhumid (0.5–0.65)	Humid (> = 0.65)	Semi-arid (0.2–0.5)	Humid (> = 0.65)	Semi-arid (0.2–0.5)	Dry subhumid (0.5–0.65)
Land use activity	Traditional vineyard and wine production	Mountainous abandoned terraces in state of natural afforestation	90% permanent pasture	Land cover dominated by commercial forest, pasture and croplands	Land cover dominated by cereal cropland (75%), in rotation with leguminous crops	Land cover dominated by annual crops and olive trees (50%), matorral and forest (35%)
Actual socioeconomic trend	Pressure on land due urbanization but strong identity and competitivity of local regional wines	Low population and agriculture activity but increase in agro-tourism activities	Abandoned pasture with an incentive from the government and PAC subsidies to increase conservation agriculture	Low agriculture production. High production of short-rotation pines but with a new tendency to change commercial (planted) short-rotation forest to conservation forest as part of the forest burned	Intense agricultural activity due to the policy incentive to make Tunisia a self-sufficient country	Intense agricultural activities for subsistence

Table 2 (continued)

	Roujan, France	Can Vila, Spain	Cannata, Italy	Macieira, Portugal	Kamech, Tunisia	Tleta, Morocco
Mean interannual sediment yield (t ha^{-1} yr^{-1})	1	88.10–6	1	~0.1 t ha^{-1} yr^{-1}without fire, 0.2 t ha^{-1} $year^{-1}$ with fire. (erosion in burnt area represents 8 and 14 t ha^{-1} $year^{-1}$)	15	29
Reference	Molenat et al. 2018	Llorens et al. 2018	Licciardello et al. 2019	Nunes et al., 2020; Nunes et al. 2018a, b	Molenat et al. 2018	Hammouda 2010

[a]Aridity index: http://www.appsolutelydigital.com/DataPrimer/map72.html?referrer=Baker

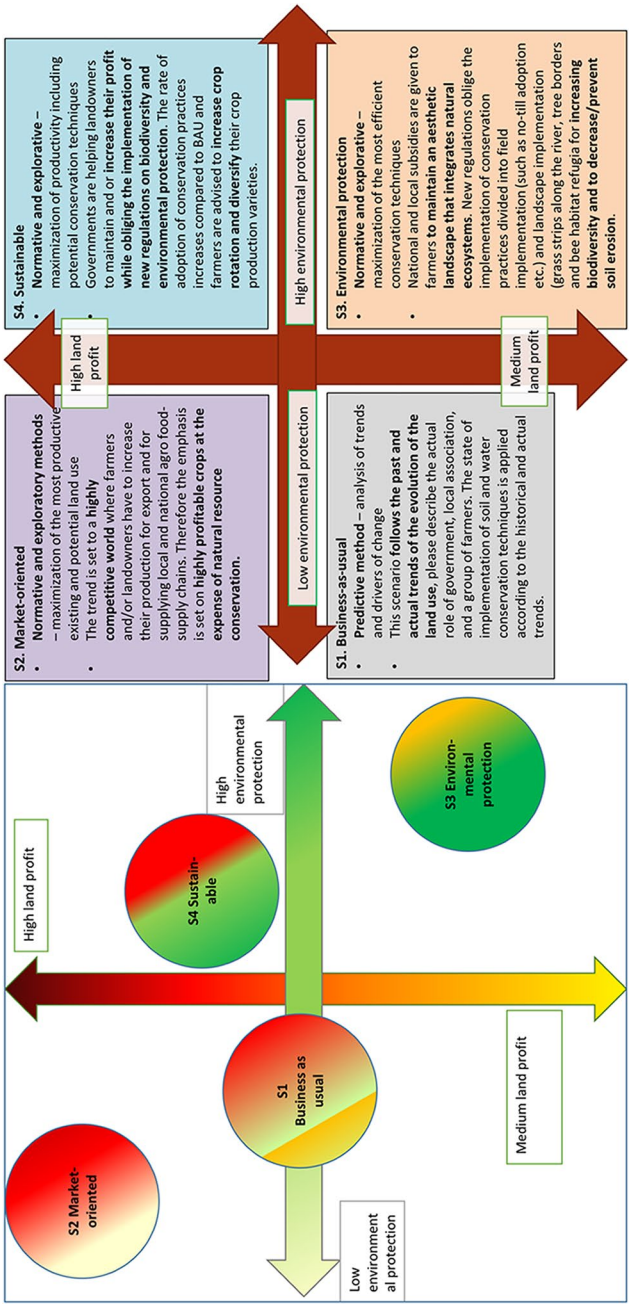

Fig. 4 Research axes of MASCC project surrounding the four narratives with the description of storylines

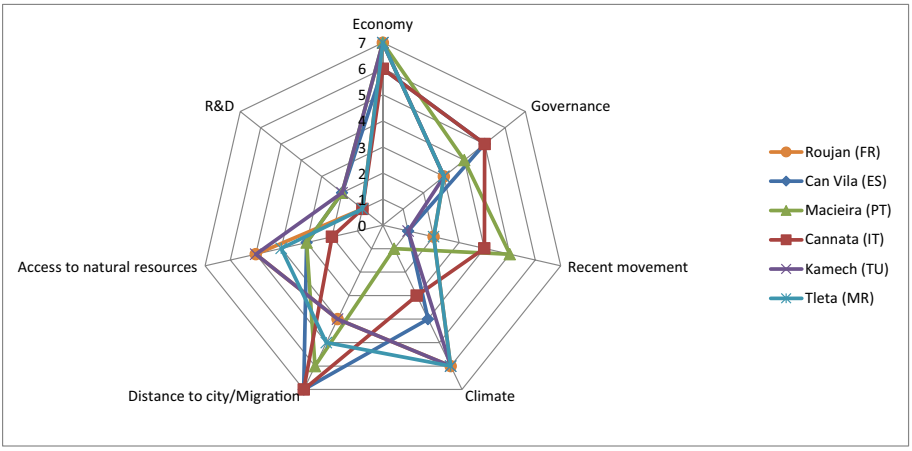

Fig. 5 Spider diagram of landscape evolution per study site with the highest ranking given to the factor that influences most the landscape according to local experts

necessary information to complete the survey on the day of the meeting between the coordinators of the project and the local team.

To illustrate our methodology, we include in the supplementary material:

- The synthesis of the participatory approaches used in each CS
- The synthesis of all the sites for survey 1
- An example of survey 1 to illustrate Macieira CS

For each CS, once survey 1 was completed, we asked the local partners to continue with the second survey to develop the narrative and land use maps scenarios for 2050. The synthesis of the elaboration of narrative and land use trends can be found in the supplementary material "survey 2 Document scenario Macieira.docx" as an example of our methodology. The detailed MASCC meetings and programs are also presented in the supplementary material.

3 Results

3.1 Step 1: Socioeconomic and biophysical contexts

A summary of the main driving factors that influence the landscape of each study site is presented below and in Appendix C. The description and the choice of each socioeconomic factor were presented in section 2 section and in Table 1. The overall results from the socioeconomic trends (Fig. 5) show that the dominant driver is "economy", especially in Roujan and Macieira sites where the value of agricultural lands or forestland is high for wine and wood production, respectively. Strong governance policy and incentives have been applied in study sites where land is abandoned; for example, in Cannata, government incentives have enhanced economic development based on agriculture and/or agrotourism. Recent movements are also present in study sites with high land abandonment (Macieira and Can Vila), while in study sites with important agriculture production such

Table 3 Emergent facts and plausible futures in each study site (aggregated results from survey 1)

	Emergent facts	Plausible futures
Roujan (FR)	• Improved wine quality • Decreased number of wine-growers, increase surface per farmer • Urbanization	• Development of high-quality wines • Agro-tourism and ecotourism • Crop diversification (organic market gardening) • Desertification of winegrowers
Can Vila (SP)	• Out-migration to cities • Incentives for ecotourism (e.g. create internet access, EU incentive)	• Ecotourism
Cannata (IT)	• Ongoing migration to cities • Lack of transparency in authorization and funding distribution • Infrastructural delay	• Integrated farming systems (agriculture + forestry + pastoralism + services + ecotourism)
Kamech (TU)	• Outmigration to cities • Intention to develop ecotourism (Wi-Fi access, EU funds)	• Orchard production • Agro-tourism and ecotourism potentials
Tleta (MO)	• Outmigration to cities • Development of free zones and car industry	• Excessive urbanization close to roads • Plantation of fruit trees on sloping lands • Conservation of forest upstream the watershed
Macieira (PT)	• Creation of forest associations to manage the land sustainably and bring technical support to landowners	• Increasing agro-tourism • Production of local fruits and market gardening to supply nearby Agueda town

as Kamech and Roujan, recent movements have a lower influence because the agriculture production has a high cultural heritage (Roujan) or strong economic government measures have been implemented (e.g. fixed price of cereals in Kamech). The distance to the city/migration scores high in three out of six sites (Can Vila, Macieira, and Cannata), where most of the rural population migrated out of the rural area to find a job in nearby cities due to historical local agriculture and/or economic collapses. On the other side, in sites such as Roujan, Kamech, and Tleta, there is a clear benefit from being close to the cities, for example, with an increase in agrotourism in local agriculture demand by neo-rural inhabitants. However, crop diversification is limited in the Roujan and Kamech sites where climate and access to natural resources are the most limiting factors to grow new crops due to erratic rainfalls and shallow soils. Research and development (R&D) has an indirect role in most of the study sites as the impact of research on landscape and society is a long-term process. For instance, in France, a prospective study LACCAVE (long-term adaptation to climate change for viticulture and oenology) has been tested for the 2015–2018 period to study climate adaptation of vineyards in terms of future water management and choice of vineyard varieties; it starts now its implementation after approval by the government. In the Tleta, research has led to innovative irrigation techniques supported by public subsidies. While in Portugal, research is mainly centred actions to prevent fires and to develop post-fire conservation techniques (see Appendix C for detailed results from survey 1 on socioeconomic context).

Emergent facts and plausible futures described by the local experts as a basis for designing scenarios are summarized in Table 3. Three sites (Macieira, Can Vila, and Kamech) have been identified with a good potential development for ecotourism as a compromise between "economic profit" and "environmental protection" exists. In Roujan, a trend in increased wine quality and crop diversification is observed to improve the system's resilience towards international wine competition and climate hazards. In Cannata, due to a lack of implementation of CAP subsidies and lack of transparency, agriculture production decreased in the last decades and thus, recent local incentives were taken from the Sicilian government to introduce organic and conservation agriculture. However, on the Tleta and Roujan sites, the recent urban and industrial development has induced pressure on arable lands. Urbanization was also boosting local agriculture productivity with the cultivation of the most productive lands but also on degrading lands. For example, fruit tree plantations have been developed on sloping fields of Tleta watershed to meet local food demand while the government implemented some soil conservation measures for the preservation of the forested lands upstream of the watershed.

3.2 Step 2: Definition of potential scenarios and narratives

The second step of the method consisted of developing narratives for the four scenarios described in section 2 based on Kriegler et al.'s approach (2012; Fig. 5). In the first scenario (S1) so-called business as usual (BAU), the actual trend of present land use and agricultural practices are used. In the second scenario (S2) so-called market-oriented, agricultural production capacities are optimized without consideration of environmental sustainability. Economic and technological development are the driving forces in the study case. In the scenario (S3) so-called nature-oriented, the impact of a protective agricultural strategy regardless of agricultural production capacities or socioeconomic acceptability is explored. Environmental measures and governance are powerful drivers of this scenario. In the last scenario (S4) "sustainable growth", both optimization of land use productivity

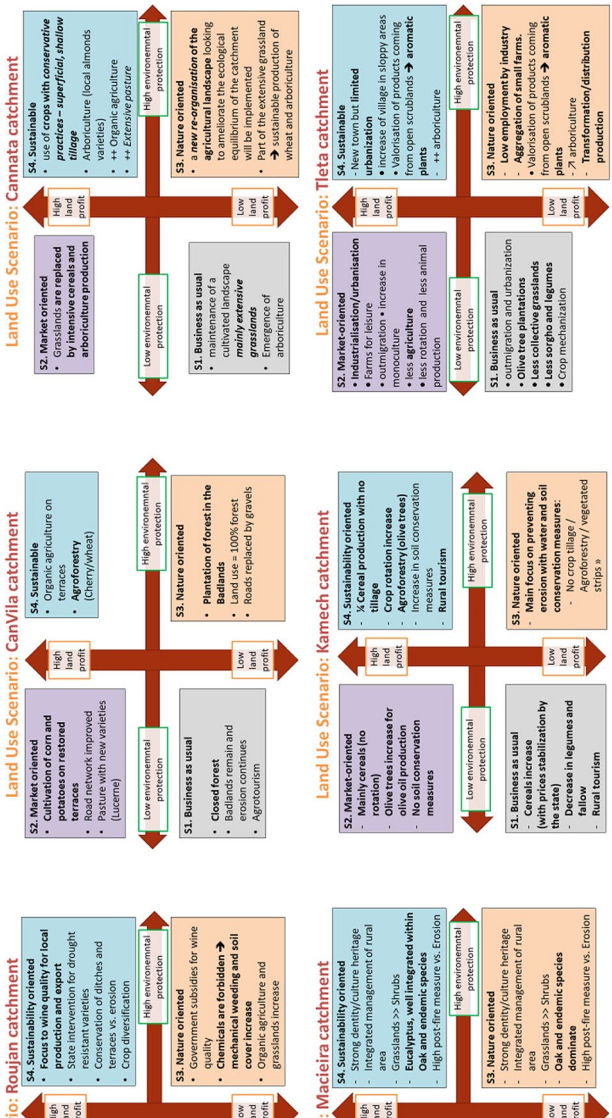

Fig. 6 Key points of the narratives for scenarios S1, S2, S3, and S4 for each study site

Table 4 Soil and water conservations practices per site (X: conservation practices already on-site, C: conservation practices assessed as "feasible and effective" to be implemented on-site by MASCC local experts)

	Roujan (FR)	Can Vila (SP)	Macieira (PT)	Cannata (IT)	Kamech (Tu)	Tleta (Mo)
Structural measures ☐ landscape level						
Terraces	X	X	X			X
Vegetated strips	C		C		C	
Alley-cropping, Hedgerow, horizontal structures						C
Agriculture measures ☐ field level						
Organic agriculture	X			C	C	C
No-tillage	C			C	C	
Controlled grazing				C		
Agroforestry		C	C		C	
Mulching			C			

and implementation of soil conservation measures have been integrated and explored. In this scenario, an equilibrium between economic, social, technological, and environmental development has been sought. The timeframe of each narrative is 30 years (2020–2050) combining four contrasted plausible LUM evolution.

While S1 and S2 scenarios are close to the SSP2 "Middle of the Road" scenario with two levels of environmental protection (low for S2 and medium for S1), social and cultural aspects are more significant in S1 than in S2 for which economic and technological development are dominant. S3 and S4 scenarios are similar to SSP1 known as "sustainable" with different levels of environmental protection (medium for S4, high for S3). Besides, while S4 scenario is a good compromise between environmental protection and economic profit, S3 is mainly oriented towards environmental protection with a strong governance drive. Narrative scenarios have been developed based on qualitative and quantitative results based on step 2. The baseline of each narrative is described in Fig. 4 and is then re-contextualized for each local context (Fig. 6).

A list of potential soil and water conservation techniques was established for scenarios S3 and S4 (Table 4). Two out of the five sites decided to restore terraces (Can Vila) and/or maintain them (Macieira). Vegetated strips have been introduced in half of the sites to control soil water erosion and runoff (mainly in sites with current intense agriculture production such as Roujan and Kamech). Alley cropping has been chosen for Tleta, which is a specific and well-adapted measure in this region. Concerning agricultural measures, while organic agriculture was already present in Roujan, it was introduced in two other sites: Cannata and Can Vila. No-tillage has been adopted in Roujan, Cannata, and Kamech, while Cannata opted for controlled grazing. Finally, agroforestry has been adopted in two sites (Can Vila and Kamech) where traditional forests and olive plantations have been respectively chosen as the perennial vegetation. In the case of Macieira, post-fire soil erosion practices such as mulching with pine needles have been selected.

Table 5 Allocation constraints in each study site (land use ending with till means tillage, land use ending with cons means conservation site-specific agriculture as defined by the local experts)

LUM	Roujan	Can Vila	Macieira	Cannata	Kamech	Tleta
Conservation-oriented crops (and local varieties)	Slope > = 10%, LowLand, size > 2 Ha	Slope < 10%; size < 100	Slope < 15%; size < 100m$_2$	Slope < 10%, size < 0.25 ha	Slope > 15% and vertic soils	Slope > 15%
Conventional crops	Slope < 10%, LowLand, size > 2 Ha	Slope < 8%; size < 100	Slope < 15%; size < 100m$_2$	Slope < 10%, size < 0.25 ha	Slope < 15% and non vertic soils	Slope < 15%
Shrubs/Natural vegetation	Slope > = 10%, HighLand, size < 2 Ha		Slope > 10%; size > 100m$_2$	Slope > 10%	Slope > 15% and vertic soils	Slope > 15%
Conservation-oriented orchards	Slope > = 10%, HighLand, size < 2 Ha	Slope < 10%; size < 1000m$_2$	Slope < 15%; size < 100m$_2$	Slope < 15%, LowLand	Slope > 15% and vertic soils	Slope > 15%
Conventional orchards	Slope < 10%, LowLand, size > 2 Ha		Slope < 15%; size < 100m$_2$	Slope < 10%, LowLand	Slope < 15% and non vertic soils	Slope < 15%
Conservation-oriented vineyard	Slope > = 10%, HighLand, size < 2 Ha					
Conventional vineyard	Slope < 10%, LowLand					
Managed grassland	Slope > = 10%, HighLand, size < 2 Ha		Slope > 10%; size > 100m$_2$	Slope < 10%	Slope: 8–20%	Slope: 8–20%
Semi-natural and natural grassland	Slope > = 10%, HighLand, size < 2 Ha		Slope > 10%; size > 100m$_2$	Slope > 10%	Slope > 10%; size > 100 m$_2$	Slope > 10%; size > 100 m^2
Forest cons and till* (primary forest and forest plantations)		Slope > 8%	Slope > 10%; size > 100m$_2$			
Agro-forestry		Slope < 10%; size < 1000				
Urban	Slope < 10%				Slope < 15% and no cracks	Slope < 15%
Road	Slope < 10%					

*Only land management differs

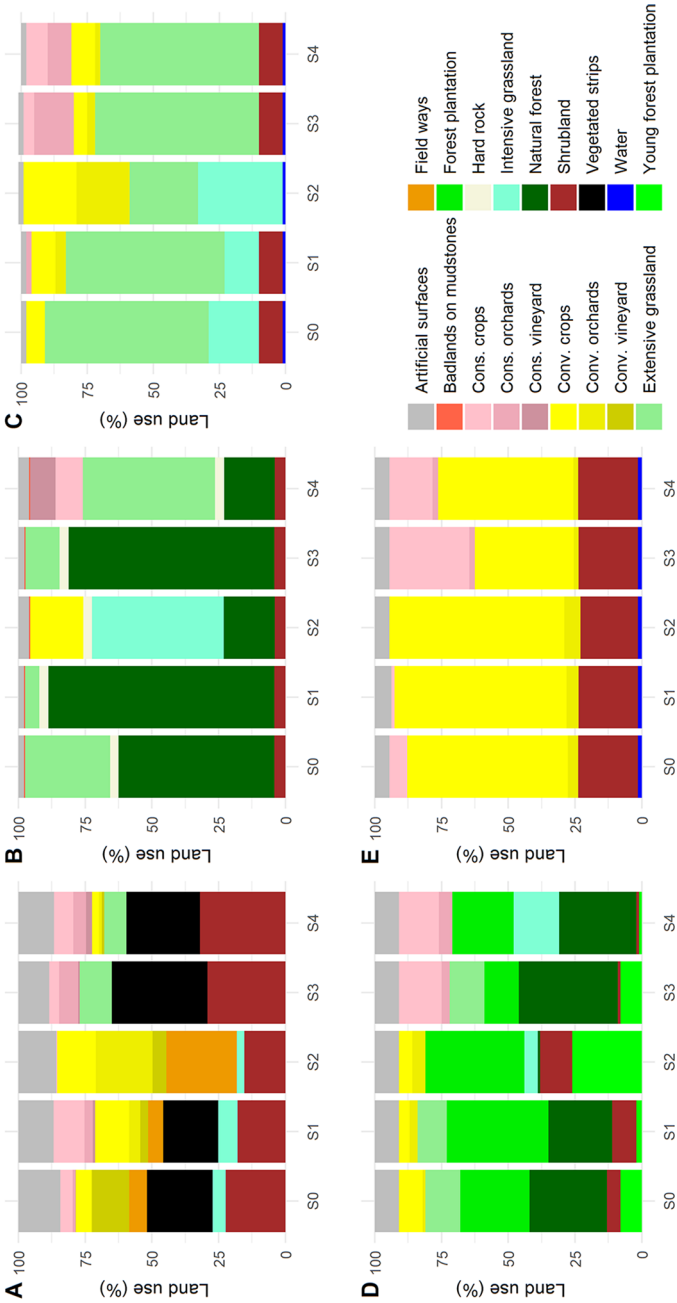

Fig. 7 Land use distribution in Roujan (**A**), Can Vila (**B**), Cannata (**C**), Macieira (**D**), and Kamech (**E**) sites. The scenarios presented are S0 (baseline), S1 (business-as-usual), S2 (market-oriented), S3 (environmental protection), and S4 (sustainable)

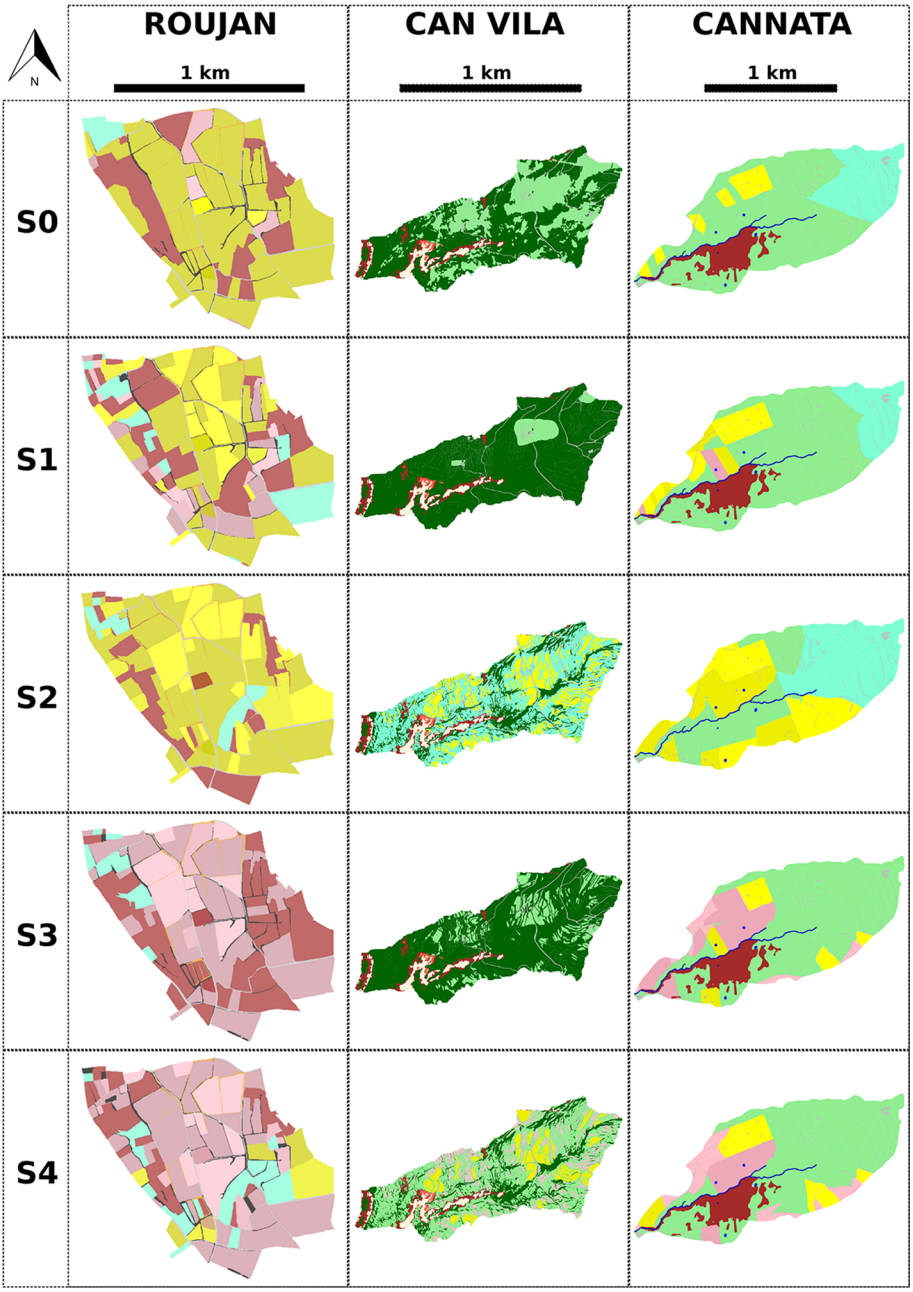

Fig. 8 Land use maps produced with the ScenaLand method for five sites. The scenarios presented are S0 (baseline) S1 (business-as-usual), S2 (market-oriented), S3 (environmental protection), and S4 (sustainable)

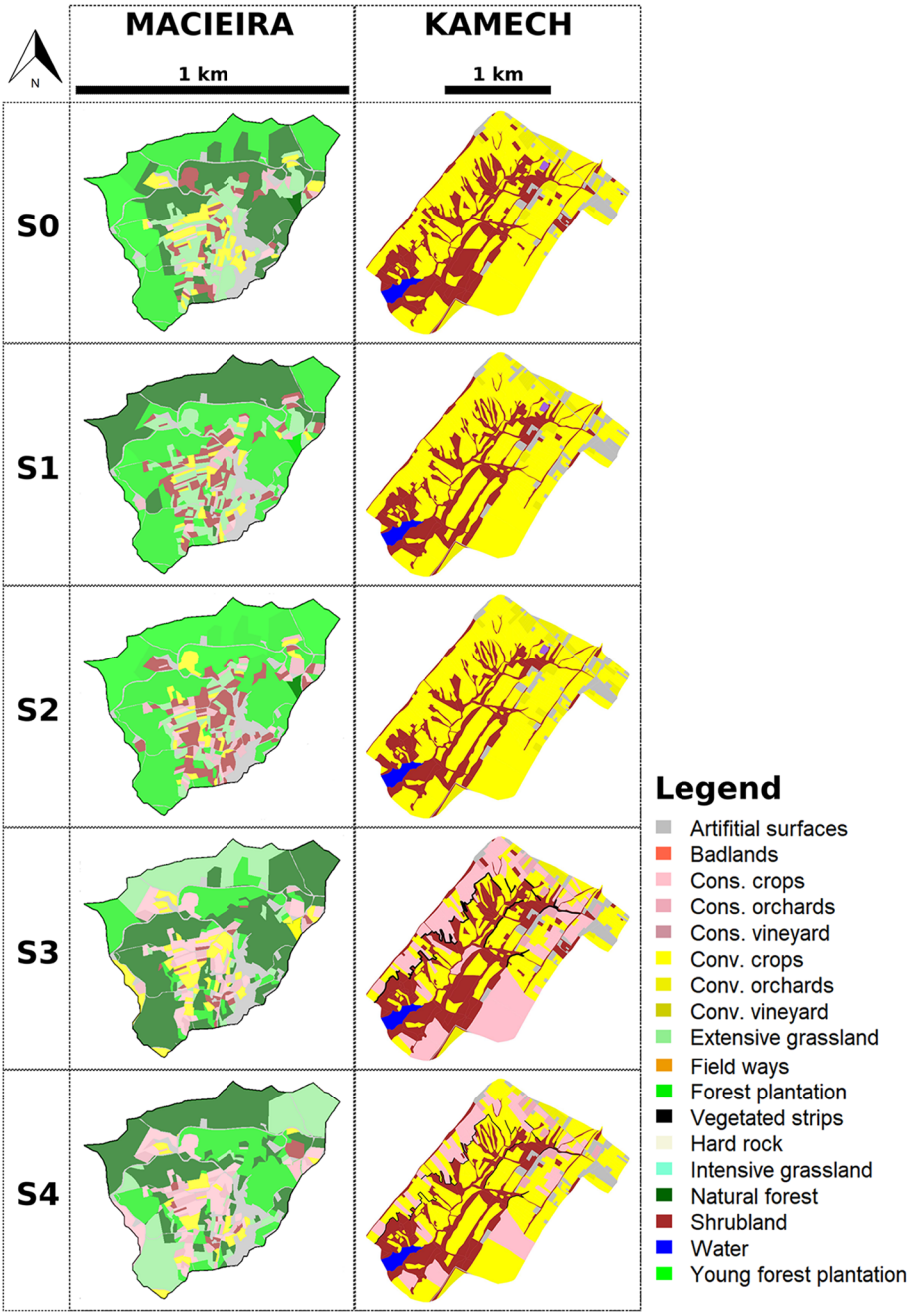

Fig. 8 (continued)

3.3 Step 3: land use maps creation

3.3.1 Spatial allocation from scenario narratives

In step 3, LUM allocation rules based on landscape characteristics (elevation, soil type, etc.) have been created for each scenario (Table 5). In general, grassland and forests were allocated to slopes and large plots while crops are allocated to flat areas with variable field sizes. When mechanized, the choice of large field size is preferable so that the use of machinery could be optimized. Experts also made sure that the field was accessible to ensure crop cultivation. Other rules have been developed by experts on crop allocation such as in Roujan, where conservation agriculture could be allocated to slopes as the use of machinery is very limited. In other sites such as in Cannata, the main biophysical constraints to agriculture production are defined by the slope and the distance to roads but also the access to machinery.

The following section presents the results of local experts' quantification of land use change and/or the introduction of new land use in the landscape (Fig. 7). In Roujan, the vineyard area has been managed following conservation agriculture practices in S1, while herbicides are partly replaced by chemical weeding in S2. Up to 30% of shrublands have been replaced by crop production in S1 and S2, the same applies to grass strips and ways (totally removed in S2 and partially removed in S1). In S3, the land use has been dominated by organic market-gardening and vineyards under conservation agriculture while shrubs and grass strips have been expanded. In S4, the area of conservation orchards, vineyards, and crops has more than doubled. In Can Vila, experts increased forest patches in S1 and S3 by + 44% and + 68%, respectively; while in S2 and S4, forested areas decreased by 68% at the expense of crops and grasslands in S2 and extensive grasslands, organic agriculture and agroforestry in S4. Terraces were maintained in S3 and S4 while agroforestry is being considered only in S4. In Macieira, traditional agriculture has been largely replaced by the plantation of eucalyptus and partly replaced by shrubs in S1 and S2. Pine plantation decreased in all scenarios due to its low profitability and sensitivity to pests and diseases, while oak trees have been re-introduced in S3 and S4 as part of biodiversity protection incentives from locals or the government. In Cannata, the traditional conventional wheat production decreased in all scenarios, except in S2 where it increased by 10%. Old varieties of Sicilian wheat have been introduced in S1 and S2 as they are highly profitable and trendy. These varieties have been also introduced in S3 and S4 with low-tillage practices and low input. The same trend applies to orchard production which was introduced as conventional in S1 and S2 and as organic and conservation orchard production in S3 and S4. Intensive pasture has been doubled in S2, while all pasture land has decreased in the remaining scenarios. In S2, shrubland has been replaced by crops and pasture. In Kamech, conventional cereals were increased in S1 and S2 up to 30% and conventional orchard production up to 57%, while conservation agriculture (cereals, legumes, and arboriculture) was introduced in S3 and S4. Part of natural vegetation and most of the fallow was replaced in S1 and S2 by agriculture production.

Finally, Fig. 8 shows the outcome of the ScenaLand method for five sites. Figure 8 shows contrasted spatially explicit scenarios coming from specific narratives compared to the baseline (S0). For example, for the site of Macieira, the baseline scenario is represented with a mix of extensive grassland and natural forest; the business-as-usual scenario (S1) presents an increase in natural forest to follow the historical and current trends; the

market-oriented scenario (S2) is mainly composed of intensive grassland mixed with conventional crops; the land use composition of the environmental protection scenario (S3) is a mix of S1 and S2 while the sustainable scenario (S4) is a scenario where the landscape is composed mainly by natural forest, extensive grassland, and conventional and conservation crops and orchards. Specific numerical repartition is presented in Fig. 7.

4 Discussion

This study presents a new methodology, named ScenaLand, to create narratives and corresponding spatially explicit scenarios that are easily applicable, site-generic, and implementable with limited time and resources. The results of this study using ScenaLand are satisfactory regarding the creation of contrasting narratives and land use scenarios to explore different LUM strategies on various soil ecosystem services such as water yield and soil erosion mitigation. Narratives have been constructed around two axes: environmental protection (mostly erosion mitigation) and economic profit coming from natural resources exploitation. ScenaLand has been applied successfully in Pastor et al. (2019) study to show high potential for erosion mitigation in S3 and S4 scenarios including climate change mitigation with the implementation of post-fire mulching and increased soil cover on steep slopes in the study site of Macieira. During the construction of scenarios, it has been observed that the socioeconomic context and the political decisions highly influenced agricultural production in each site. For example, similarities were found among the Northern Mediterranean sites of Macieira, Cannata, and Can Vila, where agricultural production is low due to rural out-migration following the decrease in agricultural products prices and the greater job opportunities in nearby cities. In Macieira, the production of eucalyptus, not very demanding in labour and providing high return value for pulp and timber, has replaced traditional agriculture (mainly corn-grassland systems). Roujan remains an exception in the Northern Mediterranean sites, as agriculture and mostly vineyard production is intensive. This is due to the increased wine quality with time maintaining the region in a leading position on the European wine market. In contrast, the Southern Mediterranean sites of Kamech and Tleta are characterized by similar agroecosystems with intense agricultural production systems; however, the political drivers differ between sites. For example, in Morocco, agricultural product imports provide 53% of food needs and agricultural exports have increased from 14 to 43% between 2003 and 2013 (National statistics). While in Tunisia, the focus on increasing agriculture production and price fixation is driven by the national policy on self-food sufficiency.

Compared to other land use models that are either focused on stakeholder engagements (Pedde et al. 2019) or fixed on developing strong land use allocation algorithms (Verburg et al. 2002, 2004; Malek and Verburg 2018), ScenaLand is a mixed bottom-up (for biophysical parameters) and top-down approach (for socioeconomic information) that is driven by both socioeconomic and biophysical contexts. Literature shows that the research objectives and the available resources to design scenarios strongly drive the type of methods to use to develop scenarios. For example, in the European project "IMPRESSIONS" (Pedde et al. 2019), the available time and resources allowed for the development of strong and downscaled SSP narratives following several stakeholders' workshops. These events allowed stakeholders to work together with game facilitation and other resources that ease communication and negotiation. Other studies such as in Stigter et al. (2017) have also used narratives with the development of scenarios for future agricultural development

and irrigation water requirements in Southern Portugal, although there was no creation of explicit land use maps to drive the model. In Choukri et al. (2020), a method developed by Hérivaux et al. (2021) based on strong socioeconomic algorithms and several stakeholder workshops for building scenarios for agricultural development and reservoir siltation in Morocco has been used. Nevertheless, such a method would require a large amount of time and resources to be implemented in a multi-site context such as in the MASCC research project when organizing several stakeholder workshops. Other simple approaches, which relied mainly on land use change analyses to assess present-day socioeconomic trends, or European-scale land use change scenarios to derive future global trends, have also been developed (Nunes et al. 2017; Serpa et al. 2015). While these approaches are arguably simpler than ScenaLand, they lack the validation knowledge provided by multiple experts (and multiple viewpoints) in the scenario design.

Finally, there are also land use allocation models that are based on strong econometric algorithms applied at a global scale such as GLOBIOM (Global Biosphere Management Model) and MAGPIE (Model of Agricultural Production and its Impact on the Environment) (Popp et al. 2014; Havlík et al. 2015). These are valuable tools to study large-scale Earth system dynamics on water use and food production. However, the spatial scale of these models is not adapted to local contexts such as erosion mitigation at the watershed level. Indeed, there is no unique LUM rule for each site (this study). At the local scale, information on socioeconomic context is often downscaled from the region such as in the Macieira case where it was difficult for experts to provide information for the village. Finally, it has been shown that methods mainly based on econometric algorithms can fail such as in a study carried out in a Swiss abandoned and naturally afforested mountainous region, where the BAU scenario has been chosen above modern and optimized scenarios due to a lack of communication with local experts concerning the other scenarios (Soliva and Hunziker 2009).

Despite the satisfactory results of ScenaLand, some improvements might be needed for the validation of LUM techniques. For example, in the MASCC project, the SWC practices have only been biophysically studied and mostly based on expert knowledge, literature review, and existing databases such as the WOCAT (World Overview of Conservation Approaches and Technologies). In some other cases, such as Macieira and Tleta, previous stakeholder workshops also provided stronger validations by local experts than in the other sites. However, it would be interesting to carry out a cost–benefit analysis using for instance the PESERA-DESMICE (Desertification Mitigation Cost-Effectiveness) approach (Fernández and Vega 2016) or evaluate the cost-benefits of soil conservation techniques (Prats et al. 2012, 2016). Furthermore, the validation of such practices can also be achieved through the implementation of scenarios via field experiments and modelling (Pastor et al. 2019; Choukri et al. 2020). It is also uncertain if Scenaland could be used for regions larger than 100 km^2 where methods based on stronger econometric algorithms might be more easily used for the map creation. However, the use of the first two steps of Scenaland could be used before the creation of the maps with another method. A recent study from Dias et al. (2020) has also used scenarios and impact models in loops so that stakeholders help to decide on the best final adaptation pathways (i.e. sets of adaptation options). Although the implementation of ScenaLand has been highly oriented to maintain and/or restore soil conservation, ScenaLand can benefit other kinds of research such as agronomic land feasibility, climate adaptation strategies, and adaptive laws. In further research, it would be interesting to test ScenaLand in larger-scale regions and contexts. Besides, and in order to implement sustainable scenarios, incentives to help farmers adopt sustainable land management practices can be investigated based on the "Polluter Pays Principle" (Valera et al. 2017) or with the introduction of payments for ecosystem services (Friess et al. 2015; Li and Zipp 2019).

5 Conclusion

With the recent actions required from the United Nations with the LDN and SDG15 on land restoration, it is necessary to design resilient landscapes including the maintenance and/or restoration of fertile and carbon-sink soils. This study presents a new methodology, named ScenaLand, to create narratives and corresponding spatially-explicit scenarios that are easily applicable, site-generic, and implementable with limited time and resources. Besides creating narratives based on the current and historical socioeconomic and biophysical conditions, ScenaLand provides guidelines to design spatially explicit land use maps to include LUM strategies and contributes to the design of resilient landscapes. The methodology is particularly suitable for studying multi-site case studies and deriving similarities and differences between sites, as illustrated in this study through its implementation within the MASCC project to mitigate soil erosion in six Mediterranean sites. ScenaLand has been designed to be site-generic, and low-time and resource consuming. Its unique way of integrating top-down regional socioeconomics information and bottom-up field experiments from various research projects resulted in a robust and simple methodology. During the first two steps, socioeconomics trends and drivers helped to develop the narratives, while spatially explicit maps were based on LUM allocation rules derived from the topographic zoning and related agricultural activities. Compared to other studies using scenarios based on solely biophysical trends, the results of this study showed that understanding the socioeconomic context of each site is a fundamental step for the development of plausible and socially accepted scenarios. Some contrasted scenarios in terms of environmental and economic performances have also been designed to test the sensitivity of the different landscape and related measures to soil erosion. However, ScenaLand is flexible enough to be used for other purposes, such as in climate adaptation strategies and adaptive laws.

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Author contribution The authors of this research paper have directly participated in the planning, execution, or analysis of this study. The authors read and approved the final edition of the manuscript.

Data availability All data generated or analysed during this study are included in this published article [and its supplementary information files].

Declarations

Conflict of interest The authors declare no competing interests.

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References

Bocco G (1991) Traditional knowledge for soil conservation in central Mexico. J Soil Water Conserv 46:346–348

Borrelli P, Paustian K, Panagos P et al (2016) Effect of good agricultural and environmental conditions on erosion and soil organic carbon balance: a national case study. Land Use Policy 50:408–421. https://doi.org/10.1016/j.landusepol.2015.09.033

Borrelli P, Robinson DA, Panagos P et al (2020) Land use and climate change impacts on global soil erosion by water (2015–2070). Proc Natl Acad Sci 117:21994–22001

Bracken LJ, Bulkeley HA, Whitman G (2015) Transdisciplinary research: understanding the stakeholder perspective. J Environ Plan Manag 58:1291–1308

Cerdan O, Govers G, Le Bissonnais Y et al (2010) Rates and spatial variations of soil erosion in Europe: a study based on erosion plot data. Geomorphology 122:167–177

Choukri F, Raclot D, Naimi M et al (2020) Distinct and combined impacts of climate and land use scenarios on water availability and sediment loads for a water supply reservoir in northern Morocco. Int Soil Water Conserv Res 8:141–153

Ciampalini R, Follain S, Le Bissonnais Y (2012) LandSoil: a model for analysing the impact of erosion on agricultural landscape evolution. Geomorphology 175:25–37

Ciampalini R, Follain S, Cheviron B et al (2017) Local sensitivity analysis of the Landsoil erosion model applied to a virtual catchment. Sensitivity Analysis in Earth Observation Modelling. Elsevier, Wales, United Kingdom, pp 55–73

Critchley WRS, Reij C, Willcocks TJ (1994) Indigenous soil and water conservation: a review of the state of knowledge and prospects for building on traditions. L Degrad Dev 5:293–314

Delgado JA, Groffman PM, Nearing MA et al (2011) Conservation practices to mitigate and adapt to climate change. J Soil Water Conserv 66:118A-129A

Dias LF, Aparício BA, Nunes JP, Morais I, Fonseca AL, Pastor AV, Duarte Santos F (2020) Integrating a hydrological model into regional water policies: Co-creation of climate change dynamic adaptive policy pathways for water resources in southern Portugal. Environ Sci Policy 114:519–532. https://doi.org/10.1016/j.envsci.2020.09.020

Dubey PK, Singh A, Raghubanshi A, Abhilash PC (2021) Steering the restoration of degraded agro-ecosystems during the United Nations Decade on Ecosystem Restoration. J Environ Manage 280:111798

Fauré E, Arushanyan Y, Ekener E et al (2017) Methods for assessing future scenarios from a sustainability perspective. Eur J Futur Res 5:17

Fernández C, Vega JA (2016) Are erosion barriers and straw mulching effective for controlling soil erosion after a high severity wildfire in NW Spain? Ecol Eng 87:132–138. https://doi.org/10.1016/j.ecoleng.2015.11.047

Friess DA, Phelps J, Garmendia E, Gómez-Baggethun E (2015) Payments for Ecosystem Services (PES) in the face of external biophysical stressors. Glob Environ Chang 30:31–42. https://doi.org/10.1016/j.gloenvcha.2014.10.013

Gerten D, Heck V, Jägermeyr J et al (2020) Feeding ten billion people is possible within four terrestrial planetary boundaries. Nat Sustain 3:200–208

Gessesse D, Gizaw AK, Hurni H (2009) Assessment of soil erosion and soil conservation practices in Angereb watershed, Ethiopia: technological and land user context. Biophysical and socio-economic frame conditions for the sustainable management of natural resources: Book of abstracts 52 (2009)

Gilbey B, Davies J, Metternicht G, Magero C (2019) Taking land degradation neutrality from concept to practice: early reflections on LDN target setting and planning. Environ Sci Policy 100:230–237
Goodspeed R, DeBoskey D (2020) Scenario planning for smaller places: Aligning methods and context. Lincoln Institute of Land Policy. Working paper WP20RG1
Gramberger M, Zellmer K, Kok K, Metzger MJ (2015) Stakeholder integrated research (STIR): a new approach tested in climate change adaptation research. Clim Change 128:201–214
Hammouda N (2010) Evolution de l'occupation des sols et de l'érosion dans le bassin versant Tleta (Rif occidental, Maroc). Institut Agronomique et Vétérinaire Hassan II. Travail de fin d'étude pour le diplôme d'Ingénieur en Agronomie: 140p. https://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers12-11/010052362.pdf. Accessed 15 Aug 2022
Havlík P, Valin H, Gusti M, Schmid E, Leclère D, Forsell N, Herrero M, Khabarov N, Mosnier A, Cantele M, Obersteiner M (2015) Climate change impacts and mitigation in the developing world: an integrated assessment of the agriculture and forestry sectors. Policy Research Working Paper 7477. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/23441
Hérivaux C, Vinatier F, Sabir M et al (2021) Combining narrative scenarios, local knowledge and land-use change modelling for integrating soil erosion in a global perspective. Land Use Policy 105:105406
Hurtt GC, Chini L, Sahajpal R, Frolking S, Bodirsky BL, Calvin K, Doelman JC , Fisk J, Fujimori S, Goldewijk KK, Hasegawa T, Havlik P, Heinimann A, Humpenöder F, Jungclaus J, Kaplan JO, Kennedy J, Krisztin T, Lawrence D, Lawrence P, Ma L, Mertz O, Pongratz J, Popp A, Poulter B, Riahi K, Shevliakova E, Stehfest E, Thornton P, Tubiello FN, van Vuuren DP, Zhang X (2020) Harmonization of global land-use change and management for the period 850–2100 (LUH2) for CMIP6. Geoscientific Model Development 13.11): 5425–5464. https://doi.org/10.5194/gmd-13-5425-2020
Jay S, Jones C, Slinn P, Wood C (2007) Environmental impact assessment: retrospect and prospect. Environ Impact Assess Rev 27:287–300
Keizer JJ, Hessel R (2019) Quantifying the effectiveness of stakeholder-selected measures against individual and combined soil threats. CATENA 182:104148
Kok K, van Delden H (2009) Combining two approaches of integrated scenario development to combat desertification in the Guadalentin watershed, Spain. Environ Plan B Plan Des 36:49–66
Kok K, Patel M, Rothman DS, Quaranta G (2006) Multi-scale narratives from an IA perspective: Part II. Participatory Local Scenario Development. Futures 38:285–311
Kok K, Pedde S, Gramberger M et al (2019) New European socio-economic scenarios for climate change research: operationalising concepts to extend the shared socio-economic pathways. Reg Environ Chang 19:643–654
Kok K, Biggs RO, Zurek M (2007) Methods for developing multiscale participatory scenarios: insights from southern Africa and Europe. Ecol Soc 13(1):8http://www.ecologyandsociety.org/vol12/iss1/art8/
Kok K, Pedde S, Gramberger M, Harrisson PA, Holman JP (2019) New European socio-economic scenarios for climate change research: operationalising concepts to extend the shared socio-economic pathways. Reg Environ Chang 1–12. Regional Environmental Change 19.3: 643–654.https://doi.org/10.1007/s10113-018-1400-0
Kriegler E, O'Neill BC, Hallegatte S et al (2012) The need for and use of socio-economic scenarios for climate change analysis: a new approach based on shared socio-economic pathways. Glob Environ Chang 22:807–822
Lagacherie P, Álvaro-Fuentes J, Annabi M et al (2018) Managing Mediterranean soil resources under global change: expected trends and mitigation strategies. Reg Environ Chang 18:663–675
Lal R (1995) Global soil erosion by water and carbon dynamics (Chapter 10). Soils Glob Chang: 131–152. https://doi.org/10.1016/j.still.2004.09.002
Lal R (2003) Soil erosion and the global carbon budget. Environ Int 29:437–450
Lal R (2014) Soil conservation and ecosystem services. Int Soil Water Conserv Res 2:36–47. https://doi.org/10.1016/S2095-6339(15)30021-6
Li X, Zipp KY (2019) Dynamics and uncertainty in land use conversion for perennial energy crop production: exploring effects of payments for ecosystem services policies. Agric Resour Econ Rev 48:328–358. https://doi.org/10.1017/age.2019.3
Licciardello F, Barbagallo S, Gallart F (2019) Hydrological and erosional response of a small catchment in Sicily. J Hydrol Hydromechanics 67:201–212. https://doi.org/10.2478/johh-2019-0003
Llorens P, Gallart F, Cayuela C, Planasdemunt MG, Casellas E, Molina, A.J, Moreno de las Heras M, Bertran G, Sánchez-Costa E, Latron J (2018) What have we learnt about Mediterranean catchment

hydrology? 30 years observing hydrological processes in the Vallcebre research catchments. Cuad Investig Geográfica/Geographical Res Lett 44: 475–502. https://doi.org/10.18172/cig.3432

Makondo CC, Thomas DSG (2018) Climate change adaptation: Linking indigenous knowledge with western science for effective adaptation. Environ Sci Policy 88:83–91

Malek Ž, Verburg PH (2018) Adaptation of land management in the Mediterranean under scenarios of irrigation water use and availability. Mitig Adapt Strateg Glob Chang 23:821–837

Maraun D (2016) Bias correcting climate change simulations-a critical review. Curr Clim Chang Reports 2:211–220

Molenat J, Raclot D, Zitouna R, Andrieux P, Coulouma G, Feurer D, Grunberger O, Lamachère JM, Bailly JS, Belotti JL, Azzez KB, Mechlia NB, Younès Louati MB, Biarnès A, Blanca Y , Carrière D, Chaabane H, Dagès C, Debabria A, Dubreuil A, Fabre JC, Fages D, Floure C, Garnier F, Geniez C, Gomez C, Hamdi R, Huttel O, Jacob F, Jenhaoui Z, Lagacherie P, Le Bissonnais Y, Louati R, Louchart X, Mekki I, Moussa R, Negro S, Pépin Y, Prévot L, Samouelian A, Seidel JL, Trotoux G,Troiano S, Vinatier F, Zante P, Zrelli J, Albergel J, Voltz M (2018) OMERE: a long-term observatory of soil and water resources, in interaction with agricultural and land management in Mediterranean hilly catchments. Vadose Zo J 17(1):1–18. https://doi.org/10.2136/vzj2018.04.0086

Moss RH, Edmonds JA, Hibbard KA et al (2010) The next generation of scenarios for climate change research and assessment. Nature 463:747–756

Nunes JP, Jacinto R, Keizer JJ (2017) Combined impacts of climate and socio-economic scenarios on irrigation water availability for a dry Mediterranean reservoir. Sci Total Environ 584:219–233

Nunes JP, Bernard-Jannin L, Rodríguez Blanco ML et al (2018a) Hydrological and erosion processes in terraced fields: observations from a humid Mediterranean region in Northern Portugal. L Degrad Dev 29:596–606

Nunes JP, Doerr SH, Sheridan G, et al (2018b) Assessing water contamination risk from vegetation fires: challenges, opportunities and a framework for progress. Hydrol Process

Nunes JP, Bernard-Jannin L, Rodríguez-Blanco ML, Boulet AK, Santos JM, Keizer JJ (2020) Impacts of wildfire and post-fire land management on hydrological and sediment processes in a humid Mediterranean headwater catchment. Hydrol Processe 34(26):5210–5228

O'Neill BC, Kriegler E, Ebi KL, et al (2015) The roads ahead: narratives for shared socioeconomic pathways describing world futures in the 21st century. Glob Environ Chang

O'Neill BC, Tebaldi C, Van Vuuren DP, Eyring V, Friedlingstein P, Hurtt G, Knutti R, Kriegler E, Lamarque JF, Lowe J, Meehl GA, Moss R, Riahi K, Sanderson BM (2016) The scenario model intercomparison project (ScenarioMIP) for CMIP6. Geosci Model Dev 9(9):3461–3482

Olsson L, Barbosa H, Bhadwal S, Cowie A, Delusca K, Flores-Renteria D, Hermans K, Jobbagy E, Kurz W, Li D, Sonwa DJ, Stringer L (2019) Land degradation: IPCC special report on climate change, desertification, land 5 degradation, sustainable land management, food security, and 6 greenhouse gas fluxes in terrestrial ecosystems. Intergovernmental Panel on Climate Change (IPCC), 1

Panagos P, Borrelli P, Meusburger K et al (2015) Estimating the soil erosion cover-management factor at the European scale. Land Use Policy 48:38–50

Parry ML (2007) Climate change 2007-impacts, adaptation and vulnerability: working group II contribution to the fourth assessment report of the IPCC. Cambridge University Press

Pastor AV, Nunes JP, Ciampalini R, Koopmans M, Baartman J, Huard F, Calheiros T, Le-Bissonnais Y, Keizer JJ, Raclot D (2019) Projecting future impacts of global change including fires on soil erosion to anticipate better land management in the forests of NW Portugal. Water 11(12):2617. https://doi.org/10.3390/w11122617

Pedde S, Kok K, Onigkeit J et al (2019) Bridging uncertainty concepts across narratives and simulations in environmental scenarios. Reg Environ Chang 19:655–666

Popp A, Rose SK, Calvin K et al (2014) Land-use transition for bioenergy and climate stabilization: model comparison of drivers, impacts and interactions with other land use based mitigation options. Clim Change 123:495–509. https://doi.org/10.1007/s10584-013-0926-x

Prats SA, MacDonald LH, Monteiro M et al (2012) Effectiveness of forest residue mulching in reducing post-fire runoff and erosion in a pine and a eucalypt plantation in north-central Portugal. Geoderma 191:115–124

Prats SA, Malvar MC, Vieira DCS et al (2016) Effectiveness of hydromulching to reduce runoff and erosion in a recently burnt pine plantation in central Portugal. L Degrad Dev 27:1319–1333. https://doi.org/10.1002/ldr.2236

Prosdocimi M, Tarolli P, Cerdà A (2016) Mulching practices for reducing soil water erosion: a review. Earth-Science Rev 161:191–203

Raclot D, Le Bissonnais Y, Annabi M et al (2018) Main issues for preserving Mediterranean soil resources from water erosion under global change. L Degrad Dev 29:789–799

Rockström J, Steffen WL, Noone K, Persson Å, Chapin FS, Lambin E, Lenton TM, Scheffer M, Folke C, Schellnhuber HJ, Nykvist B, de Wit CA, Hughes T, van der Leeuw S, Rodhe H, Sörlin S, Snyder PK, Costanza R, Svedin U, Falkenmark M, Karlberg L, Corell RW, Fabry VJ, Hansen J, Walker B, Liverman D, Richardson K, Crutzen P, Foley J (2009) Planetary boundaries: exploring the safe operating space for humanity. Ecol Soc 14(2)http://www.jstor.org/stable/26268316

Sartori M, Philippidis G, Ferrari E et al (2019) A linkage between the biophysical and the economic: assessing the global market impacts of soil erosion. Land Use Policy 86:299–312

Serpa D, Nunes JP, Santos J et al (2015) Impacts of climate and land use changes on the hydrological and erosion processes of two contrasting Mediterranean catchments. Sci Total Environ 538:64–77

Soliva R, Hunziker M (2009) Beyond the visual dimension: using ideal type narratives to analyse people's assessments of landscape scenarios. Land Use Policy 26:284–294. https://doi.org/10.1016/j.landusepol.2008.03.007

Steffen W, Richardson K, Rockström J, Cornell SE, Fetzer I, Bennett EM, Biggs R, Carpenter SR, de Vries W, de Wit CA, Folke C, Gerten D, Heinke J, Mace GM, Persson LM, Ramanathan V, Reyers B, Sörlin S (2015) Planetary boundaries: guiding human development on a changing planet. Science 347(6223):1259855. https://doi.org/10.1126/science.1259855

Stigter TY, Varanda M, Bento S et al (2017) Combined assessment of climate change and socio-economic development as drivers of freshwater availability in the south of Portugal. Water Resour Manag 31:609–628

Swart RJ, Raskin P, Robinson J (2004) The problem of the future: sustainability science and scenario analysis. Glob Environ Chang 14:137–146

TERI (2009) Impacts of relatively severe climate change in North India. Project Report 2008GW09. The Energy and Resources Institute, New Delhi, India

Terranova O, Antronico L, Coscarelli R, Iaquinta P (2009) Soil erosion risk scenarios in the Mediterranean environment using RUSLE and GIS: an application model for Calabria (southern Italy). Geomorphology 112:228–245

Valera CA, Pissarra TCT, Martins Filho MV et al (2017) A legal framework with scientific basis for applying the 'polluter pays principle' to soil conservation in rural watersheds in Brazil. Land Use Policy 66:61–71. https://doi.org/10.1016/j.landusepol.2017.04.036

van Vuuren DP, Stehfest E, den Elzen MGJ et al (2011) RCP2.6: Exploring the possibility to keep global mean temperature increase below 2°C. Clim Change 109:95–116. https://doi.org/10.1007/s10584-011-0152-3

de Vente J, Reed MS, Stringer LC, Valente S, Newig J (2016) How does the context and design of participatory decision making processes affect their outcomes? Evidence from sustainable land management in global drylands. Ecol Soc 21(2)http://www.jstor.org/stable/26270377

Verburg PH, Soepboer W, Veldkamp A et al (2002) Modeling the spatial dynamics of regional land use: the CLUE-S model. Environ Manage 30:391–405

Verburg PH, Schot PP, Dijst MJ, Veldkamp A (2004) Land use change modelling: current practice and research priorities. GeoJournal 61:309–324

Zorn M, Valjavec MB, Komac B, Bahun MV, Hrvatin M (2013) Soils of Slovenia. The geography of Slovenia: small but diverse. Cham: Springer International Publishing: 91–107

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