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A Picit Jeu: Agent-based modelling with serious gaming for a fire-resilient landscape --Manuscript Draft--

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Abstract:	Wildfire governance requires addressing driving physical, biological and socio- economic processes, by promoting the development of fire-resistant and resilient landscapes. These landscapes can best be achieved by strategies that integrate fuel management for direct prevention with allied socio-economic activities, through the collaboration of stakeholders with different and sometimes conflicting interests. This work aims to address the need for new approaches supporting the participatory process of collective decision-making, helping stakeholders explore land management strategies for landscape fire resilience. We present and discuss a methodology combining agent-based modelling with a role-playing game. It was tested in a valley of the Italian Alps, involving 23 local stakeholders in forest and pasture management in three game sessions. Evaluation was based on observation of game sessions, collection of feedback via immediate post-session debriefing and questionnaires, and long-term (multi-year) assessment carried out through semi-structured interviews. We found the methodology valuable for facilitating discussion among different stakeholders, who were able to identify context-related challenges (land fragmentation and land abandonment, stakeholders' limited collaboration, controversial drives of European funding) and possible strategies for producing a fire-resilient landscape (community management forms of pastoralists activities for maintaining land cover diversity). The approach also triggered a positive process for longer-term change. By analysing the outcomes, we are able to identify four key recommendations for future work using serious gaming for sustainable landscapes: 1) aim for an even composition of session groups, 2) consider the multiple levels of organisation in the area, 3) use the allocation of game roles to disrupt power dynamics, and 4) seek to involve the broadest stakeholder spectrum in developing the game itself.
Suggested Reviewers:	Fantina Tedim ftedim@letras.up.pt For her expertise in wildfire management in Mediterranean environment Thomas Spies Tom.Spies@oregonstate.edu
	r or his experience in agent-based modeling for wildlife management.

A Picit Jeu: Agent-based modelling with serious gaming for a fire-resilient landscape

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Dear Editor,

We are pleased to submit a revised version of our work after we have attentively addressed all the new reviewers' comments.

Best regards

The Authors

Dear Reviewers,

Thank you for your new comments. You find here a table with a description of how we have addressed each of your comments and how we have modified the manuscript accordingly.

Best regards

The Authors

Reviewers' comments	Answers from the authors
The new paragraph discussing previous works (lines 74-79) is too summarized, and	We have described better what the focus of those existing works using serious games in fire management is and why those were not
field It's not just a matter of citing papers A	suitable for the aim of our work, which is
or B or C, but of actually understanding	more in line with the principles of other
them and discussing them in context. The	serious game approaches, namely
authors should add some depth to this	ComMod (as detailed in previous and next
discussion to properly justify the need of	paragraphs).
Still regarding the name "Picit Jeu": J	We have changed the sentence as
appreciate that the authors explain the	suggested.
meaning of the game, but in line 85, the first	
time the name of the game is presented, it	
should be "creating the game *A Picit Jeu*	
using or creating a game entitled "A Picit	
current wording gives the impression that a	
Picit Jeu game is some kind of generic	
game.	
Line 64: "On the one side, agent-based	We corrected it.
modelling (ABIN) is a well-known methodology for analysing the interactions	
between people, things, places and time." -	
> "On the one hand" would be more	
appropriate.	
Line 450: "The experience does not seem to	We corrected it.
nave positively impacted should be The	
impacted" for consistency in past tense	
Fig. 6 should be a table. Further, don't paste	There has clearly been an error in
print screens to a scientific paper, with typo	uploading the wrong version of the figure,
highlights and all. It is unprofessional, to say	thank you for highlighting it. In any case, we
the least.	have changed it into a table as suggested.
Since the authors have added a table with	We have replaced the table with a more
supplementary material there is not reason	supplementary material) including also the
that the answer distributions themselves are	distribution of the answers.
not shown. Note that simply presenting	
averages on Likert-scale answers is	
"fundamentally flawed" (see page 227 of	
"Artificial Intelligence for Games" by	
Yannakakis and Togelius).	

- We present a serious agent-based game for exploring landscape fire resilience
- Our game is effective for exploring strategies and triggering transformative change
- Long-term evaluation shows impacts on stakeholders' collaboration and networks
- Stakeholders' involvement in the modelling steps enhanced the process benefits
- Attention must be paid to power imbalances and stakeholders' representation

A Picit Jeu: Agent-based modelling with serious gaming for a fire-resilient landscape

Wildfire governance requires addressing driving physical, biological and socio-economic processes, by promoting the development of fire-resistant and resilient landscapes. These landscapes can best be achieved by strategies that integrate fuel management for direct prevention with allied socio-economic activities, through the collaboration of stakeholders with different and sometimes conflicting interests. This work aims to address the need for new approaches supporting the participatory process of collective decision-making, helping stakeholders explore land management strategies for landscape fire resilience. We present and discuss a methodology combining agent-based modelling with a role-playing game. It was tested in a valley of the Italian Alps, involving 23 local stakeholders in forest and pasture management in three game sessions. Evaluation was based on observation of game sessions, collection of feedback via immediate post-session debriefing and questionnaires, and long-term (multi-year) assessment carried out through semi-structured interviews. We found the methodology valuable for facilitating discussion among different stakeholders, who were able to identify context-related challenges (land fragmentation and land abandonment, stakeholders' limited collaboration, controversial drives of European funding) and possible strategies for producing a fire-resilient landscape (community management forms of pastoralists activities for maintaining land cover diversity). The approach also triggered a positive process for longer-term change. By analysing the outcomes, we are able to identify four key recommendations for future work using serious gaming for sustainable landscapes: 1) aim for an even composition of session groups, 2) consider the multiple levels of organisation in the area, 3) use the allocation of game roles to disrupt power dynamics, and 4) seek to involve the broadest stakeholder spectrum in developing the game itself.

26 Keywords: serious game, fire risk, fire-resilient landscape, participatory research

1. Introduction

Wildfires have severe impacts on ecosystem services and human health worldwide, including casualties, negative consequences on air quality and effects on the global carbon budget (Bacciu et al. 2022). The annual cost of wildfires in the United States alone is estimated at between \$71.1 billion and \$347.8 billion (UNEP 2022), while in 2023 wildfires affected an area of more than 500 000 ha in the European Union countries, causing severe damage to the environment and producing around 20 megatonnes of CO2 emissions (San-Miguel-Ayanz et al. 2024).

Wildfire governance in a context of global change requires a strategy addressing the physical, biological, and socio-economic processes that drive the phenomenon in a landscape (Bowman et al. 2013; Bacciu et al. 2022; Kirschner et al. 2023). In Europe, land governance actions aim to manage some critical causes of wildfire impacts (e.g., landscape flammability, rural land abandonment, illegal fire uses, lack of community-based fire adaptation) by promoting the development of fire-resilient landscapes (Moreira et al. 2020). This means territories where

governance actions exert leverage on the wildfire regime so that its effects are compatible with
the delivery over time of key ecosystem services (e.g., water supply, primary productivity,
biodiversity) and with the socio-economic system in the area (e.g. agroforestry productions,
tourism, energy industry) (Fernandes 2013; Thacker et al. 2023).

Consequently, in many European territories, wildfire governance programs are in place that integrate strategic fuel management planning for direct prevention (e.g., strategic fuel breaks supporting active firefighting) with the planning of socio-economic activities that have an indirect fire regulatory effect by creating a mosaic less prone to fire in synergy with direct prevention, such as agro-silvo-pastoral value-chains, biodiversity conservation or energy supply (Tedim et al. 2016; Pais et al. 2020; Spadoni et al. 2023; Pulido et al. 2023).

However, the possibility of creating sustainable processes to achieve fire-resilient landscapes requires collaboration among multiple stakeholders (e.g., forest managers, private owners, nature conservation agencies, and enterprises in the agro-pastoral, food, energy, or tourism sectors) with interests in the territory that often appear challenging to synergize or even conflict (Canadas et al. 2016). Developing a common, shared strategy to promote integrated planning processes for fire-resilient landscapes requires participatory decision-making that facilitates adaptive learning, understanding the interests at stake, and collaboratively defining win-win strategies that activate sustainable processes over time (Otero et al. 2018, Ascoli et al. 2023).

The use of games in natural resources management has increasingly received attention in recent years for conflict mediation, social learning and collective decision-making (Madani et al. 2017; Wesselow and Stoll-Kleemann 2018; Flood et al. 2018; Rodela et al. 2019). Companion Modelling (ComMod) emerged as a gaming approach, relying on "the synergistic effects between role-playing games (RPG) and agent-based models (ABM) to facilitate information sharing, collective learning and exchange of perceptions on a given concrete issue among researchers and other stakeholders" (Ruankaew et al. 2010). On the one hand, agent-based modelling (ABM) is a well-known methodology for analysing the interactions between people, things, places and time. ABM is often used in socio-ecological system studies to integrate human behaviour models with ecological models (Kline et al. 2017) and a variety of applications in wildfire research exists in the literature (Millington et al. 2008; Charnley et al. 2017; Spies et al. 2017; Ribeiro et al. 2023). On the other hand, serious games are an innovative participatory approach to exploring, learning about, and discussing the complexity of the socio-ecological system, especially when many conflicting interests exist in it (Speelman et al. 2018). Games can support collective negotiations and help define common strategies toward a collectively recognised problem, putting into play the participants' perception of the problem and their experience.

Examples of serious games dealing with wildfire risk exist in the literature, focusing on different aspects of risk management, such as firefighting training simulation (Backlund et al. 2007, Caroca et al. 2019), emergency decision-making (Ji et al. 2024), disaster preparedness (Johns et al. 2024) and social awareness (Pereira et al. 2014). However, they were developed to strengthen risk preparedness and response, while, to our knowledge, a serious game focusing on building fire-resilient landscapes involving both direct and indirect fire regulatory processes has not been developed yet. Moreover, none of the cited works successfully represent the interaction between the diverse perspectives and priorities of local stakeholders. Representing and putting them into play is crucial for supporting a participatory process where indeed those interactions must be taken in consideration, discussed and leveraged for developing successful wildfire impacts mitigation strategies.

This work aims to address the need for collaborative decision-making to develop integrated planning processes for fire-resilient landscapes by presenting and assessing an innovative participatory approach based on ComMod principles, focused on exploring land management strategies for landscape fire resilience. We tested the methodology in a study area located in the Italian Alps, by (1) developing an ABM representing the effect of forest and pasture management actions on wildfire risk in Valchiusella, (2) creating the game A Picit Jeu¹ using the model for exploring the results of different strategies, and (3) using A Picit Jeu for involving local stakeholders in collective discussions on land management scenarios for fire prevention.

This work also intends to contribute to the research gap in impact assessment of games used in natural resource management (which has largely been absent or only short-term focused; Calderón and Ruiz 2015; Rodela and Speelman 2023) by presenting a multiple-time-frame evaluation of the impact of the game experience. A short-term assessment was supported by the observation and recording of the game sessions, and by participants' feedback via end-of-session debriefings and questionnaires. A long-term evaluation was carried out two years later by interviewed participants to explore what influence the game subsequently had on land 20 100 management decision-making and the network of stakeholders concerned. We describe the ²¹ 101 results of such a multiple-time-frame impact assessment, while discussing its advantages and limits.

The following section presents the study area and describes in detail the procedure adopted. We
 then introduce and discuss the results of the game development process, of the game sessions
 and of the evaluation steps. In the Conclusion section, we consider what lessons can be learned
 to apply in other landscapes and contexts.

⁰⁷ 2. Materials and methods

08 2.1 Study Area

The study area is Valchiusella, an Alpine valley of about 143 km² in the northwestern part of Italy, in the Piemonte region.

¹ The game's name "A Picit Jeu" is a word pun in the local dialect of Valchiusella, meaning "a small game" but sounding also close to "A Picit Feu", which literally means "over small fire" and refers to a phenomenon evolving slowly.



Fig. 1. Map of the study area. In (a) the extent of the forest cover, pioneering shrublands and grasslands is shown. The forest cover and pioneering shrubland layer are taken from the regional forest map (last update in 2016, https://www.geoportale.piemonte.it), while the grassland cover is derived by subtracting those from the "Grasslands, meadow pastures, bushes" layer (derived by elaboration of the IPLA Land Cover 2003 and available at <u>https://geoportale.igr.piemonte.it</u>). The layer does not include rupicolous grasslands. (b) and (c) place the study area at a national and regional level, respectively.

34 118 The valley's altitude ranges between approximately 400 m and 2800 m for the highest peaks. The surface is divided into eight municipalities, with a total resident population of 5161 inhabitants on 1 January 2023 (data available at https://dati.istat.it). The population has gone through a process of depopulation typical of Alpine valleys since the end of the 19th century, which was characterised by the abandonment of traditional farming activities (MacDonald et al. 2000). This process has also caused the still ongoing expansion of pioneer vegetation - tall grasses, shrubs, and trees - on abandoned pastures, with tangible effects on fire hazard (Ascoli et al. 2020, 2021). The local fire regime is characterised by a predominance of fires during winter and close to it (see ⁴⁴ 126 data available at https://www.geoportale.piemonte.it/geocatalogorp). In this season the fully cured vegetation, lower rainfall frequency, and warm, dry foehn winds increase the probability of accidental ignitions producing extensive fires (Valese et al. 2014), such as the one occurred in 48 129 April 2022 in the municipality of Rueglio, which involved around 300 ha of pastures and forests and caused severe damages to some buildings (local forest technicians, personal communication).

Valchiusella forestry area, which covers around 43% of the total surface, is shared between
 private owners and municipalities. A prominent role in forest management is played by the
 Consorzio Forestale del Canavese (CFC). The CFC was born in 2002 as a unitary management
 body for a non-administrative region including Valchiusella, with the aim to support the
 sustainable management of forests from a multifunctional perspective and through long-term
 planning. The CFC manages 1977 ha of forest surface in the valley (32% of the total forest surface)

- almost entirely belonging to seven out of eight municipalities (CFC forest technicians, personal 1 139 communication).
- 3 140 Most of the alpine pasture areas of the valley are owned by the municipalities. Farmers typically rent those lands with multiannual contracts and bring their animals to graze in summer. Usually, a nearby municipal alpine hut is rented together as a shelter for animals and a temporary б residence for farmers.
- 9 144 The existence of a variety of public and private stakeholders of forest and pasture management, 10 145 together with the challenges caused by the rural abandonment process to fire prevention, makes Valchiusella an excellent case study for the purposes of this work.
- 2.2. The game design **147**

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- The design of A Picit Jeu was based on four phases (Figure 1):
 - 1. analysis of the local context through semi-structured interviews;
 - definition of the conceptual model of the local socio-ecological system (SES);
 - 3. implementation of the agent-based model;
 - 4. definition of the role-playing game mechanics.
- Phases 3 and 4 were carried out at the same time and implied a continuous interaction with each other.
- ₂₇ 155 Three review steps were taken at different moments of the game design process. The aim was to verify the appropriateness of the representation of the socio-economic and ecological dynamics **156** of the study area context, as well as the playability of the game. They involved local technicians of the CFC and researchers in the domain of geography, land management, and wildfires.



Fig. 2. Diagram of the four-phase methodology adopted for the game design. The three review steps are represented in green boxes.

2.2.1 Context analysis 162

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163 The methodology proposed in this work for the game design aims at tailoring the game dynamics 3 164 to the specific context it is conceived for. The analysis of the context was conducted through 165 semi-structured interviews with local stakeholders, focused on the interactions between human 166 and ecosystem dynamics in the framework of wildfire risk.

167 Twenty-five interviews were carried out, involving 27 interviewees. The interviewees were 168 identified among five categories of stakeholders involved in local land management, forest 10 169 management and wildfire issues:

- Mayors or municipal administrators in charge of land management tasks contacts were provided by the CFC.
- Forest firefighter volunteers priority was given to the firemen of each local volunteer firefighter team. Four valley municipalities had their own team at the moment of the interviews: Val di Chy, Rueglio, Traversella and Vidracco. The head of the Valchiusella section was also interviewed.
- Forest workers the owners of the forestry companies registered in the official provincial list were interviewed. Other respondents were contacted thanks to the indications provided by the CFC. In addition, members of a land consortium existing in the northern part of the valley were interviewed.
 - Members of local environmental associations selected on the recommendation of • association leaders.
 - Farmers respondents were first identified among the members of a local association of • producers for the promotion of local cheese. Other interviewees were suggested by the already involved farmers ('snowballing').

34 The interview canvas was made of 20 questions focused on the personal relationship with the 185 35 36 186 local community, the experience with forest management, the role of wildfires in the ecosystem ³⁷ 187 and the existing fire prevention strategies, the local forest management status and actors, and 188 the value of ecosystem services. The interviews were carried out over around two months, so it is 40 189 possible that some early participants had the opportunity to exchange ideas about the questions' 41 190 content with later participants before their interviews. However, this is not a limitation for our 191 work given that the purpose of this activity was to get an overview of the interactions between 192 human and ecosystem dynamics and of the local challenges related to wildfire risk, instead of a 45 193 precise personal point of view. Moreover, any exchange of ideas between stakeholders already ⁴⁶ 194 happening at this time was perfectly in line with the general aim of this work of fostering 195 collaborative decision-making.

196 Interviewees' answers were analysed through thematic analysis (Braun and Clarke 2006) to 50 identify the recurrent topics and mapped into thematic areas. For each of the seven thematic 197 51 52 198 areas mapped, a specific issue directly or indirectly related to wildfire prevention in the valley was ⁵³ 199 formulated, based on the respondents' contribution. Finally, each issue was translated into a 54 200 precise purpose to be integrated into the game's design, such as a specific topic on which the 55 56 **201** game should trigger discussion or concerning which it should help a learning process.

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2.2.2 Conceptual model definition 202

2 **203** For designing game mechanics representative of the real-world situation, a conceptual model of 3 204 local Social Ecological System fire prevention issues was defined. A procedure adapted from the 205 ARDI method proposed by Étienne and colleagues (Etienne 2009; Etienne et al. 2011) was used. 206 The ARDI method was conceived in the framework of the ComMod approach for building a shared 7 207 description of the SES among the stakeholders involved in the process, representing its elements 208 by means of diagrams. In this work, the four ARDI elements and steps (Actors, Resources, 209 Dynamics and Interactions) were used by the authors as a guideline to formalize the insights ₁₁ 210 collected through the interviews into an SES conceptual model serving the design of the game 12 **211** mechanics.

¹⁴ 212 2.2.3 Agent-based model implementation

15 16 213 The SES conceptual model was then transformed into an agent-based model (ABM) in NetLogo. ¹⁷ 214 The NetLogo language was chosen because of its free access, wide diffusion in environmental 18 215 studies, ease of learning, and good user support (Kravari and Bassiliades 2015; Wilensky and 20 **216** Rand 2015). The interface tab of the model was designed to be used as the 'board' of the game by 21 **217** projecting it on a screen clearly visible to all the players. The model was created with a series of 218 commands the game master can enter during the simulation depending on players' decisions 219 about forest and pasture management actions. The game was intended to reproduce a primary 25 **220** general pattern: the less players undertake landscape management actions (e.g., by thinning and ²⁶ 221 cutting forests or grazing pastures), the higher the probability that a fire will burn a large land area. 222 The detailed description of the model following the ODD standard protocol for ABMs (Grimm et ₂₉ 223 al. 2006) and the model code itself are published in (and downloadable from) the COMSES library 30 224 (Vigna and Millington 2024).

2.2.4 Game mechanics definition 225

34 226 While coding the ABM, the game mechanics were also defined. This step was based on a 227 translation process of the actors, resources, dynamics and interactions of the SES conceptual 228 model into game roles and mechanics, such as players' actions on the board, players' interactions, game materials and spatial and temporal settings. Since this step was strictly 38 229 ³⁹ 230 dependent on the previous step and vice versa, a continuous interaction between the two was 231 necessary to shape the game mechanics to the model's possibilities and to adapt the model to 232 the needs of the gameplay.

2.2.5 Review steps 44 233

234 The first review step was carried out after the conceptual model definition phase. The main aim 47 235 was to assess the adequacy of the representation of the local SES, highlighting missing elements ⁴⁸ 236 and incorrect dynamics. It involved a forest technician, an agronomist and a naturalist-biologist, 237 all working for the CFC. They were chosen for their expertise in the relative fields and their direct 238 experience of the local context, including socio-economic dynamics.

53 **239** The game was then reviewed through two pilot sessions. The first one involved only researchers 54 **240** in geography and fire management disciplines, while the second one involved both researchers 241 and a forest technician from the CFC. The pilot sessions aimed at assessing the scientific 242 correctness of the dynamics represented and the game's playability, including the 58 **243** appropriateness of time management in the different game phases and of the supporting

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materials. These pilot sessions allowed for improvements both to the gameplay and to the ABM code.

2.3 The game sessions

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Three game sessions were organised in the valley, with the collaboration of the mayors of the municipalities where they were held. The municipalities (named A, B and C from now on to anonymise participants) were located one at the bottom of the valley, one in the middle and one in the upper part. The collaboration with the mayors was crucial for the involvement of the participants: stakeholders involved in local land and fire management, belonging to the same ₁₂ 252 categories listed in Section 2.2.1, plus local forest and naturalist experts, and citizens particularly interested in the topic of the game (Figure 3). Each participant, while bringing their personal **253** ¹⁴ 254 expertise to the participatory activity, was asked to choose a role in the game that differed from the one they had in real life.



Fig. 3. Categories of stakeholders participating in each game session.

Each session was led by a facilitator and structured with a preparation phase (presentations, instructions, role assignment, and game material allocation), a play phase, and a debriefing phase. According to Crookall (2010), debriefing is "the occasion and activity for the reflection on 43 261 and the sharing of the game experience to turn it into learning". It consists of a structured discussion about what happened during the game and how to relate it to the participants' real-life experiences (Adolph et al. 2023). The facilitator encouraged the discussion by asking relevant 47 264 questions to the group, starting by sharing observations of participants' spoken remarks, actions and behaviour during the gameplay. Some quantitative plots derived from the ABM simulation were also used. See the Supplementary Material for the guideline questions used for the debriefing discussion.

The game sessions were entirely recorded with a video camera and a recording microphone. The **269** analysis of the recorded material and the real-time observation notes made by researchers aimed at understanding the behaviours of the players, their strategies in the game, their corresponding actions in the real world, their point of view on management issues, the challenges they face in **272** their real-world roles, and their vision of the local SES. The focus was also on assessing A Picit Jeu effects on enhancing the discussion, facilitating mutual understanding, and sharing of

information. An observation protocol was developed as a guideline (see the SupplementaryMaterial).

276 2.4 The process evaluation

In addition to the direct observation and the feedback collected during the debriefing, an evaluation survey made of a mix of open and Likert-scale questions was administered to the participants at the end of each session. The survey focused on how players felt during the game, on the perceived utility of the experience, on the adequateness of the game for facilitating the discussion and understanding other stakeholders' opinions, and on the opportunity for the players to learn and share new insights on the SES dynamics (see Figure 1 in the Supplementary material for the complete list of questions).

Finally, five semi-structured interviews were conducted approximately two years after the game sessions, to assess the potential long-term direct and indirect impacts of the process on local collaborations and initiatives. The interviewees were the director forest technician of the CFC, the leader of a volunteer firefighter team, two mayors, and a member of an environmental association, all of whom had participated in the game sessions.

3. Results

3.1 Game overview

The analysis of the initial interviews with local stakeholders pointed out seven thematic areas. In Table 1 we summarize the focus of each thematic area, the specific issue directly or indirectly related to wildfire prevention in Valchiusella, and its translation into game purposes.

Table 1. Correspondence between thematic areas	, issues related to wildfire prevention and game focus
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Thematic area	Wildfire prevention issue	Game purpose
1. Economic sphere	Forest management and territorial management are now less economically sustainable than in the past.	Enhancing discussion between the different stakeholders about how to manage forest lands in an economically sustainable way.
2. Planning	Long-term and valley-level planning are often missing in Valchiusella.	Promoting discussion between decision makers about a long-term and valley- level planning project.
3. New generations	People in the valley, and specifically new generations, often are not aware of the role of territorial management in wildfire risk mitigation.	Raising awareness among the population about these topics.
4. Intergroup conflicts	Conflicts between old residents and new inhabitants exist.	Helping dialogue between different groups of inhabitants and facilitating mutual understanding.

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5. Ecological sensitivity	The interactions between ecological dynamics and socioeconomic activities are not always clear for all people.	Helping participants understand interactions between the natural ecosystem and the socio- economic system.
6. Rural abandonment	Land abandonment is a major issue, mainly for private forest parcels.	Reducing private forest parcel abandonment by promoting their collective management.
7. Wildfires	The effects of rural abandonment on fire risk are not clear for all inhabitants.	Helping participants understand the effects of rural abandonment on fire risk and the need to manage it.

In order to allow participants in game sessions to collectively analyse and discuss dynamics and challenges they face in real life, it is crucial that the challenges and mechanics represented in the game correspond to those the players deal with in their real life in the specific context. The game design was then guided by the content of the interviews, while the various review steps described in Section 2.2.5 ensured appropriate representation of the local SES and scientific accuracy of the game content. Therefore, the seven thematic areas guided the definition of the SES conceptual model based on the ARDI steps and, later, its translation into game elements and mechanics. For clarity, Figure 4 shows the components of the SES conceptual model already represented according to game mechanic categories instead of original ARDI categories: players' roles (instead of actors), land resources, players' interactions, and player-resource interactions.



Fig. 4. Overview of the game roles, land resources and interactions.

308	Four game roles were identified:
² 309 ³ 310 ⁴ 311 ⁵ 311 ⁶ 312 ⁷ 313 ⁹ 314 ¹⁰ 315 ¹¹ 316 ¹² 317 ¹³	 The municipal administration, represented by the mayor, who delegates the management of forest parcels to the technician of the forest consortium and rents the public pasture parcels to the farmers; The forest consortium, represented by a technician, who is in charge of managing (i.e. cutting and thinning) public forest; Farmers, who graze their cow herds on public pastures that they rent. One or two farmers can be in the game. Private forest owners, who manage their own forest parcel. Three forest owners are in the game.
14 15 318 16 319 17 320 18 321 19 321 20 322 21 323 22	During the game, the mayor and the technician of the forest consortium must agree on the management plan of public forests and on how to share the economic costs for thinning and the economic gains for cuts. The mayor and the farmers must negotiate the price for renting public pastures. The private forest owners can ask the forest technician for technical information, such as the stumpage value of their parcel. The forest technician is also able to assess each land parcel's wildfire hazard and can decide to share this information with the other players.
23 24 25 325 26 326 27 327 28 328 30 329 31	Three kinds of land resources were identified: forests, pastures and pioneer shrublands. These were used for characterizing the space represented by the ABM, made of 20 land parcels (Figure 5). A number of functions representing the action of the players on the land parcels were coded in the ABM: cutting and thinning the forest parcels, grazing the pasture parcels, building or maintaining the huts of the pasture parcels, converting to forest, or to pasture the pioneering shrubland parcels.
32 330	Three kinds of dynamics were also identified in the SES:
33 34 331 35 332 36 332 37 333 38 334 39 335 40 336 41 336 42 337 43 338 44 339 45 340 47 341 48 342 50 343 51 344	 Ecological dynamics: The natural reforestation of abandoned pastures, which leads to the growth of a more flammable pioneer vegetation; The behaviour of fire, which is more likely to burn more flammable lands than others; Fire hazard dependence on climate conditions; Social dynamics: The common lack of interest on the part of private forest owners in their parcels, which usually leads to their abandonment; Economic dynamics: The pastoral products market variations; The variation in the cost of forest operations, such as cut and thinning, and of wood prices because of market changes;
52 344 53 345 54 346 55 347 56 348 57 348	pasture parcels become pioneer shrubland after some rounds. Dynamic 2 was used to code the fire behaviour in case of ignition. Dynamic 4 was used to code the behaviour of four autonomous agents representing private forest owners. Dynamics 3, 5 and 6 were translated as possible scenarios to be set at the beginning of the ABM simulation.
<pre>58 59 349 60 350 61 62 63 64</pre>	Finally, a time duration of 50 years was chosen for the game, as a relevant amount of time from a silvicultural point of view. The players are asked to take actions every 10 years, for a total of five

game rounds. Between each round, the ABM simulates forest growth and the effects of their 1 352 actions on the land parcels. Moreover, at the beginning of the third or fourth round, the model simulates the behaviour of three wildfires, ignited randomly on the landscape. More thinned and younger forests are less likely to burn than older and less thinned (or unthinned) ones, while pioneer shrublands are the most likely to burn (see ODD description for more details, Vigna and б Millington 2024). During the game, the players have to deal simultaneously with the economic constraints imposed by their limited resources and the cost of their actions, and with the impact of their management decisions on the likelihood that wildfire events will affect land parcels.



Fig. 5. Screenshot of the interface of the ABM, used as the 'board' of the game. The colours of the land parcels correspond to the three different land use types and to the age of forests. The house icons represent huts on the pastures. The human figures identify the forest parcels owned by the private owner players and by the autonomous agents. Three fires have spread on the landscape in the simulation represented.

3.2 Game sessions' outcomes

During the three game sessions, the level of involvement in the activity and amusement of the participants was generally high. The mean score in the answers to the question "Did you have fun" in the final survey was 6.3 on a 1 to 7 Likert scale (see Figure 1 in the Supplementary material for a complete overview of answers to the final questionnaires). However, some participants were more active than others. This was particularly evident in Municipality A, where some participants 48 370 took a driving role in the collective decisions, while some remained more in the background and expressed less. The Municipality A session involved a higher number of participants compared to the other two, which could, in part, explain this fragmentation in participants' involvement. **373** Moreover, existing friendship links were discernible in the group and tended to affect the interactions in the game.

⁵⁵ 375 In addition, in Municipality A and B the mayors had a very active and central role in game interactions. This is partly explained by the fact that, in both situations, the mayor was playing the role of the forest technician, which is particularly influential in the game mechanics. Moreover, their real-life leadership role probably influenced their role in the game.

379 For some participants it was also easier to understand the game rules and mechanics than for 1 380 others, placing them in an advantageous position. This advantageous position allowed them to 2 381 be more influential in the collective decision-making and to guide the discussions. The mean 3 382 score of the question "Was it easy to understand the rules of the game?" on a 1 to 7 Likert scale 4 383 was 6.3 in Municipality A (median value: 6), 6.7 in Municipality B (median value: 7) and 4.8 in 5 б 384 Municipality C (median value: 5.5). In Municipality C, no participant adopted a guiding role in the 7 385 discussions and the group generally complained about the short time available for discussing the 8 386 implications of the activity during the debriefing phase, since it took them a long time in the 9 10 387 beginning to understand the game functioning. Time constraint was generally an issue. All the 11 388 sessions took place in the evening, to allow the participation of all stakeholders, particularly 12 389 farmers whose work does not include days off. However, this choice reduced the time available, 13 14 390 often at the expense of the debriefing phase.

15 The exchange of roles was generally perceived as very helpful. As an example, the forest 16 **391** 17 392 technician playing the role of the mayor in Municipality A session declared during the debriefing 18 393 that he found that "the difficulty of this is that you have to interact with multiple stakeholders at 19 394 the same time. You have to deal with many people and issues simultaneously, which differs from 20 21 395 my situation. Money comes in one way and goes out another, and, in the end, it all goes out! This 22 396 is maybe something trivial, but I was able to experience it this evening." In this regard, the 23 397 absence of some crucial stakeholders in some sessions limited the outcomes. More specifically, 24 398 in Municipality B the participants largely discussed the role of modern farming techniques and a 25 26 **399** general lack of care in land maintenance on the farmers' side in contributing to the expansion of 27 400 the pioneering shrubland on pastures. However, no farmers were present in the session to 28 401 contribute their points of view and highlight their challenges. In Municipality C, the role of CFC in 29 30 402 Valchiusella was unclear to most participants, but the absence of CFC technicians prevented a 31 403 helpful exchange of information on this point. 32

33 404 The game proved to be an effective tool in helping the discussion about land management issues 34 405 and strategies. The participants were able to identify and analyse the challenges for a fire-resilient 35 406 landscape in Valchiusella, such as land fragmentation, obstacles to stakeholders' collaboration, 36 37 **407** and controversial drives of European funding. Land fragmentation was identified as a major driver 38 408 of land abandonment, since it challenges large-scale planning of the landscape. Concerning 39 409 obstacles to collaboration, participants identified two main elements: the scarcity of economic 40 41 410 resources and a cultural aspect. Resource constraints force stakeholders to focus on their short-⁴² **411** term economic sustenance instead of long-term and shared plans, whereas the local culture 43 412 places a solid value on private properties, especially forests. Private forests are sometimes 44 413 exploited for family firewood consumption but are more often not managed at all. However, 45 46 414 owners are frequently unwilling to give up the right to manage their parcels, even when they are 47 415 not interested in doing so themselves: the land is not transferable because it was inherited from 48 416 ancestors, belongs to the family, and will go to their children. This phenomenon doesn't concern 49 50 417 new inhabitants of the valley, who are likely to be more open to forms of collective parcel 51 418 management, such as Land Consolidation Associations (Beltramo et al. 2018). Finally, on one 52 419 side, the direct funding to farming activities linked to the Common Agricultural Policy helps to 53 420 keep this traditional practice on the land, also enabling young people to start their pastoral 54 55 **421** activity; on the other side, it pushes farmers to expand the herd and graze a large extent, without ⁵⁶ 422 keeping attention to the sustainable management of pasture, since the grazed area is the only 57 423 parameter deciding the amount of funding. 58

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424 The game sessions were also helpful in brainstorming possible strategies to directly or indirectly 1 425 help the creation of a fire-resilient landscape. For example, a participant expressed the need to 2 426 diversify the spatial distribution of land cover, in line with findings about the role of landscape 3 427 spatial heterogeneity in reducing the spread and intensity of fires (Parsons et al. 2017; Vacchiano 4 428 et al. 2021). This is challenged by the widespread abandonment of private parcels and thus the 5 6 429 transition from a complex alternation of open spaces and different densities of forest cover to a 7 430 more homogeneous and dense forest cover. Another participant suggested the use of prescribed 8 ₉ 431 fire and experimental fire prevention action. Moreover, different forms of collective management 10 432 concerning pastoralist activity came out during the debriefing phases, such as a community-¹¹ 433 based cooperative for obtaining other kinds of European funding for land management and 12 434 development, a solidarity buying group for shortening the supply chain between producers and 13 14 435 consumers of milk products, and a valley consortium dairy for lowering the cost for farmers to 15 436 transform milk into cheese. 16

437 3.3 Long-term evaluation

19 438 The interviews carried out circa two years later are part of the attempt to evaluate the effect of the 20 439 experience from a broader point of view than individual game sessions, considering the game not 21 22 **440** only as a tool to facilitate discussion on the spot, but also as a positive process trigger for longer-23 441 term change. This is linked to the use of the game experience to raise awareness among the 24 442 participants about the importance of a shared planning strategy and effective land management 25 443 activities, and to foster interactions and collaboration. 26

27 444 The outcomes of the interviews proved some long-term positive effects on the collaboration 28 29 445 among the CFC and the other stakeholders, specifically in one of the municipalities, some private ³⁰ 446 owners, and the volunteer forest firefighting teams of the valley. However, they also highlighted a 31 447 different perception and awareness among the interviewees of the game sessions' role in 32 33 448 facilitating this positive process, as well as the difficulty of entirely attributing it to the game 34 449 experience. For example, a stronger collaboration between the CFC and the firefighting teams 35 450 was brought to the partnership via a financed local development project linked to fire risk. 36 451 According to the CFC director forest technician, this was made possible by the participation of 37 38 **452** both in the game sessions and, also, in an event organised one year later for sharing the research 39 453 results with the local community. However, according to the firefighting team leader, it is difficult 40 to exclude that it would have happened anyway and that a positive process was already ongoing. 454 41

42 455 Interestingly, the experience did not seem to have positively impacted the interactions between 43 $_{44}$ 456 the CFC and the local environmental associations. Both the director of the CFC and the 45 **457** environmental association member referred to the creation of a new association during the two-46 458 year period by this latter actor and some other local citizens, all new inhabitants of the valley, with 47 459 the expressed aim of preserving local forests from exploitation. Its members often denounce the 48 49 460 CFC actions as part of an exploitation process and complain about the lack of consideration for ⁵⁰ 461 their point of view. The conflict thus seems to have worsened in this case. 51

Finally, a positive effect was found in the interactions between the CFC and the University of Turin
 institution itself, thanks to the involvement of the CFC technicians not only in the game sessions
 but also in the review steps of the development process. Other collaborative activities have since
 been carried out.

Table 2 summarizes the main points presented in the Results section, by highlighting the positive
 outcomes and long-term effects of the process, as well as its challenging aspects.

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468 Table 2. Summary of the positive outcomes of the game sessions, the long-term effects of the process and its
 469 challenging aspects.

	POSITIVE OUTCOMES AND LONG-TERM EFFECTS	CHALLENGING ASPECTS
	High involvement of the participants	Different level of participants' contribution to the discussions
	Understanding of other roles' challenges	Difficulties in understanding the game rules
	Identification of the challenges for a fire-resilient landscape	Time constraints
	Identification of direct and indirect strategies for a fire-resilient landscape	Lack of stakeholders' representation in some game sessions
	Enhanced collaboration between some stakeholders	Uneven enhancement of collaboration and awareness of the process
	Enhanced collaboration between the CFC and the University of Turin	

470 4. Discussion

A Picit Jeu game sessions demonstrate the multifaceted results that can come from the collaborative process of serious gaming, which allows both the researchers and the players to **473** learn. The participants' discussions drew our attention to some issues affecting the SES, on 26 474 which planning strategies need to focus across different scales, such as the organisation of pastoral funding, the attitude of the inhabitants toward collective management, and the lack of information about CFC activities and opportunities for forest owners. At the same time, the game 30 477 sessions gave stakeholders the opportunity to identify these issues, question their points of view ³¹ 478 and start a dialogue, sometimes also resulting in strengthened collaborations. The observation of the sessions and the outcomes of the evaluation interviews allow us to discuss some focal 34 480 points and identify more general lessons valuable for others using serious gaming to negotiate or 35 481 inspire collaboration between stakeholders in developing fire-resilient (or otherwise sustainable) landscapes.

First, a significant effort needs to be made in defining the group of participants. In this work, the game sessions were organised in collaboration with the mayors of the municipalities, who 41 485 oversaw the invitation of the participants, leaving the researcher a lower control over their selection As explained by Barreteau and colleagues (2010), a requisite for the success of a participatory processes as ComMod is that the participants in the collective action dynamics accept them to the point of participating in them. What makes this possible is very often a local 46 489 anchoring, which is provided by the social capital of those who are promoting the process. The help from the village mayors, who have a dense relation network in the area, allowed us to successfully reach out to stakeholders that would have been less likely to respond to our direct **492** invitation, overcoming people's scepticism toward a novel methodology and generating interests 51 493 and curiosity instead. Even if the mayors were in charge of disseminating the invites, we put in place two measures for assuring appropriate representativeness of the stakeholders: first, the mayors were all provided with a list of stakeholder categories that needed to be involved; second, **496** when the mayors were unable or uncomfortable in inviting people from one or more categories, the researchers did it. This was the case, for example, of the members of the local environmental associations, who are often new inhabitants of the valley and whose presence in two of the three game sessions was assured by a direct invitation from the researchers.

However, despite these measures the difficulty of involving a representative of each category in
 all the sessions caused some unevenness in the composition of the groups, as highlighted in the
 Results section. The participants criticized this unevenness both during the debriefings and in the
 evaluation interviews.

5 504 Related to the previous point, in two game sessions, a certain power imbalance between the б 505 participants was felt, as the mayors were particularly influential on the game dynamics, helped 7 8 506 also by the role they were assigned. Power relations influencing the game is a crucial point in this 9 507 kind of experience and needs great attention and effort from the facilitator (Garcia et al. 2022). 10 11 508 Similarly, pre-existing relationships between the participants can make someone feel more 12 509 entitled to express their opinion to the group than others. Stakeholders with a stronger power ¹³ 510 position can impose their ideas on the discussions and ignore others, while a lack of self-14 511 confidence, freedom of expression or understanding of the issues at stake can limit a player's 15 16 **512** ability to defend their interests (Barnaud et al. 2010). In this work, a more attentive choice of the 17 513 game roles would have benefited the group dynamics, by deliberately assigning less influential 18 514 roles to the participants with more influential roles and leadership attitudes in the real world. This 19 515 is supported by the fact that no power imbalance was witnessed in the Municipality C game 20 21 516 session, where the mayor played the less influential role of a private forest owner.

22 23 **517** The second lesson learned concerns the inclusion of the game sessions in a broader participatory ²⁴ 518 process. The ComMod approach from which this work was inspired clearly places the use of the 25 519 game simulations as only one of the steps of a structured participatory process (Daré et al. 2015). 26 ₂₇ 520 Stakeholders generally engage actively in this modelling process from the early stages (Basco-28 **521** Carrera et al. 2018). The benefit of involving stakeholders in designing the model on their 29 522 perceived legitimacy of the model outcomes is well documented in the literature (Van Berkel and 30 523 Verburg 2012), and the challenges for evaluating models where this is not the case have also been 31 32 **524** demonstrated (Millington et al. 2011). This allows the decision-makers to take ownership of the ³³ 525 model, which is a requirement for the success of the process (Joffre et al. 2015). This process, 34 526 however, takes time. Because of the limited resources, we chose to involve only the CFC 35 527 technicians in ABM and game design. During gaming sessions no player ever directly questioned 36 37 528 the representation of the local SES in A Picit Jeu in terms of ecological or socio-economic 38 529 dynamics. However, two criticisms were raised during the debriefings: that the game mechanics 39 530 (i) push the players to focus on the economic value of forests and pastures at the expense of other 40 41 531 kinds of values, and (ii) could transmit the message that assigning uses other than "wood ⁴² 532 production" to forests (for example by creating a protected area with no cutting activities allowed) 43 533 is always negative, since the ABM fire behaviour simulation rewards the owner of young and 44 534 thinned forests more than the owner of old and not managed ones. These two aspects could have 45 46 535 been taken into consideration in the game development if all the stakeholders had been involved 47 536 in the creation process. 48

⁴⁹ 537 Moreover, we argue here that the benefits of involving stakeholders from the modelling step go 50 538 beyond the legitimation of the game session's results and concerns also other less tangible 51 52 **539** outcomes, such as the enhancement of networks and collaborations and the perceived 53 **540** consideration for one's perspective in the collective debate. The long-term evaluation interview ⁵⁴ 541 highlighted the benefits perceived by the CFC director forest technician on the interactions 55 542 between the CFC and other local stakeholders, as well as the University of Turin. This was made 56 57 **543** possible by the involvement of the CFC technicians in the whole process, from the revision steps ⁵⁸ 544 to the sharing of the process results with the local community. Their involvement allowed them 59 545 to have a clear understanding of the whole process and its objectives, and so benefit from it by 60

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546 strengthening the collaborations with other stakeholders of interest. On the contrary, the 1 547 environmental association members were only invited to attend the game sessions and later 2 548 stated that the experience didn't have any positive effects on making their voices heard in local 3 549 land management debates. An intermediary situation concerns the firefighting team leader, who 4 550 described the improvement in the collaboration with the CFC in the two years following the game 5 б 551 sessions, but, contrary to the forest technicians, didn't think that A Picit Jeu experience 7 552 influenced it. These very different opinions suggest that not only acquiring ownership of the model 8 553 and game tools is crucial, but also acquiring ownership of the entire process can enhance the 9 10 554 benefits of the process itself and provide the stakeholders with a greater awareness of them. 11

12 555 A significant limitation of this work is that all three game sessions were organised at the municipal ¹³ 556 level, involving almost exclusively residents of one municipality at a time. The lack of a common 14 557 perspective at the valley level on landscape planning was one of the issues identified in the initial 15 16 558 interviews. Promoting the discussion between decision-makers about valley-wide planning 17 559 projects was included in the game purposes during the initial development phase (see Table 1). 18 560 However, the absence of leadership at the valley level, which would have been fundamental in 19 ₂₀ 561 setting the meeting and inviting the participants, prevented the organisation of a game session 21 562 involving more geographically distributed participants. This precluded the exchange of points of 22 563 view and the development of a shared perspective across a larger extent than a single 23 564 municipality. Future developments in this methodology should address this point. A game 24 25 **565** session involving all the valley's mayors could be a starting point, followed by game sessions 26 566 bringing together lower-level actors from multiple municipalities to avoid the power imbalance 27 567 issues mentioned above. 28

29 568 Another limitation concerns the challenges in assessing the effects of the process. Literature on 30 569 serious gaming interventions indicates a general lack of assessment procedures that consider 31 32 **570** the overarching objective of the process, instead of learning at the individual level (Rodela and ³³ 571 Speelman 2023). Moreover, serious games are usually evaluated in a short period, with 34 572 assessment procedures implemented no more than a few months after the sessions (Calderón 35 573 and Ruiz 2015). However, the complex nature of their outcomes drove us to try to evaluate the 36 37 574 impact from a broader perspective than just the results of collective discussions at individual 38 575 sessions. A longer time scale assessment was then necessary. The interviews highlighted 39 576 interesting focal points almost two years after the game sessions. However, the impossibility of 40 41 577 isolating the effects of the serious game experience from the impacts of other events that ⁴² 578 occurred in the two years makes it challenging to attribute developments in the local context with 43 579 certainty. The assessment of this kind of process is made especially difficult by the impossibility 44 of comparing outcomes with a control sample, since finding another context with the same exact 580 45 46 **581** components and challenges is impossible. Nevertheless, it is essential to note that the 47 582 evaluation was carried out by focusing on the perception of the stakeholders themselves rather 48 583 than on an objective analysis of changes, with the aim of eliciting once again their perspective. 49

5. Conclusions

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54 585 In this work, we aimed to contribute to the literature on fire-resilient landscapes by addressing 586 the need for integrated planning approaches through the activation of sustainable processes over 587 time. We have presented a methodology inspired by the ComMod approach to support 58 **588** stakeholders in exploring land management strategies for landscape fire-resilience. The 589 methodology entails a participatory process that combines agent-based modeling and serious

590 gaming. It was tested in Valchiusella, an Italian alpine valley. Twenty-three local stakeholders 1 591 were involved in collective discussions on land management scenarios for fire prevention through 2 592 the serious game A Picit Jeu. 3

4 593 During the game sessions, the participants identified and discussed the challenges for a fire-5 594 resilient landscape in Valchiusella, such as land fragmentation and land abandonment, б 595 stakeholders' limited collaboration due to scarcity of economic resources and cultural value of 7 8 596 private property, and controversial drives of European funding. Possible strategies to help the 9 597 creation of a fire-resilient landscape also emerged, mainly related to different forms of collective 10 ₁₁ 598 management in pastoralist activities, to prevent land abandonment and maintain diversity in the 12 599 spatial distribution of land cover. 13

14 600 The observation of the game sessions and the information collected through a multi-step ¹⁵ 601 evaluation procedure confirmed the methodology's potential not only to facilitate discussion 16 602 among different stakeholders but also as a positive process trigger for longer-term change. While 17 18 603 the challenges and strategies for a fire-resilient landscape identified can be transferrable to other 19 604 contexts characterized by similar processes of land abandonment and a similar stakeholder 20 605 composition, such as other Alpine valleys, the enhanced collaboration among stakeholders 21 requires the replication of the entire participatory process. 606 22

23 607 The discussion of the outcomes of this experience, moreover, allowed us to point out some 24 25 **608** recommendations for future works using serious gaming to support the collaboration of ²⁶ 609 stakeholders in developing sustainable landscapes. First, aiming for an even composition of 27 610 session groups, where all real-life roles are represented, is crucial. Second, the group 28 29 **611** composition needs to take into account the multiple levels of organisation in the area by involving 30 612 participants across them, to bring the discussion to the wider landscape spatial scale (e.g. valley 31 613 level instead of just municipality level). In addition, careful considerations are needed about the 32 614 allocation of game roles to disrupt power dynamics and allow all the participants to contribute to 33 the debate actively. For example, avoiding allocating an influential game role to a participant with 34 615 ³⁵ 616 a real-life leadership role could be beneficial. Finally, we suggest aiming for the involvement of 36 617 the broader stakeholder spectrum in developing the game itself, as participation in the entire 37 618 process has proven to strengthen collaboration between participants. 38

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Supplementary material

802	Box 1 Guidelines questions for A Picit Jeu debriefing phase.

Triggered emotions:

- How did you feel during the game?
- Do you think that it was easy to take into consideration the idea of all the players? • Relationship with the reality:
 - Which similarities with the reality did you find in the game? •
 - Which differences?

Mutual understanding:

- What difficulties did you experience in playing your role?
- Did you expect them? •
- Do you think the same difficulties exist in reality? •
- Do you feel this game made you understand other actors' perspectives better?

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Table 1 Synthetic version of the observation protocol adopted for real-time and post analysis of the sessions.

GENERAL AIM	SPECIFIC AIM	WHAT TO ANALYSE		
Evaluating the	Assessing the ludic aspect and the	The level of participation of the		
game	ability of the game to make the	players		
	players feel involved			
	Assessing the ability of the game to	The quality of the discussions and		
	produce positive effects on the	the transformation of the players'		
	players	points of view		
	Assessing the ability of the game to	The speech of the players		
	represent the actors' reality			
	Assessing the ability of the game to	New proposals suggested by the		
	generate new strategies	players		
Understanding	Identifying the most debated	The discussions generated among		
the reality	topics	the players		
	Understanding the behaviour of	The strategies adopted by the		
	the actors	players		
	Understanding the confidence	The value accorded by the players to		
	accorded by the actors to the	the specific knowledge of the forest		
	scientific and technical knowledge	technician		

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Tot	nsəM	6.0	6.0		6.0	6.3	6.5	6.1	5.0		3.8		5.7	6.0	3.9	3.7	4.3	5.5	6.4		
	nsibəM	ß	9		5.5	6.5	9	9	ß		ß		2	9	4.5	4.5	ß	5.5	6.5		
(nsəM	5.3	5.7		4.8	6.5	6.3	6.3	5.0		4.3		5.3	6.0	4.0	4.0	4.5	5.5	6.5		
Municipality C	Numberof 0 1 2 3 4 5 6																				
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Municipality E	Numberof 0 1 2 3 4 5 6																				■2 ■3 ■4 ■5 ■6 ■7
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	nsəM	6.2	6.0		6.3	6.1 (6.6	6.1	5.9		4.3		6.3	6.0	4.7	4.3	5.1	5.7	6.2		
Municipality A	Number of respondents 0 1 2 3 4 5 6 7 8 9 10			Open question						Open question		Open question								Open question	
		Was this meeting useful?	Did this meeting meet your expectations?	What expectations were not met?	Was it easy to understand the rules of the game?	Did you have fun?	Did you feel free to express your opinions?	Were your opinions taken into account?	Are the situations depicted in the game realistic?	What aspects are not realistic, if any?	Did you learn new things about the ecological dynamics of our forests and pastures?	If applicable, what did you learn?	Was the meeting useful for you to understand the difficulties that different actors face in reality?	Was it helpful to use a playful approach?	Did this meeting change your point of view?	Will your actions change thanks to this meeting?	Did this meeting change your opinion of collective forest management?	Was the group able to make successful collective decisions?	Did the game facilitate the exchange of ideas with the other participants?	What categories of people would it be useful to participate in the same experience	
Fig. 1.	List of au	estio	ns of	the r	ost-s	sessio	on au	estio	nnai	res (t	ransla	ation	from l	taliar	n to E	nglis	h bv t	he au	thors	a). with	

Fig. 1. List of questions of the post-session questionnaires (translation from Italian to English I corresponding distribution, mean and median values of the answers to the Likert scale ones. s),

A Picit Jeu: Agent-based modelling with serious gaming for a fire-resilient landscape

Wildfire governance requires addressing driving physical, biological and socio-economic processes, by promoting the development of fire-resistant and resilient landscapes. These landscapes can best be achieved by strategies that integrate fuel management for direct prevention with allied socio-economic activities, through the collaboration of stakeholders with different and sometimes conflicting interests. This work aims to address the need for new approaches supporting the participatory process of collective decision-making, helping stakeholders explore land management strategies for landscape fire resilience. We present and discuss a methodology combining agent-based modelling with a role-playing game. It was tested in a valley of the Italian Alps, involving 23 local stakeholders in forest and pasture management in three game sessions. Evaluation was based on observation of game sessions, collection of feedback via immediate post-session debriefing and questionnaires, and long-term (multi-year) assessment carried out through semi-structured interviews. We found the methodology valuable for facilitating discussion among different stakeholders, who were able to identify context-related challenges (land fragmentation and land abandonment, stakeholders' limited collaboration, controversial drives of European funding) and possible strategies for producing a fire-resilient landscape (community management forms of pastoralists activities for maintaining land cover diversity). The approach also triggered a positive process for longer-term change. By analysing the outcomes, we are able to identify four key recommendations for future work using serious gaming for sustainable landscapes: 1) aim for an even composition of session groups, 2) consider the multiple levels of organisation in the area, 3) use the allocation of game roles to disrupt power dynamics, and 4) seek to involve the broadest stakeholder spectrum in developing the game itself.

Keywords: serious game, fire risk, fire-resilient landscape, participatory research

1. Introduction

Wildfires have severe impacts on ecosystem services and human health worldwide, including casualties, negative consequences on air quality and effects on the global carbon budget (Bacciu et al. 2022). The annual cost of wildfires in the United States alone is estimated at between \$71.1 billion and \$347.8 billion (UNEP 2022), while in 2023 wildfires affected an area of more than 500 000 ha in the European Union countries, causing severe damage to the environment and producing around 20 megatonnes of CO2 emissions (San-Miguel-Ayanz et al. 2024).

Wildfire governance in a context of global change requires a strategy addressing the physical, biological, and socio-economic processes that drive the phenomenon in a landscape (Bowman et al. 2013; Bacciu et al. 2022; Kirschner et al. 2023). In Europe, land governance actions aim to manage some critical causes of wildfire impacts (e.g., landscape flammability, rural land abandonment, illegal fire uses, lack of community-based fire adaptation) by promoting the development of fire-resilient landscapes (Moreira et al. 2020). This means territories where

7₄₀ governance actions exert leverage on the wildfire regime so that its effects are compatible with 8₄₁ the delivery over time of key ecosystem services (e.g., water supply, primary productivity, 942 biodiversity) and with the socio-economic system in the area (e.g. agroforestry productions, 1043 tourism, energy industry) (Fernandes 2013; Thacker et al. 2023).

1244 Consequently, in many European territories, wildfire governance programs are in place that 1345 integrate strategic fuel management planning for direct prevention (e.g., strategic fuel breaks supporting active firefighting) with the planning of socio-economic activities that have an indirect 1446 fire regulatory effect by creating a mosaic less prone to fire in synergy with direct prevention, such 1547 as agro-silvo-pastoral value-chains, biodiversity conservation or energy supply (Tedim et al. 2016; 1648 Pais et al. 2020; Spadoni et al. 2023; Pulido et al. 2023). 1749

18 19 50 51 20 52 21 53 22 54 However, the possibility of creating sustainable processes to achieve fire-resilient landscapes requires collaboration among multiple stakeholders (e.g., forest managers, private owners, nature conservation agencies, and enterprises in the agro-pastoral, food, energy, or tourism sectors) with interests in the territory that often appear challenging to synergize or even conflict (Canadas et al. 2016). Developing a common, shared strategy to promote integrated planning 23₅₅ processes for fire-resilient landscapes requires participatory decision-making that facilitates 24 56 adaptive learning, understanding the interests at stake, and collaboratively defining win-win 25₅₇ 26 strategies that activate sustainable processes over time (Ascoli et al. 2023, Otero et al. 2018).

2758 The use of games in natural resources management has increasingly received attention in recent 2859 years for conflict mediation, social learning and collective decision-making (Madani et al. 2017; 2960 Wesselow and Stoll-Kleemann 2018; Flood et al. 2018; Rodela et al. 2019). Companion Modelling 3061 (ComMod) emerged as a gaming approach, relying on "the synergistic effects between role-3162 playing games (RPG) and agent-based models (ABM) to facilitate information sharing, collective 3263 learning and exchange of perceptions on a given concrete issue among researchers and other 3364 stakeholders" (Ruankaew et al. 2010). On the one sidehand, agent-based modelling (ABM) is a 34⁶⁵ well-known methodology for analysing the interactions between people, things, places and time. 3566 ABM is often used in socio-ecological system studies to integrate human behaviour models with 36⁶⁷ ecological models (Kline et al. 2017) and a variety of applications in wildfire research exists in the 37⁶⁸ literature (Millington et al. 2008; Charnley et al. 2017; Spies et al. 2017; Ribeiro et al. 2023). On 38⁶⁹ the other hand, serious games are an innovative participatory approach to exploring, learning 39⁷⁰ about, and discussing the complexity of the socio-ecological system, especially when many 39 40⁷¹ 41₇₂ 41₇₃ 42 conflicting interests exist in it (Speelman et al. 2018). Games can support collective negotiations and help define common strategies toward a collectively recognised problem, putting into play the participants' perception of the problem and their experience.

4374 Examples of serious games dealing with wildfire risk exist in the literature, focusing on different 4475 aspects of risk management, such as firefighting training simulation (Backlund et al. 2007, 4576 Caroca et al. 2019), emergency decision-making (Ji et al. 2024), disaster preparedness (Johns et 4677 al. 2024) and social awareness (Pereira et al. 2014). However, they were developed to strengthen 4778 risk preparedness and response, while, to our knowledge, a serious game focusing on building 4879 fire-resilient landscapes involving both direct and indirect fire regulatory processes has not been 4980 developed yet. Moreover, none of the cited works successfully represent the interaction between 5081 the diverse perspectives and priorities of local stakeholders. Representing and putting them into 5182 play is crucial for supporting a participatory process where indeed those interactions must be 5283 taken in consideration, discussed and leveraged for developing successful wildfire impacts 5384 mitigation strategies.

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 Examples of serious games dealing with fire risk exist in the literature, such as focusing on firefighting training simulation (Backlund et al. 2007, Caroca et al. 2019), emergency decision-making (Ji et al. 2024), disaster preparedness (Johns et al. 2024) and social awareness (Pereira et al. 2014). However, to our knowledge, a serious game tackling the issue from a wider landscape fire prevention perspective and taking into consideration the diverse perspectives of local stakeholders has not been developed yet.

1491 This work aims to address the need for collaborative decision-making to develop integrated 1592 planning processes for fire-resilient landscapes by presenting and assessing an innovative 1693 participatory approach based on ComMod principles, focused on exploring land management 1794 strategies for landscape fire resilience. We tested the methodology in a study area located in the 1895 Italian Alps, by (1) developing an ABM representing the effect of forest and pasture management 1996 actions on wildfire risk in Valchiusella, (2) creating the game *A Picit Jeu¹* game using the model for 2097 exploring the results of different strategies, and (3) using *A Picit Jeu* for involving local 2198 stakeholders in collective discussions on land management scenarios for fire prevention.

This work also intends to contribute to the research gap in impact assessment of games used in 23₁₀₀ 24₁₀₁ 25₁₀₂ natural resource management (which has largely been absent or only short-term focused; Calderón and Ruiz 2015; Rodela and Speelman 2023) by presenting a multiple-time-frame evaluation of the impact of the game experience. A short-term assessment was supported by the observation and recording of the game sessions, and by participants' feedback via end-of-session debriefings and questionnaires. A long-term evaluation was carried out two years later by interviewed participants to explore what influence the game subsequently had on land management decision-making and the network of stakeholders concerned. We describe the results of such a multiple-time-frame impact assessment, while discussing its advantages and limits.

The following section presents the study area and describes in detail the procedure adopted. We
then introduce and discuss the results of the game development process, of the game sessions
and of the evaluation steps. In the Conclusion section, we consider what lessons can be learned
to apply in other landscapes and contexts.

2. Materials and methods

2.1 Study Area

The study area is Valchiusella, an Alpine valley of about 143 km² in the northwestern part of Italy, in the Piemonte region.

¹ The game's name "A Picit Jeu" is a word pun in the local dialect of Valchiusella, meaning "a small game" but sounding also close to "A Picit Feu", which literally means "over small fire" and refers to a phenomenon evolving slowly.



Fig. 1. Map of the study area. In (a) the extent of the forest cover, pioneering shrublands and grasslands is shown. The forest cover and pioneering shrubland layer are taken from the regional forest map (last update in 2016, https://www.geoportale.piermonte.it), while the grassland cover is derived by subtracting those from the "Grasslands, meadow pastures, bushes" layer (derived by elaboration of the IPLA Land Cover 2003 and available at https://geoportale.igr.piermonte.it). The layer does not include rupicolous grasslands. (b) and (c) place the study area at a national and regional level, respectively.

The valley's altitude ranges between approximately 400 m and 2800 m for the highest peaks. The surface is divided into eight municipalities, with a total resident population of 5161 inhabitants on 1 January 2023 (data available at https://dati.istat.it). The population has gone through a process of depopulation typical of Alpine valleys since the end of the 19th century, which was characterised by the abandonment of traditional farming activities (MacDonald et al. 2000). This process has also caused the still ongoing expansion of pioneer vegetation – tall grasses, shrubs, and trees – on abandoned pastures, with tangible effects on fire hazard (Ascoli et al. 2020, 2021). The local fire regime is characterised by a predominance of fires during winter and close to it (see data available at https://www.geoportale.piemonte.it/geocatalogorp). In this season the fully cured vegetation, lower rainfall frequency, and warm, dry foehn winds increase the probability of accidental ignitions producing extensive fires (Valese et al. 2014), such as the one occurred in April 2022 in the municipality of Rueglio, which involved around 300 ha of pastures and forests and caused severe damages to some buildings (local forest technicians, personal communication).

4738 Valchiusella forestry area, which covers around 43% of the total surface, is shared between
private owners and municipalities. A prominent role in forest management is played by the
Consorzio Forestale del Canavese (CFC). The CFC was born in 2002 as a unitary management
body for a non-administrative region including Valchiusella, with the aim to support the
sustainable management of forests from a multifunctional perspective and through long-term
planning. The CFC manages 1977 ha of forest surface in the valley (32% of the total forest surface)

almost entirely belonging to seven out of eight municipalities (CFC forest technicians, personal communication).

Most of the alpine pasture areas of the valley are owned by the municipalities. Farmers typically rent those lands with multiannual contracts and bring their animals to graze in summer. Usually, 12⁴⁸ 13⁴⁹ a nearby municipal alpine hut is rented together as a shelter for animals and a temporary residence for farmers.

The existence of a variety of public and private stakeholders of forest and pasture management, together with the challenges caused by the rural abandonment process to fire prevention, makes Valchiusella an excellent case study for the purposes of this work.

2.2. The game design

The design of A Picit Jeu was based on four phases (Figure 1): 21⁵⁵ 22⁵⁶ 23⁵⁷ 24⁵⁸

- 1. analysis of the local context through semi-structured interviews;
- 2. definition of the conceptual model of the local socio-ecological system (SES);
- 3. implementation of the agent-based model;
- 4. definition of the role-playing game mechanics.

Phases 3 and 4 were carried out at the same time and implied a continuous interaction with each other. 28161 29162 29163 30164 31

Three review steps were taken at different moments of the game design process. The aim was to verify the appropriateness of the representation of the socio-economic and ecological dynamics of the study area context, as well as the playability of the game. They involved local technicians of the CFC and researchers in the domain of geography, land management, and wildfires.



50¹⁶⁵ 51¹⁶⁶ 167 52 Fig. 2. Diagram of the four-phase methodology adopted for the game design. The three review steps are represented in green boxes.

2.2.1 Context analysis

The methodology proposed in this work for the game design aims at tailoring the game dynamics
to the specific context it is conceived for. The analysis of the context was conducted through
semi-structured interviews with local stakeholders, focused on the interactions between human
and ecosystem dynamics in the framework of wildfire risk.

Twenty-five interviews were carried out, involving 27 interviewees. The interviewees were identified among five categories of stakeholders involved in local land management, forest management and wildfire issues:

- Mayors or municipal administrators in charge of land management tasks contacts were provided by the CFC.
- Forest firefighter volunteers priority was given to the firemen of each local volunteer firefighter team. Four valley municipalities had their own team at the moment of the interviews: Val di Chy, Rueglio, Traversella and Vidracco. The head of the Valchiusella section was also interviewed.
- Forest workers the owners of the forestry companies registered in the official provincial list were interviewed. Other respondents were contacted thanks to the indications provided by the CFC. In addition, members of a land consortium existing in the northern part of the valley were interviewed.
 - Members of local environmental associations selected on the recommendation of association leaders.
 - Farmers respondents were first identified among the members of a local association of producers for the promotion of local cheese. Other interviewees were suggested by the already involved farmers ('snowballing').

3 3 191 3 4 192 3 5 193 3 6 194 3 7 195 3 6 294 3 7 195 The interview canvas was made of 20 questions focused on the personal relationship with the local community, the experience with forest management, the role of wildfires in the ecosystem and the existing fire prevention strategies, the local forest management status and actors, and the value of ecosystem services. The interviews were carried out over around two months, so it is possible that some early participants had the opportunity to exchange ideas about the questions' 38₉₆ content with later participants before their interviews. However, this is not a limitation for our 39 197 work given that the purpose of this activity was to get an overview of the interactions between 40₁₉₈ human and ecosystem dynamics and of the local challenges related to wildfire risk, instead of a 4199 precise personal point of view. Moreover, any exchange of ideas between stakeholders already 4200 happening at this time was perfectly in line with the general aim of this work of fostering 43201 collaborative decision-making.

1 Interviewees' answers were analysed through thematic analysis (Braun and Clarke 2006) to
identify the recurrent topics and mapped into thematic areas. For each of the seven thematic
identify the recurrent topics and mapped into thematic areas. For each of the seven thematic
areas mapped, a specific issue directly or indirectly related to wildfire prevention in the valley was
formulated, based on the respondents' contribution. Finally, each issue was translated into a
precise purpose to be integrated into the game's design, such as a specific topic on which the
game should trigger discussion or concerning which it should help a learning process.

2.2.2 Conceptual model definition

6 7208 9209 1 0210 For designing game mechanics representative of the real-world situation, a conceptual model of local Social Ecological System fire prevention issues was defined. A procedure adapted from the ARDI method proposed by Étienne and colleagues (Etienne 2009; Etienne et al. 2011) was used. The ARDI method was conceived in the framework of the ComMod approach for building a shared description of the SES among the stakeholders involved in the process, representing its elements by means of diagrams. In this work, the four ARDI elements and steps (Actors, Resources, Dynamics and Interactions) were used by the authors as a guideline to formalize the insights collected through the interviews into an SES conceptual model serving the design of the game mechanics.

2.2.3 Agent-based model implementation

1211 1212 1213 1213 1415 1617 19202 2222 22222The SES conceptual model was then transformed into an agent-based model (ABM) in NetLogo. The NetLogo language was chosen because of its free access, wide diffusion in environmental studies, ease of learning, and good user support (Kravari and Bassiliades 2015; Wilensky and Rand 2015). The interface tab of the model was designed to be used as the 'board' of the game by projecting it on a screen clearly visible to all the players. The model was created with a series of commands the game master can enter during the simulation depending on players' decisions 25/225 about forest and pasture management actions. The game was intended to reproduce a primary 26226 general pattern: the less players undertake landscape management actions (e.g., by thinning and 27227 cutting forests or grazing pastures), the higher the probability that a fire will burn a large land area. 2&28 The detailed description of the model following the ODD standard protocol for ABMs (Grimm et 29229 al. 2006) and the model code itself are published in (and downloadable from) the COMSES library 3 @ 30 (Vigna and Millington 2024).

31 2.2.4 Game mechanics definition 32231

33232 While coding the ABM, the game mechanics were also defined. This step was based on a 3 42 3 3 translation process of the actors, resources, dynamics and interactions of the SES conceptual 35234 model into game roles and mechanics, such as players' actions on the board, players' 36235 interactions, game materials and spatial and temporal settings. Since this step was strictly 37236 dependent on the previous step and vice versa, a continuous interaction between the two was 38237 necessary to shape the game mechanics to the model's possibilities and to adapt the model to 39238 the needs of the gameplay.

40 41²³⁹ 2.2.5 Review steps

4240 The first review step was carried out after the conceptual model definition phase. The main aim 43241 was to assess the adequacy of the representation of the local SES, highlighting missing elements 44242 and incorrect dynamics. It involved a forest technician, an agronomist and a naturalist-biologist, all working for the CFC. They were chosen for their expertise in the relative fields and their direct 4 243 48244 experience of the local context, including socio-economic dynamics.

47245 The game was then reviewed through two pilot sessions. The first one involved only researchers 4&46 in geography and fire management disciplines, while the second one involved both researchers 49247 and a forest technician from the CFC. The pilot sessions aimed at assessing the scientific 50248 correctness of the dynamics represented and the game's playability, including the 51249 appropriateness of time management in the different game phases and of the supporting

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materials. These pilot sessions allowed for improvements both to the gameplay and to the ABM code.

10252 2.3 The game sessions

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Three game sessions were organised in the valley, with the collaboration of the mayors of the municipalities where they were held. The municipalities (named A, B and C from now on to anonymise participants) were located one at the bottom of the valley, one in the middle and one in the upper part. The collaboration with the mayors was crucial for the involvement of the participants: stakeholders involved in local land and fire management, belonging to the same 16258 categories listed in Section 2.2.1, plus local forest and naturalist experts, and citizens particularly 17259 interested in the topic of the game (Figure 3). Each participant, while bringing their personal 1260 expertise to the participatory activity, was asked to choose a role in the game that differed from 19261 the one they had in real life.





Fig. 3. Categories of stakeholders participating in each game session.

37264 Each session was led by a facilitator and structured with a preparation phase (presentations, 3 82 65 instructions, role assignment, and game material allocation), a play phase, and a debriefing 39266 phase. According to Crookall (2010), debriefing is "the occasion and activity for the reflection on 4 (267 and the sharing of the game experience to turn it into learning". It consists of a structured 4 1268 discussion about what happened during the game and how to relate it to the participants' real-4269 life experiences (Adolph et al. 2023). The facilitator encouraged the discussion by asking relevant 4370 questions to the group, starting by sharing observations of participants' spoken remarks, actions 4471 and behaviour during the gameplay. Some quantitative plots derived from the ABM simulation 45272 were also used. See the Supplementary Material for the guideline questions used for the 46273 debriefing discussion.

4 274 The game sessions were entirely recorded with a video camera and a recording microphone. The 4&75 analysis of the recorded material and the real-time observation notes made by researchers aimed 49276 at understanding the behaviours of the players, their strategies in the game, their corresponding 50277 actions in the real world, their point of view on management issues, the challenges they face in 51278 their real-world roles, and their vision of the local SES. The focus was also on assessing A Picit 52279 Jeu effects on enhancing the discussion, facilitating mutual understanding, and sharing of

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information. An observation protocol was developed as a guideline (see the Supplementary Material).

282 2.4 The process evaluation

In addition to the direct observation and the feedback collected during the debriefing, an evaluation survey made of a mix of open and Likert-scale questions was administered to the participants at the end of each session. The survey focused on how players felt during the game, on the perceived utility of the experience, on the adequateness of the game for facilitating the discussion and understanding other stakeholders' opinions, and on the opportunity for the players to learn and share new insights on the SES dynamics (see <u>Table 2Figure 1</u> in the Supplementary material for the complete list of questions).

Finally, five semi-structured interviews were conducted approximately two years after the game sessions, to assess the potential long-term direct and indirect impacts of the process on local collaborations and initiatives. The interviewees were the director forest technician of the CFC, the leader of a volunteer firefighter team, two mayors, and a member of an environmental association, all of whom had participated in the game sessions.

3. Results

3.1 Game overview

The analysis of the initial interviews with local stakeholders pointed out seven thematic areas. In Table 1 we summarize the focus of each thematic area, the specific issue directly or indirectly related to wildfire prevention in Valchiusella, and its translation into game purposes.

Table 1. Correspondence between thematic areas, issues related to wildfire prevention and game focus.

Thematic area	Wildfire prevention issue	Game purpose				
1. Economic sphere	Forest management and territorial management are now less economically sustainable than in the past.	Enhancing discussion between the different stakeholders about how to manage forest lands in an economically sustainable way.				
2. Planning	Long-term and valley-level planning are often missing in Valchiusella.	Promoting discussion between decision makers about a long-term and valley- level planning project.				
3. New generations	People in the valley, and specifically new generations, often are not aware of the role of territorial management in wildfire risk mitigation.	Raising awareness among the population about these topics.				
4. Intergroup conflicts	Conflicts between old residents and new inhabitants exist.	Helping dialogue between different groups of inhabitants and facilitating mutual understanding.				

5	 Ecological sensitivity 	The interactions between	Helping participants
		ecological dynamics and	understand interactions
		socioeconomic activities are	between the natural
		not always clear for all	ecosystem and the socio-
		people.	economic system.
6	 Rural abandonment 	Land abandonment is a	Reducing private forest
		major issue, mainly for	parcel abandonment by
		private forest parcels.	promoting their collective
			management.
7	. Wildfires	The effects of rural	Helping participants
		abandonment on fire risk are	understand the effects of
		not clear for all inhabitants.	rural abandonment on fire
			risk and the need to manage
			it.

In order to allow participants in game sessions to collectively analyse and discuss dynamics and challenges they face in real life, it is crucial that the challenges and mechanics represented in the game correspond to those the players deal with in their real life in the specific context. The game design was then guided by the content of the interviews, while the various review steps described in Section 2.2.5 ensured appropriate representation of the local SES and scientific accuracy of the game content. Therefore, the seven thematic areas guided the definition of the SES conceptual model based on the ARDI steps and, later, its translation into game elements and mechanics. For clarity, Figure 4 shows the components of the SES conceptual model already represented according to game mechanic categories instead of original ARDI categories: players' roles (instead of actors), land resources, players' interactions, and player-resource interactions.



Fig. 4. Overview of the game roles, land resources and interactions.

Four game roles were identified:

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- The municipal administration, represented by the mayor, who delegates the management
 of forest parcels to the technician of the forest consortium and rents the public pasture
 parcels to the farmers;
- 1218-The forest consortium, represented by a technician, who is in charge of managing (i.e.1319cutting and thinning) public forest;
- 1 420-Farmers, who graze their cow herds on public pastures that they rent. One or two farmers1 321can be in the game.
- 1 622-Private forest owners, who manage their own forest parcel. Three forest owners are in the1 723game.

During the game, the mayor and the technician of the forest consortium must agree on the management plan of public forests and on how to share the economic costs for thinning and the economic gains for cuts. The mayor and the farmers must negotiate the price for renting public pastures. The private forest owners can ask the forest technician for technical information, such as the stumpage value of their parcel. The forest technician is also able to assess each land parcel's wildfire hazard and can decide to share this information with the other players.

2530 Three kinds of land resources were identified: forests, pastures and pioneer shrublands. These
2631 were used for characterizing the space represented by the ABM, made of 20 land parcels (Figure
2732 5). A number of functions representing the action of the players on the land parcels were coded
2633 in the ABM: cutting and thinning the forest parcels, grazing the pasture parcels, building or
2634 maintaining the huts of the pasture parcels, converting to forest, or to pasture the pioneering
3635 shrubland parcels.

- $\begin{array}{c} 31\\ 32^{336} \end{array} \ \ \, \mbox{Three kinds of dynamics were also identified in the SES:} \end{array}$
- 3 337-Ecological dynamics:3 4381.The natural re
 - The natural reforestation of abandoned pastures, which leads to the growth of a more flammable pioneer vegetation;
 - 2. The behaviour of fire, which is more likely to burn more flammable lands than others;
 - 3. Fire hazard dependence on climate conditions;
- 3 3 343- Social dynamics:4 3444. The comm
 - 4. The common lack of interest on the part of private forest owners in their parcels, which usually leads to their abandonment;
- 4 2846 Economic dynamics:
 - 5. The pastoral products market variations;
 - The variation in the cost of forest operations, such as cut and thinning, and of wood prices because of market changes;

4650These dynamics were crucial in characterizing the ABM. According to dynamic 1, ungrazed4351pasture parcels become pioneer shrubland after some rounds. Dynamic 2 was used to code the4852fire behaviour in case of ignition. Dynamic 4 was used to code the behaviour of four autonomous4953agents representing private forest owners. Dynamics 3, 5 and 6 were translated as possible5054scenarios to be set at the beginning of the ABM simulation.

- 51 5255 Finally, a time duration of 50 years was chosen for the game, as a relevant amount of time from a 326 silvicultural point of view. The players are asked to take actions every 10 years, for a total of five
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game rounds. Between each round, the ABM simulates forest growth and the effects of their actions on the land parcels. Moreover, at the beginning of the third or fourth round, the model simulates the behaviour of three wildfires, ignited randomly on the landscape. More thinned and younger forests are less likely to burn than older and less thinned (or unthinned) ones, while pioneer shrublands are the most likely to burn (see ODD description for more details, Vigna and Millington 2024). During the game, the players have to deal simultaneously with the economic constraints imposed by their limited resources and the cost of their actions, and with the impact of their management decisions on the likelihood that wildfire events will affect land parcels.



Fig. 5. Screenshot of the interface of the ABM, used as the 'board' of the game. The colours of the land parcels correspond to the three different land use types and to the age of forests. The house icons represent huts on the pastures. The human figures identify the forest parcels owned by the private owner players and by the autonomous agents. Three fires have spread on the landscape in the simulation represented.

3.2 Game sessions' outcomes

During the three game sessions, the level of involvement in the activity and amusement of the participants was generally high. The mean score in the answers to the question "Did you have fun" in the final survey was 6.3 on a 1 to 7 Likert scale (see <u>Table 2Figure 1</u> in the Supplementary material for a complete overview of answers to the final questionnaires). However, some participants were more active than others. This was particularly evident in Municipality A, where some participants took a driving role in the collective decisions, while some remained more in the background and expressed less. The Municipality A session involved a higher number of participants compared to the other two, which could, in part, explain this fragmentation in participants' involvement. Moreover, existing friendship links were discernible in the group and tended to affect the interactions in the game.

In addition, in Municipality A and B the mayors had a very active and central role in game interactions. This is partly explained by the fact that, in both situations, the mayor was playing the role of the forest technician, which is particularly influential in the game mechanics. Moreover, their real-life leadership role probably influenced their role in the game.

385 For some participants it was also easier to understand the game rules and mechanics than for 8386 others, placing them in an advantageous position. This advantageous position allowed them to 387 be more influential in the collective decision-making and to guide the discussions. The mean 10388 score of the question "Was it easy to understand the rules of the game?" on a 1 to 7 Likert scale 1 389 was 6.3 in Municipality A (median value: 6), 6.7 in Municipality B (median value: 7) and 4.8 in 12390 Municipality C (median value: 5.5). In Municipality C, no participant adopted a guiding role in the 13391 discussions and the group generally complained about the short time available for discussing the 14892 implications of the activity during the debriefing phase, since it took them a long time in the 15393 beginning to understand the game functioning. Time constraint was generally an issue. All the 16394 sessions took place in the evening, to allow the participation of all stakeholders, particularly 17895 farmers whose work does not include days off. However, this choice reduced the time available, 1896 often at the expense of the debriefing phase.

19₃₉₇ 20₃₉₈ 21₃₉₉ The exchange of roles was generally perceived as very helpful. As an example, the forest technician playing the role of the mayor in Municipality A session declared during the debriefing that he found that "the difficulty of this is that you have to interact with multiple stakeholders at 22400 the same time. You have to deal with many people and issues simultaneously, which differs from 23401 my situation. Money comes in one way and goes out another, and, in the end, it all goes out! This 24402 is maybe something trivial, but I was able to experience it this evening." In this regard, the 25403 absence of some crucial stakeholders in some sessions limited the outcomes. More specifically, 26404 in Municipality B the participants largely discussed the role of modern farming techniques and a 27405 general lack of care in land maintenance on the farmers' side in contributing to the expansion of 28406 the pioneering shrubland on pastures. However, no farmers were present in the session to 29407 contribute their points of view and highlight their challenges. In Municipality C, the role of CFC in 3 0408 Valchiusella was unclear to most participants, but the absence of CFC technicians prevented a 3 1409 helpful exchange of information on this point.

32 410 33 411 The game proved to be an effective tool in helping the discussion about land management issues and strategies. The participants were able to identify and analyse the challenges for a fire-resilient 34 3412 35 413 landscape in Valchiusella, such as land fragmentation, obstacles to stakeholders' collaboration, and controversial drives of European funding. Land fragmentation was identified as a major driver 36₄₁₄ of land abandonment, since it challenges large-scale planning of the landscape. Concerning 37415 obstacles to collaboration, participants identified two main elements: the scarcity of economic 38416 resources and a cultural aspect. Resource constraints force stakeholders to focus on their short-39417 term economic sustenance instead of long-term and shared plans, whereas the local culture 40418 places a solid value on private properties, especially forests. Private forests are sometimes 41419 exploited for family firewood consumption but are more often not managed at all. However, 42420 owners are frequently unwilling to give up the right to manage their parcels, even when they are 43421 not interested in doing so themselves: the land is not transferable because it was inherited from 44422 ancestors, belongs to the family, and will go to their children. This phenomenon doesn't concern 45423 new inhabitants of the valley, who are likely to be more open to forms of collective parcel 46424 management, such as Land Consolidation Associations (Beltramo et al. 2018). Finally, on one 47425 side, the direct funding to farming activities linked to the Common Agricultural Policy helps to 48426 keep this traditional practice on the land, also enabling young people to start their pastoral 49427 activity; on the other side, it pushes farmers to expand the herd and graze a large extent, without 5 (428 keeping attention to the sustainable management of pasture, since the grazed area is the only 51⁴²⁹ parameter deciding the amount of funding.

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Z430 The game sessions were also helpful in brainstorming possible strategies to directly or indirectly ⁸431 help the creation of a fire-resilient landscape. For example, a participant expressed the need to 9432 diversify the spatial distribution of land cover, in line with findings about the role of landscape 10433 spatial heterogeneity in reducing the spread and intensity of fires (Parsons et al. 2017; Vacchiano 1434 et al. 2021). This is challenged by the widespread abandonment of private parcels and thus the 12435 transition from a complex alternation of open spaces and different densities of forest cover to a more homogeneous and dense forest cover. Another participant suggested the use of prescribed 13436 14437 fire and experimental fire prevention action. Moreover, different forms of collective management 15438 concerning pastoralist activity came out during the debriefing phases, such as a community-16439 based cooperative for obtaining other kinds of European funding for land management and 17440 development, a solidarity buying group for shortening the supply chain between producers and 18441 consumers of milk products, and a valley consortium dairy for lowering the cost for farmers to transform milk into cheese. 19442

20 2⁴43 3.3 Long-term evaluation

2 2144The interviews carried out *circa* two years later are part of the attempt to evaluate the effect of the2 3145experience from a broader point of view than individual game sessions, considering the game not2 4146only as a tool to facilitate discussion on the spot, but also as a positive process trigger for longer-2 5147term change. This is linked to the use of the game experience to raise awareness among the2 6148participants about the importance of a shared planning strategy and effective land management2 7149activities, and to foster interactions and collaboration.

28450 The outcomes of the interviews proved some long-term positive effects on the collaboration 29451 among the CFC and the other stakeholders, specifically in one of the municipalities, some private 3Q₄₅₂ owners, and the volunteer forest firefighting teams of the valley. However, they also highlighted a 3 4 5 3 different perception and awareness among the interviewees of the game sessions' role in 32454 facilitating this positive process, as well as the difficulty of entirely attributing it to the game 33455 experience. For example, a stronger collaboration between the CFC and the firefighting teams 34456 was brought to the partnership via a financed local development project linked to fire risk. 35457 According to the CFC director forest technician, this was made possible by the participation of 36458 both in the game sessions and, also, in an event organised one year later for sharing the research 37459 results with the local community. However, according to the firefighting team leader, it is difficult 38460 to exclude that it would have happened anyway and that a positive process was already ongoing.

Interestingly, the experience does did_not seem to have positively impacted the interactions between the CFC and the local environmental associations. Both the director of the CFC and the environmental association member referred to the creation of a new association during the twoyear period by this latter actor and some other local citizens, all new inhabitants of the valley, with the expressed aim of preserving local forests from exploitation. Its members often denounce the CFC actions as part of an exploitation process and complain about the lack of consideration for their point of view. The conflict thus seems to have worsened in this case.

 4^{+} 68Finally, a positive effect was found in the interactions between the CFC and the University of Turin 4^{+} 68institution itself, thanks to the involvement of the CFC technicians not only in the game sessions 4^{+} 70but also in the review steps of the development process. Other collaborative activities have since 5^{+} 071been carried out.

5 1/72Figure 6Table 2summarizes the main points presented in the Results section, by highlighting the5 1/73positive outcomes and long-term effects of the process, as well as its challenging aspects.

POSITIVE OUTCOMES AND LONG-TERM	
EFFECTS	CHALLENGING ASPECTS
High involvement of the participants	Different level of participants' contribution the discussions
Understanding of other roles' challenges	Difficulties in understanding the game rules
Identification of the challenges for a fire- resilient landscape	Time constraints
Identification of direct and indirect strategies for a fire-resilient landscape	Lack of stakeholders' representation in sor game sessions
Enhanced collaboration between some stakeholders	Uneven enhancement of collaboration a awareness of the process
Enhanced collaboration between the CFC and the University of Turin	
Positive <u>outcomes</u> and long-term <u>effects</u>	Challenging aspects
High involvement of the participants	Different level of participants'
 Understanding of other roles' challenges 	contribution to the discussions
 Identification of the challenges for a fire- 	 Difficulties in understanding the game rules
	Time constraints
resilient landscape Identification of direct and indirect	
resilient landscape Identification of direct and indirect strategies for a fire-resilient landscape 	 Lack of stakeholders' representation in some game sessions
resilient landscape Identification of direct and indirect strategies for a fire-resilient landscape Enhanced collaboration between some stakeholders 	Lack of stakeholders' representation in some game sessions Uneven enhancement of collaboration
resilient landscape Identification of direct and indirect strategies for a fire-resilient landscape Enhanced collaboration between some stakeholders Enhanced collaboration and between 	 Lack of stakeholders' representation in some game sessions Uneven enhancement of collaboration and <u>awarness of the process</u>

$_{3780}^{36}$ 4. Discussion

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38481 A Picit Jeu game sessions demonstrate the multifaceted results that can come from the 39482 collaborative process of serious gaming, which allows both the researchers and the players to 40483 learn. The participants' discussions drew our attention to some issues affecting the SES, on 41484 which planning strategies need to focus across different scales, such as the organisation of 42485 pastoral funding, the attitude of the inhabitants toward collective management, and the lack of 43486 information about CFC activities and opportunities for forest owners. At the same time, the game 44487 sessions gave stakeholders the opportunity to identify these issues, question their points of view 45488 and start a dialogue, sometimes also resulting in strengthened collaborations. The observation 46489 of the sessions and the outcomes of the evaluation interviews allow us to discuss some focal 47490 points and identify more general lessons valuable for others using serious gaming to negotiate or 4 8491 inspire collaboration between stakeholders in developing fire-resilient (or otherwise sustainable) 4 g492 landscapes.

5 Q93First, a significant effort needs to be made in defining the group of participants. In this work, the5 494game sessions were organised in collaboration with the mayors of the municipalities, who5 495oversaw the invitation of the participants, leaving the researcher a lower control over their

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7496 selection As explained by Barreteau and colleagues (2010), a requisite for the success of a 8497 participatory processes as ComMod is that the participants in the collective action dynamics 9498 accept them to the point of participating in them. What makes this possible is very often a local 10499 anchoring, which is provided by the social capital of those who are promoting the process. The 11500 help from the village mayors, who have a dense relation network in the area, allowed us to 12501 successfully reach out to stakeholders that would have been less likely to respond to our direct 13502 invitation, overcoming people's scepticism toward a novel methodology and generating interests 14503 and curiosity instead. Even if the mayors were in charge of disseminating the invites, we put in 15504 place two measures for assuring appropriate representativeness of the stakeholders: first, the 16505 mayors were all provided with a list of stakeholder categories that needed to be involved; second, when the mayors were unable or uncomfortable in inviting people from one or more categories, 17506 1\$507 the researchers did it. This was the case, for example, of the members of the local environmental 19508 associations, who are often new inhabitants of the valley and whose presence in two of the three 2\$⁰⁹ game sessions was assured by a direct invitation from the researchers.

21/₅₁₀ However, despite these measures the difficulty of involving a representative of each category in all the sessions caused some unevenness in the composition of the groups, as highlighted in the Results section. The participants criticized this unevenness both during the debriefings and in the evaluation interviews.

2 + 11 2 + 12 2 + 13 2 - 5 + 14Related to the previous point, in two game sessions, a certain power imbalance between the participants was felt, as the mayors were particularly influential on the game dynamics, helped also by the role they were assigned. Power relations influencing the game is a crucial point in this kind of experience and needs great attention and effort from the facilitator (Garcia et al. 2022). Similarly, pre-existing relationships between the participants can make someone feel more entitled to express their opinion to the group than others. Stakeholders with a stronger power position can impose their ideas on the discussions and ignore others, while a lack of selfconfidence, freedom of expression or understanding of the issues at stake can limit a player's ability to defend their interests (Barnaud et al. 2010). In this work, a more attentive choice of the 34 523 game roles would have benefited the group dynamics, by deliberately assigning less influential 35 524 roles to the participants with more influential roles and leadership attitudes in the real world. This 36525 is supported by the fact that no power imbalance was witnessed in the Municipality C game 37₅₂₆ session, where the mayor played the less influential role of a private forest owner. 38

3 \$ 27 The second lesson learned concerns the inclusion of the game sessions in a broader participatory 4\$²⁸ process. The ComMod approach from which this work was inspired clearly places the use of the 41⁵²⁹ game simulations as only one of the steps of a structured participatory process (Daré et al. 2015). 42530 42531 44533 44533 45534 45534 46535 47536 47536 45536 45536 Stakeholders generally engage actively in this modelling process from the early stages (Basco-Carrera et al. 2018). The benefit of involving stakeholders in designing the model on their perceived legitimacy of the model outcomes is well documented in the literature (Van Berkel and Verburg 2012), and the challenges for evaluating models where this is not the case have also been demonstrated (Millington et al. 2011). This allows the decision-makers to take ownership of the model, which is a requirement for the success of the process (Joffre et al. 2015). This process, however, takes time. Because of the limited resources, we chose to involve only the CFC technicians in ABM and game design. During gaming sessions no player ever directly questioned 49538 the representation of the local SES in A Picit Jeu in terms of ecological or socio-economic 50₅₃₉ dynamics. However, two criticisms were raised during the debriefings: that the game mechanics 5] 340 (i) push the players to focus on the economic value of forests and pastures at the expense of other 52₅₄₁ kinds of values, and (ii) could transmit the message that assigning uses other than "wood

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production" to forests (for example by creating a protected area with no cutting activities allowed) is always negative, since the ABM fire behaviour simulation rewards the owner of young and thinned forests more than the owner of old and not managed ones. These two aspects could have been taken into consideration in the game development if all the stakeholders had been involved in the creation process.

 $12 \\ 13547 \\ 1448 \\ 1550 \\ 16551 \\ 17552 \\ 18553 \\ 19554 \\ 2955 \\ 2955 \\ 10554 \\ 2955 \\ 10554 \\ 2955 \\ 105555 \\ 105555 \\ 105555 \\ 105555 \\ 10555 \\ 10555 \\ 1$ Moreover, we argue here that the benefits of involving stakeholders from the modelling step go beyond the legitimation of the game session's results and concerns also other less tangible outcomes, such as the enhancement of networks and collaborations and the perceived consideration for one's perspective in the collective debate. The long-term evaluation interview highlighted the benefits perceived by the CFC director forest technician on the interactions between the CFC and other local stakeholders, as well as the University of Turin. This was made possible by the involvement of the CFC technicians in the whole process, from the revision steps to the sharing of the process results with the local community. Their involvement allowed them to have a clear understanding of the whole process and its objectives, and so benefit from it by 21₅₅₆ strengthening the collaborations with other stakeholders of interest. On the contrary, the 22557 environmental association members were only invited to attend the game sessions and later 23558 stated that the experience didn't have any positive effects on making their voices heard in local 24559 land management debates. An intermediary situation concerns the firefighting team leader, who 25560 described the improvement in the collaboration with the CFC in the two years following the game 26561 sessions, but, contrary to the forest technicians, didn't think that A Picit Jeu experience 27662 influenced it. These very different opinions suggest that not only acquiring ownership of the model 2&563 and game tools is crucial, but also acquiring ownership of the entire process can enhance the 29564 benefits of the process itself and provide the stakeholders with a greater awareness of them.

30 31565 32567 32567 33568 A significant limitation of this work is that all three game sessions were organised at the municipal level, involving almost exclusively residents of one municipality at a time. The lack of a common perspective at the valley level on landscape planning was one of the issues identified in the initial interviews. Promoting the discussion between decision-makers about valley-wide planning 34 569 projects was included in the game purposes during the initial development phase (see Table 1). 35₅₇₀ However, the absence of leadership at the valley level, which would have been fundamental in 36571 setting the meeting and inviting the participants, prevented the organisation of a game session 37372 involving more geographically distributed participants. This precluded the exchange of points of 3&₇₃ view and the development of a shared perspective across a larger extent than a single 39574 municipality. Future developments in this methodology should address this point. A game 40575 session involving all the valley's mayors could be a starting point, followed by game sessions 41576 bringing together lower-level actors from multiple municipalities to avoid the power imbalance 42577 issues mentioned above.

Another limitation concerns the challenges in assessing the effects of the process. Literature on serious gaming interventions indicates a general lack of assessment procedures that consider the overarching objective of the process, instead of learning at the individual level (Rodela and Speelman 2023). Moreover, serious games are usually evaluated in a short period, with assessment procedures implemented no more than a few months after the sessions (Calderón and Ruiz 2015). However, the complex nature of their outcomes drove us to try to evaluate the impact from a broader perspective than just the results of collective discussions at individual sessions. A longer time scale assessment was then necessary. The interviews highlighted interesting focal points almost two years after the game sessions. However, the impossibility of isolating the effects of the serious game experience from the impacts of other events that

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occurred in the two years makes it challenging to attribute developments in the local context with certainty. The assessment of this kind of process is made especially difficult by the impossibility of comparing outcomes with a control sample, since finding another context with the same exact components and challenges is impossible. Nevertheless, it is essential to note that the evaluation was carried out by focusing on the perception of the stakeholders themselves rather than on an objective analysis of changes, with the aim of eliciting once again their perspective.

1594 5. Conclusions

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16395 In this work, we aimed to contribute to the literature on fire-resilient landscapes by addressing 17396 the need for integrated planning approaches through the activation of sustainable processes over 18597 time. We have presented a methodology inspired by the ComMod approach to support 19598 stakeholders in exploring land management strategies for landscape fire-resilience. The 20599 methodology entails a participatory process that combines agent-based modeling and serious 21600 gaming. It was tested in Valchiusella, an Italian alpine valley. Twenty-three local stakeholders 22601 were involved in collective discussions on land management scenarios for fire prevention through 23602 the serious game A Picit Jeu.

24 25603 2604 2605 27606 During the game sessions, the participants identified and discussed the challenges for a fireresilient landscape in Valchiusella, such as land fragmentation and land abandonment, stakeholders' limited collaboration due to scarcity of economic resources and cultural value of private property, and controversial drives of European funding. Possible strategies to help the 28₆₀₇ creation of a fire-resilient landscape also emerged, mainly related to different forms of collective 2208 management in pastoralist activities, to prevent land abandonment and maintain diversity in the 3609 spatial distribution of land cover. 31

32610 The observation of the game sessions and the information collected through a multi-step 33611 evaluation procedure confirmed the methodology's potential not only to facilitate discussion 34⁶¹² among different stakeholders but also as a positive process trigger for longer-term change. While 35613 the challenges and strategies for a fire-resilient landscape identified can be transferrable to other 36⁶¹⁴ contexts characterized by similar processes of land abandonment and a similar stakeholder 3⁻⁶¹⁵ 3⁶¹⁶ 38 composition, such as other Alpine valleys, the enhanced collaboration among stakeholders requires the replication of the entire participatory process.

39617 The discussion of the outcomes of this experience, moreover, allowed us to point out some 4@618 recommendations for future works using serious gaming to support the collaboration of 41619 stakeholders in developing sustainable landscapes. First, aiming for an even composition of 42620 session groups, where all real-life roles are represented, is crucial. Second, the group 43621 composition needs to take into account the multiple levels of organisation in the area by involving 44622 participants across them, to bring the discussion to the wider landscape spatial scale (e.g. valley 45623 level instead of just municipality level). In addition, careful considerations are needed about the 4624 allocation of game roles to disrupt power dynamics and allow all the participants to contribute to 4 7625 the debate actively. For example, avoiding allocating an influential game role to a participant with 4 \$ 26 a real-life leadership role could be beneficial. Finally, we suggest aiming for the involvement of 4\$²⁷ the broader stakeholder spectrum in developing the game itself, as participation in the entire 50628 process has proven to strengthen collaboration between participants.

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Supplementary material

Box 1 Guidelines questions for A Picit Jeu debriefing phase.

Triggered emotions:

- How did you feel during the game?
- Do you think that it was easy to take into consideration the idea of all the players? Relationship with the reality:
 - indioniship with the reality
 - Which similarities with the reality did you find in the game?
 - Which differences?
- Mutual understanding:
 - What difficulties did you experience in playing your role?
 - Did you expect them?
 - Do you think the same difficulties exist in reality?
 - Do you feel this game made you understand other actors' perspectives better?

Table 1 Synthetic version of the observation protocol adopted for real-time and post analysis of the sessions.

GENERAL AIM	SPECIFIC AIM	WHAT TO ANALYSE
Evaluating the	Assessing the ludic aspect and the	The level of participation of the
game	ability of the game to make the players feel involved	players
	Assessing the ability of the game to produce positive effects on the players	The quality of the discussions and the transformation of the players' points of view
	Assessing the ability of the game to represent the actors' reality	The speech of the players
	Assessing the ability of the game to generate new strategies	New proposals suggested by the players
Understanding	Identifying the most debated	The discussions generated among
the reality	topics	the players
	Understanding the behaviour of	The strategies adopted by the
	the actors	players
	Understanding the confidence	The value accorded by the players to
	accorded by the actors to the	the specific knowledge of the forest
	scientific and technical knowledge	technician



Fig. 1. List of questions of the post-session questionnaires (translation from Italian to English by the authors), with corresponding distribution, mean and median values of the answers to the Likert scale ones.

	Munic	ipality A	Munic	ipality B	Munic	ipality C	Ave	rage
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Was this meeting useful?	6.2	6	6.3	6.5	5.3	5	6.0	6
Did his meeting meet your	6.0	6	6.2	6.5	5.7	6	6.0	6
expectations?								
What expectations were not		•		Onen				
met?				орен ц	uestion			
Was it easy to understand the	6.3	6	6.7	7	4.8	5.5	6.0	6
rules of the game?								
Did you have fun?	6.1	6.5	6.5	6.5	6.5	6.5	6.3	6.5
Did you feel free to express	6.6	7	6.7	7	6.3	6	6.5	7
vour opinions?								
Were your opinions taken into	6.1	6	5.8	5.5	6.3	6	6.1	6
account?								
Are the situations depicted in	5.9	6	3.7	3.5	5.0	5	5.0	5
the game realistic?						_		_
What aspects are not realistic.								
if anv?				Open q	juestion			
Did you learn new things about	43	fi	23	9	43	5	3.8	4
the ecological dynamics of our	4.0	Ŭ	2.0	2	4.0	J	0.0	-
forests and nastures?								
If annlicable what did you								
learn?				Open q	juestion			
Vas the meeting useful for you	63	6	5.2	5	53	55	57	6
to understand the difficulties	0.0	Ŭ	0.2	0	0.0	0.0	0.7	Ŭ
that different actors face in								
reality?								
Was it helpful to use a playful	6.0	6	6.0	6	6.0	6	6.0	6
approach?	0.0	Ŭ	0.0	Ŭ	0.0	v	0.0	Ŭ
Did this mosting change your	47	-	27	2.0	4.0	4-5-	2.0	A
point of view?	4.7	5	2.7	2.0	4.0	4.5	0.0	-
Will your actions shange	4.2	-	2.5	9.6	4.0	<u> </u>	2.7	4
thanks to this mosting?	4.3	5	2.0	2.0	4.0	4.5	3.7	4
Did this meeting change your	E 4	6	2.0	9	<u> </u>	E-0	4-2	E.
oninion of collective forest	5.1	σ	2.0	5	4.5	5.0	4.5	5
opinion of collective forest								
Mag the group oble to make	57	0	5.0	F				·
was the group able to make	5.7	9	5.5	4	5.5	5.5	3.3	9
successitut collective								
Did the same facilitate the	<u> </u>	0	0.5	7	0.5	0.5	C 4	C
ovehenge of ideas with the	0.2	v	0.5	7	0.5	0.5	0.4	σ
exchange or lueas with the								
What entropy of the set								
what categories or people								
would it be useful to				Open q	uestion			
participate in the same								
experience?								

Table 2 List of questions of the post-session questionnaires (translation from Italian to English by the authors), with the mean and median values of the answers to the Likert scale ones.

Declaration of interests

⊠The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

□The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: