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# Journal of Environmental Management

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

--Manuscript Draft--

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<b>Abstract:</b>	<p>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.</p>
<b>Suggested Reviewers:</b>	Fantina Tedim ftedim@letras.up.pt For her expertise in wildfire management in Mediterranean environment  Thomas Spies Tom.Spies@oregonstate.edu For his experience in agent-based modeling for wildfire management.

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

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Bergen, 13/09/2024

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 doesn't really convey a good idea of the field. It's not just a matter of citing papers A or B or C, but of actually understanding them and discussing them in context. The authors should add some depth to this discussion to properly justify the need of their work.	We have described better what the focus of those existing works using serious games in fire management is and why those were not suitable for the aim of our work, which is more in line with the principles of other serious game approaches, namely ComMod (as detailed in previous and next paragraphs).
Still regarding the name "Picit Jeu": I appreciate that the authors explain the 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 Jeu* using" or something similar. The current wording gives the impression that a Picit Jeu game is some kind of generic game.	We have changed the sentence as suggested.
Line 64: "On the one side, agent-based modelling (ABM) is a well-known methodology for analysing the interactions between people, things, places and time." - > "On the one hand" would be more appropriate.	We corrected it.
Line 450: "The experience does not seem to have positively impacted" should be "The experience did not seem to have positively impacted" for consistency in past tense.	We corrected it.
Fig. 6 should be a table. Further, don't paste print screens to a scientific paper, with typo highlights and all. It is unprofessional, to say the least.	There has clearly been an error in uploading the wrong version of the figure, thank you for highlighting it. In any case, we have changed it into a table as suggested.
Since the authors have added a table with the Likert answers statistics to the supplementary material, there is not reason that the answer distributions themselves are 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 have replaced the table with a more complex figure (see Figure 1 in the supplementary material), including also the distribution of the answers.

- 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.

**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 CO<sub>2</sub> 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

40 governance actions exert leverage on the wildfire regime so that its effects are compatible with  
1 41 the delivery over time of key ecosystem services (e.g., water supply, primary productivity,  
2 42 biodiversity) and with the socio-economic system in the area (e.g. agroforestry productions,  
3 43 tourism, energy industry) (Fernandes 2013; Thacker et al. 2023).

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6 44 Consequently, in many European territories, wildfire governance programs are in place that  
7 45 integrate strategic fuel management planning for direct prevention (e.g., strategic fuel breaks  
8 46 supporting active firefighting) with the planning of socio-economic activities that have an indirect  
9 47 fire regulatory effect by creating a mosaic less prone to fire in synergy with direct prevention, such  
10 48 as agro-silvo-pastoral value-chains, biodiversity conservation or energy supply (Tedim et al. 2016;  
11 49 Pais et al. 2020; Spadoni et al. 2023; Pulido et al. 2023).

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14 50 However, the possibility of creating sustainable processes to achieve fire-resilient landscapes  
15 51 requires collaboration among multiple stakeholders (e.g., forest managers, private owners,  
16 52 nature conservation agencies, and enterprises in the agro-pastoral, food, energy, or tourism  
17 53 sectors) with interests in the territory that often appear challenging to synergize or even conflict  
18 54 (Canadas et al. 2016). Developing a common, shared strategy to promote integrated planning  
19 55 processes for fire-resilient landscapes requires participatory decision-making that facilitates  
20 56 adaptive learning, understanding the interests at stake, and collaboratively defining win-win  
21 57 strategies that activate sustainable processes over time (Otero et al. 2018, Ascoli et al. 2023).

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26 58 The use of games in natural resources management has increasingly received attention in recent  
27 59 years for conflict mediation, social learning and collective decision-making (Madani et al. 2017;  
28 60 Wesselow and Stoll-Kleemann 2018; Flood et al. 2018; Rodela et al. 2019). Companion Modelling  
29 61 (ComMod) emerged as a gaming approach, relying on “the synergistic effects between role-  
30 62 playing games (RPG) and agent-based models (ABM) to facilitate information sharing, collective  
31 63 learning and exchange of perceptions on a given concrete issue among researchers and other  
32 64 stakeholders” (Ruankaew et al. 2010). On the one hand, agent-based modelling (ABM) is a well-  
33 65 known methodology for analysing the interactions between people, things, places and time. ABM  
34 66 is often used in socio-ecological system studies to integrate human behaviour models with  
35 67 ecological models (Kline et al. 2017) and a variety of applications in wildfire research exists in the  
36 68 literature (Millington et al. 2008; Charnley et al. 2017; Spies et al. 2017; Ribeiro et al. 2023). On  
37 69 the other hand, serious games are an innovative participatory approach to exploring, learning  
38 70 about, and discussing the complexity of the socio-ecological system, especially when many  
39 71 conflicting interests exist in it (Speelman et al. 2018). Games can support collective negotiations  
40 72 and help define common strategies toward a collectively recognised problem, putting into play  
41 73 the participants’ perception of the problem and their experience.

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47 74 Examples of serious games dealing with wildfire risk exist in the literature, focusing on different  
48 75 aspects of risk management, such as firefighting training simulation (Backlund et al. 2007,  
49 76 Caroca et al. 2019), emergency decision-making (Ji et al. 2024), disaster preparedness (Johns et  
50 77 al. 2024) and social awareness (Pereira et al. 2014). However, they were developed to strengthen  
51 78 risk preparedness and response, while, to our knowledge, a serious game focusing on building  
52 79 fire-resilient landscapes involving both direct and indirect fire regulatory processes has not been  
53 80 developed yet. Moreover, none of the cited works successfully represent the interaction between  
54 81 the diverse perspectives and priorities of local stakeholders. Representing and putting them into  
55 82 play is crucial for supporting a participatory process where indeed those interactions must be  
56 83 taken in consideration, discussed and leveraged for developing successful wildfire impacts  
57 84 mitigation strategies.



85 This work aims to address the need for collaborative decision-making to develop integrated  
1 86 planning processes for fire-resilient landscapes by presenting and assessing an innovative  
2 87 participatory approach based on ComMod principles, focused on exploring land management  
3 88 strategies for landscape fire resilience. We tested the methodology in a study area located in the  
4 89 Italian Alps, by (1) developing an ABM representing the effect of forest and pasture management  
5 90 actions on wildfire risk in Valchiusella, (2) creating the game *A Picit Jeu*<sup>1</sup> using the model for  
6 91 exploring the results of different strategies, and (3) using *A Picit Jeu* for involving local  
7 92 stakeholders in collective discussions on land management scenarios for fire prevention.

10 93 This work also intends to contribute to the research gap in impact assessment of games used in  
11 94 natural resource management (which has largely been absent or only short-term focused;  
12 95 Calderón and Ruiz 2015; Rodela and Speelman 2023) by presenting a multiple-time-frame  
13 96 evaluation of the impact of the game experience. A short-term assessment was supported by the  
14 97 observation and recording of the game sessions, and by participants' feedback via end-of-  
15 98 session debriefings and questionnaires. A long-term evaluation was carried out two years later by  
16 99 interviewed participants to explore what influence the game subsequently had on land  
17 100 management decision-making and the network of stakeholders concerned. We describe the  
18 101 results of such a multiple-time-frame impact assessment, while discussing its advantages and  
19 102 limits.

20 103 The following section presents the study area and describes in detail the procedure adopted. We  
21 104 then introduce and discuss the results of the game development process, of the game sessions  
22 105 and of the evaluation steps. In the Conclusion section, we consider what lessons can be learned  
23 106 to apply in other landscapes and contexts.

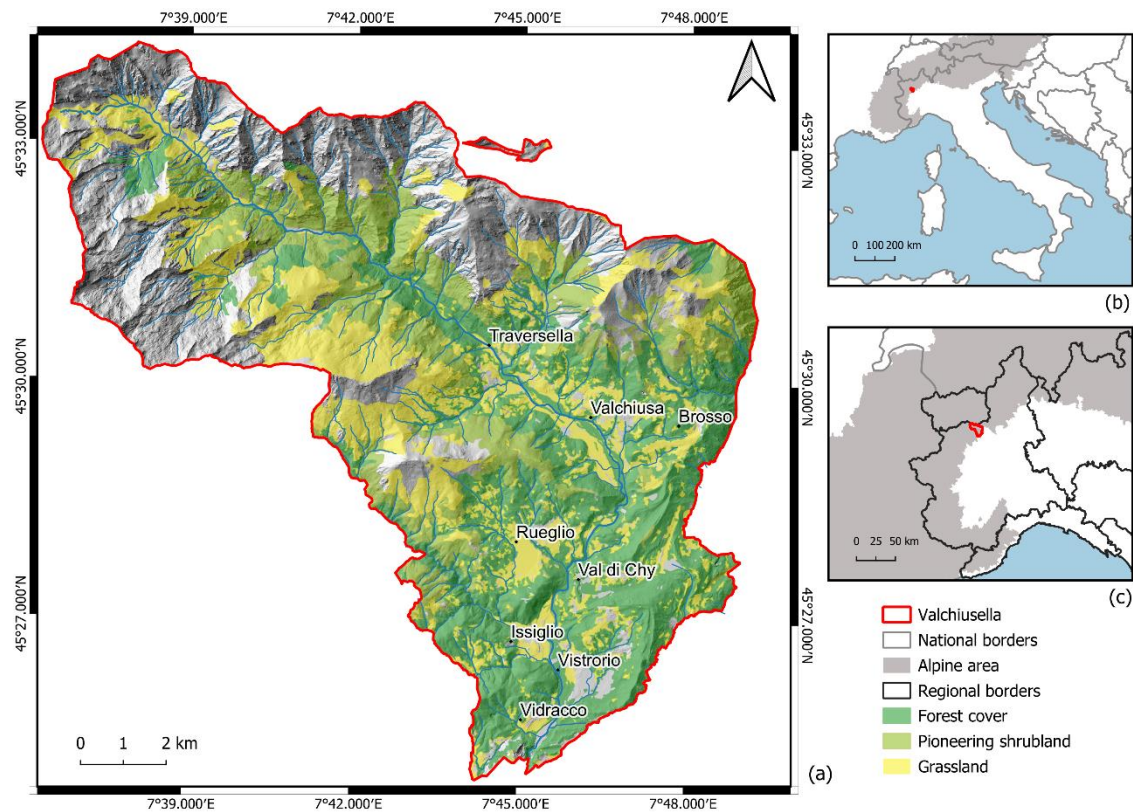
## 31 32 107 2. Materials and methods

### 33 34 35 108 2.1 Study Area

36 37 109 The study area is Valchiusella, an Alpine valley of about 143 km<sup>2</sup> in the northwestern part of Italy,  
38 110 in the Piemonte region.

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58 <sup>1</sup> The game's name "A Picit Jeu" is a word pun in the local dialect of Valchiusella, meaning "a small game"  
59 but sounding also close to "A Picit Feu", which literally means "over small fire" and refers to a  
60 phenomenon evolving slowly.  
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**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 <https://geoportale.igr.piemonte.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).

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)

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

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

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

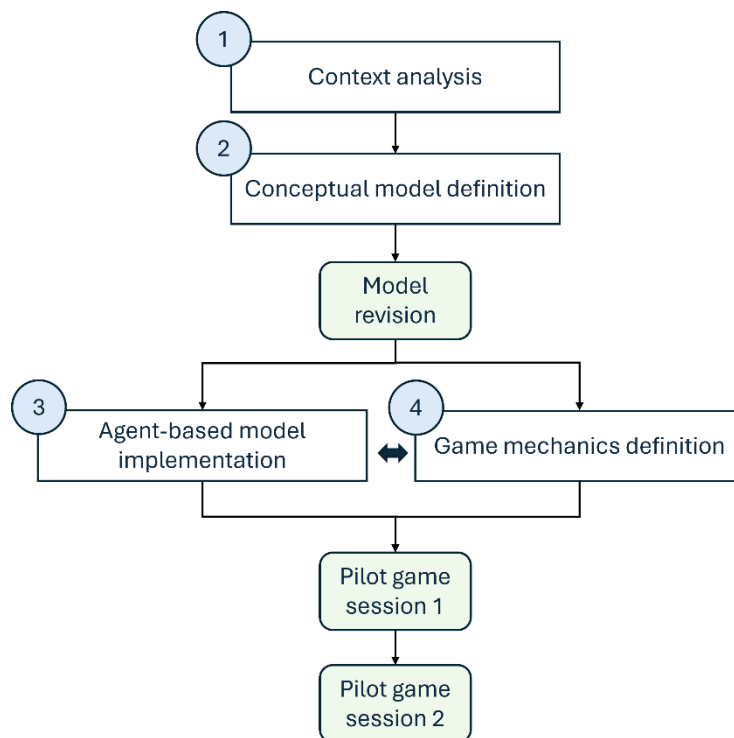
## 2.2. The game design

148 The design of *A Picit Jeu* was based on four phases (Figure 1):

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

153 Phases 3 and 4 were carried out at the same time and implied a continuous interaction with each  
154 other.

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



159  
160 **Fig. 2.** Diagram of the four-phase methodology adopted for the game design. The three review steps in  
161 green boxes.

## 162 2.2.1 Context analysis

1 163 The methodology proposed in this work for the game design aims at tailoring the game dynamics  
2 164 to the specific context it is conceived for. The analysis of the context was conducted through  
3 165 semi-structured interviews with local stakeholders, focused on the interactions between human  
4 166 and ecosystem dynamics in the framework of wildfire risk.

7 167 Twenty-five interviews were carried out, involving 27 interviewees. The interviewees were  
8 168 identified among five categories of stakeholders involved in local land management, forest  
9 169 management and wildfire issues:

- 12 170 ● Mayors or municipal administrators in charge of land management tasks – contacts were  
13 171 provided by the CFC.
- 16 172 ● Forest firefighter volunteers – priority was given to the firemen of each local volunteer  
17 173 firefighter team. Four valley municipalities had their own team at the moment of the  
18 174 interviews: Val di Chy, Rueglio, Traversella and Vidracco. The head of the Valchiusella  
19 175 section was also interviewed.
- 21 176 ● Forest workers – the owners of the forestry companies registered in the official provincial  
22 177 list were interviewed. Other respondents were contacted thanks to the indications  
23 178 provided by the CFC. In addition, members of a land consortium existing in the northern  
24 179 part of the valley were interviewed.
- 27 180 ● Members of local environmental associations – selected on the recommendation of  
28 181 association leaders.
- 30 182 ● Farmers – respondents were first identified among the members of a local association of  
31 183 producers for the promotion of local cheese. Other interviewees were suggested by the  
32 184 already involved farmers ('snowballing').

34 185 The interview canvas was made of 20 questions focused on the personal relationship with the  
35 186 local community, the experience with forest management, the role of wildfires in the ecosystem  
36 187 and the existing fire prevention strategies, the local forest management status and actors, and  
37 188 the value of ecosystem services. The interviews were carried out over around two months, so it is  
38 189 possible that some early participants had the opportunity to exchange ideas about the questions'  
40 190 content with later participants before their interviews. However, this is not a limitation for our  
41 191 work given that the purpose of this activity was to get an overview of the interactions between  
42 192 human and ecosystem dynamics and of the local challenges related to wildfire risk, instead of a  
43 193 precise personal point of view. Moreover, any exchange of ideas between stakeholders already  
44 194 happening at this time was perfectly in line with the general aim of this work of fostering  
45 195 collaborative decision-making.

49 196 Interviewees' answers were analysed through thematic analysis (Braun and Clarke 2006) to  
50 197 identify the recurrent topics and mapped into thematic areas. For each of the seven thematic  
51 198 areas mapped, a specific issue directly or indirectly related to wildfire prevention in the valley was  
52 199 formulated, based on the respondents' contribution. Finally, each issue was translated into a  
53 200 precise purpose to be integrated into the game's design, such as a specific topic on which the  
54 201 game should trigger discussion or concerning which it should help a learning process.

## 202 2.2.2 Conceptual model definition

1  
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  
4 205 ARDI method proposed by Étienne and colleagues (Etienne 2009; Etienne et al. 2011) was used.  
5 206 The ARDI method was conceived in the framework of the ComMod approach for building a shared  
6 207 description of the SES among the stakeholders involved in the process, representing its elements  
7 208 by means of diagrams. In this work, the four ARDI elements and steps (Actors, Resources,  
8 209 Dynamics and Interactions) were used by the authors as a guideline to formalize the insights  
9 210 collected through the interviews into an SES conceptual model serving the design of the game  
10 211 mechanics.  
11  
12

## 14 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  
19 216 Rand 2015). The interface tab of the model was designed to be used as the ‘board’ of the game by  
20 217 projecting it on a screen clearly visible to all the players. The model was created with a series of  
21 218 commands the game master can enter during the simulation depending on players’ decisions  
22 219 about forest and pasture management actions. The game was intended to reproduce a primary  
23 220 general pattern: the less players undertake landscape management actions (e.g., by thinning and  
24 221 cutting forests or grazing pastures), the higher the probability that a fire will burn a large land area.  
25 222 The detailed description of the model following the ODD standard protocol for ABMs (Grimm et  
26 223 al. 2006) and the model code itself are published in (and downloadable from) the COMSES library  
27 224 (Vigna and Millington 2024).  
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## 32 2.2.4 Game mechanics definition

33  
34 226 While coding the ABM, the game mechanics were also defined. This step was based on a  
35 227 translation process of the actors, resources, dynamics and interactions of the SES conceptual  
36 228 model into game roles and mechanics, such as players’ actions on the board, players’  
37 229 interactions, game materials and spatial and temporal settings. Since this step was strictly  
38 230 dependent on the previous step and *vice versa*, a continuous interaction between the two was  
39 231 necessary to shape the game mechanics to the model’s possibilities and to adapt the model to  
40 232 the needs of the gameplay.  
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## 44 2.2.5 Review steps

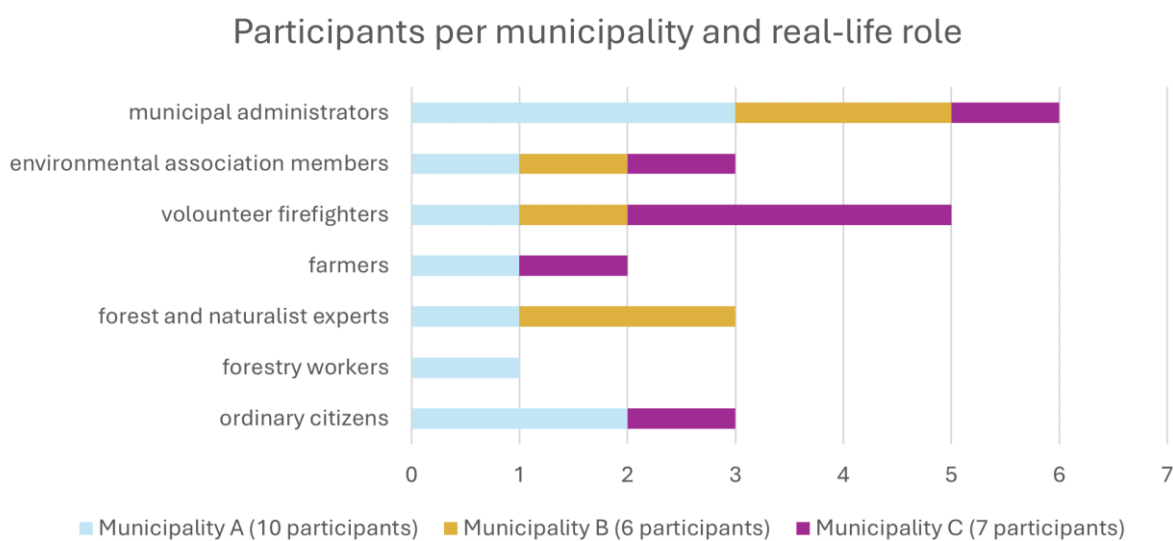
45 234 The first review step was carried out after the conceptual model definition phase. The main aim  
46 235 was to assess the adequacy of the representation of the local SES, highlighting missing elements  
47 236 and incorrect dynamics. It involved a forest technician, an agronomist and a naturalist-biologist,  
48 237 all working for the CFC. They were chosen for their expertise in the relative fields and their direct  
49 238 experience of the local context, including socio-economic dynamics.  
50  
51

52  
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  
55 241 and a forest technician from the CFC. The pilot sessions aimed at assessing the scientific  
56 242 correctness of the dynamics represented and the game’s playability, including the  
57 243 appropriateness of time management in the different game phases and of the supporting  
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244 materials. These pilot sessions allowed for improvements both to the gameplay and to the ABM  
1 245 code.

## 246 2.3 The game sessions

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



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

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

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

274 information. An observation protocol was developed as a guideline (see the Supplementary  
1 275 Material).

## 276 2.4 The process evaluation

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

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

## 289 3. Results

### 290 3.1 Game overview

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

294 **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 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.

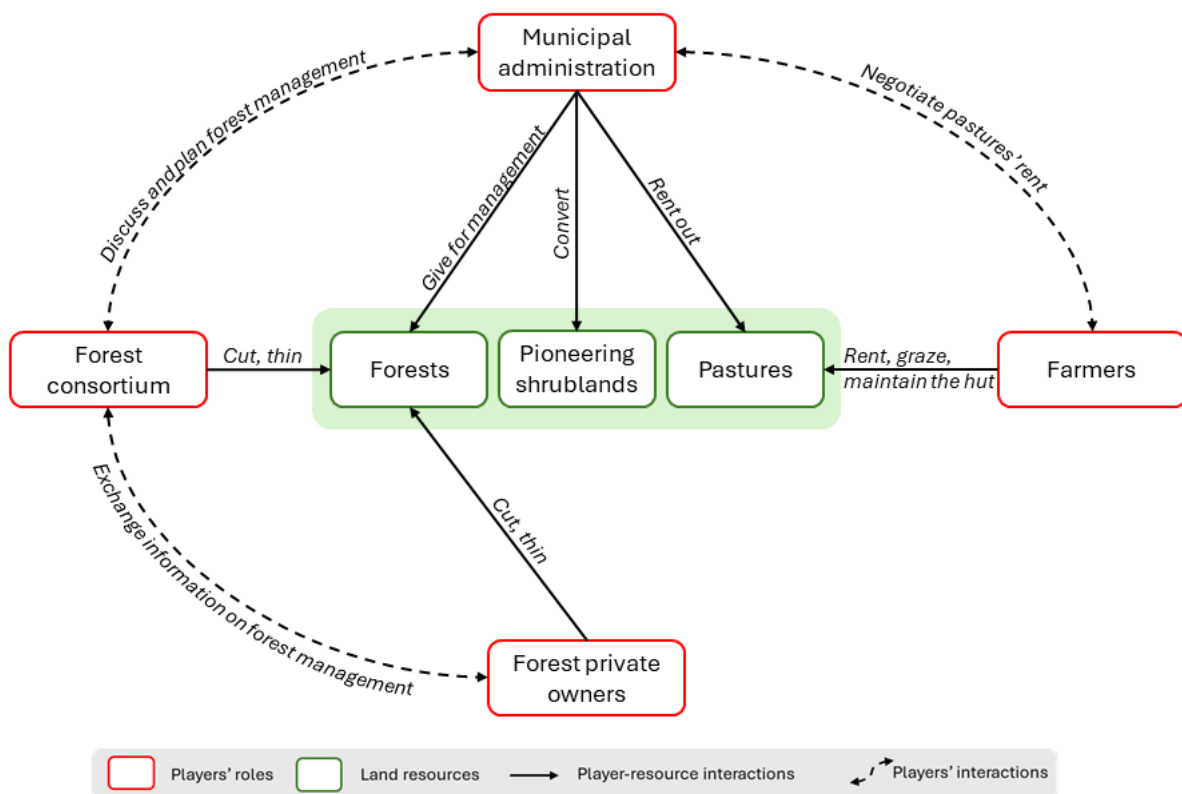


Fig. 4. Overview of the game roles, land resources and interactions.



308 Four game roles were identified:

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- 2 309 - The municipal administration, represented by the mayor, who delegates the management
- 3 310 of forest parcels to the technician of the forest consortium and rents the public pasture
- 4 311 parcels to the farmers;
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- 6 312 - The forest consortium, represented by a technician, who is in charge of managing (i.e.
- 7 313 cutting and thinning) public forest;
- 8
- 9 314 - Farmers, who graze their cow herds on public pastures that they rent. One or two farmers
- 10 315 can be in the game.
- 11 316 - Private forest owners, who manage their own forest parcel. Three forest owners are in the
- 12 317 game.
- 13

14 318 During the game, the mayor and the technician of the forest consortium must agree on the  
15 319 management plan of public forests and on how to share the economic costs for thinning and the  
16 320 economic gains for cuts. The mayor and the farmers must negotiate the price for renting public  
17 321 pastures. The private forest owners can ask the forest technician for technical information, such  
18 322 as the stumpage value of their parcel. The forest technician is also able to assess each land  
19 323 parcel's wildfire hazard and can decide to share this information with the other players.

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23 324 Three kinds of land resources were identified: forests, pastures and pioneer shrublands. These  
24 325 were used for characterizing the space represented by the ABM, made of 20 land parcels (Figure  
25 326 5). A number of functions representing the action of the players on the land parcels were coded  
26 327 in the ABM: cutting and thinning the forest parcels, grazing the pasture parcels, building or  
27 328 maintaining the huts of the pasture parcels, converting to forest, or to pasture the pioneering  
28 329 shrubland parcels.

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32 330 Three kinds of dynamics were also identified in the SES:

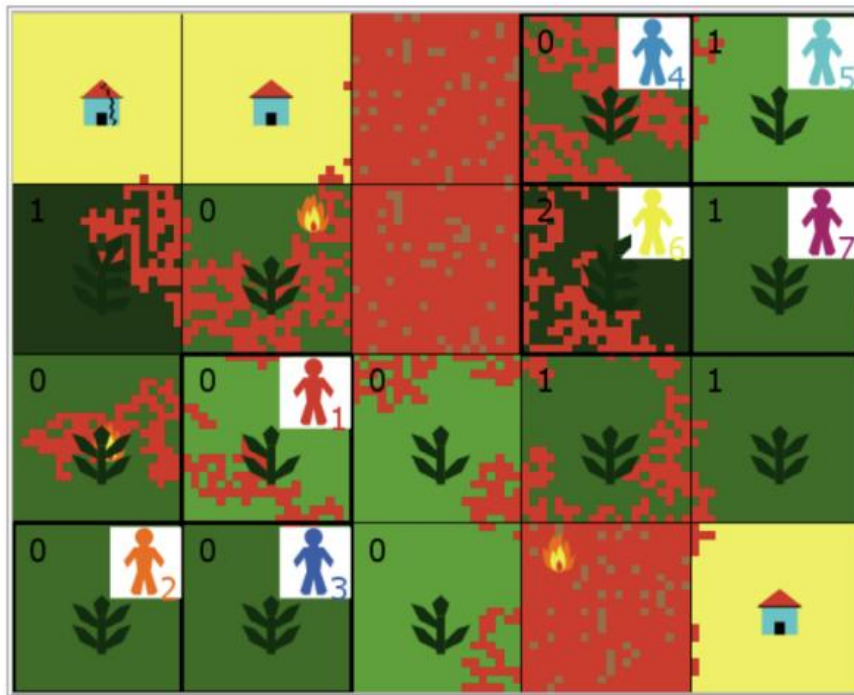
- 33
- 34 331 - Ecological dynamics:
  - 35 332 1. The natural reforestation of abandoned pastures, which leads to the growth of a
  - 36 333 more flammable pioneer vegetation;
  - 37 334 2. The behaviour of fire, which is more likely to burn more flammable lands than
  - 38 335 others;
  - 39 336 3. Fire hazard dependence on climate conditions;
- 40 337 - Social dynamics:
  - 41 338 4. The common lack of interest on the part of private forest owners in their parcels,
  - 42 339 which usually leads to their abandonment;
- 43 340 - Economic dynamics:
  - 44 341 5. The pastoral products market variations;
  - 45 342 6. The variation in the cost of forest operations, such as cut and thinning, and of
  - 46 343 wood prices because of market changes;
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51 344 These dynamics were crucial in characterizing the ABM. According to dynamic 1, ungrazed  
52 345 pasture parcels become pioneer shrubland after some rounds. Dynamic 2 was used to code the  
53 346 fire behaviour in case of ignition. Dynamic 4 was used to code the behaviour of four autonomous  
54 347 agents representing private forest owners. Dynamics 3, 5 and 6 were translated as possible  
55 348 scenarios to be set at the beginning of the ABM simulation.

58 349 Finally, a time duration of 50 years was chosen for the game, as a relevant amount of time from a  
59 350 silvicultural point of view. The players are asked to take actions every 10 years, for a total of five

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351 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  
 2 353 simulates the behaviour of three wildfires, ignited randomly on the landscape. More thinned and  
 3 354 younger forests are less likely to burn than older and less thinned (or unthinned) ones, while  
 4 355 pioneer shrublands are the most likely to burn (see ODD description for more details, Vigna and  
 5 356 Millington 2024). During the game, the players have to deal simultaneously with the economic  
 6 357 constraints imposed by their limited resources and the cost of their actions, and with the impact  
 7 358 of their management decisions on the likelihood that wildfire events will affect land parcels.



359  
 360 **Fig. 5.** Screenshot of the interface of the ABM, used as the ‘board’ of the game. The colours of the land parcels  
 361 correspond to the three different land use types and to the age of forests. The house icons represent huts on the  
 362 pastures. The human figures identify the forest parcels owned by the private owner players and by the autonomous  
 363 agents. Three fires have spread on the landscape in the simulation represented.

### 364 3.2 Game sessions’ outcomes

365 During the three game sessions, the level of involvement in the activity and amusement of the  
 366 participants was generally high. The mean score in the answers to the question “Did you have  
 367 fun” in the final survey was 6.3 on a 1 to 7 Likert scale (see Figure 1 in the Supplementary material  
 368 for a complete overview of answers to the final questionnaires). However, some participants were  
 369 more active than others. This was particularly evident in Municipality A, where some participants  
 370 took a driving role in the collective decisions, while some remained more in the background and  
 371 expressed less. The Municipality A session involved a higher number of participants compared to  
 372 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  
 374 interactions in the game.

375 In addition, in Municipality A and B the mayors had a very active and central role in game  
 376 interactions. This is partly explained by the fact that, in both situations, the mayor was playing the  
 377 role of the forest technician, which is particularly influential in the game mechanics. Moreover,  
 378 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  
5 384 Municipality C (median value: 5.5). In Municipality C, no participant adopted a guiding role in the  
6 385 discussions and the group generally complained about the short time available for discussing the  
7 386 implications of the activity during the debriefing phase, since it took them a long time in the  
8 387 beginning to understand the game functioning. Time constraint was generally an issue. All the  
9 388 sessions took place in the evening, to allow the participation of all stakeholders, particularly  
10 389 farmers whose work does not include days off. However, this choice reduced the time available,  
11 390 often at the expense of the debriefing phase.

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16 391 The exchange of roles was generally perceived as very helpful. As an example, the forest  
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  
20 395 my situation. Money comes in one way and goes out another, and, in the end, it all goes out! This  
21 396 is maybe something trivial, but I was able to experience it this evening.”* In this regard, the  
22 397 absence of some crucial stakeholders in some sessions limited the outcomes. More specifically,  
23 398 in Municipality B the participants largely discussed the role of modern farming techniques and a  
24 399 general lack of care in land maintenance on the farmers’ side in contributing to the expansion of  
25 400 the pioneering shrubland on pastures. However, no farmers were present in the session to  
26 401 contribute their points of view and highlight their challenges. In Municipality C, the role of CFC in  
27 402 Valchiusella was unclear to most participants, but the absence of CFC technicians prevented a  
28 403 helpful exchange of information on this point.

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

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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  
5 429 transition from a complex alternation of open spaces and different densities of forest cover to a  
6 430 more homogeneous and dense forest cover. Another participant suggested the use of prescribed  
7 431 fire and experimental fire prevention action. Moreover, different forms of collective management  
8 432 concerning pastoralist activity came out during the debriefing phases, such as a community-  
9 433 based cooperative for obtaining other kinds of European funding for land management and  
10 434 development, a solidarity buying group for shortening the supply chain between producers and  
11 435 consumers of milk products, and a valley consortium dairy for lowering the cost for farmers to  
12 436 transform milk into cheese.

### 17 437 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  
21 440 only as a tool to facilitate discussion on the spot, but also as a positive process trigger for longer-  
22 441 term change. This is linked to the use of the game experience to raise awareness among the  
23 442 participants about the importance of a shared planning strategy and effective land management  
24 443 activities, and to foster interactions and collaboration.

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

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

52 462 Finally, a positive effect was found in the interactions between the CFC and the University of Turin  
53 463 institution itself, thanks to the involvement of the CFC technicians not only in the game sessions  
54 464 but also in the review steps of the development process. Other collaborative activities have since  
55 465 been carried out.

58 466 Table 2 summarizes the main points presented in the Results section, by highlighting the positive  
59 467 outcomes and long-term effects of the process, as well as its challenging aspects.

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

471 *A Picit Jeu* game sessions demonstrate the multifaceted results that can come from the  
 472 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  
 474 which planning strategies need to focus across different scales, such as the organisation of  
 475 pastoral funding, the attitude of the inhabitants toward collective management, and the lack of  
 476 information about CFC activities and opportunities for forest owners. At the same time, the game  
 477 sessions gave stakeholders the opportunity to identify these issues, question their points of view  
 478 and start a dialogue, sometimes also resulting in strengthened collaborations. The observation  
 479 of the sessions and the outcomes of the evaluation interviews allow us to discuss some focal  
 480 points and identify more general lessons valuable for others using serious gaming to negotiate or  
 481 inspire collaboration between stakeholders in developing fire-resilient (or otherwise sustainable)  
 482 landscapes.

483 First, a significant effort needs to be made in defining the group of participants. In this work, the  
 484 game sessions were organised in collaboration with the mayors of the municipalities, who  
 485 oversaw the invitation of the participants, leaving the researcher a lower control over their  
 486 selection As explained by Barreteau and colleagues (2010), a requisite for the success of a  
 487 participatory processes as ComMod is that the participants in the collective action dynamics  
 488 accept them to the point of participating in them. What makes this possible is very often a local  
 489 anchoring, which is provided by the social capital of those who are promoting the process. The  
 490 help from the village mayors, who have a dense relation network in the area, allowed us to  
 491 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  
 493 and curiosity instead. Even if the mayors were in charge of disseminating the invites, we put in  
 494 place two measures for assuring appropriate representativeness of the stakeholders: first, the  
 495 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,  
 497 the researchers did it. This was the case, for example, of the members of the local environmental  
 498 associations, who are often new inhabitants of the valley and whose presence in two of the three  
 499 game sessions was assured by a direct invitation from the researchers.

500 However, despite these measures the difficulty of involving a representative of each category in  
1 501 all the sessions caused some unevenness in the composition of the groups, as highlighted in the  
2 502 Results section. The participants criticized this unevenness both during the debriefings and in the  
3 503 evaluation interviews.

5 504 Related to the previous point, in two game sessions, a certain power imbalance between the  
6 505 participants was felt, as the mayors were particularly influential on the game dynamics, helped  
7 506 also by the role they were assigned. Power relations influencing the game is a crucial point in this  
8 507 kind of experience and needs great attention and effort from the facilitator (Garcia et al. 2022).  
9 508 Similarly, pre-existing relationships between the participants can make someone feel more  
10 509 entitled to express their opinion to the group than others. Stakeholders with a stronger power  
11 510 position can impose their ideas on the discussions and ignore others, while a lack of self-  
12 511 confidence, freedom of expression or understanding of the issues at stake can limit a player's  
13 512 ability to defend their interests (Barnaud et al. 2010). In this work, a more attentive choice of the  
14 513 game roles would have benefited the group dynamics, by deliberately assigning less influential  
15 514 roles to the participants with more influential roles and leadership attitudes in the real world. This  
16 515 is supported by the fact that no power imbalance was witnessed in the Municipality C game  
17 516 session, where the mayor played the less influential role of a private forest owner.

18 517 The second lesson learned concerns the inclusion of the game sessions in a broader participatory  
19 518 process. The ComMod approach from which this work was inspired clearly places the use of the  
20 519 game simulations as only one of the steps of a structured participatory process (Daré et al. 2015).  
21 520 Stakeholders generally engage actively in this modelling process from the early stages (Basco-  
22 521 Carrera et al. 2018). The benefit of involving stakeholders in designing the model on their  
23 522 perceived legitimacy of the model outcomes is well documented in the literature (Van Berkel and  
24 523 Verburg 2012), and the challenges for evaluating models where this is not the case have also been  
25 524 demonstrated (Millington et al. 2011). This allows the decision-makers to take ownership of the  
26 525 model, which is a requirement for the success of the process (Joffre et al. 2015). This process,  
27 526 however, takes time. Because of the limited resources, we chose to involve only the CFC  
28 527 technicians in ABM and game design. During gaming sessions no player ever directly questioned  
29 528 the representation of the local SES in *A Picit Jeu* in terms of ecological or socio-economic  
30 529 dynamics. However, two criticisms were raised during the debriefings: that the game mechanics  
31 530 (i) push the players to focus on the economic value of forests and pastures at the expense of other  
32 531 kinds of values, and (ii) could transmit the message that assigning uses other than "wood  
33 532 production" to forests (for example by creating a protected area with no cutting activities allowed)  
34 533 is always negative, since the ABM fire behaviour simulation rewards the owner of young and  
35 534 thinned forests more than the owner of old and not managed ones. These two aspects could have  
36 535 been taken into consideration in the game development if all the stakeholders had been involved  
37 536 in the creation process.

38 537 Moreover, we argue here that the benefits of involving stakeholders from the modelling step go  
39 538 beyond the legitimation of the game session's results and concerns also other less tangible  
40 539 outcomes, such as the enhancement of networks and collaborations and the perceived  
41 540 consideration for one's perspective in the collective debate. The long-term evaluation interview  
42 541 highlighted the benefits perceived by the CFC director forest technician on the interactions  
43 542 between the CFC and other local stakeholders, as well as the University of Turin. This was made  
44 543 possible by the involvement of the CFC technicians in the whole process, from the revision steps  
45 544 to the sharing of the process results with the local community. Their involvement allowed them  
46 545 to have a clear understanding of the whole process and its objectives, and so benefit from it by

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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  
5 551 sessions, but, contrary to the forest technicians, didn't think that *A Picit Jeu* experience  
6 552 influenced it. These very different opinions suggest that not only acquiring ownership of the model  
7 553 and game tools is crucial, but also acquiring ownership of the entire process can enhance the  
8 554 benefits of the process itself and provide the stakeholders with a greater awareness of them.

11 555 A significant limitation of this work is that all three game sessions were organised at the municipal  
12 556 level, involving almost exclusively residents of one municipality at a time. The lack of a common  
13 557 perspective at the valley level on landscape planning was one of the issues identified in the initial  
14 558 interviews. Promoting the discussion between decision-makers about valley-wide planning  
15 559 projects was included in the game purposes during the initial development phase (see Table 1).  
16 560 However, the absence of leadership at the valley level, which would have been fundamental in  
17 561 setting the meeting and inviting the participants, prevented the organisation of a game session  
18 562 involving more geographically distributed participants. This precluded the exchange of points of  
19 563 view and the development of a shared perspective across a larger extent than a single  
20 564 municipality. Future developments in this methodology should address this point. A game  
21 565 session involving all the valley's mayors could be a starting point, followed by game sessions  
22 566 bringing together lower-level actors from multiple municipalities to avoid the power imbalance  
23 567 issues mentioned above.

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

## 52 584 5. Conclusions

54 585 In this work, we aimed to contribute to the literature on fire-resilient landscapes by addressing  
55 586 the need for integrated planning approaches through the activation of sustainable processes over  
56 587 time. We have presented a methodology inspired by the ComMod approach to support  
57 588 stakeholders in exploring land management strategies for landscape fire-resilience. The  
58 589 methodology entails a participatory process that combines agent-based modeling and serious  
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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.  
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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,  
6 595 stakeholders' limited collaboration due to scarcity of economic resources and cultural value of  
7 596 private property, and controversial drives of European funding. Possible strategies to help the  
8 597 creation of a fire-resilient landscape also emerged, mainly related to different forms of collective  
9 598 management in pastoralist activities, to prevent land abandonment and maintain diversity in the  
10 599 spatial distribution of land cover.  
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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  
17 603 the challenges and strategies for a fire-resilient landscape identified can be transferrable to other  
18 604 contexts characterized by similar processes of land abandonment and a similar stakeholder  
19 605 composition, such as other Alpine valleys, the enhanced collaboration among stakeholders  
20 606 requires the replication of the entire participatory process.  
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24 607 The discussion of the outcomes of this experience, moreover, allowed us to point out some  
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  
28 611 composition needs to take into account the multiple levels of organisation in the area by involving  
29 612 participants across them, to bring the discussion to the wider landscape spatial scale (e.g. valley  
30 613 level instead of just municipality level). In addition, careful considerations are needed about the  
31 614 allocation of game roles to disrupt power dynamics and allow all the participants to contribute to  
32 615 the debate actively. For example, avoiding allocating an influential game role to a participant with  
33 616 a real-life leadership role could be beneficial. Finally, we suggest aiming for the involvement of  
34 617 the broader stakeholder spectrum in developing the game itself, as participation in the entire  
35 618 process has proven to strengthen collaboration between participants.  
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42  
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# Supplementary material

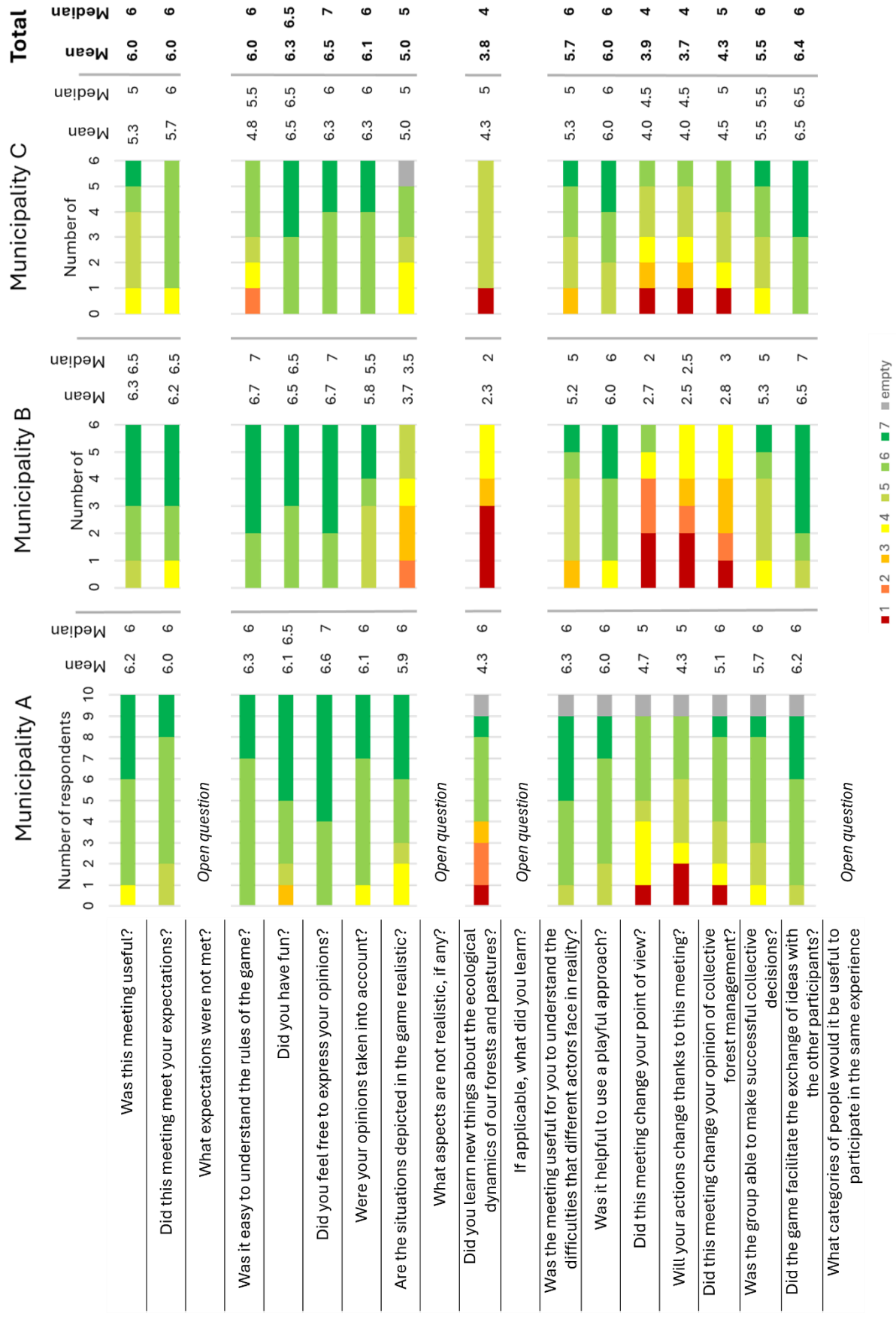
**Box 1** Guidelines questions for *A Picit Jeu* debriefing phase.

<p>Triggered emotions:</p> <ul style="list-style-type: none"> <li>• How did you feel during the game?</li> <li>• Do you think that it was easy to take into consideration the idea of all the players?</li> </ul> <p>Relationship with the reality:</p> <ul style="list-style-type: none"> <li>• Which similarities with the reality did you find in the game?</li> <li>• Which differences?</li> </ul> <p>Mutual understanding:</p> <ul style="list-style-type: none"> <li>• What difficulties did you experience in playing your role?</li> <li>• Did you expect them?</li> <li>• Do you think the same difficulties exist in reality?</li> <li>• Do you feel this game made you understand other actors' perspectives better?</li> </ul>
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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
<b>Evaluating the game</b>	Assessing the ludic aspect and the ability of the game to make the players feel involved	The level of participation of the 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
<b>Understanding the reality</b>	Identifying the most debated topics	The discussions generated among the players
	Understanding the behaviour of the actors	The strategies adopted by the players
	Understanding the confidence accorded by the actors to the scientific and technical knowledge	The value accorded by the players to the specific knowledge of the forest technician

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**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.

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# *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 (Bacchi 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 CO<sub>2</sub> 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; Bacchi 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



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7 40 governance actions exert leverage on the wildfire regime so that its effects are compatible with  
8 41 the delivery over time of key ecosystem services (e.g., water supply, primary productivity,  
9 42 biodiversity) and with the socio-economic system in the area (e.g. agroforestry productions,  
10 43 tourism, energy industry) (Fernandes 2013; Thacker et al. 2023).

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12 44 Consequently, in many European territories, wildfire governance programs are in place that  
13 45 integrate strategic fuel management planning for direct prevention (e.g., strategic fuel breaks  
14 46 supporting active firefighting) with the planning of socio-economic activities that have an indirect  
15 47 fire regulatory effect by creating a mosaic less prone to fire in synergy with direct prevention, such  
16 48 as agro-silvo-pastoral value-chains, biodiversity conservation or energy supply (Tedim et al. 2016;  
17 49 Pais et al. 2020; Spadoni et al. 2023; Pulido et al. 2023).

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19 50 However, the possibility of creating sustainable processes to achieve fire-resilient landscapes  
20 51 requires collaboration among multiple stakeholders (e.g., forest managers, private owners,  
21 52 nature conservation agencies, and enterprises in the agro-pastoral, food, energy, or tourism  
22 53 sectors) with interests in the territory that often appear challenging to synergize or even conflict  
23 54 (Canadas et al. 2016). Developing a common, shared strategy to promote integrated planning  
24 55 processes for fire-resilient landscapes requires participatory decision-making that facilitates  
25 56 adaptive learning, understanding the interests at stake, and collaboratively defining win-win  
26 57 strategies that activate sustainable processes over time (Ascoli et al. 2023, [Otero et al. 2018](#)).

27 58 The use of games in natural resources management has increasingly received attention in recent  
28 59 years for conflict mediation, social learning and collective decision-making (Madani et al. 2017;  
29 60 Wesselow and Stoll-Kleemann 2018; Flood et al. 2018; Rodela et al. 2019). Companion Modelling  
30 61 (ComMod) emerged as a gaming approach, relying on “the synergistic effects between role-  
31 62 playing games (RPG) and agent-based models (ABM) to facilitate information sharing, collective  
32 63 learning and exchange of perceptions on a given concrete issue among researchers and other  
33 64 stakeholders” (Ruankaew et al. 2010). On the one ~~sidehand~~, agent-based modelling (ABM) is a  
34 65 well-known methodology for analysing the interactions between people, things, places and time.  
35 66 ABM is often used in socio-ecological system studies to integrate human behaviour models with  
36 67 ecological models (Kline et al. 2017) and a variety of applications in wildfire research exists in the  
37 68 literature (Millington et al. 2008; Charnley et al. 2017; Spies et al. 2017; Ribeiro et al. 2023). On  
38 69 the other hand, serious games are an innovative participatory approach to exploring, learning  
39 70 about, and discussing the complexity of the socio-ecological system, especially when many  
40 71 conflicting interests exist in it (Speelman et al. 2018). Games can support collective negotiations  
41 72 and help define common strategies toward a collectively recognised problem, putting into play  
42 73 the participants’ perception of the problem and their experience.

43 74 Examples of serious games dealing with wildfire risk exist in the literature, focusing on different  
44 75 aspects of risk management, such as firefighting training simulation (Backlund et al. 2007,  
45 76 Caroca et al. 2019), emergency decision-making (Ji et al. 2024), disaster preparedness (Johns et  
46 77 al. 2024) and social awareness (Pereira et al. 2014). However, they were developed to strengthen  
47 78 risk preparedness and response, while, to our knowledge, a serious game focusing on building  
48 79 fire-resilient landscapes involving both direct and indirect fire regulatory processes has not been  
49 80 developed yet. Moreover, none of the cited works successfully represent the interaction between  
50 81 the diverse perspectives and priorities of local stakeholders. Representing and putting them into  
51 82 play is crucial for supporting a participatory process where indeed those interactions must be  
52 83 taken in consideration, discussed and leveraged for developing successful wildfire impacts  
53 84 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.~~

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 Jeu\*](#)<sup>1</sup> 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 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

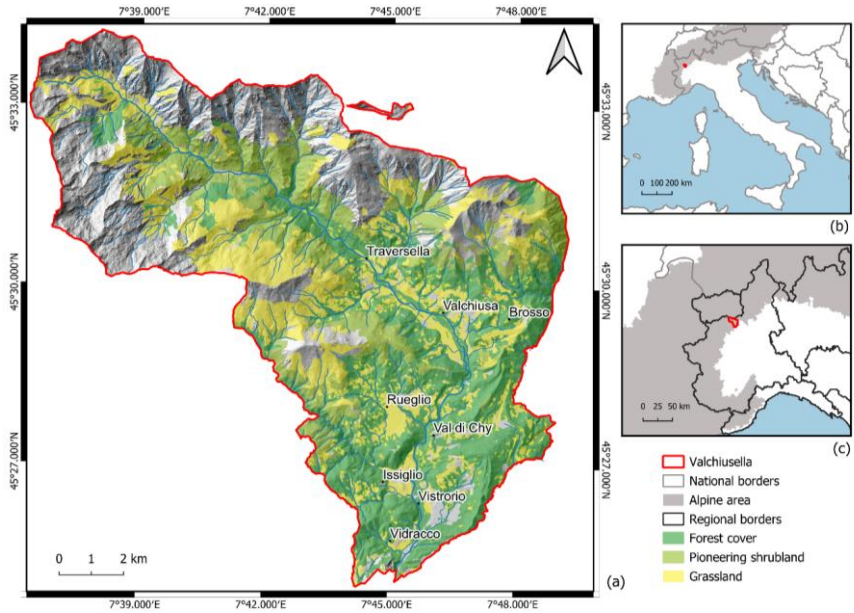
### 2.1 Study Area

The study area is Valchiusella, an Alpine valley of about 143 km<sup>2</sup> in the northwestern part of Italy, in the Piemonte region.

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<sup>1</sup> 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.

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**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 <https://geoportale.igr.piemonte.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).

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)

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

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

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

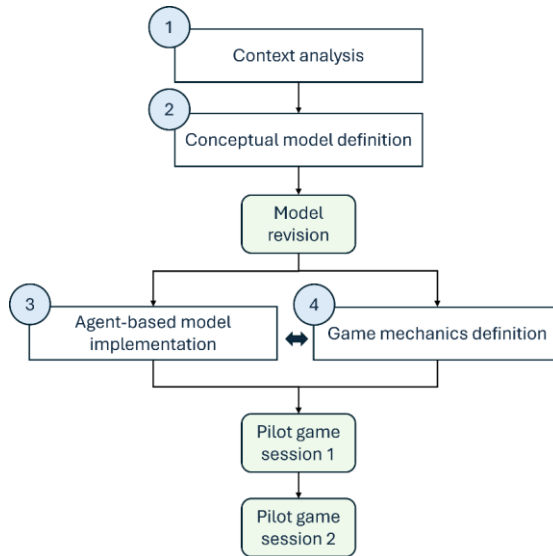
## 17 18 2.2. The game design

19 The design of *A Picit Jeu* was based on four phases (Figure 1):

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

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25 Phases 3 and 4 were carried out at the same time and implied a continuous interaction with each  
26 other.

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



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51 **Fig. 2.** Diagram of the four-phase methodology adopted for the game design. The three review steps are represented in  
52 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').

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' content with later participants before their interviews. However, this is not a limitation for our work given that the purpose of this activity was to get an overview of the interactions between human and ecosystem dynamics and of the local challenges related to wildfire risk, instead of a precise personal point of view. Moreover, any exchange of ideas between stakeholders already happening at this time was perfectly in line with the general aim of this work of fostering collaborative decision-making.

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 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.

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### 2.2.2 Conceptual model definition

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

The 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 about forest and pasture management actions. The game was intended to reproduce a primary general pattern: the less players undertake landscape management actions (e.g., by thinning and cutting forests or grazing pastures), the higher the probability that a fire will burn a large land area. The detailed description of the model following the ODD standard protocol for ABMs (Grimm et al. 2006) and the model code itself are published in (and downloadable from) the COMSES library (Vigna and Millington 2024).

### 2.2.4 Game mechanics definition

While coding the ABM, the game mechanics were also defined. This step was based on a translation process of the actors, resources, dynamics and interactions of the SES conceptual 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 dependent on the previous step and *vice versa*, a continuous interaction between the two was necessary to shape the game mechanics to the model's possibilities and to adapt the model to the needs of the gameplay.

### 2.2.5 Review steps

The first review step was carried out after the conceptual model definition phase. The main aim was to assess the adequacy of the representation of the local SES, highlighting missing elements 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 experience of the local context, including socio-economic dynamics.

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

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

### 2.3 The game sessions

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 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 expertise to the participatory activity, was asked to choose a role in the game that differed from the one they had in real life.

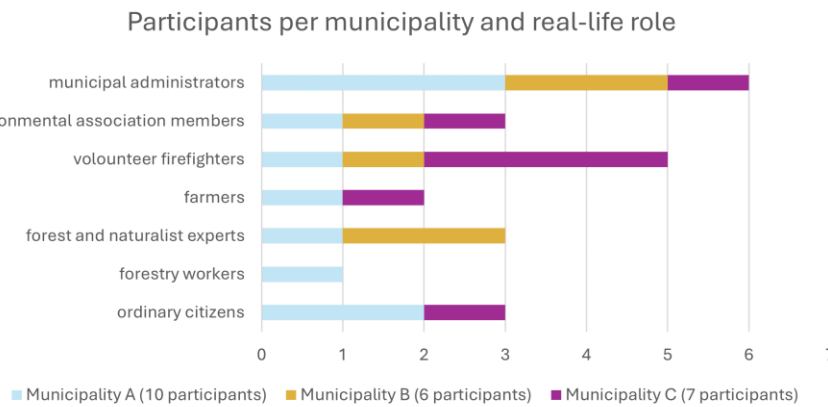


Fig. 3. Categories of stakeholders participating in each game session.

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 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 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 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 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

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

## 282 2.4 The process evaluation

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

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

## 295 3. Results

### 296 3.1 Game overview

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

300 **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 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.

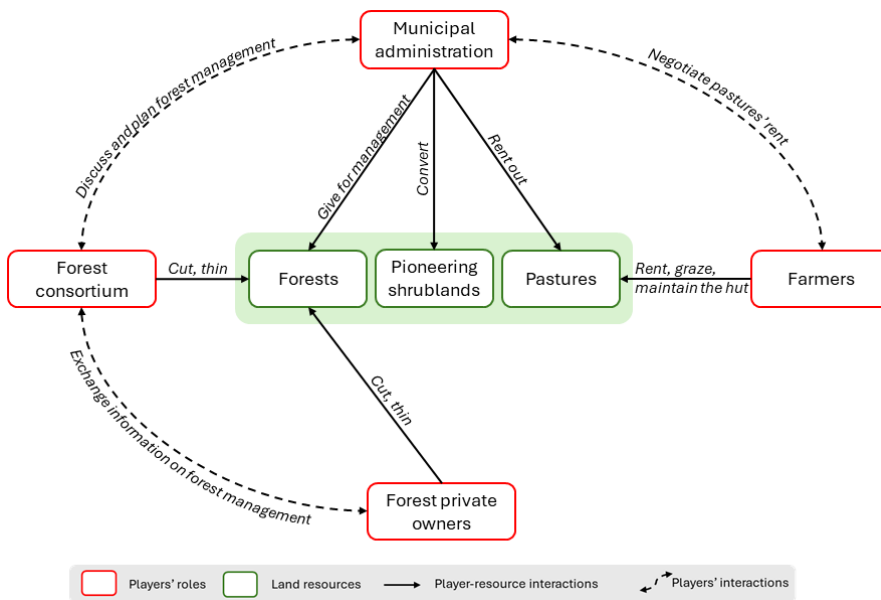


Fig. 4. Overview of the game roles, land resources and interactions.

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Four game roles were identified:

- 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.

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.

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.

Three kinds of dynamics were also identified in the SES:

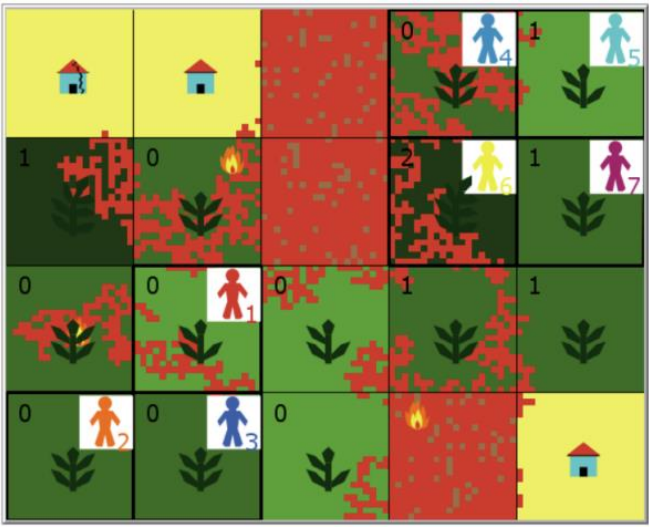
- Ecological dynamics:
  1. The natural reforestation of abandoned pastures, which leads to the growth of a more flammable pioneer vegetation;
  2. The behaviour of fire, which is more likely to burn more flammable lands than others;
  3. Fire hazard dependence on climate conditions;
- Social dynamics:
  4. The common lack of interest on the part of private forest owners in their parcels, which usually leads to their abandonment;
- Economic dynamics:
  5. The pastoral products market variations;
  6. The variation in the cost of forest operations, such as cut and thinning, and of wood prices because of market changes;

These dynamics were crucial in characterizing the ABM. According to dynamic 1, ungrazed 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.

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

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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 Table 2 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 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.

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

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 the same time. You have to deal with many people and issues simultaneously, which differs from my situation. Money comes in one way and goes out another, and, in the end, it all goes out! This is maybe something trivial, but I was able to experience it this evening.”* In this regard, the absence of some crucial stakeholders in some sessions limited the outcomes. More specifically, in Municipality B the participants largely discussed the role of modern farming techniques and a general lack of care in land maintenance on the farmers’ side in contributing to the expansion of the pioneering shrubland on pastures. However, no farmers were present in the session to contribute their points of view and highlight their challenges. In Municipality C, the role of CFC in Valchiusella was unclear to most participants, but the absence of CFC technicians prevented a helpful exchange of information on this point.

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 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 of land abandonment, since it challenges large-scale planning of the landscape. Concerning obstacles to collaboration, participants identified two main elements: the scarcity of economic resources and a cultural aspect. Resource constraints force stakeholders to focus on their short-term economic sustenance instead of long-term and shared plans, whereas the local culture places a solid value on private properties, especially forests. Private forests are sometimes exploited for family firewood consumption but are more often not managed at all. However, owners are frequently unwilling to give up the right to manage their parcels, even when they are not interested in doing so themselves: the land is not transferable because it was inherited from ancestors, belongs to the family, and will go to their children. This phenomenon doesn’t concern new inhabitants of the valley, who are likely to be more open to forms of collective parcel management, such as Land Consolidation Associations (Beltramo et al. 2018). Finally, on one side, the direct funding to farming activities linked to the Common Agricultural Policy helps to keep this traditional practice on the land, also enabling young people to start their pastoral activity; on the other side, it pushes farmers to expand the herd and graze a large extent, without keeping attention to the sustainable management of pasture, since the grazed area is the only parameter deciding the amount of funding.

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

### 3.3 Long-term evaluation

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

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

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.

**Figure 6** **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.

**Table 2.** Summary of the positive outcomes of the game sessions, the long-term effects of the process and its 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	

**Positive outcomes and long-term effects**

- High involvement of the participants
- Understanding of other roles' challenges
- Identification of the challenges for a fire-resilient landscape
- Identification of direct and indirect strategies for a fire-resilient landscape
- Enhanced collaboration between some stakeholders
- Enhanced collaboration and between the CFC and the University of Turin

**Challenging aspects**

- Different level of participants' contribution to the discussions
- Difficulties in understanding the game rules
- Time constraints
- Lack of stakeholders' representation in some game sessions
- Uneven enhancement of collaboration and awareness of the process

**Fig. 6.** Summary of the positive outcomes of the game sessions, the long term effects of the process and its challenging aspects.

## 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 learn. The participants' discussions drew our attention to some issues affecting the SES, on 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 sessions gave stakeholders the opportunity to identify these issues, question their points of view 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 points and identify more general lessons valuable for others using serious gaming to negotiate or 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 oversaw the invitation of the participants, leaving the researcher a lower control over their

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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 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 invitation, overcoming people's scepticism toward a novel methodology and generating interests 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, 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.

Related 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 self-confidence, 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 game roles would have benefited the group dynamics, by deliberately assigning less influential roles to the participants with more influential roles and leadership attitudes in the real world. This is supported by the fact that no power imbalance was witnessed in the Municipality C game session, where the mayor played the less influential role of a private forest owner.

The second lesson learned concerns the inclusion of the game sessions in a broader participatory process. The ComMod approach from which this work was inspired clearly places the use of the game simulations as only one of the steps of a structured participatory process (Daré et al. 2015). 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 the representation of the local SES in *A Picit Jeu* in terms of ecological or socio-economic dynamics. However, two criticisms were raised during the debriefings: that the game mechanics (i) push the players to focus on the economic value of forests and pastures at the expense of other 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.

Moreover, we argue here that the benefits of involving stakeholders from the modelling step go beyond the legitimization 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 strengthening the collaborations with other stakeholders of interest. On the contrary, the environmental association members were only invited to attend the game sessions and later stated that the experience didn't have any positive effects on making their voices heard in local land management debates. An intermediary situation concerns the firefighting team leader, who described the improvement in the collaboration with the CFC in the two years following the game sessions, but, contrary to the forest technicians, didn't think that *A Picit Jeu* experience influenced it. These very different opinions suggest that not only acquiring ownership of the model and game tools is crucial, but also acquiring ownership of the entire process can enhance the benefits of the process itself and provide the stakeholders with a greater awareness of them.

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 projects was included in the game purposes during the initial development phase (see Table 1). However, the absence of leadership at the valley level, which would have been fundamental in setting the meeting and inviting the participants, prevented the organisation of a game session involving more geographically distributed participants. This precluded the exchange of points of view and the development of a shared perspective across a larger extent than a single municipality. Future developments in this methodology should address this point. A game session involving all the valley's mayors could be a starting point, followed by game sessions bringing together lower-level actors from multiple municipalities to avoid the power imbalance 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.

## 5. Conclusions

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

During the game sessions, the participants identified and discussed the challenges for a fire-resilient 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 creation of a fire-resilient landscape also emerged, mainly related to different forms of collective management in pastoralist activities, to prevent land abandonment and maintain diversity in the spatial distribution of land cover.

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

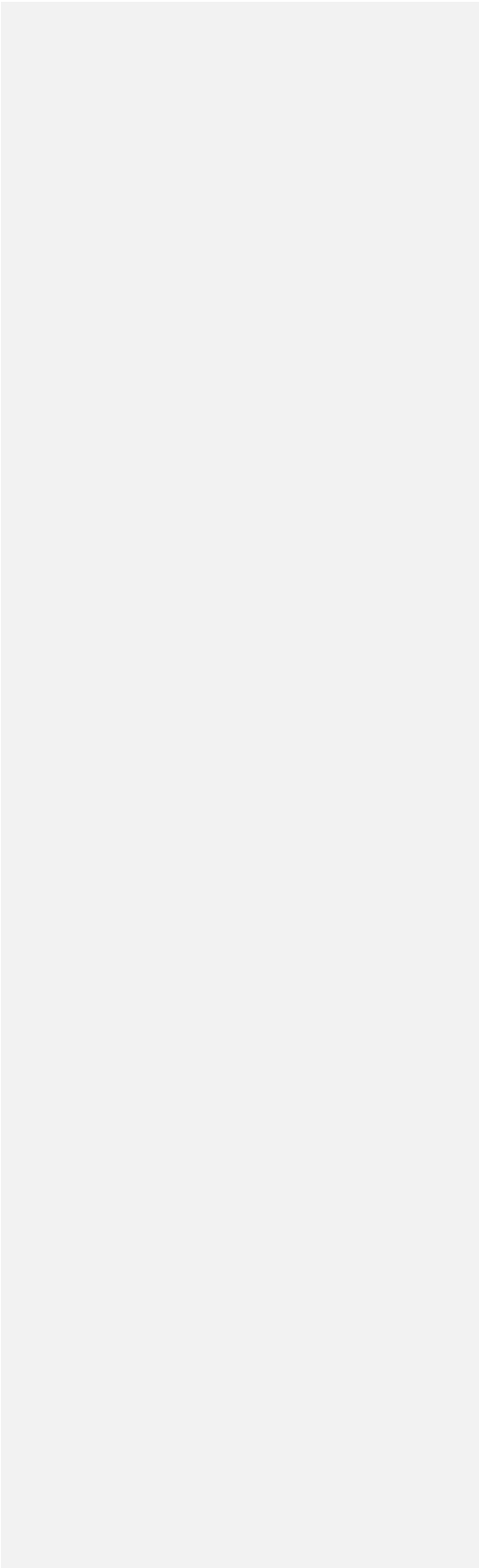
The discussion of the outcomes of this experience, moreover, allowed us to point out some recommendations for future works using serious gaming to support the collaboration of stakeholders in developing sustainable landscapes. First, aiming for an even composition of session groups, where all real-life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

- 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
<b>Evaluating the game</b>	Assessing the ludic aspect and the ability of the game to make the players feel involved	The level of participation of the 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
<b>Understanding the reality</b>	Identifying the most debated topics	The discussions generated among the players
	Understanding the behaviour of the actors	The strategies adopted by the players
	Understanding the confidence accorded by the actors to the scientific and technical knowledge	The value accorded by the players to the specific knowledge of the forest technician



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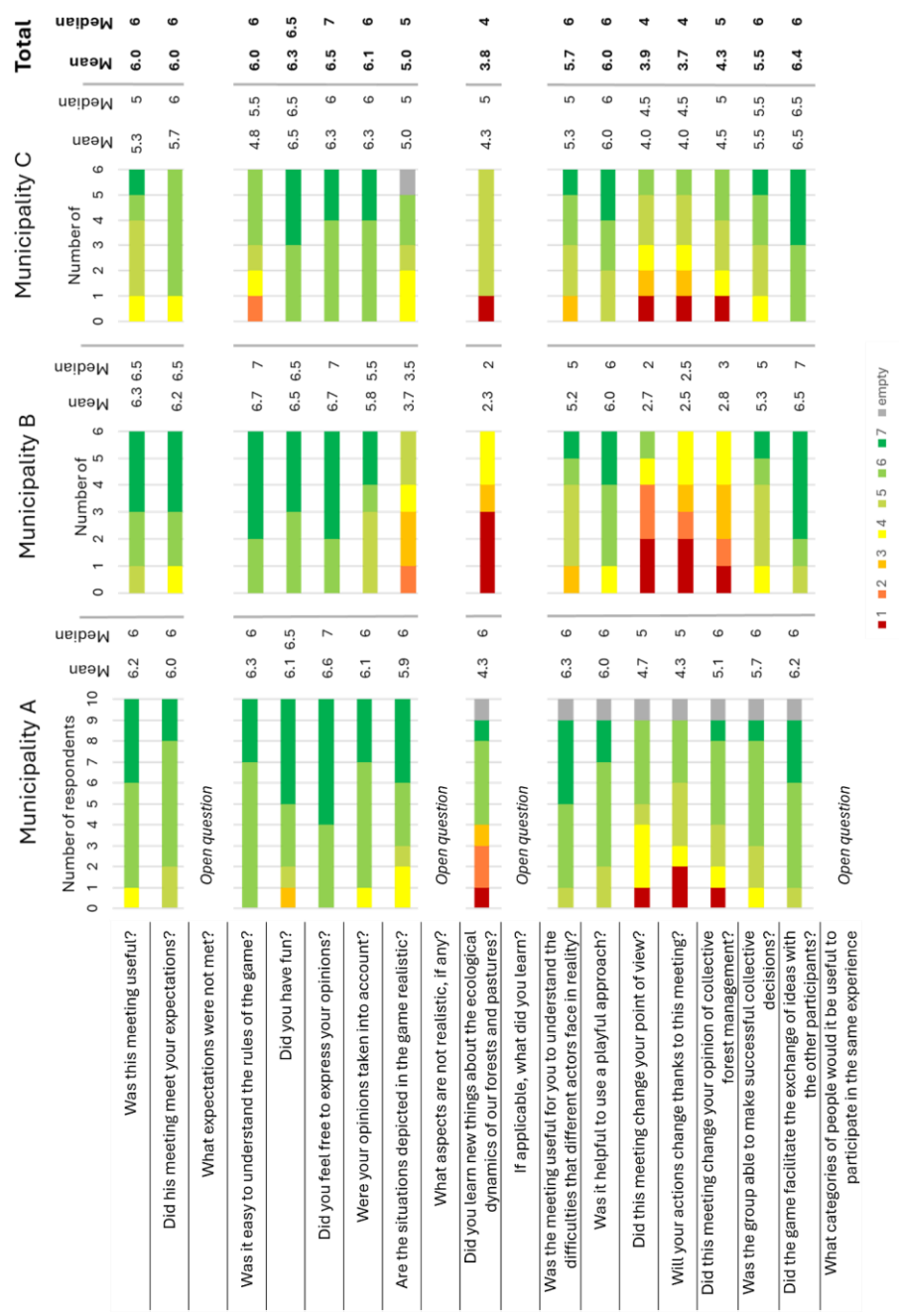


Fig. 1. List of questions of the post-session questionnaires (translation from Italian to English by the authors), with corresponding distribution, mean and median values of the answers to the Likert scale ones.

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**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:

	Municipality A		Municipality B		Municipality C		Average	
	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 expectations?	6.0	6	6.2	6.5	5.7	6	6.0	6
What expectations were not met?	<i>Open question</i>							
Was it easy to understand the rules of the game?	6.3	6	6.7	7	4.8	5.5	6.0	6
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 your opinions?	6.6	7	6.7	7	6.3	6	6.5	7
Were your opinions taken into account?	6.1	6	5.8	5.5	6.3	6	6.1	6
Are the situations depicted in the game realistic?	5.9	6	3.7	3.5	5.0	5	5.0	5
What aspects are not realistic, if any?	<i>Open question</i>							
Did you learn new things about the ecological dynamics of our forests and pastures?	4.3	6	2.3	2	4.3	5	3.8	4
If applicable, what did you learn?	<i>Open question</i>							
Was the meeting useful for you to understand the difficulties that different actors face in reality?	6.3	6	5.2	5	5.3	5.5	5.7	6
Was it helpful to use a playful approach?	6.0	6	6.0	6	6.0	6	6.0	6
Did this meeting change your point of view?	4.7	5	2.7	2.0	4.0	4.5	3.9	4
Will your actions change thanks to this meeting?	4.3	5	2.5	2.5	4.0	4.5	3.7	4
Did this meeting change your opinion of collective forest management?	5.1	6	2.8	3	4.5	5.0	4.3	5
Was the group able to make successful collective decisions?	5.7	6	5.3	5	5.5	5.5	5.5	6
Did the game facilitate the exchange of ideas with the other participants?	6.2	6	6.5	7	6.5	6.5	6.4	6
What categories of people would it be useful to participate in the same experience?	<i>Open question</i>							

**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: