Can a serious hybrid game centred on the landscape encourage the emergence of levers for collective action to reconcile agriculture and water quality?

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Summary

This work is based on the hypothesis that a participatory approach and serious game that places landscape at the centre of its focus can extend beyond individual actions in encouraging more effective concerted action to limit the contamination of watercourses due to plant protection products. An interdisciplinary approach (involving the fields of socio-anthropology, concertation sciences and earth sciences), based on co-construction workshops held with local stakeholders, has led to the creation of the CAUSERIE game. This so-called 'hybrid' game relies on a GIS model of the catchment area, namely GEOMELBA-SPIRIT, that explicitly represents the influence of the spatial distribution of typical cropping systems and landscape infrastructure (grassy strips, hedges, ditches, constructed wetlands), in order to examine the role of collective action and its associated levers. This approach has been parameterised for both viticulture and mixed farming activities.

Keywords: serious game, spatial modelling, cropping systems, agro-ecological infrastructure, landscape, integrated management scenarios

1. Introduction

The impact of plant protection products (PPPs) used in agriculture on water quality depends on both their use (quantities introduced, toxicity and mobility of the substances, application methods, etc.) and the processes by which the molecules are dissipated and conveyed from the treated plot and along their transfer routes to the watercourse (Gouy et al., 2008). Cultivation and soil maintenance methods as well as the landscape features likely to intercept runoff (meadows, ditches, paths, hedges, etc.) and sub-surface flow (constructed wetland buffer zones) also play an important role in modulating contamination (Aubertot et al., 2005). A global approach is therefore needed at the catchment scale in order to optimise corrective solutions and combine their effects on the quality of watercourses. However, the existing levers for action are most often mobilised at the farm level, without any real consultation with other farmers in the catchment area, even though any given farmer's final decision depends on complex chains of influence (individual and collective values, advice, regulations, production and product value chain, water management, societal factors, etc.) that lie beyond the scope of the individual farm. Moreover, a farmer's choices in terms of cropping systems, crop rotation and landscape infrastructure lead to changes with a potentially profound effect on the landscape, hence impacting its ecosystem functions (agricultural production, ecological, health, socio-economic, cultural, biodiversity conservation, etc.).

Against such a backdrop, this study - carried out as part of the SPIRIT and DIALECTIC projects (see Declaration of Financial Support at the end of this article) - explores the conditions behind the emergence

of territorial levers to facilitate concerted action and the mobilisation of stakeholders, in particular for implementing collective actions capable of: minimising individual investments, increasing the overall effectiveness of strategies adopted, and moving towards landscapes with greater overall resilience. The initial hypothesis here is that encouraging collective action involves sharing not only values (human, cultural, ecological, economic, etc.) but also an appreciation of the services rendered in association with public goods (agriculture, vineyards, water, air, soil, subsoil, biodiversity, landscapes, etc.) (Heinich N., 2017). The second hypothesis assumes that the use of: **i)** participatory methodologies and tools that place farmers at the heart of the various networks of interactions likely to influence their choices, combined with **ii)** a model that can be used to simulate and evaluate spatialised corrective solution scenarios integrated at the catchment scale, will facilitate the sharing of values and the co-construction of corrective solution programmes more specifically optimised and appropriate for stakeholders. Two main types of complementary actions are considered herein: a reduction in use pressures, via the transition to cropping systems that are less dependent on PPPs; and the introduction of landscape elements that act as buffer zones. This complementarity jointly influences the resulting watercourse contamination. A panel of spatial or outlet indicators is being proposed to assess the overall potential of these actions to impact not only the transfer of products to the watercourse but also other issues, like carbon balance and soil erosion.

2. A global methodology

The geographical object of study is the agricultural catchment area, spanning a few km², where water quality is created. The landscape, at the crossroads of various territorial scopes of intervention and multiple issues, has been placed at the centre to serve as a "border object"[1] and potential vector of collective action (Seguin et al., 2022). An interdisciplinary approach combining life and earth sciences, socio-anthropological sciences and concertation sciences was implemented, in conjunction with a participatory approach involving key regional actors (farmers, water managers, hunting and fishing federations, environmental associations) (Fig. 1). This approach was then deployed in catchment areas in a wine-growing context (Ardières Morcille workshop site in the Beaujolais ZABR zone) as well as mixed farming (Gimond Basin in the Monts du Lyonnais region).

More specifically, the methodology was based on:

- Semi-structured interviews of a wide range of stakeholders in the area to determine their perceptions of landscapes (interest, constraints, values and associated benefits), in order to gain a better understanding of the issues and identify existing groups and their interactions,
- Participatory workshops to collectively express the representations, practices and expectations of stakeholders with regard to the landscape, particularly in terms of agriculture and water quality, leading to the conceptualisation of exchanges in the form of a serious game to facilitate the co-construction and collective exploration of development scenarios,
- A simplified spatial hydrological model to calculate the combined effect of the location of actions undertaken, in terms of changes to cropping systems and implementation of landscape features (hedges, grassy strips, revegetation of ditches), on rapid lateral transfers and watercourse contamination by PPPs,
- The development of indicators of transfers and the potential for waterway contamination by PPPs, followed by their implementation in order to assess the impact of prospective scenarios. At the Beaujolais site, indicators were also developed to compare scenarios in terms of net carbon

[1] An object at the intersection of heterogeneous fields of activity and value systems, thus enabling actors from different fields to communicate (Trompette and Vinck, 2009).

footprint (greenhouse gas emissions and soil carbon sequestration (IFV in-house method)) and soil erosion mitigation potential.

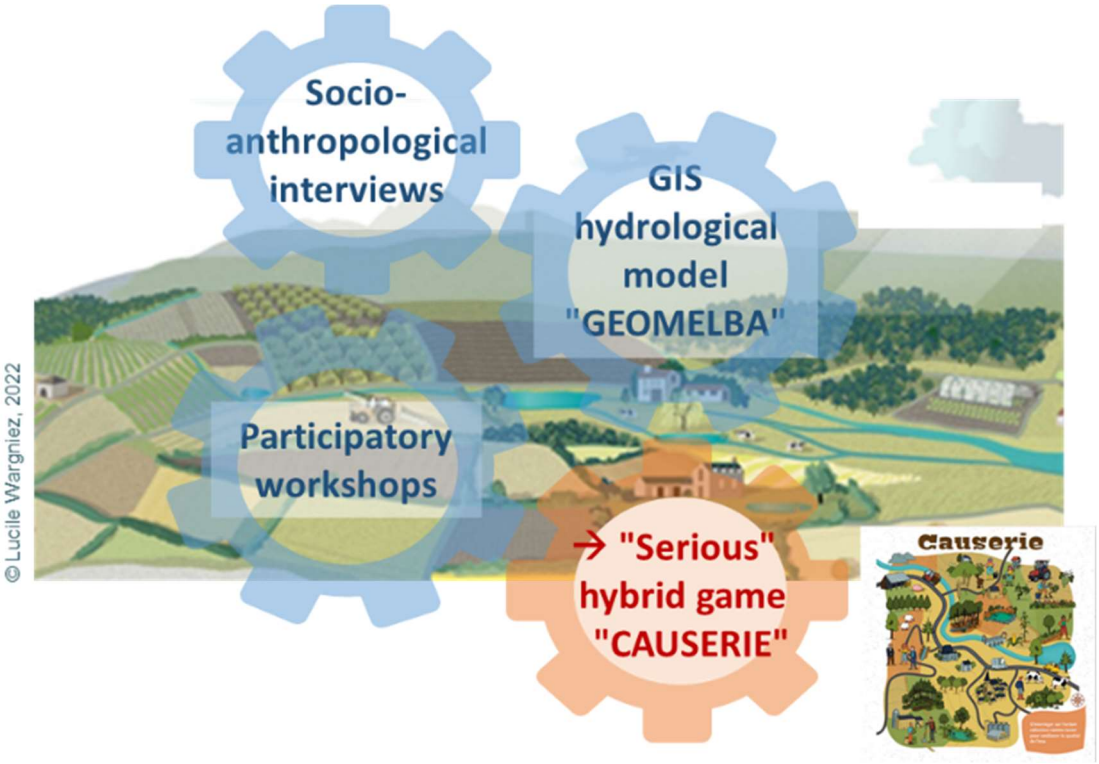

Figure 1: An interdisciplinary approach

3. Details of the methodology and associated results

3.1. Values: Underpinning farmers' individual and collective commitment

In addition to providing background information for the development of our "serious game", the socio-anthropological interviews conducted with various regional stakeholders enabled analysing the factors behind the emergence of individual and collective dynamics, in favour of more environmentally-friendly winegrowing practices. In particular, this analysis has shown the many factors that enter into a farmer's or grower's decision-making, often forcing the acceptance of compromises. Besides the socio-economic aspects cited as a determining factor in support of changes in practices, the notion of value also seems to play a key role in the various forms of commitment exhibited by farmers. More specifically, shared human, cultural and ecological values along with a defence of public goods and services (agriculture, emblematic crops, water, air, soil, biodiversity, landscapes) would appear to encourage collective action. The Beaujolais region is witnessing the rise of new ecological fronts, i.e. a space where values and ideas are coalescing around ecology (Afeissa, 2009), based on ethical and environmental values. However, the majority of farmers are not necessarily taking the 'plunge' into more virtuous approaches because of competing or even conflicting values (notably economic in nature). Certain pragmatic and facilitating measures (e.g. Biodiversity Marathon, Payments for Environmental Services, changes to AOC appellation requirements) can increase the weight ascribed to ecological values by mitigating economic or technical constraints (Armani et al., 2024). In addition, idealistic boundary objects (e.g. the notion of sustainable development, agro-ecology) or material objects (e.g. landscape, buffer zone, hedgerow) have proved to be useful in facilitating encounters, debates and the emergence of shared interests over and above the stated differences.

3.2. A simplified catchment model to help visualise the effect of practices on water quality

The aim of the developments presented in this section is to produce a model that explicitly represents the landscape elements influencing PPP transfers to the watercourse (i.e. source zones and attenuation zones) (Fig. 2).

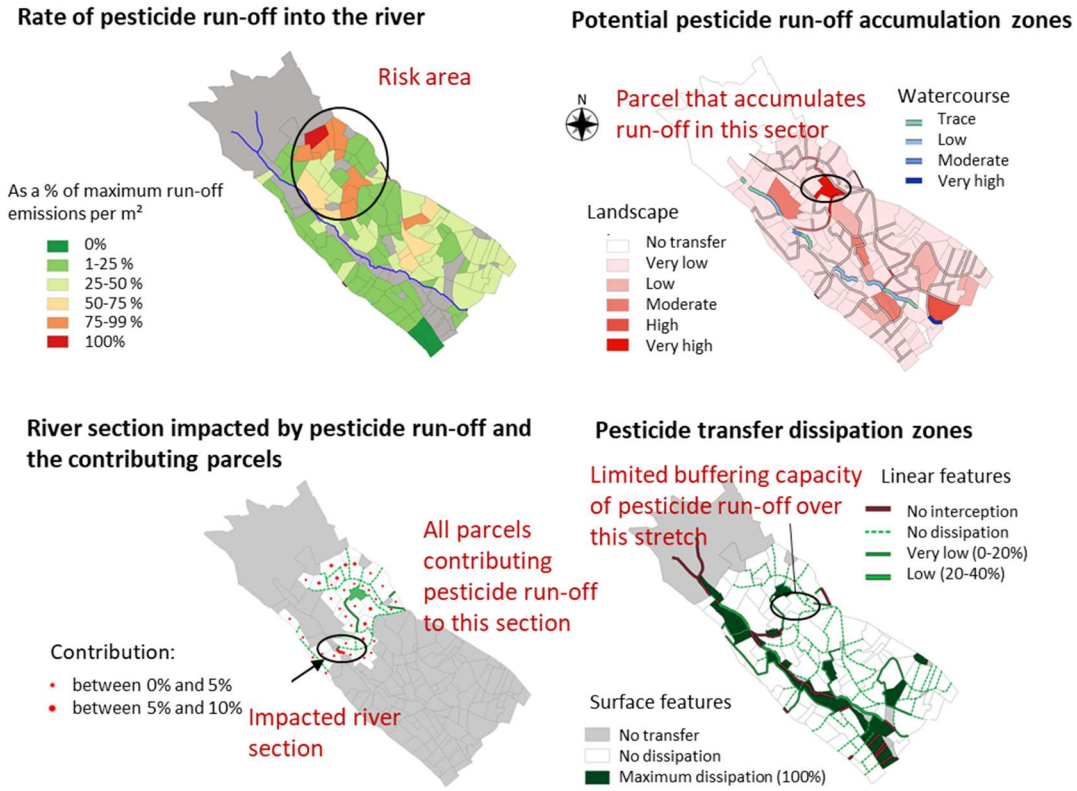

Figure 2: Examples of maps generated by GEOMELBA-SPIRIT, plus a sample interpretation shown in red (PPP: plant protection product)

Another challenge is to ensure that the results of this tool are easily understood by local stakeholders and moreover able to be quickly presented during the game sessions. To achieve this, we ran the geomatic tool GEOMELBA, initially developed to build the catchment mesh of the PESHMELBA physics-based hydrological model (Rouziès et al., 2019), yielding the GEOMELBA-SPIRIT software implemented in Qgis in the form of a Python plugin. This software enables an "on-the-fly" assessment of the effect of: changes in land use (e.g. conversion of a plot of land to grassland, restructuring and/or grassing of vines), changes in cropping systems (switch from an insurance-based treatment strategy aimed at maximising yield to an optimised treatment strategy or one that does not use synthetic products, lengthening of rotations in mixed farming, grassing of inter-row areas in winegrowing, etc.), or the installation of agro-ecological infrastructure (e.g. revegetation of a ditch, installation of a hedge or grassy strip).

GEOMELBA-SPIRIT considers the rapid transfers (runoff and drainage) responsible for both PPP contamination peaks and the main flows in the catchment areas under consideration, i.e. systems situated on bedrock (Rabiet et al., 2010). This software also accounts for average annual or even inter-annual transfer potentials, as transcribed in the form of plot emission coefficients determined by expert opinion, depending on the pressure of product use, soil cover and slope. The attenuation potentials of the landscape features acting as buffer zones are estimated on the basis of literature findings or local physical modelling (Grillot et al., 2022). By design, this tool does not represent the temporal dynamics of flows or the interactions between processes; such a simplification was required for use in participatory workshops. In contrast, the tool does visualise the spatial evolution linked to players' choices nearly instantaneously.

3.3. A "serious" game used as a consultation tool

The CAUSERIE serious game was derived from the co-construction workshops held with local stakeholders at the two study sites using the ARDI-ComMod method (Etienne, 2015). It offers the following specific features:

- Use of GEOMELBA-SPIRIT, the previously described spatial geomatics tool, to visualise in real time the consequences of players' choices at the catchment scale,
    - Accounting for inter-annual (1 game round = 3 years) spatiotemporal landscape, agro-social and economic dynamics (in particular via a farm account sheet) among the three main stakeholder categories (farmers, catchment area manager, and agricultural adviser or representative of the agricultural sector), and constraints and/or opportunities through the use of event cards (weather, economy, public policies, etc.) either drawn at random or chosen by the game master,
- Suggestion of a simulation (role-playing) to explore the possibilities of changing cropping systems (with the three levels of change corresponding to different product uses, namely: insurance-based treatments, optimised, without synthetic chemicals), locating agro-ecological infrastructure (hedges, grassy strips, ditches, constructed wetlands, etc.), and holding a final debriefing to question individual and collective actions.

This game (freely available at: https://polldiff.lyon-grenoble.hub.inrae.fr/recherche/gestion-integree-du-bassin-versant/jeu-serieux-causerie, designed to be inserted onto the gamae platform) has been configured for viticulture (archetypal Beaujolais site) and mixed farming and livestock (archetypal Gimond site) (Barreteau et al., 2023). It has been tested by professionals at the respective study sites (farmers, technical institutes, chambers of agriculture, industry actors, agricultural colleges, water and land managers, local authorities, hunting and fishing federations, environmental associations), as well as by students in the BTS viticulture-oenology curriculum (Bel Air (Rhône) and Rouffach (Haut-Rhin) agricultural colleges) and students attending IUT or Master's level courses at Lyon University.

The game was deemed credible by local stakeholders at both sites and found to be conducive to a wide range of stakeholder instruction (e.g. on the overall influence of landscape elements on PPP transfers at the catchment area scale, on the importance of locating buffer zones when considering physical relief and water flow directions, on the economic constraints of a farm to ensure a successful transition). The 'fictitious' catchment area and its projection within a landscape did make it possible to broaden the scope of the challenges and address them more specifically from the farmers' point of view. Use of the GEOMELBA-SPIRIT computer tool did not obstruct the players' attention and, to the contrary, was identified by them as a lever to both facilitating the choice of actions to be implemented within the catchment area and stimulating exchanges between the players engaged in farming and "institutional" players. In particular, the game proved to be an interesting way of resolving conflictual situations since it allowed all participants to express their points of view in an informal setting.

In terms of the game's relevance in facilitating the exploration of collective actions, results were more conclusive in the workshops involving students. In fact, a strong level of dependence was found between the players' posture and their ability to reconcile environmental values with economic constraints. The behaviours observed served to confirm that commitments to the environment are the result of negotiation between personal and collective values and the external constraints imposed on farming (in particular, market trends and weather). As such, the roles of the catchment area agency and the farm advisor appeared to be decisive in the support of risk-taking behaviour.

3.4. Distinct development scenarios

Distinct scenarios of development patterns over the next 50 years were defined for each site, on the basis of discussions held with professionals (specific interviews or debriefings once the game on the Beaujolais site had been concluded). The GEOMELBA-SPIRIT tool was implemented to visualise the impact of these scenarios, which covered a variety of cropping systems and landscape characteristics. Their comparison reveals the interest of the scenarios evolving not only towards advanced agro-ecological practices with a strong reduction in uses (thus corresponding more to a redesign of systems than to efforts favouring the continuity of conventional systems) but also towards the installation of landscape elements. The most effective scenarios for limiting PPP contamination of watercourses, as calculated by GEOMELBA-SPIRIT (Fig. 3), also improved the net carbon balance (increased carbon sequestration in the soil) and minimised erosion (Gouy et al., 2024; Carluer et al., 2024).

4. Discussion of results with local stakeholders and the emergence of levers

The various results cited above were then presented to the stakeholders in each area and discussed collectively. Generally speaking, on the Gimond site, although this presentation was specifically addressed to a technical committee of the union responsible for water management, the number of participants and the time available for discussion were limited. At the Beaujolais site, the feedback session attracted around 50 attendees, most of them winegrowers or representatives of the agricultural sector.

The GEOMELBA-SPIRIT tool attracted the attention of water managers as a potential tool to assist them choose among various action strategies. However, the farming profession has shown some reluctance with regard to scenarios based on major changes to cropping systems. If such an approach were to be adopted, it would be necessary to first demonstrate the approach's socio-economic feasibility, relative to the different socio-technical and economic situations of existing farms within the catchment area, and then propose personalised transition paths.

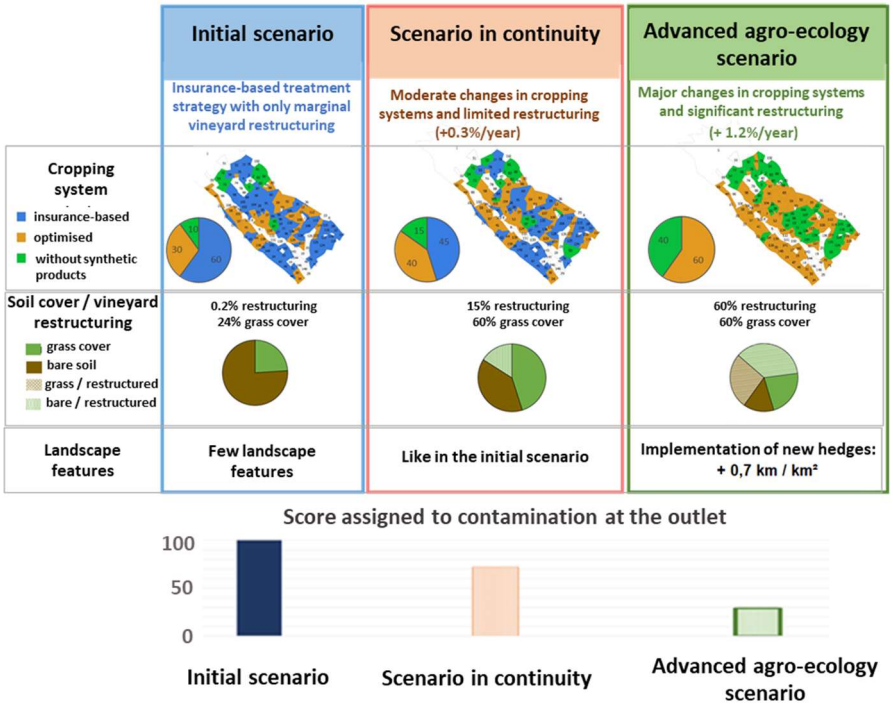

Figure 3: Example of prospective scenarios, calculated using GEOMELBA-SPIRIT, and discussed collectively with local stakeholders

Furthermore, for any change to be successful, it must make sense to and provide job satisfaction for the farmer. Landscape features and associated biodiversity are still viewed with circumspection (as reservoirs for pests, sources of constraints, etc.) even though their beneficial effects (shading, creation of a microclimate and fodder) seem to offer a solution for mitigating the effects of climate change. In all cases, a need was felt for better support and legitimisation of farmer groups engaged in more virtuous practices, to enable them to exchange ideas with other farmers and inspire emulation. At both sites, the farmers present also emphasised the importance of setting up experiments on farms and organising visits to share results in order to encourage the dissemination of innovations and their adoption.

At the winegrowing site, despite some differences in opinions, the winegrowers unanimously endorsed the importance of restoring soil fertility as an effective lever to federating their actions and guiding other actions, as fertility lies at the heart of Beaujolais vineyard resilience. Other important levers mentioned included: vineyard restructuring, collective equipment purchases, crop and landscape diversification (with priority assigned to spontaneous and controlled hedge regeneration), a diversification of activities, the introduction of resistant grape varieties, and the adoption of an energy strategy. Collectives are also better positioned to implement measures to remove certain obstacles to change (e.g. constraints linked to indirect farming methods, or to INAO specifications for the use of drought- and disease-resistant grape varieties (VIFA)).

More generally, collective actions on the ground and incentive programmes that help limit the technical and economic constraints placed on changing practices can trigger new commitments. It was also pointed out that change cannot take place all at once; it must be considered in stages to ensure economic viability. The transition phase (3 to 5 years minimum) constitutes a risk period, exacerbated by climate change, and should be more carefully monitored. Attendees at each of the two presentations stressed that the changes proposed in the scenarios did not just involve farmers but also constituted a territorial project, with a need expressed for support in risk-taking. Collectives and local authorities should play a more central role in promoting regional development initiatives that benefit both the environment and local agriculture, in addition to enhancing its value. It was also recognised that the actions envisaged in these scenarios made sense in terms of adaptation to climate change; such assessments need to be taken more fully into account in support of concrete implementation steps.

This discussion of scenarios for the catchment area ultimately led to a collective expression of the need to share experiences more effectively, by bridging the divide between organic and conventional farming. The question of governance and leadership was also raised, as was how best to structure feedback for ease of sharing. Shared experimentation sites (i.e. pilot catchment areas, Living Labs) capable of assembling research and development actors could be the focus of initiatives, trials, monitoring and special support efforts to test the feasibility of mass-scale transition actions at these levels. In short, we need to move on from the fictitious cases being modelled to an actual catchment area with all its agro-pedo-climatic, socio-economic and human diversity.

5. Conclusion

Upon completion of this work, we are now able to provide some answers to the hypotheses initially posed. With regard to the first hypothesis, the socio-anthropological interviews clearly showed that shared values and appreciation for public goods (water, biodiversity, landscapes) can encourage collective action in favour of more virtuous practices. Since the decision to act is the result of individual negotiations, during which economic and organisational constraints play an important part, incentive programmes that help limit these constraints can increase the weight ascribed to ecological and environmental values in the development of practices. Landscape has clearly emerged as a 'frontier' object likely to stimulate dialogue and the formation of groups sharing goals and interests, which in turn can lead to defining new levers for action. Such collectives might lie at the origin of new standards, to encourage other farmers and mitigate

the environmental impact of their practices. However, virtuous experiments in the field still need to be better shared and supported.

As for the second hypothesis, even though the GEOMELBA-SPIRIT tool does seem to stimulate players' moves in testing the influence of various actions, the capacity of the serious game, co-constructed on a landscape scale, to explore collective actions has only been clearly demonstrated with regard to students. It seems that the institutional attitudes of the professionals involved can stifle the players' initiatives and will take time to overcome. The discussions held during the final debriefing (i.e. how did the game play relate to real-life situations?) did serve to extend beyond the game's framework – which is an interesting outcome of "metagames" - and bring out some broader reflections, namely in terms of the obstacles and levers on the emergence of collective action. For example, the CAUSERIE game was seen by operational staff as a valuable means of encouraging consultation within an area and helping manage situations of deadlock or conflict between managers and farmers.

The game's implementation, as well as the discussions held with local stakeholders on the different prospective development scenarios, has highlighted the need for specific support during the transition phase, which involves increased costs and risks for farms (now exacerbated by climatic and economic constraints), including those opting to work collectively. Farmers are also requesting that transition paths be spelt out and adapted to the diversity of situations on the ground, along with an estimate of the associated costs/benefits for each farm. Lastly, discussions at the winegrowing site highlighted the importance of key concepts able to unite farmers beyond their technical and economic orientations, such as soil fertility, effective vine water management and the farm's energy strategy.

All in all, the CAUSERIE game and exchanges of views around the scenarios and indicators proposed did ultimately create a favourable environment for the emergence of levers for changing practices, in underscoring the importance of collective action. The use of a pool of indicators, including water quality, can assist managers in making informed decisions when confronted with multiple challenges (Préau et al., 2022). However, biodiversity issues have become controversial among the stakeholders involved in the project. With this in mind, it has been planned to study the feasibility of integrating into the GEOMELBA-SPIRIT model a calculation of landscape connectivity indicators and their potential impact on biodiversity, including pest populations and crop beneficials. It would thus be worthwhile to test the extent to which such a tool could overcome some of farmers' preconceptions regarding wild biodiversity. At the same time, work is underway to transpose the game to other agricultural contexts, in the aim of developing a methodology that can be used by those involved in diagnosis and local development.

Ethics
The authors hereby declare that all experiments were carried out in compliance with applicable national regulations.

Declaration on the availability of data and models
The data supporting the results presented in this article are available upon request from the article author.

Declaration on Generative Artificial Intelligence and Artificial Intelligence-Assisted Technologies in the Drafting Process
The authors used artificial intelligence in the initial translation process from French to English before proofreading by a professional.

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Authors' contributions
The UR G-Eau and LISODE teams contributed more specifically to developing the CAUSERIE serious game and running the workshops. The UR RiverLy team contributed to development of the GEOMELBA-SPIRIT tool. Gilles Armani, Laura Seguin and Stéphanie Malingrey conducted individual interviews at each site. Emilie Adoir and Hugo Luzi from IFV helped in setting up the CAUSERIE game and developing scenarios for the Beaujolais site.

Declaration of interest
The authors hereby declare that they do not work for, advise, own shares in, or receive funds from any organisation that could benefit from this article, and moreover declare no affiliation other than those listed at the beginning of the article.

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