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English title: Analysing the potential of serious games to raise new research questions on social-ecological systems

Titre en français : Les jeux sérieux ont-ils le potentiel de faire émerger de nouvelles questions de recherche sur les socio-écosystèmes ?

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Abstract

As transdisciplinary approaches are increasingly required to study social-ecological systems (SES) and address the complex relationships between humans and nature, this paper explores the potential of serious games (SG) as tools that can help researchers formulate new research questions. We draw on a comparative case study of six SG to explore the extent to which these games may help raise new research questions on SES. We highlight three key potential properties of these tools: allowing researchers to identify (i) knowledge gaps, (ii) mismatches between theoretical expectations and observations ("anomalies"), and (iii) neglected social-ecological interactions, which can change the researchers' representations of the systems under study. Our comparative study shows that they may be useful to identify knowledge gaps and neglected interactions, suggesting that SG have the potential to generate original research questions that would consider both people and nature in social-ecological systems.

Résumé

Alors que les approches transdisciplinaires sont de plus en plus mises en avant pour étudier les socio-écosystèmes (SES) et aborder les relations complexes entre les humains et les non-humains, cet article explore l'intérêt des jeux sérieux dans ce type de recherche, dans la mesure où ils permettent des interactions structurées et originales entre acteurs académiques et non-académiques autour de questions relatives à la gestion des écosystèmes et des ressources naturelles. A partir d'une étude comparative de six jeux sérieux, nous analysons dans quelle mesure ce type de jeux peut aider à formuler de nouvelles questions de recherche sur les SES, en analysant leur capacité à remplir trois fonctions-clés : permettre aux chercheurs d'identifier (i) des lacunes de connaissances sur les SES, (ii) des "anomalies", ou décalages entre les attentes théoriques et les observations réalisées, et (iii) des interactions socio-écologiques aujourd'hui négligées, qui pourraient modifier les représentations qu'ont les chercheurs des systèmes qu'ils étudient.

Notre étude comparative montre que ces outils peuvent être utiles pour identifier des lacunes dans les connaissances scientifiques ainsi que des interactions largement négligées dans les représentations actuelles des SES, ce qui suggère que les jeux sérieux ont un potentiel intéressant pour faire émerger des questions de recherche innovantes sur les SES.

Introduction

Exploring the relationships between humans and nature: a need for new research tools

From the perspective of an ecologist examining an ecosystem, human activities are generally considered to be an exogenous interfering force that fails to neatly fit into an ecological theory (Collins et al., 2000). Historically, ecologists have investigated the biophysical, ecological, and evolutionary processes that occur in ecosystems unaffected by human influences, and they attribute any ecological and evolutionary changes to natural variations in energy and material flows or to natural selection (Alberti et al., 2009). However, in response to the growing global environmental crises, an increasing number of ecologists call for the inclusion of humans in the study of ecosystems by integrating social sciences into their own research field. For several years, they have asserted that effective conservation policy and management require both a knowledge of ecosystems and an understanding of human societies that interact with and depend on these ecosystems (Hooper et al., 2005). The concept of social-ecological systems (SES) was thus introduced, generating a growing body of theoretical and empirical work relating to the ongoing changes and uncertainty in SES (Bretagnolle et al., 2019; Folke et al., 2010; Kates et al., 2001). This research combines transdisciplinary[1] with multiscale and multitemporal approaches, bringing together the physical, biological, and social sciences, and incorporating institutional and governance analysis. Such ambitious research calls for the development of new concepts and tools (Kaneshiro et al., 2005; Plummer & Fitzgibbon, 2004).

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[1] Interdisciplinary approaches call on a wide range of disciplines, whereas transdisciplinary research additionally includes knowledge from non-academic sources (see: Nowotny, H. (2003). "Democratising expertise and socially robust knowledge." Science and public policy **30**(3): 151-156.)

How serious games contribute to research on social-ecological systems so far

A growing body of literature on serious games (SG), that is, games used for non-entertainment purposes, has highlighted the benefit of these tools for studying complex SES (Reckien & Eisenack, 2013; Zvoleff & An, 2014). Due to the multitude of names, the term SG is used to describe any "serious games," "role-playing games," or "participatory simulations" that are "experi(m)ent(i)al, rule-based, interactive environments, where players learn by exchanging information, by taking actions and by experiencing their effects through feedback mechanisms that are deliberately built into and around the game" (Mayer, 2009).

SG use a variety of structures (e.g., with or without a digital interface) and goals (Flood et al., 2018) depending on the target audience. For the general public and scholars, SG are valuable in providing interactive tools to educate the players and promote their behavioural change (Tsai et al., 2019; Wu & Lee, 2015). For environmental managers, SG offer a creative response to the need for innovation in policy capacity building (Flood et al., 2018), especially when coupled with computerized interfaces (Ruankaew et al., 2010). Finally, researchers with an interest in environmental governance have stressed the value of SG when studying the importance of social learning in conflict resolution or as a facilitator of collaboration and dialogue (Den Haan & Van der Voort, 2018; Flood et al., 2018; Muro & Jeffrey, 2008). Given their potential, SG have been used to gain social or political insights into different SES, mostly in the management of agriculture, water systems, or climate change (Edwards et al., 2019).

As research tools that combine various disciplines and foster exchanges between researchers and practitioners, SG are useful for understanding both social and biophysical dynamics of SES. We, the authors of this article, have elaborated and/or used SG in different contexts: skills training, teaching for students in agronomy and ecology, as well as implementation in transdisciplinary projects. We started this exploratory study with the intuition, based on our experience of SG as ecologists, social scientist, geographer and agronomist, that serious games could provide unexpected benefits to researchers, and in particular could enable ecologists to formulate new research questions on SES.

We first propose three key properties for research tools or concepts that can help raise new research questions by allowing researchers to identify knowledge gaps, mismatches between theoretical expectations and observations ("anomalies"), and neglected interactions that can lead to changes in their representation of the systems under study. We then draw on a case study analysis through which we investigate whether or not SG have these properties. Finally, we summarize our results and draw conclusions regarding how SG may be used to generate new research questions on SES.

Identifying three key properties to renew research questions on social-ecological systems

Drawing on research in epistemology (see the references mentioned below), we identified three potential key properties of research tools and concepts that may help researchers open up new research fronts and thus raise new research questions.

Key Property 1: SG may allow researchers to detect knowledge gaps about the SES under investigation. The main objective of science is to advance knowledge production. This process is guided by the identification of knowledge gaps, typically revealed by establishing a state of the art. The use of interdisciplinary or even transdisciplinary approaches makes it possible to renew the way in which states of the art are established. The confrontation of various types of knowledge may outline unsolved research questions (Girard, 2013; Zvoleff & An, 2014). With game designers from multiple disciplines and stakeholders with their own empirical knowledge, SG are typically at the forefront of this process to identify knowledge gaps

(Agogué et al., 2015). SG may also lead participants to explore innovative and collective solutions, thus identifying knowledge gaps. Such a relationship between exploration of ideas and search for missing knowledge is explained by Hatchuel and Weil (2008) in terms of design theory.

Key Property 2: SG may enable researchers to detect anomalies and thus discuss or enrich existing theories. Science advances through a continuous discussion of theories (Cariou, 2019): theories may be enriched, refined, or even contested when confronted with empirical data. As Hatchuel et al. (2018) points out: “the unknown lies in the anomalies detected between a state of the art and a state of the facts.” The scouting of anomalies leads to a revision of theories and a fortiori knowledge. SG are a specific device to observe situations in which the actors who act in the same SES but do not necessarily interact in real life are invited to explore solutions together. Unlike theoretical predictions, this interaction process may allow researchers to detect anomalies and subsequently revise existing theories.

Key Property 3: SG may cause researchers to change their representations of the SES under study and take previously neglected interactions into account. Scientific knowledge builds on the representations of reality through models, concepts, and formalisms. Identifying new relations or dimensions may allow researchers to renew their representations of reality and thus identify new research questions (Toffolini et al., 2020). SG are specifically built to unveil poorly known interaction processes between humans as well as between humans and nature. They may lead ecologists to broaden their research objects from ecosystems to SES, giving rise to interaction patterns of greater complexity encompassing ecological, social, economic as well as political processes (e.g., Rakotonarivo et al., 2021, Lardon & Piveteau, 2005). Interestingly, renewed representations of SES may result from both SG design phase and implementation phase.

Methodology

Selecting a set of serious games for a comparative case study

To explore the potential benefits of SG for ecological research, we analysed the design and implementation of six SG. We selected three SG that the authors of this paper contributed to develop and another three on the basis of a preliminary survey regarding the use of SG by French ecologists. All six SG address the issues of biodiversity, natural resource management, and/or climate change (see Table 1).

Table 1: Presentation of the six case studies

1. Game and references	2. Socio-ecosystem at stake	3. Collaboration between researchers and local stakeholders	4. Game objectives	5. Inclusion of ecological issues in the game
Secoloz (Moreau, 2019; Moreau et al., 2019)	Grasslands and open landscapes on Mont-Lozère (Cévennes, southern France). Participants: breeders and national park workers.	A facilitation tool co-constructed by researchers and local national park managers.	Facilitating stakeholder discussions about ecosystem service management in open landscapes to explore opportunities for collective action by increasing awareness about social and ecological interdependencies.	Impacts of three farming practices (rock removal, meadow ploughing, and pasturing) on trade-offs among ecosystem services (fodder production, aesthetic and heritage value of landscapes, water quality, biodiversity by protecting two emblematic birds living in permanent meadows).
CapBiomasse	Fictive territory on the periphery of a large city. Participants: farmers, treatment plant manager, local elected official, and agri-food manager.	A research and teaching tool developed with researchers and UNESCO's "Man and Biosphere" network	Working on the energy transition of territories by developing cooperation between stakeholders and new infrastructure to optimize energy use of agricultural, agri-food, and urban biomass.	Three real-time indicators monitor the impact of players' choices for biomass on the reduction of greenhouse gas emissions, production of renewable energies, and agronomic value of the soil.

AdaptaMeije	Subalpine grasslands in the French Alps. Participants: local inhabitants and agricultural, institutional, tourism, and conservation representatives.	A research and facilitation tool to reflect with local actors on their adaptation to climate change by 2040.	Organizing workshops to collectively develop a desired vision of the territory and then build a SG to understand how stakeholders interact and develop good practices to reach this goal.	Few ecological aspects were included in the game: climatic data, vole and wolf population dynamics, grassland responses to management actions.
Foster Forest (Fouqueray et al., 2022)	Temperate forests in northern France. Participants: private and public forest managers, forest owners.	Initially only a research tool but later used by local forest stakeholders to organize prospective workshops.	Observing interpersonal dynamics in a participatory arena where foresters, faced with increasing climatic hazards, can innovate to design non-technical adaptation measures.	Tree inventories are simulated using a forest growth model from the ecological sciences. The model parameters gradually account for climate change. Players can access a biodiversity program based on the conservation of old-growth trees.
BiOffset (Latune, 2018)	Terrestrial ecosystems impacted by the development of three high-speed railways (southern France). Participants: farmland owners, authorities, construction companies, environmental organizations	A research tool designed from previous field studies (no co-construction with actors)	Avoiding, reducing, and offsetting biodiversity loss to achieve a “no net loss of biodiversity” on the territory represented by the game board.	The autecology of several species governs the evolution of population indicators and distribution areas, which are also affected by players’ actions. Their actions influence ecosystem service indicators (e.g., pollination, water purification).
BotNidVeau (Hardy et al., 2020)	Wet grasslands in western France. Participants: breeders, naturalists, wetland protection managers.	A research tool initiated by researchers and co-constructed with local	Studying the compromise between agricultural production, biodiversity conservation, and water management objectives in agricultural territories.	The biophysical processes affected by climatic factors and players’ decisions are water flow, grass growth, birds nesting, and reproducing. Three bird species represent bird abundance and its interaction with farming practices.

		stakeholders involved in wetland management.		Their dynamics depend on direct cattle and/or mowing disturbances as well as habitat quality in terms of water and grass levels.

Inspired by the Companion Modelling approach (ComMod) (Etienne, 2014), they were all designed in the context of French public participatory research, partially or totally co-constructed with local stakeholders. Indeed, the ComMod approach relies on the involvement of stakeholders to define and develop a model of the SES of interest. This conceptual model is then translated in a SG in accordance with the practitioners' community ethical guidelines (Barreteau et al., 2003). When relevant, ComMod practitioners can also begin with the development of a SG which is later turned into a computerized model. Here, the case studies cover a range of contrasting SES: Foster Forest aims to better understand the implementation of climate change adaptation in French forestry; BiOffset investigates the emergence of a governance system for offsetting biodiversity loss due to land development; BotNidVeau assesses the potential of new collective agri-environmental schemes for the protection of a wetland region; AdaptaMeije examines how local actors may enhance the resilience of mountain grassland landscapes to climate change; Secoloz focuses on the integrated management of ecosystem services (biodiversity, cattle breeding, water availability, tourism, etc.) in an agropastoral landscape; and CapBiomasse explores the exchanges and cooperation surrounding forest biomass mobilization for the local energy transition. For each game, we tried to identify whether it allowed the researchers to detect knowledge gaps, anomalies, and/or neglected interactions or processes.

Data collection and analysis

We conducted eight semi-structured interviews (Newcomer et al., 2015) with SG designers[2]. We informed the role-play designers of the research context of the study, and asked for their consent to participate by having them fill in a form in accordance with the rules of the General

[2] See Annex A for the characteristics of the respondents.

Data Protection Regulation (EU 2016/679). Interviews[3] dealt with the reasons why the game was implemented, how the researchers obtained the knowledge needed to build the game, the discussions that occurred during (simulation) and after (debriefing) the game, and finally, what researchers could draw from the game for their own research. We based our interviews on the classical steps described to implement a companion modelling approach, and for each one, we tried to understand: (1) their methodological approach (reading literature, conducting interviews, testing, reading literature, conducting interviews, etc.); and (2) their choices concerning the creation and implementation of the SG.

We transcribed the audio-recorded interviews and coded them according to the three key properties mentioned above. We triangulated our results using various sources of data: interviews with different researchers for two SG and documents (articles, reports, PhD theses). In addition, for each case study, at least two researchers analysed the material.

Results: Analysing the interest of serious games to foster a SES approach

Serious games may help researchers identify knowledge gaps

In all six cases, we found elements confirming the value of SG to identify knowledge gaps. This was particularly salient for Foster Forest, CapBiomasse, and Secoloz. For instance, discussions during the Foster Forest playing sessions revealed a lack of knowledge about the behavior of tree species under drought conditions. These discussions also highlighted scientific controversies on specific subjects: for instance, is carbon storage higher for old or young trees? Is a mixed forest more resilient than an even-aged forest in the face of extreme climatic events? How can this be quantified? These discussions also led to the exploration of new paths for

[3] See Annex B Interview guides for SG analysis case studies

which knowledge is missing: for instance, how can carbon storage be used as a source of income?

After several playing sessions of CapBiomasse, the game designers realized the importance of elaborating new indicators to assess the economic impact of the energy transition on the territories in question. In particular, the designers pointed out the need for new biodiversity indicators to assess the impact of an energy transition based on agricultural biomass on soil biodiversity.

The Secoloz game highlighted knowledge gaps in the ecological impact of management actions (e.g., land clearing or pebble removal) on agropastoral scrublands, especially in terms of thresholds and tipping points on lichens or soil erosion, for instance. These knowledge gaps make it difficult to elaborate definitions shared by heterogeneous stakeholders, as in the case of "natural open grasslands."

Serious games highlight surprises rather than anomalies

Our case analysis points to the "surprises" (rather than the anomalies) experienced by researchers that led to the discussion of ecological theories. For instance, the AdaptaMeije game revealed that despite the close proximity of mountain landscapes, the local inhabitants were quite disconnected from their environment. Furthermore, some stakeholders in the ski industry did not necessarily see climate change as a threat but rather as an opportunity. This was especially the case for ski industry stakeholders located in higher-altitude mountains, as they had a competitive advantage over those located in the lower mountains. Lastly, while scientists expected that enhancing solidarity, local development, and autonomy would increase the resilience of the area, the game sessions revealed that a strategy based on a strong tourism industry, which would increase incomes, would better help the inhabitants attain their goals.

In the Secoloz game, as the mayor had no means of coercion to preserve the water quality, the players spontaneously made water a priority issue and self-organized to manage its quality, thus relegating biodiversity issues to the background. This behavior was unexpected by the game designers.

Serious games may change researchers' representations of the system under study

Bioffset revealed some unexpected strategies among the members of environmental protection groups. These actors actively became involved in biodiversity offsetting systems, even though the game designers expected them to not be directly involved, as "environmental fire keepers" to keep all their power of alert. This asks the question of the consequences of including environmental protection groups as providers of offset measures, on biodiversity conservation.

Regarding AdaptaMeije, the game sessions enriched the understanding of collective action and decision-making processes. A few stakeholders, who were expected to play an active role in the collective dynamics, were instead withdrawn; the sessions also unveiled strong power games; which had an important impact on the economy and innovation dynamics. The main barriers to resilience were thus related more to sociological and political aspects than to ecology.

During the BotNidveau sessions, the farmers changed their perception of the birds chosen as part of the game. The appropriation took place during the game and allowed, through new rules, the emergence of a better exploitation of the crops as well as a conservative management of the birds.

Regarding Foster Forest, during the participatory construction of the game and the playing sessions, the researchers realized that they had overlooked two issues considered to be crucial by forest managers: (1) hunt game dynamics, which impacts tree growth and the direct income of forest owners; and (2) the reluctance about clearcutting, which modifies the landscape value and triggers strong reactions from local inhabitants.

Lessons and perspectives about the use of serious games for research on social-ecological systems

Our comparative analysis suggests that SG are relevant to help researchers identify knowledge gaps and change their representations of the SES under study. Regarding the identification of knowledge gaps, the findings highlight that the researchers involved in SG necessarily change their position (Hazard et al., 2020): from external observers, they become part of the system under study, which necessarily raises new questions about their own role and impact. To respond to non-academic questions and expectations, researchers also need to take a new perspective on their research, which may reveal some knowledge limitations. In addition, SG, as tools that generate design processes, lead to the exploration of new concepts or ideas, which may call for innovative research (Hatchuel & Weil, 2008; Vourc'h et al., 2018).

SG may trigger changes in representations among researchers for two reasons. Taking into account the social component of SES, SG highlight the importance of considering a wider range of variables as opposed to a strict use of variables coming from a single discipline as used in traditional ecological approaches for instance. In so doing, they lead to a change in representations not only in the social models but also in the ecological models. Furthermore, SG are interesting tools to collect original data from unprecedented interactions between actors. Second, SG specifically aim to identify collective solutions for the management of ecosystems. As a result, they often call for new representations of these ecosystems: when designing a SG, researchers generally require a more systemic understanding of the SES under study, thoroughly considering the interactions between people and nature (Rakotonarivo et al., 2021). SG can lead researchers to change their focus and consider processes that were formerly disregarded. They can also be used to explore and test innovative paths, which can then be investigated with more standard research methodologies (Lardon & Piveteau, 2005).

Finally, our study underlines that although SG reveal some surprises that can be useful for researchers, they are less prone to detect anomalies that could enrich especially ecological theories. This result stems from the fact that to the best of our knowledge, SG have not to date been specifically used to question ecological theories. Indeed, the underlying ecological models are often oversimplified based on the pretext that they are mainly developed to understand social processes. However, SG, especially those co-designed by scientists and other actors, could be used from this perspective, which is in line with Toffolini et al. (2020), who show that participatory design approaches can renew models in agronomy.

In conclusion, although this analysis is exploratory and would require further investigation, it suggests that SG have the potential to generate original research questions that would consider both people and nature in social-ecological systems. In order to enhance this potential, we suggest five courses of action. First, we recommend researchers undertaking SG to begin with a collective clarification of their "hidden assumptions" about the functioning of the SES and what they expect from the SG. This facilitates initial knowledge building, and it is greatly valuable for further SG design and analysis, especially if there is a non-academic commissioner. Second, we recommend to involve heterogeneous stakeholders in the SG design team, in particular for the development of the conceptual model and simulation tool. This may help revealing unexpected knowledge gaps. Third, we advocate for long term SG-based research projects in order to provide opportunities to give some feedback to the participants and to develop reflexivity on the whole process – sometimes even on a loop ending up on a lightened version of the SG. As such, changes in representations of the SES at stake could be collectively discussed. Fourth, we suggest to convince ecologists to participate in the SG workshops, and to be open to surprises about by what happens in the game/simulation, in order to gain new research insights. Finally, we recommend setting up a monitoring strategy (during the design and implementation of the game) to specifically identify moments when participants identify lacks of knowledge or interactions that were neglected, or when researchers change their representations of the system under study.

Authors' contributions

NFL, EB and JLL conceived the ideas and designed methodology; JLL and EB collected the data; TF, VS conducted the literature review; JLL, EB, TF, VS and NFL analysed the data; EB and JLL led the writing of the manuscript; JLL, TF and VS were interviewed on the SG they contributed to design. All authors wrote parts of the article, contributed critically to the drafts and gave final approval for publication.

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