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Review

A sustainable game changer? Systematic review of serious games used for agriculture and research agenda

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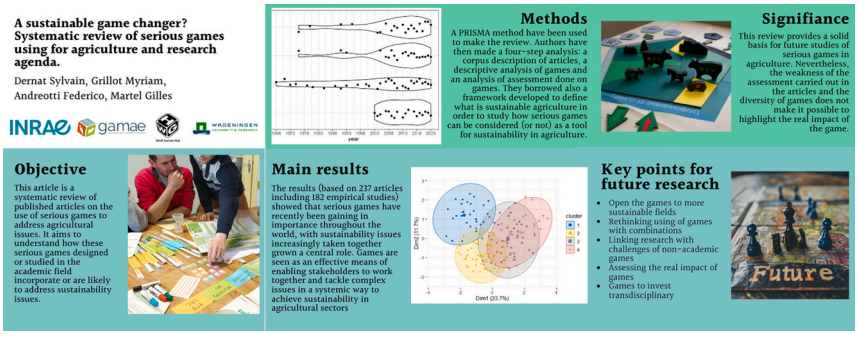
HIGHLIGHTS

- Systematic review of 237 articles on serious games in agriculture conducted using the PRISMA method.
- Serious games in agriculture serve as tools for sustainable transition, used across decades in this field.
- Shift in 2000s toward participatory and co-designed games reflects a broader understanding of sustainability issues.
- Necessity to better assess the real-world impact of agricultural serious games to inform their design and practical utility.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Serious games can be used as a tool for learning, increasing coordination, supporting decision-making processes, and other purposes that can strengthen sustainability transitions. While agriculture is an important corner stone for these transitions, little research has been done on serious games on agricultural and none on the potential link with sustainability issues.
OBJECTIVE: This article is a systematic review of published research articles on the use of serious games to address agricultural issues. It aimed to understand how these serious games incorporate or are likely to address sustainability issues.
METHODS: The process of the review is described accord to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). After data collection, we conducted a four-step analysis: i) short bibliometric analysis of the corpus, ii) descriptive analysis of the games' characteristics, iii) comprehensive analysis on sustainability based on a framework developed to define what is sustainable agriculture, iv) analysis of assessment of the games.
RESULTS AND CONCLUSIONS: Results were based on 237 articles including 182 empirical studies. We showed that the number of articles on serious games in agriculture have recently increased throughout the world. Serious games can reach different goals: i) learning, particularly on specific topics, ii) mediation and co-design, iii) research. Games can be seen as effective means to enable stakeholders to work together. In a context of

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sustainability transitions, serious games can be used to tackle complex issues. However, more effort must be undertaken to assess the real impact of the game.
SIGNIFICANCE: This review confirmed the importance of serious games in agricultural research aiming to enhance sustainability transition. We identified gaps and proposed a research agenda to further work on i) inclusion of the diversity of games, ii) rethinking using of games with possible combinations, iii) opening to broader agricultural productions, iv) assessing the real impact of the games, v) using games for transdisciplinary research.

1. Introduction

Sustainability transitions in agriculture are complex and require a systemic approach, considering the many dimensions that must be addressed, such as environment, food, and economy, among others (Pigford et al., 2018). In this perspective, renewing the design of farming systems (Prost, 2021) and implementing new tools to support them (Klerkx, 2020) become central. Sustainable transitions can be addressed by a combination of multiple research approaches (comprehensive analysis, co-design, simulation modelling) (Martin et al., 2018; Prost et al., 2023). Serious games are transversal tools to these approaches, including also learning tools for students (Le Page et al., 2016) and extension services (Andreotti et al., 2020).

According to Abt's definition, serious games are characterized by their utility rather than entertainment value (Abt, 1987). Central to this notion is the utilization of game mechanics to serve a purpose, transforming an otherwise entertaining game into a purpose-driven activity (Engström and Backlund, 2022). Serious games encompass a spectrum from professional applications to educational and mediation contexts, challenging conventional paradigms of learning. Rooted in Brougère's framework, serious games exhibit five defining characteristics: a second-degree activity, a sequence of decision-making, rule-based dynamics, uncertainty regarding outcomes, and a limited real-world impact (Brougère, 2005). These characteristics engender player immersion, fostering a state of focused engagement often termed "flow" (Csikszentmihalyi et al., 2014), conducive to learning, collaboration, and action after the game. By altering perspectives and creating immersive learning environments, serious games facilitate knowledge acquisition and application (Plass et al., 2015).

Serious games have already been widely studied and used in environmental field. Since the 2000s authors highlighted an increase in the use of serious cooperation and coordination games (Flood et al., 2018; Hallinger et al., 2020). They showed how serious games are used as a tool for education, intervention (e.g. environmental engagement, decision-making processes) or research (Rodela et al., 2019). A review of water-related serious games by Aubert et al. (2018) concluded that serious games can be effectively used in decision-making processes for water management, as well as help raise awareness about water-related environmental issues. Several studies have investigated the potential for serious games to improve environmental policymaking, including Garcia et al. (2022) and Stanitsas et al. (2019). These studies suggested that serious games can be used to simulate and evaluate policy options, as well as improve decision-making processes by integrating stakeholder perspectives and promoting collaboration. For them, serious games provide a safe and effective space for exploring policy options and developing policy solutions.

According to this literature, the main characteristics that games must have to produce an effect seem to be the design (both playful and serious) (Madani et al., 2017; Galeote et al., 2021), be adaptative and enhance interactions between users (Flood et al., 2018), have a strong narrative structure and clear goals (Gerber et al., 2021). Similarly, Gerber et al. (2021) developed an advanced classification of games on climate change based on their characteristics. They found that the narrative structure, social interaction and clarity of goals are the main characteristics to consider for educational impact. In addition to the aforementioned studies, de Salas et al. (2022) examines the behavioural and technological design aspects of serious games and their impact on environmental outcomes. The study highlights the importance of game design to target specific environmental behaviours. It points also the need to carefully evaluate the effectiveness of games for achieving environmental goals. Overall, these studies emphasized the importance of careful game design, interaction and evaluation to achieve environmental outcomes.

More specifically, in the agricultural domain (education, extension and support), serious games have long been identified as tools contributing to agricultural knowledge and innovation systems (AKIS). They can stimulate knowledge sharing and the induction of behavioural change (Klerkx, 2020, 2021) and in theory, to understanding agricultural systems transformations (Dumont et al., 2020; Dernat et al., 2022). A large diversity of games exists in the field of agriculture. They are analogue games (Salvini et al., 2016; Orduña Alegría et al., 2020; Dernat et al., 2023a), video games (Espinosa-Curiel and de Alba-Chávez, 2024), hybrid games (Martin, 2015). They had various objectives: support changes, educational or mediation. Despite this dynamic, these serious games are little studied on their inclusion of dimensions related to sustainability. Hernandez-Aguilera et al. (2020) have recently made a first review on games and agriculture. Their definition of games was much broader than what we defined above, resulting in inclusion of economic games based on game theory. These games do not consider entertainment as a founding principle and set up a reward for the players, which goes beyond the disinterested concept of play as defined by Brougère (2005). Moreover, no transversal approach has been taken so far to understand how serious games address sustainability issues in agriculture. To address this gap, we propose a systematic literature review. It aimed to understand how serious games in agriculture address sustainability issues. We first elucidated the characteristics of serious games, player profiles, and contextual factors such as farming types and geographical settings, essential for understanding their role in enhancing agricultural sustainability. Then we use a framework of sustainability in agriculture (Velten et al.'s (2015)) to identify elements in the games related to sustainability. Finally, we looked at how games were assessed (Etienne et al., 2023; Rodela and Speelman, 2023).

2. Methods

After data collection, we conducted a four-step analysis: i) short bibliometric analysis of a corpus description of articles, ii) a descriptive analysis of the games' characteristics, iii) comprehensive analysis on sustainability based on a framework developed to define what is sustainable agriculture, iv) games and an analysis of assessment done of the games.

2.1. Data collection process

To describe the identification and selection of articles, we followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) process (Moher et al., 2015; Tricco et al., 2018; Page et al., 2021). This process mobilized the use of Zotero software (Corporation for Digital Scholarship, v. 6.0.20).

2.1.1. Eligibility (inclusion/exclusion) criteria

This review focused on serious games in the sense of the theoretical

elements mentioned above (Brougère, 2005; Engström and Backlund, 2022). Pure economic games based on game theory (such as the dictator game) were thus excluded. However, in some cases when economic games were used in combination with serious games, they were included.

An agricultural production had to be included in the game. It could be global and unspecified (e.g. labelled as food for family farming) or specific to a production. All types of productions/products were considered: livestock, crops, vegetables, medicinal plants, aquaculture, honey, mushrooms, etc. Forestry production, marine resources (eg. fishing, oyster farming, etc.), rearing of wild animals (e.g. deer) were excluded. Agriculture could be considered on a wide range of levels of organisation: territorial approach, farm systems, farm networks, production chains, farms, plots. Sustainability was not a criterion as a central theme in article, in order to get a better overview on the significance of the concept for agricultural games in articles. Games had to provide knowledge or skills that could be used for sustainable transition.

No period of analysis was defined in order to have a historical vision. We kept only peer-reviewed publications and excluded publication types such as editorials, newspaper articles, biographies, autobiographies, grey literature and conference papers.

2.1.2. Information sources and search strategy

The following electronic databases were searched: Web of Science (including KCI Korean Journal Database, MEDLINE and SciELO Citation Index), and Scopus. A literature search was initially run on 14 December 2022 and rerun on 11 March 2023 to fine-tune the equation. For instance, we noted that the word “game” was not systematically used, while “role-play” was quite frequent. We added it to our final query. On agriculture, we used generic terms (agriculture, farm, farmer, farming systems, agrosystems) and some more specific terms related to sustainability practices in agriculture (agroecology, agroforestry, agroenvironnemental).

Queries carried out for each database are the following:

Web of Science (on March 11, 2023) in Topic (title, abstract and indexing)

- (game OR “serious game” OR “simulation game” OR “game-based learning” OR role-play OR roleplay) (Topic) and (agriculture OR agroecology OR agroforestry OR agroenvironmental OR agrosystems OR farmer OR farm OR “farming systems”) (Topic) and English (Languages)

Scopus (on March 11, 2023) in Title, Abstract and Key-words

- TITLE-ABS-KEY (game OR “serious game” OR “simulation game” OR “game-based learning” OR role-play OR roleplay) AND TITLE-ABS-KEY (agriculture OR agroecology OR agroforestry OR agroenvironmental OR agrosystems OR farming OR farmer OR farm OR “farming systems”) AND (LIMIT-TO (LANGUAGE, “English”))

2.1.3. Selection process

Once the corpus of articles extracted, we removed duplicates using Zotero duplicate identification strategy. Then we read titles, abstracts and keywords in order to check the relevance of each article and to exclude out of scope articles and those matching exclusion criteria. For instance, the word “game” in English also refers to wild animals often associated with hunting and farming; some articles detailed learning games for children using agricultural terms but without any link to knowledge or skills to be transmitted around agriculture extension or education.

To increase consistency, two authors independently screened the same 50 articles, discussed their choices for selection before beginning the other articles on their own. Disagreements on study selection and data extraction helped to homogenise the selection.

2.1.4. Data items selection and storage

The references of the articles were all stored in a Zotero database with sub-folders to identify each stage of the PRISMA process, thus allowing the retrieval of deleted articles at each stage (see in Supplementary material 1).

Keywords provided by the authors of the selected articles were standardised so as to retain only one form: Singular (e.g. game/games), British English, acronyms or full name depending on the term, lower case (e.g. serious game/serious game). Similarly, the names of the journals and names of the authors (last name + first name initials format) were standardised

2.2. Data analysis

For the data analysis, we classified articles according to a four-category rubric adopted by Hallinger et al. (2020): empirical studies, commentaries, conceptual papers, or research reviews. All articles (global corpus) were used for the exploratory bibliometric analysis, but only empirical studies (empirical corpus) were used for the descriptive, comprehensive and assessment analysis. These were the only articles where there was a description of the games which was required to study how sustainability was addressed by the games' mechanisms. Only empirical studies with enough data regarding our data analysis grid (see below) were included.

2.2.1. Corpus description

A bibliometric analysis was carried out using Vosviewer software (Van Eck and Waltman, 2017). It aimed to highlight the key characteristics of the global corpus: distribution of publications over time, type of articles, journals cited and, topics covered (using titles, abstracts and keywords) over time.

2.2.2. Descriptive analysis: characteristics of games

This qualitative approach involved reading all the articles of the empirical corpus. We used an existing data analysis grid to extract general characteristics of serious games related to agri-environnemental and food issues (Dernat et al., 2023a). It included describing: type of game, continent of experimentation, country of experimentation, type of agricultural production concerned (livestock, fruit, etc.), type of agriculture (organic, family, conventional), player audience, theme of the game, objective of the game (co-design / decision, learning, mediation, data collection).

The descriptive data was then compiled using R (R Core Team, 2013).

2.2.3. Comprehensive analysis: sustainability in games

Beyond the given general approach to balance economic, social, and environmental goals, Velten et al. (2015) suggested a framework to study in further details how sustainable agriculture was addressed in scientific literature (Table 1). They identified seven different strategies to reach these goals, including a combination of technical, institutional, and behavioural approaches. They also highlighted in which areas these strategies could be implemented, i.e. five field of actions. By emphasizing on the interplay between goals, strategies and fields of action, they highlighted the importance to consider the diversity of concrete solutions (strategies and field of action) to reach the general objectives.

Based on Velten et al. (2015)’s framework, we completed our descriptive data-analysis grid. As these elements were not labelled as such in the articles, we filled in the grid according to our understanding of the games.

Table 1 shows that Goals corresponded to the general objectives of the players in the game: economic, environmental, social or overarching goals. Strategies were those that could be implemented by the players in the game to achieve the Goals: adaptive management, cooperation, ecology-based strategy, economics-based strategy, holistic & complex system thinking, knowledge & science, subsidiarity. The fields of action

Table 1
Sustainable agriculture framework to analyse games articles adapted from Velten et al. (2015).

Categories	Sub-categories
Goals	Economic (development, livelihood, provision of products, thriving economy)
	Environmental (ecosystem function conservation, natural resource conservation, productive capacity, animal well-being, environment
	Social (acceptability, cultural preservation, equity, justice, fairness fulfilment of human needs, good working conditions, human health, nourishment quality of life, strong communities)
	Overarching (ethics multifunctionality safety stability & resilience)
Strategies	Adaptive management (adaptation learning & experimentation management, integration & redesign prevention substitution)
	Cooperation (collaboration & communication, participation)
	Holistic & complex system thinking (long-term perspective, scale-sensitivity, systemic thinking)
	Economics based strategy (capital asset maintenance, demand-orientation, efficiency, quality-orientation)
	Ecology based strategy (diversification ecological principles)
	Knowledge & Science (innovation, modern, traditional)
	Subsidiarity (decentralization, independence, local/regional)
Field of action	Management & technological solutions (crops & livestock management, tools resource use, technology & practices)
	Social & Human capital (organisation - knowledge, education, skills)
	Social, Political and Economic Environment (accessibility economic system infrastructure investment policy & institutions society)
	Social and Environnemental challenges (reduction, global trends)
	Agrifood system (consumption, production, supply chain)

corresponded to the elements on which players could act in the game to implement the Strategies in order to achieve their Goals.

The data was then statistically analysed using R software and a Multiple Factor Analysis (MFA), in which the data from the sustainability analysis were used as actives variables and grouped by categories (goal, strategy, field of action).

2.2.4. Assessment of games

Given the focus we have on sustainability and our objective, we looked at assessment methods for the games. Etienne et al. (2023) have adapted the New World Kirkpatrick Model with four levels to assess games from short to long term: level 1: satisfaction/participation, level 2: learning/knowledge, level 3: attitudes, level 4: actions/changes. In this review, we studied how authors of articles in the empirical corpus have assess their games based on this four steps model.

3. Results

In the presentation of the results that follow, we cited only a few articles among the most salient in the corpus to illustrate each point to avoid overloading the references. All the references of the corpus are listed in Annexe 2.

3.1. Corpus description

3.1.1. Size, types of papers, journals and growth trajectory

The search yielded 294 articles (without duplicates) (see in Supplementary material 2 and 3). It yielded 237 peer reviewed journal articles for the global corpus (57 excluded) and 182 articles for the empirical corpus (55 additional articles removed). The first document uncovered in our search appeared in 1968. Curtis (1968) described the use of a business game for teaching farm business analysis to high school and adult students (farmers).

Fig. 1 shows that between 1968 and 2004 publications in the corpus averaged about one per year. It was not until 2005 that publications increased (four per year in 2005–2012). During the subsequent decade (2013−2023), average publications boomed with 16 per year with a particularly sharp acceleration in the past five years (20 or above).

In the corpus, the number of different journals is very large (146 journals), with a diversity of disciplines and topics. *Agricultural Systems* had the highest number of publications (13, i.e. 8 % of the corpus), all articles focused on agricultural systems and decision-making tools. The

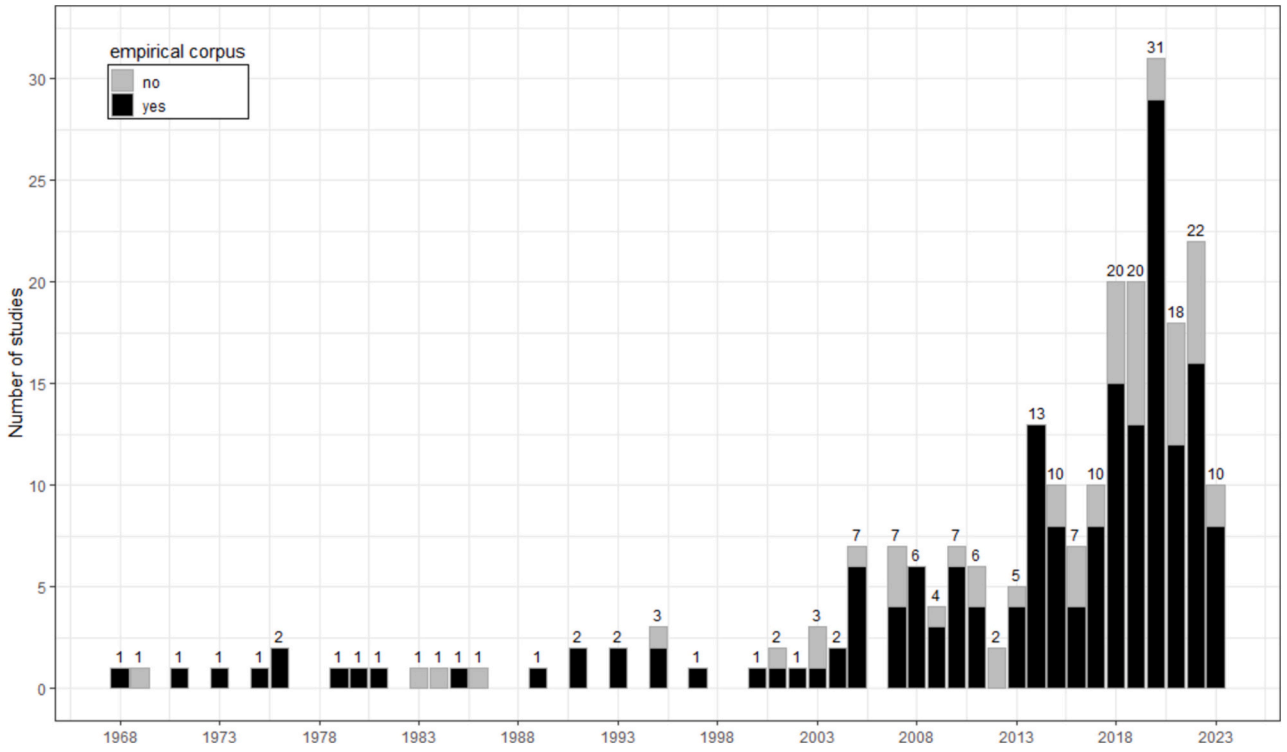

Fig. 1. Increasing number of publications on serious games in agriculture, 1968–March 2023, from global corpus ($n = 237$). Black colour: empirical cases selected for the empirical corpus, Grey: other articles.

gaming journal *Simulation & Gaming* was the second most represented journal, with seven publications focused on the theoretical aspects of the games. Two general-interest journals *Ecology & Society* and *Sustainability* with focus on environmental issues were also present (8 and 6 articles, respectively). Articles in *Agronomy for Sustainable Development* (3 reviews and 3 empirical articles) with the agroecological transition and systemic thinking. Journals oriented on simulations were also represented in the corpus: *Journal of Artificial Societies and Social Simulations* (6) and *Environmental Modelling and Software* (5). In the empirical corpus we found the same diversity in 120 journals. Since 2005, 13 articles were published in *Agricultural Systems*, 7 in *Ecology and Society* and in *Simulation and Gaming*. More recently, since 2019, 6 articles were published in *Sustainability*.

Empirical studies were the most numerous types of articles (182 articles) (e.g., Shee et al., 2015). Commentaries (10 articles) discussed the literature, reporting trends on games with selective reference to the literature, or describing the development and use of a game in practice (e.g. Redpath et al., 2018). Commentaries also referred to preliminary results from field trials, they offered incomplete descriptions of research methods and results in a case study (e.g. Cole and Stewart, 2017). Conceptual papers (26 articles) proposed means of conceptualizing games in terms of design elements, instructional processes (e.g., Daré and Barreteau, 2003) or assessment of learning outcomes (e.g. Berthet et al., 2016). Literature reviews (13 articles) systematically analysed an explicitly identified set of games articles (e.g. Dobbins et al., 1995).

3.1.2. Evolution of thematics in articles

Fig. 2 presents the evolution of the most frequent words used in titles and summaries between 2005 and today: from games centred on student technical education to games on transition with farmers and stakeholders. In the 70s–90s articles focused on educational games using "simulation" for "students". They focused on technical and economic dimensions of farms (in particular business management courses) or specifically on water. Over time, themes of the articles opened to transition towards "agroecology" and considering "trade-offs" and "challenge" of "climate changes" (e.g. Neset et al., 2020). They targeted a public of farmers and agricultural stakeholders. Around 2010–2015, the analysis showed a significant contribution in this emergence of the French researchers involving "local stakeholders", "actors", to find out through "role-play" a collective strategy to tackle various "risk". We see, for example, research carried out through Companion Modelling (Souchère et al., 2010).

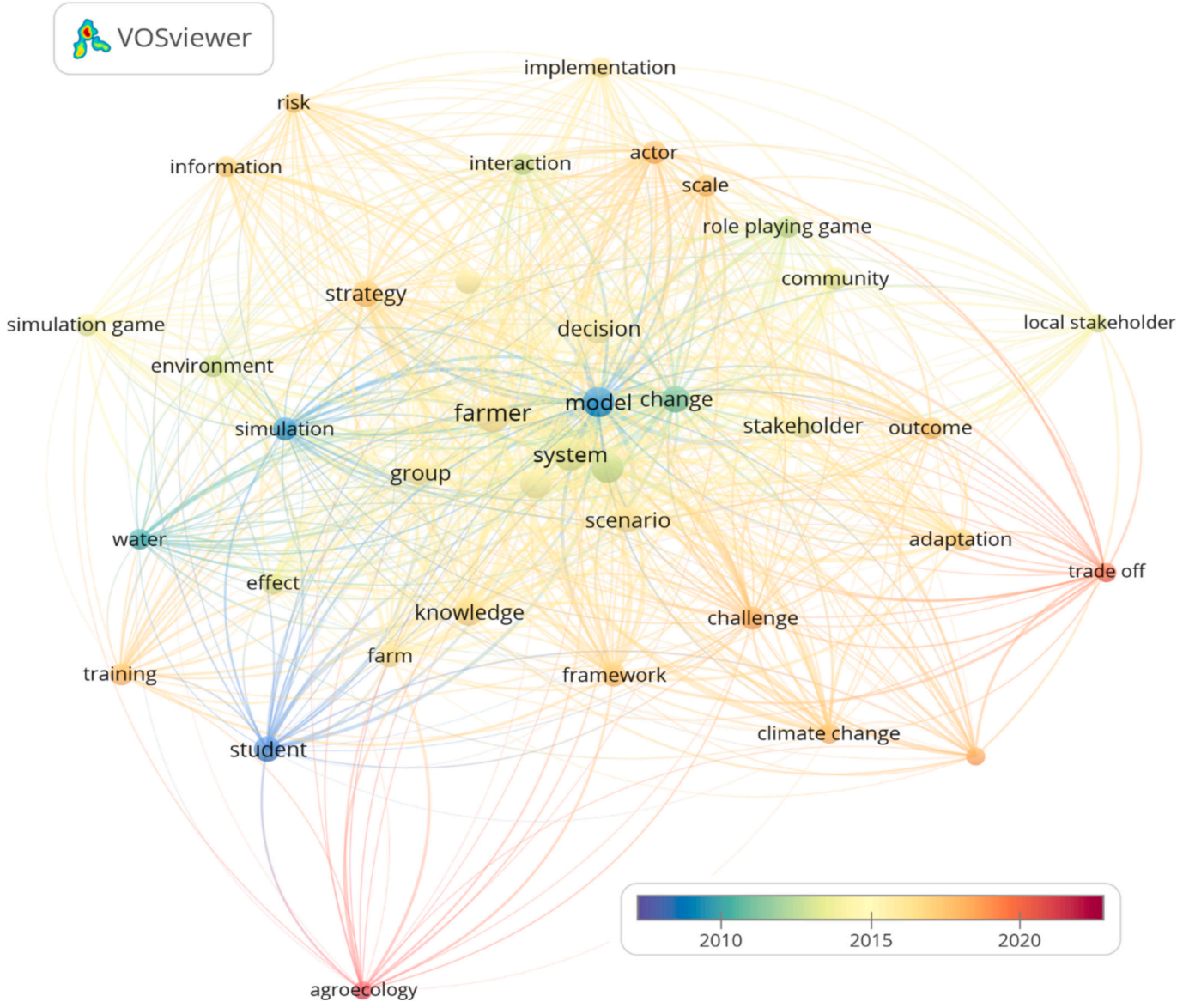

Fig. 2. Temporal keyword co-occurrence analysis of topic in the literature on serious games used for agricultural issues in the global corpus ($n = 237$).

3.2. Descriptive analysis of games used in agriculture

3.2.1. Types of agriculture and levels

About 70 % of the articles in the empirical corpus focused on crop, livestock or multi-crop livestock farming (128 articles; Fig. 3). About 19 % (34 articles) of the article did not distinguish the type of production and focused on farm management (e.g. Sonka and Batte, 1981; Stewart et al., 2000), ecosystem services (e.g. Gissi and Garramone, 2018), land resource (e.g. Ansoms et al., 2015), or response to drought (e.g. Hill et al., 2014). Other types of production, such as vinegrowing, vegetables, fruit and horticulture were more rarely addressed.

Fig. 4 shows that more than half of the articles (57 % - 103 articles) targeted meta levels (groups of farmers, landscape and/or sectors) (e.g. Arheimer et al., 2004). Farm level was the second level the most represented (28 % - 51 articles; e.g. Cheung et al., 2008), whilst micro levels (parcelled, animal, etc.) were less represented (13 % - 24 articles; e.g. Chave et al., 2019. This raises the question of how games can be used to address agricultural issues: micro levels address directly biotechnical disciplines and specific aspects of systems. For the other levels, there is a more systemic perspective, where several disciplines are often required.

3.2.2. Continent of application of the games

Games described in the empirical corpus were played in 46 different countries all over the world.

Fig. 5 shows that the most represented continent is Europe (62 articles) with especially France (21 studies). We noted 47 % of the games were played in emerging countries (85 articles). Africa and Asia were represented with 35 studies each, particularly in Thailand (7) and Indonesia (6). In most of the cases, articles were co-authored with researchers from the North and particularly from France associated to the Commod community. They mostly worked in rural area and games were seen as a way to overcome illiteracy and allow all participants to express themselves (e.g. Ruankaew et al., 2010; Barnaud et al., 2010).

3.2.3. Objectives, type of serious games and players

Games described in the articles could have multiple objectives. Learning was oldest objective described (Fig. 6, 86 articles). It was almost the sole use until the 2000s (e.g. Boehlje et al., 1973; Dobbins et al., 1995). Mediation (71 articles) and use for research (data collection, 48 articles) objectives were mostly described after 2000s when co-design of practices or foresight emerged (62 articles). Learning objective was the only objective in 52 cases (29 %). Mediation and co-design were the most combined objectives (20 cases – 11 %; e.g. Speelman et al., 2014). In most other cases objectives are taken independently (19 articles for mediation, 18 for research, 14 for co-design only). In rare cases, three objectives were combined, but never the four of them.

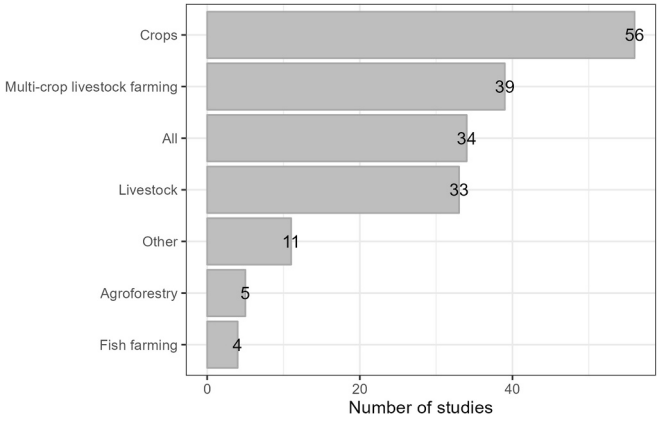

Fig. 3. Distribution of the type of agriculture production in case studies in empirical corpus (n = 182). Others: winegrowing, horticulture, vegetable farming, product nutrition quality.

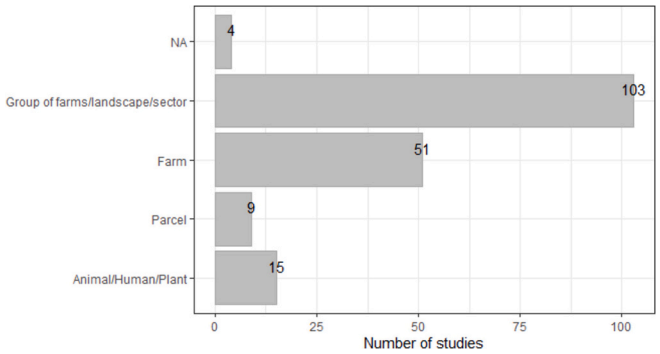

Fig. 4. Distribution of the level of the games in case studies in empirical corpus (n = 182, NA: no levels).

The hybrid format combines several formats, for instance two analogue types (notably board games and role-playing games), or a board game completed with a digital simulator. It was the most prevalent with 47 articles (Fig. 7). Analogue games were very important, whether they were board games (34 games, e.g. Dernat et al., 2023b) or role-playing games (29 games, e.g. Washington-Ottombre et al., 2010). In agricultural field, the majority of games produced are not video games, even in recent publications. This is in accordance with the observation of Martel et al. (2022) in their analysis of the french games in agricultural sector. Video games accounted for only 29 games (Jouan et al., 2020), plus 27 strictly simulation games which can be connected to video games and two haptic games (augmented reality or virtual reality). It is also interesting to note that some traditional games (such as bao) were used as a game for agricultural purposes (3 games) (e.g. Barker, 1979).

We highlighted that 39 % (71 articles) of games were primarily aimed at farmers and 25 % (46 articles) included their partners (advisers, elected officials, food processors, etc.). Educational audiences were targeted in 22 % of the articles (40) mainly students from agricultural and veterinary fields (30 articles) whilst the others aimed less specialized publics (pupils) (10 articles). We noted that, although agriculture is at the centre of many debates and societal issues, games catering to the general public (All people and Farmers and citizens) remained few (7 articles). Games dedicated only to stakeholders of agriculture that were not farmers or of territorial development (8 articles), researchers (4) or policy makers (4) were rare. This shows a notable difference with environmental games, where the target audience of policy makers is often highlighted (Garcia et al., 2022).

In most cases, games were specifically built in a research process. Few games were named (32 % of the articles), thus it was not straightforward to track the adaptations and re-use of games. Forage Rummy was the most extensively studied and deployed game. It has multiple add-ons (Martin et al., 2011; Martin, 2015; Farrié et al., 2015). Four other games have been used in two articles. All the other games were either built apparently as a “one shot” for the specific situation, or are less detailed in other publications which did not fit our selection criteria.

3.3. Comprehensive analysis: sustainability in games

The results of the descriptive analysis (Fig. 8) showed that while economic and environmental goals were present in 80 % of the games, the social goal was only considered in 60 % of the games. The goals of ethics and resilience were present in only 24 % of games. In terms of possible strategies for players in the game, there was a wide range of possibilities. Only the subsidiarity strategy was only marginally represented (19 %). The fields of action in the games that allowed players to implement strategies to achieve their goals were largely oriented towards farmers' practices and farm management (86 %). The other, more systemic solutions like actions on agrifood systems (34 %) and social

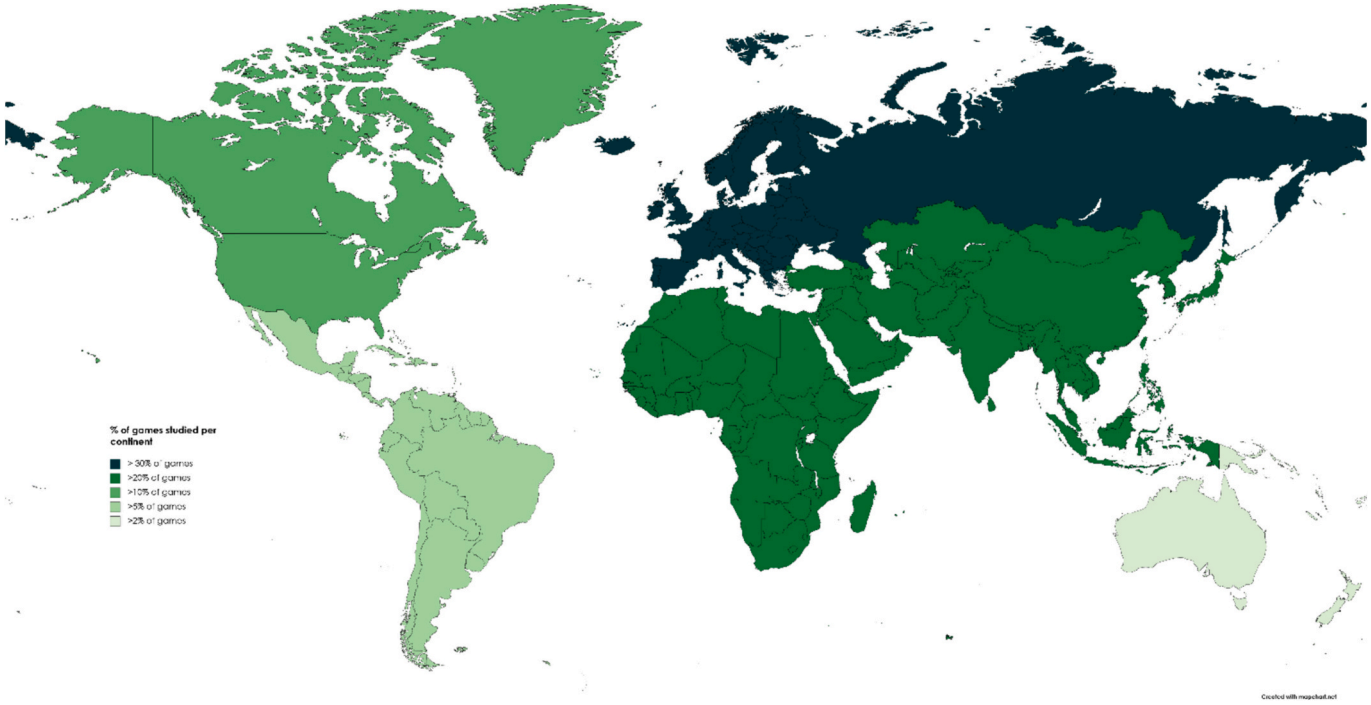

Fig. 5. Distribution of the continent area of case studies in the literature recorded (n = 182).

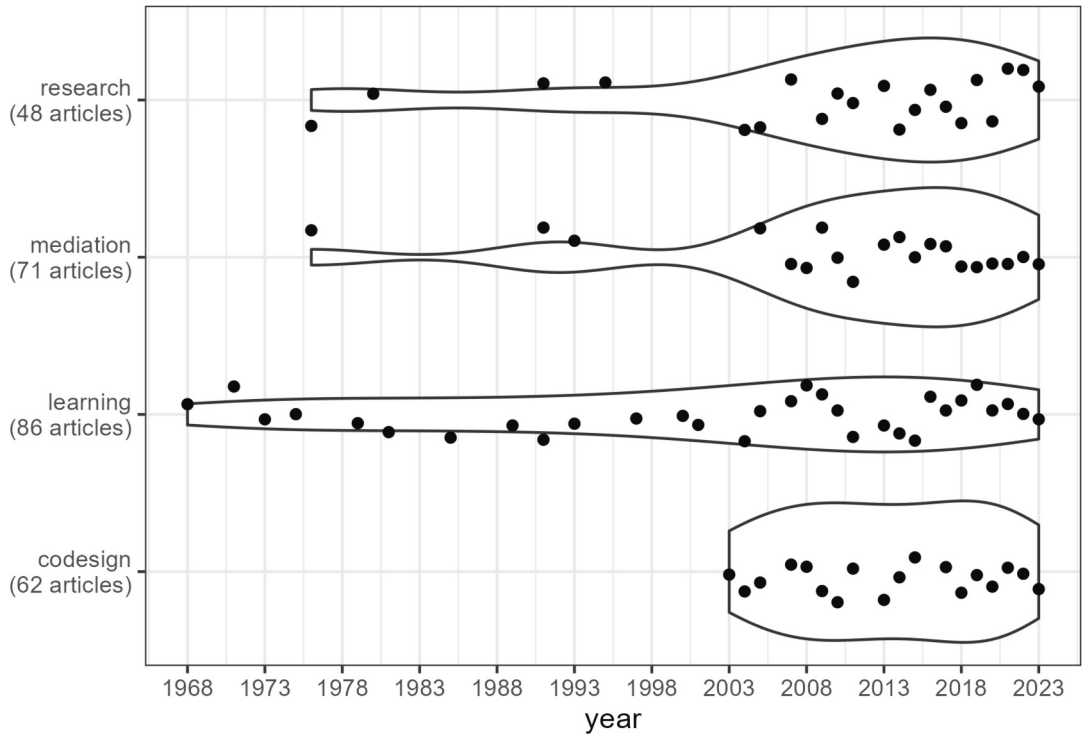

Fig. 6. Evolution of objectives of the serious games in the literature recorded in time (1968–2023) (n = 182). Every dot is an article. One article may have multiple objectives. The frequency of data points in each region is represented by the width of each curve.

solutions (transmission of knowledge, etc.) were less used in the games. Four articles did not present any sustainability principles and a few others did not present any sustainability goals but mobilized either strategies or field of action related to it (11 cases).

The MFA analysis highlighted a distribution of the games into four distinct clusters according to how they took sustainability into account (Fig. 9) (see in Supplementary material 4 and 5).

The first cluster (37 articles), "Learning for students", was mainly made of games with a learning objective (81 % of the games) and mainly aimed at students (49 %). Games operating at a micro level (plant / animal) were mostly in this cluster (73 % of the corpus; e.g. Hawkins et al., 2019). Sixty percent of the games were digital (22). Sustainability was not a goal at all in 30 % of the games (11) and when taken into account, games focused on social and/or economic goals (e.g. Anderson

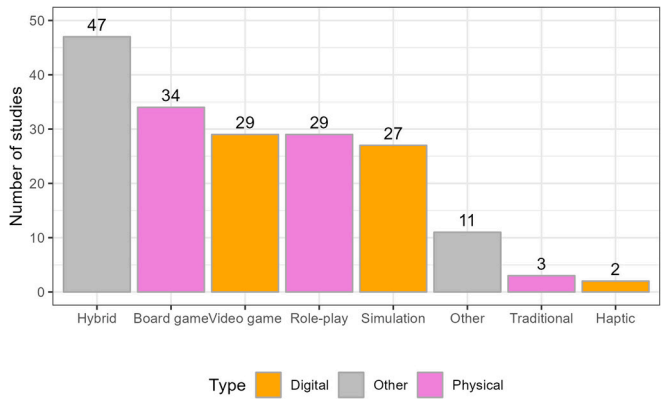

Fig. 7. Distribution of the type of games of case studies in empirical corpus (n = 182).

et al., 2020). These games mobilized knowledge as strategies to achieve the goals (e.g. O'Riordan et al., 1993).

The second cluster (62 articles), "Learning for all", joined the previous one in its learning objective (60 % of the games) with a broader audience (farmers, students and all stakeholders of agriculture in 39 %, 24 % and 22 % cases respectively). Seventy-fixe percent of the games targeting policymakers were in this cluster (e.g. Khoury et al., 2018). Seventy-eight percent of the games focused on a meta or farm level. Most games at parcel and farm level were in this group (78 % and 41 % of the corpus). Here, 73 % of the games focus on an environmental and/or economic goal (e.g. Joffre et al., 2015). A specificity of this cluster is a high representation of games having their fields of action oriented on management and technology.

The third cluster (43 articles), "Co-design with farm sectors", was made up of games with mediation and/or co-design objectives (e.g. Sachet et al., 2023) (45 % and 36 % of the corpus respectively) with few games with a learning objective (5 %). Eighty-four percent of these games targeted all the stakeholders of agriculture, including farmers and 74 % focused on a meta level (when not focusing on farm level). Only 12 % of the games were digital (5). Most of the articles (27–63 %) combined at least 3 goals: the issue of sustainability was therefore strong. To achieve them, games highlighted cooperation, adaptation and holistic strategies with a weaker emphasis on knowledge. Field of action centred on the agrifood system involving consumption, production and the supply chain (e.g. Ornetsmüller et al., 2018).

The fourth cluster (40 articles), "Co-design for all", was the group with more heterogeneity in terms of objectives, with an almost equal share for each. Research was the most represented objective in this group compared to the whole corpus (35 % of games of the corpus) (e.g. Celio et al., 2019). Games were aimed at all stakeholders of agriculture but also stakeholders of territorial development (e.g. Bonté et al., 2019). As in cluster 3, games combined 3 goals in most cases (83 %). Five or more strategies were often combined, but no specific pattern emerged, except for a strong share of games centring on strategies based on economy, ecology, subsidiarity and cooperation. Field of action were mainly focused on social and environmental challenges, social, political and economic environment as well as management and technological solutions (e.g. Dolinska, 2017).

3.4. Assessment of games

3.4.1. Global approach of assessment in experimental corpus

In 82 % of articles in the corpus (150 articles), authors carryout out an evaluation of their game. Debriefing was often used for this purpose. This is a standard recommendation for serious games, which has now become an almost required element of game design (Crookall, 2014). However, by referring to the nomenclature of Etienne et al. (2023), evaluations were mainly limited to levels 1 and 2, that is to say an

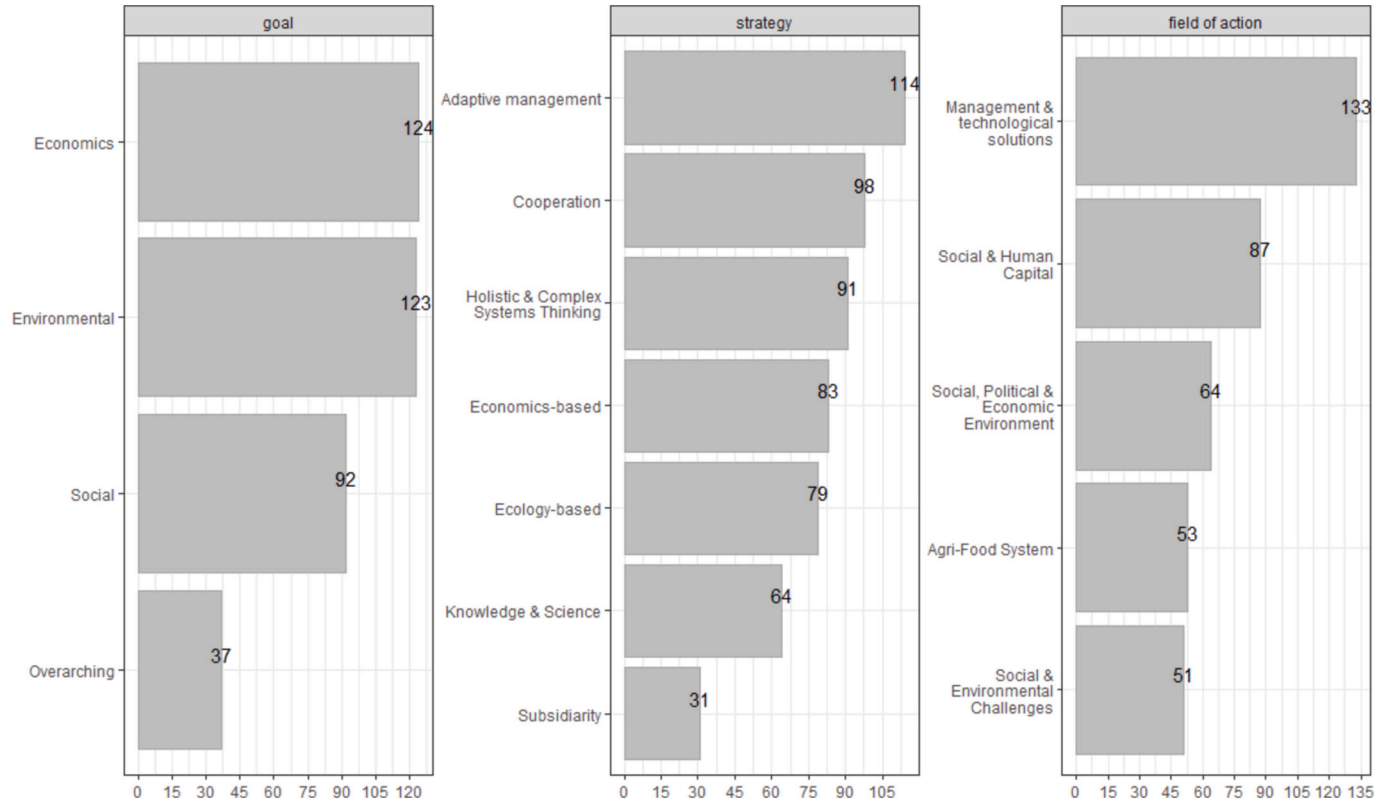

Fig. 8. Distribution of games according to the elements of analysis taken from Velten et al. (2015) ($n = 182$). Note that an article may have multiple goals, strategies and field of actions: bars cannot be summed up.

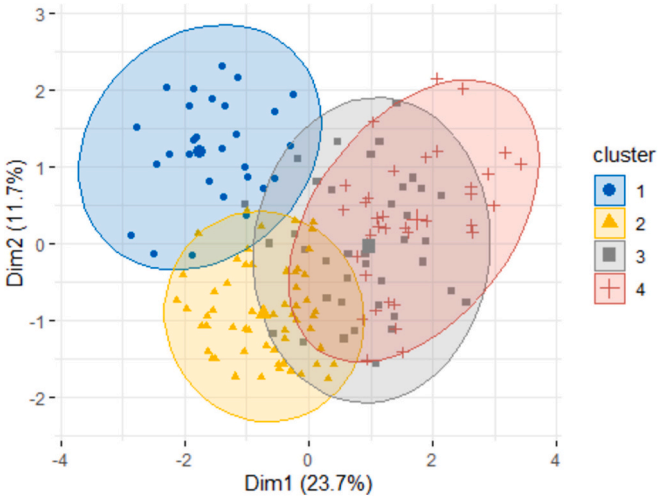

Fig. 9. MFA distribution of the case studies in the literature recorded on the first two dimensions (n = 182).

evaluation of player satisfaction and the knowledge learned (Fig. 10, 114 articles). Evaluation of the effects of the gaming experience on players' attitudes towards issues (level 3, 35 games) or their implementation (level 4, 12 games) were little or no studied (e.g. Bosma et al., 2020).

Den Haan and Van der Voort (2018), also tried to visualize this type of outcomes on games - but not as positively as we did. Based on this, it shows as a result the pertinence of the Etienne et al. nomenclature (Etienne et al., 2023) to assess impact of games.

3.4.2. *Changes in agricultural practices: Impact of the gaming session*

On the 12 games articles were the impact of the game was assessed, the assessed impacts match the field action the players have access to. We have only included games that have been assessed as having a level 4 impact, i.e. those whose impact has actually been measured by the authors. These games were very diverse, both in terms of types of agricultural production in which they were applied and the types of games or impacts assessed (Table 2).

We identified two levels of impact: farming group and farm levels. The most studied and documented changes were related to strengthening farming groups who then engage in activities within their sectors, or take part in training courses or actions in their areas (e.g. Dernat et al., 2022). Changes at farm level were less documented. They involve changes in the way the farm is managed. Game sessions allowed to test and adapt digital decision-support tools that where afterwards adopted (e.g. Gómez-Prada et al., 2020b or to plan future adaptations that were later implemented. Other on-farm changes may also be agronomic, such as new crop rotations (e.g. Dolinska, 2017).

It is important to note that these assessments often focused not only on the game sessions but on the support process in which it was situated

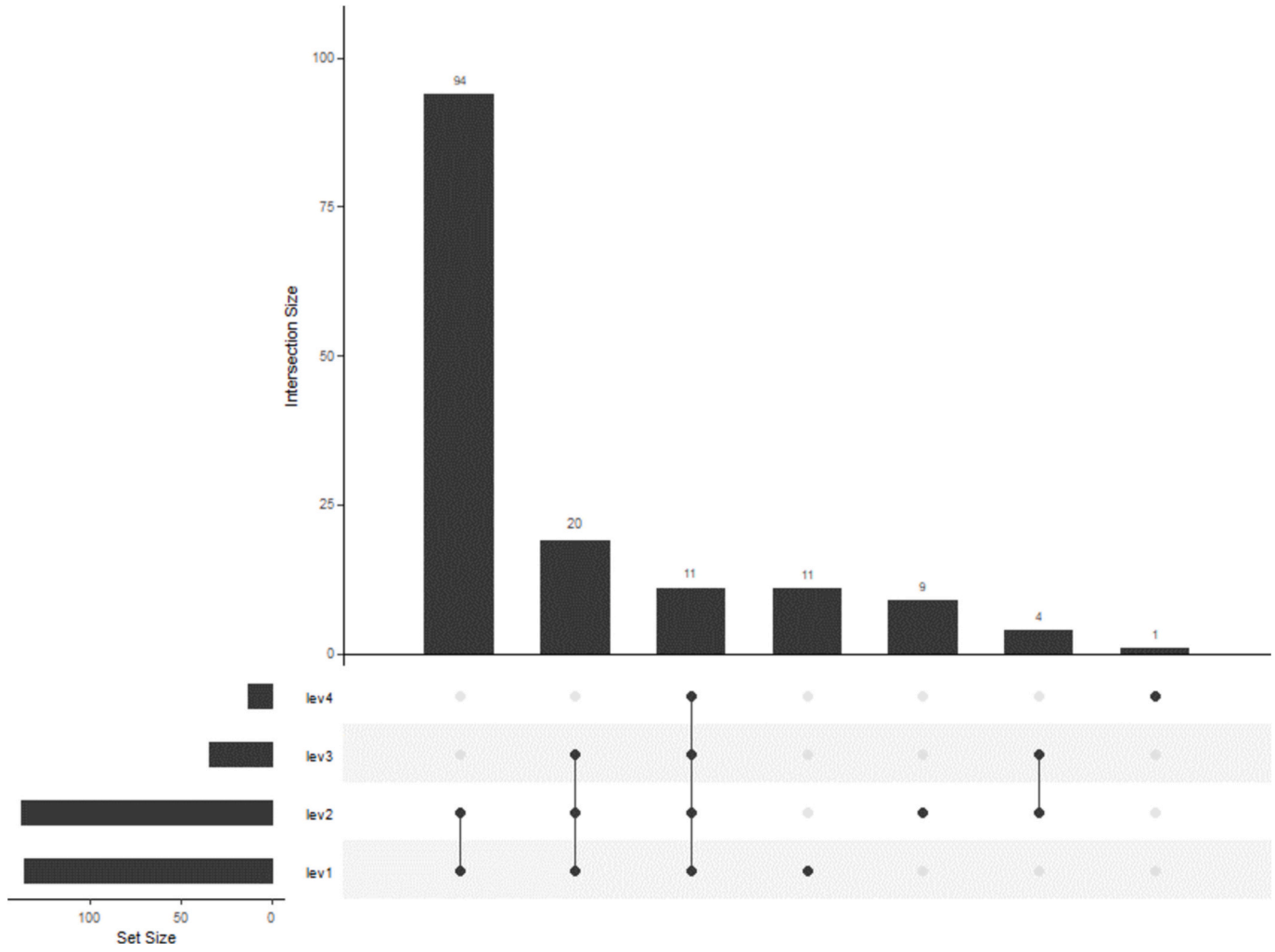

Fig. 10. Distribution of case studies in the literature recorded according to the level of assessment of the games (n = 150 articles where evaluation is undertaken).

Table 2
Impacts of games in agriculture based on the 4th level of Etienne et al. (2023) nomenclature.

Articles	Game's name	Using country	Production type	Type of game	Impact assessed
Bosma et al., 2020	ALEGAMS	Vietnam	Livestock	Board game	Three shifts in behaviour among farmers who had played the game: i) speed of new technology adoption, ii) frequency of meeting other farmers and actions taken in case of disease control, iii) better connection to the extension services and had participation in training more frequently
Dernat et al., 2023b	La Grange	France	Livestock	Board game	Implementation of actions in the territory. Inclusion of citizens in the steering committee, Setting up farmer groups
Dernat et al., 2022	Jeu de Territoire[a] La Grange	France	Multi-crop livestock farming	Board game	Engagement of farmers in the sector change, and scenarios for farm adaptations
Dolinska, 2017	LAITCONOMIE	Tunisie	Multi-crop livestock farming	Role-play	Change in farm practices: change rotation, reintroduce crops, planning…
Kuper et al., 2009	Commod[1] process game	Maroc	Multi-crop livestock farming	Role-play	Exchange of knowledge between farmers, integration into groups, setting up new projects
Lairez et al., 2020	TAKIT and another card game	Laos	Crops	Board game	Determining criteria at farm and plot level for designing new cropping systems.
Lindahl et al., 2018	No name	Inde	Livestock	Role-play	Integrating games into training and the impact on milk productivity and health monitoring
Martin et al., 2007	Microworld	Pologne	Livestock	Simulation	Farmers used economic simulation in farms to ensure ecological and profitable agricultural practices.
Gómez Prada et al., 2020a; Gómez-Prada et al., 2020b (two articles)	No name	Colombie	Livestock	Video/digital games	Medium-term use by farmers of a livestock monitoring tool on small farms to improve production.
Sachet et al., 2023	Wat-A-Game[1] process game	Colombie	Multi-crop livestock farming	Role-play	Designing alternatives land uses and organise actions
Steinke and van Etten, 2017	AgroDuos	Brésil	Multi-crop livestock farming	Board game	Helping to select new varieties with farmers.

[a] Jeu de Territoire, Commod and Wat-A-Game are global support processes that include the creation of standard games based on these methodologies. Several different games can be created from these.

(e.g. Sachet et al., 2023). These games are part of long processes and less involved in one-shot sessions than others (e.g. Bosma et al., 2020). This raises the question of what can be attributed directly to the game or what it contributes to among other tools (Etienne et al., 2023).

4. Discussion

4.1. Limits of the study

The main limitation of this study is the corpus studied.

We limited ourselves to academic publications. Non-academic games are very numerous as highlighted by Dernat et al. (2023a) in a recent review in France. Many games on agriculture are designed by associations, groups of farmers, teachers, etc. who do not publish their results. This very important set of games thus escapes the traditional academic work.

Our review was also limited to peer-reviewed publications in English. However, it appeared during the selection processes in bibliographic search engines that there were numerous existing publications in other languages, particularly in French and Chinese. The addition of articles in other languages could provide greater completeness and offer an alternative vision linked to different cultural approaches.

Moreover, there was a limit linked to the agricultural issues which was often mixed with other fields of investigation in many games, particularly broader environmental ones: forests, urbanity, etc. Certain games were not retained because agriculture was just cited as a context element but could nevertheless shed potential light on the important interconnections between agriculture and other domains in serious games. For example, the game *IMPACT: Forestry Edition* and its corresponding article was not retained despite agriculture appears as a context element of the game to understand future of forestry (Bengston et al., 2022).

4.2. A "French school" of serious games for agricultural sustainability

In France, philosophers Caillois (1961) and Henriot (1969) initiated a tradition of "game studies" emphasizing the societal and ethical dimensions of play. Aligned to this tradition French researchers, pioneered by authors of Commod group (e.g. Barreteau and Abrami, 2007; Daré and Barreteau, 2003; Etienne, 2003; Barreteau et al., 2001), or Angeon and Lardon (2008) and "Jeu de Territoire" approach, Depigny and Michelin (2007), and Martin (Martin, 2015; Martin et al., 2011), has significantly shaped the serious games for systemic approaches (Dernat, 2024). Their work paved the way for more participatory and co-designed approaches aimed at systemic changes, reflecting a broader understanding of sustainability issues and shifting away from micro-level analyses. Their influence is evident in the numerous studies from our corpus that cites them: i) in Europe; from France: e.g. Barnaud et al. (2010), Dernat et al. (2022), Ryschawy et al. (2022), the Netherlands: e.g. Speelman et al. (2014), Andreotti et al. (2020), Italy: Filippini et al. (2020), Switzerland: Salliou et al. (2021), Portugal: Esgalhado et al. (2020), Spain: Simón-Rojo et al. (2020), ii) southern America; Brazil: Moojen et al. (2023), iii) Asia; Thailand: Pruksakorn et al. (2018)), Indonesia: Sari et al. (2024), iv) northern Africa, Tunisia: Ferchichi et al. (2020). These games are often viewed as frugal and accessible innovations (Dernat et al., 2023a), particularly valuable in resource-constrained settings. They serve as crucial tools for fostering collective decision-making and addressing the social dimensions of sustainability,

4.3. Serious games in agriculture: a decision-support tool for sustainable transition

This review aligns with the observed rise in serious game design in research for agricultural issues, echoing similar trends identified by

Flood et al. (2018) and Hallinger et al. (2020). While not entirely novel, the field of agricultural game research has experienced a recent surge, mirroring the broader societal trend of gamification (Ligorio et al., 2023). This is reflected in the diverse array of journals encompassing multiple disciplines and scientific fields that now feature research on serious games.

4.3.1. Balancing large engagement and useful sustainable knowledge

We identified two contrasting perspectives on the use of serious games in agriculture in time. The first, oriented "Learning", initial, and most common view primarily sees games as knowledge transmission tools for students and professionals in agriculture or land-use planning, focusing on micro-level analysis and technical aspects.

In contrast, the second perspective, oriented "Co-design", adopts a systemic approach, emphasizing cooperation and comprehensive addressing of sustainability issues that involve broader stakeholder participation, including citizens. From a systemic perspective, serious games serve as catalysts for change, particularly in promoting themes like agroecology and sustainable agricultural practices. The game's scope broadens to encompass the territory or sector, aiming to drive systemic change.

4.3.2. Potential of serious games as decision-support tools

The complexity of sustainability concepts for existing and traditional decision-support tools present challenges to their widespread adoption, as noted by Coteur et al. (2016). We propose considering serious games for co-design in agriculture as potential decision-support tools for agricultural extension, similar to existing indicator sets, simulation models, and diagnostics. Our analysis revealed a variety of readily deployable games designed to facilitate player engagement with complex problems. Assessments on changes related to approach that included games already showed some strengthening of groups and adoption of new practices. However, there is still a substantial amount of work to be done in this regard. This emphasized the need highlighted by Klerkx (2021) for a comprehensive understanding of game utilization in agri-food innovation and transformation, including design optimization and the impact of games within extension and advisory services.

4.4. Key points emerging for future research

Looking at its contributions and limitations, our review highlighted five key points regarding research in serious games for sustainable agriculture.

4.4.1. Open the games to more sustainable fields

The sustainability of games and their objectives are central considerations. Sustainability encompasses diverse dimensions and existing knowledge that could be further integrated into games, including aspects of work, quality, management, and cultural issues. Moreover, some sectors facing significant sustainability challenges are underrepresented in game development (e.g., market gardening, arboriculture, viticulture). Recent experiences indicate growing interest from these sectors (Boulestreau et al., 2023; Rouault et al., 2020).

4.4.2. Rethinking the role of games in support

With the trend between "Codesign" and "Learning", we identify the major challenge faced by game creators for game design and facilitation in a sustainable way: balancing broad audience engagement with addressing systemic issues useful on the field. It exits already some studies which want to reconcile these perspectives with social learning as a way to build in common (García-Barrios et al., 2020; Moojen et al., 2023). On a broader level, few studies explore game integration with existing tools like farmer field schools, traditional meetings, or experimentations, with most focusing solely on game development within specific case studies. More recently, Etienne et al. (2023) demonstrated the potential for game combination and reuse across different case studies, addressing critical issues in agricultural extension. It seems a promising path.

4.4.3. Linking research with challenges of non-academic games

As mentioned earlier, a large number of non-academic games exist and will continue to be produced. This raises the question of the potential links between these games and research. A French initiative led by Gamae has created a games library[1] with a structured description of all these games to enable the widest possible community to access and disseminate existing games and mechanisms (e.g. for game design or game combination).

However, the design of academic and non-academic games also presents significant challenges for their dissemination, which need to be addressed. For example, there is often a lack of explicit description of the objective and assumptions made when creating the game, and the frequent need for a highly skilled facilitator and time to understand the often-complex rules. Games can constitute a "black-box" and unknown hypothesis might bias the message of the game. This is a barrier to easy adoption by potential users.

4.4.4. Assessing the real impact of games

Our study highlighted the importance of evaluating the effects of games. Whilst more and more games are created, few studies have conducted in-depth evaluations to assess the real-world impact of games. Evaluating the impact of games is an important area of research to be explored. Therefore, it is difficult to determine what works or not in games. This highlights a significant deficit in the study of agricultural games, echoing the points raised by Dernat et al. (2023a). The game must not become a simple gadget tool, but a real lever to demonstrate measurable improvement years after the intervention (Janssen et al., 2023). Games take part of a process, which make it difficult to identify their direct impact on changes of practices. However, evaluating their impact at both collective and farm levels remains critical. A better understanding of this may help for the game design, facilitation and inclusion of the games in broader approaches. For games that focus on technical aspects, evaluation at farm level is under-estimated, even though necessary when aiming for sustainable systems.

4.4.5. Games to invest transdisciplinary

Our results show that games could be used to bring together scientific and local knowledge. It connects directly with transdisciplinary by allowing crossing disciplines and farmers and societal knowledge (Rodela and Speelman, 2023). This would make games a tool of a transdisciplinary discipline corresponding to specific skills, methods, and theories for knowledge integration and implementation within the scope of problem-solving research (Rigolot, 2020; Gasparatos et al., 2023). Further, transdisciplinary approach would foster the inclusion of user experience and design principles strengthening research aims and participants involvement (Ditzler et al., 2018). This epistemic aspect of the game needs to be explored in greater depth in order to measure its extent in terms of research practices, particularly in relation to sustainability issues, science-policy interface and stakeholders' engagement.

5. Conclusion

This systemic literature review highlighted the relevance of games to question sustainability in agriculture.

We identified publications since the 70's with an acceleration of publications on serious agricultural games in the last ten years with a stronger presence in leading journals. However, the gaming community remains concentrated in Northern countries despite a significant number of experiments conducted in the South. Some agricultural productions

[1] Accessible on the website: https://gamae.fr.

were over-represented, such as crops and livestock, with mostly games at farm, territory or sector levels. Games were mostly analogue. We highlighted a temporal dynamic in the objective and content of the games studied. Originally oriented towards education and economic issues, nowadays more and more games embrace environmental and social themes with games used as a co-design tool with stakeholders. Games seem to be a useful tool for dealing with sustainability issues in agriculture, especially in complex situations where stakeholders do not hold all the keys for decision-making and changes and may not be aware of all issues. Our analysis showed that sustainability was addressed in our corpus according to two main trends: one more compartmentalized and technical, focusing on farmers' practices, the other, more holistic, covering all areas of sustainability and including citizens and other actors. This second trend was therefore more in line with global sustainability. It is in particular in this group that sustainability issues are more addressed with a marked tendency for serious board games. Behind this movement to mobilize the games, a scientific community was built around the 2000s in France and then spread mainly in Europe.

Our results suffered from a number of limitations due to the analysis itself (English language only, choice of parameters) but also to the field of research. However, we identified gaps and proposed a research agenda to further work on i) inclusion of the diversity of games, ii) rethinking using of games with possible combinations, iii) opening to broader agricultural productions, iv) assessing the real impact of the games, v) using games for transdisciplinary research.

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CRediT authorship contribution statement

Sylvain Dernat: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Myriam Grillot:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Federico Andreotti:** Writing – review & editing, Writing – original draft, Validation. **Gilles Martel:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2024.104178.

Data availability

Data will be made available on request.

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