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Gamification for sustainability: A systematic review of applications, trends, and opportunities

Adrian A. Mabalay

Department of Management and Organization, De La Salle University, Manila, Philippines

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ABSTRACT

This systematic review examines gamification applications for sustainability across the UN Sustainable Development Goals. Analyzing 324 peer-reviewed articles published up to 2023, it reveals a rapidly growing research field emphasizing Quality Education, Affordable Clean Energy, Sustainable Cities, Responsible Consumption, and Climate Action. Engagement, motivation, and social interaction emerge as key gamification functions. The review identifies trends, best practices, and research gaps, pointing to opportunities for rigorous empirical studies and interdisciplinary collaboration. Findings contribute to a concept integration for gamification in sustainability, informing future research and practical interventions. This work spotlights gamification's potential for driving sustainable change and achieving the SDGs.

1. Introduction

In recent years, gamification has emerged as a promising approach to promote sustainable behaviors and advance the United Nations Sustainable Development Goals (SDGs). Gamification refers to the application of game design elements in non-game contexts to engage people and motivate targeted actions (Navarro-Espinosa et al., 2022). This innovative strategy, according to Huber and Hilty (2015), has the potential to drive positive behavior change for sustainability by tapping into intrinsic motivations and providing an interactive, fun, and rewarding experience.

Researchers have begun exploring gamification across various sustainability domains related to the SDGs. For instance, Albertarelli et al. (2018) surveyed gamified systems for energy and water sustainability, highlighting game-like elements' potential to encourage resource conservation. Ro et al. (2017) tested a gamified approach to promote sustainable energy use in workplaces that demonstrated significant reductions in electricity consumption through game-based interventions. In the tourism sector, Negruşa et al. (2015) examined gamification's role in encourage sustainable practices. They reveal how gamified experiences can enhance tourists' awareness and engagement with eco-friendly behaviors. On the corporate front, Gatti et al. (2019 investigated gamification for sustainability in business simulations, which shows how game elements can improve learning outcomes related to sustainable business practices.

Despite growing interest, research in gamification for sustainability remains nascent and fragmented. Several recent reviews (see Appendix A) have explored this interaction with distinct focuses. Aubert et al. (2019) developed a framework for designing game-based approaches in sustainable water governance, finding most approaches fall under "expert-driven sustainability," showing a critical lack of "society-driven" sustainable governance methods. Latino et al. (2023) identified eight key dimensions in the agri-food industry, including social-motivational change, health-educational roles, and monitoring mechanisms. Oliveira et al. (2021) presented a theoretical framework relating game elements to behavioral attitudes in e-learning contexts, while Cruz and Rosado da Cruz (2023) revealed promising applications in promoting circular economy principles.

Through this systematic review, I aim to address three critical gaps. Firstly, we lack comprehensive reviews synthesizing findings across the full spectrum of SDGs, as most existing studies focus on limited sustainability domains. Secondly, the long-term effectiveness of gamification interventions on sustainable behavior change remains unclear and requires further investigation. Thirdly, we have limited understanding of how contextual factors and individual differences influence gamification's impact on sustainability outcomes.

I make several key contributions through this work. Firstly, to provide a comprehensive mapping of gamification applications across SDGs, in which I offer insights into underexplored areas and potential cross-pollination opportunities between different sustainability domains. Secondly, to synthesize findings on effective gamification strategies, where I identify common success factors and potential pitfalls in

E-mail address: adrian.mabalay@dlsu.edu.ph.

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gamification design for sustainability. Thirdly, to identify emerging trends and research gaps, providing a roadmap for future studies to advance our understanding of how gamification can optimally support sustainable development.

In conducting this review, I follow the bibliometric methodology, including the conceptual framework (which I termed conceptual structure) Gue et al. (2020) used in their review of artificial neural networks for sustainable development (see Fig. 1), and was patterned closely from Page et al.'s (2021) PRISMA. I searched the Scopus database for journal articles containing keywords related to gamification and sustainability. After applying inclusion and exclusion criteria focusing on peer-reviewed articles examining gamification applications for SDGs, I conduct descriptive and content analyses to map the research landscape and identify key themes and insights. The rest of this paper is structured as follows: I first provide background information and the SDGs. I then describe the bibliometric methodology ensuring transparency and reproducibility. Next, I present findings from descriptive and content analyses, offering both quantitative trends and qualitative insights. We conclude with implications for research and practice in sustainable development, along with future research directions.

Through this review, I wish to inspire more researchers and practitioners to explore gamification's potential as an innovative approach to drive sustainable behavior change and achieve the SDGs. As we face unprecedented global challenges, from climate change to social inequality, harnessing the motivational power of games could play a significant role in engaging individuals and communities in sustainable practices.

2. Background of the study

In this section, we will see an overview of key concepts and existing research relevant to gamification for sustainability. This background information sets the context for the systematic review that follows, stressing the potential of gamification as a tool for advancing Sustainable Development Goals.

2.1. Gamification

Gamification has gained significant attention from researchers and practitioners over the past decade. It involves applying game design elements in non-game contexts to engage and motivate people to achieve specific goals (Deterding et al., 2011). Koivisto and Hamari (2019) noted in their review that gamification has been applied across various domains, including education, health, marketing, and sustainability. The core idea behind gamification is to harness the motivational power of games to drive behavior change and enhance user experiences (Huotari & Hamari, 2017).

Several scholars have proposed frameworks and typologies to understand the design and implementation of gamification. For instance, Werbach and Hunter (2012) introduced the dynamics, mechanics, and components (DMC) framework, which categorizes game elements into three hierarchical levels. Dynamics refer to the high-level aspects of the gamified system, such as constraints, emotions, and narrative. Mechanics are the basic processes that drive the action forward and engage users, such as challenges, chance, competition, and cooperation. Components are the specific instantiations of mechanics and dynamics, such as achievements, badges, leaderboards, and points (Dichev & Dicheva, 2017; Sailer et al., 2017).

Another influential framework is the Octalysis framework for gamification and behavioral design developed by Chou (2015) (see Fig. 2). This framework identifies eight core drives that motivate people to engage with gamified systems: meaning, accomplishment,

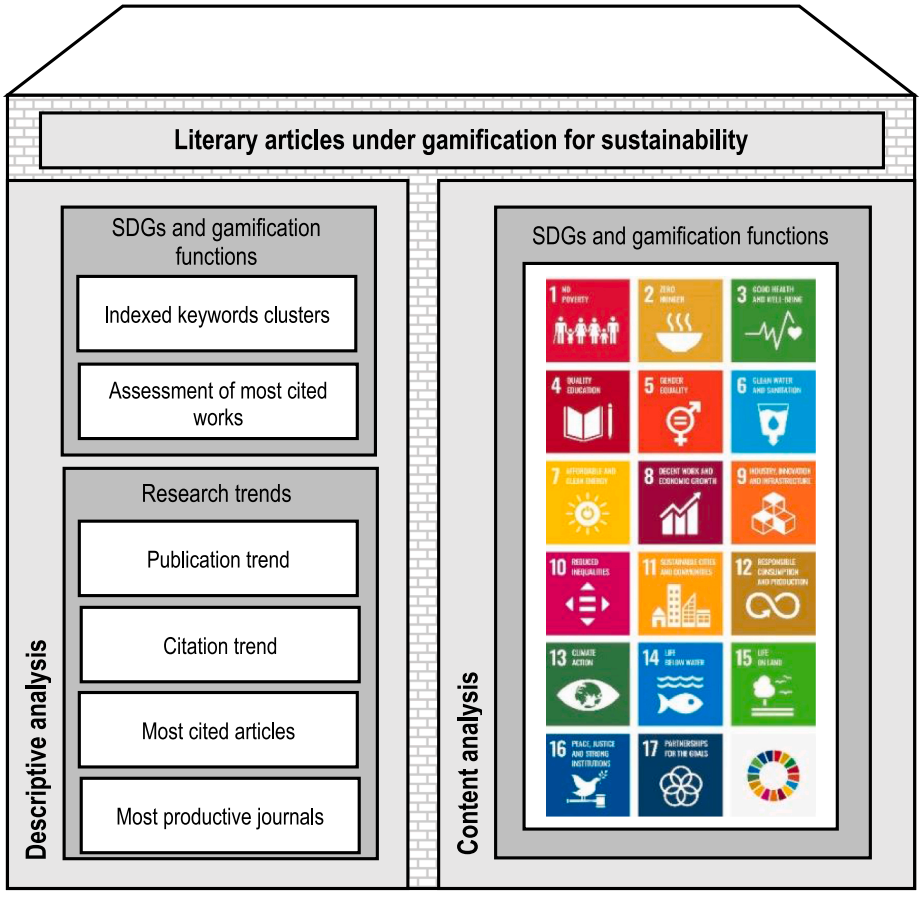


Fig. 1. Author's interpretation and conceptual structure of the systematic literature review of gamification for sustainability as inspired by Gue et al. (2020).

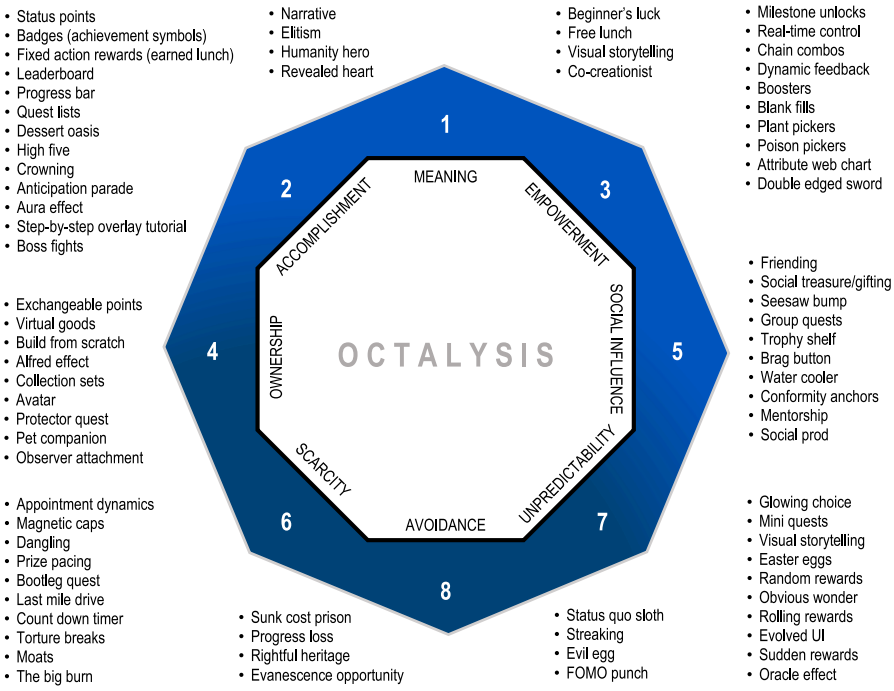


Fig. 2. Author's illustration of Chou's (2015) Octalysis framework for gamification and behavioral design.

empowerment, ownership, social influence, scarcity, unpredictability, and avoidance. Practitioners, according to Chou (2019), can create engaging and effective interventions by designing gamification experiences that tap into these core drives.

Researchers have also investigated the psychological mechanisms underlying gamification's effectiveness. Sefl-determination theory (SDT) has been widely used to explain how gamification can support intrinsic motivation by satisfying basic psychological needs for autonomy, competence, and relatedness (Ryan & Deci, 2000; Xi & Hamari, 2019). For example, Sailer et al. (2017) found that specific game design elements, such as badges and leaderboards, can enhance feelings of competence and relatedness, respectively. Other studies like that of Locke and Latham (2002) have drawn on goal-setting theory and social comparison theory (Festinger, 1954) to explain how gamification can motivate behavior change by setting clear goals and providing social incentives (Landers et al., 2018; Tondello et al., 2016).

Despite the growing evidence of gamification's potential, researchers have also identified challenges and limitations. Hamari et al. (2014) conducted a literature review and found that the effectiveness of gamification varies depending on the context and the user. They highlighted the need for more rigorous empirical studies to understand the boundary conditions of gamification's effectiveness. Similarly, Seaborn and Fels (2015) cautioned against the uncritical use of gamification and called for a more sophisticated understanding of its psychological and social implications.

2.2. Sustainable Development Goals

The United Nations adopted the 17 Sustainable Development Goals (SDGs) in 2015 as part of the 2030 Agenda for Sustainable Development. The SDGs provide a shared blueprint for achieving a better and more sustainable future for all by addressing global challenges related to poverty, inequality, climate change, environmental degradation, peace, and justice (United Nations, 2015). The goals cover a wide range of interconnected issues, from ending hunger and promoting health to ensuring access to clean energy and building sustainable cities (Griggs et al., 2013; Sachs, 2012).

Scholars have emphasized the critical role of research and innovation in achieving the SDGs. As Leal Filho et al. (2018) argued, universities and research institutions can contribute to the SDGs through education, research, and outreach activities. They can develop new technologies, practices, and policies that support sustainable development and build capacity for implementing the SDGs. However, achieving the SDGs also requires interdisciplinary collaboration and stakeholder engagement beyond academia (Messerli et al., 2019; Schneider et al., 2019).

Several studies have reviewed the progress and challenges of implementing the SDGs. Moyer and Bohl (2019) analyzed the SDG indicators and found that while progress has been made in some areas, such as reducing poverty and expanding access to electricity, significant gaps remain in other areas, such as reducing inequality and combating climate change. They highlighted the need for more ambitious and transformative actions to accelerate progress toward the SDGs. Similarly, Sachs et al. (2021) assessed the SDG performance of countries worldwide and identified key priorities for action, such as investing in human capital, promoting sustainable consumption and production, and strengthening governance and institutions.

Researchers have also explored the potential of specific technologies and approaches to support the SDGs. For instance, Vinuesa et al. (2020) examined the role of artificial intelligence (AI) in achieving the SDGs and found that AI can positively contribute to 134 targets across all 17 SDGs. However, they also identified risks and challenges, such as privacy concerns and the potential for AI to exacerbate inequalities if not developed and used responsibly. Other studies have investigated the potential of blockchain (Kshetri, 2017; Nikolakis et al., 2018), big data (Bibri, 2019; Etzion & Aragon-Correa, 2019), and the Internet of Things (IoT) (Fatimah et al., 2020; Wu et al., 2018) to support sustainable development.

As I discuss next, gamification has emerged as another promising approach to engage individuals and organizations in supporting the SDGs.

2.3. Integration of gamification and sustainability

The integration of gamification and sustainability has gained

increasing attention from researchers and practitioners in recent years. As AlSkaif et al. (2018) noted, gamification can be a powerful tool for promoting sustainable behaviors and driving progress toward the SDGs. Gamification can motivate individuals and organizations to adopt more sustainable practices and contribute to positive social and environmental impact by making sustainability challenges more engaging, rewarding, and fun (Gatti et al., 2019; Irwanto et al., 2023).

I have found several studies exploring the application of gamification in specific sustainability domains. In the context of energy conservation, Albertarelli et al. (2018) did a survey on gamification to assess sustainable energy consumption behaviors among users. They found that the apps significantly increased users' awareness and engagement with energy-saving practices. Similarly, Casals et al. (2020) and Kotsopoulos et al. (2018) investigated the use of gamification for promoting sustainable water consumptions.

In the area of sustainable consumption, several pieces of literature explored the potential of gamification to motivate sustainable food choices and reduce food waste. They found that gamification can increase consumers' willingness to make more sustainable purchases by providing feedback, rewards, and social comparison. Krath and Von Korflesch (2021) also characterized in their review the role of gamification, even in promoting sustainable transportation choices—we can say using public transit or cycling.

Gamification has also been applied to support corporate sustainability and social responsibility initiatives. Gatti et al. (2019) and Ramcilovic-Suominen et al. (2020) conducted exploratory studies of gamification in business simulations and organizational learning for sustainability. They found that gamification can enhance employees' engagement, motivation, and knowledge-sharing related to sustainable business practices. Stanitsas et al. (2019) studied the use of gamification for improving sustainability reporting and stakeholder engagement.

In the context of the SDGs, there are several studies exploring how gamification can support specific goals and targets. For example, Souza and Marques (2022) developed a framework for using gamification to promote sustainable tourism practices (SDGs 8 and 12). Nordby et al. (2016) and Irwanto et al. (2023) examined the role of gamification in supporting quality education (SDG 4) through e-learning platforms and massive open online courses (MOOCs). AlSkaif et al. (2018) investigated the potential of gamification for advancing affordable and clean energy (SDG 7) and sustainable cities and communities (SDG 11).

Although these studies evince the potential of gamification for sustainability, researchers have also identified challenges and limitations. Koivisto and Hamari (2019) noted that the long-term effects of gamification on sustainable behavior change are still unclear and require further investigation. They also emphasized the need for more diverse research methods and theoretical frameworks to understand the complex interplay between gamification design, psychological processes, and contextual factors (Hamari & Koivisto, 2015; Rapp et al., 2019). Moreover, as Ro et al. (2017) cautioned, gamification interventions for sustainability must be carefully designed to avoid unintended consequences, such as undermining intrinsic motivation or promoting unsustainable behaviors. They emphasized the importance of aligning gamification with broader sustainability goals and values and ensuring that the gamified experience supports meaningful and long-lasting change (Darejeh & Salim, 2016; Riar et al., 2022).

In contextual summary, the literature on gamification and sustainability has grown rapidly in recent years, with numerous studies exploring the potential of gamification to drive sustainable behavior change and support the SDGs. Although the evidence suggests that gamification can be an effective tool for engaging individuals and organizations in sustainability challenges, more research is needed to understand the boundary conditions, long-term impacts, and best practices for designing and implementing gamification interventions (AlMarshedi et al., 2015; Figueiredo & García-Peñalvo, 2021). In the following sections, we will delve deeper into the specific applications and trends of gamification for sustainability based on my systematic review of the literature.

3. Bibliometric methodology

I designed this systematic review following the bibliometric methodology from Gue et al. (2020) and Brandenburg et al. (2014), where they got inspiration from the PRISMA 2020guidelines (Page et al., 2021), to examine how gamification supports sustainability across the UN Sustainable Development Goals. In designing the methodology, I drew inspiration from recent high-impact stides in sustainability science (Sachs et al., 2021; Vinuesa et al., 2020) while, at the same time, incorporating elements specific to gamification research as outlined by Koivisto and Hamari (2019).

I began with a broad search in Scopus using the keywords "gamification" AND "sustainab*", focusing on peer-reviewed journal articles to ensure scientific rigor. I selected Scopus for its comprehensive coverage of interdisciplinary research and robust indexing of sustainability-related publications (Etzion and Aragon-Correa, 2019). My initial search yielded 890 documents. I then refined this to 394 papers by filtering for only articles and reviews, following Seaborn and Fels' (2015) recommendation to focus on peer-reviewed research for systematic reviews in gamification. I further narrowed to 324 articles published through 2023 to maintain currency.

I made a deliberate methodological choice to conduct two complementary levels of analysis, inspired by the multi-level analytical approach demonstrated by Hamari et al. (2014) in their seminal review of gamification effectiveness: Firstly, I performed a descriptive bibliometric analysis on all 324 articles to map the broad terrain of gamification and sustainability research. This wider lens allowed me to identify macro-level patterns in publication trends, research clusters, and citation networks that might be missed with a smaller sample. I used VOSviewer to analyze co-citation patterns and keyword clustering across this full dataset, following van Eck and Waltman's (2010) established protocols for bibliometric visualization. Secondly, I conducted an in-depth content analysis on a more focused subset of 128 articles that explicitly addressed sustainability in their core focus. I identified these articles by requiring "sustainability", "sustainable development", or "sustainable development goals" in their title, abstract, or keywords, adapting a systematic coding approach for gamification studies. This additional filtering ensured that the detailed content analysis focused on articles where sustainability was central to the research, not merely tangential.

The separate treatment of the six review articles served a distinct purpose—I made a methodological decision to exclude them from the primary analysis while, at the same time, utilizing them extensively in the literature review section. This decision stems from established systematic review principles that caution against including secondary analyses (review articles) alongside primary research in the main analysis, as this could lead to double-counting of findings and potentially skew the analysis (Moher et al., 2015). Instead, I used these review articles to provide important historical context and theoretical grounding in the introductory sections, following best practices in systematic review methodology (Snyder, 2019).

My rationale for this dual-track method stems from the field's rapid evolution and interdisciplinary nature. The broader sample of 324 articles captured emerging connections between gamification and sustainability that might be missed with stricter inclusion criteria. Meanwhile, the focused analysis of 128 articles allowed for deeper examination of specific applications and outcomes in sustainability-centered work, an approach supported by current best practices in systematic review methodology (Snyder, 2019). I detail my inclusion and exclusion criteria in Table 1, and Fig. 3 shows a visual representation of the systematic review process inspired by PRISMA guidelines. This methodology allowed me to balance comprehensive coverage with focused analysis, though I acknowledge that future reviews might benefit from applying consistent criteria across all analyses.

Table 1
Inclusion and exclusion criteria.

Criteria	Inclusion	Exclusion	Rationale
Document type	Journal articles and reviews	Conference papers, book chapters, and other document types	To focus on peer-reviewed, substantial research contributions
Language	English	Non-English languages	To ensure accessibility and consistency in analysis
Time frame	Published up to 2023	Published after 2023	To provide a comprehensive and up-to-date review of the field
Relevance	Contains "sustainability", "sustainable development", or "sustainable development goals" in the title, abstract, or keywords	Does not contain specified sustainability terms in title, abstract, or keywords	To ensure sustainability is a central focus of the study, aligning with the research question
Database	Scopus	Other databases	Scopus offers comprehensive coverage of peer-reviewed literature across various disciplines and provides robust tools for bibliometric analysis

Source: Author's compilation

4. Status of gamification for SDGs

4.1. Descriptive analysis

I conducted a descriptive analysis of the full set of 324 articles to identify overall publication trends, most productive authors and journals, and frequently cited works. This analysis illustrates a broad overview of the research landscape on gamification for sustainability.

4.1.1. Publication and citation trends

You can see in Table 2 the most cited journal articles in the dataset. Koivisto and Hamari's (2014) work on demographic differences in perceived benefits from gamification in the context of exercise tops the list with 592 citations. This study investigates how gender, age, and time using a gamified exercise service affect perceived social, hedonic, and utilitarian benefits. Hamari and Koivisto (2015) study on social influence in exercise gamification, with 345 citations, examines how social influence predicts attitudes, use, and further exercise in a gamified context. Jones et al.'s (2014) evaluation of a gamification approach to increasing fruit and vegetable consumption in schools, with 121 citations, exhibits the potential of gamification to promote healthy eating habits among children.

Illustrated in Fig. 5 are the publication and citation trends from 2013 to 2023. The number of publications has steadily increased over the years, with a notable uptick starting in 2017. The year 2021 saw the highest number of publications at 75, followed by 2022 with 60 publications. This trend shows the growing interest in gamification for sustainability research. Citations have also grown exponentially, reaching over 4500 in 2022. The increasing citation count indicates the growing impact and influence of this research area. The steep rise in citations from 2020 onwards suggests that the field is rapidly gaining traction and recognition within the scientific community.

You can see in Table 3 the publication trends among the most productive journals in the field. Sustainability (Switzerland) leads with 76 publications and 1494 total citations. This is a manifestation of the journal's significant contribution to the field. The Journal of Cleaner Production follows with seven publications and 243 citations. When considering the average citations per paper, Computers in Human Behavior stands out with 312.33 citations per paper. This indicates the high impact of its publications in this domain. Computers and Education also shows a strong performance with 128.67 citations per paper.

4.1.2. Conceptualization and analysis of gamification functions

From the 324 articles analyzed, I identified five main gamification functions that serve different purposes in sustainability contexts. These were deductively derived from past works or inductively emerged from the articles themselves (see Table 4). Although these functions can work together or might appear overlapping at first glance, each plays a unique role in supporting sustainability goals based on fundamental differences in their mechanisms, purposes, and outcomes. Let me explain how I conceptualized each function and its distinctive characteristics:

Engagement [D] emerged as the most prevalent function, appearing in 147 articles (45.4%). I found engagement specifically focusing on active participation and sustained interaction with gamified systems. For example, when analyzing Wallius et al.'s (2022) work on urban mobility, I observed engagement manifesting through measurable metrics like session frequency, task completion rates, and interaction depth. This differs fundamentally from other functions because engagement represents the quantitative aspects of user participation—the "how much" rather than the "why" or "to what end." In studies like Huang et al. (2023), users showed high engagement through regular app usage without necessarily developing sustainability-oriented motivations.

Motivation [D], present in 292 articles (90.1%), operates distinctly from engagement by focusing on the psychological drivers of participation. My analysis of studies like Souza et al. (2020) revealed motivation working through specific mechanisms such as goal-setting frameworks, achievement systems, and reward structures designed to inspire sustainability-oriented behaviors. Mahmud et al. (2020) showed this distinction clearly—while their system showed lower engagement metrics, participants displayed stronger motivation toward sustainability goals. Park et al. (2021) further reinforced this separation by showing how motivated users might engage less frequently but achieve more significant sustainability outcomes.

Appearing in 92 articles (28.4%), *social interaction* [D] serves a fundamentally different purpose from individual engagement or motivation. Through analyzing works like Lan et al. (2023), I identified this function enabling unique collaborative dynamics—peer learning, community building, and collective action specifically around sustainability challenges. The effectiveness of social features proved independent of individual engagement levels. For instance, Souza et al. (2020) documented cases where limited individual system interaction still produced strong community-level sustainability outcomes through social mechanisms.

Gameful experience [I], which can be identified in 78 articles (24.1%), focuses on the qualitative aspects of interaction rather than quantitative engagement or motivational factors. When analyzing Park and Kim (2021b) educational interventions, we can see that gameful experiences create immersive sustainability learning environments through narrative, challenge design, and aesthetic elements. This function proved distinct because high-quality gameful experiences didn't automatically correlate with high engagement or strong motivation.

And, finally, appearing in 73 articles (22.5%), *sustainability awareness* [I] means operating independently from other functions by focusing specifically on knowledge building and understanding. Through examining studies like Aubert et al. (2019), I identified this function working through unique mechanisms—visualization tools, simulation experiences, and information discovery systems. My analysis revealed cases where users developed strong sustainability awareness without corresponding motivations (behavioral changes) to highlight this function's distinct role.

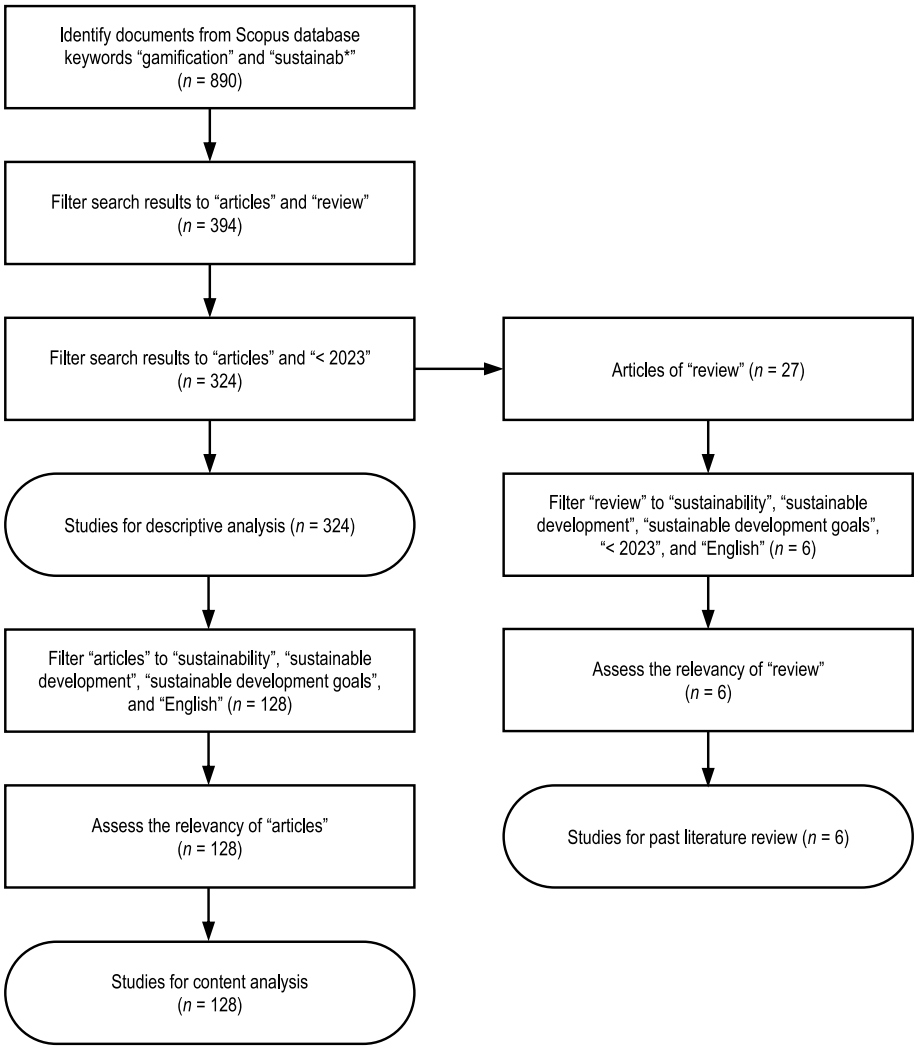


Fig. 3. Author's illustration of the scheme used in searching documents under gamification for sustainability as inspired by Gue et al. (2020).

Table 2
Most cited journal articles (n = 324).

Article	SDGs	Gamification function	Citations
Koivisto and Hamari (2014)	Good Health and Well-being (SDG-3)	Engagement, Motivation	592
Hamari and Koivisto (2015)	Good Health and Well-being (SDG-3)	Social interaction, Motivation	345
Buckley and Doyle (2017)	Quality Education (SDG-4)	Engagement, Motivation	219
Sanchez et al. (2020)	Quality Education (SDG-4)	Engagement, Motivation	159
Mitchell et al. (2020)	Decent Work and Economic Growth (SDG-8)	Motivation, Engagement	138
Fleming et al. (2016)	Good Health and Well-being (SDG-3)	Engagement, Motivation	130
Gatti et al. (2019)	Quality Education (SDG-4)	Sustainability awareness	127
Negruşa et al. (2015)	Sustainable Cities and Communities (SDG-11)	Engagement, Motivation	125
Jones et al. (2014)	Good Health and Well-being (SDG-3)	Motivation	121
Morschheuser et al. (2019)	Industry, Innovation, and Infrastructure (SDG-9)	Engagement, Motivation, Social interaction	117

Source: Author's compilation

Table 3
Publication trend among most productive journals (n = 324).

Journal	Publication	Citation	Citation per paper
Sustainability (Switzerland)	76	1494	19.66
Journal of Cleaner Production	7	243	34.71
International Journal of Environmental Research and Public Health	6	46	7.67
JMIR Research Protocols	5	111	22.2
IEEE Access Appearances	4	141	35.25
Energies	4	26	6.5
Computers in Human Behavior	3	937	312.33
Computers and Education	3	386	128.67
Journal of Business Research	3	296	98.67
International Journal of Human-Computer Studies	2	166	83

Source: Author's compilation

The analysis revealed these functions working in complex, non-hierarchical relationships. For instance, in energy conservation applications, you can find cases with high engagement and strong social interaction but limited behavior change. Similarly, some interventions achieved significant behavior change through motivation despite low engagement metrics. This pattern of independent effectiveness reinforced my decision to treat these as distinct functions rather than overlapping concepts or sequential steps.

Table 4
Gamification functions and descriptions ($n = 324$).

No.	Gamification function	Description
1	Engagement [D] (Huang et al., 2023; Wallius et al., 2022)	Motivate users to participate and interact with a system or activity
2	Gameful experience [I] (Park & Kim, 2021a, 2022)	Create an engaging and enjoyable user experience through game elements
3	Motivation [D] (Mahmud et al., 2020; Park et al., 2021; Ro et al., 2017; Shih & Jheng, 2017; Souza et al., 2020; Wang & Yao, 2020; Wemyss et al., 2018)	Drive participation and behavior change through intrinsic factors (enjoyment, mastery, purpose) and extrinsic rewards (points, badges, recognition)
4	Social interaction [D] (Lan et al., 2023; Souza et al., 2020)	Facilitate user interaction, collaboration, or competition within a system
5	Sustainability awareness [I] (Aubert et al., 2019; Souza & Marques, 2022)	Raise user awareness and understanding of sustainability concepts and practices

Note: [D]—functions that were identified deductively from past works; [I]—functions that were identified inductively from journal articles.
Source: Author's compilation

This manual coding of functions provided the foundation for the subsequent bibliometric analysis using VOSviewer, which allowed to validate and enrich these findings through automated keyword analysis, as discussed in the following section.

4.1.3. Bibliometric network analysis

To further understand the research trends in gamification for sustainability, I analyzed the bibliometric data from the 324 articles using VOSviewer—a specialized software tool designed for constructing and analyzing bibliometric networks in scientific literature. Unlike traditional citation analysis tools, VOSviewer employs sophisticated algorithms to identify meaningful relationships between concepts based on their co-occurrence patterns in academic publications. The software processes structured bibliometric data, including titles, abstracts, keywords, and citation information, to reveal the obvious and subtle connections within a research field.

Fig. 4 visualizes the cluster formation based on indexed keywords, which illustrates the important insights into the dominant themes and their interconnectedness. The varying sizes of the circles, which represent keyword frequency, paint a vivid picture of the field's focal points and emerging trends. Dominating the visual landscape, the expansive circles of "gamification" (82 occurrences), "human" (53 occurrences), and "sustainable development" (49 occurrences) emphasize the field's core focus on leveraging game elements to drive human-centered approaches to sustainability challenges (Huotari & Hamari, 2017; Koivisto & Hamari, 2014).

Keyword	Occurrences	Total link strength
gamification	82	262
human	53	346
sustainable development	49	173
sustainability	54	155
motivation	22	120
student	22	106
education	25	104
teaching	22	100

The robust connections between these primary nodes illustrate a research community deeply committed to exploring the synergies between gamification strategies and the SDGs. Through the VOSviewer analysis, we can identify four distinct thematic clusters that emerged from the keyword co-occurrence patterns.

1. *Core theoretical cluster:* Centered around "gamification" and "sustainability," showing the fundamental conceptual foundations.
2. *Educational applications cluster:* Including "education" (25 occurrences), "teaching" (22 occurrences), and "student" (22 occurrences).
3. *Behavioral change cluster:* Encompassing "motivation" (22 occurrences) and related behavioral concepts.
4. *Implementation cluster:* Focusing on practical application aspects.

A particularly fascinating cluster emerges around "motivation," "education," "teaching," and "student," which suggests a significant thrust in educational applications of gamification for sustainability. The dense web of connections here tells a story of researchers actively exploring how gamified approaches can revolutionize sustainability education, potentially addressing the crucial need for innovative pedagogies in this domain (Donath et al., 2020; Park & Kim, 2021b).

Although the prominence of education-related terms is encouraging, this also raises critical questions about potential gaps in the research terrain. The relative smallness of circles representing concepts like "climate change" and "energy efficiency (conservation/utilization)" suggests these crucial sustainability challenges may be underexplored through the lens of gamification. This visual disparity invites reflection on whether the field is adequately addressing the full spectrum of sustainability challenges outlined in the SDGs (Vinuesa et al., 2020). Moreover, the intricate network of connections between keywords paints a picture of highly interdisciplinary field, with researchers drawing connections between diverse concepts and methodologies. The total link strength values shown in Fig. 4 quantify these relationships, with higher values indicating stronger conceptual connections. This complexity, however, also hints at potential challenges in synthesizing findings and developing cohesive theoretical frameworks to guide future research practice (Seaborn & Fels, 2015).

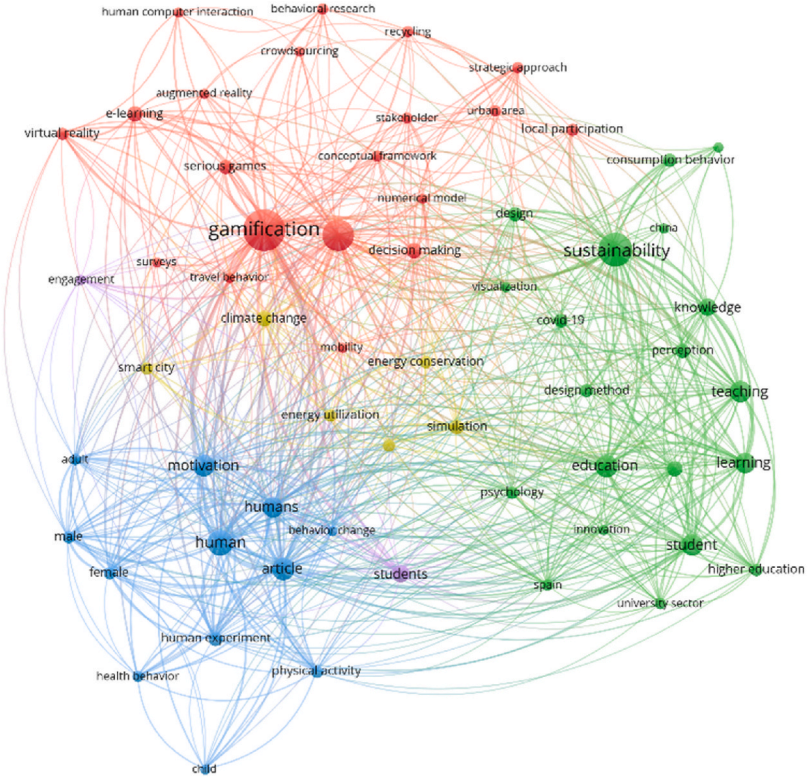
Through this systematic visualization, VOSviewer was able to help reveal not only the current state of gamification research in sustainability but also lays out potential areas for future investigation. The clustering patterns and connection strengths are insights into the maturity of certain research streams and the gaps that remain to be addressed.

4.2. Content analysis

Presented here are the findings from my in-depth content analysis of 128 peer-reviewed journal articles on gamification for sustainability. In Table 5, you can see a mapping of all 128 articles across SDGs, categorizing them based on their primary sustainability goals and gamification functions. This documentation serves multiple purposes. Firstly, it offers researchers a thorough catalog of work in each SDG domain. Secondly, it acknowledges that although many articles potentially address multiple SDGs, I have categorized them under their primary focus for analytical clarity. For instance, although an article might touch on both education (SDG 4) and sustainable cities (SDG 11), I placed it under the SDG that best represents its core contribution or the closest it can relate to. In the following sections, we can see the key trends and patterns within each major SDG category to highlight particularly innovative or influential works that exemplify important development in the field. This allows me to combine a comprehensive overview through Table 5 with focused, in-depth analysis in the narrative sections. This enables a sophisticated understanding of how gamification tackles various sustainability challenges across different domains.

4.2.1. SDGs and gamification functions

Remember that I have identified five main gamification functions earlier that were either deductively derived from past works or inductively emerged from the articles themselves. Engagement (e.g., Huang et al., 2023; Wallius et al., 2022), motivation (e.g., Mahmud et al., 2020; Park et al., 2021; Ro et al., 2017; Shih & Jheng, 2017; Souza et al., 2020; Wang & Yao, 2020; Wemyss et al., 2018), and social interaction (e.g., Lan et al., 2023; Souza et al., 2020) were the most frequently discussed



Keyword	Occurrences	Total link strength
gamification	82	262
human	53	346
sustainable development	49	173
sustainability	54	155
motivation	22	120
student	22	106
education	25	104
teaching	22	100

Fig. 4. Visualization of the cluster formation based on indexed keywords using VOSviewer (n = 324).

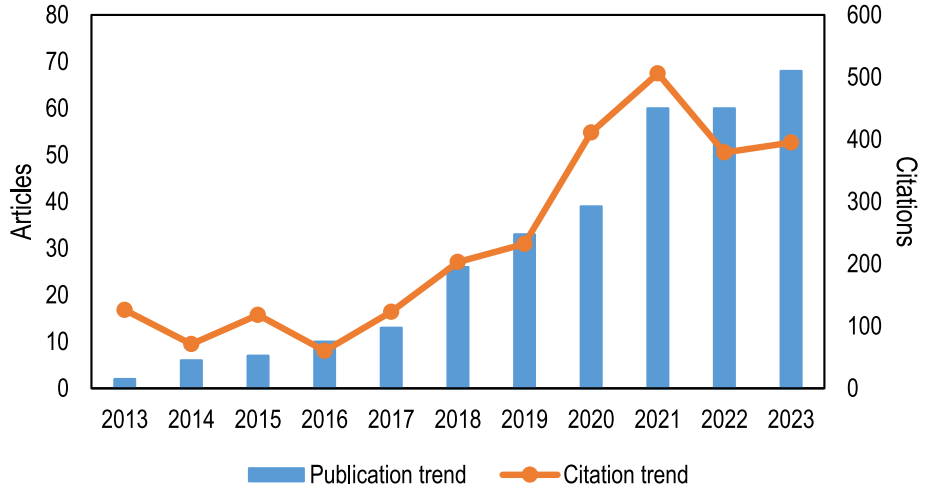


Fig. 5. Publication and citation trend from 2013 to 2023 (n = 324).

function. This underlines gamification's potential to capture attention, drive participation, facilitate collaboration, and promote sustainable behaviors in sustainability initiatives. Several articles also emphasized gamification's power to raise sustainability awareness (Aubert et al., 2019; Souza & Marques, 2022) and create gameful experiences (Park & Kim, 2021a, 2022).

From here on forward, using the 128 articles analyzed for the content analysis, 109 of which focused on five primary SDGs: Quality Education (SDG 4) was the most prevalent, with 37 articles exploring gamification applications in this domain. This was followed by Responsible Consumption and Production (SDG 12) with 26 articles, Affordable and Clean Energy (SDG 7) with 21 articles, Sustainable Cities and Communities (SDG 11) with 16 articles, and Climate Action (SDG 13) with 9 articles (see Table 5). The remaining 19 articles discussed other SDGs or sustainability issues not specifically categorized under these top five SDGs. Note that the articles in Table 5 might still have other SDG applications they relate to. However, I have categorized them closely based on their SDG-related applications. Although these articles contribute to the broader understanding of gamification applications for sustainability, they are not elaborated upon in the following subsections, which focus on the research trends and key findings for each of the top five SDGs in more detail.

4.2.2. *Research trends and effectiveness in quality education (SDG 4)*

I identified three dominant research streams in the 37 articles focusing on quality education. The first and largest stream explores *e-learning platforms and STEM education.* Donath et al. (2020) demonstrated how gamified e-learning platforms increased student motivation

Table 5
Common SDG applications ($n = 128$).

SDGs	Fields of application
SDG 4 Quality Education (37 articles)	The primary application areas were e-learning and STEM education, with studies exploring how gamification can increase student motivation, engagement, and learning outcomes (Donath et al., 2020; Mystakidis et al., 2021; Park & Kim, 2021b). Gamified applications were used to teach sustainability concepts (Mellor et al., 2018), promote sustainable behaviors (Muenz et al., 2023), and enhance education accessibility for underserved groups (Baglama et al., 2022). Other articles (31 of 37): Diaz-Lauzurica and Moreno-Salinas (2019), Ng and Lo (2022), Toriz (2019), Buckley and Doyle (2017), Sanchez et al. (2020), Gatti et al. (2019), Fernandez-Antolin et al. (2021), Gómez-Ruiz et al. (2021), Polyakova and De Ros Cócera (2022), Yllana-Prieto et al. (2021), Feltrero et al. (2023), Han et al. (2023), Zhang and Yu (2022), Shenkoya and Kim (2023), Flores-Aguilar et al. (2023), Choi et al. (2022), Clark et al. (2021), Jusas et al. (2022), Jääskä et al. (2021), Li and Chu (2021), Mahmud et al. (2020), Navarro-Espinosa et al. (2022), Nordby et al. (2016), Occhioni et al. (2023), Park and Kim (2021a), Park and Kim (2022), Park and Kim (2023), Park et al. (2021), Pineda-Martínez et al. (2023), Santos-Villalba et al. (2020), and Savolainen et al. (2020).
SDG 7 Affordable and Clean Energy (21 articles)	Gamification applications aimed to promote energy-saving behaviors among building occupants and the general public (Papaioannou et al., 2018; Ro et al., 2017). Some studies evaluated the impact of gamification on sustainable energy education (Ferreira et al., 2018; Romero-Rodriguez et al., 2019). Other articles (17 of 21): Erten et al. (2022), Fonseca i Casas et al. (2016), Mylonas et al. (2019), Mylonas et al. (2023a, 2023b), Oppong-Tawiah et al. (2020), Ozpinar (2023), Remelhe et al. (2022), Shih and Jheng (2017), Koroleva and Novak (2020), Du et al. (2020), Hsu and Chen (2021), Luger-Bazinger and Hornung-Prahauser (2021), Mulcahy et al. (2020), Wemyss et al. (2018), Whittaker et al. (2021), and Wójcik (2023).
SDG 11 Sustainable Cities and Communities (16 articles)	Gamification was also used to engage stakeholders in participatory urban planning (Fernández & Ceacero-Moreno, 2021; Mueller et al., 2018). Other articles (14 of 16): Caroleo et al. (2019), Cellina et al. (2019), Ehab and Heath (2023), Frías-Jamilena et al. (2022), Mohammed and Hirai (2021), Negruşa et al. (2015), Olszewski et al. (2020), Parygin et al. (2022), Sipone et al. (2019, 2021), Skarzauskiene and Mačiulienė (2021), Torres-Toukoumidis et al. (2022), Tripathy et al. (2020), and Wallius et al. (2022).
SDG 12 Responsible Consumption and Production (26 articles)	Key application domains were sustainable consumer behavior, manufacturing and agriculture. Several studies examined how eco-gamification can encourage sustainable consumption choices and practices (Berger & Schrader, 2016; Lin et al., 2023; Wang & Yao, 2020). Other articles (23 of 26): Aguilar-Castillo et al. (2019), Aresi et al. (2023), Bucchiarone et al. (2023), Chen et al. (2022), Cruz and Rosado da Cruz (2023), Grüger et al. (2023), Hoffman and Pfeiffer (2022), Hsu (2022), Lu and Ho (2020), Marcucci et al. (2018), Mulcahy et al. (2021), Papamichael et al. (2023), Pivec and Hsu (2020), Schaper et al. (2022), Soma et al. (2020), Sun et al. (2022), Villamil et al. (2023), Xu et al. (2020), Zawieska et al. (2022), Zhang et al. (2021), Alves et al. (2023), Guillen Mandujano et al. (2021), and Jaisli et al. (2019).
SDG 13 Climate Action (9 articles)	Studies primarily focused on using gamification to raise awareness about climate change issues, educate the public, and promote pro-environmental attitudes and behaviors (Huang et al. (2023), Fernandez Galeote et al., 2023a; 2023b, Huang et al. (2023); Wang et al., 2021). Several articles also discussed the role of gamification in supporting climate change mitigation and adaptation strategies (Capellán-Pérez et al., 2019; Wu et al., 2023). Other articles (3 of 9): Callesen and Magnussen (2021), Douglas and Brauer (2021), and Scurati et al. (2022).
Other SDGs or sustainability issues (19 articles)	Al-Mulla et al. (2022), Alzahrani and Alhalafawy (2023), Apostolopoulos and Potsiou (2022), Aubert et al. (2018), Baranyi et al. (2023), Erten et al. (2022), Isensee et al. (2022), Jacob and Teuteberg (2021), Khan et al. (2019), Koivisto and Hamari (2014), Latino et al. (2023), Lee et al. (2017), Milutinović et al. (2018), Silva et al. (2013), Souza et al. (2020), Souza and Marques (2022), Su (2018), Fleming et al. (2016), and Yoo et al. (2017).

Source: Author's compilation

in sustainability education, with their study of 150 university students showing significant improvement in test scores compared to traditional learning methods. Park and Kim (2021b) found particularly strong effects among younger learners, with engagement rates notably increasing for students in elementary and middle schools. Building these findings, Zhang and Yu (2022) and Shenkoya and Kim (2023) expanded this work by examining gamification's impact across different cultural contexts.

The second stream focuses on *accessibility and inclusion*. Baglama et al. (2022) pioneered animation-designed game-based learning for children with special needs, achieving a remarkable increase in engagement with sustainability concepts. Diaz-Lauzurica and Moreno-Salinas (2019) and Fernandez-Antolin et al. (2021) further developed this approach by incorporating universal design principles into gamified learning environments.

The third stream examines *pedagogical innovations*. Buckley and Doyle (2017), Sanchez et al. (2020), and Gatti et al. (2019) collectively advanced our understanding of how gamification elements can be integrated into traditional teaching methods. Mellor et al. (2018), for example, developed the "Safer Chemical Design Game" for high school and undergraduate students, which reports increased understanding of green chemistry principles, though they noted that long-term knowledge retention wasn't assessed. Recent work by Flores-Aguilar et al. (2023), Clark et al. (2021), and Jusas et al. (2022) has built upon these foundations to develop more sophisticated approaches to sustainable education.

Despite these promising results, it is interesting to note that most studies focus on short-term impacts. Although Muenz et al. (2023) showed improvements in sustainability literacy scores through digital educational games, they acknowledged the need for longitudinal studies to confirm lasting effects. This pattern suggests that although gamification can effectively boost immediate learning outcomes and engagement, particularly among younger learners and special needs students, we need more research on long-term educational impacts.

4.2.3. Research trends and effectiveness in affordable and clean energy (SDG 7)

Among the 21 articles theming on energy sustainability, I identified four distinct research streams, with the most compelling effectiveness evidence emerging from residential applications. The first stream

explores *residential energy consumption behavior*. Ro et al. (2017) led this work by showing a concrete decrease in household electricity use over a 4-month period using a gamified app—notably one of few studies using actual consumption data rather than self-reported behavior. Wemyss et al. (2018) expanded on this by comparing competitive versus collaborative approaches to energy conservation. More recent work by Mylonas et al. (2023a, 2023b) has integrated IoT technologies with gamification, showing how real-time feedback can enhance conservation behaviors.

The second stream examines *workplace energy management,* where effectiveness proves more challenging to measure. Ferreira et al. (2018) pioneered an IoT-based platform for public buildings, reporting increased energy efficiency awareness but struggling to quantify actual energy savings. Papaioannou et al. (2018) achieved more concrete results with their IoT-based gamified application, showing a 12 percent reduction in energy wastage, though they noted significant challenges in maintaining user engagement over time. Oppong-Tawiah et al. (2020) and Du et al. (2020) investigated how social dynamics influence workplace energy conservation, while Whittaker et al. (2021) further developed this by examining flow theory in organizational energy-saving behaviors.

The third stream focuses on *energy education,* where results have been mixed. Shih and Jheng (2017) and Erten et al. (2022) developed frameworks for selecting effective gamification elements in energy education. Romero-Rodriguez et al. (2019) found that gamification in energy sustainability MOOCs increased course completion rates but couldn't demonstrate impact on real-world energy behaviors. Luger--Bazinger and Hornung-Prahauser (2021) and Mulcahy et al. (2020) extended this work by examining how gamified interventions can bridge the knowledge-action gap in energy conservation.

A fourth emerging stream explores *innovation technologies,* though effectiveness data remains limited. Fonseca i Casas et al. (2016) and Hsu and Chen (2021) investigated augmented reality applications for energy awareness. Recent work by Ozpinar (2023) and Wójcik (2023) has begun exploring blockchain integration with gamified energy systems.

This domain (SDG 7) reveals a clear pattern: although residential gamification shows promising quantifiable results, effectiveness in other contexts remains harder to show. The most successful interventions combine real-time feedback with tangible measurements, which suggests that future work should prioritize objective metrics over self-reported data.

4.2.4. Research trends and effectiveness in sustainable cities and communities (SDG 11)

My analysis of 16 articles on urban sustainability revealed three primary research directions. Effectiveness measurement, however, proves particularly challenging in this domain. The first focuses on *urban mobility,* where Wallius et al. (2022) examined how gamification influences transportation choices. Caroleo et al. (2019) and Cellina et al. (2019) developed frameworks for evaluating sustainable mobility interventions, while Sipone et al. (2019, 2021) specifically targeted educational aspects of sustainable transportation.

The second stream addresses *urban planning and citizen engagement,* where effectiveness often remains qualitative. Fernández and Ceacero-Moreno (2021) used serious games for urban planning, where they reported increased stakeholder engagement but struggling to measure concrete outcomes. Mueller et al. (2018) found their gamified spatial simulation tool improved understanding of urban sustainability issues among municipal planners, yet its impact on actual urban development decisions remained unclear. This foundation has been built upon by Mohammed and Hirai (2021) and Parygin et al. (2022), who integrated crime prevention and innovation helix models respectively into urban gamification.

The third stream examines *tourism and community building,* with mixed effectiveness results. Negruşa et al. (2015) pioneered work on gamified sustainable tourism, later expanded by Frías-Jamilena et al. (2022). Skarzauskien and Mačiulienė (2021) and Torres-Toukoumidis et al. (2022) explored how gamification can strengthen urban communities, while Ehab and Heath (2023) investigated immersive co-design approaches.

As you can see, the urban context presents unique challenges for measuring gamification effectiveness, largely due to the complex, long-term nature of urban change. Most studies illustrate patterns of increased engagement and awareness, but translating these into measurable urban sustainability improvements remains a significant challenge for the field.

4.2.5. Research trends and effectiveness in Responsible Consumption and Production (SDG 12)

Within the 26 articles examining sustainable consumption, I found four major research threads with varying levels of effectiveness. The first themes on *consumer behavior change.* Wang and Yao (2020) analyzed the Ant Forest app, where they found increased awareness of sustainable consumption but limited evidence of long-term behavior change—while users showed increased knowledge of sustainable practices, only a small percentage maintained these behaviors after a few months. Lin et al. (2023) analyzed how gamification elements influence sustainable purchasing decisions. This work has been advanced by Hoffman and Pfeiffer (2022), Hsu (2022), and Lu and Ho (2020), who examined long-term behavioral impacts, though their findings suggest sustained change remains elusive.

Secondly is on *waste reduction and circular economy,* showing more promising measurable outcomes. Cruz and Rosado da Cruz (2023) and Alves et al. (2023) developed frameworks for circular economy gamification. Schaper et al. (2022) and Soma et al. (2020) investigated waste reduction interventions, which demonstrate quantifiable improvements in waste sorting behavior, while Papamichael et al. (2023) created unified waste metrics through gamification that enabled more precise measurement of intervention effects.

Thirdly examines *sustainable food systems,* where effectiveness varies by context. Berger and Schrader (2016) established foundational work in sustainable nutrition behavior, achieving measurable increases in sustainable food purchases over a specific period. Long-term effects, however, weren't assessed. Aresi et al. (2023) and Pivec and Hsu (2020) expanded this to school-based interventions, where it show particular success in changing youth dietary choices. Grüger et al. (2023) developed evaluation frameworks for sustainable food apps, stressing the importance of user engagement in maintaining behavioral changes.

The final stream explores *industrial applications,* where effectiveness tends to be more quantifiable in this case. Villamil et al. (2023) and Zhang et al. (2021) investigated gamification in sustainable manufacturing. Their studies show concrete improvements in resource efficiency. Bucchiarone et al. (2023) and Zawieska et al. (2022) focused on enhancing pro-environmental engagement in industrial settings, and their studies demonstrate measurable reductions in workplace resource consumption as well.

This interestingly shows that the effectiveness of gamification in this domain varies significantly by context and measurement. Industrial and waste management applications show the most concrete results, while consumer behavior change proves more challenging to sustain. This suggests that structured environments may provide better conditions for successful gamification interventions.

4.2.6. Research trends and effectiveness in climate action (SDG 13)

I identified three distinct approaches among the nine articles that focused on climate action, with effectiveness measurements varying significantly. The first examines *educational interventions,* where results focus primarily on knowledge gains rather than behavioral change. Fernandez Galeote et al. (2023a, 2023b)conducted rigorous comparisons of game-based versus traditional climate education. They found increased climate change knowledge but no significant difference in reported intentions to act. Douglas and Brauer (2021) synthesized

existing climate change games and apps, which provide a framework for future development and, at the same time, emphasizing the persistent challenge of translating awareness into action.

The second one focuses on *behavior change interventions.* This shows more promising measurable outcomes. Huang et al. (2023) showed that their sustainability game led to a reduction in household electricity consumption over few months—one of the few studies in this domain to measure tangible outcomes. Wang et al. (2021) showed how gamification can drive measurable reductions in carbon footprints. Although long-term sustainability of these changes remains unclear. Capellán-Pérez et al. (2019) developed simulation games for understanding energy transitions and climate mitigation. They realized improved comprehension of complex climate issues but struggling to link this to concrete behavioral changes.

The final stream explores *integrated approaches,* attempting to bridge the awareness-action gap. Wu et al. (2023) pioneered the integration of cultural preservation with climate action through gamification. They showed how cultural relevance can enhance intervention effectiveness. Callesen and Magnussen (2021) and Scurati et al. (2022) developed frameworks for linking climate awareness with concrete action through serious gaming. Note that effectiveness data, however, remains largely quantitative.

As we can see, studies in the climate action domain show measurable impacts through individual-level metrics like household electricity consumption and carbon footprint reduction. Several studies show success not only in increasing knowledge and short-term engagement, but also in achieving quantifiable sustainability outcomes at the household level (Cellina et al. (2024a;2024b). Although we have these studies, we can still encourage a more sophisticated and continued approach to measuring long-term behavioral change and environmental impact in climate-focused gamification.

5. Discussion

Generally speaking, the descriptive analysis reveals a growing body of research on gamification for sustainability, while the content analysis shows that gamification is being applied across a wide range of sustainability domains, with a particular focus on education consumption and production, energy, cities and communities, and climate action. The most frequently discussed gamification functions were engagement, motivation (persuasion and sustainable behavior change), and social interaction. The field is characterized by a diverse range of applications, target outcomes, and research approaches, which features the potential of gamification as a versatile tool for advancing sustainability goals. The increasing publication and citation trends, along with the prominence of influential journals and highly cited articles, evince the rising interest and impact of this research area.

My findings reveal both promising applications and critical gaps that warrant careful consideration. Although evidence suggests gamification can positively impact sustainability outcomes, particularly in education and energy domains, we must interpret these results with caution. The current research shows consistent short-term gains in awareness and engagement, but evidence of lasting behavioral change remains limited. I found the effectiveness of gamification highly depends on context, shaped by user demographics, application design choices, and the specific sustainability challenges being addressed.

In education, for example, gamification proves most effective when it combines clear learning objectives with meaningful choices that reflect real-world sustainability decisions. When examining energy-focused applications, for instance, I found the most successful implementations went beyond simple point systems to create authentic connections between player actions and actual energy consumption patterns. This helped users develop lasting energy-conscious behaviors rather than just temporary engagement with the game mechanics. The applications in sustainable cities and communities yielded particularly interesting findings as well. Rather than treating gamification as merely an engagement tool, the most effective implementations integrated it into broader urban planning processes. These applications created genuine stakeholder dialogue around sustainability challenges, using game elements to make complex urban systems more accessible and actionable for citizens.

I also identified several critical research gaps that demand attention. Firstly, we need more rigorous longitudinal studies (which often lacks in many studies) to assess whether gamification-induced behavioral changes persist over time. Although we have recent few like that of Cellina et al. (2024a; 2024b), the current literature still needs more studies about the long-term impact of these interventions. Secondly, future research must better account for contextual factors—including cultural differences, socioeconomic conditions, and existing sustainability attitudes—that influence how users respond to gamification. This contextualization is very important for developing more effective, targeted interventions.

Looking ahead, I see significant potential in combining gamification with emerging technologies to create more sophisticated sustainability interventions. Virtual augmented reality, for example, could enable more immersive experiences that help users viscerally understand complex sustainability challenges. Meanwhile, artificial intelligence could power more personalized gamification systems that adapt to individual user behaviors and motivations. However, we must approach these technological integrations thoughtfully to ensure they serve genuine sustainability goals rather than becoming ends in themselves.

These findings point to a clear need for more interdisciplinary collaboration in designing and evaluating gamification for sustainability. Together, these expertise, from game design, environmental science, behavioral psychology, and other relevant fields, can create more effective interventions that drive meaningful progress toward sustainability goals.

5.1. Methodological considerations in measuring effectiveness

There is significant variability in how studies measured the effectiveness of gamification for sustainability. Many relied heavily on self-reported data or short-term observations, which limits their reliability and generalizability. More rigorous approaches, such as Ro et al.'s (2017) use of actual energy consumption data, proved relatively rare. Few studies employed control groups or accounted for potential confounding variables like seasonal changes or concurrent sustainability initiatives. Longitudinal studies extending beyond a few months were rare, making it difficult to assess long-term effects. Having said that, it should be noted, however, that recent longitudinal studies like that of Cellina et al. (2024a; 2024b) in Swiss households lay significant insights into long-term gamification effects on energy consumption. We must do many more studies like those since gamification is best studied long-term. Additionally, the literature review shows a lack of standardized metrics across studies, which makes it difficult for cross-study comparisons. This methodological inconsistency presents a significant challenge in drawing firm conclusions about gamification's overall effectiveness for sustainability.

5.2. Concept integration and practical implications

Let me discuss my findings using Paul and Elder's (2019) SEEI approach—state, elaborate, exemplify, and illustrate—to give clear practical guidance and context for researchers and practitioners.

I identified key patterns in successful gamification implementations across different sustainability domains. These patterns show that effective gamification requires careful consideration of domain-specific characteristics, user engagement mechanisms, and contextual factors. The success of sustainability-focused gamification depends not just on game elements themselves, but on how these elements align with specific sustainability goals and user contexts.

This reveals distinct patterns across major sustainability domains. In

education (SDG 4), effective implementations emphasize progressive learning through challenges while maintaining consistent engagement. Energy conservation initiatives (SDG 7) thrive on social comparison and community elements, particularly when combined with real-time feedback systems. Sustainable consumption projects (SDG 12) succeed by making abstract environmental impacts tangible through immediate feedback and clear visualization of outcomes. Urban sustainability programs (SDG 11) require deep understanding of local community contexts and challenges.

Furthermore, the concept integration proposes that effective gamification for sustainability emerges from the dynamic interplay of five core functions: engagement, motivation, social interaction, sustainability awareness, and gameful experience. These functions work together, shaped by contextual factors, to drive psychological and behavioral outcomes across different sustainability domains. The concept suggests that success depends not on implementing individual functions in isolation, but on understanding how they complement each other within specific sustainability contexts.

Let's discuss more closely. Think of these five gamification functions as core components in a well-designed video game ecosystem. *Engagement* operates like the game engine's core mechanics—just as a game engine determines how players interact with the virtual world, engagement mechanisms establish how users interact with sustainability initiatives. It's the foundational code that powers all others systems. *Motivation* functions as the game's progression and reward architecture. Like how well-designed level systems, achievement unlocks, and skill trees keep players invested, motivational elements in sustainability gamification create meaningful advancement pathways. These might include personal sustainability goals, environmental impact scores, or resource conservation achievements. *Social interaction* mirrors the multiplayer and community features that transform solo play into collaborative adventures. Think of guild systems, cooperative missions, and leaderboards—these translate into community challenges, team-based sustainability projects, and friendly competition in environmental initiatives. Just as massive multiplayer online game players coordinate for raid encounters, users collaborate to tackle larger sustainability objectives. *Sustainability awareness* acts like a player's growing understanding of complex game mechanics and meta-strategies. Similar to how gamers progress from button-mashing puny players to strategic experts, users develop deeper comprehension of environmental systems, cause-effect relationships, and long-term impact through gamified learning. *Gameful experiences* serve as the game design document that orchestrates all these elements into a compelling whole. Like how a masterful game blends story, mechanics, and progression into an engaging journey, gameful design creates an integrated experience where sustainability actions feel natural and rewarding rather than forced or tedious.

Just as game designers must balance difficulty curves, reward schedules, and player agency, sustainability practitioners need to calibrate these gamification functions for their specific context. Too much challenge can frustrate users; too little can bore them. To those gamers like me, you know what I mean. The right mix of competitive and cooperative elements varies by community. And like how games evolve through patches and updates based on player feedback, gamification systems should adapt to user engagement patterns and emerging sustainability needs. Success in both gaming and gamified sustainability requires understanding not just individual mechanics, but how they interplay to create engaging systems that motivate lasting behavior change. A skilled designer, whether crafting virtual worlds or sustainability programs, must orchestrate these elements and maintain sight of the ultimate goal—creating experiences that are both meaningful and enjoyable for their participants.

Looking at specific implementations illustrates these principles in action. Education practitioners should focus on creating progressive challenge systems that maintain engagement while, at the same time, building knowledge systematically. Energy conservation initiatives should stress social features and real-time feedback mechanisms that help users understand their impact. Sustainable consumption programs need clear connections between individual actions and environmental outcomes. Urban sustainability projects require thorough community assessment before designing gamification elements.

The concept's practical value also lies in guiding implementation decisions. Practitioners should first assess their sustainability domain's specific needs, then strategically combine functions to meet these needs. For instance, educational initiatives might emphasize engagement and gameful experience, while community-based projects could prioritize social interaction and motivation. All functions, however, remain important—the key lies in finding the right balance for each context.

Looking ahead, this concept suggests several research directions. We need more studies examining how different function combinations produce varying outcomes across sustainability domains. Understanding these relationships could help develop more targeted interventions. Additionally, research should explore how emerging technologies might enhance specific functions or create new ways for functions to interact. Practitioners can move beyond simple point systems to create more sophisticated and effective sustainability interventions by viewing gamification through this integrative lens. The concept reminds us that successful gamification requires thoughtful orchestration of multiple elements, always in service of concrete sustainability goals.

6. Conclusions

As a wrap up, let's look at the three distinct contributions I made to our understanding of gamification for sustainability in this review. Firstly, I provide a practical concept that explains how different gamification functions work together to drive sustainable outcomes. This concept advances gamification theory by moving beyond simple function lists to show how engagement, motivation, and social interaction dynamically combine to influence behavior. Secondly, I reveal critical patterns in the effectiveness of gamification across different sustainability domains to show that intervention success depends heavily on context-specific implementation. Thirdly, I identify specific research gaps and opportunities, particularly around long-term behavioral impacts and underexplored SDGs, that must be addressed to advance this field further.

My findings have immediate practical implications for organizations implementing gamification for sustainability. I found that successful interventions share three key characteristics: they combine multiple gamification functions rather than relying on single elements, they adapt to local cultural and social contexts, and they incorporate robust measurement systems. Organizations can use these insights to design more effective sustainability initiatives. Businesses working on energy conservation, for example, should emphasize social interaction alongside traditional engagement mechanisms, while educational initiatives benefit most from combining gameful experiences with clear learning objectives.

However, I also discovered important limitations in current approaches. Most studies focus on short-term outcomes, leaving questions about lasting behavioral change unanswered. The field needs more longitudinal research, preferably using mixed methods and standardized metrics, to build a stronger evidence base. Additionally, the concentration of research in certain SDGs—particularly education and energy—leaves critical sustainability challenges underexplored.

Having the intention, I see three promising directions for advancing this field further. Firstly, researchers should investigate how emerging technologies like AI and blockchain can enhance gamification's effectiveness for sustainability. Secondly, we need more sophisticated approaches to measuring long-term impacts, ideally through multi-year studies that combine objective and subjective measures. Finally, the field must expand its focus to address underserved SDGs, particularly those related to poverty, gender equality, and marine ecosystems, among others. As organizations increasingly seek innovative ways to

promote sustainability, these findings deliver for us a roadmap for designing more effective, evidence-based interventions.

Declaration of competing interest

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

Appendix A

Matrix of Related Review Articles

Table 1
Summary matrix of past review articles on gamification and sustainability (2013–2023)

Article	Key findings	Research gaps	Future research directions
Aubert et al. (2019)	•Most game-based approaches fall under "expert-driven sustainability" •Lack of approaches supporting "society-driven" sustainable water governance	•Limited representation of diverse worldviews •Lack of co-design in game-based approaches	•Explore game-based approaches that involve a wide range of stakeholders and worldviews •Investigate user-driven development and co-design of game-based approaches
Latino et al. (2023)	•Identified eight core dimensions of gamification in the agri-food industry •Proposed a new definition of gamification in the agri-food industry	Limited consideration of processes, mechanisms, objectives, and social actors in gamification definitions	•Investigate the application of the proposed definition in other fields •Examine the effectiveness of the identified core dimensions in gamification strategies
Oliveira et al. (2021)	•Identified eight core dimensions for game-based approaches in e-learning for sustainability •Highlighted the importance of user-centricity, challenging mission, and feedback	•Lack of systematic assessment of game-based approaches in e-learning •Need for theories to understand the effectiveness of game-based approaches	•Develop research that enables the measurement of game-based approaches' goals and objectives •Connect assessment to existing theories or develop new theories for game-based approaches
Cruz and Rosado da Cruz (2023)	Highlighted the potential of gamification for sustainability education, inclusion, and social skills development in the textile and clothing industry	•Limited research on the long-term effects of gamification on sustainable behavior change •Need for diverse research methods and theoretical frameworks	•Investigate the long-term impacts and best practices for designing and implementing gamification •Explore gamification applications in other areas of the textile and clothing industry
Douglas and Brauer (2021)	•Categorized games and apps based on target sustainability domains •Discussed psychological mechanisms underlying gamification's effectiveness	•Uncertainty about why certain game-based approaches are more effective than others •Limited research on gamification for sustainable diets	•Examine the balance between fun and informative elements in game-based approaches •Explore the use of apps for collecting behavioral data related to sustainability
Pineda-Martínez et al. (2023)	•Found that gamification, video games, and game-based learning can promote sustainability education, inclusion, and social skills in higher education	•Need for research on the effectiveness of game-based approaches at different educational stages and with diverse groups •Lack of pedagogical approaches and game design principles related to sustainability education	•Investigate the impact of game-based approaches on learning outcomes at different educational •Develop guidelines for educators on implementing game-based approaches for sustainability education

Source: Author's compilation

Data availability

No data was used for the research described in the article.

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