energies

MDPI

Review

How Can We Achieve a Long-Term Effect of Serious Energy Games on the Change in Residential Electricity Demand?

Anton Belinskiy [1,*], Ioannis Lampropoulos [1,*], Hossein Nasrollahi [1], Jan Dirk Fijnheer [2], Remco C. Veltkamp [2] and Wilfried van Sark [1]

[1] Copernicus Institute of Sustainable Development, Utrecht University, Princetonlaan 8a, 3584 CB Utrecht, The Netherlands; h.nasrollahi@uu.nl (H.N.); w.g.j.h.m.vansark@uu.nl (W.v.S.)
[2] Department of Information & Computing Sciences, Utrecht University, Princetonplein 5, 3584 CC Utrecht, The Netherlands; j.d.l.fijnheer@uu.nl (J.D.F.); r.c.veltkamp@uu.nl (R.C.V.)
* Correspondence: a.belinskiy@uu.nl (A.B.); i.lampropoulos@uu.nl (I.L.)

Abstract: As global energy concerns escalate, there is a growing need for effective strategies to promote sustainable energy practices among individuals and communities. Gamification, the integration of game-design elements in non-game contexts, emerges as a promising tool to enhance user engagement and foster sustainable behaviour in energy management. In this review, we examine the theoretical aspects of gamification and its application in energy management in users' households, highlighting its potential to transform repetitive or even monotonous tasks into engaging activities, focusing on studies that measure a long-term effect. We delve into various gamified elements adopted in long-term studies, such as feedback, social interactions, point systems, leader boards, narrative-driven challenges, etc., to understand their effect on user motivation and behavioural changes. From our set of studies, we found out that strong social game elements contribute the most to the long-term behaviour change of energy usage. One more condition of behaviour change is strong positive user satisfaction: the game should be engaging. We highlight the possible limitations of gamification in an energy management situation, a strong need for better practices of design and evaluation, and innovative approaches (such as DSM; Demand Side Management) in gamification for long-term engagement in household energy management.

Keywords: serious game; energy management; behaviour change; engagement; user experience

Citation: Belinskiy, A.; Lampropoulos, I.; Nasrollahi, H.; Fijnheer, J.D.; Veltkamp, R.C.; van Sark, W. How Can We Achieve a Long-Term Effect of Serious Energy Games on the Change in Residential Electricity Demand? *Energies* **2024**, *17*, 5869. https://doi.org/10.3390/en17235869

Academic Editors: Shi-Jie Cao and Wei Feng

Received: 10 April 2024
Revised: 14 October 2024
Accepted: 29 October 2024
Published: 22 November 2024

1. Introduction

Climate change, cost of living, disputes or even wars over resources, and environmental degradation are just some of the pressing issues that society faces today. As global energy concerns (cost, scarcity, distribution, and emissions) [1] escalate, there is a growing need for effective strategies to promote sustainable energy practices among individuals and communities.

Whilst significant technological advancements have been made in renewable energy sources, energy-efficient techniques, weatherproofing, and smart grid systems, the effectiveness of these solutions ultimately depends on the engagement and behaviour of individuals and communities [2].

Energy management games have emerged as a potential tool for promoting long-term engagement in sustainable behaviours [3]. Research on gamification and serious games (games for a purpose other than to entertain) in the domain of energy consumption, conservation, and efficiency suggests that they have the potential to positively influence behaviour and cognition.

1.1. Energy Management Games

Traditionally viewed as a purely entertainment medium, video games have increasingly been recognised [4] for their potential to educate and motivate individuals to make real-world changes. The combination of engaging gameplay, the visualisation of complex concepts, and interactive experiences offered by energy management games has shown promise in driving long-term engagement and behaviour change in the field of energy management. It is also notable that serious games can be utilised to help understand complex topics, such as energy consumption and conservation, in a more accessible and interactive way than conventional methods of research and learning [2].

1.2. Gamification and Society

The practice of incorporating game elements into learning and behavioural change, known as "gamification" [5], has proven to be effective in making complex or dull tasks more engaging and motivating for individuals and/or other stakeholders involved in energy management. Additionally, the shifting societal attitudes towards gaming have created a favourable environment for the adoption of energy management games as an impactful tool [6]. It is important to note that young users from Generation Z (1997–2012) or younger demographics are particularly receptive to gamified educational approaches, along with older members of society (65+) who are open to innovative methods of learning due to the widespread use of digital devices like smartphones, tablets, energy usage apps, and more [7].

In recent years, the intersection of gamification and energy management has emerged as a novel approach to fostering sustainable behaviours within households and communities. Gamification, the application of game-design elements in non-game contexts, has gained substantial traction across various domains, notably in what is known as "serious games" [5]. Its adoption in the realm of energy management is predicated on the assumption that game-like elements can enhance user engagement, motivation, and, ultimately, the effectiveness of energy-saving measures [8].

1.3. Gaps of Knowledge and Lack of Empirical Testing

However, while the initial excitement around using gamification for serious purposes is palpable, there remains a significant gap in understanding its long-term effectiveness, especially in the context of household energy management. Numerous studies have embarked on the journey of integrating co-design methodologies, where users actively participate in the development process of gamification strategies [9]. Yet, these initiatives often face challenges in maintaining participant engagement over extended periods, with high dropout rates being a common issue [10].

Despite the promising evidence underscoring the value and potential of energy management games, it is imperative to acknowledge the significant gap in rigorous empirical testing conducted over extended durations or longitudinal studies [8].

1.4. Drawbacks of Current Projects on Energy Management

A plethora of projects leveraging games for energy management purposes have indeed demonstrated encouraging outcomes; however, an observable trend among these seemingly "successful" studies or projects is their inclination to report positive results over brief time spans, typically shorter than one month. Such studies frequently exhibit susceptibility to seasonal biases—showcasing energy savings in households transitioning from winter to spring, for example—or rely on overly simplistic methodologies for user testing, product validation, or the facilitation of meaningful behavioural change. This underscores a critical need for more comprehensive and methodologically robust research to validate the long-term efficacy and impact of energy management games on consumer behaviour and energy consumption patterns.

Behavioural change by default requires a longitudinal approach as, typically, habits tend to be formed from prolonged, repeated actions, consistency, and adherence to the intervention. Therefore, the aim of this paper will be to form a strong framework for a prospective project that will look at facilitating behavioural change and the usefulness for at-home users in energy management over an extended period of time.

This paper seeks to address these gaps by conducting a literature review of studies, which give data about their time duration and possible game effect with time in household energy management using gamification. The review aims to critically examine the existing body of work, identify the factors contributing to the waning of user engagement in extended studies, and explore strategies that could foster sustained participation and behavioural change.

Before diving into the studies and analysing them, we briefly overview the foundations in the areas constituting our area of interest: energy management and gamification/serious gaming.

1.5. Energy Management

Energy management at home is an essential aspect of promoting sustainable behaviours and reducing energy consumption. The problem is there are many ways in which energy can be wasted or used inefficiently, such as leaving lights on when not in use, using outdated, less energy-efficient appliances, or having poor house insulation [2]. Therefore, it is crucial to educate and empower individuals to adopt energy-saving habits and make informed choices regarding their energy usage [11].

An emerging approach has been to focus on community building via being part of energy communities, where individuals collectively work towards sustainable energy practices and share resources and knowledge [12]. This approach is currently being taken by projects such as community energy cooperatives, where members collaborate to generate and manage their own renewable energy. These initiatives rely on active participation and engagement from individuals, making it an ideal context for implementing gamification strategies to encourage long-term engagement and behavioural change.

This aspect of collaboration is echoed strongly by, e.g., Fijnheer et al. [13], who emphasise the importance of social interaction and cooperation in driving sustainable behaviours, especially with the addition of cooperation and collaboration as features in gamified energy management tools.

1.6. Concept of Gamification

1.6.1. Gamification and Behaviour

Gamification refers to the application of game-design elements and game principles in non-game contexts. This approach aims to enhance user engagement, organisational productivity, learning, and problem-solving, among other areas. A key concept in gamification is the creation of an environment that fosters "flow", a term coined by Csikszentmihalyi and Csikszentmihalyi [14]. Flow describes a state of complete immersion and focus on an activity, characterised by a balance between the challenge presented and the individual's skill level, leading to a heightened sense of fulfilment and motivation [14]. Deterding et al. [5] further elaborate on this by emphasising the importance of using game design elements strategically to create engaging and effective gamified systems. Hamari et al. [4] investigate the impact of gamification through a comprehensive review, demonstrating its potential to positively influence user behaviour and attitudes in various contexts.

1.6.2. Need for Gamification in Energy Management

Users may be intrinsically motivated to change their behaviour, particularly if it can lead to savings on energy bills or align with their desire for sustainability. However, historical tips like "using the washing machine at night" and "turning down the thermostat" may not always be suitable for modern usage. It is essential to explain concepts like demand-side management (DSM) and peak shaving, which are less familiar compared to traditional advice such as "turning off lights when not in use." Gamification can play a vital role in energy management by providing a compelling and engaging platform for individuals to learn about energy-saving techniques and actively participate in sustainable practices [15].

Gamification can provide the necessary motivation and engagement to overcome these challenges and encourage sustained participation in energy management [16,17]. By incorporating game elements such as goals, challenges, rewards, and feedback, gamification can make the process of learning about energy-saving techniques more enjoyable and interactive [15]. Furthermore, gamification can create a sense of competition and social interaction, allowing users to compare their energy-saving achievements with others and foster a sense of community and collaboration [17].

1.6.3. Engagement in Long-Term Studies: Challenges and the Role of Gamification

The integration of gamification strategies into long-term energy management studies within households and communities has been shown to enhance user engagement and participation [18]. This trend reflects a broader adoption of gamification across various sectors, particularly in the realm of serious games, where the engagement of participants is critical for the success and validity of the studies.

In recent years, there has been a marked increase in the application of gamification strategies to encourage sustainable energy practices. For instance, Fijnheer et al. [19] highlight how gamification can transform mundane energy-saving tasks into engaging and rewarding experiences, fostering long-term behavioural changes in households. Similarly, Xu et al. [20] demonstrate how community-level gamification initiatives can significantly enhance participation in energy-saving programmes, suggesting the scalability of such approaches. These findings support the idea that gamification can be an effective tool for promoting long-term engagement in energy management [8].

However, maintaining participant engagement in long-term studies presents significant challenges. A common issue, as noted by Nasrollahi et al. [21], is the high dropout rate among participants as well as external biases (seasonal bias, short-term results). While initial interest in gamified approaches is typically high, sustaining this engagement over extended periods proves difficult. Factors contributing to dropout rates include a lack of immediate rewards, the diminishing novelty of the gamification elements, and a potential mismatch between the game design and the participants' interests or motivations.

1.6.4. Behavioural Change

Behavioural change science, which focuses on modifying specific behaviours [22–24], involves practices, theories, and foundational knowledge related to persuasion and behavioural change. Behavioural science aims to understand and facilitate changes in targeted behaviours. Theories such as the Theory of Planned Behaviour [25], Self-Determination Theory (SDT) [26], and Octalysis [27] are frequently used to guide the design of gameful interventions. For a plethora reasons, game developers prefer SDT [28].

SDT is often favoured by game designers as it provides a framework for fostering intrinsic motivation by fulfilling players' psychological needs for autonomy, competence, and relatedness. Games designed with SDT principles tend to promote deeper engagement, sustain long-term player retention, and enhance user experience. By reducing reliance on extrinsic rewards and emphasising player choice, skill development, and social interaction, SDT-based designs lead to more meaningful and sustained behavioural changes, making it particularly valuable for serious games focused on education or behaviour modification.

Various theories explain the factors influencing an individual's ability to achieve sustained positive behavioural change, highlighting internal and external elements crucial for behavioural change. These theories should inform the design of gamification and serious games.

For successful behavioural change, intervention design theory suggests that individuals must have the capability, opportunity, and motivation to perform the desired behaviour [24]. Capability involves having the necessary knowledge and skills, motivation includes emotional responses and decision-making processes, and opportunity refers to external factors that facilitate or inhibit the behaviour.

According to behaviour change specialists, e.g., Michie et al. [29], behaviours can be influenced and driven by nine core intervention functions: modelling, environmental restructuring, training, education, enablement, persuasion, restriction, coercion, and incentivisation.

There are Behaviour Change Techniques which are linked to the functions above. They constitute theory-based methods for modifying psychological determinants of behaviour and are considered the 'active ingredients' of behaviour change interventions [29]. Examples include goal setting, feedback, task completion, etc. They are often used as game elements by game developers.

1.6.5. Gamification, Serious Games, and Change of Behaviour

Gamification can transform mundane tasks into engaging activities, thereby increasing user participation and motivation. Serious games are a subset of gamification designed with an educational or training objective in mind. These games are not just for entertainment; they aim to impart knowledge, change behaviours, or improve skills on serious topics like health, education, and in this case, sustainability.

Instrumental play offers a promising approach to engage users in learning about sustainability and energy saving in a fun and interactive way. By applying gamification principles to serious games that utilise smart meter data, we can create educational tools that are not only effective, but also enjoyable. This approach can lead to increased awareness, engagement, and, ultimately, a change in behaviour towards more sustainable living practices. However, success in this endeavour requires careful consideration of game design, user experience, data ethics, and impact measurements.

1.7. Objective of the Review

The main objective of this review is twofold: (i) to identify successful strategies or approaches to keeping users engaged over long-term studies, and (ii) to identify game elements that change users' behavioural pattern of energy consumption. By the process of the comparison and selection of influential games' elements, we can also see what other studies lacked in terms of a game structure or design in order to keep the participants engaged and to change their future consumption pattern.

2. Materials and Methods

Inspired by two review papers [8,30] in the area of empirical evidence on the effect of gamification on positive user experience and motivation [30] with respect to sustainable energy usage [8], we decided to evaluate and analyse the current studies generally in line with their approaches.

We analyse studies that measure in-game and after-game effects on electricity consumption and behavioural patterns with respect to energy saving. Of particular interest are those studies that also involve before-game measurements, focusing on game elements and study outcomes.

Our main question is what are the game elements that make people change their consumption behaviour and which elements might make them change it in the long term? Therefore, we are focused on game elements and study outcomes.

2.1. Data/Study Collection

In selecting and filtering the studies for our review, we followed the updated guidelines of PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) [31]. All authors were involved in approving our resulting selection method.

In the context of our review, we generalised the term 'energy games' to both gamified applications and serious games themselves, as we did in our recent work [21]. Energy consumption was considered from both energy usage and efficiency points of view.

The inclusion criteria for the studies selected were as follows:

1. Peer-reviewed (including conference papers).
2. Full papers (including full conference papers).
3. Explicitly described gamification or game elements.
4. Explicitly described outcomes relating to household energy consumption behaviour, including those related to energy use, efficiency, and reduction.
5. Empirical research.
6. Explained research methods.
7. Publication date from 2005 to 2024.
8. Written in the English language.

Databases:

The databases searched were those identified as relevant to information technology, social science, interaction design, psychology, and environmental science: EBSCOhost (all databases), ProQuest, ACM (Association for Computing Machinery), IEEE Xplore, Web of Science, Scopus, ScienceDirect, BioMed Central, Cambridge Journals Online, and Elsevier.

Search terms used.

- Serious games.
- Gamification.
- Electricity consumption.
- Environmental behaviours.

Search terms included terms for gamification and serious games, together with possible terms for long-term energy-related outcomes: (gamif* OR gameful OR "serious game*" OR "digital game" OR "electronic game*" OR "videogame" OR "video game").

In order to select all relevant studies due to long-term energy-related outcomes criteria, search terms were added to represent the variety of terms used to describe energy-related concepts: (AND "energy consumption" OR "energy reduction" OR "energy conservation" OR "energy monitor*" OR "electricity consumption" OR "electricity reduction" OR "electricity conservation" OR "electricity monitor*" OR "energy efficiency" OR "energy use" OR "energy saving*" OR "energy-saving" OR "energy behavior*" OR "energy behaviour*" OR "energy meter*" OR "smart-meter" OR "sustainable interaction design" OR "energy awareness" OR "energy engagement" OR "personal emissions" OR "user household" OR "household" OR "carbon-saving" OR "ecological footprint" OR "carbon emissions" OR "eco-visual*" OR "eco-feedback technology" OR "climate change "OR "Long term behavioral change" OR "Long term behavioural change").

2.2. Data Analysis

2.2.1. Categorisation of Game/Application Elements

The selected primary studies that measured the outcomes utilised a variety of game elements that were applied in different ways. The elements included feedback, social sharing, other social interactions (competition, collaboration), challenges, rewards, leaderboards, points, tips, levels, rankings, avatars, badges, and user-generated content.

2.2.2. Categorisation of Studies' Outcomes

The outcomes measured and observed by the studies included in the review are grouped into four categories, as inspired by Connolly et al. [30] and Johnson et al. [8]. These outcomes include behavioural outcomes, cognitive outcomes, learning and knowledge, and user experience (UX) outcomes. Some studies provided exact energy consumption numbers and comparisons.

Behavioural Outcomes: This encompasses both actual and projected actions external to the digital game or application, referred to as real-world or long-term behaviours (Behaviour LT), and actions related to energy undertaken by participants within the context of the game, denoted as in-game behaviours (short-term behaviour, Behaviour ST). The variety of behaviours assessed across studies mirrors the extensive scope encompassing energy consumption and efficiency. Outcomes in the real world involve both reported and actual energy use over varying terms, activities aimed at saving energy (self-reported), and the intention to adopt energy-conservative measures. Within the game, outcomes are characterised by the recognition and choice of measures to save energy and the players' objectives concerning energy efficiency goals.

Cognitive outcomes: These are associated with affective and motivational elements, comprising attitudes towards energy, the drive to adopt environmentally friendly practices, the self-recognition of energy preservation, and a predisposition towards energy conservation. It also includes awareness about energy conservation behaviour. Research indicates a pronounced correlation between specific cognitive outcomes, like attitudes, and the practice of saving energy [32].

Learning and knowledge: These entail the effectiveness of learning, pinpointing particular actions to save energy, advancements in knowledge, heightened awareness regarding environmental and energy issues, the acquisition of detailed knowledge about electronic devices, an improvement in conceptual learning and progression, and an increase in understanding related to energy usage.

User Experience: This term is indicative of the participants' perceptions and interactions with the game, covering aspects of satisfaction and the practicality of the game. The review's approach to user experience is comprehensive, incorporating subjective evaluations of the intervention, such as the ease of navigation and enjoyment, along with more tangible metrics related to the frequency of engagement with the game.

2.2.3. Studies Outcome Reporting and Analysis

Among the studies, we focused on those that measured behaviour changes during gaming (Behaviour ST) and long-term behaviour changes (Behaviour LT or behaviour in real life). We looked for studies with a summary of the overall results (both statistically significant and non-significant) with in-game and post-intervention effects provided.

3. Results

3.1. Results of Selection of Studies

Table 1 presents the aggregate count of scholarly articles retrieved from each database utilising our predetermined search terms. Moreover, it delineates the quantity of these articles deemed pertinent following an evaluative selection process.

Table 1. The total papers found in each database and the number chosen as relevant.

Database	Number of Papers Identified in the Search	Number of Papers Meeting Inclusion Criteria
ACM	39,385 (284 with data available/in households)	5 (3 later excluded—no reporting on Game Elements/Effects) = 2
Scopus	127	0
Manual Search	40	9 (4 excluded—lack of methodology/data) = 5
Science Direct	300	5 (3 excluded—lack of methodology/data) = 2
ISAGA Journal (Simulation and Gaming)	46	3 (1 excluded—lack of methodology/data) = 2
Elsevier	417	13 (9 excluded) = 4
Total	1087	30 (15)

3.2. Quality Evaluation/Assessment Results: Design, Methods, Generalisability, and Representativeness—Inter-Rater's Agreement of Evaluators

Four independent reviewers (two experts on gaming and two on energy studies) performed a quality evaluation of the 21 primary studies included in our paper, see summary Table 2. We developed a coding matrix based on their answers to check for the accuracy and consistency of the assessment. This process helps in establishing inter-rated reliability. Inter-rater reliability refers to the extent to which two or more individuals agree [33,34], which was found to be high and is expressed using Cohen's kappa [35]: $\kappa = 0.78$. It showed a sufficiently good level of agreement between reviewers with respect to the quality and relevance of the studies. Therefore, though this evaluation was still slightly subjective, we conclude that independent specialists in the field agreed on it.

Table 2. Game elements and game effects for the games with measurement of a long-term and short-term behavioural change of electricity consumption. + is positive effect, − is negative effect, 0 is no effect, NM is non-measured effect, FB is Feedback. We highlighted with green the positive long-term effect/outcome and with red, the absence of LT effect in energy reduction or behavioural change. TTM is Trans Theoretical Model.

Game and Reference	Game Elements	Game Effects
Ghost hunter [36]	FB + Tips − Points − Rewards − Challenge − Social element −	Behave LT − Behave ST + Knowledge − Cognitive + UX +
Visible Energy Trial [37]	FB + Tips − Points − Rewards − Challenge − Social element −	Behave LT − Behave ST + Knowledge + Cognitive NM UX NM
Social Power app [38]	FB + Tips − Points + Rewards + Challenge −	Behave LT + Consume LT − Behave ST + Knowledge + Cognitive +

	Social (competition, collaboration, anonymous) +	UX NM
Bellidea app [39]	FB + Tips + Points + Rewards + Challenge − TTM + Poor social dimension −	Consume LT − Behave ST + Knowledge NM Cognitive NM UX NM
EnergyLife [40]	FB + Tips + Challenge + Rewards − Social element (sharing) +	Behave LT + Behave ST + Knowledge + Cognitive + UX +
Energy Battle [41]	FB + Tips + Rewards + Challenge − Ranking (Social element) +	Behave LT + Behave ST + Knowledge NM − Cognitive (motivation) + UX +
PowerAgent [42]	FB + Tips − Avatar + Rewards + Challenge − Social element −	Behave LT − Behave ST + Knowledge + Cognitive (+/−) UX +
PowerExplorer [43]	FB + Tips + Rewards + Challenge − Social element −	Behave LT − Behave ST + Knowledge + Cognitive + UX +
MAID (Motion-based Ambient Interactive Display) [44]	FB + Tips − Rewards − Challenge − Social element (sharing) +	Behave LT + Behave ST + Knowledge NM Cognitive (motivation) + UX +
Do it in the darkness [45]	FB + Points + Rewards + Challenge + Ranking (Social element) + Social sharing +	Behave LT + Behave ST + Knowledge NM Cognitive (motivation) + UX +
eViz [46]	FB + Tips − Rewards − Challenge + Social element −	Behave LT − Behave ST + Knowledge NM Cognitive (awareness) + UX +
The Energy Challenge [47]	FB + Tips − Rewards + Challenge −	Behave LT + Behave ST + Knowledge NM Cognitive (motivation) +

	Leaderboard (Social element) +	UX +
EcoIsland [48,49]	FB + Tips − Rewards + Avatar + Challenge − Social element −	Behave LT − Behave ST− Knowledge 0 Cognitive (+/−) UX +
Power House [50,51]	FB + Tips − Rewards + Challenge + Leaderboard (Social element) + Social sharing +	Behave LT + Behave ST + Knowledge − Cognitive (motivation) + UX +
Green My Place [52]	FB + Tips − Points + Rewards + Challenge + Social elements +	Behave LT + Behave ST + Knowledge + Cognitive − UX +
Eco [53]	FB + Tips − Points − Rewards − Challenge + Social elements +	Behave LT + Behave ST − Knowledge + Cognitive + UX +
Energy Cat [54]	FB + Tips − Points − Rewards − Challenge + Social elements +	Behave LT + Behave ST + Knowledge − Cognitive + UX +
Watt Family, Temperature Defender, Power Raid, Fully Loaded [55]	FB + Tips − Points − Rewards − Challenge + Social elements −	Behave LT + Behave ST + Knowledge − Cognitive + UX +
Power School [56]	FB + Tips − Points + Rewards + Challenge + Social elements −	Behave LT − Behave ST + Knowledge − Cognitive + UX +
Playful Cyber–Physical System [57]	FB + Tips − Points − Rewards − Challenge + Social elements −	Behave LT − Behave ST + Knowledge − Cognitive + UX +
Cool Choices [11]	FB − Tips +	Behave LT + Behave ST +

	Points – Rewards – Challenge + Social elements +	Knowledge – Cognitive + UX +
2020 Energy [58]	FB + Tips – Points – Rewards – Challenge + Social elements –	Behave LT – Behave ST + Knowledge + Cognitive + UX +

To analyse the quality of each study, we computed the sum of the quality scores across the first four of them (design, analysis, generalisability, and evidence support) for each study, obtaining the mean values between our (generally agreed) evaluators. We denoted this as a combined quality of a study. The ranges of the combined quality across the studies are from 5 to 11, with quality = 8.5 being a median. We stated that a study is of high quality if its combined quality was more than 8.5.

Then, we analysed the quality of each of the four features. Interestingly, the most highly evaluated was the quality of the supporting evidence: around 80% of the studies had excellent evidence support. Thus, we can generally trust them. The most poorly evaluated feature was the generalisability of studies: there were no highly generalisable studies at all, 52% were poorly generalisable, and 48% were of medium generalisability. Only 19% of the studies had a high-quality appropriate design (RCT or quasi-experimental), 71% had a medium-quality design, and only 10% had a poor design. A little more balanced is the analysis/methods: the majority of studies (85%) had high- and medium-quality analyses, equally divided.

As a recommendation for future developers, we recommend paying extra attention to the appropriate design of their study and to its generalisability: a good sample size and fair representativeness across the population of users.

Furthermore, the quality of the studies included in this review was assessed based on four key criteria: design, analysis, generalisability, and supporting evidence. As shown in Figure 1, the quality of the studies varied significantly across different evaluators, with a range of quality scores from 5 to 11. The highest agreement was observed in the evaluation of supporting evidence, whereas the lowest agreement was seen in the generalisability of the studies. The computed Kendall's W [59] of concordance for the four evaluators was significant, indicating an acceptable level of agreement (W = 0.85, $p < 0.05$). This underscores the importance of a rigorous study design and broader representativeness in future gamification research.

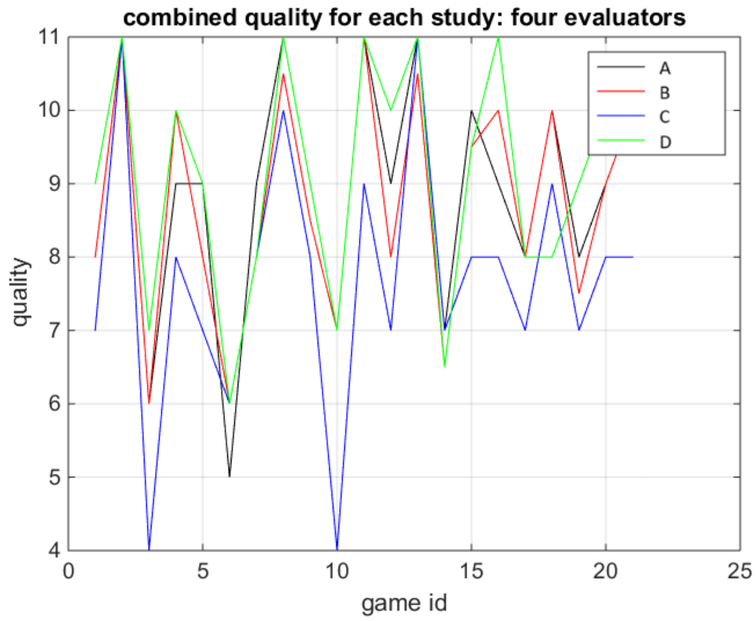

Figure 1. Combined quality ratings for each study evaluated by four independent reviewers. The y-axis represents the quality score, with a maximum possible score of 11. The x-axis represents individual game IDs (n = 21). Variability across different evaluators is displayed, illustrating the spread of quality ratings. This visual representation underscores the need for consistent design and methodological rigour across studies to ensure generalisability and reproducibility of findings.

3.3. Support and Implementation of Behavioural Change Theories into Studies' Design

Many of the authors of our studies use behavioural change theories to support their game design. These theories provide a foundation for understanding how game elements can influence behaviour, motivation, and engagement in the context of sustainability and environmental education.

Most studies incorporate well-established behavioural change theories such as SDT [26], Social Cognitive Theory (SCT) [60], TPB [25], Capability, Opportunity, a Motivation-Behaviour (COM-B) model [24,61], a Fogg Behaviour Model (FBM) [62], and others to underpin their game design. These theories have helped to shape game mechanics and elements to effectively influence user behaviour and promote sustainability. The integration of these theories ensures that the games are not only engaging, but also scientifically grounded in behaviour change principles.

Below is an overview of the behavioural change theories mentioned in several studies.

Cowley and Bateman [52] utilise SDT and Social Learning Theory (SLT) [60] in the Green My Place game. These theories are used to design game elements that promote intrinsic motivation (e.g., autonomy, competence, and relatedness) and encourage behaviour modelling and social learning through feedback and social comparison. The game uses challenges, social elements, and feedback mechanisms to enhance participants' environmental awareness and motivation for sustainable behaviours.

Hafner et al. [54] utilise SCT and TPB in the Energy Cat game. SCT focuses on observational learning, social influence, and self-efficacy, while TPB emphasises the role of attitudes, subjective norms, and perceived behavioural control in predicting behaviour. The game is designed to incorporate social influence, peer pressure, and social comparison to drive behavioural change, leveraging the social elements highlighted in SCT and TPB.

Mulcahy et al. [55], in their design of gamified apps for sustainable behaviour, draw on SDT and the Behaviour Change Wheel (BCW) [24], particularly the COM-B model. SDT is used to encourage intrinsic motivation, while COM-B is employed to identify behavioural determinants and tailor game mechanics. The game design includes feedback, rewards, and user engagement strategies that enhance the users' capability, opportunity, and motivation to change their behaviour.

Ouariachi et al. [58] apply the Elaboration Likelihood Model (ELM) [63] and Constructivist Learning Theory (CLT) [64] to support cognitive engagement and knowledge consolidation in their 2020 Energy game. These theories suggest that deeper processing and engagement with the content lead to more enduring attitude changes. Game elements such as the narrative, interactive challenges, and feedback are used to encourage the deep processing and learning of environmental concepts. This notion is echoed by Burke in his exploration of trends and strategies in the field of Gamification [65].

The Cool Choices game by Ro et al. [11] is based on FBM and Nudge Theory. FBM combines elements of motivation, ability, and triggers to drive behavioural change, while Nudge Theory focuses on subtle changes in the environment that can "nudge" people toward desired behaviours. The game uses simple prompts, cues, and rewards to lower barriers to sustainable behaviour and provide continuous motivation and feedback.

Kiatruangkrai et al. [56] developed Power School and they employ Social Influence Theory and Goal-Setting Theory. Social Influence Theory is used to emphasise peer influence and social norms, while Goal-Setting Theory focuses on the effectiveness of setting clear, achievable goals to motivate behavioural change. The game design includes points, levels, leaderboards, and group-based challenges to leverage social influence and goal setting to promote energy-saving behaviours.

Lu [57] utilises SDT and Contextual Behavioural Science (CBS) in their Playful Cyber-Physical System, focusing on how context-aware systems can influence motivation and behaviour by providing real-time feedback and adaptive challenges. The Internet of Things (IoT)-enabled system uses adaptive feedback, context-aware prompts, and challenges to enhance user engagement and motivation, tailoring interventions to individual user contexts.

The Energy Piggy Bank serious game by Hedin et al. [66] is built on the COM-B model SDT. COM-B is used to identify factors that need to change for behaviour change to occur, and SDT is used to design game elements that foster intrinsic motivation. The game incorporates behaviour change techniques such as monitoring, feedback, social comparison, and prompts to encourage energy-saving behaviours through different player types (Bartle's Player Types) [67].

In the study on the Ghost Hunter game, Banerjee and Horn [36] do not explicitly mention well-established behaviour change theories like SCT or TPB; it leverages the concept of cultural forms and the idea of learning through play. The game's design encourages both parental involvement and intergenerational learning, aligning with theories that emphasise social learning and family dynamics in behavioural change.

Cellina et al. [39] incorporate Persuasive Technology principles and Social Norms Theory in their Bellidea app. It is based on the premise that interventions that leverage social influence can lead to sustainable behaviour changes. The study includes both eco-feedback and gamified elements to motivate users to reduce energy consumption over an extended period. The design aligns with Social Norms Theory and Persuasive Technology, which emphasise the role of social influence and feedback in shaping behaviour.

The study by Gustafsson et al. [42] employs SLT and Situated Learning as foundational theories. Their game PowerAgent is designed to encourage energy-efficient behaviours by combining cognitive and behavioural learning principles. The game allows players to first learn about energy-saving behaviours symbolically through a platform game and then enact these behaviours in real-world settings, promoting behaviour changes through observational learning and reinforcement.

The study on PowerExplore*r* by Gustafsson et al. [43] discusses the use of Self-Perception Theory, Cognitive Dissonance Theory, and Classical Conditioning. The game aims to encourage long-term behaviour changes by providing instant feedback on energy consumption through a real-time sensor system. This feedback helps players associate their actions directly with energy use, supporting associative learning.

The study on the eViz game [46,68] utilises concepts from psychology, such as the importance of making the invisible (energy use) visible, to trigger attention and facilitate memory, emotions, and goals related to energy conservation. The use of thermal imaging is a specific visualisation tool grounded in psychological theories about attention and behaviour change, such as vividness and emotional engagement.

3.4. Game Elements and Game Outcomes/Effects

3.4.1. Game Elements Analysis

The most effective game elements across the studies are Social Elements, Feedback Incorporation, Points/Rewards, and Challenges. These elements work best when combined to cater to different player types and motivational factors, ensuring both engagement and sustained behaviour changes. Games that integrate these elements thoughtfully are more likely to succeed in promoting sustainable behaviour and achieving their educational or behavioural objectives. Moreover, these elements appeal to both intrinsic and extrinsic motivation [26,69], catering to different player types, which makes them versatile tools for game designers seeking to foster pro-environmental behaviours and educational outcomes.

Effectiveness of Specific Game Design Elements Across Studies

Several studies illustrate how game elements can influence behaviour changes in both short-term and long-term contexts. For instance, some elements are effective in the short-term but lose their impact over time, while others show potential for fostering enduring change.

In the study by Odom et al. [47] on the EnergyAware game, typical game design elements such as points, levels, or leaderboards are absent. Instead, eco-visualisations are used as interactive tools that provide immediate, dynamic feedback. These visual feedback mechanisms make energy consumption visible and easily understood, helping to engage users and raise awareness. However, the study suggests that, while effective at promoting short-term behaviour changes, visual feedback alone may not sustain long-term engagement. Without additional motivational elements such as challenges or social comparisons, the long-term impact of such feedback is limited.

Similarly, Hargreaves et al. [37] in the Visible Energy Trial employ real-time feedback, a gamified feature that provides users with immediate responses to their energy usage. While real-time feedback initially raises awareness and encourages short-term changes, its effectiveness diminishes over time as users become accustomed to the information (practice/familiarity) and the monitors fade into the background. This highlights the need for additional motivational features, such as goal setting or progress tracking, to sustain long-term engagement.

In contrast, Wemyss et al. [38] demonstrate the long-term impact of game elements such as social comparison and challenges in their Social Power app study. In this intervention, social comparison was achieved through neighbourhood challenges, while gamification elements like points, leaderboards, levels, and challenges were integrated into a mobile app. The study found that while reward-based elements like points were effective in generating initial engagement, their impact faded over time. Non-reward elements—such as detailed feedback, social sharing, and informed choice—proved more successful in maintaining long-term behavioural change. This combination of reward-based and non-reward elements created a more sustainable form of engagement, though the challenge remained in keeping the game elements fresh and compelling.

In the Power House study, Reeves et al. [50,51] utilised social comparison and feedback systems, designed to allow users to see their energy consumption compared to their neighbours. The study found that these elements motivated users to reduce their energy usage, illustrating the effectiveness of combining social comparison with progress tracking. However, it was also noted that long-term sustainability requires a broader combination of elements, including personalised goals, feedback, and social interaction, to maintain engagement over time.

Similarly, Senbel et al. [45] in the Do it in the darkness game compared various motivational strategies, such as goal setting, real-time feedback, and social comparison. Social comparison proved particularly effective in maintaining engagement and motivating energy-saving behaviours. Goal setting was also beneficial, especially when paired with progress-tracking feedback. However, the study noted that the effectiveness of these elements depended on their continued relevance and personalisation.

In the Bellidea app [39], an app-based study on household electricity use, gamification elements such as badges, levels, points, and challenges were integrated into a mobile app. Social elements were also utilised through community-wide challenges and progress tracking. The initial impact of these game elements was strong, leading to significant reductions in energy use. However, as with many gamified interventions, the effectiveness declined over time as the novelty of the game wore off. The study highlighted the importance of adaptive features, such as context-specific information and continuously evolving challenges, to sustain long-term engagement.

Insights from Specific Game Elements

Several key game elements were identified as particularly effective or needing improvement across the reviewed studies:

1. Social Elements
   Social elements, such as peer comparison, collaboration, and competition, are among the most powerful tools for promoting behavioural change. Studies such as Hafner et al. [54] and Cowley and Bateman [52] illustrate the effectiveness of social elements in leveraging peer influence, social norms, and collective action to drive sustained behavioural change. These elements tap into intrinsic motivation by fostering a sense of belonging and social accountability, making them especially effective in long-term engagement strategies.
2. Feedback Incorporation
   Feedback was consistently rated as a highly effective game element across multiple studies. It provides users with real-time information on their performance, allowing them to track their progress and adjust their behaviour accordingly. For example, Hafner et al. [54] and Lu [57] demonstrated the effectiveness of personalised and context-aware feedback in maintaining long-term behavioural change. Feedback that is immediate, actionable, and tailored to the user's context tends to be the most effective in sustaining engagement over time.
3. Points and Rewards
   Points and rewards are widely used as motivational tools, offering immediate gratification and encouraging short-term behaviour changes. In studies such as Ro et al. [11] and Hedin et al. [66] points and rewards were effective in engaging participants, particularly those who are driven by competition. However, their impact tends to diminish over time as users become accustomed to the rewards. For long-term behaviour changes, points and rewards need to be supplemented by intrinsic motivators, such as meaningful feedback or social elements.
4. Challenges
   Challenges were found to be highly effective in promoting sustained engagement, especially when they were well-calibrated to the user's abilities. Studies, such as by Cowley and Bateman [52] and Ouariachi et al. [58], show that challenges encourage users to push beyond their comfort zones, promoting deeper cognitive engagement

and fostering a sense of accomplishment. The balance between difficulty and achievability is key; challenges should require effort but remain within the user's reach, following the principles of Flow Theory.

In summary, the reviewed studies highlight the importance of selecting and combining game elements thoughtfully to foster both short-term and long-term behavioural change. Elements such as feedback, points and rewards, challenges, and social dynamics are highly effective when used in conjunction with one another. The distribution of strongly implemented game elements in our data set are shown in Figure 2.

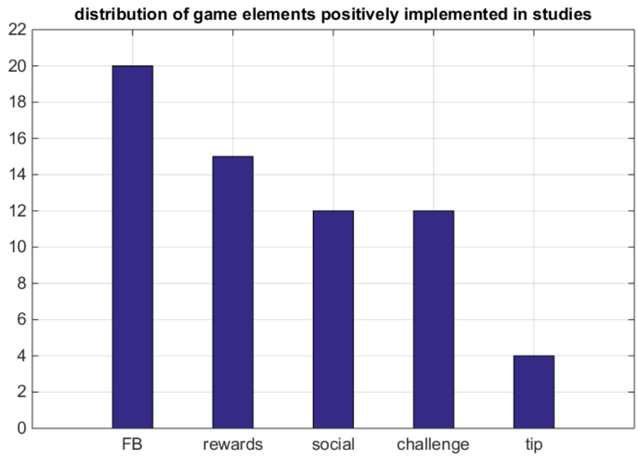

Figure 2. Distribution of strongly implemented game elements in our data set.

However, while extrinsic motivators like points and rewards may drive initial engagement, they often need to be complemented by deeper, intrinsic elements such as personalised feedback and social engagement to maintain their long-term impact.

Future game designs should focus on integrating adaptive, context-aware features to keep the game experience fresh and engaging over time.

3.4.2. Game Effects

Together with ST and LT effects, many of the selected games measured UX (user experience) and cognitive and knowledge effects to see the distribution of positively measured game effects, as shown in Figure 3. The cognitive and knowledge effects (when measured) were mainly increased, except for controversial evidence [49]. However, $n = 1$ is too small a number to analyse the possible reasons.

More interesting is the absence of UX measurements for three other studies [37–39]. Two of them are very well documented quasi-experimental studies with good sample sizes and control groups, which used mobile apps for energy-saving purposes. They all reported no LT effect on the energy consumption pattern. Could it be that a weakened attention to the users' enjoyment and flow is a reason for the low effect? Another reason could be a waning of users because of very frequent reminders—the user experience started decreasing. Again, $n = 3$ is not enough for a sound conclusion.

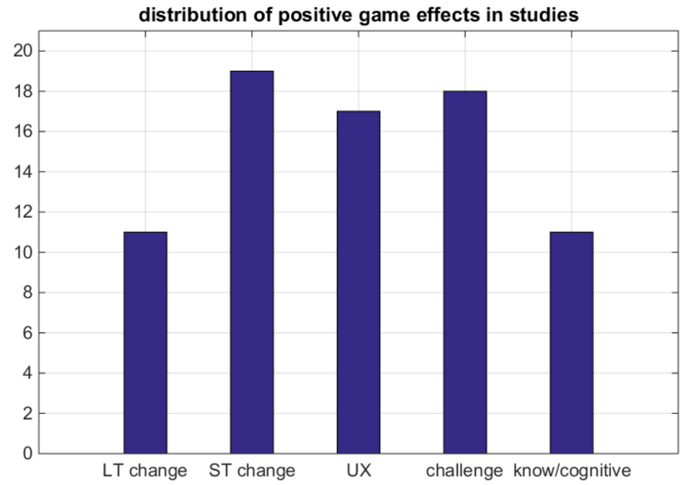

Figure 3. The most frequent positive game effects within the selected games (which measured LT effect).

The 21 selected studies are summarised with respect to their elements and outcomes in Table 2. We highlighted with green the positive strong long-term (LT) effect/outcome and with red, the poor or absent LT effect in energy reduction or behavioural change. We also highlighted the social dimension of game elements in green when any social element was employed and with red when it was poor or lacking. In this way, one can see that the colour in the column of game elements mainly corresponds to the colour in the game effect column.

One should distinguish between the non-measured effect (NM) and the poor or negative effect (−) in the column of game effects. In the column of game elements, (−) denotes a poor/absence of a particular element, however.

3.5. Association of Strong Social Game Elements and Long-Term Behavioural Change

Across the studies reviewed, social elements emerge as a key factor in fostering long-term behavioural change, particularly in the context of energy conservation. Games with strong social components consistently show positive outcomes in sustaining behaviour changes over time. The association between social elements and long-term behavioural change is evident, as these elements engage players in ways that tap into fundamental human motivations such as belonging, accountability, and social influence.

3.5.1. Why Social Elements Lead to Long-Term Behavioural Change?

There are several underlying mechanisms that explain why social elements are particularly effective in promoting sustained behavioural changes:

1. Social Norms and Peer Influence
   Social elements work by establishing and reinforcing new social norms. When individuals observe others engaging in pro-environmental behaviours, they are more likely to adopt these behaviours themselves, either to fit in or to gain approval from the group. This process leverages the powerful motivator of social conformity, leading to the internalisation of new habits that can persist over time.
2. Sense of Belonging and Community
   Games that incorporate team-based challenges or collaborative elements foster a sense of belonging to a community. This connection reinforces behaviour changes as individuals are more likely to maintain behaviours that align with their group identity. When participants feel that their efforts contribute to a shared goal, the behaviour becomes a part of their social identity, making it more sustainable.
3. Social Accountability and Reinforcement
   Social elements like leader boards, team scores, and collaborative tasks introduce a sense of accountability. Participants are motivated to maintain their behaviours not

just for personal reasons, but to avoid letting down their team or to achieve collective goals. This dynamic encourages sustained engagement, as individuals feel responsible not only for their own performance, but also for the success of the group.

4. Intrinsic Motivation and Relatedness
According to Self-Determination Theory, social elements enhance intrinsic motivation by satisfying the psychological need for relatedness. When individuals feel connected to others and perceive their actions as meaningful within a social context, they are more likely to continue engaging in those actions. This sense of relatedness fosters deeper engagement and contributes to longer-lasting behaviour changes.

The relationship between social elements and long-term behaviour change is supported by evidence from multiple studies.

Hafner et al. [54] describe that social influence, peer pressure, and social comparison were key drivers of behaviour changes in their Energy Cat game. The study found that when users observed others engaging in energy-saving behaviours, they were more likely to adopt these behaviours themselves. This reflects Social Cognitive Theory, which posits that people learn by observing and imitating others within their social environment. The study demonstrated that these social elements were effective in creating lasting changes by normalising sustainable behaviours within the group.

Cowley and Bateman [52] used team-based challenges and leader boards in the Green My Place game to create a sense of community and collective effort. The study reported that participants who engaged more deeply with the social elements were more likely to sustain their behaviour changes over time. This aligns with SDT, where the need for relatedness is a key factor in maintaining intrinsic motivation. The shared goals and sense of belonging fostered by the game reinforced positive behaviours, making them more sustainable in the long term.

Hedin et al. [66] incorporated social comparison and team contributions to motivate users. Participants in the Energy Piggy Bank game performed energy-saving actions to earn points for their team, which enhanced both individual and collective motivation. The study found that social elements were particularly effective in maintaining engagement for "Socializers," who are motivated by social connections. By combining social comparison with rewards and feedback, the study demonstrated that social elements help reinforce habits and encourage continuous participation, particularly in group settings where collective outcomes depend on individual actions.

In the Cool Choices game, Ro et al. [11] used a mix of competition and collaboration to encourage sustainable behaviours. Players worked both individually and as part of a team, creating a dynamic where social interactions played a critical role in maintaining behavioural change. The combination of social influence with game mechanics like rewards helped sustain behaviour changes by fostering a culture of sustainability within the group.

Finally, we looked into the integration of Social Elements and Behaviour Change Theories. The studies reviewed also highlight how social elements are grounded in established behaviour change theories, further explaining their effectiveness.

- Social Cognitive Theory (SCT) is exemplified in the Hafner et al. study [54], where behavioural change is driven by peer influence and social observation. SCT suggests that people are more likely to adopt behaviours they observe in others, particularly when those behaviours are reinforced by positive social feedback.
- Self-Determination Theory (SDT), as seen in Cowley and Bateman [52], explains the role of intrinsic motivation in sustaining long-term engagement. By fostering a sense of relatedness and belonging, social elements enhance intrinsic motivation, which is crucial for maintaining behaviour change.
- Social Norms Theory is particularly relevant in studies like Ro et al. [11] and Cellina et al. [39], where social comparisons and community-based interventions create a collective expectation of pro-environmental behaviour. By aligning individual actions with group norms, these games promote sustained engagement and behavioural adherence.

We can conclude that across the reviewed studies, strong social elements are consistently associated with long-term behavioural change. Whether through social norms, peer influence, community engagement, or social accountability, these elements tap into fundamental social motivations that help sustain behavioural change beyond the initial intervention. The effectiveness of social elements, however, depends on thoughtful game design. Elements such as team challenges, leader boards, and social comparisons must be carefully integrated into the game mechanics to create a balance between individual and collective motivations.

The evidence suggests that games incorporating social dynamics are more effective at fostering sustained behavioural change. By leveraging the power of social influence, community support, and intrinsic motivation, these games create a context in which desired behaviours become embedded within social identities, making them more likely to persist over time. Future game designs should continue to explore how social elements can be enhanced and adapted to maximise their impact on long-term behavioural change.

3.5.2. Quantitative Measure of Game Elements and Game Effect

To be more quantitative, we decided to run a statistical test on the association of the first three game elements with long-term behavioural change. We assume that if a game element is significantly associated with this LT change, then it might be responsible for this behaviour change.

We found that there is a strong, statistically significant association of social dimension on long-term energy consumption patterns/behavioural change (Fisher exact test, the two-tailed $p = 0.003$, the result is significant at $p < 0.01$), see also Appendix A. However, we did not find an association of long-term behavioural change with other frequent game elements, such as FB and rewards (Fisher exact test, two-tailed, $p = 1.00$).

3.6. Case Studies

In the realm of serious games, achieving long-term behavioural change is a key objective, particularly in domains such as energy conservation. This review examines three successful games that not only demonstrate significant long-term behavioural effects, but also exhibit high levels of user engagement and satisfaction, factors that likely contribute to their success. The games, i.e., EnergyLife [40], Cool Choices [11], and Energy Cat [54], are notable for their innovative use of game mechanics, feedback systems, and social dynamics, fostering sustained engagement and pro-environmental behaviours. Analysing the design elements and research outcomes of these case studies sheds light on how serious games can be effectively designed to promote long-term behavioural change and enhance environmental education.

3.6.1. Case Study 1, EnergyLife

The first case study focuses on EnergyLife, a mobile game designed to raise energy awareness and encourage energy-saving behaviours within households [40]. By utilising wireless sensors attached to household appliances, EnergyLife provides real-time and historical feedback on energy consumption. The game's core objective is to improve users' knowledge and motivation for sustainable energy conservation through a combination of interactive feedback, quizzes, tips, and social engagement features. The study was conducted over a three-month period, involving eight households in Finland and Italy. Wireless sensors collected energy consumption data, which were communicated to users through the mobile app, alongside educational content designed to encourage energy-saving behaviours. User engagement, usability, and satisfaction were evaluated using system logs, usability tasks, satisfaction questionnaires, and group interviews, with social elements like community features fostering peer learning and engagement.

The results revealed that participants found the game useful for managing their energy consumption, with elements like quizzes and tips particularly appreciated. However, engagement levels varied across households; some used the app routinely, while others applied it to specific goals such as avoiding blackouts. The game successfully increased the awareness of energy-draining behaviours, such as leaving devices on standby, leading to immediate behaviour changes and, for some, the development of longer-term habits. Despite its effectiveness, the study identified several usability challenges, including inconsistent feedback delivery, overly complex game mechanics, and technical bugs. These issues prompted a redesign, leading to the introduction of “Smart Advice” tips that provided more personalised and contextualised feedback. The revised game also included four levels, each corresponding to different stages of user awareness, from goal setting to habit maintenance.

Although EnergyLife was successful in promoting both short- and long-term behaviour changes, the feedback system’s inconsistencies impacted the user experience. While tips were informative, their irregular delivery disrupted the gameplay. The points and rewards system, though present, had unclear effects on user motivation, suggesting that it could be refined to enhance engagement. Challenges such as quizzes added value, but were seen as overly complex by some users, potentially limiting accessibility. Ultimately, the game proved effective at raising immediate awareness and maintaining energy-saving behaviours over time, although technical issues somewhat hindered the overall experience.

The research design of EnergyLife, which involved a pre-test/post-test approach with a small sample size of eight households and no control group, limited the ability to draw strong causal conclusions about the game’s impact. While the study provided valuable insights into behaviour change and engagement, the absence of a randomised controlled trial (RCT) reduced its rigour.

Nonetheless, the study’s combination of questionnaires, interviews, and system logs offered a comprehensive view of user engagement and feedback, though a more robust statistical analysis could have strengthened the findings. Despite its limitations, the EnergyLife study remains highly relevant to this review, as it offers key lessons in how persuasive technology can be used to promote sustained engagement in serious games for sustainability.

3.6.2. Case Study 2, Cool Choices

The second case study, Cool Choices, shifts the focus towards the use of competition and collaboration to encourage sustainable behaviour [11]. Designed to engage players in various environmental actions, Cool Choices incorporates game elements such as points, rewards, challenges, and social interactions, all aimed at motivating both individual and collective behavioural changes. Its primary focus is on fostering immediate behaviour shifts as well as long-term sustainability. The study employed a quasi-experimental design and a mixed-method approach, combining surveys, observations, and behaviour tracking to measure short- and long-term behaviour changes among participants. This comprehensive approach provided a detailed understanding of how the game influenced sustained engagement.

The results of Cool Choices demonstrated its strong effectiveness in promoting sustainable behaviours. The participants exhibited increased environmental awareness and knowledge retention following gameplay, and the integration of various game elements—particularly points, rewards, and social engagement—was highly rated. The game balanced competitive elements with opportunities for collaboration, which appealed to a wide range of player types, encouraging both personal responsibility and group efforts. In terms of the design, Cool Choices excelled in its use of well-structured elements that motivated behavioural change. The points and rewards systems were particularly effective, while challenges provided variety and encouraged deeper participation. Social elements, such as the ability to share progress with peers and engage in team-based activities, kept players engaged throughout the game.

The game successfully promoted immediate behaviour changes, such as reducing energy consumption, and facilitated long-term habit formation. The participants also demonstrated improved knowledge retention, with many retaining key environmental lessons learned during gameplay. The user experience was positive overall, with participants finding the game both engaging and easy to navigate. The study's robust evaluation, utilising a combination of self-reported surveys, observational data, and behaviour tracking, provided a multidimensional perspective on the game's impact, strengthening the validity of the conclusions. The combination of competition and collaboration was particularly effective in fostering long-term engagement, making Cool Choices a benchmark example of how gamified interventions can promote sustained environmental behaviour changes.

3.6.3. Case Study 3, Energy Cat

The final case study, using the Energy Cat game, explores the use of social dynamics to influence sustainable behaviours [54]. The game focuses on peer pressure, social comparison, and collaborative activities to engage users, embedding energy-saving actions within a social framework. This method (dual methods) of combining collaborative and cooperative elements also allows the game to be appealing to more types of players. By leveraging these social dynamics, the game aims to motivate both individual and group behaviour changes, making it particularly effective for long-term sustainability. Like Cool Choices, this study utilised a quasi-experimental design, incorporating surveys, interviews, and behavioural observations to assess the game's impact on both immediate and long-term behavioural change.

The results of Energy Cat were highly positive, with the game scoring particularly well in areas such as feedback incorporation, challenges, and social elements. The use of social dynamics, especially peer pressure and social comparison, was central to the game's ability to engage participants and drive behavioural change. These elements not only encouraged short-term behaviour changes, but also contributed to the development of long-term habits, with participants showing lasting energy-saving behaviours. The game's design strategically combined timely and actionable feedback with achievable challenges, ensuring that players remained motivated throughout. However, the most powerful aspects were the social elements, which created a sense of accountability and collective responsibility, proving to be a strong motivator for sustained behaviour change.

Players reported high levels of engagement and satisfaction, finding the game both enjoyable and educational. The study's comprehensive evaluation—employing both qualitative and quantitative methods—provided a robust analysis of the game's impact, with the use of mixed methods strengthening the overall credibility of the findings. Energy Cat stands out for its innovative approach to using social dynamics to drive sustainable behaviours, offering a compelling model for how serious games can be embedded within social settings to promote meaningful and sustained behaviour changes.

In conclusion, these three case studies demonstrate the potential of serious games to foster long-term behavioural change, particularly in the context of sustainability. By utilising various game elements, from feedback and social interaction to educational content, these games successfully engage users in ways that promote both immediate actions and lasting habits. Each case study offers valuable insights into how game mechanics can be refined to better achieve these outcomes, providing important guidance for the development of future serious games aimed at environmental education and behavioural change.

4. Discussion

This review critically examined the impact of applied games on energy efficiency behaviours, highlighting both the potential and limitations of current research. Given the narrow selection criteria, including language constraints and the exclusion of projects under a non-disclosure agreement (NDA), our analysis reveals a significant gap in high-quality studies, with many failing to demonstrate long-term effects or to adequately describe their methodologies. This has led to a potential overestimation of the positive impacts of applied games due to publication bias. Furthermore, our discussion explored the role of game elements such as feedback, challenges, and social interaction in fostering motivation and a positive user experience, despite the lack of evidence linking these elements to a sustained energy consumption reduction. Through a nuanced exploration of the existing literature, this introduction sets the stage for a deeper understanding of the complexities and challenges faced in harnessing applied games for environmental sustainability.

4.1. Limitations

Limitations in the selection of the papers need to be acknowledged. The review was constrained by the search terms, databases used, and selection criteria, such as only including studies with measured long-term effects (which is known to be a small number [8]), English language publications, and projects that are not under an NDA, and more.

Our assessment of the primary research question was restricted by the low number of studies (1.38%, 15 out of 1087) meeting the selection criteria. Many of those found were deemed to be of a relatively low quality due to poorly described interventions, and issues with data collection and analysis that weakened the accuracy and reliability of conclusions drawn. Few rigorous empirical assessments have been published on the tangible impact of applied games on energy efficiency behaviours. It is possible that the publication bias has led to an overly positive picture emerging concerning applied games; studies finding no impact may be under-represented in the published literature. Unfortunately, a formal assessment for potential publication bias based on available data could not be conducted.

On a different note, significant within-group variation in energy use was observed in the reviewed studies, along with small sample sizes, which likely reduced statistical power and decreased the likelihood for detecting significant differences. This obscures our understanding of how applied games truly impact this domain's related behaviour changes significantly.

In addition, several reviewed studies lacked statistical significance testing or failed to describe their analyses altogether while relying on self-reported behaviours, which introduces the possibility for social desirability bias affecting the results—previous research has shown notable disparities between self-reported and observed behaviour regarding energy efficiency. It is also noteworthy that certain short-term studies started comparing energy usage during Winter Months, then would compare the results to Spring/Summer months, and due to the obvious effects of warmer weather in European Countries/North America/Canada, the positive results of a reduction in energy usage can be attributed to seasonal biases.

It is also worth noting that certain studies like the enCOMPASS study [70], whilst being well-designed and with detailed reporting, seem to be not very concerned with the user experience. At least, they did not report it. It is not really clear why. However, an assumption that we can make based on the reporting is that the challenges, game balance, flow, and actual mechanics/dynamics/aesthetics that build up the game are somehow neglected. Even when developing a serious game for the validation of a research question, the "game" element (good design, engaging gameplay, playfulness, etc.) should not be sacrificed. Cellina et al. [39] and Fraternali et al. [70] themselves remarked that overly notifying new challenges and invitations to play the game were met with a weakened response (user fatigue) and decreased user engagement.

Furthermore, there is scarce research assessing long-term effects—the majority of studies focused solely on short-term periods without follow-ups after completion, possibly leading to sustained observations over time or the emergence of new post-data collections of positive habits formed after its completion into doubt.

4.2. Game Elements

A variety of game elements were employed in the investigated studies, with the most common inclusions being feedback, challenges, social elements (sharing, ranking, competition, and collaboration), rewards, leader boards, and points. There were many studies on the relative impactfulness of specific game elements [8,30,71]. The majority of them are known to contribute to motivation and a positive UX. Many papers, e.g. [8,71], pointed out that feedback, challenge, and rewards are often applied as tools to promote energy conservation and appear to be an effective strategy and initial support in energy saving. However, we did not find any statistical association between these elements and long-term energy consumption reduction. Maybe our sample size is not enough for conclusions.

Social elements are explored less: only two studies, Power Explorer [43] and Do it in the darkness [45], found evidence for the value of competition and social sharing as a means of encouraging participants. Our analysis suggests that the dynamics of user participation and engagement may hinge on social factors and enduring modifications in behaviour regarding electricity consumption reduction. Given the intrinsic social nature of humans, social interactions play a pivotal role in shaping our behaviours. Furthermore, it is imperative to underscore that for a game to exert a significant influence on behavioural modification and motivation beyond the experimental phase, it must not only be interactive and foster engagement, but also exhibit a well-designed user experience, despite its imperfections. The absence of such elements can diminish the intended impact on behavioural change and motivation [38,39].

4.3. Game Effects

As already described in Section 3.4.2, cognitive and knowledge effects were mainly increased. Also, a positive attitude towards the game or experience playing the game was almost commonly reported as the user experience outcome. However, three studies did not report on UX measurements [37–39]. They all reported no LT effect on the energy consumption patterns, potentially referring to a weakened attention to the users' enjoyment and flow [72]. And again, as mentioned in other reviews, it is not possible (due to the low participation, representative, and sample size) to study if any dependency exists between the demography (age, social group, and region) and game effects, such as UX, behaviour changes, cognition, and knowledge gain.

4.4. Challenges in Gamification for Energy Management

Gamification in energy management, which uses game mechanics to promote energy-saving behaviours, faces several challenges that limit its effectiveness. These challenges include waning user engagement, difficulties in technological implementation, and limitations in behaviour change sustainability [73]. Despite the initial success of gamified interventions, these challenges necessitate a more comprehensive understanding of user motivation, technological integration, and long-term impacts.

4.4.1. Waning User Engagement

One of the major challenges faced by gamification in energy management is maintaining user engagement over time. Early-stage user engagement is often high due to the novelty and intrinsic motivation fostered by game elements, such as rewards, competitions, or leader boards. However, research shows that this enthusiasm often declines as users lose interest in repetitive game mechanics or fail to see substantial benefits beyond short-term rewards.

Studies highlight that many gamified systems in energy management do not sufficiently address long-term user motivation [4]. For example, the initial excitement surrounding rewards-based mechanisms (e.g., points and badges) tends to diminish once users perceive these rewards as insufficient to sustain their interest or when the external motivators no longer feel relevant. Self-determination theory [26,69] suggests that to sustain engagement, users need to feel autonomous, competent, and connected to the activity's purpose. This observation is also echoed by studies delving into relationships between gamified experiences and intrinsic needs satisfaction [74]. In gamified energy platforms, where users may be encouraged to adopt energy-saving habits, maintaining intrinsic motivation through social comparison, meaningful feedback, and progress tracking is crucial.

Moreover, gamification's effectiveness is often limited by the difficulty of translating virtual rewards into real-world behavioural change. Users may enjoy competing in challenges or receiving badges, but unless these game elements lead to lasting energy-saving habits, the impact of gamified interventions remains superficial. Research in behavioural change suggests that integrating elements such as personalised feedback and context-specific goals may be more effective in maintaining long-term engagement [75].

However, there is a different approach: do we really want people to be engaged for a very long time (forever?), or do we want a robust change in their behaviour once they have learned and been trained with a game? Thus, an ideal (and more realistic) scenario would be relatively short and effective play in a way where we prioritise "meaningful" engagement over basic duration-based engagement. Thus, in theory, following the lessons learnt by the stable change of behaviour without reminding is saving energy on a constant basis. What we need is the robustness of behaviour change, discussed below.

4.4.2. Robustness of Behaviour Change

The second challenge is to make the behaviour changes induced by gamified systems are sustainable in the long term. Many interventions focus on short-term engagement, using extrinsic rewards like badges or rankings, which can be effective for initiating behaviour changes, but may not lead to lasting habits. Without deeper behaviour change mechanisms, such as integrating energy-saving behaviours into users' lifestyles, the effectiveness of gamified interventions may wane once users stop using the platform.

Research indicates that behaviour change techniques (BCTs), such as goal setting, feedback, and social support, can be effective in promoting sustainable behaviour changes [29]. However, gamified platforms often fail to incorporate these techniques in ways that lead to long-term energy conservation. For instance, users may achieve short-term goals, but without continued reinforcement or evolving challenges, their motivation to maintain energy-saving behaviours diminishes.

4.4.3. Technological Implementation Difficulties

And finally, one more challenge is the technological complexity of implementing gamification in energy management systems. Energy consumption data must be accurately tracked, monitored, and visualised in ways that are meaningful to users. This requires integration across multiple devices, sensors, and platforms, many of which may have compatibility issues or require costly upgrades.

Smart meter integration, for example, is crucial for providing real-time data on energy usage, which is a cornerstone of many gamified systems. However, issues such as inconsistent data collection, latency, and user privacy concerns can complicate the seamless implementation of gamified energy management solutions. Users may experience delays in feedback or inaccurate measurements, which reduces trust in the system and diminishes its perceived utility. Furthermore, privacy concerns arise when detailed energy consumption data are shared, especially on platforms that promote social comparison or community challenges.

Another technological challenge is ensuring the scalability and accessibility of gamified platforms. Energy management solutions need to cater to diverse user bases with varying levels of technological literacy, access to smart devices, and energy consumption patterns. Ensuring that gamified interventions are inclusive and accessible requires significant effort in the design and user interface customisation, which is not always prioritised in early-stage development.

4.5. Future Trends and Development Prospects' Potential Impacts

Despite these challenges, the future of gamification in energy management shows promising prospects, thanks to advancements in both technology and behavioural science. Several trends are shaping the development of more effective gamified systems:

1. Flexibility

One significant direction is the move towards incorporating flexibility in energy use. While energy conservation remains vital, shifting focus toward demand side management and flexible energy usage—such as adjusting consumption to align with peak and off-peak periods—can yield more dynamic and resilient energy systems. This is particularly important for integrating renewable energy sources that may not be available continuously. Flexibility in energy use promotes better synchronisation with the availability of renewable energy and allows for reducing strain on the grid during peak times. The development of gamified applications that incorporate flexibility metrics will be key in the near future. These systems will need to encourage users to not only conserve energy, but also adapt their consumption patterns based on real-time grid conditions.

The GAIM [76] and RESCHOOL [77] projects in which the authors are involved are in the process of exploring these approaches, focusing on community-based energy solutions and incorporating social dynamics into flexible energy use scenarios. This includes features like real-time feedback on energy consumption during high-demand periods, or introducing rewards for shifting energy use to times when renewable energy is more abundant. Future trends should increasingly emphasise the integration of gamified elements that promote such adaptive energy behaviours, ensuring both conservation and flexibility are embedded within user engagement models.

2. Artificial Intelligence and Machine Learning

Artificial Intelligence (AI) and Machine Learning (ML) can personalise the gamified experience by analysing user behaviour, energy consumption patterns, and motivational triggers. These technologies can enable dynamic adjustments to game elements, ensuring that the system continues to challenge and engage users over time. For instance, AI can customise feedback or create personalised energy-saving goals based on real-time data, fostering more meaningful user engagement.

3. Integration with Smart Homes and IoT and DSM

As smart home technology and IoT continue to develop, gamification can be seamlessly integrated with a wider array of devices, making energy management more intuitive. For example, a gamified system could automatically adjust thermostats, lights, or appliances based on user-set goals, turning energy-saving into a more automated and effortless process. Incorporating DSM strategies into these smart systems will also allow for peak-shaving and load-shifting, where users can be rewarded for using energy at non-peak times, further promoting grid stability and efficiency.

4. Social and Community-Based Engagement

Future gamified platforms are likely to place greater emphasis on social and community-based engagement. Platforms that encourage competition or collaboration among neighbourhoods or peer groups could leverage the power of social influence to promote energy-saving behaviours. For flexibility, this could include features such as neighbourhood-wide alerts encouraging users to collectively reduce energy use during grid stress events, fostering a community-level response to energy management.

In summary, we suggest focusing on Intrinsic Motivation and Well-Being. To address waning user engagement, future gamified energy management systems may place a greater emphasis on intrinsic motivation by fostering a sense of purpose and well-being. Gamification that highlights the environmental impact, personal achievement, and community benefits—rather than just extrinsic rewards—is more likely to sustain long-term behavioural change.

5. Conclusions

After exploring the available studies measuring long-term effects of energy gaming, we conclude that a positive effect of long-term energy saving behaviour is possible. It seems to be supported by the social interaction elements of the games. Good user experience might play an important role; therefore, developers should remember to make a game playful and engaging for the user.

This review acknowledges limitations in its methodology and scope due to the specificity of search terms, databases utilised, and selection criteria—including a focus on studies with measured long-term effects in English language publications not under non-disclosure agreements. The scarcity of studies fulfilling these criteria, coupled with their generally low methodological quality, restricts the robustness of our conclusions. Issues such as poorly described interventions, data collection, and analysis challenges have potentially compromised the accuracy and reliability of findings, while the possibility of publication bias towards positive outcomes cannot be dismissed. Additionally, the observed within-group variance in energy usage, alongside small sample sizes, likely diminished the statistical power of these studies, complicating efforts to detect significant behavioural changes attributable to applied games. The reliance on self-reported data further introduces the risk of social desirability bias, which has been shown to diverge from actual behaviour, particularly in energy efficiency contexts. Seasonal biases in energy usage, due to the timing of some studies, and a general neglect of user experience in game design were also noted as limitations that could influence the efficacy of serious games in promoting energy conservation. Moreover, the review identified a dearth of rigorous empirical assessments on the long-term impact of serious games on energy-efficient behaviours, with a predominance of short-term studies lacking in follow-up. This raises questions about the sustainability of observed behaviour changes and the potential for emerging positive habits post-intervention. Thus, while certain studies like the enCOMPASS study [70] showcase detailed design and reporting, the overarching emphasis on the "game" element's significance in enhancing user engagement and research validity remains a critical consideration moving forward.

6. Recommendations

Given the findings from the current literature review, which highlight the potential for serious energy management games to foster long-term energy-saving behaviours, particularly through the incorporation of social interaction elements, we strongly recommend future studies to delve deeper into the specific mechanisms by which these social features influence behaviour change over time. Additionally, the critical role of user experience in maintaining engagement underscores the need for interdisciplinary research that bridges game design, psychology, and environmental science.

This could involve experimental studies that systematically manipulate game design elements to evaluate their impact on both immediate engagement and sustained energy conservation behaviours. Furthermore, longitudinal studies that track participants' energy consumption patterns post-interaction with serious games would offer invaluable insights into the real-world efficacy of these tools. Lastly, considering the rapid evolution of digital technologies, exploration into emerging platforms and modalities (e.g., virtual reality, augmented reality, and mobile applications) for serious energy management games could broaden the scope of engagement strategies and their applicability in diverse demographic and socio-economic contexts.

We would recommend splitting areas of focus for future researchers into two categories.

6.1. Identification/Formulation of Successful Strategies for Long-Term (Or Effective) Engagement

In order to facilitate this, there will be a need for a comprehensive meta-analysis: A critical need exists for meta-analyses that aggregate and scrutinise data across multiple serious game studies. Such analyses could highlight patterns regarding which game design elements (e.g., narrative, challenges, rewards, and social features) consistently correlate with higher user engagement over time.

Comparative Studies: Research that would directly compare different game mechanics and their effects on user engagement would be invaluable. This could include A/B testing within games to see which features retain players' attention and motivate continued play across diverse user demographics.

Quality of User Experience Research: Studies focusing explicitly on the user experience, incorporating qualitative insights (e.g., interviews, focus groups) alongside quantitative metrics (e.g., gameplay time, frequency of play), could provide a richer understanding of what keeps users engaged. This should also include research on accessibility and inclusivity to ensure broad applicability.

Longitudinal Studies with Follow-up Assessments: There is a need for studies that not only track immediate engagement, but also perform follow-up assessments months or years after the initial game interaction to evaluate long-term retention and engagement strategies.

6.2. Influencing Users' Behavioural Pattern of Energy Consumption

Mechanism-Based Research: Insight into the psychological mechanisms (e.g., motivation, habit formation, and social norms) by which serious games influence energy consumption behaviours would guide the development of more effective game designs. This requires interdisciplinary studies that bridge psychology, game design, and environmental science.

Real-World Impact Studies: To draw conclusions about changing behaviour patterns, research must extend beyond self-reported measures to include objective metrics of energy consumption. This involves longitudinal studies that monitor actual energy usage before, during, and after game interaction.

Segmentation and Personalisation Studies: Understanding how different user segments respond to game interventions could reveal personalised strategies that are more effective at changing behaviour patterns. This necessitates research into how demographic, psychological, and contextual factors influence the effectiveness of serious games in energy management.

Cross-Cultural and Socio-Economic Research: since energy consumption behaviours and responsiveness to game interventions can vary significantly across cultures and socio-economic backgrounds, studies that explore these variations are crucial for developing universally effective engagement strategies.

6.3. Recommendations for Energy Management for Practitioners and Policymakers

Based on the analysis of our selected studies which measure the long-term effects of gamification, we would like to offer some specific recommendations for energy management practitioners and policymakers to design and optimise gamification strategies and evaluate their implementation.

For practitioners we suggest:

- Designing Effective Gamification Strategies.

We suggest for practitioners to utilise a Personalisation and User-Centric Design. It is important to tailor Experiences to User Segments. Thus, practitioners should design gamified interventions that are customised for different user groups (e.g., homeowners, tenants, students, or corporate employees). By analysing user behaviours, preferences, and energy consumption patterns, practitioners can create personalised goals and rewards that align with the specific needs and habits of these segments.

Another approach might be to utilise data and AI for personalisation. One can use artificial intelligence and machine learning to create adaptive systems that evolve with user behaviour. Personalised feedback, dynamic goal-setting, and real-time energy consumption data should be incorporated to keep users engaged over the long term.

- Integrating Social Elements and Community Engagement.

Social Elements and Community Engagement happen to be very effective tools to ensure long-term behavioural change. One can integrate them by Promoting Peer Comparisons and Social Influence. It is advised to encourage friendly competition or collaboration among peers, neighbours, or colleagues. Social comparisons, such as leaderboards or energy usage benchmarks, can drive engagement and motivate sustained behavioural change.

It is possible to stimulate collective Action through Communities. Thus, energy-saving goals can be designed for groups (e.g., neighbourhoods or office teams) to foster a sense of shared responsibility. Group goals and rewards encourage users to work together, multiplying the impact of individual actions.

- Incorporating Meaningful Rewards and Recognition

It might be fruitful to incorporate Meaningful Rewards and Recognition by using Intrinsic and Extrinsic Motivators. While rewards like points and badges can initiate engagement, long-term success requires intrinsic motivators, such as a sense of purpose or personal achievement. Gamified strategies should include both extrinsic rewards (such as energy-cost savings, rebates, or prizes) and intrinsic rewards (such as progress toward sustainability goals or personal well-being).

Real-time feedback on energy-saving efforts, paired with tangible progress tracking, can keep users motivated. Highlighting positive environmental impacts or financial savings helps users see the real-world effects of their efforts.

- Link Gamification with Long-Term Sustainability.

Instead of relying solely on short-term engagement, one can design gamification elements that encourage habit formation. Introduce small, manageable tasks that users can complete daily or weekly to integrate energy-saving behaviours into their routines.

Enhance users' understanding of energy conservation by including educational content that connects their actions to larger environmental goals. Explain how reducing energy usage contributes to mitigating climate change and emphasise the broader social and environmental impacts.

- Evaluating and Optimising Implementation Outcomes.

Enhance evaluation by using Behavioural and Technical Metrics. Policymakers and practitioners should adopt a comprehensive evaluation framework that assesses both behavioural changes and technological effectiveness. Key performance indicators (KPIs) could include a reduction in energy consumption, user engagement rates, retention levels, and the achievement of behavioural goals over time.

Include measures of a Long-Term Impact. It is suggested to avoid focusing only on short-term results. Regularly assess whether the gamified intervention leads to a lasting behavioural change by tracking users' energy consumption patterns over extended periods (e.g., six months to a year). Longitudinal studies can reveal whether participants sustain new habits after the novelty of the gamified system has worn off.

Implement Behavioural Change Techniques (BCTs). It is good practice to evaluate the effectiveness of specific BCTs (e.g., feedback, goal setting, and social comparisons) in promoting sustainable energy-saving behaviours. This will help refine which techniques work best in different contexts and for different user groups.

- Incorporating User Feedback and Iterative Design.

It is imperative to conduct Usability Testing. Gather user feedback through surveys, focus groups, or usability tests to understand how users interact with the gamified system. This can reveal potential barriers or friction points that reduce engagement. Iteratively refine the design based on user input to enhance the system's usability and accessibility.

People find it helpful to use A/B Testing for Optimisation. Implement A/B testing (split your user base into two groups and show two different versions of analysis, with the goal to find the more successful version) or randomised control trials (RCTs) to compare different design elements (e.g., types of rewards, goal difficulty levels, or feedback mechanisms) and evaluate which variations lead to better outcomes in terms of user engagement, energy savings, and behavioural change.

- Addressing Technological Barriers.

Energy management systems need to provide accurate and timely data. Invest in reliable sensors, smart meters, and data integration platforms that can track energy usage in real-time and relay this information seamlessly to users. Delays or errors in data feedback can undermine user trust and engagement.

Policymakers should create guidelines to protect user privacy when collecting and sharing energy consumption data, especially in gamified systems that promote social comparison. Transparent data handling practices and robust cybersecurity measures are essential to building trust and participation.

For Policy Makers we recommend the following approaches:

- Support Open Standards and Interoperability.

Promote Compatibility Across Platforms. Governments and industry stakeholders should encourage the use of open standards and interoperability protocols for smart meters, sensors, and other devices. This ensures that gamified systems can easily integrate with various energy management platforms, reducing barriers to widespread adoption.

Facilitate Access to Data for Innovation. Encourage data sharing between utilities, energy providers, and third-party developers to foster innovation in gamified energy management solutions. Policymakers should create regulatory frameworks that allow for secure, anonymised data sharing, which can accelerate the development of new gamified interventions.

- Incentivise Gamified Energy Management Programmes.

Provide Financial Incentives for Participation. Governments can offer tax breaks, subsidies, or rebates to households and businesses that participate in gamified energy-saving programmes. This can encourage a broader adoption and increase the likelihood of achieving national energy conservation goals.

Encourage Corporate and Public Sector Adoption. Large institutions and corporations often have significant energy footprints. Policymakers can introduce initiatives that encourage or mandate the use of gamified energy management systems in public buildings, schools, and large businesses to reduce energy consumption on a larger scale.

- Focus on Energy Equity.

Ensure Inclusivity for Low-Income Households. Policymakers should ensure that gamified energy management programmes are accessible to all socioeconomic groups, particularly low-income households. Programmes should be designed to accommodate households with a limited access to smart technologies, and financial incentives should be targeted to encourage participation from under-represented groups.

Create Community-Based Gamified Interventions. Policymakers can collaborate with local governments and community organisations to create neighbourhood-wide or community-based gamified interventions. This could encourage collective energy-saving efforts in areas where individual access to smart technology may be limited.

Overall, to maximise the impact of gamification in energy management, practitioners and policymakers must design user-centric, personalised systems that uses both intrinsic motivation and social influence. Gamified systems need to be integrated with technology and ensure data accuracy and privacy. Evaluation frameworks should focus on long-term behavioural change and sustainability, supported by rigorous testing and user feedback. By scaling gamification efforts through open standards, financial incentives, and community-based approaches, energy management can contribute significantly to achieving global energy conservation goals.

Author Contributions: Conceptualization, A.B. and I.L.; methodology, A.B., I.L. and R.C.V.; software, A.B.; validation, R.C.V., I.L. and H.N.; formal analysis, A.B. and I.L.; investigation, A.B., I.L. and R.C.V.; resources, A.B, I.L. and W.v.S.; data curation, A.B.; writing—original draft preparation, A.B.; writing—review and editing, A.B., H.N., I.L., R.C.V. and W.v.S.; visualization, A.B.; supervision, I.L., J.D.F., R.C.V. and W.v.S.; project administration, I.L. and W.v.S.; funding acquisition, I.L., R.C.V. and W.v.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by the Dutch Research Council (NWO), the project Long-term consumer and community empowerment in energy applications through inclusive Game design, Artificial Intelligence, and system Modelling (GAIM), grant number KICH1.ED03.20.022, and by the European Union's Horizon Europe research and innovation programme, the project Strategies and tools for Incentivisation and management of flexibility in Energy Communities with distributed Resources (RESCHOOL), grant number 101096490.

Data Availability Statement: Data are available on reasonable request from the authors.

Acknowledgments: We acknowledge the RESCHOOL project and the GAIM project partners, as well as staff members at Utrecht University who helped with feedback and support during the writing of the paper. Special thanks go to Irina Abnizova for statistical consultancy and advice on the paper. Last but not least, a shoutout goes to Lonneke Rooijakkers for assistance in formatting the paper.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. Contingency Tables and Outputs of Fisher Exact Test on Elements Versus Effect of Games

The additional information provided in this appendix supports the main text by offering additional details and evidence that enrich the reader's understanding of our study. Section 2 in this paper delves into the statistical analysis of the elements present in the games and their association with long-term behavioural effects on players. Through contingency tables and Fisher's exact test results, we explore two main elements: social elements and feedback mechanisms within the games, thus answering the question "is there significant association between social element and long-term behaviour?".

- Table A1 examines the association between social elements in the games and their impact on long-term behavioural change. The statistically significant results suggest a strong correlation.
- Table A2 looks at the feedback elements, finding no statistically significant association with long-term behavioural change, indicating that feedback alone may not be sufficient to instigate lasting changes.
- Table A3 investigates the role of rewards in the games, showing a strong association with positive long-term behavioural outcomes.

These statistical analyses provide evidence of the positive correlation of social game elements in promoting long-term behavioural change towards more sustainable energy usage practices.

Table A1. Association of Long-Term behaviour effect and social elements of the game using Fisher's exact test. The association between rows (Social elements) and columns (LT Behaviour Change) is statistically very significant. The Fisher exact test statistic value is 0.0003. The result is significant at $p < 0.01$.

	LT+	**LT−**
Social +	10	1
Social −	1	9

Table A2. Association of Long-Term behaviour effect and Feedback (FB) elements of the game using Fisher's exact test. The two-tailed p value equals 1.0000. The association between rows (FB) and columns (LT Behaviour Change) is considered not to be statistically significant.

	LT+	**LT−**
FB +	10	11

FB −	0	0

Table A3. Association of Long-Term behaviour effect and Reward elements of the game using Fisher's exact test. The two-tailed p value equals 1.0000. The association between rows (rewards) and columns (LT Behaviour Change) is considered to be not statistically significant.

	LT+	LT−
rewards +	10	0
rewards −	10	1

References

1. IEA 2024. CO_2 Emissions in 2023. Available online: https://www.iea.org/reports/co2-emissions-in-2023 (accessed on 17 October 2024).
2. Morganti, L.; Pallavicini, F.; Cadel, E.; Candelieri, A.; Archetti, F.; Mantovani, F. Gaming for Earth: Serious games and gamification to engage consumers in pro-environmental behaviours for energy efficiency. *Energy Res. Soc. Sci.* **2017**, *29*, 95–102.
3. Liu, S.; Shukla, A. Serious Games as an Engaging Medium on Building Energy Consumption: A Review of Trends, Categories and Approaches. *Sustainability* **2020**, *12*, 8505.
4. Hamari, J.; Koivisto, J.; Sarsa, H. Does Gamification Work?—A Literature Review of Empirical Studies on Gamification. In Proceedings of the 47th Hawaii International Conference on System Sciences, Waikoloa, HI, USA, 6–9 January 2014; pp. 3025–3034.
5. Deterding, S.; Dixon, D.; Khaled, R.; Nacke, L. From Game Design Elements to Gamefulness: Defining Gamification. In Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments, Tampere, Finland, 28–30 September 2011; pp. 9–15.
6. Ouariachi, T.; Elving, W. Accelerating the Energy Transition Through Serious Gaming: Testing Effects on Awareness, Knowledge and Efficacy Beliefs. *Electron. J. e-Learn.* **2020**, *15*, 410–420.
7. Beck, D. Special Issue: Augmented and Virtual Reality in Education: Immersive Learning Research. *J. Educ. Comput. Res.* **2019**, *57*, 1619–1625.
8. Johnson, D.; Horton, E.; Mulcahy, R.; Foth, M. Gamification and serious games within the domain of domestic energy consumption: A systematic review. *Renew. Sustain. Energy Rev.* **2017**, *73*, 249–264.
9. Fischer, B.; Östlund, B.; Dalmer, N.K.; Rosales, A.; Peine, A.; Loos, E.; Neven, L.; Marshall, B. Co-Design as Learning: The Differences of Learning When Involving Older People in Digitalization in Four Countries. *Societies* **2021**, *11*, 66.
10. Andrew, L.; Barwood, D.; Boston, J.; Masek, M.; Bloomfield, L.; Devine, A. Serious games for health promotion in adolescents—A systematic scoping review. *Educ. Inf. Technol***. 2022**, *28*, 5519–5550.
11. Ro, M.; Brauer, M.; Kuntz, K.; Shukla, R.; Bensch, I. Making Cool Choices for sustainability: Testing the effectiveness of a game-based approach to promoting pro-environmental behaviors. *J. Environ. Psychol.* **2017**, *53*, 20–30.
12. Koltunov, M.; Pezzutto, S.; Bisello, A.; Lettner, G.; Hiesl, A.; van Sark, W.; Louwen, A.; Wilczynski, E. Mapping of Energy Communities in Europe: Status quo and review of existing classifications. *Sustainability* **2023**, *15*, 8201.
13. Fijnheer, J.D.; van Oostendorp, H.; Giezeman, G.-J.; Veltkamp, R.C. Competition in a household energy conservation game. *Sustainability* **2021**, *13*, 11991.
14. Csikszentmihalyi, M.; Csikszentmihalyi, I.S. *Optimal Experience: Psychological Studies of Flow in Consciousness*; Cambridge University Press: Cambridge, UK, 1992.
15. Casals, M.; Gangolells, M.; Macarulla, M.; Forcada, N.; Fuertes, A.; Jones, R.V. Assessing the effectiveness of gamification in reducing domestic energy consumption: Lessons learned from the EnerGAware project. *Energy Build.* **2020**, *210*, 109753.
16. Lampropoulos, I.; Alskaif, T.; Schram, W.; Bontekoe, E.; Coccato, S.; van Sark, W. Review of energy in the built environment. *Smart Cities* **2020**, *3*, 248–288.
17. AlSkaif, T.; Lampropoulos, I.; van den Broek, M.; van Sark, W. Gamification-based framework for engagement of residential customers in energy applications. *Energy Res. Soc. Sci.* **2018**, *44*, 187–195.
18. Nykyri, M.; Annala, S.; Silventoinen, P. Review of Demand Response and Energy Communities in Serious Games. *IEEE Access,* **2022**, *10*, 91018–91026.
19. Fijnheer, J.D.L.; van Oostendorp, H.; Veltkamp, R.C. Enhancing Energy Conservation by a Household Energy Game. In *Games and Learning Alliance*; GALA 2018. Lecture Notes in Computer Science; Gentile, M., Allegra, M., Söbke, H., Eds.; Springer: Cham, Switzerland, 2019; Volume 11385, pp. 257–266.
20. Xu, L.; Francisco, A.; Taylor, J.E.; Mohammadi, N. Urban Energy Data Visualization and Management: Evaluating Community-Scale Eco-Feedback Approaches. *J. Manag. Eng.* **2021**, *37*, 04020111.
21. Nasrollahi, H.; Lampropoulos, I.; Werning, S.; Belinskiy, A.; Fijnheer, J.D.; Veltkamp, R.C.; van Sark, W. Review of serious energy games: Objectives, approaches, applications, data integration, and performance assessment. *Energies* **2023**, *16*, 6948.
22. Hastings, J.; Michie, S.; Johnston, M. Theory and ontology in behavioural science. *Nat. Hum. Behav.* **2020**, *4*, 226.
23. Michie, S.; Hyder, N.; Walia, A.; West, R. Development of a taxonomy of behaviour change techniques used in individual behavioural support for smoking cessation. *Addict. Behav.* **2011**, *36*, 315–319.

24. Michie, S.; Van Stralen, M.M.; West, R. The behaviour changes wheel (BCW): A new method for characterising and designing behaviour change interventions. *Implement. Sci.* **2011**, *6*, 42.
25. Ajzen, I. The theory of planned behaviour: Reactions and reflections (TPB). *Psychol. Health* **2011**, *26*, 1113–1127.
26. Deci, E.L.; Ryan, R.M. Self-Determination Theory. In *Handbook of Theories of Social Psychology*; Van Lange, P.A.M., Kruglanski, A.W., Higgins, E.T., Eds.; Sage: London, UK, 2012; pp. 416–437
27. Chou, Y.-K. *Actionable Gamification, Beyond Points, Badges, and Leaderboards*; Octalysis Media: Shanghai, China, 2015.
28. Tyack, A.; Wyeth, P. Exploring relatedness in single-player video game play. In Proceedings of the 29th Australian Conference on Computer-Human Interaction, Brisbane, QLD, Australia, 8 November–1 December 2017; pp. 422–427.
29. Michie, S.; Richardson, M.; Johnston, M.; Abraham, C.; Francis, J.; Hardeman, W.; Eccles, M.P.; Cane, J.; Wood, C.E. The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: Building an international consensus for the reporting of behavior change interventions. *Ann. Behav. Med.* **2013**, *46*, 81–95.
30. Connolly, T.M.; Boyle, E.A.; MacArthur, E.; Hainey, T.; Boyle, J.M. A systematic literature review of empirical evidence on computer games and serious games. *Comput. Educ.* **2012**, *59*, 661–686.
31. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* **2021**, *372*, 71.
32. Du, J.; Pan, W. Evaluating energy saving behavioral interventions through the lens of social practice theory: A case study in Hong Kong. *Energy Build.* **2021**, *251*, 111353.
33. Perry, J.C.; Henry, M. Studying Defense Mechanisms in Psychotherapy Using the Defense Mechanism Rating Scales. In *Defense Mechanisms: Theoretical, Research and Clinical Perspectives*; Hentschel, U., Smith, G., Draguns, J.G., Ehlers, W., Eds.; Elsevier: Amsterdam, The Netherlands, 2004; pp. 165–192.
34. McHugh, M.L. Interrater reliability; the kappa statistic. *Biochem. Medica* **2012**, *22*, 276–282.
35. Cohen, J. A coefficient of agreement for nominal scales. *Educ. Psychol. Meas.* **1960**, *20*, 37–46.
36. Banerjee, A.; Horn, M.S. Ghost Hunter: Parents and Children Playing Together to Learn About Energy Consumption. In Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction (TEI '14), Munich, Germany, 16–19 February 2014; Association for Computing Machinery: New York, NY, USA, 2014, pp. 267–274.
37. Hargreaves, T.; Nye, M.; Burgess, J. Keeping energy visible? Exploring how householders interact with feedback from smart energy monitors in the longer term. *Energy Policy* **2013**, *52*, 126–134.
38. Wemyss, D.; Castri, R.; Cellina, F.; De Luca, V.; Lobsiger-Kägi, E.; Carabias, V. Examining community-level collaborative vs. competitive approaches to enhance household electricity-saving behavior. *Energy Effic.* **2018**, *11*, 2057–2075.
39. Cellina, F.; Simão, J.V.; Mangili, F.; Vermes, N.; Granato, P. Sustainable mobility persuasion via smartphone apps: Lessons from a Swiss case study on how to design point-based rewarding systems. *Travel Behav. Soc.* **2023**, *31*, 178–188.
40. Gamberini, L.; Corradi, N.; Zamboni, L.; Perotti, M.; Cadenazzi, C.; Mandressi, S.; Jacucci, G.; Tusa, G.; Spagnolli, A.; Björkskog, C.; et al. Saving is Fun: Designing a Persuasive Game for Power Conservation. In Proceedings of the 8th International Conference on Advances in Computer Entertainment Technology (ACE '11), Lisbon, Portugal, 8–11 November 2011; Association for Computing Machinery: New York, NY, USA, 2011; Volume 16, pp. 1–7.
41. Geelen, D.; Keyson, D.; Boess, S.; Brezet, H. Exploring the use of a game to stimulate energy saving in households. *J. Des. Res.* **2012**, *10*, 102.
42. Gustafsson, A.; Katzeff, C.; Bang, M. Evaluation of a pervasive game for domestic energy engagement among teenagers. *Comput. Entertain.* **2009**, *7*, 54.
43. Gustafsson, A.; Bång, M.; Svahn, M. Power Explorer: A Casual Game Style for Encouraging Long Term Behavior Change Among Teenagers. In Proceedings of the International Conference on Advances in Computer Entertainment Technology (ACE '09), Athens, Greece, 29–31 October 2009; Association for Computing Machinery: New York, NY, USA, 2009; pp. 182–189.
44. Salvador, R.; Romão, T.; Centieiro, P. A Gesture Interface Game for Energy Consumption Awareness. In *Advances in Computer Entertainment*; ACE 2012. Lecture Notes in Computer Science; Nijholt, A., Romão, T., Reidsma, D., Eds.; Springer: Berlin/Heidelberg, Germany, 2012; Volume 7624, pp. 352–367.
45. Senbel, M.; Ngo, V.D.; Blair, E. Social mobilization of climate change: University students conserving energy through multiple pathways for peer engagement. *J. Environ. Psychol.* **2014**, *38*, 84–93.
46. Stone, B.; Guest, R.; Pahl, S.; Boomsma, C. 2014. Exploiting Gaming Technologies to Visualise Dynamic Thermal Qualities of a Domestic Dwelling: Technical and Human Factor Challenges. In Proceedings of the BEHAVE'14: The 3rd European Conference on Behaviour and Energy Efficiency, Oxford, UK, 3–4 September 2014.
47. Odom, W.; Pierce, J.; Roedl, D. Social Incentive & Eco-Visualization Displays: Toward Persuading Greater Change in Dormitory Communities. In Proceedings of the Public and Situated Displays to Support Communities Workshop at OZCHI 2008, Cairns, QLD, Australia, 9 December 2008.
48. Takayama, C.; Lehdonvirta, V.; Shiraishi, M.; Washio, Y.; Kimuram, H.; Nakajima, T. ECOISLAND: A System for Persuading Users to Reduce CO_2 Emissions. In Proceedings of the 2009 Software Technologies for Future Dependable Distributed Systems, Tokyo, Japan, 17 March 2009; pp. 59–63.
49. Kimura, H.; Nakajima, T. EcoIsland: A persuasive application to motivate sustainable behavior in collectivist cultures. In Proceedings of the Nordic Conference on Human-Computer Interaction: Extending Boundaries (NordiCHI '10), Reykjavik, Iceland, 16–20 October 2010; Association for Computing Machinery: New York, NY, USA, 2010; pp. 703–706.

50. Reeves, B.; Cummings, J.J.; Scarborough, J.K.; Flora, J.; Anderson, D. Leveraging the engagement of games to change energy behaviour. In Proceedings of the 2012 International Conference on Collaboration Technologies and Systems, Denver, CO, USA, 21–25 May 2012; pp. 354–358.
51. Reeves, B.; Cummings, J.J.; Scarborough, J.K.; Yeykelis, L. Increasing Energy Efficiency with Entertainment Media: An Experimental and Field Test of the Influence of a Social Game on Performance of Energy Behaviors. *Environ. Behav.* **2015**, *47*, 102–115.
52. Cowley, B.; Bateman, C. Green my place: Evaluation of a serious social online game. Green my place: Evaluation of a serious social online game designed to promote energy behaviour change. *Int. J. Serious Games* **2017**, *4*, 71–90.
53. Fjaellingsdal, K.S.; Klockner, C.A. Gaming green: The educational potential of Eco—A digital simulated ecosystem. *Front. Psychol.* **2019**, *10*, 2846.
54. Hafner, R.J.; Pahl, S.; Jones, R.V.; Fuertes, A. Energy use in social housing residents. Energy use in social housing residents in the UK and recommendations for developing energy behaviour change interventions. *J. Clean. Prod.* **2020**, *251*, 119643.
55. Mulcahy, R.; Russell-Bennett, R.; Iacobucci, D. Designing gamified apps for sustainable consumption: A field study. *J. Bus. Res.* **2020**, *106*, 377–387.
56. Kiatruangkrai, W.; Leelarasme, E.; Siricharoen, W.V.; Maneerat, P. Energy saving by gamification method: Case study at a public, school, Thailand. *Int. Energy J.* **2017**, *17*, 163–170.
57. Lu, C.H. IoT-enabled adaptive context-aware and playful cyber-physical system for everyday energy savings. *IEEE Trans. Hum. -Mach. Syst.* **2018**, *48*, 380–391.
58. Ouariachi, T.; Gutiérrez-Pérez, J.; Olvera-Lobo, M.-D. Can serious games help to mitigate climate change? Exploring their influence on Spanish and American teenager's Attitudes/Pueden los serious games ayudar a mitigar el cambio climático? Una exploración de su influencia sobre las actitudes de los adolescentes españoles y estadounidenses. *PsyEcology* **2018**, *9*, 365–395.
59. Field, A.P. Kendall's Coefficient of Concordance. In *Encyclopedia of Statistics in Behavioral Science*; Balakrishnan, N., Colton, T., Everitt, B., Piegorsch, W., Ruggeri, F., Teugels, J.L., Eds.; Wiley StatsRef: Hoboken, NJ, USA, 2014; p. 8.
60. Bandura, A. Self-efficacy: Toward a unifying theory of behavioral change. *Psychol. Rev.* **1977**, *84*, 191–215.
61. Schwarzer, R. Modeling Health Behavior Change: How to Predict and Modify the Adoption and Maintenance of Health Behaviors. *Appl. Psychol.* **2008**, *57*, 1–29.
62. Fogg, B.J. A Behavior Model for Persuasive Design. In Proceedings of the 4th International Conference on Persuasive Technology (Persuasive '09), Claremont, CA, USA, 26–29 April 2009; Association for Computing Machinery: New York, NY, USA, 2009; Volume 40, pp. 1–7.
63. Petty, R.E.; Cacioppo, J.T. *Communication and Persuasion: Central and Peripheral Routes to Attitude Change*. Springer: Berlin/Heidelberg, Germany, 1986.
64. Bada, S.O. Constructivism Learning Theory: A Paradigm for Teaching and Learning. *IOSR J. Res. Method Educ.* **2015**, *5*, 66–70.
65. Burke, B. *Gamify*; Routledge: New York, NY, USA, 2014.
66. Hedin, B.; Lundstrom, A.; Westlund, M.; Markstrom, E. The energy piggy bank—A Serious Game for Energy Conservation. In Proceedings of the 2017 Sustainable Internet and ICT for Sustainability (SustainIT), Funchal, Portugal, 6–7 December 2017; pp. 1–6.
67. Bartle, R. Hearts, Clubs, Diamonds, Spades: Players who suit MUDS. 1996. Available online: https://mud.co.uk/richard/hcds.htm (accessed on 17 October 2024).
68. Pahl, S.; Goodhew, J.; Boomsma, C.; Sheppard, S.R. The Role of Energy Visualization in Addressing Energy Use: Insights from the eViz Project. *Front. Psychol.* **2016**, *7*, 92.
69. Ryan, R.M.; Deci, E.L. Self-Determination Theory. In *Encyclopedia of Quality of Life and Well-Being Research*; Maggino, F. Ed.; Springer: Cham, Switzerland, 2023; pp. 6229–6235.
70. Fraternali, P.; Herrera, S.; Novak, J.; Melenhorst, M.; Tzovaras, D.; Krinidis, S.; Rizzoli, A.E.; Rottondi, C.; Cellina, F. enCOMPASS—An integrative approach to behavioural change for energy saving. In Proceedings of the 2017 Global Internet of Things Summit (GIoTS), Geneva, Switzerland, 6–9 June 2017, pp. 1–6.
71. Abrahamse, W.; Steg, L.; Vlek, C.; Rothengatter, T. A review of intervention studies aimed at household energy conservation. *J. Environ. Psychol.* **2005**, *25*, 273–291.
72. Seligman, M.E.P.; Csikszentmihalyi, M. Positive Psychology: An Introduction. *Am. Psychol.* **2000**, *55*, 5–14.
73. Derksen, M.E.; van Strijp, S.; Kunst, A.E.; Daams, J.G.; Jaspers, M.W.; Fransen, M.P. Serious games for smoking prevention and cessation: A systematic review of game elements and game effects. *J. Am. Med. Inform. Assoc.* **2020**, *27*, 818–833.
74. Xi, N.; Hamari, J. Does gamification satisfy needs? A study on the relationship between gamification features and intrinsic need satisfaction. *Int. J. Inf. Manag.* **2019**, *46*, 210–221.
75. Horne, M.; Hill, A.; Murells, T.; Ugail, H.; Irving; Chinnadorai, R.; Hardy, M. Using avatars in weight management settings: A systematic review. *Internet Interv.* **2020**, *19*, 100295.

76. GAIM. Dutch Research Council Project: Long-Term Consumer and Community Empowerment in Energy Applications Through Inclusive Game design, Artificial Intelligence, and System Modelling. 2024. Available online: https://www.nwo.nl/en/projects/kich1ed0320022 (accessed on 17 October 2024).
77. RESCHOOL. Horizon Europe project: Strategies and tOOls for Incentivization and Management of Flexibility in Energy Communities with Distributed Resources. 2024. Available online: https://cordis.europa.eu/project/id/101096490 (accessed on 17 October 2024).