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Gamification and serious games within the domain of domestic energy consumption: A systematic review

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ABSTRACT

Energy consumption is a significant and critical social issue. Gamification and serious games offer a means of influencing people regarding energy consumption. A systematic review of articles (written in English) was conducted according to the specifications of the PRISMA checklist, in order to examine the literature and assess empirical support for the effectiveness of gamification and serious games in impacting domestic energy consumption. The search strategy included a combination of terms relating to gamification and serious games, and domestic energy consumption. Only primary studies reporting empirical data relating to the value of gamification and serious games on energy consumption were included. More comprehensive selection criteria were applied throughout the selection process (reported in full in the main text). Twenty-five primary studies published in 26 research articles were included in the final review. The findings indicate that gamification and serious games appear to be of value within the domain of energy consumption, conservation and efficiency, with varying degrees of evidence of positive influence found for behaviour, cognitions, knowledge and learning and the user experience. A common feature across many articles reviewed was the limited amount and quality of empirical evidence, which suggests that more rigorous follow-up studies are required to address this gap. The article makes specific recommendations to help address this challenge.

1. Introduction

The conservation of energy constitutes a significant and pressing social issue. Despite efforts to transition to a renewable energy economy, the world is slow to give up its dependency on fossil fuels as its primary energy source. At a time characterised by overpopulation and overconsumption, emission-intensive energy production that drives anthropogenic climate change is a serious global concern. The additional threats of resource depletion and a rapidly emerging energy-hungry middle class in developing economies compounds the seriousness of the issue. Scarcity and an urgent need for energy conservation and reduction manifest at the level of the individual with ever-increasing living costs. This represents another factor in the urgent need to reduce domestic energy consumption, with large proportions of even developed economies living near or even below the poverty line [1,2].

Households represent an important target group, with total energy consumption in the household sector and residential CO_2 emissions rising since 1990 [3]. Human behaviour and its determinants play a key role in energy usage, however, efforts to target behavioural change have produced varying levels of success [4]. An emerging area of focus is the use of serious games and gamification as tools to motivate, engage and educate people regarding energy consumption and related concerns.

Serious games and the use of gamification share a common goal; to shape human behaviour (or attitude and cognitions) through the intrinsically motivating qualities used in well-designed digital games. Serious games are defined as "*any form of interactive computer-based game software for one or multiple players to be used on any platform and that has been developed with the intention to be more than entertainment*" [5]. While gamification is most simply defined as "*…the use of game elements in non-game contexts to improve user experience and user engagement*" [6]. Thus, the distinction between the two is that serious games are fully fledged games (e.g., a digital role-playing game in which the player completes challenges or quests designed to educate them about nutrition), while gamification refers to the application of parts of games in a non-game setting (e.g., a mobile phone app designed to track and encourage exercise that uses levels, points and badges). In practice it is sometimes difficult to reliably distinguish the two as the point where a highly gamified application or tool crosses the line to becoming a game can be blurry and is highly subjective. Regardless, both serious games and gamification capitalise

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on the popularity and engaging nature of recreational (non-serious) digital games with a view to enabling change in the real world. Within the current review the term "applied games" is used to refer to serious games and gamification collectively [7].

As gamification is a relatively new concept, key theoretical understandings are still emerging. One relatively well received notion is that of 'meaningful gamification' [8]. Nicholson distinguishes between reward-based gamification (e.g., points, levels, leaderboards, achievements, or badges) and meaningful gamification, which draws on game design elements such as play, exposition, choice, information, engagement and reflection. Based on self-determination theory [9], and the distinction between intrinsic motivation (the drive to do something without external rewards and for its own sake) and extrinsic motivation (performing an activity to attain some separable outcome), Nicholson suggests that rewards-based gamification may be suitable for immediate and short-term changes, but that for long-term change meaningful gamification may be required. This aligns with the point of view of other prominent gamification theorists [10,11] who have likewise proposed that gamification's effects may be primarily extrinsically (as opposed to intrinsically) motivating and that any changes to motivation may be short term.

Serious games have seen steady interest in industry and academia over approximately the last decade [12] and gamification has become increasingly popular since it emerged around 2010 [13]. However, while both are being widely applied, the empirical evidence regarding their effectiveness is still emerging. The most thorough review of serious games to date was conducted by Connolly and colleagues [12], and while it found support for the effectiveness of game based learning, the authors noted that further research was needed. Similarly, recent reviews of the evidence supporting the effectiveness of gamification, while broadly positive [7,13], note that any positive effects are "... greatly dependent *on the context in which the gamification is being implemented, as well as on the users using it*" [14].

Regardless, existing reviews either approach applied games across domains (precluding any evaluation of their effectiveness with respect to energy consumption), focus on domains other than energy consumption [15] or look at specific Information Communication Technology mediums [16]. Despite the lack of a clear understanding of the efficacy of applied games in the energy consumption domain, these tools are being utilised to influence domestic energy consumption across a range of academic, governmental and commercial settings. Based on this increasing use of these techniques, the evidence for the context- and audience-specificity of gamification effectiveness, as well as the broader debate about gamification's overall effectiveness, the current study sought to closely examine the empirical evidence for the effectiveness of applied games in the domestic energy consumption domain.

Our objective was to examine empirical evidence reported on the value of applied games within the domain of domestic energy consumption and conservation (both efficiency gains and actual reduction). In order to achieve this objective we reviewed empirical studies that assessed the impact of applied games on a range of energy-related variables in users. Variables were limited to those determined as relevant to energy consumption occurring within a strictly domestic context. The overarching question we aim to explore in the current review is:

Does current research provide evidence that applied games are effective in influencing users with respect to domestic energy consumption?

2. Methods

2.1. Protocol and registration

The review protocol was developed by the authors to comply with the specifications of the PRISMA checklist [17], a rigorous and widely-used reporting guideline for systematic reviews. A recently published systematic review of high quality and with a similar research question [12] was used as a template for developing the protocol. All authors were involved in approving the final review protocol.

In the present review, gamification is defined according to Deterding and colleagues [6] as "*...the use of game elements in non-game contexts*" and serious games are defined as "*...game[s] in which education is the primary goal, rather than entertainment*" [18]. To enhance clarity and acknowledge significant theoretical overlap, the phrase 'applied games' will be used to broadly reference both concepts throughout the review.

Energy in the context of the present review refers specifically to electricity. However, for the purpose of this review we did not exclude studies that deal with electricity as well as other sources of energy in the home such as natural or propane gas. Within a domestic context, energy consumption refers to electricity used for lighting, heating, cooling, cooking, and to power household appliances. Whilst we use 'energy consumption' as the umbrella term for all studies relevant to this review's focus, we distinguish energy conservation between energy efficiency gains and energy reduction. Energy efficiency is the use of less energy to provide the same service and receive the same output, and energy reduction is a decrease in or avoidance of the use of and demand on an energy service. While both mechanisms can contribute to energy conservation, the Khazzoom-Brookes postulate demonstrates a paradoxical relationship between energy efficiency gains and consumption whereby a positive correlation occurs that in fact leads to an increase in energy consumption [19].

2.2. Eligibility criteria

The following inclusion and exclusion criteria were applied to the studies identified in the database search:

Inclusion criteria:

- Peer-reviewed (including peer-reviewed conference papers)
- Full-papers (including full conference papers)
- Explicitly stated and described gamification mechanic/s or elements, game or game elements or activities
- Clearly described outcomes relating to household energy consumption/conservation behaviour, including those related to both energy use and/or efficiency and/or reduction
- Empirical research

- Explained research methods / methodology / analysis

Exclusion criteria:

- Gamification or game element/activity mentioned but not part of the research being conducted
- Energy consumption and/or conservation mentioned but not part of the research being conducted
- Research focusing on environments other than the domestic household (i.e. workplace, school)
- Theoretical, conceptual papers without empirical data
- Short papers reporting on research in progress
- Extended abstracts and posters
- Publications written in a language other than English

2.3. Information sources

Electronic databases were searched in the review, as well as a manual search of the reference lists of key papers. Searches were performed between 27th March and 16th April 2015. The databases searched were those identified as relevant to information technology, social science, interaction design, psychology and environmental science: EBSCOhost (all databases) (n =1061), ProQuest (n =271), ACM (Association for Computing Machinery) (n =151), IEEE Xplore (n =179), Web of Science (n =10), Scopus (n =323) ScienceDirect (n

Table 1
Number of articles from each information source.

Database	No. papers identified	No. meeting inclusion criteria
ACM	154	3
BioMed Central	13	0
Cambridge Journals Online	95	0
EBSCOhost (all databases)	1142	3
ProQuest	306	1
IEEE Xplore	182	0
Science Direct	498	1
Scopus	402	11
Web of Science	21	1
Manual search	18	8
Total	**2831**	**26**

=492), BioMed Central (n =13), Cambridge Journals Online (n =92). An additional 16 records were identified through a manual search of the reference lists of key articles in an effort to include all available studies (see Table 1).

2.4. Search

Search terms included terms for gamification and serious games in conjunction with possible terms for energy-related outcomes. In order to capture all relevant studies according to the gamification and games criteria, search terms were selected to represent the variety of gaming formats that might emerge within the scope of applied games as per their definition in the present review. Terms relating to play were not included due to interest in the explicit use of applied games of some description. While it is recognised that this may exclude relevant studies where such terms are not used (e.g. playful, persuasive and pervasive applications), these were deemed to fall outside the scope of the current review.

(gamif OR gameful OR "serious game*" OR "digital game" OR "electronic game*" OR "videogame" OR "video game").*

In order to capture all relevant studies according to the energy-related outcomes criteria, search terms were selected 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 meter*" OR "sustainable HCI" OR "sustainable interaction design" OR "energy awareness" OR "energy engagement" OR "personal emissions" OR "carbon saving" OR "ecological footprint" OR "carbon emissions" OR "eco-visuali*" OR "eco-feedback technology" OR "climate change").

2.5. Study selection

Papers identified by search terms in the initial database search were screened in two stages: first by title only, and second by both title and abstract. This was performed by a single researcher, with a small sample independently examined by a second researcher at each screening stage. Papers that progressed through the two stages of screening underwent a full-text assessment for eligibility. This was performed by a single researcher. Two additional researchers examined the results of the full-text eligibility assessment, to ensure compliance with the selection criteria. Following the full-text eligibility assessment, a total of n =26 papers representing 25 primary studies were found to be eligible for review.

2.6. Data collection process

Data was extracted from the 25 primary studies included in the review using a data extraction form developed for use in the present study (appendix). The data extraction form was developed as a spreadsheet by a single researcher, and was loosely based on the Cochrane Consumers and Communication Review Group's data extraction template [20]. The form was not piloted, and was populated by the same single researcher by whom it was developed. No actions were taken to seek additional information from paper authors, with all relevant information identified within the published papers.

The data extraction process identified some cross-over in the papers eligible for review, with two papers found to report the same data from the same primary study and another two found to report different data collected from the same primary study. This was addressed in data extraction by grouping articles reporting data from the same primary study.

2.7. Data items

The variables for which data were sought included those related to the publication of the article (discipline, author/s, year of publication, journal), aim(s) of study, hypothesis, research question(s), the intervention (game description, modality, elements, and category), study design (setting, outcome/s, outcome measure/s, method/s of assessment, and reliability and validity), sampling (inclusion and/or exclusion criteria, sample size and characteristics (including age), recruitment and selection), data collection (who, duration, instrument/s, reliability and validity), data analysis (method/s and rationale), and results (findings and statistical significance).

2.8. Game classification

The games or gamification elements described in each of the primary studies were categorised based on their degree of digitisation and integration with the real world. The categories 1–3) were devised by researchers in the present study and are described below:

1. Fully digital games that have no real world integration but are aimed at influencing the real world (e.g. learning to reduce energy consumption within a virtual apartment)
2. Games that may be digital but have some integration with the real world (e.g. the digital game prompts an action in the real world or pervasive or augmented reality games)
3. Games with no digital elements that occur, and are thus fully integrated, in the real world (e.g. monitoring your shower time by showering for the length of a song)

2.9. Quality assessment

The studies included in the review were assessed for quality based on the protocol developed and applied by Connolly and colleagues [12] in a systematic review of a similar nature. Papers were assessed for quality across five dimensions and scored between 1 and 3, with 3 denoting high, 2 denoting medium and 1 denoting low for each criterion. The final scores for quality were calculated between 5 and 15, with 15 indicating the highest possible level of quality according to the assessment tool. All eligible studies were independently coded by two reviewers.

The five dimensions as described by Connolly and colleagues [12] were adapted for the present review and are outlined below:

1. How appropriate is the research design for addressing the question identified in this review. Papers were coded as:

- High =3, e.g. use of randomised control trials

- Medium =2, e.g. quasi-experimental controlled study
- Low =1, e.g. case study, single subject-experimental design, pre-test/post-test design

2. How appropriate are the methods and analysis?
3. How generalisable are the findings of this study to the target population with respect to the size and representativeness of the sample. To what extent would the findings be relevant across age groups, gender, ethnicity, etc.?
4. How relevant is the particular focus of the study (including conceptual focus, context, sample and measures) for addressing the question or sub-questions of this review?
5. To what extent can the study findings be trusted in answering the study question(s)?

Quality assessment of the 25 primary studies eligible for review was undertaken independently by two researchers. A coding matrix was also developed to streamline and increase the accuracy and reliability of the quality assessment process. While this does not address subjectivity in the coding of the papers, it does assist in the establishment of inter-rater reliability. To resolve differences in scoring, an iterative process of quality assessment was adopted. This approach was endorsed by Sirriyeh and colleagues [21] in their development of a 16-item quality assessment tool (QATSDD) for methodologically diverse research articles. QATSDD was used to assist in the development of the coding matrix used in the present study.

Inter-rater reliability regarding the quality coding of the papers was determined by calculating Cohen's kappa using IBM SPSS Statistics 22. The inter-rater reliability (ρ) for the total scores was .818, showing a good level of agreement between the two coders with respect to the quality of the papers.

2.10. Synthesis of results

No meta-analysis was conducted as the primary studies included in the review did not report sufficient statistical information to calculate the necessary effect sizes. Synthesis of the results focusses on a discussion of the empirical trends in the data.

3. Results

3.1. Study selection

2831 papers fit the initial inquiry (see Fig. 1), which decreased to 2518 after duplicates were removed (n =313). A total of 2518 papers were screened by title, resulting in the removal of 2255 papers for a range of exclusionary factors, including incorrect publication type (n =152), published in a language other than English (n =17), and irrelevant overall based on title (n =2086). A total of 263 papers progressed to the second stage of screening, which involved application of the selection criteria to the title and abstract. A total of 191 papers were excluded as a result of the second stage of screening. The exclusionary factors for removal at this stage of screening were more detailed, with the breakdown as follows: incorrect publication type (n =18), theoretical / conceptual only (n =27), irrelevant outcome (n =23), examining applied games outside the energy consumption domain (n =47), examining energy consumption and/or efficiency but without incorporating applied games in the research (n =38), and irrelevant overall (n =38).

A total of 72 papers remained to be assessed for eligibility based on their full-text. The eligibility assessment process resulted in the exclusion of 46 full-text papers for various exclusionary factors, including papers of a descriptive nature only (n =17), no specification of energy consumption and/or efficiency (n =11), no specification of gamification and/or games (n =5), examining energy consumption and/or efficiency within a context other than the household (n =5), mentioning gamification and/or games but not part of research (n =3), theoretical papers (n =3), reporting pre-testing data only (n =1), and repeat publications (n =1). A total of 26 papers representing 25 primary studies were deemed eligible for review and progressed to quality assessment (see Table 2 for details on all papers included in the full review).

The results of one intervention was published across two separate research papers [22] and [23], and therefore considered to represent one primary study. Another two studies reported data from the same intervention, however, were considered to represent separate primary studies due to methodological differences [24,25].

3.2. Study designs

A range of study designs were represented across the 25 studies, with the majority employing analytic designs to quantify the relationship between the intervention and specified outcome/s. Descriptive studies comprised a small proportion of the studies, as is expected in a review of empirical evidence.

A mixed methods approach was adopted by the majority of the studies (n =17), however, exclusively quantitative (n =5) and qualitative (n =2) studies were also featured. The majority of studies were based on a survey study design (n =11), followed by quasi-experimental study designs (n =5). Other study designs included case studies (n =2), pilot studies (n =2), and qualitative study designs (n =2). Only one longitudinal field study and one randomised control trial (RCT) were identified.

3.3. Study sample

The included studies involved a total of 4026 participants, however, many studies failed to report or did not clearly articulate participant numbers. For example, some studies referred to families or households and did not clarify the exact number of participants. Sample sizes ranged from 5 (in a rapid usability assessment) to 2580 (in a survey to broadly characterise the target population), however, participant numbers were generally less than 200.

Little information was provided relating to the recruitment and selection of participants. The recruitment of participants was generally conducted by convenience sampling, namely via identification of participants through researchers' personal networks (email listings, acquaintances and family members). Some studies reported having conducted random probability sampling, however, the true representativeness of these samples is unclear due to selection of participants from research subject pools or via other methods, and generally insufficient information has been provided with which to confirm that true randomisation had been carried out. In a few cases, authors constructed purposive samples in order to target a specific subset of the population.

The selection of participants for inclusion in the studies in the majority of cases did not appear to be based on any particular set of characteristics, apart from in the small number of studies identifying their sampling strategy as purposive. In these studies, certain participant traits were especially selected. Many studies provided limited or no information regarding the study sample. Thus it was difficult to assess the adequacy of the study sample in terms of size and representativeness.

The age of participants ranged from 6 years to 55 years. Participant characteristics were broad. The most widely represented group were young adults, with participants generally clustered between the ages of 18 and 30. This information is based on only half of the studies included in this review, as 13 of the studies failed to provide any information pertaining to the age of the participants in the study sample.

The setting for the studies varied, despite the focus of the systematic review on energy-related concepts within a domestic

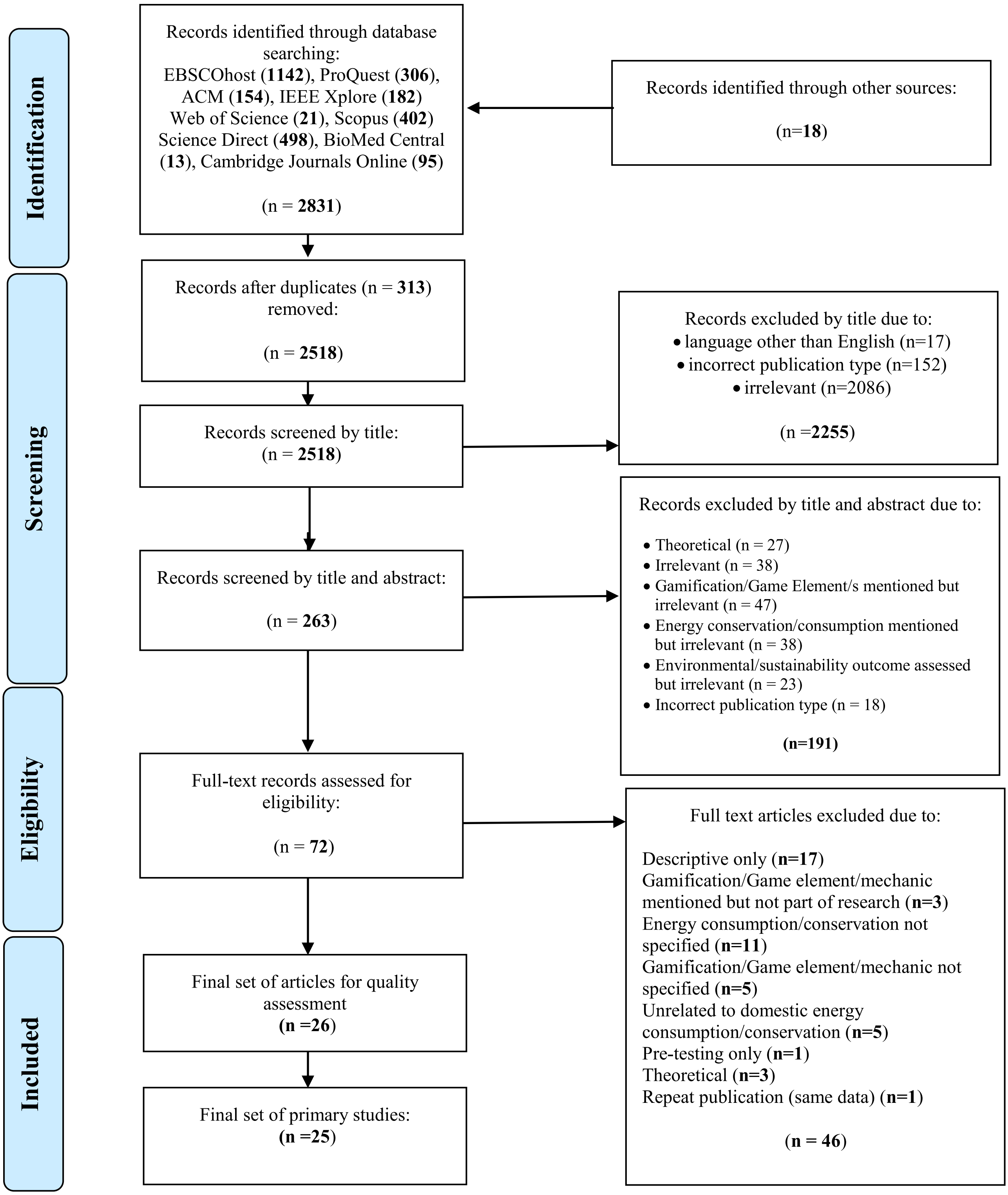

Fig. 1. Flow diagram for study selection.

domain. The settings included household (n =7), laboratory (n =6), classroom (n =3), university dormitory (n =4), university campus (n =1), workplace (n =1) and in the participants' private space (uncharacterised) (n =1). No information was provided regarding the setting for three of the studies.

3.4. Data collection and analysis

Data was predominately a mixture of quantitative and qualitative, with a number of studies triangulating data to strengthen their results and conclusions. The most frequently employed method of data collection was the questionnaire, which was used to collect quantitative and/or qualitative data in 22 studies. The format and mode of delivery of the questionnaires varied, however, online and paper-based tools administered by the researcher and consisting entirely of quantitative items predominated. In some cases, multiple questionnaires were employed to measure a range of variables at various time-points. For the collection of qualitative data, interviews were the most common

Table 2
Included paper details.

Author, Year	Game, modality	Aims/Objectives	Study design; *data collection*	Data analysis	Game element/s	Outcome/s (Effect +/-)	Results	Sample size	Participants	Quality
(Al Mahmud et al. 2007)	**iParrot**, mobile app (prototype)	Design a persuasive agent that can encourage energy conservation in a home setting	Mixed methods, Survey; *Questionnaire*	Statistical	Feedback	User Experience (+)	Friendliness, trust and gender influence willingness of users to comply with social agent.	30	18 Male, 12 Female	Low
(Banerjee & Horn 2014)	**Ghost hunter**, mobile app	Support informal learning for parents and children in homes	Qualitative; *Observations, Interviews*	Not described	Feedback	User Experience (+) Knowledge (-) Behavioural (in-game) (+)	Increase in awareness of household energy consumption No increase in understanding of kWh Gameplay encouraged discussions about household consumption and infrastructure.	7 families (22 individuals)	13 adults, 9 children (2 girls, 7 boys, average age 6.78 years)	High
(de Vries & Knol 2011)	**EnerCities**, non-mobile (online)	Examine effectiveness of the game on several energy-related attitudes	Quantitative, Quasi-experimental (between-participants) design; *Questionnaire*	Statistical	Levels, Social Sharing, Points, Rewards	Cognitive (attitudes) (+)	Significant increase in attitudes towards saving energy and performing specific energy-related household behaviours.	653	235 Female, 418 Male, average age 16.40 years	Low
(Dorji et al., 2014)	**Residence Energy Saving (RES)-battle**, non-mobile (computer game)	Investigate the effectiveness of the RES-battle in improving students' learning performance of energy consumption and conservation, and gender differences.	Quantitative, Survey; *Questionnaire*	Statistical	Feedback	Knowledge (+) User Experience (+)	Improvement in conceptual learning, attitudes and knowledge of energy consumption and conservation, No gender differences	68	Secondary school students	Low
(Gamberini et al. 2011)	**EnergyLife**, mobile app	Assess the satisfaction/ acceptance and usability of the game.	Mixed methods, Field study; *Questionnaire, Interviews, Access Logs*	Statistical, Thematic	Feedback, Tips, Challenges, Social Sharing, Rewards	User Experience (+) Behavioural (in-game) (+)	Positive results for acceptance and usability of application. Users found game interface enjoyable. Perceived as useful in the management and awareness of energy consumption and effective in changing consumption habits.	8 households (24 individuals)	11 Male, 13 Female, average age 34.87 years	High
(Geelen et al. 2012)	**Energy Battle**, non-mobile (online)	Assess the impact of Energy Battle on household energy consumption and savings.	Mixed methods, Survey, Pre-post testing; *Questionnaire, Interviews, Energy Meters*	Not described	Feedback, Rankings, Tips, Rewards	Cognitive (motivation) (+) Behavioural (+)	Household energy consumption reduced during gameplay, and remained below baseline directly post-intervention for 6/10 households. Participation motivated by prizes and potential energy savings. Direct feedback and prizes were the most motivating game elements for energy	20 student households (2-5 people in each)	Students	Low

(continued on next page)

Table 2 *(continued)*

Author, Year	Game, modality	Aims/Objectives	Study design; *data collection*	Data analysis	Game element/s	Outcome/s (Effect +/-)	Results	Sample size	Participants	Quality
							saving			
(Gustafsson et al., 2009)	**Power Explorer**, mobile app	Examine if pervasive games can achieve post game behavioural effects.	Mixed methods, Quasi-experimental (between-participants) design; *Questionnaire, Interviews, Energy Meters, Observations, Access Logs*	Statistical, Thematic	Feedback, Avatars	Behavioural (+) Knowledge (+/-) User Experience (+) Cognitive (attitudes) (+/-)	Positive game experience of users. Decrease in electricity consumption achieved during game period but not Post-game period Significant positive change in players' attitude to saving energy, increase in explicit knowledge of power rating on appliances	15	Teenagers (12-14 years) and their families	High
(Gustafsson et al., 2009)	**Power Agent**, mobile app	To evaluate and analyse a pervasive game designed to encourage positive behaviour change	Mixed methods, Quasi-experimental (between-participants) design; *Energy Meters, Interviews*	Thematic	Challenges, Feedback, Tips	Behavioural (+/-) Knowledge (+) User Experience (+) Cognitive (motivation) (+)	Reduction in energy consumption achieved during gameplay, but no long -term effect Participation motivated by competitive and social aspects of the game. Energy conservation strategies and knowledge gained influenced through game sessions.	6	Teenagers (3 Male, 3 Female) and their families	High
(Kimura & Nakajima 2011); (Takayama et al. 2009)	**EcoIsland**, both mobile app and non-mobile (online)	To explore design strategies applied in persuasive applications to encourage users to perform eco-friendly activities	Mixed methods, Survey, Pre-post testing; *Questionnaire, Interviews, Energy Meters, Activity Log*	Not described	Rewards, Feedback, Avatars	Behavioural (-) Cognitive (attitudes) (+) Cognitive (motivation) (-)	Kimura: No energy consumption behaviour change and no evidence of impact on intrinsic motivation to engage in eco-friendly activities. Change in self-reported attitude due to the feedback. Higher reporting of eco-friendly activities as game progressed (week 3 Vs. week 2). Takayama: Increased levels of awareness and knowledge of environmental issues.	6 families (20 individuals)	Parents (47-58 years) with 1-2 children (15- 24 years)	Low
(Knol & De Vries 2011)	**EnerCities**, non-mobile (online)	Examine if game can offer engaging environment to	Mixed methods, Quasi-experimental (between-participants)	Statistical	Levels, Social Sharing, Rewards	User Experience (+)	Increase in awareness of energy and environmental related issues and	76	Students	High

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Table 2 (continued)

Author, Year	Game, modality	Aims/Objectives	Study design; ***data collection***	Data analysis	Game element/s	Outcome/s (Effect +/-)	Results	Sample size	Participants	Quality
		encourage learning about energy saving	design; *Questionnaire*			Cognitive (awareness, attitudes) (+) Knowledge (+)	improvement in attitudes towards behaviours relating to household energy consumption.			
(Kuntz et al., 2012)	**iChoose**, non-mobile (online)	To describe lessons learnt from utilizing game mechanics to reward participants for changes they make in their real lives.	Quantitative, Case study; *Questionnaire, Activity Log*	Not described	Points, Leaderboards, Social Sharing, Rewards	Behavioural (+)	Increased activity to save household energy and number of regular conversations about sustainability both during and after gameplay. Reporting of new sustainable actions taken as part of the game	230	Employees	Low
(Lee et al. 2012)	**Kukui Cup**, non-mobile (online)	To describe Makahiki and the Kukui Cup, and provide a brief review of the foundational research.	Mixed methods, Survey; *Questionnaire, Interviews, In-game Tracking*	Not described	Points, Levels, Challenges, Rewards, Feedback, Badges, Leaderboards	User Experience (+)	Positive user experience and attitudes towards game Design errors leading to reduced player motivation and interest Raffle game most interesting incentive to participate.	41	First year students	Low
(Lee et al. 2013)	**Greenify**, non-mobile (online)	To explore the feasibility and potential value of a social, crowdsourced, gamification-based system	Mixed methods, Pilot study; *Formative Assessment, Questionnaire, Interviews, In-game Tracking*	Not described	Social sharing, Challenges, Points, Leaderboards, User-generated Content, Avatars	Behavioural (+) Cognitive (awareness) (+) User Experience (+)	High level of behaviour change as a result of the game Participants reported positive user experience and greater awareness of personal impact on environment. Social interaction/sharing identified as powerful game feature in terms of motivating action.	26	Adult students (8 Male, 18 Female)	Low
(Mesquita et al. 2013)	***Untitled***, non-mobile (computer game)	To assess the impact of the virtual game in the teaching and learning process	Quantitative, Survey; *Questionnaire*	Not described	Challenges	Cognitive (motivation) (+) User Experience (+) Knowledge (+)	Increase in participants ability to retain, discuss and apply information related to the game theme.	43	High school students	Low
(Nguyen 2014)	***Untitled***, mobile app (prototype)	Examine if prototype can increase awareness, energy savings and avoidance of energy peak times	Qualitative, Usability Testing	Researcher Observation	Social Sharing, Leaderboards, Feedback, Challenges, User-generated Content, Tips	User Experience (+) Cognitive (motivation) (+/-)	Leaderboards and social sharing as the most motivating game elements. All participants felt it would lead to increased energy awareness and reduced energy consumption, but	5	3 Males, 2 Females, 21-43 years	Low

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Table 2 *(continued)*

Author, Year	Game, modality	Aims/Objectives	Study design; *data collection*	Data analysis	Game element/s	Outcome/s (Effect +/-)	Results	Sample size	Participants	Quality
							not during energy peaks.			
(Odom et al., 2008)	**The Energy Challenge**, non-mobile (online)	To obtain key insights related to the design of effective eco-visualization (EV) displays for student dormitory communities.	Qualitative, Survey; *Interviews, Conceptual Evaluations*	Not described	Feedback, Rewards, Leaderboards	User Experience (+) Behavioural (+) Cognitive (motivation) (+)	Electricity use reduced during game period (estimated 33,008 KWh combined saved). Social incentive and competition identified as important factors in motivating participation and conservation behaviour.	Not specified	Student dormitory residents	Low
(Peham et al., 2014)	**ecoGator**, mobile app (prototype)	To evaluate the gamification strategy of ecoGator in terms of motivation, understanding and ease of use.	Mixed methods, Survey, Usability Testing; *Questionnaire, Task Series, Interviews*	Not described	Rewards, Points, Levels, Leaderboards, Challenges, Tips	User Experience (+)	Perceived as user-friendly and useful for learning about energy saving Found to be most successful for individuals already sensitive to energy saving.	15	5 participants from each target group	Low
(Pisithpunth et al. 2014)	**The Growth**, non-mobile (computer game prototype)	To investigate the possibility of using serious games to modify players' consumption patterns.	Mixed methods, survey and usability testing; questionnaire, interviews	Thematic	Challenges	Cognitive (motivation) (+) User Experience (+) Knowledge (+)	Majority of users motivated by desire to cut personal spending and learn about new technologies and actions that can reduce personal energy consumption. All participants able to recall and discuss articles from game, with energy saving and emerging technologies the most recalled topics.	17	Male, 22-29 years	Low
(Reeves et al. 2015)	**Power House**, non-mobile (online)	To test whether a combination of game features built into a professional game could cause people to make energy-efficient choices.	Lab experiment: Mixed methods, RCT; *Interviews, Observations, Questionnaire.* Field study: Quantitative, Quasi experimental (within-subject) design; *Energy Meters*	Statistical	Points, Leaderboards, Challenges, Feedback, Social Sharing	Behavioural (+)	Significant increases in energy efficient behaviours but small decreases in electricity usage during gameplay relative to 30-day periods before and after play.	40, 51	Field study: adults, 21 Male, 30 Female, 18-55 years. Not described for the lab experiment	High
(Salas-Prat et al. 2014)	**Personal Energy**, both, mobile app and non-mobile (online)	To learn about end-users of the Personal Energy platform.	Quantitative, Quasi-experimental (pre-test-post-test control) design; *Questionnaire, Meter Data*	Statistical, Clustering analysis	Points, Badges, Social Sharing, Challenges, Rankings, Leaderboards, Feedback	User Experience (+) Behavioural (+)	Three types of user identified based on differing attitudes and beliefs towards energy efficiency: environmentalist saver, comfort-oriented indifferent and environmentalist investor. Evidence of an increase in	400, 87	Participants of the 'Rubi Brilla Project'	High

(continued on next page)

Table 2 *(continued)*

Author, Year	Game, modality	Aims/Objectives	Study design; *data collection*	Data analysis	Game element/s	Outcome/s (Effect +/-)	Results	Sample size	Participants	Quality
							electricity savings by all users.			
(Salvador et al., 2012)	**Motion-based Ambient Interactive Display (MAID)**, non-mobile (other platform)	To evaluate the usability, gameplay and effects on users of MAID.	Mixed methods, User evaluation study; *Questionnaire, Observations*	Not described	Feedback, Social Sharing	User Experience (+) Cognitive (motivation) (+)	Game successful in providing useful domestic energy consumption information, and appeared to have a persuasive effect in motivating users to change their behaviour.	26	21 Male, 5 Female	Low
(Senbel et al., 2014)	**Do It In The Dark**, non-mobile (online)	To identify the motives for participation and determine the overall effectiveness of an energy conservation competition short and medium-term	Mixed methods, Quasi-experimental (pre-test post-test control) design; *Meter Data, Focus Groups, Questionnaire*	Statistical	Feedback, Points, Social Sharing, Rankings, Challenges, Rewards	Behavioural (+) User Experience (+) Cognitive (motivation) (+)	short- and medium-term energy reduction, and increased intentions to engage in energy reduction actions after the competition Increased levels of energy-related conversations and positive peer-pressure also reported. Points and prizes effective as initial incentive, while challenges and social interaction motivated sustained engagement.	201	Student dormitory residents	High
(Stone et al. 2014)	**eViz**, non-mobile (computer game)	To investigate the efficacy of the eViz virtual apartment concept.	Mixed methods, Pilot study; *Questionnaire, Observations, In-game Tracking*	Statistical, Thematic	Challenges, Feedback	User Experience (+) Cognitive (awareness) (+) Behavioural (in game) (+)	Positive user experience and usability results, with user-friendliness of platform, energy interest, motivation and perceived responsibility identified as important factors Game encouraged thoughts related to energy use in own home to an extent, however most likely for users interested in energy efficiency	40	18 Male, 22 Female	High
(Tsai et al., 2012)	**Super Delivery**, non-mobile (online)	To investigate the learning effectiveness of knowledge acquisition after playing Super Delivery	Mixed methods, Case studies; *Observations, Interviews, Performance Tests, Audio- and Video-recordings*	Qualitative, Document Analysis	Challenges, Rankings, Leaderboards, Social sharing	Knowledge (+/-) User Experience (+)	Empirical effectiveness of Super Delivery unclear due to difference in effectiveness of knowledge acquisition levels amongst users. Prior knowledge, playing motivation and online game experience identified as	8	Sixth-grade students (4 Male, 4 Female)	High

(continued on next page)

Table 2 (*continued*)

Author, Year	Game, modality	Aims/Objectives	Study design; *data collection*	Data analysis	Game element/s	Outcome/s (Effect +/-)	Results	Sample size	Participants	Quality
							factors indirectly influencing the effectiveness of knowledge acquisition			
(Yang et al. 2012)	**ECOPET**, non-mobile (computer game)	To examine how the ECOPET system affects users' self-awareness, learning motivation and willingness to conserve energy.	Mixed methods, Qualitative design, Survey; *Questionnaire, Observations, Video-recordings*	Statistical	Feedback, Tips, Levels, Avatars, Challenges	Cognitive (awareness, motivation) (+)	Significantly promoted learning motivation willingness to conserve energy and self-awareness and	23	Graduate students (15 Male, 8	Low
						Knowledge (+)	knowledge of energy conservation		Female)	
						User Experience (+)				

technique (n =13), followed by observations (n =4) and video recordings (n =2). Quantitative data was collected from energy meters or monitors (n =7), game server logs (n =7) and self-reported activity logs (n =2). Other methods included audio recordings, focus groups, user photographs (taken during an intervention), and various tools employed in the context of a usability testing protocol (including think-aloud verbal protocol, document analysis and task series).

Reporting of the duration of data collection by each of the primary studies was poor. Based on the information provided, data collection ranged from 3 weeks to over a year, with the majority extending for a period of between 1 and 4 months. Data analysis was poorly reported by many of the eligible studies, with the majority failing to identify key aspects of the process and results (e.g., method of data analysis including techniques used to determine statistical significance was often not identified). Quantitative data analysis employed predominantly statistical methods (including significance testing (*t*-test), univariate (ANOVA) and multivariate (MANOVA) testing, correlational analysis, Mann-Kendall testing, and descriptive statistics), while thematic analysis was the primary method of analysis for qualitative data.

3.5. Quality assessment

The quality of the studies ranged from 5 to 12. The mean rating for the 25 primary studies was 7.5, and the modal rating was 6. Papers rated 7.5 or over (above average) were considered to provide methodologically stronger evidence in the context of the review question. The basis for determining this cut-off point was similar to the strategy employed by Connolly and colleagues [12], which used the mode and mean. Due to the relatively low quality of the studies in the current review, the mean was used on its own to determine the quality cut-off point.

Twelve of 25 primary studies (48%) were assessed to be of higher quality (quality score of 7.5 or greater). The remaining 13 studies were given a quality score of less than 7.5 and therefore were considered to provide less methodologically strong evidence in the context of the review question.

3.6. Applied game type

The applied games reviewed in the present study were delivered in various modalities, using a range of platforms including online web applications, computer games, motion-detectors, and mobile applications. For simplicity, the applied games were classified into two broad categories; dedicated mobile applications (games and gamified tools delivered via a mobile application) and non-mobile applications (games and gamified tools delivered via personal computer (as opposed to mobile devices). Within the review, 7 studies focussed on dedicated mobile applications, 15 on non-mobile applications and 2 studies involved delivery as both a mobile application and via alternative platforms incorporated within the non-mobile classification. Among the 15 non-mobile applications, interventions included online applications (n =9), computer games (n =5) and other platforms (n =1).

The interventions were further classified in terms of whether they more closely resemble a serious game or a gamified application/tool. Exactly half of the interventions described by the studies included in the review (n =12) were serious games [24–36]. The other half (n =12) presented gamified applications/tools [22,23,37–47].

The games and gamified tools were categorised based on their level of digitisation and integration with the real world, as per the classification developed for use in the present study (described in methods). The majority of the games and gamified tools/applications (n =13) demonstrated a certain level of integration with the real world (category 2), followed closely by fully digital games with no real world integration (category 1) (n =12). No games or tools/applications were classified into category three (games with no digital elements).

Table 3
Frequency of use of applied game elements.

Applied Game Element	Count
Avatars	4
Challenges	15
Feedback	17
Leaderboards	9
Levels	5
Rewards	10
Social Sharing	11
Points	8
Tips	6
Rankings	4
Badges	2
User-generated content	2

3.7. Game elements

The 25 primary studies eligible for review represent a range of game elements embedded in a variety of ways. The specific number of time each element was employed in the studies reviewed is shown in Table 3 (below). In order of frequency, these included feedback, challenges, social sharing, rewards, leaderboards, points, tips, levels, rankings, avatars, badges and user-generated content.

It was common for a number of game elements to be incorporated into each intervention, with only five embedding one game element only. Two to three game elements were embedded in seven interventions, four to five were embedded in eight interventions, and greater than 5 were embedded in five of the interventions reviewed.

3.8. Studied outcomes

The outcomes assessed by the 25 primary studies included in the review are grouped into four categories as per the high level classification proposed by Connolly and colleagues [12]. These are: behavioural outcomes, cognitive outcomes, and learning and knowledge acquisition outcomes. The additional outcome category of user experience has been added as a fourth category to adequately classify all identified outcomes.

Behavioural outcomes included both actual and intended behaviour outside the game or application (referred to as real world behaviours), and energy-related behaviours taken by participants within the applied game (referred to as in-game behaviours). The kinds of behaviours measured varied significantly between studies, reflecting the breadth of the domain of energy consumption and efficiency. Real world behavioural outcomes included energy consumption (reported and actual, short, medium and long term), energy saving activities/actions (self-reported) and intention to engage in energy-saving behaviour. Behavioural outcomes within the applied game included the identification and selection of energy-saving actions (in the context of the applied game) and user purpose in terms of energy-related goals.

Cognitive outcomes were related to affective and motivational factors, and included energy-related attitudes, motivation to engage in eco-friendly behaviour, self-awareness of energy conservation, and willingness to conserve energy. There is evidence of a strong relationship between certain cognitive outcomes, such as attitudes, and energy saving [4,48].

Learning and knowledge acquisition outcomes included learning effectiveness, identification of specific energy saving actions, knowledge gains, change in awareness of environmental and energy-related issues, gain of explicit knowledge of electrical appliances, conceptual learning performance and progression, and the gain of knowledge of energy consumption.

User experience refers to the participant's attitudes towards and engagement with the applied game and includes outcomes relating to both user satisfaction and usability [49]. In the present review, the scope of user experience was broad and thus incorporated variables ranging from subjective responses to the intervention, such as ease of navigation and enjoyment, as well as more objective measures relating to amount of use of the applied.

The most popular outcome category was user experience (n =20), followed by cognitive (n =15), behavioural (n =13), and knowledge (n =9). Within the behavioural category, the majority of studies (n=10) looked at real-world behaviour and a minority at in-game behaviour (n=3). It was common for multiple outcomes to be measured, with the majority of the studies eligible for review (n =17) measuring more than one outcome. Few studies reported data relating to the role of specific game elements in the results of the intervention and the level of influence of its particular features in relation to the target population/s. However, as shown in Table 4, it is possible to gain a sense of the trend in terms of the common effects (positive, negative or mixed) associated with each outcome category. As can be seen, the impact of applied games on the user experience was consistently positive, the impact on in-game behaviours was consistently positive and the impact on real-word behaviours was almost always (90% of the time) positive and otherwise mixed/neutral. For cognitive and knowledge related outcomes the evidence is more mixed (though predominantly positive). For cognitive outcomes the majority (80%) of effects were positive with some (20%) evidence of mixed/neutral results. Finally, for knowledge related outcomes, although the majority (67%) of effects were positive, there was also evidence of a negative effect and some (22%) mixed/neutral effects (11%).

Table 4
Positive, mixed and neutral effects of applied games across outcome categories.

Outcome	Positive	Mixed	Negative	Number of times assessed
User Experience	20	0	0	20
Cognitive	12	3	0	15
Behavioural (real world)	9	1	0	10
Knowledge	6	2	1	9
Behavioural (in-game)	3	0	0	3

3.9. Discipline

The studies represented a range of disciplines (identified based on publication venue), including education, computer and information science, business and economics, and science and communication. The most widely represented discipline was computer and information science (n =12), which included publications from a number of specialised interest areas including persuasive technology, informatics, gaming and human-computer interaction (HCI). The second most popular discipline was education, with seven studies examining the evidence from an educational perspective. Publications included those from education broadly, as well as from the more specialised areas of learning science, innovative learning, e-learning and distance education. Other disciplines represented included business and economics, energy efficiency, industrial design and engineering, behavioural sciences, communication studies, and community and regional planning, with one study published in each aforementioned area.

3.10. Reported effects

The effect of applied games on energy-related outcomes was largely positive, with exclusively positive effects demonstrated in 19 of the 25 studies. No studies reported a solely negative effect, however, both positive and negative effects were observed in 6 studies.

4. Discussion

The popularity of applied games as a novel approach to encouraging real-world change is supported by the large number of articles captured in the initial search. The limited number of empirical articles remaining after application of the selection criteria suggests applied games within the domain of domestic energy consumption is yet to be comprehensively examined. The majority of papers included in the review (n =21) were published in 2010 or later, with 11 published in the last three years.

The final 26 papers and 25 primary studies eligible for review represent great diversity in terms of research methodology, interventional design and framework, and disciplinary focus. The range of disciplines undertaking research which examines a games-based approach to domestic energy consumption confirms the area is of broad interest and applicability. This suggests a shift away from the mono-disciplinary focus of interventions to influence energy-related behaviours previously identified [4].

The review has demonstrated that there is a small body of evidence which suggests applied games can have a positive effect on energy-related domains and can potentially influence behaviour or behavioural antecedents. The reliability of these results is partially undermined by shortcomings identified in the methodologies of the reviewed studies, including small sample sizes, poorly described methodologies, limited use of validated measures to quantify outcomes, absence of controls, presentation of descriptive statistics only, and narrow data collection timeframes. Some of these limitations are inherent to particular fields, such as purposefully small sample sizes in exploratory design research intended to produce rich qualitative insights, or narrow data collection timeframes that are commonplace in case study research conducted by higher degree research students. The present review does not critique or object to the peer review assessments that the selected papers underwent. The papers are categorised as low quality only with respect to the aim of the present review (assessing the empirical evidence they provide regarding the effectiveness of applied games in this domain), and indeed, these papers may be considered high quality based on other aims and criteria.

4.1. Game elements

A variety of game elements were employed in the studies, with the most common inclusions being feedback, challenges, social sharing, rewards, leaderboards and points. As described below, there is evidence for these having various positive influences across impact types. Unfortunately, few studies compare the impact of differing game elements, which precludes many conclusions regarding the relative impactfulness of specific game elements. Of the five papers that did compare game elements only two were rated as high quality. Gustafsson [28] and Senbel [47] both found evidence for the value of competition and social sharing as a means of encouraging participants. Additionally, Senbel [47] found that points and prizes worked as an initial incentive but other game elements (e.g., challenges) were more useful throughout the period of participation.

Looking across the full range of papers (regardless of whether the impact of specific game elements was isolated), the present review aligns with that of Abrahamse and colleagues [4] in finding that feedback is often applied as a tool to promote energy conservation and appears to be an effective strategy. Similarly, the current study aligns with Abrahamse et al. in providing support for the utility of rewards as a means to encourage energy savings. In addition to providing further support for these existing connections, the present review provides evidence of the common use of challenges as a means to engage people in energy conservation and initial support for an associated positive impact.

4.2. User experience

Empirical evidence was identified for a wide range of outcomes within the four classifications, with positive effects reported in all 25 studies and negative effects in just 6. The most frequently measured variables were classified as user experience (n =20). This was also the most successful classification, with positive effects observed in all 20 of the eligible studies investigating user experience. Of these, only 7 were high quality (as per our own ratings). A positive attitude towards the game or experience playing the game was the most commonly reported user experience outcome amongst the high quality studies [28,29,34,35,38,47]. This suggests that users generally respond positively to applied games, however, in the context of the review, user experience is not regarded as an outcome that adds weight to the evidence that applied games are effective in influencing domestic energy consumption. Additionally, it is unfortunately not possible to effectively explore whether any relationship exists between key demographics (e.g., age) and the user experience of applied games as no studies test for this and many studies do not report the required demographic information.

4.3. Cognitive outcomes

Cognitive outcomes were measured in 15 studies, all of which reported positive effects. Two studies reported both positive and negative effects. These were further classified into attitudes (n =4), motivation (n =10), and awareness (n =4). A total of 4 studies measuring cognitive outcomes were classified as high quality (as per our own ratings), with quality assessment scores of 7.5 or greater. Despite clear interest in the impact of applied games on cognition in the context of domestic energy consumption, there was limited evidence to demonstrate the actual effect of the intervention in terms of the cognitive outcome measured. The high quality studies reported positive changes in attitudes towards energy saving behaviour [24,28] and increases in awareness of domestic energy consumption [34]. Negative effects relating to cognitive outcomes were reported by two studies, one of which was assessed as high quality. Gustafsson [28] found that while players indicated a more positive attitude towards energy saving as a result of engagement with Power Explorer, they displayed a more negative attitude towards the environment in general. The authors attribute this finding to the "*…occurrence of cognitive dissonance induced by the esthetic message of the game*". Overall, the results of these studies provide a basis for understanding the importance of cognitive outcomes in the context of the review, however a much greater body of evidence is required to determine the true effect.

4.4. Behaviour (real world)

Popular opinion that applied games lead to real-world behaviour change was found to be largely supported. It should be noted though, only some of the supporting papers were assessed as providing high quality evidence. Specifically, a positive effect for real-world behavioural outcomes was observed in nine of the ten eligible studies examining this outcome, five of which were assessed to be of high quality [28,29,32,46,47]. The effects reported by the high quality studies were all positive, with the exception of the absence of a long-term effect in terms of reduction of energy consumption observed by Gustafsson and colleagues [29]. Kimura and Nakajima [22] reported a lack of effect, with no energy consumption behaviour change observed whatsoever, however, this study was assessed as poor in quality.

Behaviour change was examined in various contexts, predominantly the consumption of energy in self-reported and actual terms. Intentions to mitigate energy consumption or modify a related behaviour were also measured. Two studies measured behaviour change using self-reported measures only [40,42], while six studies measured actual behaviour change with energy use data

[28,29,32,39,46,47]. Only one study measured behaviour change using both actual and self-reported measures [22,23]. Interestingly, no significant correlation was found between self-reported and actual measures, in that, most participants reported they were more conscious of the environment, but this was not reflected in their actual energy consumption. However, as the authors note, this may reflect the short period in which energy consumption was measured as well as the fact the study was conducted during a holiday period in which differing patterns of energy consumption might be expected. The study conducted by Odom and colleagues [44] described actual behaviour change data in terms of a reduction in energy consumption, however, did not describe the method of data collection. Interestingly, despite the popularity of applied games within the field of marketing, purchase behaviour was measured by one study only [45].

There was also large variation in the periods of data collection, with baseline data collected for between 1 and 5 weeks pre-intervention. Behavioural data collected during the intervention occurred within a range of immediately post-gameplay to 4 weeks, and the timeframe for data collection post-intervention varied from 4 to 18 weeks. Large variations between the studies in how behavioural outcomes were conceptualised and quantified weakens the ability to make clear cut conclusions regarding the required or ideal timeframes for an effect to occur.

Of the studies measuring behaviour using energy consumption data, two limited the observation of behaviour change to during the intervention [22,23,46]. The remaining five examined behaviour change both during and post-intervention [28,29,32,39,47]. Only one study observed no change in energy consumption as a result of their intervention [22,23]. The remaining six studies reported a reduction in energy consumption during the intervention, however, the extent and nature of the behaviour change differed greatly. Although five of the studies reporting positive effects were assessed to provide higher quality evidence in the context of the review, this is still a relatively small number of studies upon which to base any broad level conclusions. Certainty around such conclusions is also limited by the differing measures used across studies. Overall, however, these studies provide encouraging initial evidence of the utility of applied games for short-term changes in energy consumption behaviour.

The efficacy of applied games in terms of mid to long-term behaviour change was less well-substantiated, with only one high quality study reporting a statistically significant decline in energy consumption post-intervention [47]. The other three high quality studies measuring post-intervention behaviour change reported either too small or not statistically significant changes [28,32], or no sustained effect whatsoever [29]. Geelen also reported post-intervention behaviour change, however, this study did not meet the criteria for high quality. Self-reported behavioural data also provided some evidence to support the efficacy of applied games in influencing behaviour [40,42], however, these studies were not assessed as high quality. Overall, it appears that when a follow-up was included in the study design, positive behaviour changes as a result of the intervention were not maintained. However, it is possible that the lack of mid to long-term behaviour change is related to a focus, in the reviewed studies, on what Nicholson [8] refers to as reward based gamification (e.g., points, levels, leaderboards, achievements, or badges). None of the studies reviewed focused specifically on meaningful gamification (e.g., play, exposition, choice, information, engagement and reflection), which has been theorised to be more likely to lead to longer term changes. Overall, the results suggest that applied games (and particularly gamification) are likely to be effective for short term behaviour change, but further research, incorporating greater diversity of types of applied games, is needed to properly assess the implications for longer term change.

The reliability and accuracy of the reported real-world behaviour outcomes and subsequent generalisations are compromised by methodological issues in a large proportion of the reviewed studies, even in those assessed as higher quality. Explicit issues with data collection was reported in a number of studies, including incomplete data retrieval [39], and data corruption [46]. In studies collecting energy usage data to quantify actual behaviour, there were inconsistencies in the kinds and quantities of appliances measured and the comprehensiveness of electrical usage data collected. Not all studies measuring behaviour had control groups, with only 5 of the 10 studies measuring behaviour change actually reporting the incorporation of a control group in the study design [28,29,32,46,47]. There were also large differences in control group characteristics and the extent to which confounding variables were controlled for, with Reeves and colleagues [32] conducting the only study which controlled for household differences. As households who participate in studies of this nature may differ on key variables such as motivation level, income, and education, generalisation of results can be difficult and undesirable.

4.5. Behaviour (in game)

Behavioural outcomes within the game were observed in 3 studies [26,34,38], all of which were assessed as high quality. There was minimal overlap in terms of the outcomes measured, with each study investigating in-game behaviour from a different perspective. Stone and colleagues [34] examined the identification of energy-saving actions and the level of participant movement and exploration within a virtual apartment, and reported that participants confident in their ability to identify actions interacted with the game to a greater extent. The nature of participant interaction was also investigated by Banerjee and Horn [26], though the focus was on how game activity was structured and whether it evoked cultural forms (e.g., the game hide-and-seek). Observational data indicated gameplay was dominantly structured around physical assistance and conceptual elaboration, however, no evidence supported the expression of cultural forms. Participant behaviour in terms of purpose was examined by Gamberini and colleagues [38], with findings indicating that specific goal orientated access, such as checking the consumption of a particular appliance, predominated over more generic goals such as browsing the platform.

4.6. Knowledge and learning

Positive effects were observed in 7 of the 8 eligible studies examining knowledge and learning related outcomes, however, only 3 were assessed as higher quality [26,28,29]. As two of these studies also reported negative effects, the strength of the evidence in support of applied games to improve knowledge and learning related to energy consumption is mixed. The overall findings are further complicated by variation in the conceptualisations of knowledge and learning and subsequently how they have been measured. It appears that there is stronger evidence for the efficacy of applied games in influencing a user's understanding of household energy consumption and conservation within a broader context, with all three of the high quality studies reporting increases. Less success was reported for the communication of more specific information, with Banerjee and Horn [26] reporting a poor understanding of the concept and relevance of kilowatt hours (kWh) and Gustafsson and colleagues [28] reporting marginal increases in knowledge of appliance power rating but a decrease in the ability to determine task-specific energy usage. Gustafsson and colleagues postulate that the decline in knowledge may be due to participants learning only about devices relevant to them, but also note that they found contradictions between quantitative and qualitative data leading them to question the accuracy of the results. Inconclusive results in relation to knowledge acquisition was reported by Tsai and colleagues [35], and thus the empirical effectiveness of the intervention was deemed unclear. Knowledge and learning related outcomes examined by studies assessed as lower quality generally reported an increased ability of users to recall key themes from the game [27,30,31,36].

5. Limitations

A number of limitations of the current review should be acknowledged. The review was limited (by definition) by the search terms chosen, the databases used and the selection criteria (e.g., only english language publications). More broadly, our assessment of the primary research question was limited by the relatively low number of studies that met the selection criteria and by the fact that within those selected many studies were found to be relatively low quality. Many of the problems relate to poorly described interventions, issues related to data collection and analysis and related weakening of the accuracy and reliability of conclusions drawn. Overall few rigorous, empirical assessments of the tangible impact of applied games on energy efficiency behaviours have been published. Relatedly, it may be that publication bias has meant that an overly positive picture of applied games is emerging. It may be that studies that find no impact of applied games are less commonly submitted or accepted for publication. Unfortunately, it is not possible to formally assess the potential impact of publication bias based on the data available in the currently reviewed studies.

On the other hand, within the studies reviewed, large within-group variation was found with respect to energy use. Coupled with small sample sizes, there is likely to be reduced statistical power in many studies and an associated decrease in likelihood of significant differences being found. This means the true picture of the impact of applied games in this domain is somewhat obfuscated. Additionally, many studies included in the review did not conduct statistical significance testing or failed to describe their analysis altogether. Similarly, many studies relied on self-reported behaviour which leaves open the possibility that some results reflect a social desirability bias. Previous research has found significant differences between self-reported and observed behaviour related to energy efficiency [4,50]. Finally, there is a dearth of research assessing the long-term effects of applied games. The majority of studies did not measure long-term effects focussing on short data-collection periods and follow-ups. As a result it is possible that positive changes observed may not be sustained over time or that new positive behaviours or habits may have emerged post-data collection completion.

6. Conclusions

The current review aimed to explore what evidence exists that applied games (gamification and serious games) are effective in influencing users with respect to domestic energy consumption. This goal was identified in response to the urgent need to consider new approaches to motivating individuals to become more energy aware and to translate this knowledge into action. It has been identified that it is essential to consider macro- and micro-level variables that may influence household consumption patterns [51]. The evidence summarised in the current review provides encouraging initial evidence that applied games can have a positive influence in the domestic energy conservation domain, but overall this review provides a good foundation for further work as opposed to conclusive evidence.

Several key areas of focus for future work emerge from the current review. Firstly, there is a need for more quantitative empirical research. Understandably, given the relative youth of the area of focus, much of the existing research is exploratory in nature. More specifically, there is a clear need for studies that isolate the impact of applied games (e.g., RCTs, quasi-experimental studies) in comparison to no intervention and more traditional interventions. Similarly, there is a need for qualitative research that more clearly identifies people's thoughts and motivations in relation to potential energy conservation interventions. Secondly, a number of more specific questions remain unanswered. It is not yet known how the impact of applied games varies across different user groups, nor is it possible to know which game elements are most effective. Thirdly, it is important that research explores the effectiveness of applied games over a longer timeframe. Finally, while user experience is a key element of applied games, research that goes beyond this outcome to include cognitive, learning and behavioural measures will greatly strengthen understanding of the field.

It can be concluded that applied games generally provide a positive user experience with all studies reporting positive impacts on this outcome. With respect to cognitive outcomes, there is consistent evidence of improved attitudes towards and awareness of energy conservation issues. In almost all studies, applied games appear to lead to improvements in self-reported and actual energy conservation behaviour but it is not yet clear whether these changes persist long-term. With respect to knowledge and learning, applied games appear to be effective means of improving general knowledge of energy consumption and conservation, but it is less clear that they are effective for communicating more specific knowledge. Overall, there is emerging evidence of the value of applied games as a means of reducing domestic energy consumption with further research needed to answer key outstanding questions.

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Conflict of interest

None.

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