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Empowering consumers to repair: The utility and acceptability of a serious game to examine decision-making behaviour regarding home appliances in Ireland

Emma Delemere [a,b,*], Paul Liston [a]

[a] Centre for Innovative Human Systems, Trinity College Dublin, Ireland
[b] School of Psychology, Dublin City University, Ireland

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ABSTRACT

As efforts to empower consumers to repair home appliances increase, analysis of the behavioural biases driving premature replacement is needed. Serious games, such as the EVIDENT serious game, provide a promising means to explore these biases and aid consumer energy decision making. However, for serious games to be effective, they must be acceptable and usable, and accurately reflect real-world contexts. As such, this manuscript seeks to 1) identify the real-world factors impacting decisions to repair or replace home appliances; and 2) explore the usability and acceptability of the EVIDENT serious game as a means to examine energy decision making. Six interactive workshops were conducted (n = 44) consisting of focus group discussions, questionnaires, and co-located game play. Positive feedback on the use of serious games to explore residential repair or replace decision making was noted. While initial challenges with usability and acceptability of the serious game were identified, significant increases in both arose following iterative incorporation of workshop feedback. Key themes arising from focus group discussions on repair/replace decision making included *what does it mean, invisible impacts, shifting cultural values* and *trust.* These findings highlight the uniquely challenging nature of energy decision making, and the resulting need for multi-level interventions to increase repair, with the interconnecting role of individuals, businesses, communities, and policy clearly noted.. Taken together, these results highlight the importance of user inclusion across the energy serious game design and piloting process to support both utility and broader social and ecological validity.

1. Introduction

Energy consumption is under increasing focus in the context of soaring energy prices, with increases of 14 % for electricity and 25.6 % for gas across Europe between 2021 and 2022, necessitating emergency measures to reduce pressure on households and businesses [1]. In tandem, as part of global emissions targets European Member States have committed to reducing energy consumption by 40 % by 2030 [2]. In response widespread reductions in energy consumption are needed. Efforts are hampered however by the uniquely challenging nature of energy behaviour change, with energy a somewhat invisible resource for which feedback on consumption is lacking [3]. While efforts to reduce household energy consumption to date have focused on increasing the salience of energy use through real-time feedback displays (i.e. [4]), or enhanced billing [i.e. [5]), there is a need to develop accessible and engaging means of linking energy behaviours in practice, allowing consumers to explore energy decision making in safe, informative contexts. One such approach is serious games. Serious games involve the application of gaming elements in non-traditional contexts [6], to facilitate social learning and experimentation. Scenarios which cannot be feasibly created in real-world contexts are mimicked within these games, allowing the exploration of complex social challenges, while removing risk of real-world consequences [7,8]. Serious games also allow researchers increased control over contingencies encountered by players when compared to real-world environments. Serious games allow individuals to more clearly see the impact of their energy decision making in practice [3], addressing 'action inertia', a common barrier to environmental behaviour change [9]. However, for serious games to be effective they must accurately reflect real-world contexts [10], and be usable for both vulnerable populations [10], and digital natives [3]. One

* Corresponding author at: Centre for Innovative Human Systems, Trinity College Dublin, Ireland.
E-mail address: delemere@tcd.ie (E. Delemere).

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means through which real-world factors can be more effectively considered and included within serious games is through user inclusion in design. This approach can aid both acceptability and validity by ensuring cultural narratives, expectations and social rules are considered and included within serious game play. The present manuscript presents the development and piloting of the EVIDENT serious game and seeks to analyse its usability and acceptability across population groups to enhance its validity and impact.

Despite technological and scientific advances [11] emissions continue to rise, suggesting alternative approaches are required address this challenge [12,13]. As the behaviour of humans underpins many climate harmful activities (i.e. deforestation; consumption; [14]), the need for behaviour-based approaches to address these challenges is clear [15]. While energy behaviour change interventions are effective [16], significant focus across the literature has been directed towards consumption-based solutions (i.e. purchasing energy efficient appliances; swapping to electric vehicles). While these studies demonstrate the potential impact of behaviour-based solutions to climate challenges, this emphasis on consumption-based solutions, and associated neglect of cultural, community or dissemination-based solutions, may be counterproductive. As consumption-based approaches involve continued purchase of consumer goods under the auspices of acting to protect the environment, they do not act to reduce cultural and systemic factors contributing to over-consumption, a key contributor to climate challenges [17]. While integration of behavioural strategies within consumption-based solutions have led to promising results [18], these approaches are too readily relied upon due to their congruence with capitalism and associated cultural inertia [17]. Green consumption represents a flawed solution to climate change as it perpetuates economic growth and consumerist approaches incompatible with a sustainable culture [17]. In this context, a shift in focus towards interventions which prioritise circular economies, mindful consumption and extended product lifecycles is warranted.

The EVIDENT serious game is an online life simulation game, which explores the behavioural biases impacting decisions to repair or replace home appliances, including information framing, financial and environmental literacy, and delay discounting. Repair/replace decisions were selected due to the high prevalence of premature home appliance replacement [19,20], and its impact on waste, resource use and CO_2 emissions [21], alongside recent policy initiatives addressing consumer right to repair [22]. To effectively address early replacement, analysis of the behavioural biases impacting these decisions is needed. Energy related financial literacy [23,24], or the financial and energy-related knowledge and skills required to make effective decisions, is one such factor thought to impact consumer energy decision making, leading to choices which do not maximise consumer welfare [25]. While the impact of financial literacy on energy decision making has been explored [26,27], its impact on repair/replace decision making remains outstanding. In addition research has yet to determine how financial literacy interacts with other factors such as environmental literacy [28], socio-demographics or energy cultures [29]. A further factor hypothesised to impact repair/replace decision making is information at point-of-sale. While information framing within energy bills has been the focus of significant attention and policy [5,30], analysis of the impact of informational frames at repair/replace decision points remains outstanding [31]. The EVIDENT serious game seeks to explore the impact of these factors on decisions to repair or replace home appliances, and through this support consumers to make more effective decisions in the future through addressing these biases.

However, for the EVIDENT serious game to meet its objectives, in-game contingencies must mimic those within the real-world, capturing social, cultural, and other contextual factors effectively, while remaining engaging and usable for a wide audience. Challenges with attrition, engagement and interest in serious games have been found even for digital natives, with many serious games overly focused on educational aims, at the cost of user enjoyment [3]. Concerns have also been raised regarding inequalities in access to serious games. Boomsma et al. [10] examined the suitability of a serious game to reduce energy consumption by social housing residents. Concerns were raised by participants regarding financial and technological barriers to access, preventing use by households. These findings were echoed by a recent systematic review and content analysis of behaviour change techniques within serious games for energy efficiency which identified significant concerns around inclusion of structurally vulnerable groups within such serious games [32]. When considered in the context of the wide-scale behaviour change needed, these findings emphasise the importance of ensuring that serious games do not further widen existing digital divides. One means through which barriers to serious game use can be best identified and addressed is through co-design and piloting. Through the inclusion of all population groups, particularly those who are vulnerable or traditionally excluded from research, proactively in the design of serious games, acceptability and utility can be enhanced.

In line with this, pro-active analysis of the acceptability and usability of the EVIDENT serious game was necessitated. One means to facilitate this is through user input into design. While the importance of including users in the development of serious games has been posited [10,33], it has been the subject of limited research to date [34–36]. While user input into energy related serious games has been the subject of some past analysis (i.e. [3,10]), such activities are commonly completed following serious game development, rather than in tandem. Piloting is one such means through which user input can be attained. Such an approach provides a means to validate the EVIDENT serious game using an iterative approach to feedback and input. Piloting facilitates early and ongoing user input within the design process [37,38], and is beneficial when considering complex cultural and social contexts [39], such as repair/replace decision making. However, while piloting appears a promising solution to support the development of serious games, such approaches may provide a narrow line of sight into the real-world contexts in which repair/replace decisions are faced, particularly for vulnerable or underrepresented groups for whom less is known across the literature on the factors impacting the decision-making context. While piloting allows for iterative feedback on game usability, accessibility, and acceptability to be determined, consideration of contextual variables impacting the target behaviour may not emerge if not directly sought. One means to address this limitation is through qualitative analytic approaches, which allow for in-depth analysis of individual barriers, facilitators and challenges associated with energy decision making. Through exploring broader perspectives on energy decision making, greater understanding of contextual factors which impact behaviour in real-world settings can be attained and thusly integrated within the serious game. As such, to ensure that the EVIDENT serious game had high social and ecological validity, alongside strong usability and accessibility, qualitative analysis of the factors which impact repair/replace decision making for residential consumers was conducted in tandem with user piloting activities. Gugerell and Zuidema [40] argue that traditional piloting and codesign approaches appear limited in ensuring meaningful narratives are included for specific vulnerable or sub population groups. In contrast, they noted that by balancing specific experimentation approaches (i.e. traditional piloting) and broader shared spaces, regional or group narratives can be better identified and captured within energy serious games [40].

This manuscript outlines the development and piloting of the EVIDENT serious game, alongside the methods employed to determine its usability and acceptability. Specifically, the perceived impact of the serious game on naturally occurring opportunities to repair or replace an appliance is determined, alongside the factors which impact repair or replace decisions for consumers in natural settings. Through this fulsome analysis, a clear understanding of the factors which impact repair/replace decision making for residential consumers was determined and can be applied both within the EVIDENT serious game, and more broadly.

2. Materials and methods

2.1. EVIDENT serious game

A key aim of the European Union Horizon 2020 funded EVIDENT research project (bEhaViOural Insights anD Effective eNergy policy acTions; www.evident-h2020.eu), is to evaluate behavioural and technological energy efficiency interventions, and through this inform policy. The EVIDENT serious game has two primary aims. Firstly, it seeks to establish the impact of socio-demographic factors, environmental literacy, and financial literacy on consumer willingness to pay for the repair of home appliances. Secondly, it aims to identify the impact of information and education mediated through a serious game on consumer in-game and real-world repair/replace decision making. The EVIDENT serious game is a virtual life simulation game within which players must manage a virtual home, while maintaining their characters' basic needs (such as hunger, warmth, and hygiene), finances and energy consumption. Players of the game can move around their virtual home, completing daily activities (i.e., mealtimes, washing, entertainment etc.) while making energy decisions. Players receive immediate feedback on the financial, wellbeing and energy impacts of each decision they make within the game through visual gauges on the top left of their screens (see Fig. 1). Within the game the user will be advised that an appliance has broken and must determine if it should be repaired or replaced. Depending on the players' initial decision, a negotiation with a repairperson will ensue, to establish willingness to pay for repair. Feedback on the decision will then be provided. The player will then return to maintaining their home and make further repair/replace decisions using this information.

2.2. Protocol

Between August and October 2022, six pilot usability workshops were conducted (online = 4; in-person = 2). The first five of these workshops explored the usability of the initial serious game, with a final workshop examining an updated version which responded to initial feedback. Co-located play occurred across online and in-person workshops, with online attendees encouraged to leave cameras and microphones on as they played. Workshops took between 60 and 90 min to complete and were structured as follows: 1) introduction to the session; 2) game play; 3) post-game survey; 4) group discussion; and 5) discussion of behavioural biases in energy decision making (see Fig. 1).

2.3. Participants

A total of 44 individuals from Ireland participated in 6 serious game workshops, with 2–12 individual attendees per group. Workshops with unique versions of the serious game took place across August (1 workshop; n = 12), September (4 workshops; n = 26) and October (1 workshop; n = 6) of 2022. Of workshop attendees 36 individuals selected to also complete post-game surveys. This discrepancy arose primarily from workshop 4, where 1 of the 9 attendees only elected to complete the survey due to time constraints of the session. Recruitment was conducted using two approaches. Firstly, community groups supporting underrepresented populations (i.e., senior citizens, renters, landlords and low household income areas) were contacted and invited to co-host workshops for their members. Secondly, invitations to participate were circulated via the EVIDENT platform and social media. Participant characteristics are presented in Table 1 below.

2.4. Materials

2.4.1. EVIDENT serious game

As described in Section 2.1 above, within the game individuals are faced with a series of choice points around their energy behaviour, with a particular focus on decisions to repair or replace appliances which

Table 1
Serious game usability participant characteristics.

Domain	Response options	Total (n = 36)	August (n = 12)	September (n = 18)	October (n = 6)
Age	18–30	6	2	3	1
	31–40	6	–	5	1
	41–50	13	4	7	2
	51–60	5	–	3	2
	>61	6	6	–	–
Household income	Prefer not to say	3	–	1	2
	Less than €50,000	16	8	7	1
	€50–76,000	8	4	3	1
	€76–100,000	6	–	4	2
	€101–200,000	1	–	1	–
	>€201,000	2	–	2	–
Employment status	Full-time employment	21	5	15	1
	Part-time employment	4	–	–	4
	Retired	6	6	–	–
	Student	5	1	3	1
Residential status	Homeowner	23	6	14	3
	Renter	13	6	5	3
	Landlord	–	–	–	–

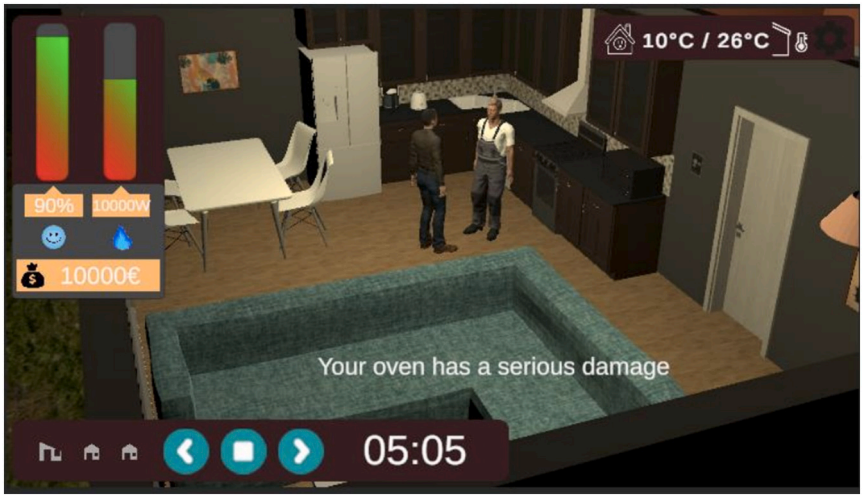

Fig. 1. Sample gameplay.

have broken. A key choice faced within the game is whether to repair or replace a broken appliance, and where selected their willingness to pay for repair. As such, participants are faced with an appliance that breaks within their home and are presented with a series of choices. Feedback on financial, energy and environmental impacts of each decision is provided to support more effective future decision making. The player will then return to typical game play and face further repair/replace decisions using this feedback.

2.4.2. Choice experiments

The EVIDENT serious game consists of a series of three choice experiments, outlined in detail below.

2.4.2.1. Stated preference choice 1. When an appliance breaks the player must first determine if they would like to 1) repair; 2) replace with an identical appliance, 3) replace with a better energy rated appliance; and 4) replace with a lesser energy rated appliance. For all options the cost, kilowatts per hour (Kw/h) and an average cost for one kilowatt per hour is provided (see Fig. 2).

2.4.2.2. Stated preference choice 2. Choice 2 is as per choice 1, with the addition of information on the monthly cost to run for each option, increasing the salience of the financial information (see Fig. 3).

2.4.2.3. Discrete choice. Following this, a discrete choice experiment is presented, which determines willingness-to-pay for a repair. The options presented to players at this choice point will be dependent on responses at choice 2, with those who selected repair presented with increasingly expensive costs to repair, and those who selected replace presented with increasingly less expensive costs to repair. Detail on the repair cost applied per appliance is presented in Table 2 below.

2.4.2.4. Landlord/tenant specific choice. An additional discrete choice experiment is presented for landlords and tenants to examine the willingness of tenants to pay a small fee for a better rated appliance and landlord willingness to accept such a payment. As no landlords participated in the current analysis, this choice point was not faced by participants in the current study.

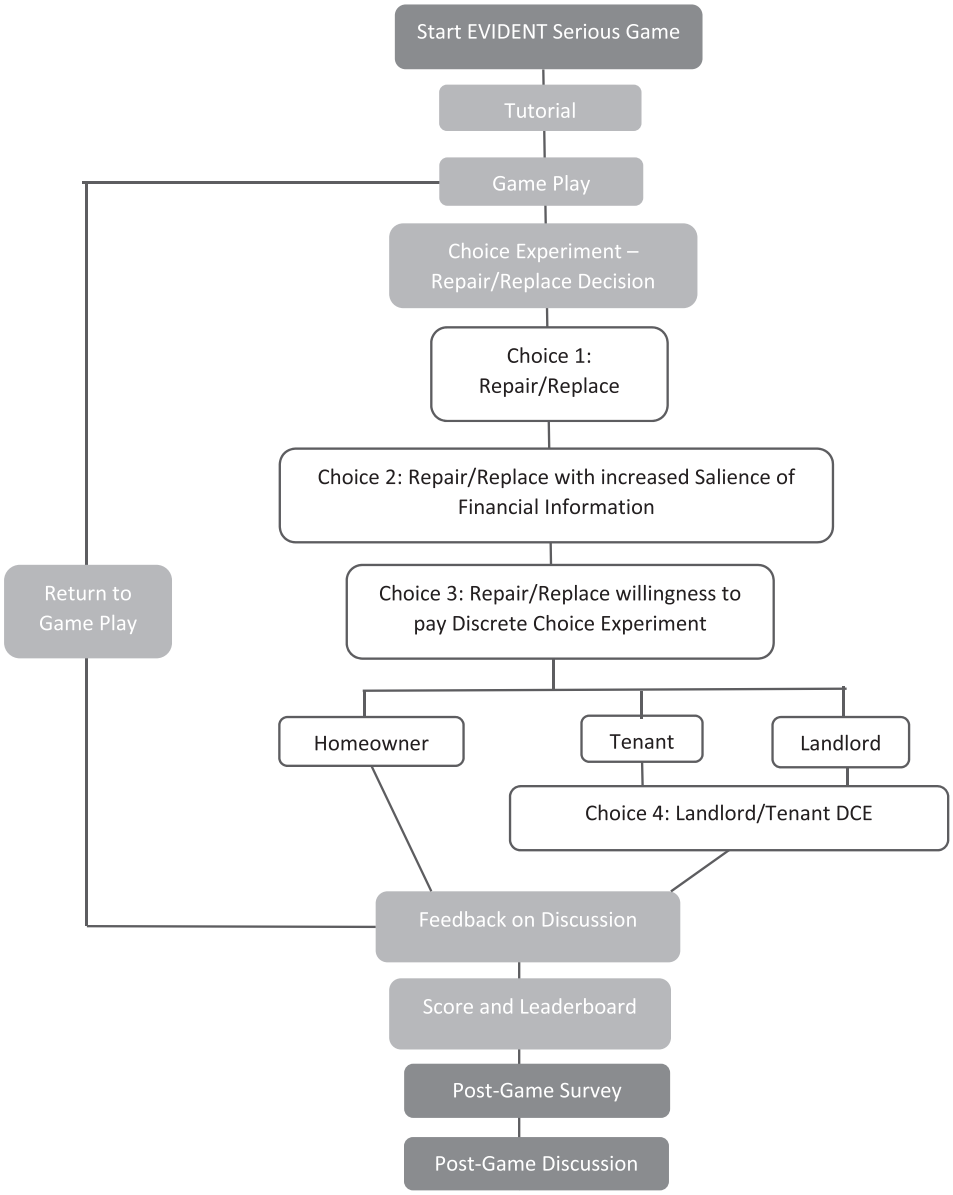

Fig. 2. Usability testing protocol.

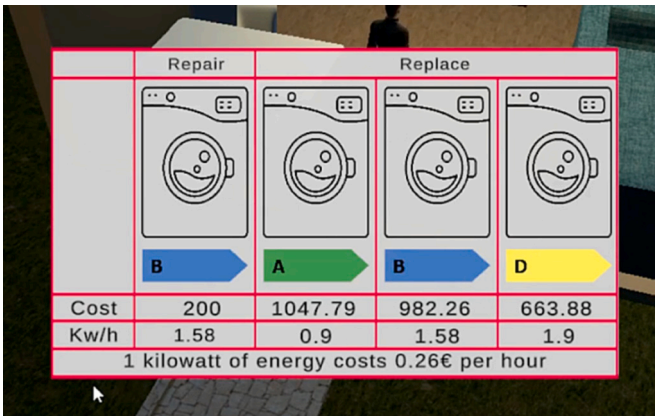

Fig. 3. Serious game choice 1.

Table 2
Serious game discrete choice willingness-to-pay.

	Energy class	Washing machine	Fridge	Dishwasher	Oven
Replacement appliance cost	A	€837.93	€939.05	€1047.79	–
	B	€599.43	–	€982.26	€1397.33
	D	€425.11	€792.68	€663.88	€933.85
	F		€459.12		€586.71
Repair cost initial		€200	€200	€200	€200
Repair cost maximum		€470	€500	€900	€1000

2.4.3. Post-game survey

Following the game, participants completed a brief survey consisting of 1) the System Usability Scale (SUS; [41]); and 2) player experience survey. All questions were responded to using a Likert scale from 1 (completely disagree) to 5 (completely agree). The SUS consists of 10 questions and provides information as to how easy or difficult a serious game is to use. Responses to the SUS were reversed (where applicable), summed and multiplied by 2.5 to get an overall score (minimum = 25; maximum of 125), with a score of <68 suggesting a need for modification [41]. Game acceptability was determined through seven player experience questions, which explored enjoyment, understanding and willingness to recommend to peers. Responses to questions were summed to get an overall score (minimum = 7; maximum = 35).

2.5. Focus group discussion

Following survey completion, group discussion occurred (see Table 3 for the interview guide), facilitated by the researcher. This discussion sought to explore two areas: 1) serious game usability/acceptability; and 2) environmental barriers and facilitators to repair/replace decisions in real-life contexts.

2.6. Data analysis

Survey data was downloaded from Qualtrics and analysed using the Statistical Package for the Social Sciences (SPSS). Descriptive analyses were conducted to determine serious game usability and acceptability. Focus group discussions were transcribed and replayed to ensure accuracy. Two approaches to analysis were used. For questions pertaining to the usability of the serious game itself, narrative synthesis was used. All other qualitative data was analysed using a reflexive thematic approach [42,43], using recursive application of Braun and Clarke's six step sequence [44]. As such, the following steps were undertaken. 1) Transcripts were re-read to increase familiarity with data. 2) NVivo was used to apply codes to the data, highlighting the important features. Both latent and semantic codes were applied, with all codes re-read in the absence of the transcript to ensure they held. 3) Themes were then generated based on the data, with codes allocated to relevant themes. All themes were derived directly from the data and were not anticipated in advance as per Tong et al.'s [45] consolidated criteria for reporting qualitative research. 4) Once completed, themes were reviewed to ensure data representation. 5) Themes were then defined and named. 6) Results were written up.

Table 3
Survey questions.

Questions	Response options
The System Usability Scale [43]	
(All questions to be responded to from populated dropdown options)	
I think that I would like to use this system frequently.	Strongly Agree.
I found the system unnecessarily complex.	Agree.
I thought the system was easy to use.	Neither Agree nor
I think that I would need the support of a technical person to be able to use this system.	Disagree.
	Disagree.
I found the various functions in this system were well integrated.	Strongly Disagree.
I thought there was too much inconsistency in this system.	
I would imagine that most people would learn to use this system very quickly.	
I found the system very cumbersome to use.	
I felt very confident using the system.	
I needed to learn a lot of things before I could get going with this system.	
Player experience	
Please mark how much you agree or disagree with the following statements	
The game was fun to play	Strongly Agree.
I understood how to play the game	Agree.
I feel I learned something from playing the game	Neither Agree nor
The game is too long	Disagree.
The displays were easy to understand	Disagree.
It was easy to follow the prompts	Strongly Disagree.
It was easy to follow the icons	
I would recommend this game to a friend	
The game moved too slowly	
I was motivated to achieve a high score	
Discussion prompts	
What are the things you consider when choosing to repair or replace an appliance?	
What did you like about this game?	
What do you think needs to be improved?	
Do you think the game captures the factors that a person may consider when choosing to repair or replace an appliance? If not, what is missing?	
Please share any other feedback or suggestions you may have.	

2.7. Ethical approval

Full ethical approval was obtained from Trinity College Dublin's School of Psychology Research Ethics Committee (Approval ID: SPREC092021-09). Full informed written consent to participate was obtained from each participant.

3. Results

To explore the potential of the EVIDENT serious game to support energy decision making in in-game and natural environments, the present analysis sough to determine 1) the usability and acceptability of the game itself through the post-game survey; alongside focus group discussions to determine 2) the perceived impact of energy decision making within the EVIDENT serious game on naturally occurring opportunities; and 3) the factors which impact repair or replace decisions for consumers in natural settings, to enhance the ecological validity of in-game decision points. Through this mixed methods approach a clear understanding of the factors which impact repair/replace decision making for residential consumers both in-game and in natural settings was

determined and can be applied both within the EVIDENT serious game to enhance its impact. Results from both post-game surveys and focus group discussions are presented in detail below.

3.1. Post-game survey

To establish the overall usability of the serious game SUS was conducted. SUS responses across individual survey items are presented in Fig. 4 below. Respondents broadly agreed that they would need additional support to use the game (mean = 3.44; SD = 0.98) and that they would need to learn a lot before playing (mean = 3.11; SD = 1.19). Participants responded negatively to comments indicating that the game was easy to use (mean = 1.85; SD = 1.03), that the functions of the game were well integrated (mean = 2.22; SD = 0.97) and that they would play the game again (mean = 2.15; SD = 1.16). Positively, when comparing initial workshops to the final workshop, participants were much more likely to want to play the game again (mean = 4; SD = 0.86 versus mean = 2.22; SD = 1.51), agree that the functions of the game were well integrated (mean = 3; SD = 0.85 versus mean = 2.22; SD = 1.12), and disagree that the game was unnecessarily complex (mean = 1.5; SD = 0.97 versus mean = 3.2; SD = 1.23) (Fig. 5).

SUS scores obtained across serious game workshops are presented in Table 4 below. While initial SUS scores suggest poor usability, with ratings of 42.7 and 47.5 obtained across the initial five focus groups, significant increases in the SUS were observed for the final focus group (72.5). As a score of 68 or above has been found to denote a game which is usable and acceptable [31], this suggests an overall utility of the serious game. While positive, it should be noted that this score is below the mid-point of the scale, suggesting improvements in utility are possible.

To establish the acceptability of the EVIDENT serious game, and whether serious games may be an appropriate mechanism to explore such energy and repair/replace decision making, a player experience survey was conducted. Results indicated difficulties in the initial August workshop understanding the display (mean = 2.15; SD = 1.43), prompts (mean = 1.92; SD = 0.48), and icons (mean = 1.96; SD = 1.29). In the initial August workshop participants responded negatively to items pertaining to being motivated to get a higher score (mean = 2.44; SD = 1.37), and that they had fun (mean = 2.48; SD = 0.51). However, again results of the final workshop are higher, and suggest player experience may have been effectively addressed. Specifically, scores obtained within the October workshop for ease of understanding displays (mean = 3.5; SD = 1.5), prompts (mean = 3; SD = 1.47), and icons (mean = 3; SD = 1.29) were higher than for previous focus groups, suggesting improvements in these domains. Further participants agreed that the goal of the game made sense (mean = 4.5; SD = 0.83) and that they would recommend the game (mean = 3.5; SD = 0.81) (Fig. 6).

Results of the post-game survey suggest both the usability and acceptability of the EVIDENT serious game, suggesting that the serious game structure may be appropriate forum to explore energy decision making, and specifically repair/replacement decision making for home appliances. This is promising, however for such a game to reflect natural energy decision making contexts, or to have impact on actual energy decision making and associated behaviours, analysis of the ecological validity of the EVIDENT serious game is required, results of which are detailed in Section 3.2.

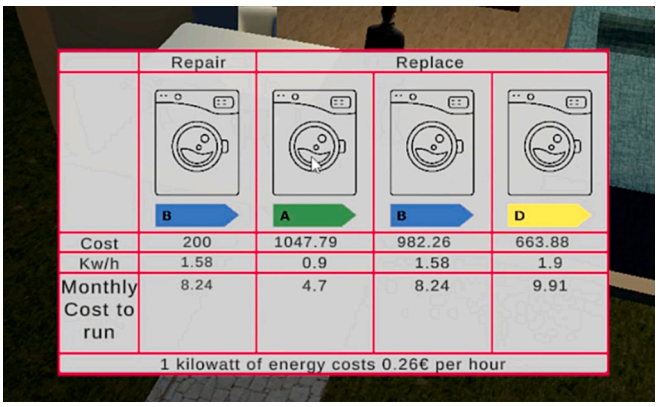

Fig. 4. Serious game choice 2.

3.2. Focus group discussion

To determine the extent to which energy decision making, and repair/replace behaviours were effectively captured in the serious game a series of focus groups were conducted. A total of six focus group discussions were held to explore 1) the usability, acceptability, and external validity of the serious game; and 2) factors impacting repair/replace decisions for consumers. Focus group discussions had an average duration of 36 min and 28 s (range = 25.19–41.35). Through this, greater insight into the factors impacting energy decision making in the serious game and natural environments are established, allowing for in-game amendments to better align the two decision contexts thus increasing likelihood of generalisation of in-game behaviours to non-game settings. As contingencies encountered by underrepresented groups (i.e., renters, low-income households) were deemed more likely to be absent from the game due to a lack of research on the topic to draw from, oversampling of these groups was conducted.

3.2.1. Serious game usability and acceptability

While participants felt that the serious game was a novel and engaging means to address energy decision making, several key aspects required attention to enhance acceptability and usability. Specifically, clearer detail on how to engage with the game was needed. The tutorial was highlighted as a key means through which this could be achieved. Participants reported that the initial tutorial was too passive, impeding application of learnings in practice. A need for a more interactive tutorial which guides users to act within the game was felt to be needed. Explicit, clear feedback on how individual in-game behaviour impacts each of the indicators (finance, energy, and comfort) was needed to provide users clarity on what they should be doing. Participants noted that while this is in place for some appliances (i.e., dirty dishes to remind users to clean), this could be applied across the game. Positively, participants enjoyed the idea of trying to manage their energy consumption while keeping their avatar alive and learning how best to act. This positivity held also for the repair/replace decisions. Many participants felt that this was a decision that they had faced in the past, and one that they struggled with. As such, the opportunity to learn how to approach these decisions through a serious game was appreciated. Fulsome detail on key themes identified pertaining to the usability of the serious game are presented in detail in Table 5 below.

3.2.2. Repair/replace decision making

A second focus of discussion was the real-world factors which impact repair/replace decisions for participants. Key themes identified included *what does it mean, invisible impacts, shifting cultural values* and *trust.* Each theme points to key factors impacting real-world decision making which require inclusion within game play to support ecological validity of the game itself. Each are described in individual subsections below.

3.2.2.1. What does it mean?. A key theme across discussions was poor awareness and understanding of energy ratings and consumption. While participants were aware of the existence of energy ratings, few understood what letters on the scale reflected.

> "A++ and all that kind of stuff, kind of, in gods names what does that mean."
>
> Group 2

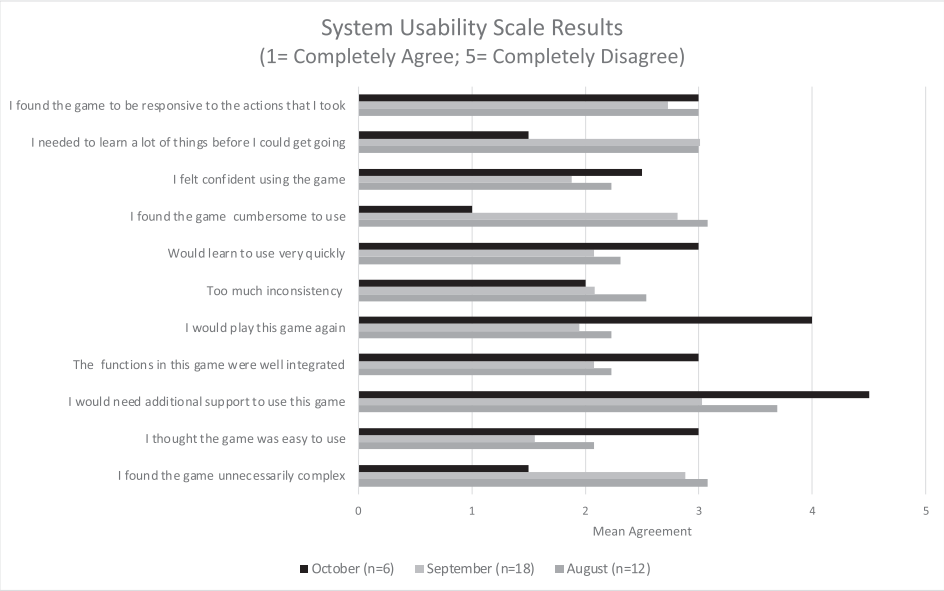

Fig. 5. System Usability Scale.

Table 4
SUS scores across workshops.

Workshop	SUS score
August workshop (n = 1)	42.7
September workshops (n = 4)	47.51
October workshop (n = 1)	72.5

In the absence of fulsome understanding, general heuristics were generalised to this context, with colour and relationship to other letters used.

"Probably an A+ because the fact that it is open so frequently"
Group 3

Instead of focusing on ratings, participants highlighted the importance of other aspects of appliances which impact energy use. Commonly reported factors included appropriately sized appliances (i.e., choosing a small washing machine for single adult homes), off-peak times, monitoring appliance use (i.e., laptops and gaming), and reducing unnecessary appliances where possible (i.e., washing by hand rather than using dishwashers). Awareness of the multitude of factors impacting the efficiency of appliance energy use was clear.

"When you're choosing an appliance, is to choose something that suits your need.... it's a huge oven that you, you know, that's heating up every time you want to use it. If you just put it in pizza, it's kind of, you're wasting"
Group 2

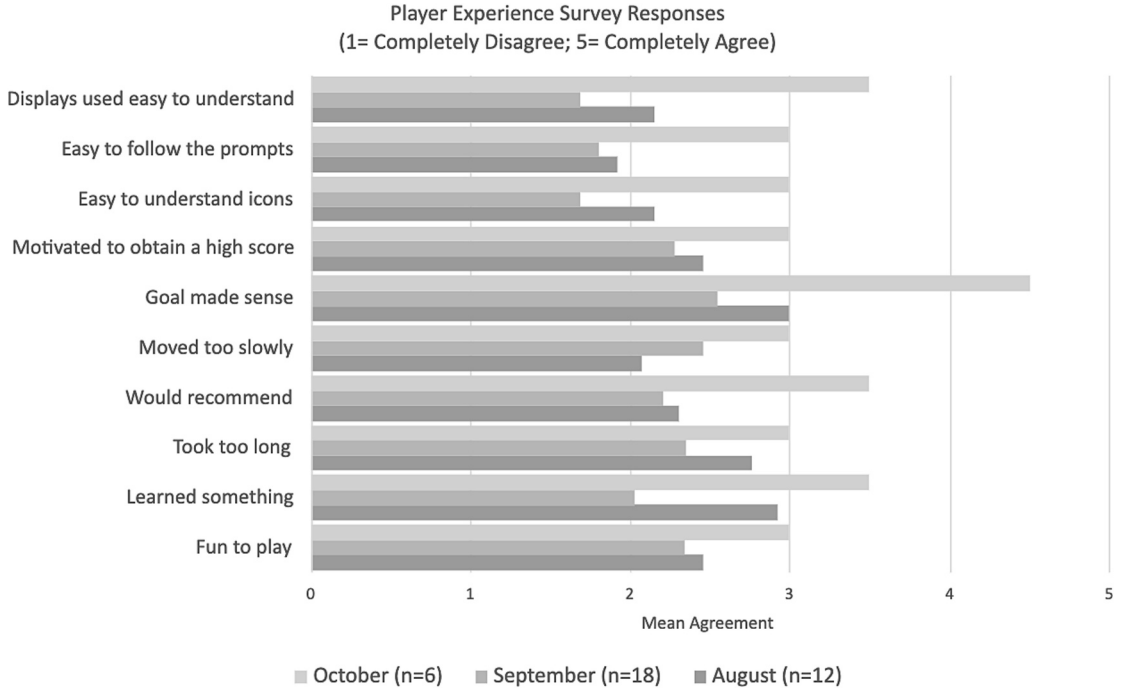

Fig. 6. Serious game player experience responses.

Table 5
Key themes on serious game usability.

Theme	Indicative quote
Need for a more active tutorial	"I think maybe more instructions… what are we aiming to do here? You know the thermostat is there, if you turn it down, X happens, that kind of thing." Workshop 3 "You know, sometimes when you do start a game… they say to move right and move left, so you get used to the control. That will be a handy thing if an arrow would come up and let you, you know, mess around with the moves a little bit" Workshop 3
Difficulty understanding how to navigate the space and complete actions	"You know when you first go into it, and you're reading through, you know, this is the thermostat and down here it'll tell you this. If you could click back on that and it would explain what it was 'cause by the time I'd started and was moving around, I'd forgotten what one of the little bubbles at the top or at the bottom meant. And then I was like, OK, I don't know, I don't know what to do now" Workshop 3
Difficulty understanding aim	"It just it takes a few minutes to get the hang of it. There's a kind of a maybe, I don't know if I don't usually play games like this, but I think there's a lot going on." Workshop 3 "I wasn't really clear on the objective" Workshop 2
Impact of difficulty understanding	"To be honest with you, I'd probably say no and just click out of it, you know. It's a little bit cumbersome." Workshop 3 "I don't have very much patience with stuff like this" Workshop 3
Need for feedback on actions within the game	"Some sort of reward. So, you are learning from that, and you're getting rewarded by making the right choices as well." Workshop 2 "I think icons over the actual appliances that you're …. Or like even just like the way that little circle was going around the hamburger thought on the screen wasn't very obvious. Like it was hard to spot when that popped up, whereas if it was like over the oven, like 'bing' kind of thing like even just like a light bulb that was like loading up or something?" Workshop 4
Need for more choices	"The more choices you put in, the more engaging this is" Workshop 4

3.2.2.2. Invisible impacts. The invisible nature of energy consumption was a key factor impacting repair/replace decision making, and broader energy consumption within a home. The absence of timely and clear consequences for energy use was felt to hamper motivation to reduce energy use. This held particularly for those not directly responsible for energy bills.

> "Because they don't pay bills, you see they're a little bit indifferent to the cost"
>
> Group 3

Where consequences for energy decisions were encountered, they were felt to be somewhat ineffective, often due to the complexity of feedback (i.e., Kw/h) impeding fulsome understanding, and the absence of meaningful comparators. Instead, more meaningful, emotive consequences were felt to be needed.

> "I think maybe you know if you boil the kettle full, you know, this is what happened.…it's the equivalent of one tree or two trees or that kind of thing. I think something like that is handy to just make you think it's, you know, it's more kind of like a visual mental image."
>
> Group 3

Invisible consequences held also for repair/replace, due to the mismatch between the highly uncertain consequences of repair (likelihood of successful repair, lifespan, cost, etc.), and the more certain impacts of replacement (i.e., fixed cost, perceived lower risk of immediate breaking). Risk of further negative impacts, and the initial cost of seeking repair further reduced willingness.

> "€60 for a call out. You kind of balk and you go am I gonna have to pay that and then end up buying a new one anyway?"
>
> Group 6

While self-repair was touted as a solution by some, the perceived risk reduced willingness to explore this further.

> "For electric appliances, is there not some sort of a hazard with like fire insurance? If you fix an electrical appliance yourself, you're not under any kind of warranty then."
>
> Group 4

Participants perceived the importance of different consequences as variable at an individual level. Should an individual's basic needs not be met, social consequences (i.e., peer approval, social norms) for engaging in pro-environmental behaviour was insufficient. Immediate, personal consequences were perceived to overrule long-term societal benefits.

> "And most people out there, they would want to recycle, they would want to take the products. But in that immediate moment, if I have to choose between a quick meal or … the flooded kitchen. That's going to take immediate priority over viewing this global issue as wider, as like wider consumption problems"
>
> Group 1

For repair/replace decisions, financial consequences appeared most impactful. The impact of temporal discounting is clear, with the lower upfront cost of a replacement preferred.

> "Somebody whose dad had a TV repair thing. And he got to the stage he closed his business 'cause he said it was easier, it was cheaper than getting the parts, to go and buy a new TV."
>
> Group 5

Temporal discounting is further exacerbated by poor clarity of repair costs, with replacements viewed as cheaper and certain, in comparison to the uncertain costs of repair both up front and over time, even if such a repair would result in savings over time.

> "If it breaks down, the repair coming out is very costly. The cost benefit is done and say right goodbye, you just have to buy it and that's it. Yeah, you have no choice."
>
> Group 2

3.2.2.3. Shifting cultural values. The need for shifting cultural values was noted across three levels. These are a) norms and values; b) responsibility; and c) skillsets.

Shifting norms and values. The need for significant changes in the values and norms embedded within the broader culture was noted. While individual efforts were felt to be important, for large scale change to occur a shift in culture is needed.

> "Does that not require a whole change of mindset around production and manufacturing?"
>
> Group 1

In tandem, the norms and values of individuals also must shift, with value assigned to low consumption behaviours, rather than materialistic ones.

> "There's a huge change that's needed in the way people, I mean social status, and how you appear in collecting these objects around you that are brand new, and the newest car."
>
> Group 1

For this shift in values to occur, community engagement was felt to

be needed. Ensuring community members, particularly children, are taught to value items and the skills needed to maintain the longevity of these items was noted.

> "Put the emphasis on the value of being able to repair…. We're very much the throwaway society, so you know, teaching the kids to do that would be brilliant…. what could I do if I could repair it? Or what could I do with all the different bits?"
>
> Group 6

For such a cultural shift to emerge, policy which supports low-impact and low-consumption communities should be prioritised.

> "Yeah, so we shouldn't be writing policy for more objects in the world. Everything has to be justified at this stage"
>
> Group 1

A shift in the social norms around repair was felt to have emerged in recent times. While an emphasis on repair appeared common in past generations, this focus on salvaging items was felt to have disappeared.

> "It's probably a bit of a generational thing. Like I know my dad would have fixed everything and my mam would have sowed up everything, everything was repaired. We grew up in that culture. I think in the last generation a lot has been lost"
>
> Group 4

Shifting responsibility. Alongside this shift in cultural values and norms comes a need to re-consider who is held responsible for supporting the repairability of items. At present, emphasis on consumer responsibility to change behaviour is noted. However, the highly complex nature of energy decision making, and the imbedded knowledge needed to successfully traverse these decisions impedes consumers from being successful in this context. As such, a high level of burden is placed on those who are likely unable to effect meaningful change.

> "It's coming back down to that with social responsibility keeps getting put on the people who can't afford to have these conversations, or they don't have time to have these conversations". Group 1

Those who are disadvantaged were perceived to be unduly burdened in this context.

> "I don't think like from a working-class perspective people have time to think about these problems. Yeah, and as much as I would love to go out and think and engage with these things, yeah, if I'm constantly working to survive, the last thing I'm thinking about is my energy consumption"
>
> Group 1

The social context of repair/replace decisions also appeared impactful. As many respondents lived with others, decision making was impacted by the attitudes, values, and preferences of these other residents. As such, control of energy decisions is shared across those in the home, with negotiation needed to reach agreement. This poses challenges where other residents are not motivated to engage in pro-environmental behaviours. This appears particularly challenging in rental properties, where significant pressure is placed on those seeking to reduce energy consumption as their behaviour is met with social disapproval or incongruent behaviour by other residents.

> "It's a house share, so it's like each for their own. I mean, we have a good relationship, but like, you know, they're not turning off lights. They're not putting things on standby. And this is actually depressing me thinking about it. You know, like going into the winter knowing that they don't care and that all I'm doing going around 'turn off this'"
>
> Group 4

This effort, when met with no change on the part of residents negatively impacted motivation to engage in similar efforts in the future.

> "You can get tired of your own voice in those situations too"
>
> Group 5

In this context, there a shift in focus is needed to those who can affect large scale change without relying on individual consumer capacity, knowledge, and skill. Specifically, the companies who make and distribute such appliances.

> "I do think there's a bit of like idealism on that. Again, putting it to repair puts it on the consumer to fix it and not the corporation...I actively tried to get my coffee machine repaired, but then I got an e-mail just to say we're just going to send you another one"
>
> Group 1

This was perceived to apply to product development also, with manufacturers needing to prioritise energy efficiency in appliance design, rather than additional features which may negatively impact consumption. However, for this to emerge the consequences of such a change in focus (i.e., sales volumes), must be aligned. Again, this highlights the interrelated nature of all actors within the system, most keenly consumers and manufacturers.

> "And what are the manufacturers doing? For instance, I only use a maximum of two of the programs on my washing machine… And I don't really need anything else. You know, I'm just wondering, why do we have so much choice"
>
> Group 2

3.2.2.4. Shifting skills. A further perceived barrier was the lack of repair skills within communities. An absence of available and skilled tradespersons, alongside a lack of repair skills for individuals themselves, was noted. A high response effort appeared required to seek repair, with challenges encountered in obtaining skilled repair people.

> "It's really hard to get repairs done on anything. Like, that just isn't an option. Most of the time you're kind of forced to buy something new because there's nobody who can repair something."
>
> Group 1

Reluctance on the part of repair people to repair broken appliances was also noted, with many who contacted repair people persuaded to replace the appliance instead.

> "I have heard that a lot that a lot of people when they call the repair person, they'll just say ah hear, look don't bother get a new one."
>
> Group 3

Participants noted that while in the past communities would have local sources of knowledge and resources (i.e., local businesses, experts etc.) which would be sought when an appliance broke, these no longer exist. The importance of these local, trusted hubs was felt to be a significant barrier to repair.

> "Years ago, there used to be where I grew up like an electronic shop where you would go in, and they would repair it for you.... It doesn't exist anymore. And there is a very definite need for that. And it's very dear, and it's hard to find someone."
>
> Group 4

3.2.2.5. Trust. Poor trust in appliance manufacturers and distributers was also noted, negatively impacting willingness to consider repair. Trust in the quality of appliances was observed to be low, with a prevailing sense that nothing is built to last.

> "That's the thing you know, stuff is made to break."
>
> Group 3

Instead, appliances were felt to be built to be replaced frequently, increasing company sales.

> "Built in obsolescence is what it's about."
>
> Group 1

Participants noted challenges exercising rights under warranties, with hurdles met to obtaining repair in this manner.

> "I cannot get the company to send a repairman out to me, even though my parts are guaranteed for 10 years, but they're so dragging their heels and sending somebody out to me."
>
> Group 6

Additional requirements to qualify for a warranty were reported, many of which were not noticed at point-of-sale and thus voiding cover.

> "What they say is well, have you filled out the guarantee form? And if you haven't filled out the guarantee form, then you're not guaranteed."
>
> Group 1

4. Discussion

With the increasing need to empower consumers to repair home appliances, analysis of the behavioural biases impacting these decisions is needed. This research sought to explore the utility of the EVIDENT serious game to examine and address these biases by providing guidance to players on navigating complex energy decisions. Specifically, this research sought to 1) explore the usability and acceptability the EVIDENT serious game; and 2) identify the real-world factors impacting repair/replace decision making to ensure their appropriate inclusion within the serious game. Results obtained suggested the acceptability and usability of the EVIDENT serious game, with initial challenges to both identified and addressed across workshops. Positively, the final version of the EVIDENT serious game met SUS usability guardrails [41], suggesting initial barriers to use such as screen navigation and clarity of aims were effectively addressed. Similarly, while initial workshop participants highlighted difficulties understanding the game aims, and a hesitancy to recommend the game to others, scores increased following the final workshop suggesting acceptability of the final serious game. With regards the factors impacting repair/replace decisions in real-world contexts, themes arising included *what does it mean, invisible impacts, shifting cultural values* and *trust.* These results highlight the uniquely challenging nature of energy decision making, with the consequences of such decisions often delayed and uncertain, hampering individual decision making. Further, results highlight the need for multi-level, rather than consumer-specific interventions to increase appliance repair, with the interconnecting role of individuals, businesses, communities, and policy clearly noted. Taken together, these results highlight the importance of user inclusion across the energy serious game design and piloting process to support both utility and broader social and ecological validity. Through identifying key aspects of energy decision making which require consideration such as those identified above and addressing them within energy interventions such as serious games, more effective solutions and supports can be developed.

Positively, results obtained lend support the use of serious games to explore complex energy decision making, such as repair/replace. As noted above, participants valued the opportunity to explore energy decision making through serious games, and to experiment in an environment removed from the financial risks which would impact real-world choices. Participants also responded positively to the opportunity to practice making these complex decisions. While many participants had encountered these choices in real-world contexts, they found them difficult to manoeuvre, and as such valued the opportunity to practice making these decisions in a virtual context. Interestingly, and in contrast to the finding of Boomsma et al. [46], participants did not raise concerns regarding technical or financial barriers to the use of the serious game, suggesting limited impact of a digital divide. This is promising, particularly in the context of the generally low income and mixed age of workshop participants. Additional analysis of player demographics following full serious game recruitment may be valuable and provide insight as to whether inequalities in access may be encountered for population groups.

The importance of user input into serious game design is clear from the present analysis and lends support to the use of interactive pilot workshops as a means to achieve this. While challenges to the usability and acceptability of the initial version of the EVIDENT serious game were found across SUS, player experience and focus group data, these were effectively addressed using workshop feedback. This is demonstrated in SUS scores which, while initially below acceptable limits, increased by 41 % between workshops 1 and 6. This is particularly important in the context of the observed low player tolerance for usability barriers within serious games, with many attendees noting that they would quit a game should they find it difficult to use, rather than problem solve issues encountered. As noted by Järvinen et al. [46], functional playability of serious games is of utmost importance, as a positive gaming experience cannot occur should the game have poor usability. The inclusion of focus groups to facilitate the acquisition of qualitative data appeared particularly beneficial and permitted identification of usability concerns not captured within the questionnaires. Examples include the need for in-game feedback and specific navigational challenges. This is congruent with the recommendations of Moizer et al. [47] who found the absence of qualitative analysis as a limitation to serious game usability analyses. As such, to reduce the risk of attrition effort to is needed to ensure usability for all player types, particularly those unfamiliar with online games such as these. The approach above appears one means through which this may be achieved.

Results of the present analysis highlights several challenges to participant engagement within the serious game, with a need for clearer goals, more choices and less passive tutorials noted. Engagement is thought to be linked with the players' perceptions of how difficult or easy a game may be [48], with a careful balance between the two required to achieve immersion within the game [49]. These challenges to engagement appear consistent with past research which highlighted the importance of ensuring that equal weight in serious game design is given to educational, gamification and player enjoyment aspects [3]. This suggests that while serious games may offer a novel means of exploring energy decision making, analysis is required to determine how such games may best capture and retain player engagement. Behavioural approaches may be one such avenue to address this.. By effectively leveraging behaviour change principles within serious games, increased player engagement and motivation may be attained. A recent review found that while behavioural change techniques were commonly included in serious games for energy efficiency, consideration of the mechanisms of change underlying their use was often absent, limiting impact in practice [32]. As such, while behavioural approaches may be of benefit, fulsome consideration as to how they are applied is needed. The impact of behavioural strategies on engagement is demonstrated in the results of the present analysis, with a behavioural skills training approach applied to the serious game tutorial prior to the final to address concerns raised. This approach appeared effective, as evidenced through the increase in both SUS and player experience scores and focus group discussion. These results highlight the potential role for behavioural approaches such as behavioural skills training, within serious games to support player engagement. Additional analysis however is needed to determine how such strategies may be best embedded within serious games.

In the context of the relatively invisible nature of energy use and decision making, a key theme arising from this analysis, efforts are needed to increase the salience and timeliness of the consequences of energy use to support learning. More frequent and salient feedback on in-game behaviour for players was needed to provide direction on how to engage with the game. This is consistent with past research which highlights the importance of immediate feedback on learning within

serious games [50], with game generated results and feedback one means to achieve this [51]. Again, efforts to address this within the EVIDENT serious game appeared effective as demonstrated in final SUS and player experience data. Following workshop five, the serious game was updated to provide participants more information on the impact of their actions on their energy, financial and comfort gauges. Specifically, text appeared to provide feedback on the action, and the impact on the gauges shown (i.e., 'careful increasing the heat too high, look how much your energy use has risen'). Additionally, prompts to complete activities of daily living, and feedback following their completion, were made more salient, with associated icons made larger. Ensuring individuals can see the impact of energy decisions more clearly is one clear benefit of serious games, allowing individuals to try different approaches to energy decision making and observe the consequences. Qualitative data also highlights the invisibility of energy consequences as a broader challenge, and one which impacts repair/replace decisions also. Further, this lack of feedback was perceived to impact temporal discounting, with the certain consequences of replacement preferred over the likely lower cost, but uncertain consequences of repair. As such, in the absence of clear consequences of repair, the perceived certainty of replacement is preferred. Future efforts to facilitate consumer decision making in this context should consider hoe consequences of decisions may be made more salient to consumers, and the impact of this on behaviour.

Several limitations to the present analysis are noted. The first of these is the relatively low volume of participants across serious game workshops. As demographic data suggests good distribution of participants across age, income, and employment types, it was felt that good representation of the general population was obtained, though low-income households were somewhat overrepresented. Further, as participants self-selected to attend, this group may be particularly motivated in environmental or sustainability issues, posing some bias to results obtained. However, this risk was likely minimised through the use of community groups (which were non-environmental in focus) to host workshops. As such, attendees may have joined who were active in the community group, but not particularly motivated towards environmental topics. A further limitation to the current analysis is the use of a researcher to facilitae the serious game workshops. As a member of the research team hosted each workshop, there may have been an impact of the observer effect on feedback obtained, with participants reticent to be overly critical. However, consistency across free-text questionnaire responses (conducted anonymously) and focus group transcripts suggests this may not have been the case. A final limitation is the absence of data on initial user input into the serious game design. While initial input into the serious game design was captured prior to its development through a focus group, these discussions were not recorded preventing analysis of the transcript in the present analysis. Inclusion of user input on initial game concepts within the current manuscript may have been of benefit. Finally, the broader context of energy price increases poses an additional limitation. As this study was conducted at a time where energy security and pricing were highly discussed, findings and general interest in this topic may have been impacted.

To conclude, while serious games appear a promising means to explore complex energy decision making, such as repair/replace, user input into design is of pivotal importance to ensure usability, acceptability, and external validity. While pilot workshops appear an effective means to gather user input, results highlight the importance of both qualitative and quantitative approaches within these workshops to ensure sufficiently rich and detailed insight is gathered.

CRediT authorship contribution statement

Emma Delemere: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Paul Liston:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Paul Liston reports financial support was provided by Horizon Europe.

Data availability

Data will be made available on request.

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