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Play and learn: Serious games in breaking informational barriers in residential solar energy adoption in the United States

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ABSTRACT

Recent literature states the importance of using behavioral science to address the persistent gaps between the technical potential of low carbon technologies and the actual adoption of these technologies. With the goal of addressing this important gap, in this study we investigate the efficacy of *serious games* – games with a primary purpose other than entertainment – to overcome informational and perceptive barriers to broader adoption of solar energy in the residential sector. Using a randomized control trial design with playing a trivia-style game as the treatment condition, we assess the impact of serious games on effecting behavioral antecedents toward solar energy in residential energy customers, applying the Theory of Planned Behavior (attitudes, norms, and perceived behavioral control). Our findings indicate that serious games are effective in bridging the information gap and enabling participants to feel agency, warranting further investigation of the effectiveness of this intervention strategy on behavioral change applied at large scale.

1. Introduction

The adoption of solar energy – widely assumed to be pivotal to a new energy transformation – has been hindered by persistent information gaps [1–8]. However, providing information alone has not proven sufficient to bridge information gaps or motivate behavior change [9–11]. Here we explore a different approach – known as "serious games" – in which participants actively engage with actionable information presented through a game interface, in this case a trivia-style game. Using a randomized control trial (RCT) design we assess the potential of serious games (i.e., games with a primary purpose other than entertainment) to influence the antecedents of behavior, attitudes, norms, and the perception of control, as set forth in the Theory of Planned Behavior (TPB), which then impact intentions and behavior [12], toward solar energy among residential energy customers.

Technically complex knowledge areas such as solar energy are easily misunderstood [5,13–16]. Additionally, the motivations of potential solar adopters continue to evolve [17,18], which increases the need for communication methods that can target multi-dimensional information gaps for diverse customer base. Thus solar adoption serves as a compelling test bed, due to its complex nature as an innovative, capital-intensive, and pro-environmental durable good. When deciding whether to adopt solar customers need to process a range of information in a decision-making context that includes the interplay of social, behavioral, economic, and technological factors. But information alone is not sufficient [8,9,19] to change public perceptions, address inaccurate anchoring, or correct misunderstandings and prematurely formed conclusions common to residential energy use [5,6,20]. Providing information in a passive or static format allows for overlooking differences with existing perceptions or for confirmation bias (the tendency to interpret information to confirm preconceptions). Furthermore, according to the "ostrich effect" pointed out by Karlsson et al. [21] information may be avoided entirely if an expectation of negative information exists, such as a *perception* of unaffordability for solar [7]. Thus correcting misperceptions may require a different approach to communicating information when the aim is to correct misunderstanding, deter confirmation bias, circumvent the ostrich effect, or address inaccurate anchor points [22,23]. Serious games offer a holistic approach for addressing such complex decision contexts marred by information gaps, as they can confront misperceptions, reduce information search costs, and challenge multi-dimensional information gaps, all known barriers to the adoption of solar energy.

The study presented here is intended to advance the understanding of the potential of serious games to bridge information

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gaps by first determining if serious games are useful and impactful in the context of bridging information gaps in solar energy. While the benefits of gamification can be specific to the game design and mechanics, which, having many facets (e.g., motivational affordances, subject matter, game genre, audience), makes generalization of game results difficult [24,25], the impact of specific game design elements is beyond the scope of this study. To mitigate the confounding factors associated with game design elements, as further discussed in Section 3, we have selected a relatively simple, straightforward game design (compared to designs such as multi-level, simulation, virtual world, etc.). Thus our findings relate to the impact of the relatively simple game we use in our experiment – a trivia-style game involving a few game elements – rather than to the differential impact of the individual game elements themselves. Within that context, our findings support the potential of serious games to bridge information gaps and enable participants to feel agency. Thus, applied at a large scale serious games could prove effective in activating the passive customer base, helping unlock emissions reductions in the residential sector.

2. Background and related literature

In contrast to providing information through "passive" channels (such as through pamphlets or e-flyers), a more interactive approach to presenting information, such as via a trivia game, could potentially challenge misperceptions and prompt reexamination of the original content [26–28]. The interactive nature and motivational affordances provided by a gamified platform [29] could provoke the reassessment of solar energy necessary to bridge information gaps, establish accurate anchor points, and increase agency in conservation and solar adoption decisions. However, there have been few systematic studies along these lines, particularly with regard to behavior change and non-student populations [26,30].

Connolly et al. [26] identify only twelve RCTs in their review of computer games and serious games studies related to learning, skill enhancement, and engagement. Of these twelve studies, six focused on knowledge acquisition, only one focused on behavior change, and none of these addressed energy topics. A 2016 update of this review using the same methodology identifies an increase in the quality and number of studies related to serious games [31]. Silk et al. examined the effectiveness of multiple modes of communication to impact nutrition education [32]. In that study, website and game modalities faired best on attention, and the website ranked highest among the modalities for attention, understanding of content, learning, and intent to use for additional information. Silk et al. note that the results may be indicative of the audience preferences and the appropriateness of the game to the domain of the study. Additionally, the design and quality of a game can be instrumental to an intervention's success [33–35]. These are important points because given the potential costs of game interventions matching the game design to the population and domain of interest may be necessary to maximize the benefits of game based interventions.

In the energy domain a number of studies have used games to target energy efficiency behavior. Orland et al. implemented an RCT in the workplace using sensors to measure and provide feedback through a game interface with short-term reductions in energy consumption, but these energy savings did not persist in the eight weeks following game play [36]. An RCT study using a commercial quality game developed by Reeves et al. proved effective in reducing energy use among college students by 2%, but the savings did not persist in the 30-day follow-up [35]. Gustafsson et al. found both increased energy efficiency behavior and increased attitude toward energy efficiency, but the significant difference between game and control groups declined shortly thereafter [37]. The effectiveness of games in reducing energy consumption is encouraging; however, the lack of persistence presents a challenge for ongoing behavior change. These results suggest that such interventions may prove more effective with one time behaviors, such as solar adoption, that do not need to be repeatedly sustained beyond the adoption. Here we study the use and effectiveness of online serious games due to their unique ability to combine information delivery, real-time feedback, and normative cues, which are each effective intervention strategies for catalyzing behavior change [10,26,38–41]. To assess the effectiveness of serious games in this context, we investigate the influence of serious games to act on the antecedents of intentions and behavior as set forth in TPB.

The TPB model is frequently applied to understand energy-related behavior, pro-environmental behavior, and sustainable choices [3,42–47]. TPB identifies three antecedents of *intentions* to perform a behavior: *attitudes* toward the behavior formed from behavioral beliefs – beliefs about the likely outcomes of a behavior and the evaluations of those outcomes; *subjective norms* formed from the normative expectations of others and motivation to comply with such expectations; and *perceived behavior control* (PBC) based on beliefs regarding factors that may enable or hinder the behavior [12,48]. The behavioral intention, thus formed, and PBC then directly impact *behavior*.

In a meta-analysis of nearly 200 TPB studies across many applications (education, health, energy, etc.), Armitage and Conner [49] found that 39% of variance in intention and 27% of variance in behavior could be explained through TPB. A meta-analysis specifically on pro-environmental studies also finds that 27% of variance in behavior can be accounted for by TPB, and that 53% of intentions are accounted for by PBC, attitude, and moral norm [44]. Furthermore, a recent meta-analysis of interventions based on TPB finds a mean effect size of 0.50 for changes in behavior and effect sizes ranging from 0.14 to 0.68 for antecedents of behavior [50]. Bamberg et al. [42] leverage TPB to evaluate the effectiveness of a behavioral intervention on travel-mode choice, a pro-environmental behavior, adding past behavior as an additional antecedent of future behavior [42]. They find past behavior has limited effect on future behavior when the conditions or context of the behavioral decision change. This is particularly relevant to technologies such as solar for which changing economics (e.g., declining prices, changing electricity prices, and new business models) and technological advancement (e.g., higher efficiency, greater reliability, and product integration) are consistent features of the landscape. Effectively communicating this changing context to potential adopters becomes critical in the decision-making process to adopt or reject a technology as it evolves.

3. Methods

In order to impact the behavioral antecedents and consequently the intentions and behaviors toward adoption of solar energy that follow, we designed the game content to specifically address the attitudinal, normative, and control factors in the TPB framework.[1] The experimental design includes: (1) a pre-game survey to capture measures of existing TPB constructs (attitudes, norms, and PBC), intentions, and behaviors, (2) a two-week gap for the treatment cohort ("game cohort") to play *Energy Games*, a real-time trivia game based on the Ringorang® platform, and (3) a post-game survey to capture changes in those same TPB constructs, intentions, and behaviors. The post-game survey was launched immediately following the game to reduce attrition and the chance of exposure to other sources of information, which would make causal

[1] As noted below in Sections 3.1 and 5, this study does not include analysis of behavior change, but rather focuses on the antecedents and intentions that lead to behavior change.