Journal of Environmental Management 351 (2024) 119948

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Effectiveness of conservation messages to reduce households' GHG emissions: A serious-gaming experiment

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ARTICLE INFO

Handling editor: Raf Dewil

Keywords:
Household consumption
Food-energy-water nexus
Resource conservation
Serious game
Intervention messages

ABSTRACT

Households play a critical role in reducing greenhouse gas emissions. However, there have been few studies of household conservation from the perspective of the nexus of food, energy, and water (FEW) consumption. This study's objective is to understand the effects of different types of intervention messages for inducing conservation of FEW resources and reducing carbon emissions at the household level in the U.S. Employing a serious-gaming approach, we developed the HomeRUN (Home Role-play for Understanding the Nexus) game, which allows players to act as homeowners and take behavioral and technological upgrade actions in a computer-simulation setting. The types of messages tested include social comparisons and resource-reduction measures across FEW sectors as well as information about the health, economic, and environmental impacts of FEW consumption. A game experiment with U.S. university students finds that social-comparison messages on food and energy consumption, but not on water, lead to significant reductions in household carbon emissions. In addition, messages associated with each type of FEW resource tend to lead to an immediate action corresponding to the particular FEW domain. These insights support a prioritization of intervention messaging for coordinated FEW conservation efforts at a household level.

1. Introduction

Household consumption is a significant contributor to greenhouse gas (GHG) emissions. Including indirect emissions from electricity production, residential emissions account for 16.2% of the total in the United States (U.S.) (EPA, 2017). On-farm agricultural activities, primarily from livestock, fertilization, rice cultivation, and soil management, directly contribute nearly 10% of U.S. GHG emissions. Globally, food systems contribute about one-third of total anthropogenic greenhouse gasses including pre- and post-production emissions as well as land cover change (Tubiello et al., 2021). Nearly 5% of total GHG emissions in the U.S. come from water supply and treatment (Griffiths-Sattenspiel and Wilson, 2009). The U.S. household consumption generated more than 15% of the global GHG emissions in 2009. Among the total carbon footprint, the GHG emissions that occurred in the U.S. (domestic carbon footprint) were equivalent to 82.3% of the total U.S. GHG emissions. The remaining 17.7% total carbon footprint GHG emissions were generated outside the U.S. (overseas carbon footprint) (Song et al., 2019). These facts highlight the opportunity for household actions to reduce GHG emissions by reducing food, energy, and water (FEW) resource consumption (Wilkinson et al., 2009). Achieving net-zero global GHG emissions will require approximately 85% emissions reduction across all sectors over the next three decades (Rockström et al., 2017). Achieving this goal will likely necessitate changes in how households with currently high consumption levels consume FEW resources. For households there are various behavior change options across heating, transport, food, and housing that could decrease GHG emissions significantly (Zajicek-Farber et al., 2012).

Household behavioral change and technological upgrades have been recognized as central to any effective climate change mitigation designed to achieve net-zero GHG emissions (Allen et al., 2019; Carmichael, 2019). Dietz et al. (2009) reported that near-term greenhouse gas reductions can be achieved through voluntary adoption of available technologies in U.S. homes without new regulatory measures. They

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https://doi.org/10.1016/j.jenvman.2023.119948
Received 2 June 2023; Received in revised form 29 September 2023; Accepted 23 December 2023
Available online 1 January 2024
0301-4797/

estimate that a 7.4% reduction in the U.S. national emissions can be reached using household voluntary behavioral changes, including adoption of home weatherization, efficient appliances, thermostat setbacks, and low-flow showerheads. Successful outcomes of a policy in this arena include changes in energy use behavior and adoption of energy-efficient equipment (National Research Council, 2011).

Clearly, the transition to low-carbon, more efficient technologies that are critical to reducing GHG emissions cannot be accomplished without accounting for human behavior (Gram-Hanssen, 2013). Engaging and supporting the public in making behavioral changes requires researchers, policymakers, and institutions to understand the types of interventions that effectively guide individuals towards low-carbon choices (Berman et al., 2019). There has been relatively little consideration of how this outcome might be achieved. Practical behavioral approaches need to impact the long-term by changing human habits and values of individuals, institutional systems, and societies. People need to be engaged and informed and need to be willing to change their behavior for climate-change mitigation to take place (Moore, 2012).

Serious gaming has been applied to address sustainability issues, examining preferences, intentions, policies, and environmental impacts (Madani et al., 2017). It reveals insights into conservation behavior within a safe and realistic game setting. Serious games have long been used to educate players about energy transition, sustainability, and related actions, although few games focus on FEW consumption and conservation measures (Gerber et al., 2021; Stanitsas et al., 2019). In a comparative study, Chen et al. (2017) found that rich game environments are more effective for learning about energy conservation than simpler games. For school-aged children, Knol and De Vries (2011) highlighted the positive impact of digital games on energy consumption education, emphasizing the importance of engaging game elements. Wu et al. (2020) conducted a study suggesting that serious games can potentially change householders' domestic practices in a safe, fun, and interactive environment, enabling them to explore alternative ways of meeting energy-consumption targets. However, a systematic review of games in the household energy consumption domain by Johnson et al. (2017) included 25 studies but revealed a lack of quality data and strong evidence for game effectiveness. Douglas and Brauer (2021) reached similar conclusions in their study on gamification, board games, and apps for sustainability, emphasizing the need for further research to understand the specific effects of game elements on promoting sustainable behavior.

One way to provide information and encourage sustainable behavioral change is through providing intervention messaging. Intervention messages (IMs) refer to messages or prompts strategically integrated into the gameplay to influence players' behavior, actions, or decisions (Ahn et al., 2015; Agusdinata et al., 2023). Intervention messages can take various forms, including text-based pop-up messages, audio cues, visual prompts, on-screen notifications, character dialogues, or interactive elements that steer players in a particular direction or offer guidance. Their content and timing are carefully designed to align with the objectives of the serious game. They are a crucial component of serious games (Muhamad and Kim, 2020).

Most of the existing research using IMs for resource conservation assesses either the effectiveness of a single type of message or focus on a single consumption sector (e.g., Berman et al., 2019), and there are myriad studies comparing the effectiveness of different IM types in a single experiment (e.g. Goldstein et al., 2008; Costa and Kahn, 2013; Abrahamse and Steg, 2013). However, the consideration of integrated FEW resources consumption and emission impacts at the household level is still lacking. A serious-gaming (SG) approach with appropriately designed gameplay is well suited to studying the effectiveness of IMs in facilitating a reduction in household GHG emissions (Duke, 1980; Prensky, 2001; Barreteau et al., 2007; Reckien and Eisenack, 2013; Fjællingsdal and Klöckner, 2019). For this purpose, we developed a serious game called HomeRUN (Home Role-playing for Understanding the Nexus) to model and simulate the FEW resources consumption of an average U.S. household. By incorporating behavioral and technological household actions in the game, we examine which IMs influenced the greatest reduction in GHG emissions.

The main objective of the study was to understand whether or not intervention messages affect FEW consumption and encourage conservation, and if so, which types of messages are most effective. We selected the serious game approach for our behavioral study for several reasons. First, serious games allow learners to experience situations that are difficult to create in the real world for reasons of safety, cost, and time (Susi et al., 2007). Second, using standardization of procedures, serious games can simulate real-world scenarios and contexts, allowing us to study behavior in environments that closely resemble the situations of interest (Williams-Bell et al., 2015). Third, serious games provide a platform for us to design controlled experiments with immediate feedback to participants in order to study the impact of messaging on resource consumption behavior (Domínguez et al., 2013). Lastly, serious games enable built-in data collection mechanisms that capture behavioral data, such as choices and interactions with in-game objects, reducing the potential for human error in data collection (Westera et al., 2014).

The remainder of the paper is structured as follows. Section 2 reviews the state of the literature on both intervention messaging and the serious games approach and presents our hypotheses. Section 3 describes our game design and data. In Section 4, we present the results of game data analysis that answers the question of which messages caused people to conserve the most. The discussion in section 5 provides highlights from the results, policy implications, and study limitations. We conclude with a summary of findings and a direction for future work.

2. Literature review and hypothesis

2.1. FEW nexus and household consumption

The direct and indirect relationships of household level consumption, conservation, and waste on what is produced, used, and emitted throughout the FEW nexus are numerous: water and energy are used, for example, to manufacture synthetic fertilizer, grow crops, produce post-harvest food items, and prepare food in homes (Floress et al., 2022; Watkins et al., 2019). Energy is needed to produce and deliver clean water to the home, as well as treat wastewater generated by household activities (e.g., Ananda, 2018), and water is a critical input to many energy sources (Jin et al., 2019). Habitual food consumption choices at home and away from home have varying impacts on energy and water resources - as well as GHG emissions - from production, preparation, consumption and (potentially) waste of food products (Dai et al., 2020). Despite difficulties associated with specifying direct and indirect effects of household level behaviors across the FEW nexus, some are recognized as more impactful, while others are easier for householders to implement. For example, there are greater reductions in GHG emissions from eliminating or reducing consumption of dairy, but one-time or infrequent purchasing choices, as well as direct conservation of water and energy, are easier for householders to implement (Floress et al., 2022). The cost-effectiveness of conservation choices may also not be clear to household decision makers. For example, technological efforts to conserve water and energy in homes have included certifications to influence appliance purchasing decisions like EnergyStar and WaterSense, but these programs may not account for operating costs (Geglio et al., 2021).

2.2. Behavioral psychology of household FEW resource consumption

Behavioral science is crucial for confronting the complex challenges posed by global climate change (Gifford et al., 2011; Davidson and Kecinski, 2022). In particular, behavioral psychology plays a central role in understanding household resource consumption patterns, encompassing energy, water, and food. Numerous studies have demonstrated that individual and collective behaviors within households significantly impact resource utilization and conservation (Gifford et al., 2011; Abrahamse et al., 2005). Regarding energy consumption, research has shown that behavioral interventions, such as providing real-time feedback on energy usage or implementing energy-saving competitions, can effectively reduce energy wastage (Abrahamse et al., 2007; Schultz et al., 2007). In the context of water, psychological factors like attitudes, perceived norms, and habits shape water consumption behaviors (Stern, 2000; Mckenzie-Mohr, 2011). Behavioral interventions, such as setting water-saving goals or utilizing social norm-based campaigns, have demonstrated their effectiveness in encouraging water conservation (Torres and Carlsson, 2018; Nolan et al., 2008). Additionally, in the issue of food consumption, psychological factors like portion size preferences, dietary choices, and meal planning have been linked to food waste (Steffen et al., 2012; Quested et al., 2013). By employing behavioral strategies like mindful eating practices and reducing plate sizes, households can contribute to the reduction of food waste (Verain et al., 2015). Understanding the intricacies of behavioral psychology is therefore crucial for designing effective interventions aimed at promoting sustainable household resource consumption practices.

2.3. Intervention messages

An intervention is a purposeful action by an agent to create change (Midgley, 2000). It is a precise set of events devised to put into practice action of known dimensions (Fixsen et al., 2005). The most effective interventions combine several policy tools to address multiple barriers to behavior change, such as the use of social marketing along with structural changes (McKenzie-Mohr, 2011). Messages about climate change, for instance, are intended mainly to promote predefined behavior change in the recipient (e.g., reducing dairy and meat consumption) (Amelung and Funke, 2015). The effectiveness of messages concerning climate change is closely tied to their ability to bring about specific, predetermined behavioral changes in the audience (Fixsen et al., 2005). These messages are strategically crafted to inspire actions that can mitigate the impact of climate change, such as reducing carbon emissions or adopting sustainable practices. Effectiveness is determined by how these messages prompt individuals to take the desired actions, like reducing energy consumption, using public transportation, or supporting eco-friendly actions. This effectiveness is assessed through various means, including surveys, data analysis, and monitoring actual behavior changes. In essence, the effectiveness of climate change messages hinges on their capacity to translate awareness and concern into tangible, eco-conscious actions.

2.3.1. Information or knowledge deficit interventions

Messages focusing on providing information about resource consumption that will help audience members pursue personal and societal action may prove effective (Maibach et al., 2008), but non-targeted, general information has inconsistent results and may even increase the prevalence of undesired behaviors. The effects of providing information or increasing knowledge appear mixed and inconsistent across domains. A study by Whitehair et al. (2013) indicates that messages aimed at increasing awareness of food waste trigger a significant decrease in waste behaviors. Similarly, feedback messages based on real-time energy use data and user-friendly displays installed in various college dormitories on the Oberlin College campus coupled with an energy use competition resulted in an energy use reduction of 56% over two weeks (Petersen et al., 2007). However, Seyranian et al. (2015) compared norms, identity, and knowledge messaging and found that the knowledge messages were associated with an increase, rather than decrease, in water consumption.

2.3.2. Impact messages

Messages about impacts may appeal to target audience values by indicating what is at stake for them, such as personal health and the quality of the environment. Impact messages may influence emotions like fear, guilt, shame, pride and hope, and thus recipients' understanding and motivation to act on a message. Asensio and Delmas (2015) found that messages about environmental and health-related impacts decrease household electricity consumption, although the lasting effects of the messages are small (Nisa et al., 2019).

2.3.3. Social comparison/normative interventions

Nisa et al. (2019) found that strategies of social comparison are among the most effective to promote climate change mitigation by individuals and households. Social comparison messages can activate moral costs of resource use by shifting normative beliefs as well as recipients' "correcting" their conservation behaviors to maximize utility (Taylor et al., 2018). Anderson et al. (2017) found dorm residents reduced their energy consumption when they were "highly influenceable" by social norms, as well as when messages were delivered for longer time periods. Allcott (2011) studied the effectiveness of social comparison messages in over 600,000 U.S. residences and concluded that the energy usage reduced by 2.0%–6.3% when neighbors' household energy consumption was provided. Normative social influence was found in a study of Californians to be the most powerful IM for reducing residential energy consumption, even though the same respondents rated normative information as the least motivating (Nolan et al., 2008). Goldstein, Cialdini and Griskevicius (2008) found that the use of normative appeals to encourage more hotel guests to reuse hotel towels was more effective compared to the use of conventional messages that simply stress the environmental benefits of towel reuse. The normative message was made even stronger by a framing (e.g., "The majority of guests in this room reuse their towels") such that consumers can identify more closely with the majority, imagine the behavior in question, and envision themselves adopting it. These studies are consistent with others finding norms and identity to be related to household FEW resources conservation (Floress et al., 2022; Van der Werff et al., 2013). However, a better understanding of the psychological drivers behind water consumption is still needed to efficiently frame conservation messages (Corral-Verdugo et al., 2003; Addo et al., 2019).

2.4. Serious-gaming approach

The notion of serious games (SGs) refers to applications in which games are used for purposes other than mere entertainment (Girard et al., 2013). The suitability and potential of the serious gaming approach as a method of experiment rest on the fact that games are an integral part of all known human cultures involving competitive exercises (Huizinga, 2014). Studies confirm that simulation games help players increase their awareness of real-world issues and comprehend course subjects (Hirose et al., 2004; Philpot et al., 2005). Simulation-based SGs are increasing because of growing interest in their application in a broad range of application areas such as public policy, defense, sustainable development, and healthcare (Zyda, 2005; Peters and Van de Westelaken, 2014).

Game-based learning in simulated SGs creates a significantly greater potential for learning over other media (Gee, 2004; Prensky, 2001; Squire, 2008). The creation of immersive and engaging environments is a practical way in which players can explore and learn. Current technologies in the development of SGs allow players to experiment with realistic simulations using animations, graphics, and an interactive environment that effectively explains course content and allows the development of players' skills (Deshpande and Huang, 2011). The gameplay of SGs engages the user in a pedagogical journey and positively impacts the players' analytical and strategic skills, comprehension, memory and recall, and social skills, such as collaboration, negotiation, and shared decision-making (Mitchell and Savill-Smith, 2004). SGs can be designed to be used in an intervention study by constructing opportunities for reflection on the game's subject matter (Rodela et al., 2019).

One specific SG genre is role-playing games (RPGs) that have two key attributes: i) player's role that improves with experience and ii) a well-defined storyline (Rollings and Adams, 2003). An RPG encourages higher-level mental stimulation and exploration of the depths of their empathy (Sundberg, 2016). The gameplay sessions of an RPG facilitate behavior consistent with the actions of the specified role (Nelson and Norton, 2005) and help in learning, planning, applying, visualizing, and reflecting (Podleschny, 2008). They fit well with a learning-by-doing approach by offering stakeholders a place to learn about the trade-offs between decisions in the safe experimentation environment of the game (Mayer, 2014).

The current research using IMs for resource conservation tends to focus on either the effectiveness of a single group of messages or within a single consumption sector. Theories of how individual and household environmental decision-making is impacted by SG play are emerging, but they primarily focus on the energy area. As an experimental method for improving an understanding of practical environmental sustainability challenges, a serious game-based approach is appropriate because it offers opportunities to obtain first-hand experiences that may be otherwise too costly, difficult, or time consuming to do in real-world scenarios (Squire, 2002; Corti, 2006; Madani et al., 2017). Used as intervention study tools, SGs can trigger learning about the subject matter and change behavioral practices (Flood et al., 2018).

In our study, we build upon some key assumptions supporting the use of serious gaming methods. Firstly, games inherently increase engagement and motivation (Kapp, 2012), harnessing intrinsic motivation for more enjoyable and effective learning. Breuer and Bente (2010) emphasize the importance of fun in maintaining participant engagement. Additionally, serious gaming capitalizes on active, personalized and experiential learning, surpassing passive instruction (Greitzer et al., 2007). This knowledge gained in the gaming context can transfer to real-life situations (Kriz, 2003). Lastly, games can provide instant feedback on actions taken, allowing learners to adjust and learn from their mistakes (Bellotti et al., 2013).

2.5. Research questions and hypotheses

Each of the major types of IMs (specific behavior, social comparison, and impact) can be effective in nudging people towards resource conservation behaviors. However, simultaneous consideration of FEW resources and their inter-related consumption is still lacking. The comparison between the effectiveness of different types of IMs in a single experiment has not been adequately researched. Using an RPG approach, this study expands the scope of IM studies to cover integrated FEW consumption. Instead of focusing only on a single domain, it considers the three FEW sectors within a single experiment.

The overall goals of the research project were to understand whether or not intervention messages affect FEW consumption and encourage conservation, and if so, which types of message are most effective. Since messaging and behavioral responses to this messaging tend to be context specific, undertaking this intervention research in a serious game enables us to control the context of the messaging. This research is unique because it 1) investigates messaging at the food, energy and water nexus-something that has been limited in scope to date and 2) multiple types of interventions are given in the same context enabling a comparative approach to effectiveness. The research questions are defined as follows:

1. How effective are intervention messages intended to decrease consumption of FEW resources, and in turn GHG emissions, in a simulated SG environment at the household level?
2. Which of the three types of intervention messages for conservation (specific behavior, social comparison, impact) are most effective?

Given the evidence presented earlier, we hypothesize the following:

1. Reduction measure IMs will yield more conservation actions than baseline messaging within each food, energy, or water sector and overall.
2. Impact IMs will yield more conservation actions than baseline messaging within each food, energy, or water sector and overall.
3. Social comparison IMs will yield more conservation actions than baseline messaging within each food, energy, or water sector and overall.
4. Social comparison IMs will yield more conservation actions than reduction measures or impact messaging.

3. Methods

3.1. Research design

Our research design consists of three components: role-playing game (RPG) development, experiment, and analysis (Fig. 1). The RPG development brought together scientists and practitioners in the game design process, a transdisciplinary approach involving different scientific disciplines including psychology, economics, engineering, and climatology (Agusdinata and Lukosch, 2019). The RPG experiment involved college students at U.S. universities. The game session was designed to engage participants and get feedback for improving the RPG. The details are described in Section 3.4. We performed statistical analysis to determine the effectiveness of IMs in changing consumption behavior (Section 4). Our research concludes with a discussion of implications for our research, along with with *caveats* and suggestions for future work.

3.2. HomeRUN role-playing game (RPG)

HomeRUN RPG was developed to study IM effectiveness for shaping sustainable FEW consumption behaviors by randomly introducing IMs before each round of play (Agusdinata and Lukosch, 2019). HomeRUN was developed using Unity, which is a cross-platform game engine developed by Unity Technologies and is embedded on a website using Unity WebGL.

3.2.1. Household actions related to FEW resources

In this study, HomeRUN simulated thirty-four household actions. These include six food, fourteen energy, four water, four "wonder" (i.e., altruistic behaviors, such as offsetting carbon emissions), and six indulgent (i.e., hedonic behaviors such as taking a vacation and eating out) actions. All the options were available for players to choose after seeing an intervention message in each round so that each participant had an equal opportunity to take all the different types of actions. Table 1 provides some examples of the types of actions and their associated capital cost and carbon emission reductions. Fig. 2 shows some of the options as they appear in the HomeRUN user interface.

3.2.2. Intervention messages within HomeRUN

In the HomeRUN gameplay sessions, ten IMs were flashed for 20 s in a randomized order across the ten game rounds before the start of each round. An example is shown in Fig. 3. There are four types of messages: (a) reduction messages, (b) social comparison messages, (c) sector-wise impact messages, and (d) baseline messages (Table 2). The baseline message did not always appear first. The players were able to take action after each message.

3.2.3. HomeRUN gameplay

HomeRUN gameplay had ten rounds, with each round representing one year. The game's currency was gold, where one unit was approximately equal to U.S.$100. A player received 40 gold units every round, which is about two-thirds of the annual savings of an average American family. There were three types of actions players could take: (1)

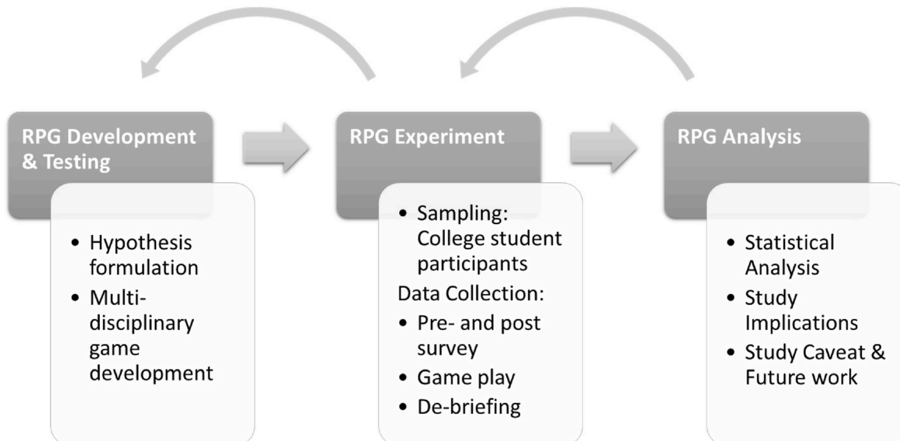

Fig. 1. Research design phases and elements.

Table 1
Household actions related to FEW resources.

Household actions	Capital cost	Cost-savings per year	Carbon reductions per year (mtCO2e)
Water-related actions			
Install low-flow showerhead	$30	$94	0.4
Install low-flow toilet	$520	$18	0.1
Energy-related actions			
Install solar PV	$31,341	$1290	3.9
Use LED light bulb	$10	$42	0.1
Food-Related actions			
Reduce food waste by 20%	0	$400	0.4
Reduce dairy consumption by 50%	$200	0	0.3
Indulgent actions			
Install a swimming pool	$15,000		−4.5
Have a fancy dinner with wine and steak	$250		−0.1
Wonder actions			
Offset housing footprint	$347		17.36
Offset transportation footprint	$236		11.8

Source: CoolCalifornia, 2017.

household actions related to individual FEW sectors, (2) wonder actions, and (3) indulgent actions. Each action requires spending gold (i.e., capital cost), while some actions result in increased gold in later game

Fig. 3. An example of an intervention conservation message shown at the start of the round in the HomeRUN RPG.

Fig. 2. A screenshot of RPG HomeRUN interface showing options of household actions.

Table 2
Intervention messages used in HomeRUN RPG (appeared once in randomized order).

Message type	Message content
Baseline Message (Base)	Have a good game!
Consumption reduction messages	
Reduction Measure-Food (RM-F)	Cutting your meat consumption in half can reduce your total household contribution to climate change by 10%.
Reduction Measure-Water (RM-W)	Installing low-flow showerheads will reduce your water use by 20%, also reducing your CO2 emissions.
Reduction Measure -Energy (RM-E)	Changing your compact fluorescent lightbulbs (CFL) to light-emitting diodes (LEDs) can reduce your CO2 emissions from electricity use by 3%.
Social-comparison messages	
Social Comparison-Energy (SC-E)	Last round, your energy use was 20% more than the average game player.
Social Comparison-Food (SC–F)	Last round, your food consumption was 20% more than the average game player.
Social Comparison-Water (SC–W)	Last round, your water consumption was 20% more than the average game player.
Impact messages	
Economic Impacts (I-Econ)	The average American household annually spends $1351 on their electricity, $1050 on their water bill, and $6600 on food.
Health Impacts (I-Health)	If all households continue to use the average amount of food, energy, and water, the average American can expect to experience 2 days in a typical year by 2100 when the heat and humidity are so high that it will be unsafe to remain outdoors.
Wildlife Impacts (I-Wild)	If households continue to use the average amount of food, energy, and water, we can expect climate change to reduce insect numbers and decrease insect-eating bird populations by 2050.

sessions (i.e., cost savings). The first two types of actions–FEW conservation and wonder actions–result in carbon reductions, whereas indulgent actions result in increased carbon emissions (i.e., negative carbon reductions). All actions give players joy (positive psychological consequences of pro-environmental behavior), and the player with the highest joy won the game. A flow diagram of gameplay is shown in Fig. 4. The values for the technological and behavioral actions were taken from a tool called the Cool California carbon footprint calculator developed at the University of California Berkeley (CoolCalifornia, 2017).

3.3. Study participants

Study participants included 157 students from five U.S. universities. The students were recruited through various multi-disciplinary courses by offering them extra credit for participating in the study. The Institutional Review Board (IRB) of Arizona State University approved the study (STUDY00011584).

Half of the participants were female (50%), and slightly more than half were first-year students (54%). Around one third of the students were majoring in natural sciences (34%), followed by engineering (28%) and social sciences (21%) (the rest were undeclared). One third of participants had liberal political views (34%), whereas 13% of the participants had conservative political views, and the remainder indicated no preference. Almost half of the participants identified as Democrats (47%), 22% identified as independents, and 15% identified as Republicans, with 6% indicating “No preference” and 10% “I Don’t know” responses.

3.4. Experimental design

The study participants were emailed a document that briefly described the project and contained the information regarding different elements of the gameplay session. Due to the novel coronavirus, all gameplay sessions were online, and all participants completed the gameplay session unsupervised and on their computers. The elements of the gameplay session were sequentially located on a dedicated website. The first element of the study was to complete a short (~10 min) online pre-survey that collected demographic information (political identification, gender, major) and baseline knowledge about FEW conservation options in terms of their cost and emission impacts. Once each participant completed the pre-survey, they were asked to view a 7 min 37 s long tutorial about HomeRUN that was hosted on YouTube and embedded in the game website.

After the pre-survey and tutorial, participants began to play the RPG. The playtime was approximately 35 min and consisted of 10 rounds. The online version of HomeRUN was designed for a single player. At the start, the participant was asked to familiarize themself with the game for 1 min. Before each round, a randomized IM (see Table 2) was flashed for 20 s, followed by 90 s of gameplay per round. At the end of the round, the summary (carbon reduction and number of actions for each option

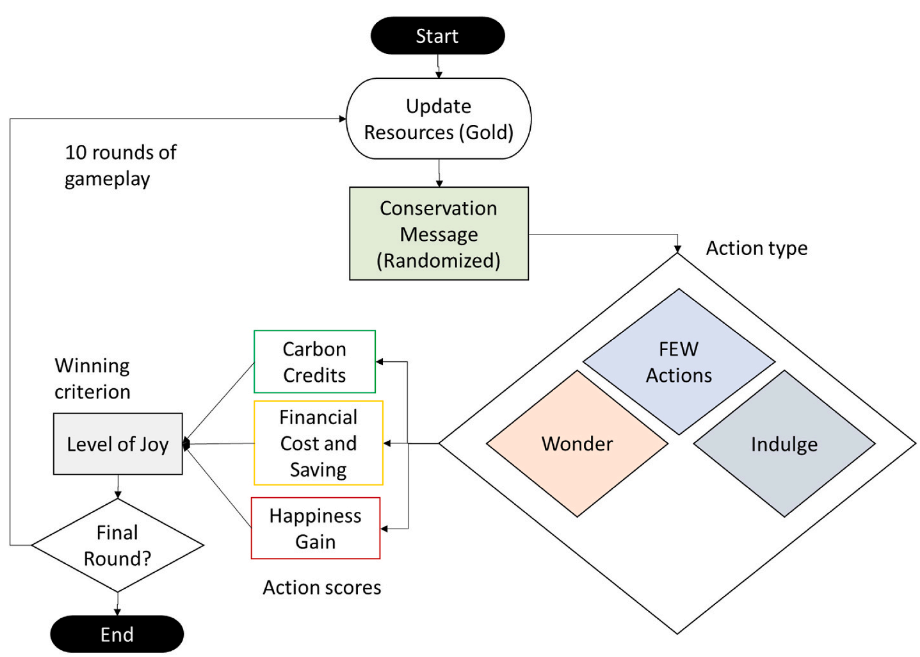

Fig. 4. Flow diagram of a gameplay session of HomeRUN.

category) was shown in a bar chart for 1 min. The carbon reduction of each player was explained in terms of taking an equivalent number of cars off the road. After the 10 rounds, a summary of all actions was shown to the participants. Finally, participants were asked to complete a post-survey with questions about game design, flow experience, and other feedback regarding their gameplay experience which took approximately 7 min. In total, the experimental sessions took about 1 h to complete. The data were analyzed using Microsoft Excel and Statistical Package for the Social Sciences (SPSS). Evaluation of the gameplay session was done using the game data to analyze mean total actions, mean total carbon reductions and mean carbon reductions per action.

4. Results and analysis

4.1. Relative effects of intervention messages

We present the results based on the hypothesis specified in section 2.5. The players' individual actions and emission impacts were aggregated across intervention messages into three categories: (1) mean total actions, (2) mean total carbon reductions, and (3) mean carbon reductions per action taken (Table 3). Overall, the mean carbon reductions per IM was 389, the mean number of actions across all ten rounds was 14.8, and the mean carbon reductions per action taken was 26.3. The exposure to the social comparison energy (SC-E) message resulted in the most carbon reductions (Mean = 434), whereas the exposure to the economic impact (I-Econ) message produced the least carbon reductions (Mean = 365). The exposure to only three IMs–social comparison food (SC–F), social comparison energy (SC-E), and reduction measure food (RM-F)–produced more carbon reductions (Mean = 416) than the overall mean carbon reductions (Mean = 389). This underscores the significant influence of these three specific informational messages on household consumption choices and associated carbon reductions. It is important to note that the potential for carbon reductions remained the same across all informational message domains, as the action items were not tied to the specific messages.

The effects on carbon reductions are compared across different message types of IMs (baseline, reduction measures, impact-focused, and social comparisons). Exposure to the social-comparison messages produced the most carbon reductions and carbon reductions per action (Mean = 412 and Mean = 26.6, respectively). It is followed by the baseline (Mean = 384 and Mean = 26.5, respectively) and reduction-measures messages (Mean = 380 and Mean = 26.4, respectively). The impact-focused messages yielded the lowest carbon reductions (Mean = 375) as well as carbon reductions per action (Mean = 25.9). Thus, only the social comparison messages group had above-average carbon reductions in both absolute terms and on a per-action basis.

In terms of carbon reduction per action, the baseline message (i.e., "Have a good game!") actually outperformed all impact-focused and water-related (both RM-W and SC-W) messages. This result further confirms the limited effect of water-related messages. It also indicates the relatively insignificant effect of messages associated with health, economic, and environmental impacts of conservation.

A repeated-measures ANOVA determined that mean carbon reductions differed significantly by intervention message types (F (9, 1404) = 2.072, $p < .03$)). Post hoc pairwise comparisons using the Bonferroni Least Significant Difference test (Cabin and Mitchell, 2000) showed that ten pairwise comparisons are statistically significant, while also correcting for the possibility of an inflated Type I error, as shown in Table 4. The social-comparison food (SC–F) and social-comparison energy (SC-E) messages resulted in significantly higher carbon reductions than several other messages. Specifically, the SC-E messages resulted in significantly larger emissions reductions when compared to all of the impact-based messages and the baseline, while the SC-F messages outperformed two of the impact-based messages and one reduction-measure message. Thus, the hypothesis that social comparison messages are more effective than reduction measures and impact messages is partially supported.

4.2. Immediate effects of intervention messages

Similar to the effects on GHG emissions, we found that the intervention messages on food and energy had stronger effects on the immediate FEW action taken by the players in the gameplay (in each round for all 10 rounds). The affiliation of the first action taken by the players at the start of each round, after being exposed to the intervention

Table 4
Statistically-significant pairwise comparison of mean carbon reductions in relation to message type.

Pairwise Comparison	P-value
Social Comparison Food	
SC-F and RM-W	.017
SC-F and I-Econ	.040
SC-F and I-Wild	.006
Social Comparison Energy	
SC-E and Base	.019
SC-E and SC-W	.012
SC-E and RM-E	.011
SC-E and RM-W	.002
SC-E and I-Econ	.005
SC-E and I-Wild	.001
SC-E and I-Health	.023

Table 3
Carbon reduction for each group of intervention messages.

	Mean total actions	Mean total carbon reductions [10*mtCO_2e/year]	Mean total carbon reductions per action taken [10*mtCO_2e/year]
Social-comparison messages			
SC-F	15.7	419	26.7
SC-E	15.6	434	27.8
SC-W	15.1	384	25.4
Mean	***15.5***	***412***	**26.6**
Reduction-measure messages			
RM-F	14.8	394	26.6
RM-E	14.1	380	27.0
RM-W	14.3	367	25.7
Mean	***14.4***	***380***	**26.4**
Impact-focused messages			
I-Health	15.2	387	25.5
I-Econ	14.5	372	25.7
I-Wild	13.8	365	26.4
Mean	***14.5***	***375***	**25.9**
Baseline message			
Base	14.5	384	26.5
Overall	**14.8**	**389**	**26.3**

message, is shown in Fig. 5. The energy group had the highest percentage of the first action after being exposed to eight IMs, whereas the food group had the highest percentage after being exposed to two IMs (i.e., RM-F and SC-F). However, the two water-related IMS (RM-W and SC-W) also led to significantly more water-related actions at the start of the next round, compared to the baseline message, even though more first actions were still taken from the energy group. Overall, the RM and SC messages led to more first actions being in the same food, energy, or water category, compared to the baseline message. The impact messages led to slight increases in energy-related first actions.

5. Discussion

5.1. Key highlights

The game data analysis revealed that exposure to social comparison energy (SC-E), social comparison food (SC–F), and reduction-measure food (RM-F) IMs resulted in the top three carbon reductions, respectively. The remaining messages yielded less than mean carbon reductions. The SC-E message yielded the most carbon reductions. This result is in line with previous studies (e.g., Allcot, 2011; Taylor et al., 2018) and indicates that understanding of energy use and savings could have significant potential to reduce GHG emissions (Attari et al., 2010; Spence et al., 2011). The exposure to the social comparison water (SC–W) message produced slightly less than mean carbon reductions. Furthermore, emissions from water use are linked with energy use. In contrast to the finding of Addo et al. (2019), the reduction-measure water (RM-W) message was not that effective and yielded the second lowest carbon reductions.

Comparing carbon reductions from the four message groups show that only social comparison messages yielded significantly more carbon reductions than the other messages did. This strengthens the finding of a meta-review by Nisa et al. (2019) that social comparison interventions are the most effective in promoting environmentally friendly household actions. The results from the comparison of message groups further supports the hypothesis that social comparison messages result in significantly more carbon reductions than other message types.

Surprisingly, exposure to reduction-measure and impact-focused messages had lower carbon reductions - albeit not statistically significant-than that of the baseline message. We can attribute this result to the following factors. First, it is possible that its simplicity and positive tone ("Have a good game!") resonated more with the participants, making them more inclined to take environmentally friendly actions. Second, participants may have experienced message fatigue with the other intervention messages. In contrast, the baseline message was unexpected and stood out, possibly garnering more attention and engagement. Third, it is possible that these messages were confusing if they contained details that were not relatable to the participants. As the game does not offer insights into the mechanisms or the degree of attention given to these messages, further research and analysis would be needed to determine the exact reasons behind this finding. Additionally, understanding the specific characteristics of the study participants and their individual responses could provide more insights into why the baseline message was more effective for them.

The actions simulated in HomeRUN belong to five groups, and the first action taken at the start of each round was generally from the energy group even though each participant had equal opportunity to do all five different types of actions. The highest frequency for energy actions is 61% in response to the reduction measure energy (RM-E) message, followed by 57% for the social comparison (SC-E) message. There were two instances where food actions had the highest response – 40% after being exposed to the reduction measure food (RM-F) message, and 42% for the social comparison food (SC–F) message. The increase in first actions related to food after being exposed to the food-specific message endorses the finding of Whitehair et al. (2013). In the rounds where SC-W and RM-W were flashed, the water actions were taken at least three times more than in the eight other rounds. The reduction-measure water (RM-W) message led to 43% of the players choosing the first action from the water group, thus confirming the findings of Seyranian et al. (2015), who found that households receiving specific water-saving strategies

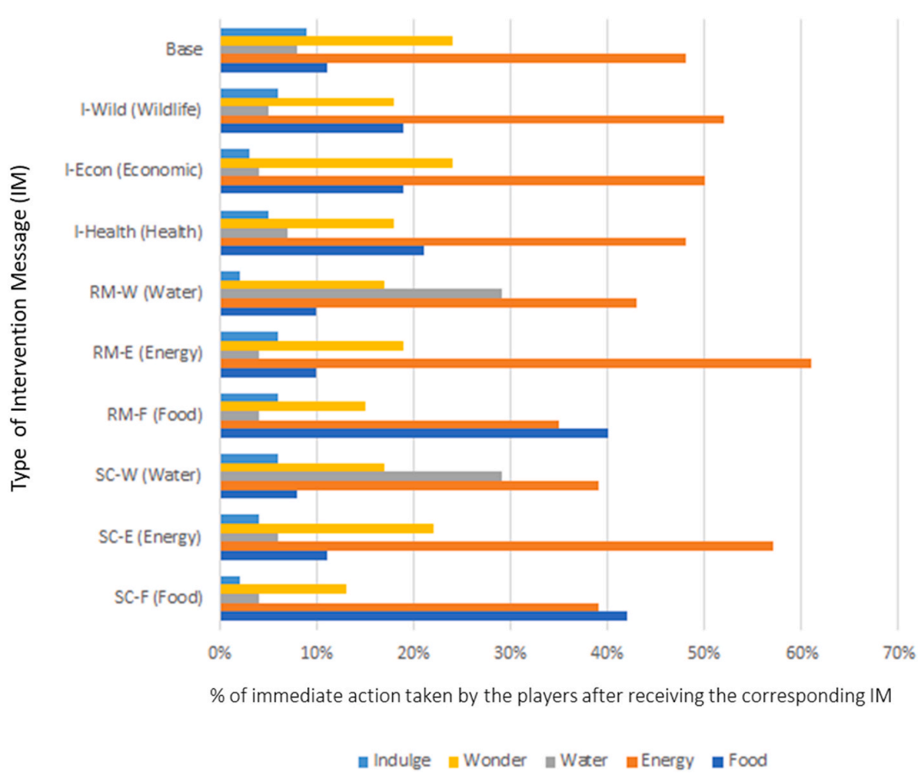

Fig. 5. The percentage of first action for each action category.

conserve more water. The impact-focused messages yielded the best response in terms of energy actions after energy-specific messages, thus agreeing with the findings of Asensio and Delmas (2015).

In summary, first, with respect to Fig. 5 (percentage of first action for each action category), it was noted that all RM and SC messages led to more first actions being in the same food, energy, or water category, compared to the baseline message. This has important implications for messaging, specifically the potential for encouraging conservation behavior through the use of periodic reminders. Second, it was noted that the impact messages led to more first actions in the energy category, possibly because of their cost-effectiveness with respect to GHG reductions, compared to other household actions. Third, some potential limitations of the study were highlighted, including message fatigue and misunderstanding of messages. Finally, the potential benefits of tailored messaging are emphasized. Hence, tailored IMs, in general, have a significant effect on the choices players make during the gameplay (Brinberg et al., 2000), and the use of SG facilitated the process of testing the efficacy of IMs in the targeted population (Fixsen et al., 2005; Bird, 2008).

5.2. Policy implications

The results of this study point to some opportunities for policy design and actions. First, the efficacy of social comparison messages, especially on energy and food consumption, confirms electricity utilities' IMs and may suggest intensifying those efforts, as well as extending them to the food domain. Similarly, municipalities can encourage reduction of food waste by delivering messages comparing solid waste production among neighborhoods, using trash collection data as a proxy where food/compost waste data are not available. Alternatively, a social comparison message can include both energy and food consumption instead of a separate message for each individual FEW domain (Ayres et al., 2013). This encourages municipalities and electricity utility companies to work together to create joint messages for households.

Second, our results demonstrate a strong influence of message type on the first action taken. When a message related to energy appears, for example, players tend to respond to the message by taking action associated with energy consumption. The percentage of food (water) actions also increases following a corresponding food (water) message. It seems that the IM focuses the attention of the participant and directs action, known as availability heuristic, through which our judgments and decisions are influenced by recent or easily accessible information (e.g. Hayibor and Wasieleski, 2009). This result suggests that policy-makers and utilities can send a periodic reminder message that would encourage conservation behavior.

Third, our results indicate that promoting water conservation based on GHG emissions impact may not be effective, although that may be because GHG reductions are modest in comparison to the cost of actions in this game (e.g., installing a low-flow toilet is $500 for the same GHG reduction as using an LED light bulb at a cost of $10). Efforts to reduce household water-related GHG emissions may be better focused on energy efficiency and renewable energy options at water and wastewater facilities, which account for ~35% of municipal energy budgets in the U.S. (EPA, 2017). A better understanding of the psychological drivers behind water consumption and conservation is still needed (e.g., Corral-Verdugo et al., 2003).

6. Conclusion

Sustainable food, energy, and water resource consumption can significantly reduce GHG emissions. Successful nudging for such behaviors, however, requires an intimate knowledge of messaging that resonates and inspires actions with households. In this study, we experimented using the HomeRUN SG to assess the effectiveness of different intervention messages for conservation. Despite limitations, the results of this study increased our understanding of which intervention messages can be most effective in supporting conservation efforts to reduce households' GHG emissions. Confirming previous findings from empirical studies, it is found that social comparison messages are effective in reducing greenhouse gas emissions. The unique findings from this study are that social norming messages have the most significant effect on reducing GHG emissions - performing better than straight reduction or impact messaging in a gaming context.

This initial study also provided insights into whether home consumers perceive and integrate the connections between food, energy, and water behaviors and their impacts on households' greenhouse gas emissions. While energy domain actions were the most frequently taken, people did respond to the domain of the messaging. Gamers' first actions were most often directly related to the domain highlighted in the message.

While confirming the finding the social norm messaging is effective (as found previously) this research has been able to test the norming message in direct comparison to impacts, reductions, and a neutral control message. This is unique from most studies. In addition, in a review of interventions studies approaches and domains, Berman et al. (2019) found that very few investigate more than one domain within a single experiment like this FEW study did. Just as comparative data on effectiveness of type of IM is useful, comparative data on FEW domain messaging and which domain gamers choose to spend their resources in order to reduce GHG emissions (food, energy, water) are insights not gleaned in previous studies on consumption.

Furthermore, serious games offer an exciting and flexible platform for behavioral experiments. SG design aligns well with principles and concepts within behavior analysis, with applied and basic research possibilities. We demonstrated that a serious gaming environment and an appropriately designed gameplay concept could potentially reveal insights into consumption behaviors that may be too costly and impractical to obtain in a real-world setting. There is also the opportunity through pre-surveying participants to understand how gamers' "real life" identities that they bring to the game (i.e., their personal values, race, class and gender) influence how they interpret the gaming context and influence the decisions they are making. The gaming setting can be used as a precursor to gauge the performance of alternative policies and inform a selection and full-scale implementation of the best policy.

While studies such as this can be useful to understand real-world conservation behaviors, using simplified scenarios in gaming situations may not be fully generalizable to real-life decision-making and behaviors. Constraints in the physical world are not present in the gaming environment, the behaviors do not have to be sustained over any period of time, and the costs and benefits are more clearly identified than they might be in the real world. Similarly, the messages are very short and simple and do not perfectly mimic how people learn about climate issues in a complex media environment. Finally, the participation of college students rather than actual homeowners may limit the generalizability of our results.

For future work, this study can be extended by playing the game with actual homeowners, comparing results with actual actions of households and long-term monitoring of household emissions. The game can also be adapted to target different population segments, especially the youth. An increasing youth interest in games opens opportunities to use the popular platform as a new way to teach youth about real-world issues in a way that will be engaging and entertaining for them.

CRediT authorship contribution statement

Datu Buyung Agusdinata: Conceptualization, Methodology, Software, Resources, Validation, Formal analysis, Data curation, Investigation, Writing - original draft, Writing - review & editing, Visualization, Supervision. **Muhammad Hanif:** Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Rachael Shwom:** Conceptualization, Methodology, Investigation, Resources, Formal analysis, Validation, Writing - review & editing. **David Watkins:** Conceptualization, Resources, Writing - review & editing, Supervision, Project administration. **Kristin Floress:** Formal analysis, Validation, Resources, Writing - review & editing. **Cara Cuite:** Formal analysis, Validation, Resources, Writing - review & editing. **Kathleen E. Halvorsen:** Conceptualization, Writing - review & editing, Supervision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Datu Buyung Agusdinata reports financial support was provided by National Science Foundation.

Data availability

Data will be made available on request.

Acknowledgments

This work is supported by the U.S. National Science Foundation [Award no. 1639342].

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