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A Playful Approach to Household Sustainability: Results From a Pilot Study on Resource Consumption

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Abstract

Background. U.S. households produce a significant amount of greenhouse gas emissions, indicating a potential to reduce their carbon footprints from changing food, energy, and water (FEW) consumption patterns. Behavioral change to FEW consumption is needed, but difficult to achieve. Interactive and engaging approaches like serious games could be a way to increase awareness of possible measures, leading to more sustainable behavior at a household level. This study looks into the experiences and effects of a digital game for homeowners with the potential to reduce FEW resource consumption impacts.

Intervention. In this study, we developed and implemented a digital game to explore its potential to raise awareness of the consumption and conservation of FEW resources and the efficacy of conservation messages. This study aims to measure learning outcomes from game participation and to assess the suitability of the game for informing resource conservation actions.

Methods. We tested a proof-of-concept of a digital four-player game, called HomeRUN, with 28 homeowners. The data collected include homeowners' values and preferences with regard to FEW resources. The patterns of game

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actions are analyzed with an emphasis on the effectiveness of conservation messaging in informing household consumption behavior.

Results. About 65% of the respondents agree that they gained a better understanding of the greenhouse gas emission impacts of FEW resource consumption after playing the game. Over 57% of the respondents agree that the game experience would influence their future consumption behavior, while a quarter of the respondents are unsure. Overall, we demonstrate the HomeRUN game has potential as a tool for informing conservation efforts at a household level.

Keywords

carbon emissions, food-energy-water nexus, learning, resource conservation, serious game

Introduction

Addressing sustainability issues entails accounting for interactions between human behaviors, technological options, and policies. Such complexities provide a suitable context for applying a gaming approach (Huber & Hilty, 2015). In particular, the activities taking place within households account for a significant share of total greenhouse gas (GHG) emissions. A typical U.S. household emits GHG emissions of about 48 metric tons annually CO_2 (Jones & Kammen, 2011). Residential energy use accounts for roughly 20% of GHG emissions (Goldstein et al., 2020). Food systems contribute between 19 to 29% of the total anthropogenic greenhouse gases (Vermeulen et al., 2012). Nearly 5% of total GHG emissions comes from the water sector (Griffiths-Sattenspiel & Wilson, 2009). The GHG intensity of U.S. households underlines the importance of sustainable household consumption behavior in reducing overall GHG emissions (Shwom & Lorenzen, 2012). Globally, the expected rising demand for resources and the increasing household GHG emissions due to population growth and economic prosperity will further intensify the challenges to reduce FEW consumption (Bazilian et al., 2011).

Behavioral change and technological options have been recognized as central to any effective response to climate change mitigation to achieve net-zero GHG emissions (Allen et al., 2019; Carmichael, 2019). In U.S. homes, potential for near-term reductions can be achieved through behavioral changes without needing new regulatory measures by altering adoption and use of available technologies (Dietz et al., 2009). The change in energy use behavior and adoption of energy-efficient equipment is considered a successful policy (National Research Council, 2011). However, a transition to low-carbon and more efficient technologies—that are critical for reducing GHG emissions—cannot be accomplished without accounting for human behavior (Gram-Hanssen, 2013). Engaging and supporting the public in making behavioral changes require researchers, policymakers, and institutions to understand the types of interventions that effectively guide individuals towards low-carbon choices. There has been relatively little consideration of how this outcome might be achieved (Moore, 2012). Practical behavioral approaches need to impact the long-term changing habits and values and holistic involvement of individuals, systems, and social practices across all levels of society. People need to be engaged, informed, be willing to participate, and change their behavior for climate-change mitigation to take place (Moore, 2012).

Within this context, serious-gaming approaches have been applied to address sustainability issues (Madani et al., 2017). In particular, such approaches have been used to explore the complexities and feedback among preferences, behavioral intentions, policies, and environmental impacts (Barreteau et al., 2001; Villamor & Noordwijk, 2011). This approach has been used to uncover insights regarding potential conservation behavior by revealing preferences and action intentions, suggesting what individuals may do given certain conditions in a safe but realistic environment (i.e., the game setting). A relatively small number of games, however, have focused on FEW consumption behavior and conservation measures (Gerber et al., 2021; Stanitsas et al., 2019).

Serious games are often used to educate players on energy transition, sustainability, and related actions for quite a while. In a comparative study, Chen et al. (2017) explored the effects of digital on college students' learning for knowledge of energy conservation. They showed that a rich game environment had a positive effect on the learning, and a stronger effect than a simpler game. Focused on school-aged children, Knol and De Vries (2011) showed that the use of digital games in the space of energy consumption is not common, but that these games can have a positive impact on the learner. Results of their review also showed that many games did not put the focus on engaging game elements, but on the topic of the game itself. This may lead to a lower engagement of the learner.

A study carried out by Wu et al. (2020) suggests that serious games can have a potential impact on changing the domestic practices of householders, in a safe, fun, and interactive environment. Games may enable householders to investigate alternative ways of meeting energy-consumption targets and realize the limits to their energy-saving potential.

A systematic review of games within the domain of household energy consumption by Johnson et al. (2017) included 25 studies on the subject. However, the authors state that the evaluation of data shows a lack of quality, and that there is no strong evidence for the effect of the games found in this space. Douglas and Brauer (2021) come to similar conclusions in their study comparing the effects of gamification, board games, and apps for sustainability. They conclude that a lot is still unknown when it comes to specific effects of game elements in promoting specific (i.e., more sustainable) behavior, and more research is needed.

In this pilot study, we used the serious-gaming approach as an alternative tool to raise awareness for measures that may reduce FEW-resource consumptions. To this end, we applied a transdisciplinary process for game development, in which social actors from outside academia, including NGOs, government, industry, and community members, were involved (Agusdinata & Lukosch, 2019). Building on the transdisciplinary design process, we developed a digital game called HomeRUN to learn about interdependencies among natural, social, and engineered systems within the FEW nexus, and about couplings between climate impact messaging and actors' decisions related to resource consumption. A pilot study involving 28 homeowners was conducted to assess the efficacy of intervention messages and game learning impacts. The study included a pre- and post-test survey to evaluate players' learning and game experience, a gameplay phase, and a de-briefing. The whole session was designed to measure the learning happening during the gameplay and to create insights into the experiences of the players. This paper describes the product of game development and the results of the pilot implementation.

The rest of the paper has the following structure. The next section discusses challenges for promoting sustainable household FEW resource consumption and how behavioral science and games for sustainability can nudge people towards more sustainable consumption behavior. Next, we describe the game design elements and implementation. Preliminary results are discussed covering homeowners' values and preferences, a summary of patterns of game actions, and potential game impacts in terms of raising awareness and changing consumption behavior. The paper concludes with lessons learned, implications of the study, and suggestions for future work.

Behavioral Science and Games for Resource Conservation

Sustainable Household FEW Resource Consumption

The conservation of household resources is a multifaceted challenge. Most people lack knowledge about the carbon footprint of their everyday lives (Røpke, 2009). Better knowledge about the impacts of household actions and tailored feedback about household resource consumption may result in sustainable consumption. A household with sustainable resource consumption needs knowledge and input about voluntary behavior changes (Semenza et al., 2008) and the adoption of technological advances (Barisa et al., 2015) to being able to change its behavior towards FEW resource consumption.

U.S. households are essential in contributing to current and future food, energy, and water (FEW) nexus consumption impacts. The consumption of U.S. households is very carbon-intensive; even the carbon footprint of the lowest income group (i.e., less than 15k USD/year) is about 2.3 times the world average (Feng et al., 2021). The interest in research about household greenhouse gas (GHG) emissions has increased (Hertwich, 2005; Reinders et al., 2003; Zhang et al., 2015), and researchers highlight the importance of improving consumption for a sustainable future (Hartmann & Siegrist, 2017). The negative environmental impacts of household consumption are often invisible in our everyday lives (Røpke, 2009), partly due to the complex interaction between the FEW nexus and households having insufficient knowledge and understanding of consumption impacts (Herrmann et al., 2018). The intensity of household

GHG emissions and ignorance about the consumption impacts highlights the need for education about effective actions to reduce emissions.

Some tools that could influence FEW consumption in a household level include regulatory (e.g., energy efficiency standards; Palmer et al., 2013) and economic policy instruments (e.g., cap and trade program; Shammin & Bullard, 2009). Particularly relevant to our study is the communication-based tools that include information provision, social marketing campaigns, education, and participatory dialogue (e.g., Gray & Bean, 2011; Johnson & Karlberg, 2017). These approaches can potentially reduce direct household greenhouse gas emissions by 20% in the U.S. (Dietz et al., 2009). Information about environmental impacts and monetary costs has been shown to impact both direct energy and water use (Liu et al., 2015; Sønderlund et al., 2016). Furthermore, it has also become apparent that economic and environmental considerations alone are often not sufficient to motivate behavior change (Heberlein, 2012) and that social influence approaches have been effective (Abrahamse & Steg, 2013).

Behavioral Science, Sustainable Behavior, and Games

Understanding how games must be designed to affect behavior requires looking beyond the boundaries of game science (Stanitsas et al., 2019). Our game design aims at having a direct impact on individual actions and decisions by educating players, and by making them aware of actions they can take—on a household level—related to their resource consumption. Thus, we look at behavioral science that provides valuable insights to drivers of human behavior and how to nudge people to adopt more sustainable practices (Schultz et al., 2007). Social norms play a role in driving or guiding social behaviors and actions (Aarts & Dijksterhuis, 2003; Goldstein & Noah, 2008), such as accepted behaviors in certain circumstances, for example, preferring a daily shower over a weekly bath as in many western households. Games allow insights into social norms and behaviors, as well as into complex problems such as climate change. They can contribute to the development of new ideas and relationships of players on the topic of climate change, following the idea that widespread but incorrect mental models about climate change and related dynamics could pose a problem for effective climate action, leading to inappropriate decisions (Gerber et al., 2021). This mapping study found that the majority of games addressing climate change topics focused on climate change mitigation (92 games, 80%), while 24 games (21%) were themed on climate change adaptation (Gerber et al., 2021, 15). Stanitsas et al. (2019) found 77 games that address aspects of sustainability, such as energy conservation, water management, and eco-innovation.

To foster understanding of the need for sustainable consumption, and related actions individuals can take, innovative educational tools such as serious or simulation games can be used. These can incorporate so-called intervention messages (IMs). Intervention messages are a particular technique that has been used to initiate change for unhealthy or risky behaviors (Fjeldsoe et al., 2009). A literature review shows that more than 90 studies addressed the connection between social norms and sustainable behavior

(Yamin et al., 2019). Related to sustainable behavior, Sparkman and Walton (2017) show that information on how the behavior of others changes, can impact decisions on consumption at a household level.

Effective interventions to change behaviors share some common characteristics. To overcome multiple barriers to behavioral change, interventions employ multiple policy tools such as incentives and persuasive messaging and target multiple actors including individuals, communities, and businesses (Dietz et al., 2009). The "Games for Change" initiative is a notable example of how games are used to address societal challenges by changing knowledge, attitudes, and behavior (www.gamesforchange.org/). However, according to a study by Abraham and Jayemanne (2017), there is still a critical problem faced by climate change activists: the significant remaining resistance to the acceptance that climate change is occurring. Games could be one instrument for raising awareness on this issue (a so-called "eco-centric" perspective) and highlighting concrete actions to take.

Serious Games for Sustainability

Serious or simulation games (SGs) are types of games that are used for purposes beyond just entertainment (Susi et al., 2007). The number of SGs that address sustainable behavior in particular has grown over the last 10–15 years. Serious or simulation games are guided by experiential learning theory (Kiili, 2005; Kolb, 1984; Prensky, 2007), making them a good fit with the learning-by-doing approach in sustainability issues, offering stakeholders a place to learn about the trade-offs between decisions in the safe experimentation environment of a game (Mayer, 2009). McGonigal (2011) has recognized how we might capitalize on the success of games to address significant societal issues, stating, "If we take everything game developers have learned about optimizing human experience… I foresee games that tackle global-scale problems like climate change and poverty." (p. 14).

Among the many interesting results generated by the work of Stanitsas et al. (2019, 934), the one most relevant to our work is the insight that "Holistic understanding of sustainability values is the most important educational outcome of an SG that addresses sustainability principles. Some games are getting closer to this goal, others not so much." It highlights that awareness is a crucial topic in games for sustainability, but concrete actions seem not to be prominent. The study by Abraham and Jayemanne (2017) states that the extent of existing work on SG for climate change is largely restricted to "edutainment" games, which lack both the artistry and mainstream engagement sufficient to make contributions to the public understanding of the issues related to current climate challenges. Already in 1997, Ulrich collected games that dealt with the topics related to environmental issues, followed by a special issue of this journal, Simulation & Gaming, in 2007 (Barreteau et al., 2007).

A review on games dealing with the topic of climate change by Reckien and Eisenack (2013) assumes a broad spectrum of games in this area, with games differing in thematic outlook, thematic depth, methodological format, target groups, type, and motivation of game development. They found that the majority of the games identified had school children and school students as the main target group, with role-playing and management games the dominating type of game. A number of games address resource issues and energy consumption, or make explicit reference to carbon footprint, which is determined by decisions taken during the game. Most of the games focus on a local or global level of the problem of climate change. According to a systematic literature review carried out by Stanitsas et al. (2019), the number of games reported in scientific literature has further grown, but there is still a lack of evidence of their effect. Many of the games analyzed can be played individually or in teams, and the majority of the games have been designed to educate students, professionals, and stakeholders. The analysis showed which dimension of sustainability is addressed—differentiating between economic, social, and environmental dimensions. The reviewed games address a variety of learning values like motivation, socialization, and understanding, as well as learning positionings, like behaviorism and humanism. However, concrete actions at the household level have not been mentioned by the authors of the study.

Game Design and Implementation

Design Elements of the Game

The HomeRUN game aims to facilitate learning higher-order skills (Charsky, 2010) and understanding of complex problems. These intentions are related to several stages within the game, namely a) information about consumption options for the individual FEW sector, b) social comparison feedback, c) suggested behavior changes to reduce consumption, and d) information about impacts of FEWs consumption beyond the household in terms of climate change and social equity, both globally and intergenerationally. Our game development follows a classical approach of defining design specifications, development, prototype testing, and implementation of the final product (Duke & Geurts, 2004; Wenzler, 1996).

The effectiveness of games in understanding human behaviors and affecting change towards more sustainable behaviors has been well documented (Kiili, 2005; Lin et al., 2013; Prensky, 2007). Given this potential, we developed the HomeRUN game for the conservation of FEW resources at a household level. Table 1 summarizes the key features and design specifications of the HomeRUN game.

Homeowners Options for Behavior and Investment Decisions. HomeRUN represents a wide range of decisions that a household makes when it comes to the FEW nexus (Figure 1). In this nexus, decisions in the game are grouped into actions associated with food, energy, and water resources, respectively. The food options cover actions such as reducing food waste and meat and dairy consumption. The energy options range from changing light bulbs to installing solar PV panels. The water-related decisions include options for more efficient water-use technologies. The "wonder" options, an additional element in the game, represent altruistic behaviors such as offsetting carbon emissions.

Table 1. Key Features of the HomeRUN Game.

Target audience	The game targets particularly U.S. homeowners. The average U.S. household is represented in terms of household size and income level. Resource consumption is based on U.S. data.
Objectives	Research: Improve understanding of households' decision-making rationale in consuming food, energy, and water resources at home. Policy: Raise awareness of the impacts of FEW consumptions on GHG emissions and promote sustainable consumption behavior. Policy: Explore the effect of conservation messaging and technology upgrading on FEW resource consumption.
Mode of use	Educational: Raise awareness and encourage higher-order skill learning by understanding the complexity of resource consumption at households.
Resource and payoff model	To win, players need to collect and maximize points on the JOY indicator. The indicator combines three elements: financial gain, psychological satisfaction, and carbon emissions reduction. For financial resources, household disposable income is represented by GOLD resources used to pay for the course of actions.
Duration of play	One round represents a period of one year in real life. A total of ten rounds is simulated where each round lasts for 90 seconds. With pre-and post-surveys and game tutorial, the total session time is about 45 minutes.
No. of game players	A single game is played by four players.
Randomness elements	The intervention messages at the beginning of each round are randomized. The options for behavioral and technological upgrade actions also appear in random order in each round.
Development software platform	Unity game engine platform (unity.com) was used for the development of the game. The game can be played on PCs and tablets and is currently only available for Windows operating systems.
Accessibility of the game	A single-player version of the game can be accessed through: https://asuhomerun.github.io/

Since, in reality, households make a range of decisions beyond just conservation behaviors, we included "indulge" actions such as taking a vacation and eating out, and "wonder" actions such as offsetting transport emissions and adopting green electricity. Lastly, a "do-nothing" option is included. To facilitate more intuitive navigation for making decisions, the alternative options are further clustered into types of activities including "Get something to eat," "Get yourself cleaned up," and "Get entertained". The research team defined the related activities based on the most common decisions made on a household level in the U.S. The action types reflect the range of options based on the carbon reduction potential from the highest (fuel-efficient vehicle) to the lowest (low-flow showerheads) (Dietz et al., 2009).

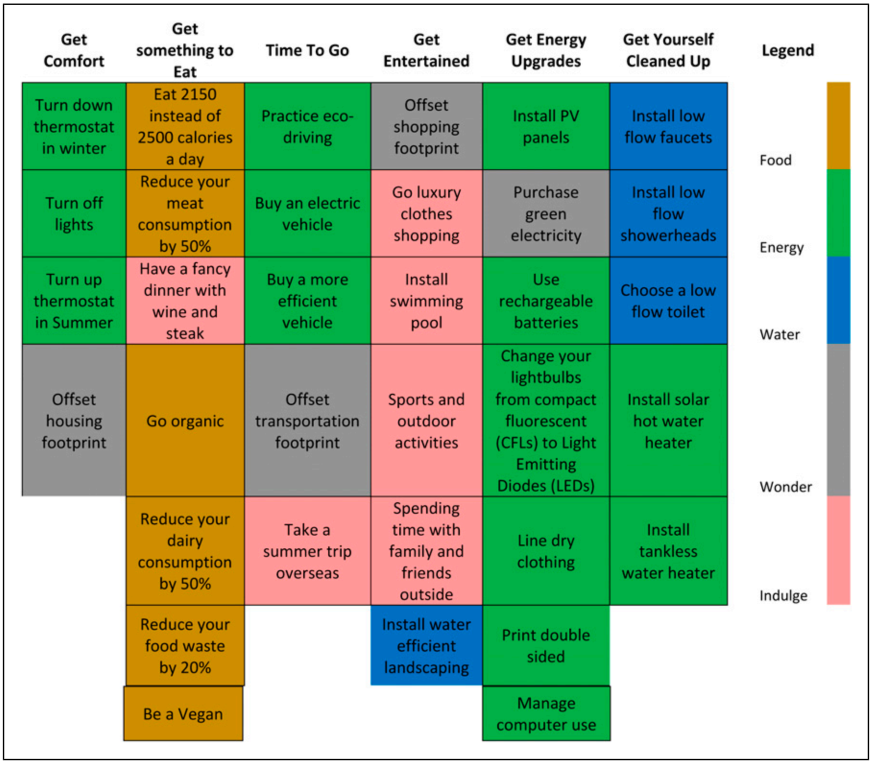


Figure 1. HomeRUN decision options across action categories.

Each decision has three attributes: capital cost, annual cost savings, and carbon emissions impacts. We use the CoolCalifornia Calculator for Households & Individuals tool (http://www.coolcalifornia.org) to derive the values for each decision. Table 2 summarizes decision attributes for some of the technological investment options.

For indulge and wonder options, the attributes are slightly different. Instead of cost savings, a measure of utility called pleasure is considered (Table 3 and Table 4), which has diminishing marginal utility (Lane, 2000). The more a particular indulge action is taken, the less pleasure (utility units) the player gets.

Given the alternative options and game set up, the HomeRUN game flow is shown in Figure 2. The game starts with each player receiving 60 units of gold (the currency of the game), which are spent on alternative decisions under food, energy, water, wonder, and indulge categories. As the game progresses, the impacts on carbon emissions, psychological pleasure, and financial gain/loss all contribute to a player's Joy, which is the game-winning criterion.

Table 2. Technological Measures for Conserving FEW Resources.

Technological measures	Capital cost	Cost-savings per year	Carbon reductions per year (mtCO2e)
Water-related technologies			
Low-flow shower	$30	$94	0.4
Low-flow toilet	$520	$18	0.1
Energy-related technologies			
Solar PV	$31,341	$1290	3.9
LED light bulb	$10	$42	0.1
Food-Related technologies			
Reduce food waste by 20%	0	$400	0.4
Reduce your dairy consumption by 50%	$200	0	0.3

Table 3. Indulge Measures in HomeRUN.

Indulge measures	Cost	Carbon emissions impact	Utility unit (Pleasure)
Install a swimming pool	$15,000	4.5 mtCO2e	100
Have a fancy dinner with wine and steak	$250	0.1 mtCO2e	5
Take a summer vacation	$1776	4.5 mtCO2e	65

Table 4. Wonder Measures in HomeRUN.

Wonder measures	Cost	Carbon emissions impact	Utility unit (Pleasure)
Offset Housing Footprint	$347	17.36 mtCO2e	178
Offset Transportation Footprint	$236	11.8 mtCO2e	121
Purchase Green Electricity	$78	3.9 mtCO2e	40

Pre- and Post-Game Surveys. To explore the players' attitudes towards household energy consumption and the learning effect of the game, the study follows a pre- and post-test research design. The pre-game survey was designed to collect data on homeowners regarding: (a) values and preferences, (b) mastery of related knowledge, and (c) demographics. Using a 7-point Likert scale (Joshi et al., 2015), a set of questions probes aspects deemed important in daily life. The respondents were given statements such as "Changing my diet could reduce my carbon footprint" and "I make eco-friendly choices in relation to my water usage whenever I possibly can." They were then asked to rate the extent to which they agree with such statements using the Likert scale (1: totally disagree to 7: totally agree).

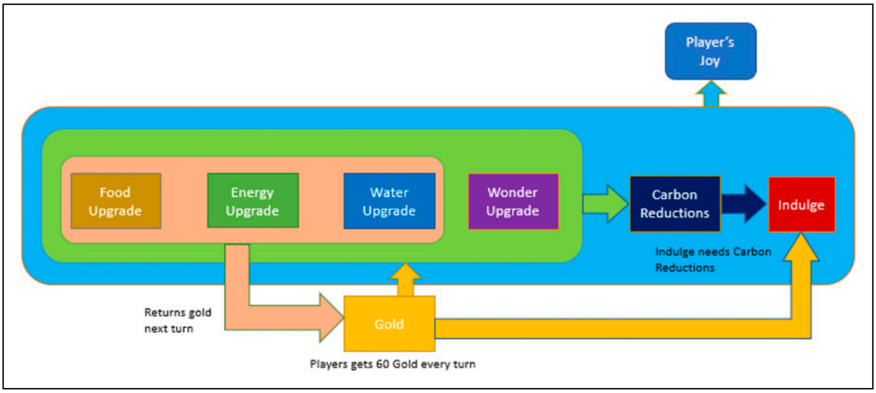
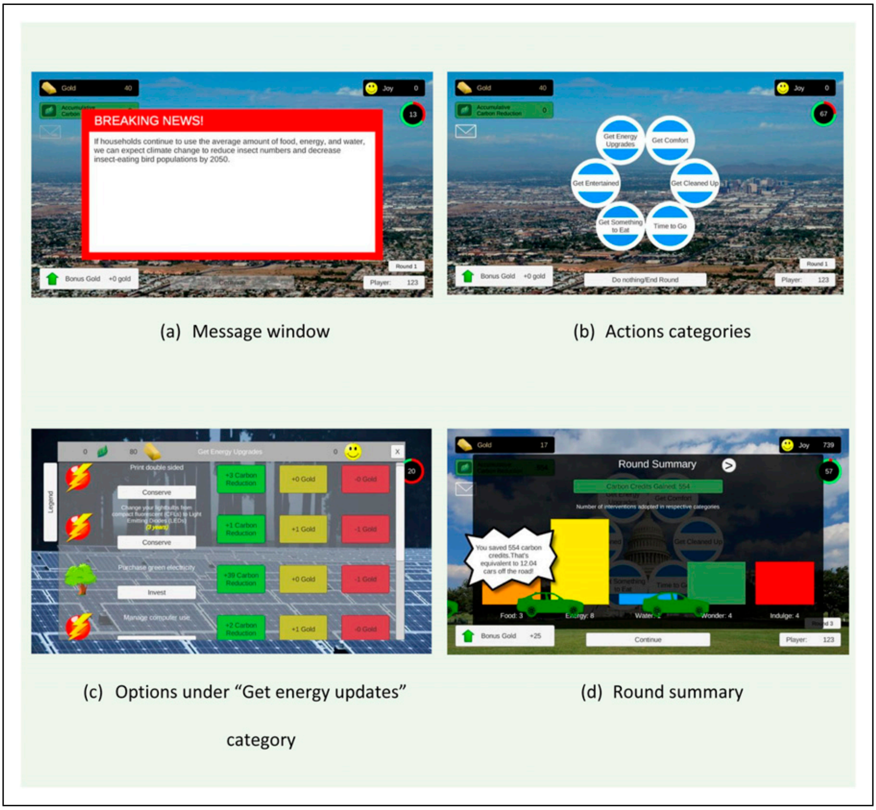


Figure 2. Game flow connecting game elements and the winning criterion.

The relative preferences over the availability, affordability, and impact across the FEW areas are registered using pairwise comparison questions. The questions on factual knowledge test the knowledge about emissions impacts from various household activities. The survey also asks about measures that produce the largest carbon reduction and are the most cost-effective. Demographic questions cover race and gender, political views, profession, and educational background. The post-game survey collects data on game experience and added values in terms of raising awareness and potential impact for behavior change, and (c) learning. Analysis of the pre-game survey includes the application of the analytic hierarchy process (AHP; Saaty, 2008) to calculate an importance index that reveals the importance of a nexus across FEW resources. Lastly, a comparison of the pre-and post-game responses to factual knowledge questions establishes whether a player learned from playing the game.

Conservation Messages. In HomeRUN, we translated social norming into ten messages a player may receive during the game (Table 5). Each message has a main emphasis and can be categorized as follows: (a) Type 1: Reduction measure messages, (b) Type 2: Social comparison messages, and (c) Type 3: Impact-focused messages. These messages are used as feedback mechanisms in the game, and to highlight the real-world consequences of a certain decision within the game.

HomeRUN Graphical User Interface. Figure 2 exhibits example screenshots of the HomeRUN user interfaces, which play an important role in creating an immersive game experience. At the beginning of each round, a randomized conservation message is shown as breaking news (Figure 3a). Categories of household activities are then presented (Figure 3b), each of which leads to a list of decision options and their attributes (Figure 3c). At the end of the game, a summary of the decisions taken is shown (Figure 3d). The amount of greenhouse gas reduction is presented as an equivalent number of cars taken off the road.



(a) Message window

(b) Actions categories

(c) Options under "Get energy updates" category

(d) Round summary

Figure 3. HomeRUN game user interfaces.

Game Implementation

A game session constitutes a participant providing consent, completing the pre-game survey, watching a tutorial video, playing the game, completing the post-game survey, and having a debriefing.

Game Sessions. Three game sessions were organized for the pilot study. We collaborated with two municipalities in Arizona (Figure 4a and b) that are actively promoting sustainable consumption behaviors among their residents. Furthermore, another reason why they were invited to participate was the diversity of their population in terms of racial and socio-economic status. In the two sites, tablets were used with a game administrator overseeing the game sessions. In addition, a session was held in Tempe, AZ with university students and faculty from across the U.S. (Figure 4c).

Table 5. Household Resource Conservation Messages.

Condition Description (Randomly assigned to rounds)		Message content
Type 1: Reduction measure messages	Reduction Food Measures (RFM)	Cutting your meat consumption in half can reduce your total household contribution to climate change by 10%.
	Reduction Water Measures (RWM)	Installing low-flow showerheads will reduce your water use by 20%, also reducing your CO_2 emissions.
	Reduction Energy Measures (REM)	Changing your compact fluorescent lightbulbs (CFL) to light emitting diodes (LEDs) can reduce your CO_2 emissions from electricity use by 3%.
Type 2: Social comparison messages	Social Comparison Energy (SCE)	Last round, your energy use was 20% more than the average game player.
	Social Comparison Food (SCF)	Last round, your food consumption was 20% more than the average game player.
	Social Comparison Water (SCW)	Last round, your water consumption was 20% more than the average game player.
Type 3: Impact-focused messages	Baseline Message (Base)	The average American household consumes 10,766 Kilowatt-hours of electricity, 32,850 Gallons of water, and 2.4 million calories of food per year.
	Economic Impacts (Econ)	The average American household annually spends $1351 on their electricity, $1050 on their water bill, and $6600 on food.
	Health Impacts (HI)	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 in 2100 when the heat and humidity are so high that it will be unsafe to remain outdoors.
	Ecological Impacts (Ecl)	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.
	Future Generations (FG)	If all households continue to consume the average levels of food, energy, and water, children that are currently 5 years old will live on earth with a different climate.

Respondents. Table 6 summarizes the main demographic characteristics of the respondents. For the pilot study, we did not consider specific criteria for selecting respondents but approached possible participants randomly. Most respondents are white professionals in academia, and majority have a moderate or liberal political view, based on their own responses.

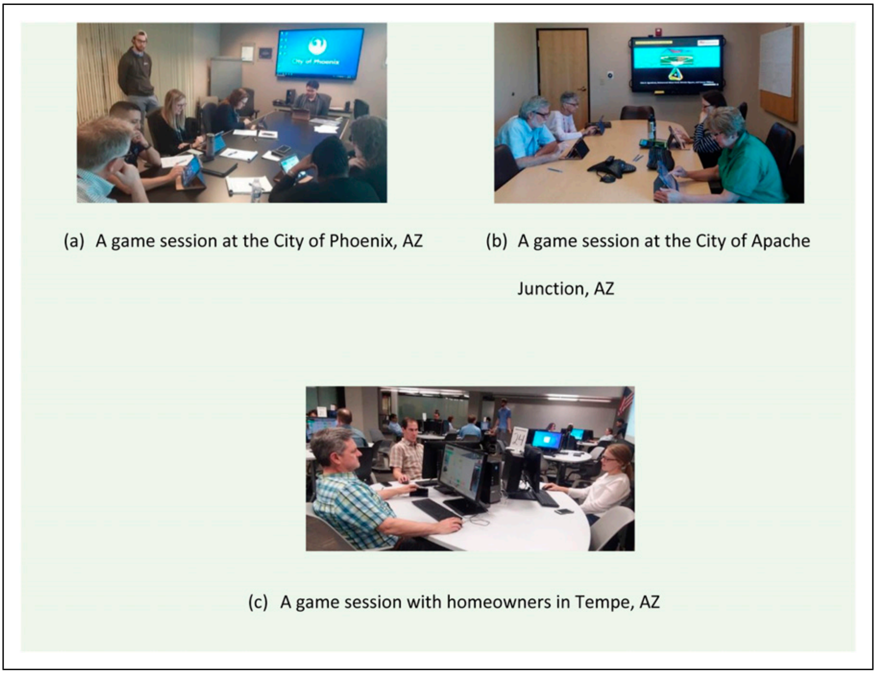


Figure 4. HomeRUN game sessions.

Data Collection, Compilation, and Analysis. Surveys are created using Google forms and data is stored as an Excel file. Game logs are stored as text files on the host computer or tablet. They are then emailed to a Gmail account of one of participating researchers. All participants were provided workstation numbers randomly. Surveys (pre and post) and game data were then matched using the workstation number. Python code was developed to read the text files to create a .csv file. This protocol was approved by Arizona State University's Institutional Review Board. We used both SPSS and Excel for statistical analysis and visualization.

Pilot Results and Analysis

Values and Preferences

We use the AHP method to determine an importance index for FEW resources based on the pairwise comparison data obtained in the pre-game survey. Figure 5 shows the frequency distribution of the aggregated value of the index, which is derived from averaging across the three aspects: availability, affordability, and emissions impact of the FEW resources. AHP analysis involving three elements will reveal equal importance if each element has an index value of 0.333. Results show that the food (Mean = 0.37)

Table 6. Respondent Characteristics.

No. of respondents	28	Highest level of education	• Doctoral Degree: 9 • Master's Degree: 8 • Associate's Degree (Occupational or Academic): 1 • Professional Degree: 3 • Bachelor's Degree: 3 • Some College, no Degree: 4
Gender and age	• Female: 12 • Male: 16 Mean age: 47 years	Profession (Sector)	• Government: 5 • Academia: 16 • Private sector: 2 • NGOs: 1 • Retired: 4
Race	• Hispanic, Latino, or Spanish origin: 2 • White: 24 • Asian: 1 • African American: 1	Political view	• Conservative: 1 • Very conservative: 1 • Liberal: 9 • Very liberal: 4 • Moderate: 11 • Do not know: 2 • No response: 0

and water (M = 0.38) indices are comparable in importance to participants, whereas the energy index has a slightly lower value (M = 0.25). The results indicate that the game respondents did not perceive the importance across the FEW sectors equally.

Patterns of Game Actions

We tabulated the number of actions in the ten rounds across action categories (Figure 6). The total number of actions increases as the game progresses as a result of players accumulating more financial resources (i.e., gold). As the number of actions per round associated with FEW and wonder becomes stable, players spend more of their resources on indulge actions.

The effect of conservation messages (described in Table 4) on actions taken is also analyzed. Figure 7 compares the average emissions reduction (in Metric tons of carbon dioxide equivalent, or MTCO2e) per action across the eleven messages. For messages that include reduction measures (type 1), those related to food consumption had the highest average emission reduction. Similarly, for social comparison messages (type 2), those concerning food consumption also led to the highest emissions reduction. For both types of messages, water and energy-related messages ranked second and third, respectively, in terms of impact. For the type 3 messages (i.e., focused-area type), the economic impact and baseline messages produced the most impact, whereas messages focusing on future generation impacts had the least.

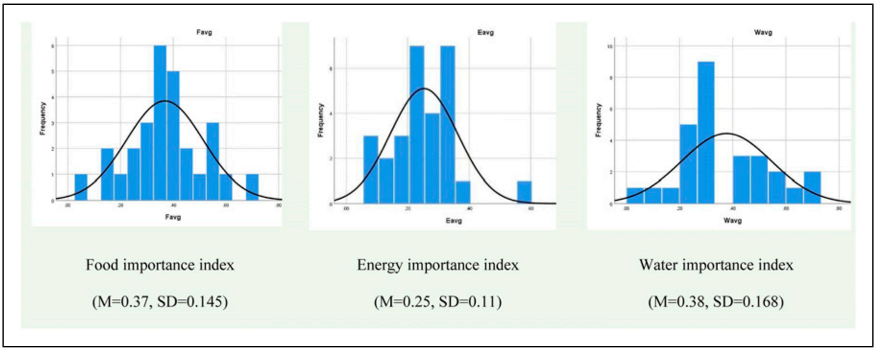


Figure 5. Aggregated importance index of food, energy, and water sector.

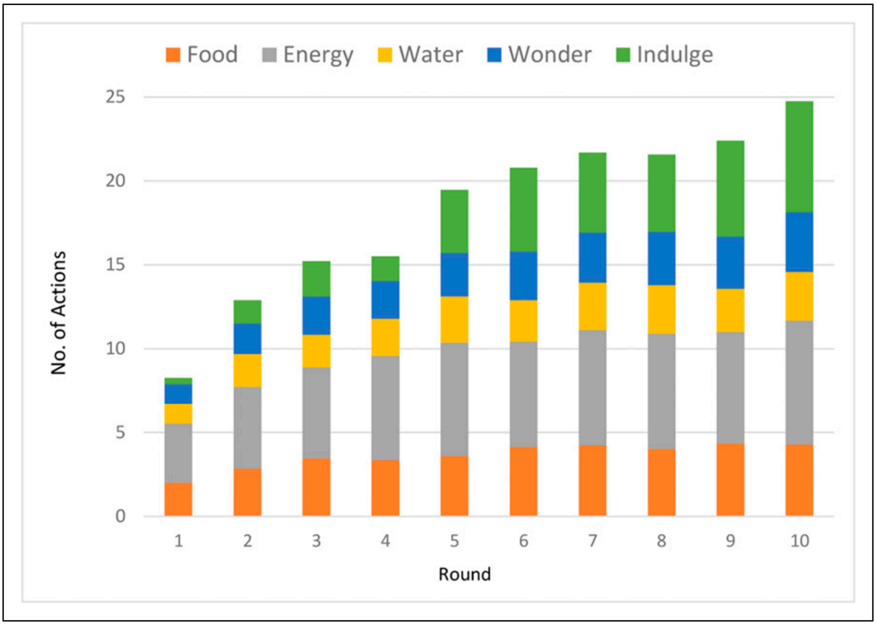


Figure 6. The number of actions per round across action categories.

Evaluation of Game Learning Impacts

Based on the post-survey responses, we evaluate four aspects of game impacts (Figure 8). First, on the overall experience of game playing, over 85% of the respondents found the game interesting and stimulating (i.e., agree or strongly agree) (Figure 8a). Second, almost 80% of the respondents supported the idea that the game adds value to education

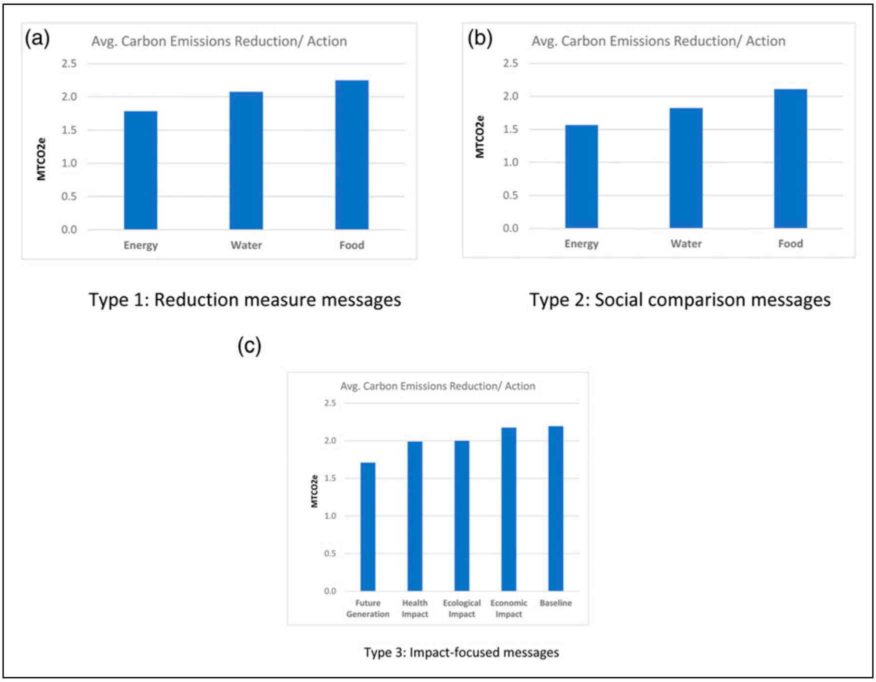


Figure 7. Carbon emissions reduction per action across conservation messages.

and training (Figure 8b). Third, about 65% of the respondents agreed that they gained a better understanding of the emissions impacts of FEW consumptions (Figure 8c). Lastly, over 57% of the respondents agreed that the game experience would influence their future consumption behaviors, while a quarter of the respondents are unsure (Figure 8d).

Next, based on post-game survey responses, we evaluate the factual knowledge of the respondents about the most impactful FEW decision options in terms of emissions reduction and cost savings. Figure 9 shows the distribution of responses to the two questions, with the red star marking the correct answer. A plurality of respondents correctly identified shifting to a vegan diet as the highest-impact food decision in terms of emissions reduction, along with purchasing a more efficient vehicle as the energy-related decision having both the highest emissions and cost savings impacts. The most uncertain responses were with respect to the water-related decisions, with nearly as many "I don't know" responses as correct responses (Figure 9c)

Lastly, we evaluate whether players remember the detailed information contained in the conservation messages that were shown during the game. In the post-survey, we provide three messages with incorrect information and two messages with correct information and asked the players to consider the messages to be true or false. For the three messages with incorrect information, only about 25% of the players identified any

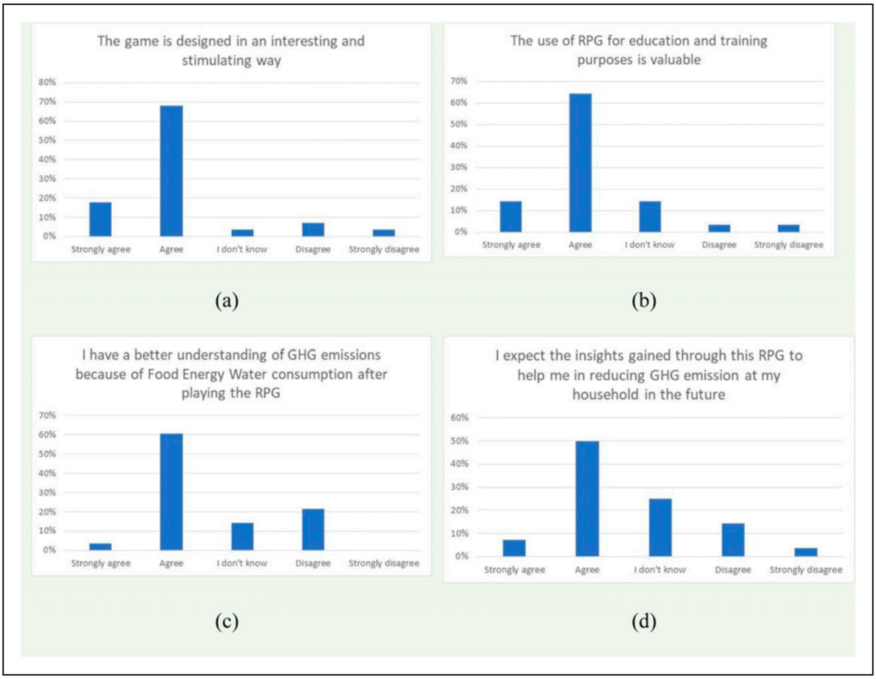


Figure 8. Aspects of game learning impacts.

of them as being true. In contrast, over 97% of the players correctly recalled the two actual messages that appeared in the game. This result indicates that players had a high recollection of the information shown during the game.

Game Debriefing

Game debriefing is an important part of a game study, in which players are given an opportunity to reflect, comment on, and discuss the gameplay session (Kriz, 2010; Schwāgele et al., 2021; van den Hoogen et al., 2016). For HomeRUN, the facilitator of the session led the debriefing after gameplay, and later the questionnaires were administered. Several important points were raised during the debriefing of HomeRUN. First, it had been assumed that players have a basic knowledge of the game terms. However, it was noticed that some of the terminologies used in the game may not be fully understood, given the diverse socio-economic background of homeowners. These terms include "offset," "footprint," "eco-driving," and "green electricity." Similarly, some product terminology such as "PV panels" and "faucets" might be familiar to some segments of the population but not others. In addition, the term "2500 calories" for food consumption might be hard to relate to daily activities. One suggestion to remediate this issue was to create and incorporate a glossary of terminologies. A second issue raised

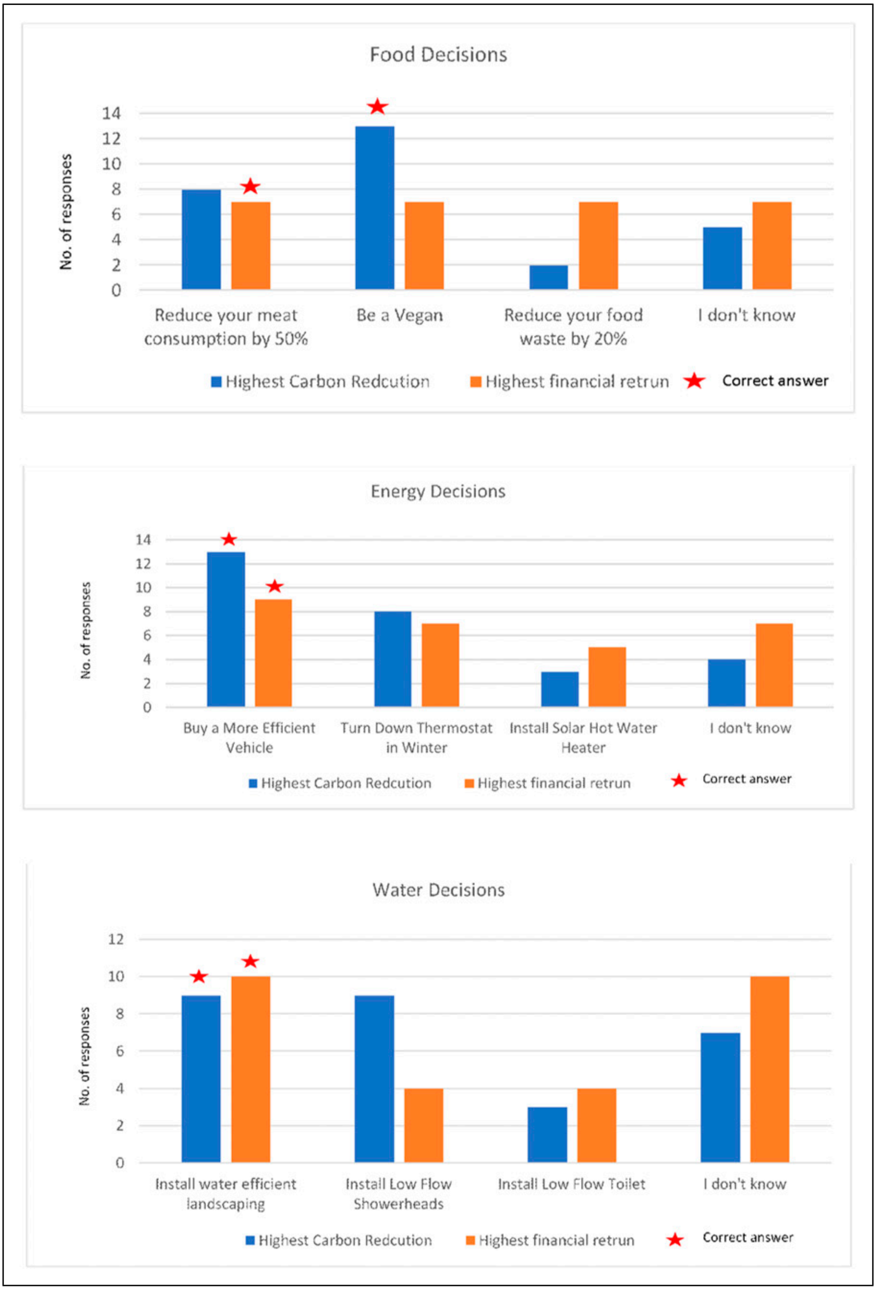


Figure 9. Factual knowledge learning: most impactful decisions.

was customization to the local context. As mentioned above, HomeRUN was designed to represent the average U.S. household in terms of decision options and impacts. The suggestion was to incorporate some options that homeowners can more easily associate with their local setting. In the city of Phoenix, Arizona, for example, there is a high awareness of conserving water used for landscape irrigation, which takes about 70% of household water consumption, compared with only 30% nationally. Third, respondents suggested a game ending with a positive message to encourage resource conservation—that small actions and sacrifices at home can make a significant difference in environmental impacts while not affecting the quality of life. This would increase the willingness of the game players to commit to real-world action.

Finally, some suggestions for improving game features and experience were given. One suggestion was to increase the duration that the conservation message is displayed to give more time to digest the message. Another suggestion was to provide interactive visuals that allow players to get additional educational information related to some of the options and carbon impacts.

Concluding Remarks and Implications for Practice

Serious games are a pervasive element of our culture and offer intriguing platforms for developing awareness of complex problems such as climate change and related resource consumption, as well as for analytic work on player behavior and behavior change. Complex sustainability issues can be addressed by gaming approaches. In real-life as well as simulated decisions, homeowners and house occupants consider their personal values, resource constraints, incentives, and the availability and affordability of options. Aspects of climate change and related resource consumption can be translated into game elements as illustrated through the example of HomeRUN, providing an opportunity for players to test decisions and actions in a safe, simulated environment before applying them in the real world.

This paper builds on a transdisciplinary game development process towards the development of a serious game. Social actors including municipal city officials were asked for their input and participated in the pilot study implementation. This involvement created a sense of ownership of the game product. The transdisciplinary process, as demonstrated in the pilot study, indicates the participatory involvement of different actors to help reduce GHG emissions from FEW consumptions at the household level. The gameplay session introduced information, and players demonstrated experiential knowledge. After playing the game, respondents had a better understanding of the emissions impacts of FEW consumptions. Based on the post-game survey, the game experience could lead to changed future consumption behaviors of the majority of players.

Overall, the pilot study confirms the potential impacts of a serious gaming approach in raising awareness of emissions impacts of household FEW resource consumption. Measuring a change of behavior, however, would require a more direct intervention and monitoring of actual household consumption. The pilot study itself points to some insights for policymaking. Conservation messaging can be tailored to homeowners' profiles in terms of demographics and core values. From a policy perspective, insights from the game can inform policymakers to test actual policy implementation, which is important since some of the interventions are costly to implement and hence cannot afford experimentation. To this end, the game can be used for testing policy-relevant hypotheses about behavioral intentions that drive sustainable household consumption, based on theoretically justified behavior change interventions used in past research.

Furthermore, to implement the game and its design ideas, core implications should be considered:

- When designing games to raise awareness for complex issues such as climate change, it is helpful to make use of data sets that represent realistic data and create clear feedback mechanisms in the game that refer to the realistic data and concrete measures.
- To test the game, it is key to find a committed and diverse group of users for whom the topic of the game is meaningful.
- Clear messaging that can be broadly understood, as well as a clear relation to the local context, is important for the acceptance and usefulness of the game.

For future work, we have identified several game features to develop from the feedback of the players and our observation of the game session. First, a four-player game set-up would provide a good opportunity for adopting game theory perspectives in game design (Bolton, 2002; Roungas et al., 2019), which Meijer & Perpinya (2012) defines as "the mathematical approach of analyzing calculated circumstances where a person's success is based upon the choices of others (p. 277)." Although the current version of the game addresses the individual level of decisions towards resource consumption, a future, multiplayer version could also include the collective impact of certain decisions and actions, for instance, in a drought scenario. In this scenario, when the four players fail to collectively reduce carbon emissions by a certain threshold, water shortages would occur affecting everyone by increasing the cost of food, energy, and water. This would add another dimension, the collective one, to the game. Second, policy scenarios could be added, such as a carbon cap-and-trade scheme, in which homeowners will be rewarded financially if they emit carbon below their allowance. This would allow for testing out such policies before they are implemented in real life, that is, assessing their acceptance and barriers to implementation, which could be useful for policymakers. Third, by working with municipalities and utility companies, the game can be further integrated into their conservation initiatives. For example, they could use the game when engaging with the community and when building awareness of the need for more customer-friendly resource conservation strategies. Lastly, a Spanish version of HomeRUN would make the game more accessible to the Latino communities across the U.S.

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