Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Psychology

ELSEVIER

Review

Gamification to prevent climate change: a review of games and apps for sustainability

Benjamin D. Douglas and Markus Brauer

Abstract

Gamification, the application of game design principles to a nongaming context, has been used to promote pro-environmental behaviors. Such principles have been implemented in board games, team competitions, electronic games, smartphone apps, and in apps that researchers developed primarily to collect data. We review the games and apps that have been evaluated in empirical research in the last 5 years and provide a list of apps and games that have yet to be tested. Gamification has been used for sustainability education, energy reduction, transportation, air quality, waste management, and water conservation. Although we do not know yet why certain games and apps are more effective than others, gamification appears to be a promising avenue for preventing climate change.

Addresses

Department of Psychology, University of Wisconsin–Madison, 1202 W. Johnson St., Madison WI 53706, USA

Corresponding author: Brauer, Markus (markus.brauer@wisc.edu)
Email address: bdouglas3@wisc.edu (B.D. Douglas)

Current Opinion in Psychology 2021, **42**:89–94

Edited by **Mark A. Ferguson** & **Michael T. Schmitt**

This review comes from a themed issue on **42 Psychology of Climate Change (2021)**

For a complete overview see the Issue and the Editorial

Available online 1 May 2021

https://doi.org/10.1016/j.copsyc.2021.04.008

Keywords

Gamification, Games, Apps, Climate change, Sustainability.

Climate change poses an existential threat to human life. Although it is caused by human activities, changing environmentally harmful behaviors has proven a difficult task. Games and smartphone applications (i.e., apps) present an opportunity to increase sustainable behaviors. We provide a brief review of games and gamification in the context of sustainability. Included in this review are studies examining the effectiveness of board games, electronic games, and apps (both gamified apps and apps used for data collection). The relevant studies can be broadly categorized into four topics: sustainability education, energy reduction, transportation/air quality, and waste management/water conservation. We will discuss each of these topics in the following context.

Gamification consists of applying game design principles to a nongaming context such as changing energy consumption habits [1]. The principles of gamification include clear progression paths with achievable goals, levels and rewards, giving players agency over their actions, making use of strategy and novelty to engage players, providing feedback, making use of social comparison or competition, encouraging cooperation between players, or various combinations of these principles [2–5]. Gamification helps create an environment in which individuals are intrinsically motivated to engage with material related to the area where behavior changed is desirable [6]. In the context of board games, researchers have emphasized specific principles for effective gaming including offering a multitude of roles an individual could take on to address the problem under consideration, mimicking the interactions of society and having goals that cause players to reflect on their behavior [7]. While there are several reviews of gamification in the context of sustainability, most are purely theoretical and discuss only a small sample of games which usually have not been evaluated in controlled trials [8–13]. Our review takes a different approach by focusing on games and gamified interventions, including gamified apps, which have been empirically tested in either a lab or an applied setting.

Sustainability education

Gamification, particularly through board games, can be an effective way to educate people about sustainability in general. For example, playing the 'Oil Springs' expansion of the popular board game 'Settlers of Catan' led to increased pro-sustainability attitudes and self-reported sustainable behaviors [14]. Graduate students who played 'Factory Heroes,' a game designed to improve sustainability leadership in the context of manufacturing, reported increased knowledge of sustainable manufacturing practices [15]. However, this finding is from a pilot test and need to be replicated before the game can be used as an intervention in an applied context. Board games have also shown to be an effective platform for education about biodiversity [16]. For example, the 'Keep Cool' board game was found to

increase youths' feelings of personal responsibility for sustainability and the belief in international cooperation for finding solutions to climate change [17]. Researchers have theorized that board games may be particularly effective for visualizing the effect that an individual has on other players and consequently the environment [18]. In addition, board games may be an effective tool for researchers measuring environmental attitudes when working with children [19]. While these results are promising, none of the reviewed studies tested behavioral outcomes resulting from playing sustainability-themed board games. In addition, interventions designed to increase knowledge about a topic rarely lead to behavior change unless a lack of knowledge was preventing individuals from adopting a certain behavior, such as recycling [20]. Future studies examining the effects of educational interventions should consider what barriers to behavior change are removed by providing information to participants.

Energy reduction

Decreasing home energy usage is one area where games and gamified apps have the potential to encourage sustainable behavior. "Cool Choices" is a game in which players compete as a team to reduce energy usage over a multiweek period. Players claim points in the game for engaging in either one-time or recurring sustainable behaviors. These pro-environmental actions are made visible to other players on the game's online leaderboard. An evaluation study revealed that playing 'Cool Choices' led to long-term reductions in electricity consumption, especially among individuals who initially consumed high amounts of energy [21]. Other researchers found that playing 'Energy Cat,' a game designed for touch-tablets in which participants attempt to make a virtual home energy efficient, led to neither significant long-term reductions in electricity and gas usage [22] nor to better knowledge about energy consumption [23]. These results may be explained by participant reports that the game needed clearer instructions, appeared juvenile, and was not fun. Such a conclusion would be consistent with the frequently made claim that games are more effective when they are entertaining [2].

Evaluation studies of gamified apps yield promising results. For example, use of 'Powersaver Game' or 'Reduce Your Juice' led players to reduce their energy consumption upon completion of a four-month trial [24,26], whereas 'enCOMPASS' or 'Apolis Planeta' led to long-term reductions in household energy usage [25,1]. Common characteristics of these gamified apps include a mechanism to report goals for sustainability, a dashboard to track progress, and some form of social comparison with other app users. 'Ringorang'—a smartphone app with customizable trivia questions—was found to increase intentions to install solar panels and accelerate the timeline with which participants planned to install them [27]. Nevertheless, it is unclear exactly how long the effects of gamified apps last. Wemyss et al. [28] evaluated the long-term effects of 'Social Power,' an app that connects to the household's smart meter and provides weekly energy saving challenges. One year after the participants used the app, researchers observed no difference in electricity usage between households in the treatment group, which had been encouraged to use the app at least once per week, and households in the control group.

To reduce energy consumption in the workplace, researchers developed the gamified app 'My Backyard Garden,' which led to reduced electricity consumption specific to computer-related energy usage [29]. Another app, 'Grid Responsive Society through Building Automation Systems', effectively encouraged a variety of energy saving behaviors in an office setting such as turning off lights when not in use [30]. In an educational context, the use of the apps 'Abouit'and 'Labels for your Planet,' in conjunction with traditional teaching methods, improved undergraduate business students' energy consumption habits, as well as their knowledge about sustainability [31].

Transportation and air quality

Several studies have examined how apps and games can be used to deliver messages, track data, and reduce carbon emissions related to transportation, as well as promote alternative forms of transportation [32–36]. The 'Mordor Sharper' game, which simulates the experience of carpooling, was used to examine how gamification can encourage carpooling in Warsaw, Poland [37,38]. Estimates based on the study's results revealed that if the gamified app could decrease the number of cars on the road by 20,000 cars per day, emissions from fossil fuels in Warsaw would reduce by over 30,000 metric tons per year. Similarly, the 'Kids-Go-Green' app improved students' knowledge about sustainable methods for travel [39].

It is unknown which specific features of gamification are most effective for increasing user engagement with sustainable-transportation themed apps [40]. When researchers reviewed apps relevant to both transportation and diet, they discovered that there was not a single app that gave players feedback on carbon emissions from these two domains simultaneously [41]. Furthermore, they found no app emphasizing the shared benefits to an individual's health and the environment from transportation methods such as biking. When air pollution was framed as a health concern, participants diagnosed with respiratory problems were more likely to engage with an app called 'AirForU'that reported the air quality in their local area [42]. While some behavior changes did occur (such as exercising inside instead of outside on days with poor air quality), the authors did not report whether these changes were statistically or

substantively significant. The authors did report however that engagement with the app declined for 90% of participants within 12 weeks.

Behavioral data collection has been identified as one of the key contributions that psychologists can make for the mitigation of climate change [43]. Apps may provide a useful tool for researchers to collect data about transportation. For example, 'Individual Persuasive Eco-Travel Technology' collects data about participants' travel, automatically processes this information to provide sustainable travel alternatives through pop-up messages in the app, and offers users points to further encourage sustainable travel [44]. However, successful implementation of 'Individual Persuasive Eco-Travel Technology' requires a significant time commitment from participants to obtain accurate travel data. In another study, the app 'GoEco!' was used to successfully track travel patterns and provided feedback to participants about how to reduce the carbon impact of their travel [34,45]. As scientists continue to study apps as a tool for data collection, it is important to balance the desire to unobtrusively collect detailed personal information (such as travel patterns) with participant privacy [46], particularly as perceived risk of data leakage is one reason individuals may opt out of engaging with these apps [47].

Waste management and water conservation

In an intervention designed to increase recycling behavior, tourists were encouraged to use an app called 'WasteApp' to locate recycling bins in several cities [48]. 'WasteApp'was effective at increasing recycling for users who perceived the app as useful. However, participants' expectation of a reward (rewards being one of the central gamification elements tested in the study) was negatively correlated with user satisfaction, and no correlation was found between expectation of a reward and recycling behavior. Other studies of 'WasteApp' found that the intention to use 'WasteApp' was lower for participants who considered it risky to provide personal information (despite no personal information actually being collected by the app) [47].

Water conservation is another context where researchers have tested whether sustainability can be promoted through games and gamified apps. In a study examining how to increase engagement with a community dashboard for water-related event preparedness (e.g., planning to conserve water during a drought), researchers compared how different gamification elements affected the frequency with which participants connected to the platform [49]. Participants, particularly those who were interested in helping others and supporting their community, reported being motivated to prepare for water-related events in response to the use of gamification elements such as getting points for reading articles provided on the dashboard. Similarly, adding a visualized component to water meters via an app which simultaneously set water conservation goals, provided incentives for water conversation, and allowed for social comparison with other users resulted in reduced water consumption [50]. Board games such as 'Water Ark' have been found to increase knowledge about and perceived personal responsibility for water resources [51,7]. Similarly, adolescents who played 'Ocean Limited,'another board game, demonstrated increased cooperative problem solving related to marine sustainability (e.g., planning a response to or preventing future oil spills) [52].

Psychological mechanisms

Several psychological theories can explain why certain aspects of gamification are effective. Gifford [53] suggests 29 barriers (or 'dragons') to pro-environmental behaviors some of which can be addressed by gamification. For example, games can educate individuals about which pro-environmental behaviors they should adopt or instruct them on how to undertake sustainable behaviors they were not aware of. Thus, games and apps could reduce the ignorance barrier for individuals who do not know what behaviors they should adopt. Engaging in pro-environmental behaviors in the context of a game or app can also reduce the perceived risks of those behaviors. For example, if an individual anticipates risks from biking to work—either from the time commitment, physical risk to safety, or a belief that they will not be able to maintain the habit—an app could help plan an efficient, safe route, and prove an incentive structure to help maintain the habit.

White et al. [54] propose the SHIFT model for adopting pro-environmental behaviors. Games can be useful in overcoming the social influence, habit formation, and tangibility components to behavior change described in the SHIFT model. Leader boards and team-based activities, common features of games, are based on social influence. One component of social influence, social norms, are beliefs about how people currently behave or how people should behave. If a game or app compares the behavior of players and rewards those who engage in certain behaviors it is possible for games to establish pro-environmental behaviors as socially normative. Another component of the SHIFT model is habit formation. By practicing pro-environmental behaviors in the context of a game, an individual might repeat that behavior after the game ends, thus turning the behavior into a habit. The SHIFT model argues that because the effects of climate change are not immediately palpable, individuals may not feel compelled to change their behavior. Games and apps

may alleviate this barrier by giving tangible pro-environmental goals with immediate rewards for completing the desired behaviors.

The theoretical frameworks proposed by Gifford [53] and White et al. [54] were supported in a recent meta-analysis examining the psychological mechanisms that lead to pro-environmental behaviors [55]. Specifically, social norms, self-efficacy, and the belief that climate change is happening were among the strongest predictors of adaptive behaviors. Each of these mechanisms can be influenced by games and apps. While researchers have not yet determined which specific aspect of games and gamification best promote pro-environmental behavior, many aspects of gamification align with psychological mechanisms for behavior change.

Conclusion

Games and gamified apps show promise as a tool to promote sustainable behaviors, particularly in comparison with other methods for behavior change [56]. Apps that use elements of gamification, such as providing feedback or earning points for a behavior, are generally rated more positively by users than apps that attempt to change behavior by providing information alone [57]. Gamification can lead to longer-term psychological engagement than other behavior change methods such as nudging [56]. In order to assist future researchers investigating the effects of gamification in the domain of sustainability we have compiled a list of available games and apps.[1] For each game and app we provide a brief description and state whether or not it has already been empirically evaluated.

There is much about gamification that we do not know. It is still unclear why certain attempts at gamification are more effective at promoting behavior change than others. Similarly, we know little about the balance between fun, engaging games, and games that are primarily informative. It is also the case that while there are many studies on topics such as transportation and energy saving, other areas such as sustainable diets have yet to receive the same attention in relation with gamification [9]. As technology continues to develop and our ability to collect behavioral data improves, researchers should continue to investigate the use of apps as a tool for data collection. In sum, the recent extant literature presents a promising picture for the use of gamification and apps in the fight against climate change.

Conflict of interest statement

Nothing declared.

[1] The list is available at: https://osf.io/qbx2u/?view_only=7a94cd2344614e78855a43cd5cf55392.

References

Papers of particular interest, published within the period of review, have been highlighted as:

* of special interest
** of outstanding interest

1. Csoknyai T, Legardeur J, Abi Akle A, Horváth M: **Analysis of energy consumption profiles in residential buildings and impact assessment of a serious game on occupants' behavior**. *Energy Build* 2019, **196**:1–20, https://doi.org/10.1016/j.enbuild.2019.05.009.

2. Morford ZH, Witts BN, Killingsworth KJ, Alavosius MP: **Gamification: the intersection between behavior analysis and game design technologies**. *Behav Analyst* 2014, **37**:25–40, https://doi.org/10.1007/s40614-014-0006-1.

3. Sharma S, Siu KWM: **Gaming as a driver for social behaviour change for sustainability**. In *International conference on applied human factors and ergonomics*. Cham: Springer; 2017, July: 258–266, https://doi.org/10.1007/978-3-319-60639-2_27.

4. Berman H, Shwom R, Cuite C: **Becoming FEW conscious: a conceptual typology of household behavior change interventions targeting the food-energy-water (FEW) nexus**. *Sustainability* 2019, **11**:5034, https://doi.org/10.3390/su11185034.

5. * Iweka O, Liu S, Shukla A, Yan D: **Energy and behaviour at home: a review of intervention methods and practices**. *Energy Research & Social Science* 2019, **57**:101238, https://doi.org/10.1016/j.erss.2019.101238.
A review of behavior-change methods in the context of sustainability. This review provides a concise summary of behavior-change approaches including gamification, the most effective of which include community engagement, feedback, and goalsetting.

6. ** Wee SC, Choong WW: **Gamification: predicting the effectiveness of variety game design elements to intrinsically motivate users' energy conservation behaviour**. *J Environ Manag* 2019, **233**:97–106, https://doi.org/10.1016/j.jenvman.2018.11.127.
Provides a thorough review of different gamification approaches. This review emphasizes the value of participant autonomy for engagement with games and provides a theoretical framework for understanding gamification through Self-Determination Theory.

7. Cheng PH, Yeh TK, Chao YK, Lin J, Chang CY: **Design ideas for an issue-situation-based board game involving multirole scenarios**. *Sustainability* 2020, **12**:2139, https://doi.org/10.3390/su12052139.

8. Seaborn K, Fels DI: **Gamification in theory and action: a survey**. *Int J Hum Comput Stud* 2015, **74**:14–31, https://doi.org/10.1016/j.ijhcs.2014.09.006.

9. Berger V, Schrader U: **Fostering sustainable nutrition behavior through gamification**. *Sustainability* 2016, **8**:67, https://doi.org/10.3390/su8010067.

10. Morganti L, Pallavicini F, Cadel E, Candelieri A, Archetti F, Mantovani F: **Gaming for Earth: serious games and gamification to engage consumers in pro-environmental behaviours for energy efficiency**. *Energy Research & Social Science* 2017, **29**:95–102, https://doi.org/10.1016/j.erss.2017.05.001.

11. Albertarelli S, Fraternali P, Herrera S, Melenhorst M, Novak J, Pasini C, Rizzoli AE, Rottondi C: **A survey on the design of gamified systems for energy and water sustainability**. *Games* 2018, **9**:38, https://doi.org/10.3390/g9030038.

12. Hallinger P, Wang R, Chatpinyakoop C, Nguyen VT, Nguyen UP: **A bibliometric review of research on simulations and serious games used in educating for sustainability, 1997–2019**. *J Clean Prod* 2020, **256**:120358, https://doi.org/10.1016/j.jclepro.2020.120358.

13. * Ouariachi T, Li CY, Elving WJ: **Gamification approaches for education and engagement on pro-environmental behaviors: searching for best practices**. *Sustainability* 2020, **12**:4565, https://doi.org/10.3390/su12114565.
The authors of this review article detail several psychological principles of gamification such as providing feedback to users and if the game is fun. They then analyze a selection of games based on these criteria.

The authors of this paper offer best practices for designing serious games.

14. Chappin EJ, Bijvoet X, Oei A: **Teaching sustainability to a broad audience through an entertainment game—The effect of Catan: oil Springs**. *J Clean Prod* 2017, **156**:556–568, https://doi.org/10.1016/j.jclepro.2017.04.069.

15. Despeisse M: **Teaching sustainability leadership in manufacturing: a reflection on the educational benefits of the board game Factory Heroes**. *Procedia CIRP* 2018, **69**:621–626, https://doi.org/10.1016/j.procir.2017.11.130.

16. Tsai JC, Cheng PH, Liu SY, Chang CY: **Using board games to teach socioscientific issues on biological conservation and economic development in Taiwan**. *J Baltic Sci Educ* 2019, **18**: 634, https://doi.org/10.33225/jbse/19.18.634.

17. Meya JN, Eisenack K: **Effectiveness of gaming for communicating and teaching climate change**. *Climatic Change* 2018, **149**:319–333, https://doi.org/10.1007/s10584-018-2254-7.

18. ** Fjællingsdal KS, Klöckner CA: **Green across the board: board games as tools for dialogue and simplified environmental communication**. *Simulat Gaming* 2020, https://doi.org/10.1177/1046878120925133. 1046878120925133.
Through a series of focus groups, this article explores what makes boardgames an effective tool for promoting sustainable behavior and includes an overview of popular boardgames relevant to sustainability.

19. Otto S, Evans GW, Moon MJ, Kaiser FG: **The development of children's environmental attitude and behavior**. *Global Environ Change* 2019, **58**:101947, https://doi.org/10.1016/j.gloenvcha.2019.101947.

20. Schultz W: **Knowledge, information, and household recycling: examining the knowledge-deficit model of behavior change**. In *New tools for environmental protection: education, information, and voluntary measures*. Edited by Dietz T, Stern PC, National Academy Press; 2002:67–82. https://books.google.com/books?id=gqNTAgAAQBAJ&lpg=PT13&ots=_viaGRsFUr.

21. Ro M, Brauer M, Kuntz K, Shukla R, Bensch I: **Making Cool Choices for sustainability: testing the effectiveness of a game-based approach to promoting pro-environmental behaviors**. *J Environ Psychol* 2017, **53**:20–30, https://doi.org/10.1016/j.jenvp.2017.06.007.

22. Casals M, Gangolells M, Macarulla M, Forcada N, Fuertes A, Jones RV: **Assessing the effectiveness of gamification in reducing domestic energy consumption: lessons learned from the EnerGAware project**. *Energy Build* 2020, **210**:109753, https://doi.org/10.1016/j.enbuild.2019.109753.

23. Hafner R, Fuertes A, Pahl S, Jones R, Boomsma C, Gangolells M, Casals M: *Results and insight gained from applying the EnergyCat energy-saving serious game in UK social housing*. 2020, https://doi.org/10.17083/ijsg.v7i2.333.

24. Fijnheer JDL, Van Oostendorp H, Veltkamp R: **Household energy conservation intervention: a game versus dashboard comparison**. *International Journal of Serious Games* 2019, **6**: 23–36, https://doi.org/10.17083/ijsg.v6i3.300.

25. Koroleva K, Melenhorst M, Novak J, Gonzalez SLH, Fraternali P, Rizzoli AE: **Designing an integrated socio-technical behaviour change system for energy saving**. *Energy Informatics* 2019, **2**: 30, https://doi.org/10.1186/s42162-019-0088-9.

26. Mulcahy R, Russell-Bennett R, Iacobucci D: **Designing gamified apps for sustainable consumption: a field study**. *J Bus Res* 2020, **106**:377–387, https://doi.org/10.1016/j.jbusres.2018.10.026.

27. Rai V, Beck AL: **Play and learn: serious games in breaking informational barriers in residential solar energy adoption in the United States**. *Energy Research & Social Science* 2017, **27**: 70–77, https://doi.org/10.1016/j.erss.2017.03.001.

28. Wemyss D, Cellina F, Lobsiger-Kägi E, De Luca V, Castri R: **Does it last? Long-term impacts of an app-based behavior change intervention on household electricity savings in Switzerland**. *Energy Research & Social Science* 2019, **47**: 16–27, https://doi.org/10.1016/j.erss.2018.08.018.

29. ** Oppong-Tawiah D, Webster J, Staples S, Cameron AF, de Guinea AO, Hung TY: **Developing a gamified mobile application to encourage sustainable energy use in the office**. *J Bus Res* 2020, **106**:388–405, https://doi.org/10.1016/j.jbusres.2018.10.051.
In addition to testing the effectiveness of gamification to reduce electricity in the workplace, this the authors of this paper detail a five-stage process for developing an app including how to implement elements of gamification.

30. Iria J, Fonseca N, Cassola F, Barbosa A, Soares F, Coelho A, Ozdemir A: **A gamification platform to foster energy efficiency in office buildings**. *Energy Build* 2020, **222**:110101, https://doi.org/10.1016/j.enbuild.2020.110101.

31. Alonso-Martínez D, Jiménez-Parra B, González-Álvarez N, Godos-Díez JL, Cabeza-García L: **Taking advantage of students' passion for apps in sustainability and CSR teaching**. *Sustainability* 2019, **11**:779, https://doi.org/10.3390/su11030779.

32. Weber J, Azad M, Riggs W, Cherry CR: **The convergence of smartphone apps, gamification and competition to increase cycling**. *Transport Res F Traffic Psychol Behav* 2018, **56**: 333–343, https://doi.org/10.1016/j.trf.2018.04.025.

33. Bowden H, Hellen G: **A data driven, segmentation approach to real world travel behaviour change, using incentives and gamification**. In *Towards user-centric transport in europe*. Cham: Springer; 2019:173–182, https://doi.org/10.1007/978-3-319-99756-8_12.

34. Cellina F, Bucher D, Mangili F, Veiga Simão J, Rudel R, Raubal M: **A large scale, app-based behaviour change experiment persuading sustainable mobility patterns: methods, results and lessons learnt**. *Sustainability* 2019, **11**: 2674, https://doi.org/10.3390/su11092674.

35. Ferron M, Loria E, Marconi A, Massa P: **Play&Go, an urban game promoting behaviour change for sustainable mobility**. *Interaction Design Architecture Journal* 2019, **40**:24–25.

36. Anagnostopoulou E, Urbančič J, Bothos E, Magoutas B, Bradesko L, Schrammel J, Mentzas G: **From mobility patterns to behavioural change: leveraging travel behaviour and personality profiles to nudge for sustainable transportation**. *J Intell Inf Syst* 2020, **54**:157–178, https://doi.org/10.1007/s10844-018-0528-1.

37. Olszewski R, Pałka P, Turek A: **Solving "smart city" transport problems by designing carpooling gamification schemes with multi-agent systems: the case of the so-called "mordor of Warsaw"**. *Sensors* 2018, **18**:141, https://doi.org/10.3390/s18010141.

38. Olszewski R, Turek A: **The mordor shaper—the Warsaw participatory experiment using gamification**. In *ICT Systems and sustainability*. Singapore: Springer; 2020:255–264, https://doi.org/10.1007/978-981-15-0936-0_26.

39. Marconi A, Schiavo G, Zancanaro M, Valetto G, Pistore M: **May). Exploring the world through small green steps: improving sustainable school transportation with a game-based learning interface**. In *Proceedings of the 2018 international conference on advanced visual interfaces*; 2018:1–9, https://doi.org/10.1145/3206505.3206521.

40. Andersson A, Hiselius LW, Adell E: **Promoting sustainable travel behaviour through the use of smartphone applications: a review and development of a conceptual model**. *Travel Behaviour and Society* 2018, **11**:52–61, https://doi.org/10.1016/j.tbs.2017.12.008.

41. Sullivan RK, Marsh S, Halvarsson J, Holdsworth M, Waterlander W, Poelman MP, … Spence JC: **Smartphone apps for measuring human health and climate change co-benefits: a comparison and quality rating of available apps**. *JMIR mHealth and uHealth* 2016, **4**:e135, https://doi.org/10.2196/mhealth.5931.

42. Delmas MA, Kohli A: **Can apps make air pollution visible? Learning about health impacts through engagement with air quality information**. *J Bus Ethics* 2020, **161**:279–302, https://doi.org/10.1007/s10551-019-04215-7.

43. Swim JK, Stern PC, Doherty TJ, Clayton S, Reser JP, Weber EU, Gifford R, Howard GS: **Psychology's contributions to understanding and addressing global climate change**. *Am Psychol* 2011, **66**:241, https://doi.org/10.1037/a0023220.

44. Piras F, Sottile E, Calli D, Meloni I: **Automatic data collection for detecting travel behavior: the IPET platform**. *Procedia Computer Science* 2018, **134**:421–426, https://doi.org/10.1016/j.procs.2018.07.189.

45. Bucher D, Mangili F, Cellina F, Bonesana C, Jonietz D, Raubal M: **From location tracking to personalized eco-feedback: a framework for geographic information collection, processing and visualization to promote sustainable mobility behaviors**. *Travel Behaviour and Society* 2019, **14**:43–56, https://doi.org/10.1016/j.tbs.2018.09.005.

46. Beierle F, Tran VT, Allemand M, Neff P, Schlee W, Probst T, Pryss R, Zimmermann J: **Context data categories and privacy model for mobile data collection apps**. *Procedia Computer Science* 2018, **134**:18–25, https://doi.org/10.1016/j.procs.2018.07.139.

47. Lidia AC, Julio RT, Petra DSP, Rafael PJ: **How to encourage recycling behaviour? The case of WasteApp: a gamified mobile application**. *Sustainability* 2018, **10**:1544, https://doi.org/10.3390/su10051544.

48. Aguiar-Castillo L, Clavijo-Rodriguez A, Saa-Perez D, Perez-Jimenez R: **Gamification as an approach to promote tourist recycling behavior**. *Sustainability* 2019, **11**:2201, https://doi.org/10.3390/su11082201.

49. * Koroleva K, Novak J: **How to engage with sustainability issues we rarely experience? A gamification model for collective awareness platforms in water-related sustainability**. *Sustainability* 2020, **12**:712, https://doi.org/10.3390/su12020712.
In response to the idea that individuals will not prepare for the effects of climate change until a disaster occurs locally, this article examines how to encourage communities to prepare for future water-related issues. The authors of the article also explores how individuals may respond differently to various attempts at gamification.

50. Novak J, Melenhorst M, Micheel I, Pasini C, Fraternali P, Rizzoli AE: **Integrating behavioural change and gamified incentive modelling for stimulating water saving**. *Environ Model Software* 2018, **102**:120–137, https://doi.org/10.1016/j.envsoft.2017.11.038.

51. Cheng PH, Yeh TK, Tsai JC, Lin CR, Chang CY: **Development of an issue-situation-based board game: a systemic learning environment for water resource adaptation education**. *Sustainability* 2019, **11**:1341, https://doi.org/10.3390/su11051341.

52. Koenigstein S, Hentschel LH, Heel LC, Drinkorn C: **A game-based education approach for sustainable ocean development**. *ICES (Int Counc Explor Sea) J Mar Sci* 2020, **77**:1629–1638, https://doi.org/10.1093/icesjms/fsaa035.

53. Gifford R: **The dragons of inaction: psychological barriers that limit climate change mitigation and adaptation**. *Am Psychol* 2011, **66**:290, https://doi.org/10.1037/a0023566.

54. White K, Habib R, Hardisty DJ: **How to SHIFT consumer behaviors to be more sustainable: a literature review and guiding framework**. *J Market* 2019, **83**:22–49, https://doi.org/10.1177/0022242919825649.

55. van Valkengoed AM, Steg L: **Meta-analyses of factors motivating climate change adaptation behaviour**. *Nat Clim Change* 2019, **9**:158–163, https://doi.org/10.1038/s41558-018-0371-y.

56. Lieberoth A, Holm N, Bredahl T: **Selective psychological effects of nudging, gamification and rational information in converting commuters from cars to buses: a controlled field experiment**. *Transport Res Part F* 2018, **55**:246–261.

57. Beck AL, Chitalia S, Rai V: **Not so gameful: a critical review of gamification in mobile energy applications**. *Energy Research & Social Science* 2019, **51**:32–39, https://doi.org/10.1016/j.erss.2019.01.006.