Acta Psychologica 252 (2025) 104687

Contents lists available at ScienceDirect

Acta Psychologica

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

Gamify to persuade: A systematic review of gamified sustainable mobility

Simone Bassanelli [a,*], Riccardo Belliato [a,b], Federico Bonetti [a], Martina Vacondio [a,c], Federica Gini [a,c], Lorenzo Zambotto [c], Annapaola Marconi [a]

[a] Fondazione Bruno Kessler, Via Sommarive, 18, 38123 Trento, Italy
[b] University of Udine, Via Palladio, 8, 33100 Udine, Italy
[c] University of Trento, Via Calepina, 14, 38122 Trento, Italy

ARTICLE INFO

Keywords:
Gamification
Behavioral change
Mobility
Transportation
Persuasion
Game elements
Sustainability

ABSTRACT

The increasing need to address climate change has intensified efforts to promote green transportation options, such as cycling and public transit. Over the past few decades, gamification—the integration of game-like elements into non-game contexts to motivate and engage people in adopting new behaviors—has emerged as a strategy to encourage the use of sustainable transportation. This literature review examines how gamification has been used to drive the adoption of green transportation. Following the PRISMA methodology, 49 documents were initially screened, leading to a final selection of 14 papers. We analyze the stakeholders involved, the game elements, the external rewards (e.g., financial incentives), and persuasive strategies employed, and the overall effectiveness of these initiatives both in the short and in the long term. We also explore the relationship between game elements and persuasive approaches, offering insights into how they are related. Finally, we propose a research agenda that emphasizes the exploration of different game elements and the need for a multidisciplinary approach to designing gameful systems that promote sustainable behaviors.

1. Introduction

The increasing need to mitigate climate change and reduce urban congestion has intensified efforts to promote green transportation options such as cycling, walking, public transport, and car sharing (Avril et al., 2024). As transportation significantly contributes to greenhouse gas emissions, fostering a shift toward more sustainable mobility behaviors is crucial (Winkler et al., 2023). In transportation planning, mobility refers to the capacity for movement and the ability to travel from one location to another using various modes of transport to fulfill everyday needs. This concept differs from accessibility, which is defined as the ease of reaching or obtaining a specific service or activity (Reindl et al., 2023). However, administrators are responsible for upholding citizens' rights to mobility and ensuring smooth access to local services and activities, while also working to reduce the economic, social, and environmental impacts of the mobility system. Tackling this issue requires a holistic strategy that makes efficient use of current mobility resources and encourages the integration and adoption of innovative mobility services, ultimately creating a cohesive, effective, and sustainable mobility ecosystem (Bassanelli et al., 2024a). Green transportation, which can be defined as a mode of transportation that has a lower negative impact on both human health and the environment compared to conventional transportation services (Björklund, 2011), offers numerous benefits. These include mitigating environmental risks (e.g., reduced air pollution, greenhouse gas emissions, and ecosystem degradation from fossil fuel consumption and urban sprawl), addressing societal challenges (e.g., traffic congestion, noise pollution, and health burdens from pollution-related illnesses), and reducing individual risks (e.g., accidents and the health consequences of sedentary lifestyles tied to car dependency). Additionally, green transportation contributes to energy and resource sustainability, pollution reduction, accident prevention, enhanced road safety, improved travel security, and optimized traffic flow and speed (Shah et al., 2021). Nevertheless, encouraging people to adopt eco-friendly transportation options remains a persistent challenge, as these changes often involve breaking established habits and navigating barriers related to convenience, comfort, and perceived effort (reflecting a lack of accessibility). Moreover, innovative policies, infrastructures, and services may fail to reach their full potential if they are not supported by efforts to raise citizens' awareness and encourage their participation in the transformation process, gradually but

* Corresponding author at: Via Guido Rossa, 473, 51100, Pistoia (Italy).
E-mail addresses: sbassanelli@fbk.eu (S. Bassanelli), rbelliato@fbk.eu (R. Belliato), fbonetti@fbk.eu (F. Bonetti), martina.vacondio@unitn.it (M. Vacondio), fgini@fbk.eu (F. Gini), lorenzo.zambotto@studenti.unitn.it (L. Zambotto), marconi@fbk.eu (A. Marconi).

https://doi.org/10.1016/j.actpsy.2024.104687
Received 16 October 2024; Received in revised form 20 December 2024; Accepted 26 December 2024
Available online 6 January 2025

significantly shaping their mobility behaviors (Vesco, 2015). Hence, it is crucial for citizens to be well informed about the mobility services available in their city and to understand their true value, including factors such as time, cost, and environmental impact. Increased awareness enables individuals to recognize the consequences of their everyday decisions, such as their effects on traffic, greenhouse gas emissions, and social costs (Petersen et al., 2020). Eco-friendly transportation is generically promoted through various strategies, including self-monitoring, feedback, challenges, goal-setting, social comparison, rewards, and gamification (Anagnostopoulou et al., 2018). These strategies aim to encourage eco-friendly travel behaviors, such as using public transportation, cycling, or walking, by leveraging visual feedback (e.g., CO_2 emissions), personalized suggestions, and social incentives. The effectiveness of these interventions often depends on tailoring to individual user needs, integrating real-time contextual information, and ensuring the availability of sustainable transport options (Anagnostopoulou et al., 2018).

When referring to persuasion, we intend the process of influencing people's attitudes, intentions, or actions through non-coercive means by leveraging cognitive, emotional, and social dynamics. A persuasive strategy refers to techniques or approaches designed to influence and motivate users to adopt desired behaviors, attitudes, or decisions. These strategies can include the use of rewards, social comparison, competition, and social learning (Oyibo, 2024). In psychology, this concept is rooted in foundational theories in the fields of social (Cialdini & Goldstein, 2004; Cialdini & Trost, 1998), cognitive (e.g., Theory of Planned Behavior; Ajzen, 1991), and motivational psychology (e.g., Self-Determination Theory; Deci & Ryan, 1985). These theories identify mechanisms of influence where individuals' attitudes, beliefs, or behaviors are altered in response to messages or external cues. In gameful design, persuasion is applied as a tool to nudge behavioral change by embedding psychological principles into interactive and engaging systems (Fogg, 2002). For instance, game elements such as leaderboards use social proof, a persuasive mechanism where individuals conform their behavior with perceived social norms, to encourage competition and social comparison (Cialdini & Goldstein, 2004). In a similar manner, feedback and progress tracking tap into Self-Determination Theory, promoting intrinsic motivation by fulfilling needs for competence, autonomy, and relatedness (Ryan & Deci, 2000).

Gamification represents one of the approaches that take inspiration from video games to motivate and engage people in adopting specific desirable behaviors. Together with serious games—systems that take inspiration from commercial video games but designed with a primary serious purpose beyond mere entertainment (Deterding et al., 2011)—, gamification has emerged as a promising approach to promote behavior change in various fields, including health (Johnson et al., 2016), education (Bucchiarone et al., 2023b), and sustainability (Boncu et al., 2022). Gamification is a subset of persuasive technologies, designed to influence attitudes and behaviors through gameful elements and strategies (Huber & Hilty, 2015). Specifically, gameful systems employ persuasive techniques to motivate users to adopt particular behaviors (Alahäivälä & Oinas-Kukkonen, 2016; Fogg, 2002; Hamari et al., 2014). Despite being often considered as a single persuasion strategy (Krath & Von Korflesch, 2021), gamification carries significant overlaps with other persuasion strategies. In fact, in the rest of this paper, we will treat strategies like rewards and social comparison as integral parts of gamification, following established definitions of the term. Challenges, for example, are a classic hallmark of gamified approaches (Gallego-Durán et al., 2019; Kazhamiakin et al., 2016; Khoshkangini et al., 2021; Reindl et al., 2023), and it would be difficult to argue that their implementation does not involve gamification in some way.

Gamification is generally defined as "the use of game design elements in non-game contexts" (Deterding et al., 2011); however, during recent years, numerous definitions have been presented that leverage different elements of gameful systems. For instance, Zichermann, 2011 defined it as "the process of using game-thinking and game mechanics to engage users and solve problems", tying in more with the video game world, suggesting how the use of game mechanics—rather than just the elements themselves—, thus components also tending toward playfulness, can increase user engagement. Differently, Huotari and Hamari (2017) defined gamification as "a process of enhancing a service with affordances for gameful experiences in order to support users' overall value creation", emphasizing its implementation as the enhancement of an existing service rather than the creation of an entirely new one. Moreover, according to Hamari (2019), the use of gamification is associated with skill development, increased motivation, enhanced creativity, playfulness, engagement, and overall well-being, reflecting the positive benefits commonly attributed to play and gaming.

By game element (or affordances), we mean any fundamental component or feature of a game that contributes to its structure, gameplay, or overall experience. Game elements are designed to engage players, create challenges, and provide rewards or feedback. They are the building blocks that define the mechanics, dynamics, and aesthetics of a gameful system (Hunicke et al., 2004). By incorporating elements such as points, levels, and social recognition, these systems can engage and motivate users to alter their behavior in a more playful and rewarding manner (Bassanelli et al., 2022), and at the same time promote people's awareness (Kazhamiakin et al., 2015). However, one limitation in the adoption of gamification lies in the widespread use of unchanging designs for diversified behaviors, target users, and application contexts. This issue, often referred to as the *one-size-fits-all* approach, can undermine the effectiveness of gamification due to a lack of personalization tailored to specific goals. Indeed, factors such as player type, personality traits, cultural background, and the behavior being encouraged significantly influence the impact of gamification, either enhancing or hindering its motivating and engaging effects. Addressing this limitation requires a more nuanced approach to the design of gameful systems that considers these contextual and individual differences (Bassanelli et al., 2024b; Koivisto & Hamari, 2019; Tondello et al., 2018). Other than game elements, existing research highlights that a one-size-fits-all approach is also ineffective since users are motivated by different persuasive strategies (Kaptein et al., 2012; Orji et al., 2013, 2014; Paiva et al., 2016). As shown in Orji et al. (2018), the persuasive effect of game elements significantly varies based on users' player type. Personalization, therefore, plays a critical role in enhancing the persuasive impact of gamified systems (Kaptein et al., 2012; Orji, 2014).

Gamification effectiveness in promoting behavioral change is supported by several psychological theories (Krath et al., 2021). Among the most widespread, Self-Determination Theory (SDT) underlies the fulfillment of psychological needs for autonomy, competence, and relatedness, which gamified systems often address through personalized challenges, feedback tools, and social elements (Ryan & Deci, 2000). Flow theory complements this by showing that an optimal experience arises when a task's difficulty is balanced with users' skills, thus fostering deep engagement (Csikszentmihalyi, 1990). Social Cognitive Theory (SCT) emphasizes the role of self-efficacy and observational learning: people learn by observing others and gain confidence by witnessing their success, for example thanks to the implementation of leaderboards and social rewards (Bandura, 1986). Goal-Setting Theory underscores the importance of setting clear, achievable objectives and offering feedback to reinforce commitment to behavioral goals (Locke & Latham, 2002). Finally, the Transtheoretical Model of Behavior Change (TTM) offers a framework for understanding the stages that users move through when changing behavior and helps support gameful design by identifying how gameful interventions can support transition, for example from pre-contemplation to maintenance phases (Prochaska & Velicer, 1997). This theoretical foundation guides our understanding of how gameful design can effectively motivate sustainable mobility behavior.

In the realm of sustainable mobility, gameful systems hold significant potential to motivate individuals to shift from carbon-intensive transportation methods to greener alternatives (Wang et al., 2022). In the domain of mobility, gamification has been used as one of the persuasive strategies to encourage sustainable transportation choices, such as eco-driving or adopting sustainable mobility habits (Fogg, 2002; Huber & Hilty, 2015; Takayama et al., 2009). EcoIsland (Takayama et al., 2009), for example, uses gamification to reduce household consumption by showing a virtual island threatened by the rising level of the ocean, that can be saved through reduced emissions. By leveraging enhanced motivation, enjoyment, and competition, these systems aim to foster voluntary adoption of sustainable or active transport modes, such as walking, cycling, or public transit, and promote eco-friendly driving behaviors. It is important to notice how the design of gameful systems is affected by the area of the application, and the adoption of game elements is influenced by the goals set (Koivisto & Hamari, 2019). While most principles can be transferred from one domain to another, specific game elements might affect users differently. For example, competition is considered highly motivating, but might not represent the best choice in the educational context (Orosz et al., 2013; Ryan & Reeve, 2021). Unlike traditional applications of gamification that might focus on increasing the frequency of actions, the primary goal here is to encourage meaningful and sustainable behavioral change. For example, it is crucial to avoid incentivizing unnecessary travel solely to boost in-game performance, as such counterproductive behaviors could undermine the intended outcomes. Safety is another critical consideration in gamified interventions for mobility. Whether users are driving, cycling, or walking, the design of interactions and feedback mechanisms must ensure that they remain focused on navigating their environment safely and effectively. Striking the right balance is essential: gamified elements should engage and motivate users without becoming overly distracting.

Recent reviews have highlighted the significant role of gamification in encouraging sustainable mobility practices. Wallius and Köse (2023) focused on how gamified eco-driving systems motivate drivers to adopt more energy-efficient behaviors by offering engaging, game-like experiences. Similarly, Boncu et al. (2022) explored the impact of serious games and gamified mobile apps in promoting pro-environmental information and fostering attitudes that encourage sustainable behaviors. Reindl et al. (2023) examined how gamification can influence commuters to make more sustainable mobility choices, identifying key game elements and transport modes used to drive behavior change. Miao et al. (2022) demonstrated the effectiveness of gamification as a learning tool in promoting pro-environmental behavior through interactive learning experiences. Chandra et al. (2024) reviewed gamification's implementation in public transportation apps, discussing its potential to motivate users to switch from individualized transportation modes to more sustainable public options. Additionally, Wallius and Hamari (2020) explored the use of motivational technologies, including gamification, serious games, and persuasive technology, in enhancing transportation safety. Wang et al. (2022) systematically map the adoption of gamification in transportation, examining its elements, benefits, methods, and challenges. Finally, Avril et al. (2024) provided a broad overview of gamification in the transport sector, emphasizing its capacity to motivate and engage users toward adopting sustainable mobility practices.

However, these reviews often lack standardization in reporting the game elements used across the studies they analyze, with inconsistent terminology (e.g., *badges* and *medals*) and varying categorizations. Only a few reviews have attempted to standardize these elements, including Miao et al. (2022), who utilized the Octalysis framework (Chou, 2019), Chandra et al. (2024), who employed the MDA framework (Hunicke et al., 2004) and Werbach and Hunter (2012)'s game element hierarchy, and Avril et al. (2024), drawing from Zichermann, 2011, albeit with limited comprehensiveness. Furthermore, within the existing reviews, only Avril et al. (2024) acknowledged the importance of empirical evidence, pointing out that its absence raises concerns about the effectiveness of gamification in the transport and mobility sector. Moreover, only two reviews—Avril et al. (2024) and Reindl et al. (2023)—reported on the specific modes of transportation examined. Additionally, none of the existing reviews provide a detailed analysis of the persuasion strategies adopted in gamification to promote behavioral change.

Despite numerous studies on persuasion in gamification (Llagostera, 2012) and numerous reviews on sustainable mobility in gamification, it is not totally clear what persuasive approaches are most effective when there is a need to promote behavioral change, especially when promoting new sustainable transportation modalities. To address this element, we conducted a review with a systematic approach, aiming to link the use of game elements to specific persuasive components. We stated three research questions:

RQ1. What eco-sustainable travel methodologies are being promoted?

RQ2. How are gamification elements and persuasive techniques combined to promote sustainable transportation?

RQ3. To what extent are these gameful applications effective in promoting sustainable transportation use?

This paper presents a systematic approach to analyzing the existing literature on the use of gameful systems to promote green transportation. The aim is to identify persuasive strategies (explicit and emergent) and game elements that have been employed to influence transportation behaviors and their interaction, assess the effectiveness of these interventions, and identify key factors contributing to their success or failure. Through this analysis, we seek to offer insights into the role of gameful design in fostering sustainable transportation behaviors, with implications for policymakers, urban planners, and system designers seeking to encourage eco-friendly mobility. Section 2 presents the methods used for the literature search, paper selection, and data retrieval. Section 3 reports the results collected from the full-text analysis of the included papers. In Section 4 we answer the research questions previously stated. We conclude the paper with the conclusions and a research agenda in Section 5.

2. Methods

2.1. Literature search

The literature search was carried out using the Scopus database. This platform was selected as it covers books and book chapters, other than scientific publications (Huang et al., 2020). Opting for a limited number of comprehensive databases, rather than multiple smaller ones, was considered beneficial to maintain rigor and clarity (Paré et al., 2015). We used the query "`(TITLE-ABS-KEY (gamif*) OR TITLE-ABS-KEY (gameful) AND TITLE-ABS-KEY (green) OR TITLE-ABS-KEY (sustainab*) AND TITLE-ABS-KEY (transport*) OR TITLE-ABS-KEY (mobility) OR TITLE-ABS-KEY (commut*) AND TITLE-ABS-KEY (experiment) OR TITLE-ABS-KEY (intervention) OR TITLE-ABS-KEY (controlled AND trial))`", as the search terms "gamif*", "sustainab*", "transport*", and "commut*" take into account all possible forms derived from the roots. The search was limited to conference papers, journal articles, articles in press, and book chapters, all written in English, in order to exclude non-academic sources and reviews. The search fields were defined as title, abstract, and keywords. The objective of this query was to capture all the pertinent literature on gameful applications promoting green and sustainable mobility, focusing specifically on studies with empirical evidence of their use.

A literature search was performed in September 2024, yielding 30 results from the Scopus database. Subsequently, a snowballing technique was applied by two different authors independently (author #1 and author #2), identifying an additional 19 papers by analyzing the title and abstract of the references of the initially retrieved documents. The inclusion of the documents followed a consensus-based approach. This process resulted in a total of 49 documents being selected for title and abstract screening.

2.2. Selection of papers for inclusion in the review

All records were managed using ASReview Lab (Van De Schoot et al., 2021). The first two authors conducted the title and abstract screening independently (author #1 and author #2) through a double-blind review process. No disagreements arose between the authors during this stage. Of the 49 documents, 18 were excluded due to not containing any relevant gameful approaches or data. Consequently, 31 articles were retained for full-text review.

Full-text versions of the papers were obtained. For articles that were not immediately accessible, we reached out to the authors via email or through academic networking platforms like ResearchGate[1] to request complete versions. A total of two papers were retrieved through this method. All papers were obtained successfully, with none remaining unavailable. Full-text screening was performed using the Covidence tool,[2] by 4 different authors (author #1, author #2, author #3, and author #5). The authors were trained before the screening phase. In accordance with the Cochrane Handbook for Systematic Reviews of Interventions (Chandler et al., 2019), the screening and the following data collection procedures were carried out using a consensus-based approach, which ensures that criteria are applied consistently, and that consensus can be reached, reducing the risk of bias and improving the reliability of evaluations (Boutron et al., 2019). For all decisions without unanimity among authors, ad-hoc meetings were held with the entire team to reach a shared decision.

The inclusion criteria, determined by considering the purpose of the research, were as follows: (i) written in the English language, (ii) focused on gamification in promoting green and sustainable transportation (excluding multipurpose applications reporting a general behavior change, i.e., a generic improvement in sustainable habits, or specifically reducing consumption in households, etc.), and (iii) contained evidence or behavioral data for the effectiveness of the systems (including data on tracks, sustainable kilometers, CO_2, and avoiding studies with only usability or user experience). The study selection process is reported as recommended by the PRISMA guidelines (Page et al., 2021) in Fig. 1.

2.3. Data analysis

The final review included 14 articles. Data from the documents was collected: the authors first made a list of key elements to extract from the papers to provide answers to the research questions (see Section 1). The first six authors then proceeded to a full-text read and recorded the relevant information in a shared file using a balanced double-blind process. Each paper was randomly assigned to two of the seven authors and independently analyzed. All conflicts were resolved through meetings by the whole group and were merged into a single file.

2.3.1. Data coding

The articles that met the inclusion criteria were coded using data categorization, taxonomies, and categorizations from the literature where necessary. The following elements were extracted from the papers.

2.3.1.1. Demographics. Number of participants involved in the gamified campaigns and the number of participants who participated in the studies, the category of participants (i.e., students, local citizens, sex, and age) were identified.

2.3.1.2. Tool. The names of each gameful system used were reported. Some studies utilized more than a single gameful system.

2.3.1.3. Game elements. Game elements used in the gameful systems and their co-occurrences were analyzed. Initially, each author reported the game elements as described within the paper. Then, independently, they proceeded to categorize the elements according to the taxonomy of Toda et al. (2019b), which includes five macro-categories, namely *performance*, *social*, *personal*, *ecological*, and *fictional*. The use of a taxonomy stems from the need to have a reference language when game elements are reported and described. The choice of Toda et al. (2019b)'s taxonomy, specifically, stems from two reasons: (i) this taxonomy presents a description of macro-categories, allowing authors to categorize individual game elements based on function; and (ii) the game elements included in the taxonomy have been evaluated through expert consultation, reporting good comprehensibility, description and coverage (see Toda et al., 2019a); and (iii) the taxonomy is widely recognized and utilized in gamification research, providing a common reference language for studies in this domain.

Performance elements are related to the environment response, which can be used to provide feedback to the users; they include *points*, *levels*, *acknowledgments* (badges, etc.), *stats*, and *progression*. The social dimension is related to the interactions between the users. It includes *competition*, *cooperation*, *social pressure*, and *reputation* (i.e., rank). The personal dimension is related to the user that is using the environment. It includes *objective*, *novelty*, *sensation*, *puzzle*, and *renovation*. Ecological elements reflect the environment in which the gamification is being implemented. They include *time pressure*, *chance*, *rarity*, *economy*, and *imposed choice*. Fictional is a mixed dimension that is related to the user and the environment, tying their experience with the context. It includes *narrative* and *storytelling*. Some elements can be classified into different categories. The category is selected according to the use that is identified by the authors. For example, leaderboards can be considered as competition, reputation, or social pressure. Game elements were retrieved from studies by looking for examples and illustrations where available, and by inferring them from the system descriptions when needed. During the data coding phase, each author involved in the analysis not only reported game elements according to Toda et al. (2019b)'s taxonomy, but specified how the game elements were related to each other and the dynamics created. It was then possible to indicate game elements as belonging to more than one category. Later, ad-hoc meetings were held with the entire team to reach a shared decision involving a consensus agreement approach.

2.3.1.4. External reward. The different categories of external rewards used to motivate participants (e.g., money or discounts associated with mobility outcomes) were described.

2.3.1.5. Persuasion strategies. Authors reported the different persuasion strategies adopted and linked to game elements, external rewards, and other in-game components to promote sustainable transportation use. The *ComTech* taxonomy of Oyibo (2024) was used to report a reliable categorization of the persuasion strategies and their subcategories. Specifically, we selected the part of the taxonomy named *Persuasive Design* which aims to provide a structured approach for designing persuasive systems for promoting behavioral change. This part of the taxonomy is divided into three macro categories *primary task support*, *dialog support*, and *social support*, each with second-order categories and details.

Primary task support entails persuasive strategies aimed at supporting the users to engage in the target behavior by simplifying and structuring the tasks. It includes two second-order categories: *facilitation* and *adaptation*. Facilitation includes strategies such as *self-monitoring*, *goal-setting*, and *action planning* which help users to track and structure their behaviors. Adaptation refers to strategies that tailor the gamified system to the users' needs and includes for example *customization* and *personalization*.

Dialog support refers to strategies aimed at engaging users by

[1] https://www.researchgate.net/.

[2] https://www.covidence.org/.

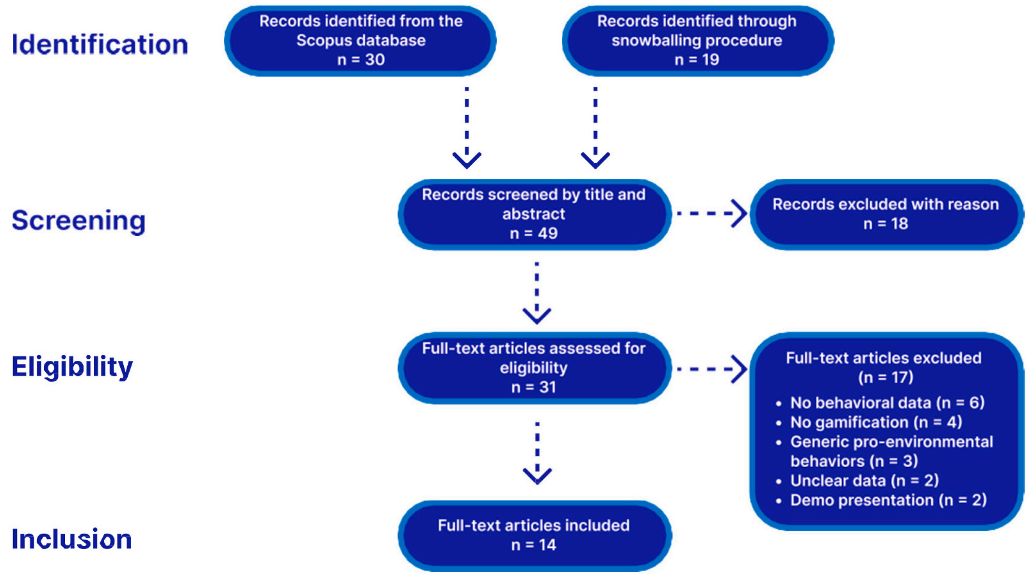


Fig. 1. Study selection process.

reinforcing behaviors and providing feedback. It includes two second-order categories as well: *nudging* and *incentive*. Nudging refers to subtle suggestions and prompts which usually require no direct interaction; it includes for example *choice architecture*, *notifications*, and *reminders*. Incentive refers to all the positive or negative reinforcements, including for example *reward* and *punishment*, thus using behavioral psychology to promote desired actions.

Finally, social support entails persuasive strategies leveraging social influence to promote and sustain behavioral change. It includes two second-order categories: *collaboration* and *learning*. Collaboration includes strategies such as *cooperation*, *competition*, and *comparison* aimed at creating a supportive and competitive environment by engaging with others. Learning instead includes strategies that encourage users to learn how to behave based on how others in the game behave; it includes strategies such as *role modeling*, *social proof*, and *social learning*.

2.3.1.6. Intervention effectiveness. Authors collected information on the types of data that have been reported in the various studies, creating an ad-hoc taxonomy for these. This taxonomy is partitioned into two macro-categories according to the distinction used in the review of Koivisto and Hamari (2019): *behavioral* and *psychological* data. In terms of behavioral data, we considered measures and indicators pertaining to users' in-game performance, which have been classified into four distinct categories: *trips logging*, encompassing data on self-reported trips; *distance tracking*, representing the measurement of user travel distances via GPS; *resource saving*, comprising metrics indicating reductions in emissions or resource utilization; and *health measures*, which encompass data on health benefits for users, such as calories expended. In terms of psychological data, the authors collected data from questionnaires and interviews about the perceived individual changes fostered by the intervention (i.e., *mobility habits* and *behavioral change*) as well as engagement-related data such as *user experience*, *motivation*, and the *overall assessment* of the intervention.

Other data included in this review include *CO_2 emission reduction*, *sustainable kilometers*, *overall results* (positive, mixed or negative), *intervention duration*, check on the presence of *follow-up*, which were the *encouraged means of transportation* analyzed, and the *effectiveness* of sustainable transportation (i.e., in which category of means of transportation there was an increase or decrease in usage due to the gameful system).

2.3.1.7. Scientific reliability. The reliability of each study was assessed. With the term 'reliability' we refer to the methodological soundness (an example being the inclusion of a power analysis) and the adequacy of the data collected (an example being the sample size). Although there are corroborated methodologies in the literature, we identified that these methodologies did not apply to our case, as almost all articles would score poorly according to other methodologies (e.g., Connolly et al., 2012). In fact, according to Koivisto and Hamari (2019), in many gamification articles, the reporting of methods, data, analysis, and results is often unclear. Then, we identified a-priori a less restrictive methodology, providing as output a categorical division into *poor*, *average*, *good*, or *excellent* scientific reliability. For this feature, each author involved in the data extraction and coding, analyzed study design, sample size, data collected, standardized methodologies, possible power analysis and effect size, and the different analyses run (inferential and non-inferential), reporting a category based on the percentage of these elements reported correctly within the studies (e.g., 0 %–25 % low scientific reliability, 25 %–50 % average scientific reliability, 50 %–75 % good scientific reliability, 75 %–100 % excellent scientific reliability). Since articles can vary greatly in methodology, we decided not to settle on a set of specific hard requirements but rather to rely on an ad-hoc heuristic. For this reason, a manuscript where quantitative research was described could reach, for instance, 'good' reliability if at least 50 % of the standard methodological practices related to quantitative research were carried out and reported. An article that adequately described its sample size, that reported a normality check and a standardized methodology, but did not conduct a power analysis and had suboptimal sample size, could reach a score of 'average'.

Moreover, in our framework we considered all procedures that carefully assess the trustworthiness and rigor of both quantitative and qualitative analyses. For qualitative research, this included a consideration of whether the study design and analysis methods were clearly reported, thematic trends were well-supported by data, and the authors demonstrated reflexivity. While some scholars suggest the inclusion of effect size analysis for qualitative data (e.g., Onwuegbuzie, 2003), others, such as Braun and Clarke (2021), critique its necessity, advocating instead for deliberate and reflective practices that prioritize context and meaning. Recognizing these contrasting epistemological positions, we adopted a balanced approach to analysis rigor, acknowledging that effect size is one of multiple valid strategies to enhance trustworthiness, but not a definitive requirement. By including diverse practices, our framework supports a pluralistic view of qualitative research quality. For example, statistical techniques like Cramer's V for nominal variables (Sun et al., 2010), odds ratios for binary variables (Bland & Altman, 2000), or canonical correlations for complex relationships (Onwuegbuzie, 2022) can offer quantification where appropriate, but we emphasize their complementary role within a broader interpretative process. This flexibility allows the framework to respect different epistemological stances while promoting comprehensive and transparent reporting of methods and analyses. In this way, we aim to provide a nuanced and inclusive perspective on methodological rigor, accommodating both quantitative metrics and qualitative reflexivity to foster a holistic evaluation of scientific reliability. The decision flow is depicted in Fig. 2.

The complete process of exclusion and inclusion, as well as the data extracted from the 14 articles, are available in Supplementary Material.[3]

3. Results

3.1. Demographics

Many of the studies included in the review investigated gamified applications aimed at the general population (9 occurrences), while only a minority were dedicated to specific demographics such as commuters (3 occurrences) (Bowden & Hellen, 2019; Kazhamiakin et al., 2015; Khoshkangini et al., 2021), teachers (3 occurrences) (Bassanelli et al., 2024a; Biondi et al., 2022; Bucchiarone et al., 2023a), high school students (2 occurrences) (Bassanelli et al., 2024a; Bucchiarone et al., 2023a), primary school students (2 occurrences) (Biondi et al., 2022; Rogelj et al., 2024), kindergarten children (1 occurrence) (Biondi et al., 2022), and employees (1 occurrence) (Wunsch et al., 2016). On one occasion (Biondi et al., 2022) also parents were involved as they accompanied children to school by bike. As they were not the primary focus of the intervention and did take part in the gamified initiative, we considered them as *indirect* stakeholders.

The initiatives varied widely in the number of participants included, involving from 13 (Froehlich et al., 2009) to 92,500 (rounded) (Biondi et al., 2022) users (Weber et al., 2018). Most of them included more than 100 participants, with only three (3) studies engaging fewer users (Cellina et al., 2019; Froehlich et al., 2009; Kazhamiakin et al., 2015). The studies with the most participants had a numerosity of 92,500 (rounded) (Biondi et al., 2022), 66,726 (Weber et al., 2018), and 28,043 (Rogelj et al., 2024). It is important to stress that in Biondi et al.'s study the number of participants is given by the sum of three years of interventions (around 26,000 in 2017, 31,900 in 2018, and 34,615 in 2019), and it is not specified if part of the children participated in more than one intervention. Surprisingly, only Weber et al. (2018) targeted the general population, while the other two initiatives were specifically for primary and kindergarten children. Most studies, despite targeting a broader audience, had a limited number of users participating in the data collection, therefore lowering the numerosity of the sample. For example, Cellina et al. (2019) recruited an initial pool of 599 participants, but collected all the necessary data from 52 users only.

Most studies (5 occurrences) targeted participants between 20 and 50 years of age (Cellina et al., 2019; Froehlich et al., 2009; Máca et al., 2020; Weber et al., 2018; Wunsch et al., 2016), while one study included participants between 16 and 70 years of age (Bassanelli et al., 2024a), one study has users from 14 years of age on (Bowden & Hellen, 2019), and another study had participants between 6 and 14 years of age (Rogelj et al., 2024). The remaining studies did not report participants' age (Biondi et al., 2022; Bucchiarone et al., 2023a; Ferron et al., 2019; Kazhamiakin et al., 2015, 2016; Khoshkangini et al., 2021). In some cases, users' age range was not defined a-priori, but was determined by those participants who completed the demographic questionnaires. For example, in Bassanelli et al. (2024a), the gamified apps were dedicated to citizens aged 14 or older, but only users from 16 to 70 completed the questionnaires. As most of the behavioral and especially psychological data collected refer to those participants who took part in the data collection, we decided to consider those participants when reporting the demographic information. For the same reason, we decided not to report any demographic information about users' gender, since there was no consistency among the various papers in reporting this data (i.e., some reported the gender of the participants recruited at the beginning of the campaign, while others reported only that of the participants considered in the data analyses). In any case, all studies selected participants of any gender, with no distinctions made a-priori.

3.2. Tools

Most studies included present unique tools, while a pool of papers describes different versions of the same tool (*Play&Go*) as it progressed over the years (Bassanelli et al., 2024a; Bucchiarone et al., 2023a; Ferron et al., 2019; Kazhamiakin et al., 2016; Khoshkangini et al., 2021): Urban Mobility Campaign (UMC), High School Challenge (HSC), Play-&Go (P&G), and Kids Go Green (KGG). Other tools studied are *GoEco!* (Cellina et al., 2019), *BetterPoints* (Bowden & Hellen, 2019), *GreenGame with ViaggiaRovereto* (Kazhamiakin et al., 2015), *Cyclers* (Máca et al., 2020), *UbiGreen* (Froehlich et al., 2009), *Love to Ride* (Weber et al., 2018). All of them are smartphone or mobile phone applications, representing the most simple and user-friendly tools to track mobility. *Biking Tourney* (Wunsch et al., 2016), instead, uses a web application in order to self-report sustainable trips.

The remaining two articles present classroom initiatives, in which tools like class posters and trip diaries are preferred. This is the case of Rogelj et al. (2024), with their initiative *Let's Walk (With Rosie the Chicken)*, and Biondi et al. (2022), which, however, did not report the name of the initiative.

3.3. Game elements

Most papers reported competition (13 out of 14; except for Froehlich et al., 2009), acknowledgments (11 occurrences; all the documents except for Bowden & Hellen, 2019; Froehlich et al., 2009; Wunsch et al., 2016), points (10 occurrences; all the documents except for Cellina et al., 2019; Froehlich et al., 2009; Rogelj et al., 2024; Wunsch et al., 2016), and objectives (10 occurrences; all the documents except for Biondi et al., 2022; Froehlich et al., 2009; Rogelj et al., 2024; Wunsch et al., 2016) as game elements used in the gameful systems (Table 1). Other categories such as progression (6 occurrences; Bassanelli et al., 2024a; Bucchiarone et al., 2023a; Cellina et al., 2019; Froehlich et al., 2009; Khoshkangini et al., 2021; Weber et al., 2018), cooperation (6 occurrences; Bassanelli et al., 2024a; Bowden & Hellen, 2019; Bucchiarone et al., 2023a; Rogelj et al., 2024; Weber et al., 2018; Wunsch et al., 2016), and novelty (4 occurrences; Cellina et al., 2019; Kazhamiakin et al., 2015, 2016; Rogelj et al., 2024) were also noted, but in a smaller quantity. The majority of the elements reported (a total of 32 occurrences) are related to performance, while elements of social (23 occurrences), personal (15 occurrences), and ecological (4 occurrences) have been reported in smaller amounts. No game elements related to the fictional dimension were identified.

Among these, only Bassanelli et al. (2024a); Bucchiarone et al. (2023a); Ferron et al. (2019); Kazhamiakin et al. (2016); Khoshkangini et al. (2021); Máca et al. (2020) reported tailoring the gameful design to their target users (e.g., personalized challenges based on users' characteristics). The rest of the publications included did not adopt—or did not report it in the paper—tailored designs, falling in the use of a one-size-fits-all approach.

To gain a better perspective on the game elements employed in the studies, and to contribute to answer **RQ2**, we looked at the co-occurrences between game elements by employing co-occurrence matrices. Fig. 3 depicts the interaction within game elements. In terms of macro-categories, we register a total of 12 co-occurrences between

[3] https://osf.io/mv2td/?view_only=1108df2cc9074d4882b286bf9d854e32.

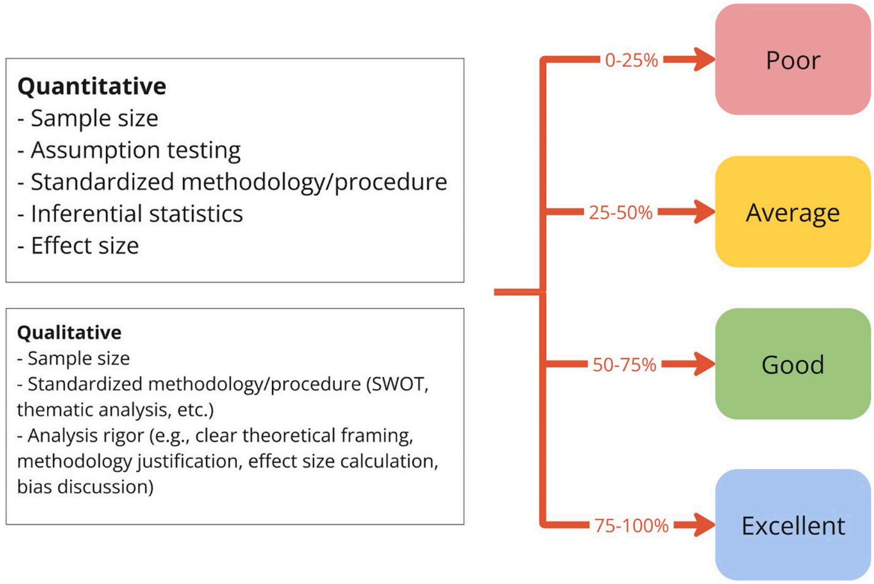


Fig. 2. Rationale behind our scientific reliability evaluation.

performance-related and social-related elements, as well as between performance-related and personal-related elements. To a lesser extent, interactions have been identified between personal-related and social-related elements (11 occurrences). The other categories show a total of 4 co-occurrences with the other ones (Fig. 3a). Fictional does not show any occurrence. In terms of micro-categories, Fig. 3b reports high co-occurrences of competition and acknowledgment (11 occurrences), competition and objectives (10 occurrences), competition and points (10 occurrences), points and acknowledgment (9 occurrences), objectives and acknowledgment (9 occurrences), and objectives and points (9 occurrences). Note that the co-occurrences are not cumulative and hide overlaps. The high co-occurrence within these factors might reflect the extensive use of the points, badges, and leaderboards triad (PBL) in gameful systems (Chou, 2019), as they are mainly referred into the categories of points (points), acknowledgment (badges), competition (leaderboards) and objectives (what determines earning points and moving up in the leaderboard ranking).

3.4. External rewards

Along with game components, most of the gameful systems proposed external rewards based on performance or participation. The rewards most commonly used in these studies are different tangible rewards (9 occurrences), money (6 occurrences), vouchers and discounts (2 occurrences), and experiences (1 occurrence). Only Wunsch et al. (2016)'s paper did not present some external rewards. Specifically, external rewards considered in the papers are items and money according to participation (Cellina et al., 2019; Froehlich et al., 2009), weekly and final prizes based on app results (Bassanelli et al., 2024a; Ferron et al., 2019; Kazhamiakin et al., 2016), points exchange for vouchers and discounts (Bowden & Hellen, 2019), free pass for the bike-sharing (Ferron et al., 2019; Kazhamiakin et al., 2015), financial rewards based on sustainable kilometers (Bucchiarone et al., 2023a; Máca et al., 2020), school material (Bucchiarone et al., 2023a), gadgets for children, organized class excursions, and financial support for the amelioration of schools' cycling facilities (Biondi et al., 2022). One paper (Weber et al., 2018) generically mentions prizes as external rewards without going into details. An overview of the external rewards categories is depicted in Table 2.

3.5. Persuasion strategies

We employed the ComTech taxonomy by Oyibo (2024) to systematically identify the persuasive strategies utilized in the selected articles through a double-blind consensus-based method (an overview is presented in Table 3). This approach allows this study to collocate the persuasive elements in a broader known taxonomy, thus contributing to the generalizability and replicability of this type of analysis.

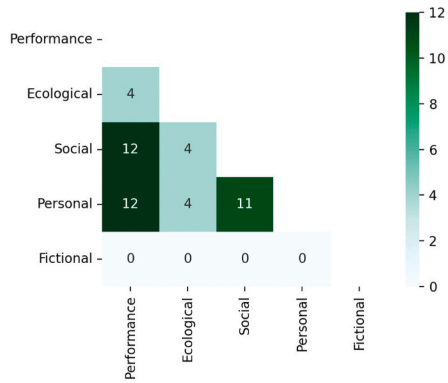
The analysis of the persuasive strategies showed that, among the selected studies, the macro category most frequently used was social support (34 occurrences) followed by dialog support (20 occurrences), with primary task support (15 occurrences) being the least used. This finding indicates the emphasis given to social comparisons in this type of gameful systems and reveals an underutilization of planning and tracking people's own behaviors as a persuasive strategy. Within the social support category, nearly all the studies (13 out of 14), Froehlich et al. (2009) representing the only exception, used some form of competition and social comparison, 6 studies used cooperation, while only Cellina et al. (2019) used social learning as an additional persuasive strategy. These results align with the widely known popularity of social comparison methods, such as leaderboards and challenges, in gameful systems. However, they also shed light on the underrepresented use of shared learning and leveraging societal norms to foster sustainable behavior change.

The dialog support category reveals an interesting pattern. Almost all the selected studies (13 out of 14), except for Wunsch et al. (2016), employed some form of incentive, particularly reward, revealing a systematic reliance of these gamified systems on rewards as drivers of sustainable behaviors. Fewer studies applied nudging strategies such as reminder (1 occurrence; Cellina et al., 2019), feedback (2 occurrences; Cellina et al., 2019; Froehlich et al., 2009), and notification (4 occurrences; Bowden & Hellen, 2019; Cellina et al., 2019; Máca et al., 2020; Weber et al., 2018). The use of this diversified group of strategies in the nudging subcategory identifies maintaining engagement through consistent interaction a common feature of these types of persuasive systems.

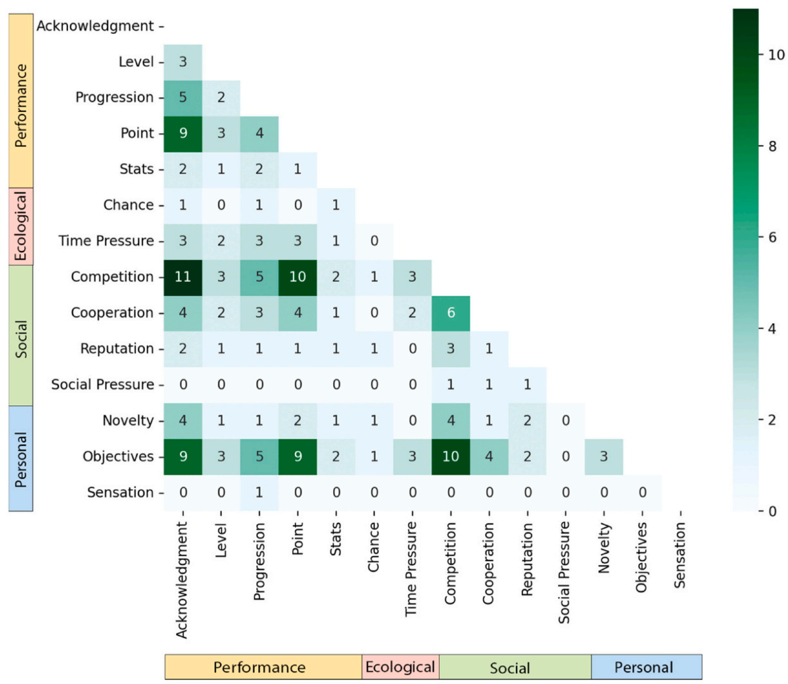
Finally, in the primary task support category, facilitation strategies were used in 9 occurrences, with self-monitoring (6 occurrences) and goal-setting (2 occurrences; Bowden & Hellen, 2019; Cellina et al., 2019) being particularly prominent while only Kazhamiakin et al. (2015) utilized also action planning. These results highlight the emphasis on helping individuals plan and track their behavior,

Table 1
List of game elements identified for each paper. Game elements were extracted according to the taxonomy by Toda et al. (2019b). Only game elements found in the studies are reported.

Authors	Performance					Social				Personal			Ecological		Total
	Points	Level	Aknowledgment	Stats	Progression	Competition	Cooperation	Social pressure	Reputation	Objectives	Sensation	Novelty	Time pressure	Chance	
Bassanelli et al. (2024a)	•	•	•	•	•	•	•			•			•		9
Biondi et al. (2022)	•		•			•									3
Bowden and Hellen (2019)	•					•	•			•					4
Bucchiarone et al. (2023a)	•	•	•		•	•	•			•			•		8
Cellina et al. (2019)			•	•	•	•			•	•		•		•	8
Ferron et al. (2019)	•		•			•				•					4
Froehlich et al. (2009)					•						•				2
Kazhamiakin et al. (2016)	•		•			•				•		•			5
Kazhamiakin et al. (2015)	•	•	•			•			•	•		•			7
Khoshkangini et al. (2021)	•		•		•	•				•			•		6
Máca et al. (2020)	•		•			•				•					4
Rogelj et al. (2024)			•			•	•					•			4
Weber et al. (2018)	•		•		•	•	•			•					6
Wunsch et al. (2016)						•	•	•	•						4
Total	10	3	11	2	6	13	6	1	3	10	1	4	3	1	



(a) Game element second-order category co-occurrence. Note that the co-occurrences are not cumulative and hide overlaps.



(b) Game element co-occurrence. Game elements were extracted according to the taxonomy by Toda et al. (2019a). Only game elements found in the studies are reported. Note that the co-occurrences are not cumulative and hide overlaps. The fictional category was omitted as it was absent.

Fig. 3. Interaction within second-order and first-order game elements reported in the studies included in the review.

suggesting that gamification approaches often focus on empowering users to set goals and monitor their own progress. Notably, 6 studies (Bassanelli et al., 2024a; Bucchiarone et al., 2023a; Ferron et al., 2019; Kazhamiakin et al., 2016; Khoshkangini et al., 2021; Máca et al., 2020) incorporated personalization as a persuasive strategy to promote sustainable mobility. The adaptation of gamification strategies to individual users is a critical component for long-term engagement and behavior change.

To gain a deeper understanding of the persuasive strategies used in the studies, we employed a co-occurrence matrix, similar to the approach used for the game elements. Fig. 4 shows the co-occurrences of second-order and first-order persuasion categories respectively. The most notable overlap in terms of co-occurrences of second-order categories is between collaboration and incentive (represented by reward alone), which occurred 12 times. All 12 times comparison and competition occurred together (see Fig. 4a). Cooperation co-occurred with reward 5 times, each time with both comparison and competition. The second most notable overlap is between incentive and facilitation: 8 overlaps in total, with reward being the only incentive strategy, and the contribution of the following facilitation strategies: action planning (1), goal-setting (2), and self-monitoring (6) (see Fig. 4b; numbers are not cumulative). Studies that focused on adaptation also show the tendency to include collaboration (6 overlaps where competition and comparison occurred together), and reward strategies (6). Part of this can be probably summarized by the term ‘personalized challenge’ (coupling especially competition with personalization), a technique that was pursued by studies such as Ferron et al. (2019), Kazhamiakin et al. (2016), Khoshkangini et al. (2021), Bucchiarone et al. (2023a), and Máca et al. (2020).

3.6. Bridging game elements and persuasion strategies

Evaluating the initiatives included in the current review highlighted the persuasive role played by game elements. We worked backward to link the game elements (GEs) according to Toda et al. (2019b)'s taxonomy to the persuasive strategies (PSs) included in Oyibo (2024)'s

Table 2
List of external rewards reported.

Authors	Tangible Rewards	Money	Vouchers and Discounts	Experiences
Bassanelli et al. (2024a)	•	•		
Biondi et al. (2022)	•	•		•
Bowden and Hellen (2019)			•	
Bucchiarone et al. (2023a)	•	•		
Cellina et al. (2019)	•	•		
Ferron et al. (2019)	•			
Froehlich et al. (2009)		•		
Kazhamiakin et al. (2016)	•			
Kazhamiakin et al. (2015)			•	
Khoshkangini et al. (2021)	•			
Máca et al. (2020)		•		
Rogelj et al. (2024)	•			
Weber et al. (2018)	•			
Wunsch et al. (2016)				
Total	9	6	2	1

taxonomy, as none of the papers referred to which persuasive strategies were employed to promote behavioral change. As mentioned in Section 1, game elements refer to the building blocks that define the mechanics, dynamics, and aesthetics of a game (Hunicke et al., 2004). Persuasive strategies, on the other hand, are techniques or approaches designed to influence and motivate users to adopt desired behaviors, attitudes, or decisions. While game elements represent the key components of a gameful system, their relationship to persuasive strategies is shaped by how they are applied within the system. This relationship is not inherently one-to-one: the same game element can align with multiple persuasive strategies based on its specific implementation. For instance, a leaderboard might foster competition by encouraging rivalry or social comparison by displaying relative rankings. At the same time, a single game element can be used to cater to multiple persuasive strategies. Furthermore, not all game elements serve as persuasive strategies, nor do all persuasive strategies stem exclusively from game elements. Persuasive strategies can also emerge from other application features, such as notifications or tailored prompts, which function outside the scope of gamification. Fig. 5 presents a Sankey diagram showing the relationship between game elements and persuasive elements in the analyzed initiatives. In some cases, Toda et al. (2019b)'s and Oyibo (2024)'s taxonomies share the same name to refer to the game element and the persuasive strategy. While the two do not necessarily overlap, we may refer to both in the same sentence (e.g., the persuasive strategy of cooperation stems from the game element of cooperation). For this reason, we add "(GE)" when we are referring to the game element, and "(PS)" when we are referring to the persuasive strategy (e.g., cooperation (PS) stems from cooperation (GE)) for brevity. The persuasive strategy of *reward (incentive)* was provided by using *acknowledgments* (GE i.e., badges) and *points* (GE) in 11 out of 13 initiatives. Specifically, only in Froehlich et al. (2009) the authors solely used external rewards (money) as an incentive, while Wunsch et al. (2016) did not use the *incentive* persuasive strategy. Of the other game elements in the performance category, *level* (GE) was not linked to any element of Oyibo's taxonomy, as it was not used as a persuasive element in the initiatives; while *stats* (GE) and *progression* (GE) mostly served as *self-monitoring* (PS) tools, included in the macro-category of *facilitation* (PS). *Facilitation* (PS) is also created through some of the game elements of the *personal* category, as the apps' *objectives* (GE) fostered *goal setting* (PS; $N = 2$) and *action planning* (PS; $N = 1$) when they allow users to, respectively, set their goals, and choose how to achieve them. The remaining game elements falling under the category *objectives* (GE) were persuasive elements of *personalization* (PS; $N = 6$) when they were tailored according to the users. These represent the only use of *adaptation* (PS) as a persuasive strategy for the adoption of sustainable mobility. In the *ecological* category (GE), none of the game elements included in the initiatives (*time pressure* $N = 3$; *chance* $N = 1$) worked as persuasive elements. The persuasive strategy of *collaboration* (PS) showed a complete alignment with game elements categorized under *social* features (22 instances). Specifically, the game element *competition* contributed to *competition* (PS) and *social comparison* (PS) across all 13 occurrences. Additionally, *comparison* (PS) was facilitated through game elements like *reputation* (GE), observed in three (3) cases, and *social pressure* (GE), which appeared once. Moreover, *reputation* (GE) also promoted *social recognition* (PS) in three (3) instances, reinforcing another persuasive strategy linked to *collaboration* (PS). The strategy of *cooperation* (PS) was consistently supported by the game element *cooperation* (GE) in all 6 occurrences. Finally, the categories of *learning* (PS) and *nudging* (PS) rarely had a corresponding game element. The only exception is made by a single occurrence of the game element *sensation* that was used as *nudging* (PS).

3.7. Intervention effectiveness

The objective of this section is to examine the extent to which the authors of the studies promoted sustainable modes of transportation and to ascertain the efficacy of gamified interventions in influencing the transportation habits of stakeholders.

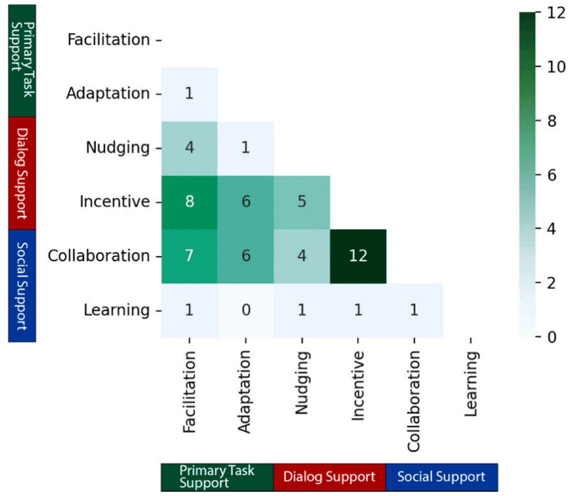
3.7.1. Data collection

Almost all studies have used behavioral and psychological measures to analyze the effectiveness of gameful systems and their associated mobility campaigns. Behavioral measures include the trip log (11 occurrences), distance tracking (8 occurrences), resource-saving (3 occurrences), and health measures (1 occurrence). The only study that did not use behavioral measures was Wunsch et al. (2016), which involved only perceived behavioral change as effectiveness evaluation. Analysis of travel, sustainable Km, and CO_2 emission reduction was done by in-game tracking via GPS, whereas only three (3) gameful systems did not provide for its implementation, and one did not consider it during the analysis (Weber et al., 2018), and thus required users to track manually. Specifically, Biondi et al. (2022) and Rogelj et al. (2024) required users to manually report trips, while Wunsch et al. (2016) only reported psychological measures. An overview of the data reported in the studies is depicted in Table 4. Some authors reported the sustainable km that were traveled during the studies, and, notably, some of them have put side by side the actual reduction of CO_2 emission. Bassanelli et al. (2024a) reported a total of 157,928 sustainable Km, equivalent to a reduction of 34.8 tons of CO_2 emissions, Bucchiarone et al. (2023a) reported a total of 280,000 sustainable Km, equivalent to a reduction of 25 tons of CO_2 emissions, Ferron et al. (2019) reported a total of 244,394 sustainable Km, Máca et al. (2020) reported a total of 542.7 sustainable Km, and Cellina et al. (2019) reported a reduction in CO_2 emissions of 33.1 gCO_2/Km and 1.439 gCO_2/Km in two difference cities due to the app use.

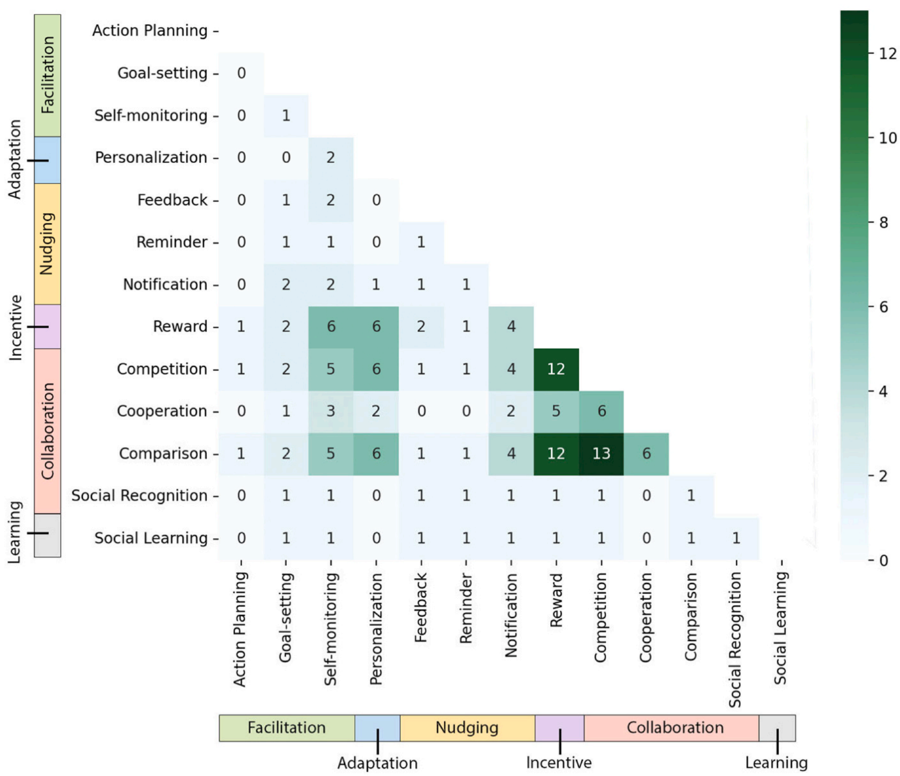
The psychological measures that were tracked throughout the surveys are mobility habits (9 occurrences), behavioral change perception (6 occurrences), user experience (5 occurrences), motivation (5

Table 3
Overview of persuasive techniques identified for each paper. The elements were extracted according to the taxonomy by Oyibo (2024). Only persuasive elements found in the studies are reported.

Authors	Primary Task Support				Dialog Support				Social Support					Total
	Facilitation			Adaptation	Incentive	Nudging			Collaboration				Learning	
	Action Planning	Goal-Setting	Self-Monitoring	Personalization	Reward	Feedback	Notification	Reminder	Cooperation	Competition	Comparison	Social Recognition	Social Learning	
Bassanelli et al. (2024a)			•	•	•				•	•	•			6
Biondi et al. (2022)					•					•	•			3
Bowden and Hellen (2019)		•			•		•		•	•	•			6
Bucchiarone et al. (2023a)				•	•				•	•	•			5
Cellina et al. (2019)		•	•		•	•	•	•		•	•	•	•	10
Ferron et al. (2019)				•	•					•	•			4
Froehlich et al. (2009)			•		•	•								3
Kazhamiakin et al. (2016)				•	•					•	•			4
Kazhamiakin et al. (2015)	•				•					•	•			4
Khoshkangini et al. (2021)			•	•	•					•	•			5
Máca et al. (2020)				•	•		•			•	•			5
Rogelj et al. (2024)			•		•				•	•	•			5
Weber et al. (2018)			•		•		•		•	•	•			6
Wunsch et al. (2016)									•	•	•			3
Total	1	2	6	6	13	2	4	1	6	13	13	1	1	



(a) Co-occurrence of second-order category persuasion strategies. Note that the co-occurrences are not cumulative and hide overlaps.



(b) Co-occurrence of persuasion strategies coded according to the taxonomy by Oyibo (2024). Note that the co-occurrences are not cumulative and hide overlaps. For example, Competition and Comparison have both high values but they always occur together.

Fig. 4. Interaction within second-order and first-order persuasion strategies reported in the studies included in the review.

occurrences), and overall assessment (2 occurrences). Two (2) studies analyzed also other components, such as participants preferences for rewards (Bassanelli et al., 2024a), and safety perception (e.g., urban barriers) (Weber et al., 2018). Five (5) studies also assessed the tool's effectiveness in promoting behavioral changes (Bassanelli et al., 2024a; Bowden & Hellen, 2019; Ferron et al., 2019; Kazhamiakin et al., 2015, 2016).

3.7.2. *Study duration*

The studies lasted between one week (Froehlich et al., 2009; Rogelj et al., 2024) and 6 months (Bowden & Hellen, 2019; Bucchiarone et al., 2023a; Ferron et al., 2019) continuously. An exception is represented by the studies of Bucchiarone et al. (2023a), Biondi et al. (2022), and Weber et al. (2018), which involved users for a limited period but for several consecutive years. An overview of the effectiveness of the studies is depicted in Table 5, which includes the encouraging sustainable transportation modes considered, the effectiveness of the different transportation means, the overall reported outcomes, the length of the study, and the presence of a follow-up analysis.

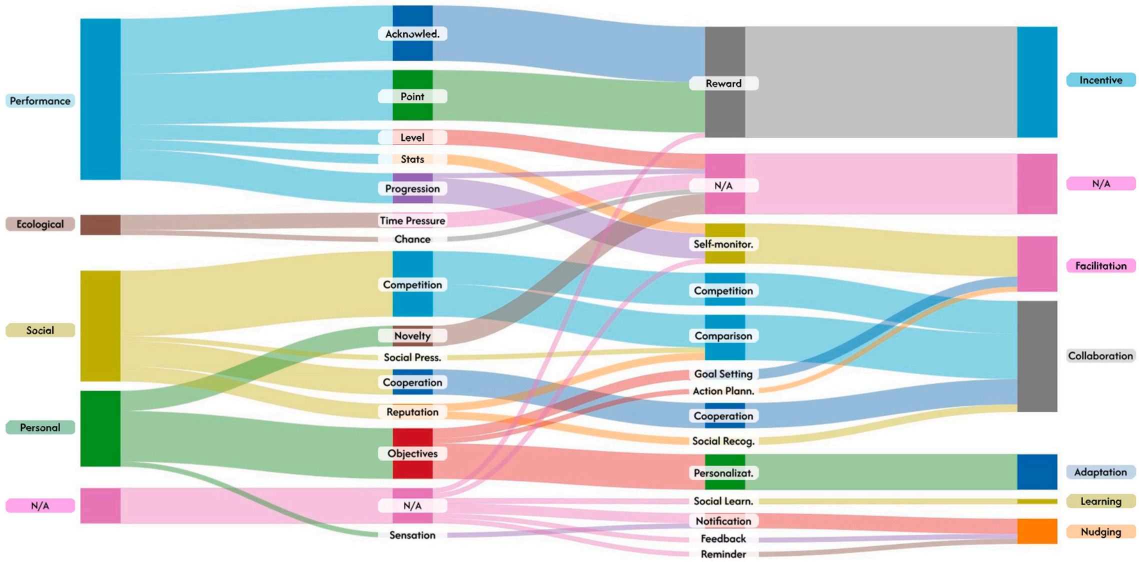


Fig. 5. Sankey diagram representing the correspondence between game elements and persuasive strategies in the included papers. N/A represents the lack of correspondence within the taxonomies.

Table 4
Overview of the different data collected in each study. The main categorization into behavioral and psychological outcomes is taken from Koivisto and Hamari (2019), and tailored to the scope of this review.

Authors	Behavioral				Psychological						Tool effectiveness	Total
	Distance tracking	Trips logging	Resource saving	Health measures	Mobility habits	Behavioral change	User experience	Motivation	Overall assessment	Other		
Bassanelli et al. (2024a)	•	•	•		•	•	•	•		•		7
Biondi et al. (2022)		•										1
Bowden and Hellen (2019)	•	•			•						•	4
Bucchiarone et al. (2023a)	•	•	•	•	•	•	•	•			•	9
Cellina et al. (2019)			•						•			2
Ferron et al. (2019)	•	•			•	•	•	•			•	7
Froehlich et al. (2009)		•			•		•	•				4
Kazhamiakin et al. (2016)	•	•			•		•				•	5
Kazhamiakin et al. (2015)	•	•				•					•	4
Khoshkangini et al. (2021)	•	•			•							3
Máca et al. (2020)	•	•			•							3
Rogelj et al. (2024)		•			•							2
Weber et al. (2018)		•				•				•		3
Wunsch et al. (2016)						•		•	•			3
Total	8	11	3	1	9	6	5	5	2	2	5	

Table 5
Overview of the studies, the means of transportation considered, the outcomes and the length of the interventions. Some studies reported different intervention campaigns with different duration: UMC = Urban Mobility Campaign, HSC = High School Challenge, P&G = Play&Go, KGG = Kids Go Green.

Authors	Encouraged means of transportation				Effectiveness for transportation	Outcomes	Length	Follow-up
	Bike	Walk	Public Transport	Car sharing/ pooling				
Bassanelli et al. (2024a)	•	•	•	•	Increased Bike Usage Increased Walking Generic Increase in Sustainable Mobility	Positive	UMC: 4.5 months HSC: 2 months	No
Biondi et al. (2022)	•				Increased Bike Usage	Mixed	1 month for 3 years	Yes
Bowden and Hellen (2019)	•	•	•	•	Reduced Private Vehicles usage	Positive	6 months	No
Bucchiarone et al. (2023a)	•	•	•	•	Increased Bike Usage Generic Increase in Sustainable Mobility	Positive	P&G: 6 months KGG: 2 school years HSC: 4 months	No
Cellina et al. (2019)	•	•	•	•	Not reported	Mixed	12 weeks	Yes
Ferron et al. (2019)	•	•	•		Reduced Private Vehicles usage Increased Bike Usage Increased Walking Increased Public Trasportation Increased Train Usage	Positive	6 months	No
Froehlich et al. (2009)	•	•	•		Not reported	Mixed	1–4 weeks	No
Kazhamiakin et al. (2016)	•	•	•		Increased Bike Usage Increased Walking Generic Increase in Sustainable Mobility	Positive	9 weeks	No
Kazhamiakin et al. (2015)	•	•	•		Reduced Private Vehicles usage Increased Bike Usage	Positive	5 weeks	No
Khoshkangini et al. (2021)	•	•	•		Increased Walking Increased Bike Usage Generic Increase in Sustainable Mobility	Positive	12 weeks	No
Máca et al. (2020)	•				Increased Bike Usage	Positive	4 weeks	No
Rogelj et al. (2024)	•	•	•		Generic Increase in Sustainable Mobility	Positive	1 week	No
Weber et al. (2018)	•				Generic Increase in Sustainable Mobility	Positive	1 month for 3 years	Yes
Wunsch et al. (2016)	•				Reduced Public Trasportation Usage Reduced Private Vehicles usage Increased Bike Usage	Positive	6 weeks	No

3.7.3. *Means of transportation*

With regard to the promotion of specific means, the majority of the articles (10 out of 14) did not advocate for a particular mode of transportation. These include walking, bicycling, and public transportation (including bus and train). Only four (4) (Bassanelli et al., 2024a; Bowden & Hellen, 2019; Bucchiarone et al., 2023a; Cellina et al., 2019) studies considered car sharing and carpooling systems as viable options and only Rogelj et al. (2024) explicitly cited micro-mobility means such as scooters, roller blades, or skateboards in the game rules, but they were not included in Table 5, as empirical data on those means of transportation were not reported. The remaining four (4) studies (Biondi et al., 2022; Máca et al., 2020; Weber et al., 2018; Wunsch et al., 2016) focused on promoting the use of bicycles, mainly for urban and home-work commuting.

3.7.4. *Mobility change*

Then, we examined whether the articles documented a variation, either in absolute or relative terms, in the utilization of sustainable transportation modes prior to the intervention or in comparison to a control group. However, it was not possible to merge the data following a meta-analysis procedure, given the great heterogeneity of the evaluation methods and the features selected for evaluation. In greater detail, 11 out of 14 studies indicated positive outcomes associated with the intervention, including an increase in sustainable commuting. The remaining three (3) studies reported mixed outcomes with various motivations: Cellina et al. (2019) argued that the study did not show significant effects in all considered experimental groups, Biondi et al. (2022) noticed that the intervention effects were not sustained after the campaign ended, while Froehlich et al. (2009) could not draw certain conclusions due to the size of the user sample. Focusing on single studies, six (6) out of them reported a general increase in sustainable commuting, without analyzing the effect of each means of transportation separately. Only four (4; Bowden & Hellen, 2019; Kazhamiakin et al., 2015; Wunsch et al., 2016; Ferron et al., 2019) studies reported a decrease in unsustainable commuting. Wunsch et al. (2016) also reported a decrease in public transportation usage, but this result was considered positive by the authors, indeed the study focused on promoting the use of bicycles in the home-work commute at the expense of motorized vehicles. The most detailed article is Ferron et al. (2019), which analyzed the change of habits for each user, in terms of preferred transportation means, before and after the intervention. Two (2) articles do not report any data about variation in commuting habits (Cellina et al., 2019; Froehlich et al., 2009).

3.8. *Scientific reliability*

As described in Section 2, each of the 14 articles was given a scientific reliability score based on quality, following the procedure shown in Fig. 2. Most of the studies demonstrated average study quality (7 papers; Bucchiarone et al., 2023a; Cellina et al., 2019; Ferron et al., 2019; Kazhamiakin et al., 2015; Khoshkangini et al., 2021; Rogelj et al., 2024; Weber et al., 2018), while four (4) showed poor scientific reliability (Biondi et al., 2022; Bowden & Hellen, 2019; Froehlich et al., 2009; Wunsch et al., 2016). Good and excellent scientific reliability were shown by two (2; Bassanelli et al., 2024a; Kazhamiakin et al., 2016) and one (1; Máca et al., 2020) studies, respectively. Only Bassanelli et al. (2024a) used a validated questionnaire for psychological measures.

4. Discussion

In this section, we discuss the findings reported in Section 3 by answering the research questions stated in Section 1.

4.1. RQ1. What eco-sustainable travel modalities are being promoted?

In the majority of articles, users were still afforded the flexibility to select their preferred method of transportation within the context of the game, and there is a significant consensus regarding the classification of transportation modes as sustainable, with different levels of sustainability for each transportation means. However, regrettably, none of the aforementioned studies have documented the rationale behind this classification. Walking, bicycling, and public transportation are widely recognized as sustainable options, while carpooling and car-sharing systems are considered sustainable by a smaller proportion of experts. This may be attributed to the limited availability of these services and the complexity they introduce to trip validation. Regarding studies focusing on a single means of transportation, all of them focused on the bicycle for various motivations, including changing commuting behavior (Biondi et al., 2022; Wunsch et al., 2016) or assessing the effectiveness of this type of mobility campaigns in various urban contexts (Máca et al., 2020; Weber et al., 2018).

4.2. RQ2. How are gamification elements and persuasive strategies combined to promote sustainable transportation?

The game elements identified in the reviewed studies are predominantly focused on the *performance* and *social* dimensions, and this is reflected by a higher frequency of persuasive elements in the incentive and collaboration macro-categories. The widespread use of performance elements such as competition, acknowledgments (badges), points, and objectives suggests that motivating users through goal-oriented, reward-based systems remains central to gameful systems in promoting sustainable transportation. Furthermore, the prominence of competition and social comparison within the social support category of persuasive strategies highlights the value of leveraging social dynamics to promote behavior change (Oyibo & Vassileva, 2017). Studies frequently incorporated leaderboards, rankings, and challenges to stimulate engagement through competition, while some also included cooperation and social learning, albeit to a lesser extent. This emphasis on social comparison strategies aligns with the goal of creating a community of users who can influence one another's transportation choices, making it a potent strategy in gamification design (Oyibo & Vassileva, 2017). According to several studies (Loria et al., 2020; Manero et al., 2016; Tondello et al., 2016; Tondello & Nacke, 2019), players have different characteristics—e.g., cultural background, demographics, goals, gaming experience— that may affect the preferences for different game typologies, mechanics, and how they interact within gameful systems and with other players. Indeed, according to Loria et al. (2020), some players may have some specific characteristics—e.g., preferences for social mechanics, inclination for collaboration, social visibility, consistency, leadership, expertise, charisma, and networking positioning—that positively affect many of their community constituents, improving performances and increasing the retention of behaviors over time.

The extensive reliance on the PBL triad indicates the common practice of using tangible progress markers to sustain user engagement. The high co-occurrence of competition with other elements (e.g., acknowledgment, objectives, and points) reflects the popularity of leaderboards and competitive challenges in these systems. These findings are consistent with the literature, which emphasizes competition as a powerful motivator to drive behavior change (Sepehr & Head, 2013), especially when coupled with objectives that guide user progression (Tondello et al., 2018).

In contrast, *personal*, *ecological*, and *fictional* elements are less frequently applied, with no occurrences of fictional elements identified. This suggests a gap in the use of storytelling or narrative-driven experiences to foster sustainable transportation, mainly due to the inherent nature of these types of gameful systems, as they need to interfere as little as possible with user activities. Additionally, the underrepresentation of ecological elements, such as time pressure, rarity, and chance, indicates that while performance-based systems dominate, the environment in which the game mechanics operate is often underutilized as a tool for engagement. It is noteworthy that the ecological dimension, represented by chance and time pressure, does not find a corresponding persuasive category. It is therefore conceivable that in the current set of gameful systems for sustainable mobility, certain elements have no persuasive consideration, as their functionality is that of entertainment or engagement rather than persuading users. It is in fact this concurrence of motivational, persuasive, entertaining, and engagement-related elements that make a gameful system effective. While this is not the case, in different designs or contexts of application, ecological game elements assume a persuasive connotation. For instance, in e-learning applications (e.g., Duolingo, Kahoot!, and Classcraft) ecological elements are considered important to assess users' progress and maintaining high user motivation in the long term (Toda et al., 2019b; Zecri et al., 2021).

For some persuasive strategies, including social learning, feedback, and reminder, predominantly inherent in the macro-categories of nudging and learning, no consideration was identified within the reported game elements. Specifically, feedback in gameful systems provides information about user performance or actions. It can take various forms, such as points, badges, or notifications. However, persuasive feedback specifically aims to influence user behavior by fostering awareness, motivating actions, or reinforcing desirable outcomes. Indeed, persuasive feedback should be designed to guide users toward predefined goals or benchmarks, and it fosters intrinsic motivation by addressing psychological needs such as competence (showing progress) and autonomy (offering actionable insights) (Ryan & Deci, 2000). It requires tailoring to individual goals, preferences, and behaviors, which demands sophisticated system design and data processing. For example, using a visual representation of reduced carbon emissions tied to user actions connects behavior directly to broader environmental goals, making it more impactful than abstract rewards like points (Fogg, 2002). While feedback in gamification can assume various forms (e.g., points, badges, etc.), the descriptions of the gameful systems in the included papers do not allow a further understanding of the feedback used and whether it assumes a persuasive value. Therefore it is also possible that our evaluation of game elements as *lacking of persuasive feedback* is an underestimation of the true picture.

Overall, this may be due to the inherent difference between nudging and gamification: nudging typically operates in a non-interactive, passive manner by subtly shaping the decision-making environment without requiring active user input, whereas gamification relies on active interaction and engagement through game elements that emphasize performance, progression, and socialization. Nonetheless, these approaches are not mutually exclusive; gamification and nudging can complement each other by integrating subtle behavioral prompts from nudging with interactive game elements, thereby guiding decisions while maintaining motivation and participation (Afshar Jalili, 2020; Byrne et al., 2022; Lieberoth et al., 2018).

Regarding *external rewards*, tangible incentives are a major component across the studies. Monetary rewards, vouchers, and discounts are commonly offered as short-term motivation for participation, indicating that financial incentives continue to play a significant role in bringing participants closer to making these environmentally sustainable transportation choices. According to the Self-Determination Theory, relying heavily on external rewards undermines long-term commitment, which is instead supported by intrinsic motivation (Deci, 1971). External rewards or economic incentives appear to be better suited for encouraging behavior change in (gamified) activities that are mandatory (Ryan et al., 2008), such as in the case of school or work initiatives (e.g., Let's Walk with Rosie the Chicken; Rogelj et al., 2024). On the other hand, in-game rewards are more effective for intrinsically motivated users (Bucchiarone et al., 2023a), who may react negatively to external, tangible, or economic rewards (e.g., Play&Go; Kazhamiakin et al., 2016). It becomes clear that choosing the right type of rewards, based on the context of the application, is essential to provide users with the right motivators.

In summary, it is evident that these systems rely on simple designs, primarily centered on external rewards and the PBL (Points, Badges, and Leaderboards) triad. The utilization of points, badges, and leaderboards is a common feature across most initiatives, along with the presence of external rewards. Performance and social game elements therefore work as the main source of persuasion – and specifically as incentives and collaboration elements – in the gameful systems included in the current review. Other persuasion strategies, on the other hand, do not involve the use of game elements, like in the case of nudging which derives from mechanisms such as notifications and reminders rather than game-like features. Finally, some of the game elements did not work persuasively in the initiatives, such as the ecological elements of time-pressure and chance.

It is important to note that the relationship between game elements and persuasive strategies is based solely on the way game elements were applied in the initiatives included in the current systematic review, rather than a theoretical alignment. Therefore, it is possible that different applications of game elements might lead to a varying relationship among the elements of the two taxonomies. Further research in this area is required.

4.3. RQ3. To what extent are these gameful applications effective in promoting sustainable transportation use?

From the considerations made in Section 4.1, it can be concluded that the main common goal among all studies is to reduce car usage for frequent and short-to-medium-distance travels, almost ignoring long-distance ones. From Table 5 it can be noticed that almost all studies reached this objective, and, if not, the motivations were analyzed or were evident in the articles. Apart from Froehlich et al. (2009), whose results were mainly due to the study typology, other two studies reported mixed outcomes, highlighting two issues in gamification for behavioral change: (i) interventions are all the more ineffective the more the desired behavior is already present in the target population (Cellina et al., 2019); and (ii) the difficulty of prolonging the retention of the behavior after the intervention. These problems may be attributed to superficial game design focused only on game elements and one-size-fits-all strategies, ignoring engagement and motivational aspects, which can be addressed by introducing tailored game elements (Khoshkangini et al., 2021), such as personalized challenges (Kazhamiakin et al., 2016). Indeed, when the system use is enjoyable, the chances of engaging with it in the long-term may be increased (Koivisto & Hamari, 2019).

The emphasis on extrinsic rewards, though effective for short-term behavior modification, raises concerns regarding the sustainability of long-term behavioral change. According to the Self-Determination Theory, while external rewards can serve as strong initial motivators, they may contribute to a decline in intrinsic motivation over time. Consequently, excessive dependence on extrinsic rewards may jeopardize the persistence of behavior change once the rewards are no longer present. This highlights the importance of designing systems that incorporate a balanced approach, utilizing both external and in-game rewards (Ryan et al., 2008). Recent research in environmental psychology shows mixed results on the effectiveness, especially in the long term, of incentives to promote specifically pro-environmental behaviors. Extensive literature presents incentives as an effective tool to promote different kinds of pro-environmental behaviors and financial disincentives/penalties as an effective strategy to prevent environmentally harmful behaviors (Dobson & Bell, 2005; Nordfjærn & Rundmo, 2019; Steg & Vlek, 2009). Meta-analytic efforts demonstrated that financial incentives can lead to a small-to-medium effect ($d = 0.36$) on pro-environmental behaviors when the incentives are used, and even after they are removed ($d = 0.41$; Maki et al., 2016). However, recent works on sustainable transportation and dietary choices found that, while financial incentives led to significant increases in pro-environmental choices—such as cycling or choice for vegetarian meals—, the behavioral changes did not persist after the incentives were removed (Kaiser et al., 2020; Kroker & Lange, 2024). Moreover, research illustrates that while financial incentives, especially cash incentives, are more effective in promoting recycling behavior, non-cash incentives show stronger results in areas like green transportation behaviors (Maki et al., 2016). Taken together, these results suggest that even though incentives can be effective in promoting pro-environmental behaviors, for this category of behaviors their impact is nuanced and might depend on the type of behavior targeted or the type of incentives employed.

Overall, the studies demonstrated that gameful systems can be effective in promoting green transportation, particularly in the short to medium term. However, not all studies showed a corresponding decrease in car use. For these systems to be truly impactful, increases in sustainable transportation should be accompanied by a reduction in more polluting modes of transport. Additionally, only a few systems provided data on the distance traveled or the reduction in CO_2 emissions, with some studies highlighting these as important learning tools to raise awareness about environmental impact and support long-term behavioral change (Bassanelli et al., 2024a; Bucchiarone et al., 2023a). Another key issue was the inconsistency in the metrics used to assess behavioral change. In some cases, trips were manually reported by users, increasing the potential for data inaccuracies, while other studies used automated logging systems. Moreover, many studies relied heavily on self-reported data regarding mobility habits and perceived behavior changes, with only eight (8) providing reliable tracking of distances traveled. The lack of baseline behavioral data further limits the ability to fully assess the effectiveness of these interventions in achieving actual behavioral change.

5. Conclusion

In the current literature review, we analyzed a final pool of 14 papers concerning gamified initiatives to promote green transportation, such as walking, biking, and using other means of public transport. Our analysis provided valuable insights into the interplay between game elements and persuasive strategies within gamified systems aimed at fostering sustainable transportation behaviors. It suggested that performance-based game elements—such as points, badges, leaderboards, and objectives—are frequently aligned with incentive-based persuasion strategies, including rewards, goal-setting, and competition. Social elements like collaboration and comparison were also shown to be effective in leveraging social dynamics to promote behavior change, particularly through competition and social recognition. The high co-occurrence of game elements with persuasion strategies in the incentive and social support categories suggests that gameful systems primarily rely on extrinsic motivators like points and badges to drive behavior change. However, the limited use of personalized and ecological game elements, as well as the under-utilization of persuasive strategies like feedback, social learning, and nudging indicates a gap in the design of these systems. This gap may reduce the potential for long-term behavior retention, as these underutilized strategies are critical for fostering intrinsic motivation and deeper engagement. Moreover, while gameful systems have proven effective in promoting short-term adoption of greener transportation modes, particularly through competition and external rewards, the sustainability of these changes remains uncertain. The findings suggest that the balance between game elements and persuasive strategies is crucial for long-term effectiveness. Systems overly reliant on extrinsic rewards risk losing their impact once these incentives are removed, underscoring the need for designs that incorporate more intrinsic motivators and personalized experiences.

Future research should explore deeper integration between game elements and a broader range of persuasive strategies, particularly those that promote intrinsic motivation and long-term behavior change. By enhancing the personalization, ecological relevance, and emotional engagement of gamified interventions, designers can create more effective and sustainable systems to encourage green transportation behaviors. Ultimately, while the interaction between game elements and persuasion strategies has shown promising results, refining this relationship will be key to ensuring lasting success in promoting sustainable mobility.

5.1. Research agenda

Gameful systems offer a promising approach to promoting sustainable transportation by integrating game elements and persuasive strategies to influence behavior. This section outlines a comprehensive research agenda to address the key challenges and opportunities identified in this review. The agenda is designed to guide future research efforts aimed at refining the interplay between game elements and persuasion techniques, with a focus on fostering long-term, eco-friendly transportation habits, improving studies' quality and results reliability. Through this targeted research agenda, we seek to advance the field of gamification to foster green transportation. We propose multiple research challenges (**RC**) for each point in the future agenda.

5.1.1. Future agenda point 1 - integrating research-based alignment between psychological determinants and pro-environmental behaviors into gameful systems

Gameful systems designed to promote behaviors aimed at mitigating climate change have often failed to consider the peculiarities of these types of behaviors in terms of scope of impact, level of complexity, need for collective involvement, and temporal horizon (e.g., Gifford, 2011; Milinski et al., 2008; Nyborg et al., 2016; Steg & Vlek, 2009; Sterman, 2011; Van der Linden, 2015; Whitmarsh, 2009), and therefore the necessity of a distinct approach to promoting them. Extensive research efforts in the field of environmental psychology mapped the psychological drivers of pro-environmental behavior (for reviews and meta-analyses see: Bamberg & Möser, 2007; Gifford, 2011; De Groot, 2018) and current research proposes a road map to increase the effectiveness of behavioral strategies to promote pro-environmental behaviors by aligning them with specific psychological determinants (van Valkengoed et al., 2022). Future studies should leverage interdisciplinary collaborations (**RC1**), implement theory-driven gamified systems personalizing game elements (e.g., feedback, challenges, and goals) based on preferred personal psychological drivers (**RC2**), and test this framework's effectiveness in producing long-term mitigation of climate change (**RC3**).

5.1.2. Future agenda point 2 - identifying the effectiveness of game elements and their combinations

The findings of this review highlight that most gameful systems rely heavily on a limited subset of game elements—particularly performance and social elements (e.g., points, badges, leaderboards). However, there is a lack of detailed analysis regarding the individual and combined effectiveness of these elements in driving long-term behavioral change (Domínguez et al., 2013; Koivisto & Hamari, 2019; Seaborn & Fels, 2015). For example, while competition is a commonly used motivator, its overuse may alienate users who prefer collaborative or non-competitive approaches. Similarly, the underrepresentation of ecological elements (e.g., time pressure, chance) and the complete absence of fictional elements suggest missed opportunities for diverse engagement strategies. To address these gaps, future research should systematically evaluate the role of individual game elements across contexts, assessing their contributions to key outcomes such as motivation, engagement, persuasion, and long-term retention of sustainable mobility behaviors (**RC4**). In the context of sustainable mobility, user characteristics are particularly relevant in shaping how game elements are perceived and engaged with. For example, individuals with high risk tolerance may be more willing to try time-sensitive challenges, such as earning rewards for using alternative routes or public transport during off-peak hours, while risk-averse users may prefer predictable incentives like accruing points for consistent use of eco-friendly modes of transportation (Aguiar Castillo, Rufo Torres, De Saa Pérez, & Pérez Jiménez, 2018). Similarly, social orientation can significantly influence engagement (Gini et al., 2023). Users with a competitive orientation (e.g., *Killers* in the Hexad framework; Tondello et al., 2016) might respond well to leaderboards that rank users based on their carbon footprint reduction or the number of kilometers traveled using sustainable modes (e.g., biking, walking, or public transport). Conversely, users with a preference for collaboration (e.g., *Socializers* or *Philanthropists*) could benefit from team-based goals, such as neighborhood challenges to collectively achieve a target reduction in car usage. Additionally, environmental attitudes play a crucial role: users already motivated by sustainability goals may prefer elements that emphasize ecological impacts, such as visualizing the CO_2 saved from their actions, whereas less motivated users might require extrinsic rewards, such as discounts on services or public recognition.

Designing a system that caters to all user characteristics is inherently complex, as tailoring to one profile risks disengaging others. Therefore, future studies should explore how to combine game elements strategically to create balanced systems that engage diverse user types in promoting sustainable mobility (**RC5**). For instance, integrating both competitive and cooperative mechanics—such as team-based competitions—may appeal to a broader audience by leveraging the strengths of multiple game elements simultaneously. Alternatively, the system may adapt its mechanics in real-time, offering appropriate game elements to different users, similarly to challenges in Khoshkangini et al. (2021) but on a higher and broader level, involving not only the difficulty, frequency, and other parameters of game elements but also their type and design. This approach would ensure that gameful systems foster engagement across varying psychological characteristics, supporting the goal of promoting long-term sustainable behaviors.

5.1.3. Future agenda point 3 - enhancing data reliability in gamification studies

This review, in line with other references in the gamification literature (Bassanelli et al., 2022, 2024a; Koivisto & Hamari, 2019; Seaborn & Fels, 2015), revealed significant methodological limitations in gamification studies, particularly in data collection and measurement approaches. For example, many studies relied on self-reported data for mobility habits and behavioral changes, introducing potential biases and inaccuracies. Furthermore, the lack of baseline behavioral data and standardized metrics for evaluating behavior change hinders the ability to compare studies and assess the true impact of interventions. Only eight studies in this review provided reliable tracking of distances traveled, and few accounted for CO_2 emission reductions, despite their importance in assessing environmental outcomes. To address these limitations, future research must prioritize the adoption of standardized and validated measurement instruments for assessing engagement, motivation, and behavioral change (**RC6**). Pre-post study designs should be more widely implemented to establish baseline behaviors and verify the effectiveness of interventions over time. Automated and objective tracking methods, such as GPS-based logging or integrated app-based systems, should replace or complement self-reported data to improve accuracy. Additionally, efforts should focus on developing shared frameworks for evaluating both short-term engagement and long-term retention of sustainable behaviors, enabling more robust comparisons across studies and fostering meta-analytic research.

5.2. Limitations of this review

In this review, we have followed the suggestions by Chandler et al. (2019) to ensure its quality, in terms of both rigor and relevance. The review procedure has been described in detail to ensure the clarity of the process, and to enable replication of the procedure. Furthermore, the goals of the review have been explicitly stated in order to ensure the suitability of the chosen methods for the expressed goals. However, the chosen perspective and methods limit the review in different ways. The present review focuses on the phenomenon of gamification on an overview level. There is evidently variation, for example in how gamification has been defined in the different publications, or how the various game elements and persuasive strategies have been defined and implemented. Given the high divergence in the elements reported in the studies, and especially in the publication domain (different venues need different content), it was not possible to go into further detail about individual studies. In the coding and analysis processes, some abstraction has obviously been necessary, which has consequently caused some details of the studies to be lost. However, we followed the suggestions by Webster and Watson (2002) to structure the review and organize the concept matrices (Tables) to ensure clarity of data. Furthermore, the literature search was limited to the Scopus database. While we are confident of the comprehensiveness of our literature search, it is nevertheless possible that some publications have been missed due to either not being among the indexed venues, or due to indexing errors within the databases (as is the case with any review study). In any case, the potential number of missed publications is likely to be meager, and their inclusion is likely to affect the results of the review very negligibly. Future reviews could consider a multi-database approach to mitigate these limitations, ensuring broader coverage and representation of the literature, and extend the literature search to other languages besides English.

CRediT authorship contribution statement

Simone Bassanelli: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Riccardo Belliato:** Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation. **Federico Bonetti:** Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Methodology, Investigation, Formal analysis, Data curation. **Martina Vacondio:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Investigation, Formal analysis. **Federica Gini:** Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Lorenzo Zambotto:** Methodology, Formal analysis, Data curation. **Annapaola Marconi:** Writing – review & editing, Writing – original draft, Validation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actpsy.2024.104687.

References

Afshar Jalili, Y. (2020). I rather share my knowledge: Applying gamification approach and nudge theory to develop an incentive system. *VINE Journal of Information and Knowledge Management Systems, 50*(2), 203–217.
Aguiar Castillo, L., Rufo Torres, J., De Saa Pérez, P., & Pérez Jiménez, R. (2018). How to encourage recycling behaviour? The case of wasteapp: A gamified mobile application. *Sustainability, 10*(1544), 1–20.
Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes, 50*(2), 179–211.
Alahäivälä, T., & Oinas-Kukkonen, H. (2016). Understanding persuasion contexts in health gamification: A systematic analysis of gamified health behavior change support systems literature. *International Journal of Medical Informatics, 96*, 62–70.
Anagnostopoulou, E., Bothos, E., Magoutas, B., Schrammel, J., & Mentzas, G. (2018). Persuasive technologies for sustainable mobility: State of the art and emerging trends. *Sustainability, 10*(7), 2128.
Avril, E., Picco, A., Lescarret, C., Lemercier, C., Arguel, A., & Caroux, L. (2024). Gamification in the transport and mobility sector: A systematic review. *Transportation Research Part F: Traffic Psychology and Behaviour, 104*, 286–302.
Bamberg, S., & Möser, G. (2007). Twenty years after Hines, Hungerford, and Tomera: A new meta-analysis of psycho-social determinants of pro-environmental behaviour. *Journal of Environmental Psychology, 27*(1), 14–25.
Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Prentice-Hall.
Bassanelli, S., Bucchiarone, A., & Gini, F. (2024a). Gamidoc: The importance of designing gamification in a proper way. *IEEE Transactions on Games*. Advance online publication.
Bassanelli, S., Gini, F., Bucchiarone, A., & Marconi, A. (2024b). Promoting green mobility through gamified transportation campaigns. In *GamiFIN* (pp. 183–193).
Bassanelli, S., Vasta, N., Bucchiarone, A., & Marconi, A. (2022). Gamification for behavior change: A scientometric review. *Acta Psychologica, 228*, Article 103657.
Biondi, B., Romanowska, A., & Birr, K. (2022). Impact evaluation of a cycling promotion campaign using daily bicycle counters data: The case of cycling may in Poland. *Transportation Research Part A: Policy and Practice, 164*, 337–351.
Björklund, M. (2011). Influence from the business environment on environmental purchasing—Drivers and hinders of purchasing green transportation services. *Journal of Purchasing and Supply Management, 17*(1), 11–22.
Bland, J. M., & Altman, D. G. (2000). The odds ratio. *Bmj, 320*(7247), 1468.
Boncu, S., Candel, O.-S., & Popa, N. L. (2022). Gameful green: A systematic review on the use of serious computer games and gamified mobile apps to foster pro-environmental information, attitudes and behaviors. *Sustainability, 14*(16), 10400.
Boutron, I., Page, M. J., Higgins, J. P., Altman, D. G., Lundh, A., Hróbjartsson, A., & Group, C. B. M. (2019). Considering bias and conflicts of interest among the included studies. In *Cochrane handbook for systematic reviews of interventions* (pp. 177–204).
Bowden, H., & Hellen, G. (2019). A data driven, segmentation approach to real world travel behaviour change, using incentives and gamification. In *Towards user-centric transport in Europe: Challenges, solutions and collaborations* (pp. 173–182).
Braun, V., & Clarke, V. (2021). One size fits all? What counts as quality practice in (reflexive) thematic analysis? *Qualitative Research in Psychology, 18*(3), 328–352.
Bucchiarone, A., Bassanelli, S., & Marconi, A. (2023a). How to foster sustainable behaviors through multi-campaigns rewarding mechanisms: The air-break experience. *Sustainability, 15*(6), 5198.
Bucchiarone, A., Savary-Leblanc, M., Le Pallec, X., Cicchetti, A., Gerard, S., Bassanelli, S., … Marconi, A. (2023b). Gamifying model-based engineering: The papygame experience. *Software and Systems Modeling, 22*(4), 1369–1389.
Byrne, J., Ito, T., & Furuyabu, M. (2022). Digitally nudged learning: A nudged gamification study intervention. *International Journal of Emerging Technologies in Learning (iJET), 17*(12), 42–60.
Cellina, F., Bucher, D., Mangili, F., Veiga Simão, J., Rudel, R., & Raubal, M. (2019). A large scale, app-based behaviour change experiment persuading sustainable mobility patterns: Methods, results and lessons learnt. *Sustainability, 11*(9), 2674.
Chandler, J., Cumpston, M., Li, T., Page, M. J., & Welch, V. (2019). *Cochrane handbook for systematic reviews of interventions*. Hoboken: Wiley.
Chandra, F. W., Sukmaningsih, D. W., & Kristian, W. (2024). A systematic literature review of gamification in public transportation. In *2024 IEEE 14th symposium on computer applications & industrial electronics (ISCAIE)* (pp. 407–412). IEEE.
Chou, Y.-K. (2019). *Actionable gamification: Beyond points, badges, and leaderboards*. Packt Publishing Ltd.
Cialdini, R. B., & Goldstein, N. J. (2004). The science of persuasion. *Annual Review of Psychology, 55*, 591–621.
Cialdini, R. B., & Trost, M. R. (1998). Social influence: Social norms, conformity, and compliance. *The handbook of social psychology, 2*, 151–192.
Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers & Education, 59*(2), 661–686.
Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. Harper & Row.
De Groot, J. I. (2018). *Environmental psychology: An introduction*. John Wiley & Sons.
Deci, E. L. (1971). Effects of externally mediated rewards on intrinsic motivation. *Journal of Personality and Social Psychology, 18*(1), 105.
Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*. Springer Science & Business Media.
Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness: Defining "gamification". In *Proceedings of the 15th international academic MindTrek conference: Envisioning future media environments* (pp. 9–15).
Dobson, A., & Bell, D. (2005). *Environmental citizenship*. Mit Press.

Domínguez, A., Saenz-de Navarrete, J., De-Marcos, L., Fernández-Sanz, L., Pagés, C., & Martínez-Herráiz, J.-J. (2013). Gamifying learning experiences: Practical implications and outcomes. *Computers & Education, 63*, 380–392.

Ferron, M., Loria, E., Marconi, A., & Massa, P. (2019). Play&go, an urban game promoting behaviour change for sustainable mobility. *Interaction Des. Archit. J, 40*, 24–25.

Fogg, B. J. (2002). Persuasive technology: Using computers to change what we think and do. *Ubiquity, 2002*(December), 2.

Froehlich, J., Dillahunt, T., Klasnja, P., Mankoff, J., Consolvo, S., Harrison, B., & Landay, J. A. (2009). Ubigreen: Investigating a mobile tool for tracking and supporting green transportation habits. In *Proceedings of the sigchi conference on human factors in computing systems* (pp. 1043–1052).

Gallego-Durán, F. J., Villagrá-Arnedo, C. J., Satorre-Cuerda, R., Compañ-Rosique, P., Molina-Carmona, R., & Llorens-Largo, F. (2019). A guide for game-design-based gamification. In *, 6. Informatics* (p. 49). MDPI.

Gifford, R. (2011). The dragons of inaction: Psychological barriers that limit climate change mitigation and adaptation. *American Psychologist, 66*(4), 290.

Gini, F., Bassanelli, S., & Bucchiarone, A. (2023). The role of game modality in the outcomes of gamification: A research agenda. *GamiFIN*, 67–78.

Hamari, J. (2019). *Gamification* (pp. 1–3). The Blackwell encyclopedia of sociology.

Hamari, J., Koivisto, J., & Pakkanen, T. (2014). Do persuasive technologies persuade?-a review of empirical studies. In *, 9. Persuasive technology: 9th international conference, PERSUASIVE 2014, Padua, Italy, May 21–23, 2014. Proceedings* (pp. 118–136). Springer.

Huang, C.-K., Neylon, C., Brookes-Kenworthy, C., Hosking, R., Montgomery, L., Wilson, K., & Ozaygen, A. (2020). Comparison of bibliographic data sources: Implications for the robustness of university rankings. *Quantitative Science Studies, 1* (2), 445–478.

Huber, M. Z., & Hilty, L. M. (2015). Gamification and sustainable consumption: Overcoming the limitations of persuasive technologies. In *ICT innovations for sustainability* (pp. 367–385). Springer.

Hunicke, R., LeBlanc, M., & Zubek, R. (2004). Mda: A formal approach to game design and game research. In *, 4. Proceedings of the AAAI workshop on challenges in game AI* (p. 1722). San Jose: CA.

Huotari, K., & Hamari, J. (2017). A definition for gamification: Anchoring gamification in the service marketing literature. *Electronic Markets, 27*(1), 21–31.

Johnson, D., Deterding, S., Kuhn, K.-A., Staneva, A., Stoyanov, S., & Hides, L. (2016). Gamification for health and wellbeing: A systematic review of the literature. *Internet Interventions, 6*, 89–106.

Kaiser, F. G., Henn, L., & Marschke, B. (2020). Financial rewards for long-term environmental protection. *Journal of Environmental Psychology, 68*, Article 101411.

Kaptein, M., De Ruyter, B., Markopoulos, P., & Aarts, E. (2012). Adaptive persuasive systems: A study of tailored persuasive text messages to reduce snacking. *ACM Transactions on Interactive Intelligent Systems (TiiS), 2*(2), 1–25.

Kazhamiakin, R., Marconi, A., Martinelli, A., Pistore, M., & Valetto, G. (2016). A gamification framework for the long-term engagement of smart citizens. In *2016 IEEE international smart cities conference (ISC2)* (pp. 1–7). IEEE.

Kazhamiakin, R., Marconi, A., Perillo, M., Pistore, M., Valetto, G., Piras, L., Avesani, F., & Perri, N. (2015). Using gamification to incentivize sustainable urban mobility. In *2015 IEEE first international smart cities conference (ISC2)* (pp. 1–6). IEEE.

Khoshkangini, R., Valetto, G., Marconi, A., & Pistore, M. (2021). Automatic generation and recommendation of personalized challenges for gamification. *User Modeling and User-Adapted Interaction, 31*, 1–34.

Koivisto, J., & Hamari, J. (2019). The rise of motivational information systems: A review of gamification research. *International Journal of Information Management, 45*, 191–210.

Krath, J., Schürmann, L., & Von Korflesch, H. F. (2021). Revealing the theoretical basis of gamification: A systematic review and analysis of theory in research on gamification, serious games and game-based learning. *Computers in Human Behavior, 125*, Article 106963.

Krath, J., & Von Korflesch, H. F. (2021). Designing gamification and persuasive systems: A systematic literature review. *GamiFIN*, 100–109.

Kroker, V., & Lange, F. (2024). Financial and prosocial incentives promote pro-environmental behavior in a consequential laboratory task. *Journal of Environmental Psychology, 96*, Article 102331.

Lieberoth, A., Jensen, N. H., & Bredahl, T. (2018). Selective psychological effects of nudging, gamification and rational information in converting commuters from cars to buses: A controlled field experiment. *Transportation Research Part F: Traffic Psychology and Behaviour, 55*, 246–261.

Llagostera, E. (2012). *On gamification and persuasion* (pp. 2–4). Rio de Janeiro, Brazil: Proceedings of the SBGames.

Locke, E. A., & Latham, G. P. (2002). Building a practically useful theory of goal setting and task motivation: A 35-year odyssey. *American Psychologist, 57*(9), 705–717.

Loria, E., Pirker, J., Drachen, A., & Marconi, A. (2020). Do influencers influence?–analyzing players' activity in an online multiplayer game. In *2020 IEEE conference on games (CoG)* (pp. 120–127). IEEE.

Máca, V., Ščasnỳ, M., Zvěřinová, I., Jakob, M., & Hrnčíř, J. (2020). Incentivizing commuter cycling by financial and non-financial rewards. *International Journal of Environmental Research and Public Health, 17*(17), 6033.

Maki, A., Burns, R. J., Ha, L., & Rothman, A. J. (2016). Paying people to protect the environment: A meta-analysis of financial incentive interventions to promote proenvironmental behaviors. *Journal of Environmental Psychology, 47*, 242–255.

Manero, B., Torrente, J., Fernandez-Vara, C., & Fernandez-Manjon, B. (2016). Investigating the impact of gaming habits, gender, and age on the effectiveness of an educational video game: An exploratory study. *IEEE Transactions on Learning Technologies, 10*(2), 236–246.

Miao, H., Saleh, M. S. M., & Zolkepli, I. A. (2022). Gamification as a learning tool for pro-environmental behavior: A systematic review. *Malaysian Journal of Social Sciences and Humanities (MJSSH), 7*(12), e001881.

Milinski, M., Sommerfeld, R. D., Krambeck, H.-J., Reed, F. A., & Marotzke, J. (2008). The collective-risk social dilemma and the prevention of simulated dangerous climate change. *Proceedings of the National Academy of Sciences, 105*(7), 2291–2294.

Nordfjærn, T., & Rundmo, T. (2019). Acceptance of disincentives to driving and pro-environmental transport intentions: The role of value structure, environmental beliefs and norm activation. *Transportation, 46*(6), 2381–2396.

Nyborg, K., Anderies, J. M., Dannenberg, A., Lindahl, T., Schill, C., Schlüter, M., … Carpenter, S. (2016). Social norms as solutions. *Science, 354*(6308), 42–43.

Onwuegbuzie, A. J. (2003). Effect sizes in qualitative research: A prolegomenon. *Quality and Quantity, 37*, 393–409.

Onwuegbuzie, A. J. (2022). Towards full (er) integration in mixed methods research: The role of canonical correlation analysis for integrating quantitative and qualitative data. *PUBLICACIONES, 52*(2), 11–34.

Orji, R. (2014). *Design for behaviour change: A model-driven approach for tailoring persuasive technologies*. PhD thesis,. University of Saskatchewan.

Orji, R., Mandryk, R. L., Vassileva, J., & Gerling, K. M. (2013). Tailoring persuasive health games to gamer type. In *Proceedings of the sigchi conference on human factors in computing systems* (pp. 2467–2476).

Orji, R., Tondello, G. F., & Nacke, L. E. (2018). Personalizing persuasive strategies in gameful systems to gamification user types. In *Proceedings of the 2018 CHI conference on human factors in computing systems* (pp. 1–14).

Orji, R., Vassileva, J., & Mandryk, R. L. (2014). Modeling the efficacy of persuasive strategies for different gamer types in serious games for health. *User Modeling and User-Adapted Interaction, 24*, 453–498.

Orosz, G., Farkas, D., & Roland-Lévy, C. (2013). Are competition and extrinsic motivation reliable predictors of academic cheating? *Frontiers in Psychology, 4*, 87.

Oyibo, K. (2024). Comtech: Towards a unified taxonomy of persuasive techniques for persuasive technology design. *Computers in Human Behavior Reports, 14*, Article 100372.

Oyibo, K., & Vassileva, J. (2017). Investigation of social predictors of competitive behavior in persuasive technology. In *, 12. Persuasive technology: Development and implementation of personalized technologies to change attitudes and behaviors: 12th international conference, PERSUASIVE 2017, Amsterdam, the Netherlands, April 4–6, 2017, proceedings* (pp. 279–291). Springer.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., … Brennan, S. E. (2021). The prisma 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*.

Paiva, R., Bittencourt, I. I., Tenório, T., Jaques, P., & Isotani, S. (2016). What do students do on-line? Modeling students' interactions to improve their learning experience. *Computers in Human Behavior, 64*, 769–781.

Paré, G., Trudel, M.-C., Jaana, M., & Kitsiou, S. (2015). Synthesizing information systems knowledge: A typology of literature reviews. *Information & Management, 52*(2), 183–199.

Petersen, S. A., Petersen, I., & Ahcin, P. (2020). Smiling earth—Raising awareness among citizens for behaviour change to reduce carbon footprint. *Energies, 13*(22), 5932.

Prochaska, J. O., & Velicer, W. F. (1997). The transtheoretical model of health behavior change. *American Journal of Health Promotion, 12*(1), 38–48.

Reindl, A., Juppe, M., Graf, P., Putz-Egger, L.-M., & Schildorfer, W. (2023). The use of gamification to change commuters mobility behavior: A literature review. *GamiFIN*, 37–46.

Rogelj, B., Planinc, T. R., Repe, B., & Klun, M. I. (2024). Education for sustainable mobility in Slovenia: Using gamification to influence the travel habits of children. *European Journal of Geography, 15*(2), 81–93.

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist, 55* (1), 68–78.

Ryan, R. M., Patrick, H., Deci, E. L., & Williams, G. C. (2008). Facilitating health behaviour change and its maintenance: Interventions based on self-determination theory. *European Health Psychologist, 10*(1), 2–5.

Ryan, R. M., & Reeve, J. (2021). Intrinsic motivation, psychological needs, and competition: A self-determination theory analysis. *The Oxford Handbook of the Psychology of Competition*, 240–264.

Seaborn, K., & Fels, D. I. (2015). Gamification in theory and action: A survey. *International Journal of Human-Computer Studies, 74*, 14–31.

Sepehr, S., & Head, M. (2013). Competition as an element of gamification for learning: An exploratory longitudinal investigation. In *Proceedings of the first international conference on gameful design, research, and applications* (pp. 2–9).

Shah, K. J., Pan, S.-Y., Lee, I., Kim, H., You, Z., Zheng, J.-M., & Chiang, P.-C. (2021). Green transportation for sustainability: Review of current barriers, strategies, and innovative technologies. *Journal of Cleaner Production, 326*, Article 129392.

Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of Environmental Psychology, 29*(3), 309–317.

Sterman, J. D. (2011). Communicating climate change risks in a skeptical world. *Climatic Change, 108*, 811–826.

Sun, S., Pan, W., & Wang, L. L. (2010). A comprehensive review of effect size reporting and interpreting practices in academic journals in education and psychology. *Journal of Educational Psychology, 102*(4), 989.

Takayama, C., Lehdonvirta, V., Shiraishi, M., Washio, Y., Kimura, H., & Nakajima, T. (2009). Ecoisland: A system for persuading users to reduce co2 emissions. In *2009 software technologies for future dependable distributed systems* (pp. 59–63). IEEE.

Toda, A. M., Klock, A. C., Oliveira, W., Palomino, P. T., Rodrigues, L., Shi, L., … Cristea, A. I. (2019a). Analysing gamification elements in educational environments using an existing gamification taxonomy. *Smart Learning Environments, 6*(1), 1–14.

Toda, A. M., Oliveira, W., Klock, A. C., Palomino, P. T., Pimenta, M., Gasparini, I., Shi, L., Bittencourt, I., Isotani, S., and Cristea, A. I. (2019b). A taxonomy of game elements for gamification in educational contexts: Proposal and evaluation. In 2019 IEEE 19th international conference on advanced learning technologies (ICALT), volume 2161, pages 84–88. IEEE.

Tondello, G., Premsukh, H., & Nacke, L. (2018). A theory of gamification principles through goal-setting theory. In *Proceedings of the 51st Hawaii international conference on system sciences, page 1118*. Hawaii International Conference on System Sciences.

Tondello, G. F., & Nacke, L. E. (2019). Player characteristics and video game preferences. In *Proceedings of the annual symposium on computer-human interaction in play* (pp. 365–378).

Tondello, G. F., Wehbe, R. R., Diamond, L., Busch, M., Marczewski, A., & Nacke, L. E. (2016). The gamification user types hexad scale. In *Proceedings of the 2016 annual symposium on computer-human interaction in play* (pp. 229–243).

van Valkengoed, A. M., Abrahamse, W., & Steg, L. (2022). To select effective interventions for pro-environmental behaviour change, we need to consider determinants of behaviour. *Nature Human Behaviour, 6*(11), 1482–1492.

Van De Schoot, R., De Bruin, J., Schram, R., Zahedi, P., De Boer, J., Weijdema, F., … Ferdinands, G. (2021). An open source machine learning framework for efficient and transparent systematic reviews. *Nature Machine Intelligence, 3*(2), 125–133.

Van der Linden, S. (2015). The social-psychological determinants of climate change risk perceptions: Towards a comprehensive model. *Journal of Environmental Psychology, 41*, 112–124.

Vesco, A. (2015). *Handbook of research on social, economic, and environmental sustainability in the development of smart cities*. IGI Global.

Wallius, E., & Hamari, J. (2020). Motivational technology as a way of enhancing transportation safety: A systematic review of previous research. In *Gamifin* (pp. 92–102).

Wallius, E., & Köse, D. B. (2023). Gamified eco-driving: A systematic literature review. In *GamiFIN conference* (pp. 184–191). CEUR-WS.

Wang, W., Gan, H., Wang, X., Lu, H., & Huang, Y. (2022). Initiatives and challenges in using gamification in transportation: A systematic mapping. *European Transport Research Review, 14*(1), 41.

Weber, J., Azad, M., Riggs, W., & Cherry, C. R. (2018). The convergence of smartphone apps, gamification and competition to increase cycling. *Transportation Research Part F: Traffic Psychology and Behaviour, 56*, 333–343.

Webster, J., & Watson, R. T. (2002). Analyzing the past to prepare for the future: Writing a literature review. *MIS Quarterly, 26*(2), 13–23.

Werbach, K., & Hunter, D. (2012). *For the win* (vol. 51). Philadelphia: Wharton Digital Press.

Whitmarsh, L. (2009). Behavioural responses to climate change: Asymmetry of intentions and impacts. *Journal of Environmental Psychology, 29*(1), 13–23.

Winkler, L., Pearce, D., Nelson, J., & Babacan, O. (2023). The effect of sustainable mobility transition policies on cumulative urban transport emissions and energy demand. *Nature Communications, 14*(1), 2357.

Wunsch, M., Stibe, A., Millonig, A., Seer, S., Chin, R. C., & Schechtner, K. (2016). Gamification and social dynamics: insights from a corporate cycling campaign. In *, 4. Distributed, ambient and pervasive interactions: 4th international conference, DAPI 2016, held as part of HCI international 2016, Toronto, ON, Canada, July 17–22, 2016, proceedings* (pp. 494–503). Springer.

Zecri, E., Ouzzif, M., & El El Haddioui, I. (2021). Study of the use of gamification elements in e-learning applications. In *Proceedings of the 4th international conference on networking, information systems & security* (pp. 1–5).

Zichermann, G. (2011). *Gamification by design: Implementing game mechanics in web and mobile apps*. Oreill y & Associates Inc.