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A Survey on the Design of Gamified Systems for Energy and Water Sustainability

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Abstract: In a world affected by the constant growth and concentration of the population in urban areas, the problem of preserving natural resources has become a priority. A promising approach to resource conservation is demand management, i.e., the ability to positively influence the behaviour of the population towards more sustainable consumption. Information and Communication Technology (ICT) tools have shown a great potential in influencing consumers' behaviour, which could be exploited for the common good. However, the design of so-called persuasive systems for environmental purposes is a challenging task, because it cannot be based solely on the utilitarian motivation of users, but must be able to trigger a broader range of engagement factors deeply rooted in the human psychology. In this paper, we review the main design principles and models at the base of a class of persuasive system that exploits gamification and Games with a Purpose (GWAPs) to engage users towards sustainability; we identify the most commonly used incentive mechanisms for inducing behavioural changes; and present a selection of gamified systems for energy and water conservation. From such a survey, we distill design guidelines to be applied in the design of demand management socio-technical systems.

Keywords: behavioral change system; Human Computation; gamification; serious games; persuasive games; energy; water

1. Introduction

Socio-technical systems intended to induce behavioural changes in the usage of common goods, such as energy and water, are often referred to as persuasive systems [1], or behavioural change support systems (BCSS) [2]. In [1], persuasive systems are defined as interactive systems designed for attitude and/or behaviour change, which closely resembles the definition of a BCSS, i.e., "a socio-technical information system with psychological and behavioural outcomes designed to form, alter or reinforce attitudes, behaviours or an act of complying without using coercion or deception" [2] (p. 1225). As persuasive systems focus on a voluntary change of behaviour, their design requires a reflection on the underlying psychological processes the systems seeks to influence [3]. This includes an analysis of the motivational drivers of the user and of the specific determinants of the behaviour one seeks to change. Indeed, for any behavioural change to happen, one must be capable of performing actions, have the opportunity to do so, and be motivated to act [4]. Motivation is particularly important in contexts involving the conservation of natural resources or environment protection, such as in water or energy saving. In general, the consequences of water/energy saving actions are not immediately visible to the consumers due to the low frequency of billing and to the invisibility of consumed energy. In addition, the positive resulting environmental impact achieved remains out of sight. Additionally, while in households the financial incentive to save water/energy is quite strong as cost per m^3 (respectively, kWh) is relatively high, in other contexts where the consumer is not responsible for the water/energy bill, this incentive falls short (e.g., in schools or public buildings). Consequently, water/energy consumers need a strong motivation to engage in saving actions, both at home and in public spaces, such as in the workplace or at school.

Motivation theories and persuasive system design principles are keys for the development of a wide class of digital applications directed to the general public, which must engage their users for the purpose of fulfilling a given task or inducing behavioural change (e.g., reducing water/energy consumption). The operationalisation of motivation theories and persuasive system design principles into the development of specific systems capable of engaging users is an active research subject of the Human Computation field, broadly defined as the area that studies the development of socio-technical systems where humans and computers cooperate to address a task or achieve a goal. This novel and broad class of socio-technical systems comprises gamified applications and games with a purpose (GWAPs), in which the well-proven mechanisms of games are exploited to drive engagement and retention.

In this overview paper, after introducing gamified systems and GWAPs (Section 2), we review their main design principles and models and summarise the most commonly used incentive mechanisms aimed at inducing behavioural changes (Section 3). Then, we overview a selection of gamified systems for energy and water sustainability (Section 4) and distill design guidelines to be applied by researchers and practitioners in the field (Section 5). Our conclusions are offered in Section 6.

2. Human Computation, Gamification and Games with a Purpose

The new computation paradigm of Human Computation [5] is defined as an approach to digital system development in which interactions of users and among users are harnessed to help in the accomplishment of tasks or attainment of a goal. According to Quinn and Bederson [6], a system belongs to the area of Human Computation when human collaboration is facilitated by the computer system and not by the initiative of the participants. The common baseline of the approaches that exploit humans in computing is the intelligent partition of functionalities between machines and human beings: networked machines are used for task splitting, coordination, communication, goal attainment verification and result collection; humans participate with their intuition, behaviour and decision-making power [7].

Human Computation can assume a variety of forms, according to the scale at which humans are engaged, the tasks they are called to solve, and the incentive mechanisms that are designed to foster participation [6]. Several principal approaches can be recognised:

- *Gamified applications*: These are conventional application addressing a business goal (e.g., water or energy billing), extended with features normally found in games, to promote user's engagement and activity [8].
- *Games with a Purpose (GWAPs)*: GWAPs focus on exploiting the natural attractiveness of games to recruit people to solve complex problems that involve human intelligence [9,10]. They embed a problem-solving task into an enjoyable user experience, which can be conducted by individuals or groups. Several game design paradigms have been studied [10] and the mechanics of users' involvement has begun to be modeled formally [11]. GWAPs have addressed such tasks as adding descriptive tags and recognising objects in images, checking the output of Optical Character Recognition (OCR) for correctness, helping protein folding and multiple sequence alignment algorithms in molecular biology and comparative genomic research [12].

- *Social Mobilisation*: This approach addresses problems with time constraints, where the efficiency of task spreading and of solution finding is essential. The DARPA Network Challenge [13] is a notable example: the teams had to determine the coordinates of ten red weather balloons placed at unknown locations in the United States. The winning team employed a novel recursive incentive mechanism that permitted them to locate all balloons in less than nine hours. Applications are also found in safety critical sectors, such as civil protection [14] and disease control [15].
- *Human sensors*: These approaches exploit the diffusion of mobile terminals and the fact that more and more of these devices are equipped with sensors [16,17] to trigger the real-time collection of data to realise time-critical decision support systems and emergency management. Application areas include pollution monitoring [18], traffic and road condition control [19,20], and earthquake monitoring [21]. Human behavioural patterns in the usage of mobile phones have also been exploited to detect levels of activity to examine the effects of the spreading of seasonal diseases [22].
- *Crowdsourcing*: This approach manages the assignment of work to an open community of executors [23], typically with a Web interface that can be used by work providers, who can specify the piece of work they need (e.g., collecting addresses of business companies, classifying products by category, geo-referencing location names, etc.); and by work performers, who can enrol, declare their skills, and take up and perform a piece of work. In addition to the web interface, some platforms offer Application Programming Interfaces (APIs), whereby third parties can integrate the distributed work management functionality into their custom applications. Examples of crowdsourcing solutions are Amazon Mechanical Turk [24] and Microtask.com [25]. Application areas are the most varied: speech transcription, translation, form filling, content tagging, and user evaluation studies are a few examples.

Human Computation can be applied to the management of environmental resources, such as energy and water, which are by definition shared and distributed, and demand new approaches based on the contribution of individuals. Traditionally, the management of natural resources has been performed with a centralised approach, based on static policies (usually coded as laws and regulations), thus neglecting the intrinsically dynamic nature of both the systems and the management processes ruling their evolution. Human Computation can open up opportunities for the involvement of stakeholders: from the definition of the objectives and of the performance indicators, to the selection of the most appropriate management and even personal consumption decisions.

In the following, we focus on gamified applications and GWAPs, which are the categories of Human Computation that apply more deeply persuasive system design principles.

2.1. Gamified Applications

A gamified application is a traditional application addressing a business or environmental goal, extended with game-like features [8], such as: the registration of users and the maintenance of their profiles and interaction (play) history, the qualification of some actions as game actions, the establishment of achievements, the recognition of achievement with rewards, and the insertion of users in a competition system. An example of gamified application can be a community web site, where users sign up to perform actions, such as posting resources or requesting help. Some of the user's actions can be considered as game actions and associated with a reward, for example with a certain number of points. Achievements can also be defined, for giving special rewards to the most active users: for example, users recognised as helping other users may achieve the status of "experts". Finally, the status of users can be made public, for example in a leader board, to promote the most performing users and stimulate participation. Gamification features can be added to an application for a variety of objectives: to improve user engagement, data quality, and timeliness, and to learn a particular task or business activity [26].

2.2. Games with a Purpose (GWAPs)

A Game with a Purpose is a game, in which players generate useful data or assume novel behavioural patterns as a by-product of playing [9]. GWAPs normally employ pre-existing game genres (e.g., action, puzzle, word, and simulation games) and embed a task in the most appropriate game action. Gamified applications and GWAPs differ in that application gamification normally serves the purpose of increasing the performance of users of an existing application with respect to given business or sustainability objectives, whereas GWAPs address a particular computational task or behaviour change goal with an ad hoc application exploiting human intervention. In application gamification, predefined business actions are mapped to game actions; in GWAP design, game actions predefined in the game genre are mapped to useful tasks.

3. Persuasive System Design Theory

The design of a BCSS is a challenge of fusing insights from Human–Computer Interaction (HCI) research, in terms of both motivational and persuasive design, with insights from behavioural psychology. From an HCI perspective, designing for behavioural change is perceived through the lens of the 'affordance' concept, which refers to a perceptual property that hints at a possible usage of the object in a given situation and is immediately or intuitively recognised by instinct or education [3,27,28]. In other words, elements in systems can be designed in such a way that they afford a certain behaviour of the user. While this can be perceived as a subtle kind of persuasion, persuasive systems differ from affordance design, in the sense that persuasive systems have the explicit overall design goal of influencing the target behaviour through interaction with the system [3].

In the rest of this section, we discuss persuasive system design models by Fogg [1,29], and Oinas–Kukkonen [2,30].

3.1. Fogg's Behaviour Model

Fogg [29] postulated a persuasive system model whose basic assumption is that, for a target behaviour to happen, a person must have sufficient motivation, sufficient ability, and an effective trigger. Fogg claimed that the likelihood of behavioural change to happen increases with an increasing motivation and ability. For system designers, this means that there are two options to increase the likelihood of behavioural change to happen: increasing the motivation, and increasing the ability by making the desired behaviour easier.

However, a strong motivation and high ability are insufficient. A trigger is needed to set off behavioural change. This happens when three conditions are simultaneously met: (1) The trigger must get noticed by the users; (2) The trigger must be associated to the target behaviour; and (3) The trigger must be well-timed, at a moment where both the motivation and the ability is high. Fogg introduced the concept of a behavioural activation threshold: the ability level and motivation level must be above this threshold for a trigger to set off the target behaviour. To increase user motivation, the design of behavioural change support systems can appeal to different motivations for behavioural change, e.g., pleasure/pain, hope/fear, and social acceptance/rejection.

Furthermore, Fogg stated that the task of system designers is to increase ability by ensuring simplicity of the system. Simplicity is achieved when the amount of time, money, physical effort and brain cycles needed to perform the target behaviour are as limited as possible, as well as the extent to which one needs to go against social norms and to change existing habits.

According to Fogg, triggers are subdivided into three types:

- A *spark*: This type of trigger is designed for people lacking motivation to perform according to the target behaviour and leverages motivational elements inspiring an emotional reaction (e.g., hope or fear).
- A *facilitator*: This trigger targets users that have high motivation but lack ability. It tries to convince them that achieving the target behaviour is easier than what they believe.

- A *signal*: This trigger is used when people have both the ability and the motivation to perform the target behaviour. A signal simply serves as a reminder to engage in the target behaviour.

Figure 1 shows that low scores on ability (x-axis) and/or motivation (y-axis) are unlikely to induce behavioural change. The trigger factor can be placed anywhere inside the plane defined by the motivation and ability.

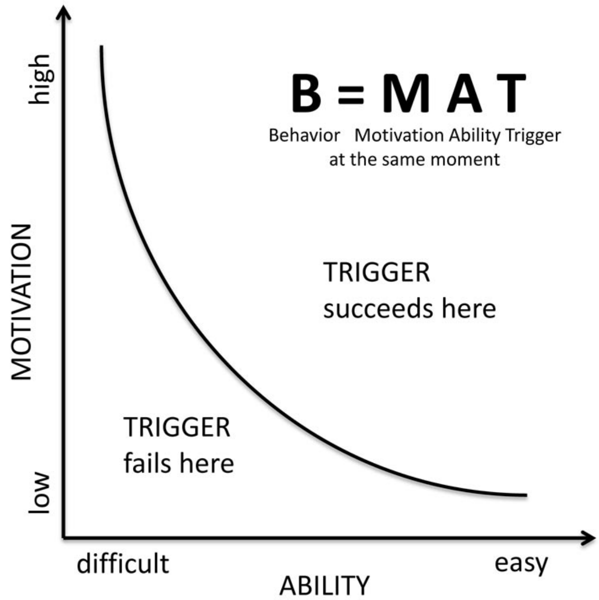

Figure 1. Fogg's Behaviour Model [29].

Despite its frequent usage, this model is fairly limited in its validity. First, the work is not grounded in psychological theory about behavioural change. For example, it is unclear which factors contribute to motivation and ability. Additionally, a range of other non-motivational factors often found to impact behavioural change are not addressed by this model, such as underlying attitudes, beliefs, personal and social norms, and the habitual nature of many behaviours. Furthermore, the model does not make explicit how the suggested design principles can and should be transformed into software requirements and further implemented as actual system features [30]. Despite these shortcomings, the importance of triggers as drivers for behavioural change is important for the context of energy consumption. Energy and water usage behaviour can be characterised by a low level of involvement and attention, while a significant share of the behaviour is driven by habits. In such context, triggering the attention of the users is of key importance.

3.2. Oinas–Kukkonen's Persuasive System Design (PSD) Model

The Persuasive Systems Design (PSD) model defined by Oinas and Kukkonen in [2,30] addresses the conceptual design of a behavioural change system in three subsequent steps. As a first step, a set of seven design postulates must be considered. Second, an analysis of the persuasion context is required. Finally, the persuasive software features must be modelled.

3.2.1. Design postulates

Oinas and Kukkonen posed seven design postulates common to all BCSSs. The postulates combine insights from user acceptance literature with insights from behavioural psychology.

P1 ICT is never neutral, as the introduction of an ICT system always has some influence on the user. In that sense, persuasion should be considered as a process during which the goals of the user may change, and not as a single event. BCSSs should be able to cope with such changes over time.

P2 Consistency is needed, as people like their views of the world to be consistent. This postulate indicates potential for behavioural change, since, by pointing out inconsistencies between, e.g., attitudes and behaviour, people are inclined to change their behaviour when the dissonance is strong enough.

P3 Direct and indirect routes to persuasion must be employed: users who are capable of actively processing the content of the persuasive message can be persuaded via direct strategies, whereas users who rely on simple cues and heuristics for evaluating the message content should be approached via indirect routes.

P4 Persuasion is often of incremental nature, rather than radical. A BCSS should enable users to make incremental steps towards the target behaviour, while clearly communicating the final goal. Encouraging users to perform small incremental steps is easier than persuading them to take big steps.

P5 The designed system should serve the envisioned purposes while meeting generic usability and system performance criteria, such as responsiveness, lack of errors, quality of information, visual appeal, ease-of-use, etc.

P6 Persuasion through a BCSS must be unobtrusive to a user's primary tasks. This postulate implies that an opportune moment should be identified at which the persuasive message can be delivered without disrupting the user's primary activities.

P7 Persuasion must always be transparent. This postulate requires to be open about the designer and the assumptions behind the BCSS to avoid losing its trustworthiness and persuasive potential.

Note that these design postulates are not fully specific to the context of a BCSS, as postulates 1, 5, 6, and 7 are applicable to any information system, and as such have received substantial attention in the user acceptance and user experience literature (e.g., [31,32]).

3.2.2. The Persuasion Context

The persuasion context encompasses *intent*, *event*, and *strategy*. In this model the intent refers to the specific behavioural outcomes and changes the BCSS intends to achieve. Oinas and Kukkonen [2] developed an Outcome/Change matrix (reported in Table 1) containing nine different potential intentions of a BCSS.

Table 1. O/C Matrix from [2].

	C-Change	B-Change	A-Change
F-Outcome	Forming an act of complying	Forming a behaviour	Forming an attitude
A-Outcome	Altering an act of complying	Altering a behaviour	Altering an attitude
R-Outcome	Reinforcing an act of complying	Reinforcing a behaviour	Reinforcing an attitude

A forming outcome (F) means the formulation of a new behavioural pattern. An altering outcome (A) means that an existing behavioural response needs to be changed. The change can be in frequency, intensity, or duration of the behaviour. A reinforcing outcome (R) means that existing attitudes or behaviours are strengthened, making them more resilient to change. While quitting a behaviour is not part of this matrix, Oinas and Kukkonen stated that quitting a behaviour often entails forming behavioural pattern (F).

As a second element of the persuasion context, the 'event' must be considered. A central part of the event analysis is to consider the use context and in particular the features arising from the problem domain. The characteristics of the user also need to be considered. For example, people have individual differences which influence their information processing, such as differences in the need for cognition. Furthermore, developments in the user's life may influence how they process persuasive messages. Additionally, the understanding of the user's goals is important, which includes current progress towards their achievement, and past experiences with regard to the goals. Finally, self-efficacy needs to be taken into account.

Building on the original PSD model, Halttu et al. [33] extended the event model to cover the situational use context, the long-lasting user context, and the technology context. The situational context comprises personal (e.g., evoked emotions), physical (e.g., location), privacy (e.g., the private or public nature of use), and task-related factors. The user context is comprised of personality and social factors, while the technology context includes service factors and device factors. A strategy for behavioral change must comprise the analysis of the message that is delivered through the BCSS to induce behavioural change, as well as the choice between a direct and indirect persuasion approaches. The route selection depends on the information processing capabilities and motivation of the user to evaluate the content of the persuasive message. In cases where the user is able to do so, a direct route is opportune. Otherwise, an indirect route needs to be taken. Note that, given the abundance of information users in the information era are confronted with, users increasingly rely on indirect routes to process information.

3.2.3. Persuasive Software Features

Finally, persuasive software features must be considered. Oinas and Kukkonen distinguished primary task support, computer–human dialog support, system credibility, and social influence as persuasive system principles. The principles should be perceived as optional elements rather than requirements for each BCSS.

The complete persuasive system design process model containing persuasion postulates, the persuasion context and the persuasive software features is depicted in Figure 2.

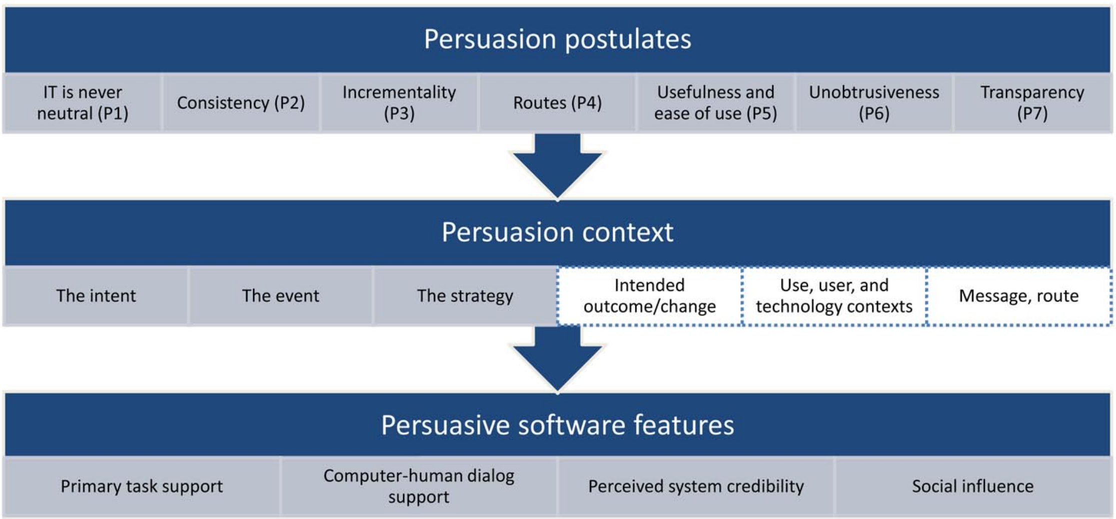

Figure 2. Persuasive system design model [2].

As the design postulates are argued to be applicable to all persuasive systems, they would need to be carefully tested against empirical evidence to be treated as such. Even though the authors evaluate exemplary studies in the light of the PSD model, no specific evidence is provided for the validity of the design principles. In addition, the principles can be elaborated and tailored to the specific setting of behavioural change support systems to be practically useful. In a recent review of the state-of-the-art in persuasive systems theory, Spagnolli et al. [3] raised several issues designers should take into account: (i) Users of persuasive systems should be empowered to perform a behaviour, and be able to reflect on it, to avoid the so-called punishment–reward trap, which refers to a simplistic persuasive rationale where users are merely being conditioned to behave in a certain way. (ii) The individual factors (or behavioural determinants) that predict the targeted behaviour should be identified and analysed in detail. (iii) Contextual aspects must be taken into account, particularly in cases where there is an interdependency between other people. In such cases, when an individual changes his/her behaviour, the routines of other people are also affected. For these situations, the focal point should move away from the individual to the network of individuals and resources [3].

3.3. Gamification and GWAP Design Principles and Models

Applications of user-centred design principles are necessary to avoid meaningless, or even harmful, gamification. Nicholson [34] claimed that dependence upon extrinsic rewards for motivation should be replaced by connections between the non-game activity and needs or goals in the user's life. The resulting user-centred gamification is expected to result in longer-term and deeper engagement between participants in non-game activities and supporting organisations.

As a first step towards a gamified incentive model that is differentiated by user motivations, we discuss different theoretical models that analyse the player types, gameplay environment, emotional responses to gameplay, and the relationship between motivation and ability in games. The models help to understand how game and gamified application designers can make people want to play or engage and persist in their activity, given the differences in motivation among participants.

3.3.1. Bartle's Player Categorisation

Different players have various desires in games and the factors of the game they perceive as important are also different [35]. Therefore, to create the right motivation for people to play game, we should understand the characteristics of various players. In [36], Bartle categorised players into four roles: Achievers, Explorers, Socializers and Killers (see Figure 3).

- *Achievers* are players who want to gain points, levels, equipment and other concrete measures of success; they are competitive and enjoy beating difficult challenges, either set by the game or by themselves. The more challenging is the goal, the more rewarded they tend to feel.
- *Explorers* like to explore the world, not just its geography, but also the finer details of the game mechanics. These players may end up knowing how the game works and behave better than the game creators. They know all the mechanics, short-cuts, tricks, and glitches that exist in the game and work hard on discovering more.
- *Socializers* are often more interested in having relations with the other players than playing the game itself. They help to spread knowledge and a human feel, and are often involved in the community aspect of the game (e.g., managing guilds or role-playing).
- *Killers* prefer to provoke and cause drama and impose them over other players according to the game possibilities.

Some players can have characteristics of all four types at the same time. However, most of them do not. On average, the population of players is distributed as follows: 80% socializers, 50% explorers, 40% achievers, 20% killers.

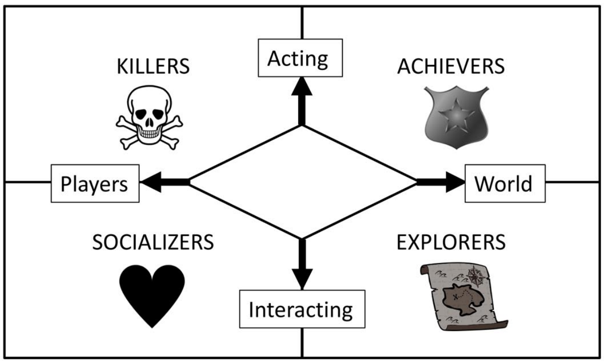

Figure 3. Bartle's player taxonomy [36].

3.3.2. Kim's Social Engagement Verbs

Inspired by Bartle's work, Kim developed a framework of "Social Engagement Verbs" [37], which captures the motivational patterns seen in modern social gaming and social media by attributing an action to the four types of players in Bartle's taxonomy [36]: Compete, Collaborate, Explore, and Express.

According to Kim, achievers are players who like to compete. Socializers, on the other hand, prefer collaboration over competition: collaboration is driving many of today's most innovative and influential social systems (from Facebook "likes" to Kickstarter projects), and people who enjoy collaboration like to "win together" with others, and be part of something larger than themselves. Explorers are interested in exploring contents, people, and tools. People who enjoy exploring are motivated by information, access and knowledge; stand-alone points will be meaningless to them. This type of players are attracted by word-games and knowledge based systems. For killers, self-expression is a key driver for modern social gaming and social media; it is also a major motivator for engagement and purchases. People who enjoy self-expression are motivated by greater abilities to showcase their creativity and express who they are.

3.3.3. Radoff's Gameplay Model

The gameplay model defined by Radoff [38] builds upon Bartle's taxonomy and tries to explain why people play games for fun. It adopts a bidimensional space representation (see Figure 4): the horizontal axis describes the number of players involved in an element of gameplay, from single player (left) to massive multiplayer games (right); the vertical axis represents the metric used to communicate to players whether they are 'winning' in the category of motivation (as you go upwards, you move from very quantitative to more qualitative rewards). The two axes divide the space into four quadrants which categorise different motivators, respectively defined as:

- *Immersion*: Stories, roleplaying, exploration, imagination, and a sense of connectedness to the world of the game.
- *Achievement*: Sense of progress, mastery of skills and knowledge, etc.
- *Cooperation*: Player involvement in activities where they are helping each other, through creativity, shared adversity, etc.
- *Competition*: Player involvement where individuals complete over scarce resources, comparison, and win/loss situations.

It follows that, depending on the number of players and type of rewards, different motivational strategies should be adopted to involve the users.

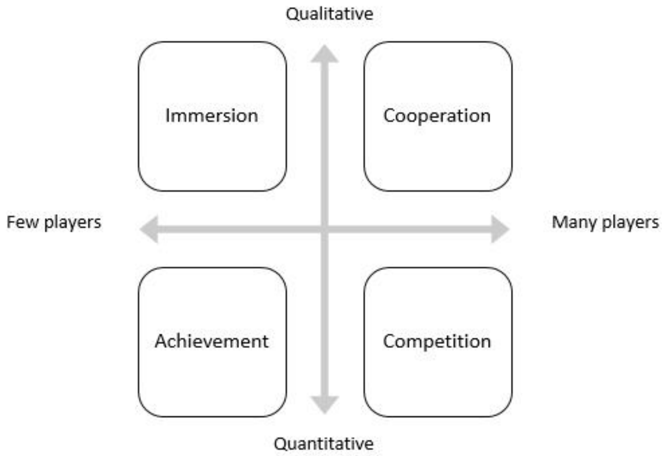

Figure 4. Radoff's gameplay model [38].

3.3.4. Lazzaro's Player Emotion Model

Lazzaro mentions four key factors influencing the emotions of players while playing games [39]:

- Hard Fun: "Emotions from Meaningful Challenges, Strategies, and Puzzles" [39]. The challenge in the game focuses on attention and rewards progress for players, which creates emotion by structuring experience towards the pursuit of a goal. The game needs to have feedback on progress and success of players to inspire their creativity of strategies. Game difficulty and player skills must therefore be well balanced through levels.
- Easy Fun "grabs attention with ambiguity, incompleteness, and detail" [39]. Easy fun focuses on maintaining the player's attention rather than on the winning condition. Ambiguity, incompleteness, and details are combined to create a living world, which satisfies players' sense of curiosity, and induces them to play the game to discover something new. The feeling of exploration and adventure is interesting to players.
- Altered States "generate emotion with perception, thought, behaviour, and other people" [39]. These factors produce changes in the players' internal state of mind and personal emotions by means of game stimuli.
- The people factor "creates opportunities for player competition, cooperation, performance, and spectacle" [39]. This factor is important to players who play to spend time with other people, especially with their friends. Therefore, games for social interaction and enjoyment comes from interaction with other people. Games that support both cooperative and competitive modes offer a wider variety of emotional experiences, whereas multiplayer games leverage the people factor.

3.3.5. The Hexad Framework

Marczewski [40] proposed a gamification user typology model that aims at relating the user's personality to the gamification elements in order to provide a customised experience in terms of motivators and improve engagement. The model is based on a research on human motivation, player types, and hands-on design experience [41]. The proposed typology enables the classification of users of gamified systems based on intrinsic (perception of an activity been enjoyable, entertaining or fulfilling) and extrinsic (expected outcomes of executing a task, i.e., getting rewards) motivational factors. It consists in six main user types (see Figure 5):

- *Socialisers*: They are motivated by interaction and social connections.
- *Free Spirits*: Their motivation is driven by creation, autonomy and exploration.

- *Achievers*: They are in a constant search for challenges, self-improvement and skill mastery are their main motivations.
- *Philanthropists*: The search for purpose and meaning in the activities, and helping others is their motivation and reward.
- *Players*: The seek to collect rewards and to compete.
- *Disruptors*: They are motivated by change and aim at disrupting the system in positive or negative ways.

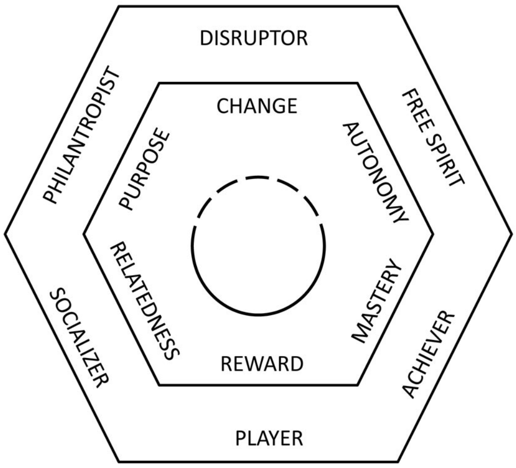

Figure 5. Marczewski's user types hexad framework [41].

These types are then divided into three categories:

- *Intrinsic* users' motivation is strongly related with the activities or tasks they perform, motivation raises from the enjoyment and the engagement of the user in the task itself. User groups in this category are: socialisers, free spirits, achievers and philanthropists.
- *Extrinsic* users are mainly driven by rewards and can be subdivided into four subtypes that are analogous to the intrinsic types: Self-seekers are similar to philanthropists but they expect a reward for their help or contribution. Consumers are similar to achievers: they will learn or develop skills if there is a reward involved. Networkers are similar to socializers but they search connections they can benefit from. Finally, exploiters are similar to free spirits, but they explore the boundaries of the systems searching for ways to gain rewards from errors or holes in the system.
- *Disruptors* seek to disrupt other users or the system itself in any feasible way. They are divided in four subtypes: grievers, whose only motivation is to affect other users in a negative way; destroyers, who will try to break the system by hacking it or finding bugs; influencers, who try to change the way the system works by using their influence on others; and improvers, who as ethical hackers try to find problems in the system and fix them or report them.

The model proposes to identify the user types in the systems and design the gamification elements according to the motivation of each type, e.g., provide "Socialisers" with social networks connectivity, statuses and elements of social pressure; design challenges, quest and badges for "Achievers"; create customisation and exploration features for "Free Spirits"; and provide creativity tools and voting mechanisms for "Disruptors" to change their mindset toward a positive interaction or to use their influence to positively change and/or improve the system.

Persuasive design principles help drive the development process of a behavioural change application, by focusing the design process around the goals of stimulating motivation, ensuring ability to act, and providing effective triggers. When the behavioural change system includes GWAPs or gamification elements, the player models help set the level of engagement competition and cooperation that best comply with the context and behaviour change goals. In environmental scenarios, it is often the case that mild competition models, based on a proper mix of social sharing of actions, rewards and achievements, are best fit to the design goal of inducing resource conservation.

4. Overview of Selected Gamified Systems for Sustainability and Sustainable Consumption

Computer games, as computer-mediated behavioural change tools, offer new ways to persuade the player, which match well with the rhetoric concepts exposed by Fogg [42] (triggers, motivation and ability).

Some recent contributions in environment and sustainability games focus on power conservation, environmental awareness, fossil energy use and water. Tables 2–5 compare some persuasive games specific for energy and water management along their main distinctive features:

- *Mechanics* describes the type of the game.
- *Roles* lists the roles assumed by the players.
- *Players* defines the number of players that engage in a game round.
- *Feedback* specifies whether the game can interact with players during a round.
- *Issues* summarises the main problems highlighted by the game.
- *Focus* refers to the core persuasive/educational objective of the game.
- *Target* identifies a specific population of players targeted by the game.
- *Data collection* specifies if the game play is based on real data (e.g., actual consumption data) or aims at collecting data (e.g., photos of the environment).
- *Platform* specifies the technological environment/device for which the game is designed.
- *Technology* characterises the implementation languages and frameworks.

The next subsections illustrate a subset of GWAPs and gamified applications for energy and water saving reported in the above mentioned tables, as most representative examples of motivations and design principles for inducing a behavioural change towards more efficient resource usage.

Table 2. Summary of sustainability games features. Games analysed: eVIZ [43], ecoPet [44], Joulebug [45], WeSpire [46], Plan It Green [47], Water wars [48], Atoll Game [49].

	eVIZ	**ecoPet**	**Joulebug**	**WeSpire**	**Plan It Green**	**Water Wars**	**Atoll Game**
Technology	Unity 3D	N/A	Android/iOS	Web/Android/iOS	Flash	N/A	VisualWorks and CORMAS platform
Roles	Residence Occupant/Family	Family	Family	Shareholders	Policymaker/Mayor	Stakeholders	Family
Feedback	Continues Real Time feedback of the user actions over the environment	Tips, in-game alerts	Continuous feedback on money saved and CO2 reduction	In game alerts	No Feedback	Message	N/A
Mechanics	Simulation	Challenge Based	Achievements based on action fulfillment	Challenge Based	Simulation	Turn based	Rpg computer assisted
Issues	Energy Consumption Reduction	Raise awareness and energy conservation	Sustainability and resource management	Resource Management	Energy Urban Planning	Policies, variable weather conditions	Policies, variable weather conditions, scarcity
Players	Single Player	Single Player	Single Player (Social competition)	Single Player	Single Player (Social Competition)	Multiplayer with chat	Up to 16 players
Focus	Domestic Energy preservation	Consumption and waste reduction	Energy and water efficient use	Emission, energy, water, waste and fuel management	Energy efficiency and community wellbeing	Interaction among inhabitants	Land/water allocation conflicts
Target	Household Residents	Students/Young adults	Teenagers and young adults	Employees	Students	New Mexico residents	Tarawa atoll residents and policy makers
Platform	PC/Oculus Rift	PC	Mobile devices	Web and mobile devices	Web	Web and mobile devices	PC supported board game
Data collection	Simulated Data	N/A	Connects with Utilities	N/A	N/A	Interviews	Semi-automatic software

Table 3. Summary of sustainability games features. Games analysed (cont.): Catchment Detox [50], FloodSim [51], Aqua Republica [52], Irrigania [53], Run the river [54], SeGWADE [55], Drop! The Question [35].

	The Basin Challenge/ Catchment Detox	**FloodSim**	**Aqua Republica**	**Irrigania**	**Run the River**	**SeGWADE**	**Drop! The Question**
Technology	Flash	Flash	Unity	VisualBasic ASP.NET	N/A	HTML5 and WebGL	Java
Roles	Policymakers	Flood policy strategist	Mayor	Farmer	Decision maker	Water Distribution Systems managers	Water expert
Feedback	Messages in game and leaderboard	Messages in game	Messages in game	No feedback	In game alerts	Continuous and instant feedback to players	No feedback
Mechanics	Turn based	Turn based	Turn based	Turn-based strategy game	Simulation	Model simulation	Trivia
Issues	Policies, variable weather conditions, scarcity	Floods	Policies, variable weather conditions	Governance and management of common resources	Balancing water use between various water consumers	Water Distribution Systems design decisions	General water culture
Players	1–2 players	Single player	Single player	Single player	Single player	Single player	Single player
Focus	Manage a river catchment	Raising awareness on flooding policies	Conflicts and trade-offs in a river basin	Water sharing policies, water scarcity	Water management policies	Drinking water distribution systems	Interesting facts on water and water consumption
Target	Teenage students	UK residents	Everyone	Students	Kids	Students	Family
Platform	Web	Web	Web (portable)	Web	Mobile phones and tablets	Windows, Linux, iOS and Android	Android mobile devices
Data collection	N/A	N/A	Numerical models (Mike Basin)	Discussion in class	Based on actual and modelled historic data	Feedback computed with hydraulic simulation engine based on EPANET	N/A

Table 4. Summary of sustainability games features. Games analysed (cont.): Ecogator [56], Social Power Game [57], Makahiki [58], Power House [59], Less Energy Empowers You (Ley) [60], Wattsup [61], enCOMPASS [62].

	ecoGator	**Social Power Game**	**Makahiki**	**Power House**	**Less Energy Empowers You (LEY)**	**Wattsup**	**enCOMPASS and Funergy**
Technology	Java	Java/Objective C	Javascript/Python	N/A	Java	Javascript	Java
Roles	Family	Family	Student	Family	Family	Student	Family and employees
Feedback	Messages in game	Messages in game	No feedback	No feedback	N/A	Alert in game	Mobile notifications
Mechanics	Trivia	Challenge based	Challenge based	Simulation and strategy	Challenge based	Challenge based	Achievement and challenge based
Issues	Consumption awareness and decision making	Community engagement in energy saving and awareness	Energy waste, consumption awareness	Raise awareness and energy conservation	Consumption awareness and behavioural change	Energy consumption reduction	Raise awareness and energy conservation
Players	Single player	Multiplayer	Single player (Social competition)	Single player	Single player	Single player (Social competition)	Single player (Social competition)
Focus	Choosing energy efficient devices	Energy efficiency and community wellbeing	Engaging individuals in energy saving and raising awareness	Engagement in energy efficiency and waste reduction	Consumption and waste reduction	Consumption and waste reduction	Energy efficiency and behavioural change
Target	General Public	Swiss residents	Students	Kids and teenagers	General public	Students	Household inhabitants and public building employees
Platform	Android	Android and iOS	Web	Windows	Android	Web (Facebook App)	Android and iOS
Data collection	N/A	Connects with Utilities	Smart meters	Simulated Data	Smart meters	Smart meters	Connects with Utilities

Table 5. Summary of sustainability games features. Games analysed (cont.): Water Mansion [63], Water Flavors [64], Water saving calculator [64].

	Water Mansion	Water Flavors	Water Saving Calculator
Technology	Unity	Java	Java
Roles	Family	Family	Family
Feedback	N/A	N/A	No feedback
Mechanics	Simulation	Trivia	Trivia
Issues	Consumption awareness and money saving	Raise awareness of water consumption and education	Consumption awareness and money saving
Players	Single player	Single player	Single player
Focus	Efficient water consumption and its relationship with economic savings	Educate about water importance and usage	Educate about water efficient consumption and its relationship with economic savings
Target	Family	Domestic consumers	Domestic consumers
Platform	Web	Web	Web
Data collection	N/A	N/A	N/A

4.1. Energy Saving Games and Gamified Applications

4.1.1. Ecogator

Ecogator is an efficiency advisor smartphone application focused on efficient energy consumption. It provides two operation modes: the shopping mode assists consumers at sale points to identify the most efficient appliances, whereas the day-to-day mode aims at increasing awareness of sustainable and efficient use of products [56]. The features of the shopping mode include the possibility of scanning the appliances energy labels: using that information the application provides the consumer with indications about the efficiency of the appliance such as the annual running cost of the appliance and the total cost of the product life time. The application also allows for comparison between two scanned products to empower the user in the decision-making process. The day-to-day mode provides money saving and efficient energy use tips. The gamification concept consists in awarding points to the users for actions such as scanning appliances labels, using the comparison or calculation functions, reading tips and execute social media actions as sharing tips. Earning points allows moving forward on a series of levels, where a set of questions and quizzes test the gained knowledge and present challenges to the user. When a certain level is reached the user is rewarded by entering a prize contest. The application evaluation in real life indicated that EcoGator was perceived as a good shopping assistant but less powerful as a tool for raising awareness. The authors evaluated the application only in terms of user acceptance [56].

4.1.2. Social Power Game

Social power game is a mobile game application aimed at exploring the potential of social interactions and game mechanics in driving people towards long term behaviour changes in the field of sustainable energy consumption. The application aims at connecting an entire neighbourhood to facilitate the collaboration and exchange between a multitude of people to increase collective energy-saving practices; to support mutual improvement in the adoption of more sustainable life styles; and to favour the viral diffusion of best practices. This approach seeks to provide a collaborative, action-oriented model for social learning in the context of a challenging neighbourhood-based energy-saving contest. Its features include tracking of household electricity consumption in a personalised way with easy-to-read visuals; visualisation of the electricity consumption trend over time; visualisation of the effect of user actions; team challenges to collaborate and compete; and information provisioning to users about how to make more efficient uses of energy. The gamification mechanism is based on two principal elements [57]: the players that represent the household dimension, and the energy hives that represent collective and social dimension (i.e., energy-related points of interest like transport stop or infrastructure, grocery stores, etc.). When users register to the game, they are assigned to one team and are provided with individual challenges (e.g., goals to reach), collaborative tasks (e.g., discovering the energy hives and report them in the application social map), and cooperation tasks that require coordination with others in order to be completed. The players get points by completing any of those tasks; they also receive information about how to make efficient use of the shared resources. Another objective of the game is to raise awareness of the energy use in user's surroundings. The competition takes place between teams through visual comparison of the actions of each team including achieved points, average consumptions, and the individual player's contribution to his team achievements. Players are awarded with badges for their individual achievements and for continuous or outstanding contributions to their teams [57]. Some preliminary results from the pilot show that 75% of the households participating in the project reduced their historical consumption between 1% and 25% [65].

4.1.3. Makahiki

Makahiki is an open source game engine aimed at rising people's awareness about energy conservation. It facilitates the implementation of "serious games" (i.e., fully functional games with a specific purpose such as education of a subject or training on a skill [66]) that motivates players to learn about energy issues, improve their intuition about energy consumption, and understand how to use energy more efficiently in their normal life [58]. The engine integrates with Watt Depot, an open source web service which collects and stores consumption power data and provides near real-time consumption tracking. The application leverages Google visualisations to present electricity consumption data in a dynamic and understandable way: the visualisation can be personalised by the user adding profile information and tracking their actions, events and commitments. As the software is intended for university dorms visualisation, it allows for comparison with other floors or other buildings. To promote energy consumption awareness, the platform supports the creation of actions, commitments and daily energy goals. Actions go from replacing a light bulb in a desk lamp, to attending meetings organised by pro-environment organisations. Commitments are requests made by the dorm administration, e.g., committing to turning off the lights in the lounge when they are not in use. Finally, goals are actions that the entire dorm floors participate in [58]. Daily energy goals require floor's members to vote on how much they plan to reduce their floor's energy consumption and then, attempting to accomplish such goal. The players get points for any of these actions.

The scenario where the application was deployed and tested was the following [58]: smart meters were installed in four student residence halls; towers (buildings belonging to a residence hall) and floors competed to minimise energy usage. To earn points, players should perform certain tasks and make public commitments to adopt more sustainable behaviours. Points were also aggregated to a get the floor's overall performance. The game included elements such as the smart grid game (organising tasks and commitments); the daily energy goal; the raffle game where people could earn a ticket to win a variety of prizes; two-people collaborative tasks; and an additional layer for top players. To attract more players, a referral system was set in which users received points for inviting their friends to the platform, and the new registered users got points by providing the email of the person that invited them. As part of the evaluation of the platform, four points emerged: (i) focus groups and usability evaluations improved the player experience; (ii) the game required a good, planned and intensive communication strategy for its adoption; (iii) identifying social influencers and incentivising them can create a positive impact in the adoption process; and (iv) prizes and incentives had to be deeply analysed and planned since it is hard to find right incentives when the player population is diverse.

Other projects and social experiments have followed a similar approach, e.g., "Do it in the dark", which encourages competition between student residences to reduce their average energy consumption [67].

4.1.4. Power House

Power House is an online game that connects home smart meters and social networks, leveraging engagement mechanisms to promote desired real-world energy behaviours [59]. The household energy consumption pattern is tracked through its local energy provider and sent back to the game environment where it is used to influence player in-game behaviour and saving abilities, options, rewards and social reputation. The real-word consumption behaviour affects the development of the game producing advantages or disadvantages to the players. Players are provided with a dashboard that displays information about their consumption during the last 24 hours and compares it to past consumption data. Players can review their scores, the results of competitions with other players and teams and the number of virtual credits earned. Virtual credits can be spent on in-game items, or on real world items offered by the utility company. Among the social features there is a chat forum for the players to ask questions and make comments; a virtual neighborhood view where players can visualise the houses and achievements of their friends; and a leaderboard that allows players to view their own achievements and the ones of their team and compare them with the achievements of their friends (all these features are supported through a Facebook connection). Moreover, the players can challenge their friends in energy saving competitions.

The gameplay consists on a virtual house where family members need to be assisted in their day-to-day activities: the player oversees turning on and off appliances (lights, TV set, computer, coffee machine, etc.) and keeps track of the activities of every member of the family as long as possible to reduce waste, the points system is based on the ability to minimise the amount of electricity consumed by the family [59]. The game is designed to reflect in the virtual appliances the amount of energy consumption that they have in real life to enhance player awareness. The game was tested in two settings [68]: the first was a laboratory experiment where the subjects were asked to play the game for 30 min; during this time, five appliances remained turned on. Results showed that the game positively affected the efficient use of energy perception as the subjects started to turn off the appliances after the gaming period. The second setting was a field test in which subjects were asked to execute a series of tasks in the game that would take approximately 17 days; after this period, it was observed that the energy consumption of the households was significantly lower than the 30 days before and 30 days after the test. These results show that the game was indeed able to positively influence the consumption behaviour of the players; however, the game mechanics were not able to influence the long-term behaviour.

4.1.5. Less Energy Empowers You (LEY)

"Less Energy Empowers You" (LEY) proposes a persuasive pervasive-based serious game approach to help people understand domestic energy usage and change their habits [60]. The platform consists in three main components: a sensor platform, a supporting web-based information system and a mobile game application. The sensor platform provides real time data to the mobile application and the web application, where data are stored along with the game rules. This system also provides data visualisation to the historical data. The game offers two modes: in the single mode, players are challenged to bring their energy consumption to an optimal level to achieve the maximum amounts of points, which are awarded to the players also by answering quizzes or inviting people to join the platform. It is important to notice that the game ranks the consumption levels according to the official European energy efficiency rating, which presents the energy efficiency of residences on a scale of A (most efficient) to G: using this scale gives the user a real overall measurement of the household energy efficiency. The completion mode allows the players to challenge one or multiple other players in a sustainability-based quiz competition that occurs during an established period. At the end of the period, users are ranked and points are awarded to the users according to their position on the ranking.

Another game feature of the mobile application is the house avatar, through which the player can monitor the household consumption and receive alerts. The avatar can be personalised and the players can also set their profile information [60].

4.1.6. Wattsup

Wattsup is a Facebook-based application that displays energy consumption and CO_2 emission data, giving the users the ability to compare household data with their friends. The aim of the project is to encourage energy saving by using live and historical energy feedback in a social-normative context. The project consists on using Wattson Sensors and monitors [69] to get and store the consumption information from the households, the data is then transmitted to a server which makes it available for a desktop application and a Facebook gamified application. The application designers conducted a series of interviews with focus groups to determine what information was important for the users, concluding that kilowatts where not representative enough for the users, and added other metrics like the approximate amount of CO_2 that is released to produce certain amount of energy and the approximate cost for the user's consumption [61]. The Facebook application shows this information in three different views: (i) *My Energy* shows user's current consumption; (ii) *Friends* compares the consumption against a selected friend; and (iii) *Rankings* is a leaderboard where the users are ranked on daily basis depending on their consumption. Users are enabled to make comments on their ranks and view other people's comments.

The application was evaluated in two settings [61]: in the first setting, some users started using the platform without access to the Facebook application; in the second setting, users could access the application. Results showed that the first group lowered the consumption thanks to the monitoring but the reductions of the second group were considerably higher. Moreover, in the second setting, it was observed that users spent most of the time on the rankings interface, viewing and commenting on the rankings table. The results suggest that social interaction can effectively motivate participants to reduce the household consumption [61].

4.1.7. enCOMPASS and Funergy

The enCOMPASS project [62] aims at developing an holistic socio-technical system for energy saving. It develops a gamified web application accessible via PC and mobile phone, which enables an interactive visualisation of energy consumption: users can explore they consumption patterns by time granularity (e.g., on daily, weekly or monthly basis), by consumption source, by user context, and activity type. The individual consumption is compared to reference values typical of the user's household and family type and the system provides warnings to above-average consumers, as well as personalised suggestions on how to reduce consumption (leveraging a recommender system that tailors recommendations based on the user profile and consumption history, while taking into account appropriate comfort levels for a given user and context).

Users are stimulated to perform recommended actions by means of two gamified elements: (i) gamified rewards (points, badges, achievements, tangible prizes) which can be earned via different types of game-mechanics such as goal setting (e.g., personal saving goals rewarded by bonus points and real rewards such as vouchers), social comparison and social collaboration (e.g., collecting points in teams for performing energy saving actions, competing with others); and (ii) a serious game called *Funergy* [70] (see Figure 6), which combines a physical board-game with a digital app. *Funergy* is a simple cooperative game (players try to reach the best possible final score collaborating with each other) organised in rounds. During every round, the players must reach an "energy level value" by playing their cards. The cards are "wild", i.e., they have a range of values and a QR code. The ranges are essential to reach the precise common score since players can pick in the range the value they need to get to that score. Players can expand this range, thus increasing their chances to get to the fixed score they need, by answering a multi-choice question provided via the associated mobile app when scanning the QR code on the card. Moreover, user achievements in *Funergy* are converted into points in the web portal, which will eventually enable the players to redeem rewards.

Figure 6. The "Funergy" game integrated with the enCOMPASS gamified application [70].

4.2. Water Saving Games and Gamified Applications

4.2.1. Urban Water and Water Mansion

Urban Water is a project aimed at developing and testing an intelligent water management platform for the efficient and integrated management of water resources in urban areas [71]. More in detail, the project aim was a 50% reduction of urban water waste over five years of operation. The platform provides tools to manage data coming from smart meters, process information to forecast water demand and water supply availability, detect leakages in the water supply network, support decision-making of water authorities and water distributors, and empower customers to reduce their water consumption. The platform consists on several components, the main one is the customer portal that offers consumption monitoring, consumption forecast, and billing access information. Besides these functionalities, the portal features a serious game, Water Mansion [63], which seeks to raise consumers' awareness about efficient water consumption and its relationship with economic savings. In the game, users should execute a series of tasks involving day-by-day actions, such as washing their hands, cleaning the dishes or filling the swimming pool. Each of these actions increase the consumption and reduces the "gold" that the user owns. The objective is to learn how to reduce consumption to save more "gold". The users are awarded a certain amount of "green drops" if in a given period the consumption is reduced with respect to previous periods.

4.2.2. Waternomics, Water Flavors and Water Saving Calculator

Waternomics [64] is a project aimed at providing personalised and actionable information about water consumption and water availability to individual households, companies and cities in an intuitive and effective manner, at a time-scale relevant for decision making. Access to this information will increase end-user awareness and improve the quality of the decisions for decision makers in companies and in governments. The project aims to accomplish these objectives by combining water usage-related information from various sources and domains to offer water information services to end-users, supporting personalised interaction with water information services, conducting knowledge transfer from energy management systems to water management systems, enabling sharing of water information services across communities of users, and enabling open business models and flexible pricing mechanisms responsive to both demand and climate/environmental conditions. Additional project goals are the introduction of water footprints (i.e., demand response and accountability) in the water sector; the interactive engagement of the consumers to enable efficient water consumption and behavioural change; the enactment of ICT-enabled water management by providing relevant tools and methodologies for water-related issues to corporate decision makers and municipal area managers. For what concerns the game framework, the Waternomics platform [64] provides a leaderboard that shows the highest scores achieved by the users in the different game applications. The platform offers two games of trivia-like fashion. The first one is "Water Flavors": it asks the player to make educated guesses about how much water is necessary to produce certain products. In case of correct guess, the player is awarded with points. This way, the game aims at creating awareness by educating the player about the importance of water in the production of food and other products of common use. The information used in the game is retrieved from the Water Footprint Organisation. The second game is called "Water saving calculator": in the first stage, it provides a collection of water saving tips, in a second phase the player is asked to answer a set of questions by performing calculation based on the information provided by the tips. Players get points for the right answers and extra information for the wrong ones. The objective of the game is to make the players aware of the amount of water they are consuming and the potential savings that they can reach by changing some behaviours.

4.2.3. SmartH2O and Drop!

The SmartH2O project developed a gamified ICT platform to establish a communication channel and a continuous feedback-loop between water users and utility companies, providing consumers with information on their consumption in near real-time while enabling water utilities to plan and implement strategies to reduce or reallocate water consumption. This was achieved by exploiting collected information about how the consumers adapt their behaviour as a reaction to different stimuli, such as awareness campaigns and changes in regulations or prices. To this aim, smart water meters were leveraged for collecting high frequency consumption data, which are used to provide high granularity information to water utilities on the state of the distribution network. At the same time, the collected information was employed to stimulate a change in water consumption behaviour. The ICT platform is available on web and on mobile devices via a downloadable application. It incorporates smart metering, social computation, data visualisation, big data analytics to model user behaviour, and gamification to engage consumers in the process. As inducing long term behavioural changes is a challenging task that involves psychological, social and cultural factors, the project incorporates a mix of multiple engagement strategies. All actions undertaken by the consumer, in all the different applications (web portal, mobile app and even an educational game) are logged. Based on such action logs and on the metered consumption data, a gamified framework is managed in which consumers are encouraged to save water through a mechanism that assigns points, badges and prizes based on the full spectrum of their actions; leaderboards and weekly/monthly competitions provide a social dimension to the game and increase engagement and motivation to participate by creating a sense of community. Moreover, through the game, the users are encouraged to provide detailed profile information about their demographics and their household configuration: such data are greatly valued by utility companies, as their analysis can provide important insights on the factors that drive the demand trends.

As a complement to the interfaces provided by the consumer web portal and mobile app, SmartH2O has also designed a water board game, called Drop!, with a digital extension, called Drop! The Question (see Figure 7). The Drop! board game is assigned as a reward to the users of the consumer web portal that achieve a minimum level of activity. It exploits a very popular home and family-oriented entertainment scheme, called "push your luck". In this class of games, the players repeat an action (e.g., drawing a card) until they decide to stop, due to an increased risk of losing points or the next turn (e.g., drawing a negative card). The Drop! board game is designed around the basic idea that a game does not need to be educational. The game metaphor is simple yet engaging: Lily is a young and clever girl who wants to save water. Lily's friend is a monster who does things in exactly the opposite way: the monster spills water. During the game, players do not need to answer questions or prove their knowledge to win, as is winning is determined by luck. The cards showing Lily are good cards and let the player score positive points, while the monster cards give players negative points. At the end of the game, players can transform the monster cards with negative points into positive points, by scanning a QR code on each monster card and answering a question received through their mobile phone or tablet. By playing the game within a household, saving water becomes a topic of conversation. This stimulates a water saving culture within the household, which in turn is a strong predictor of water consumption [72]. Playing the board game, and answering questions in the mobile app game increases knowledge. Users are incentivised to play the game in two distinct but related ways: the game design of the Drop! game itself, and the link with the gamified portal. Answering questions in the mobile game is awarded with points on the consumer portal.

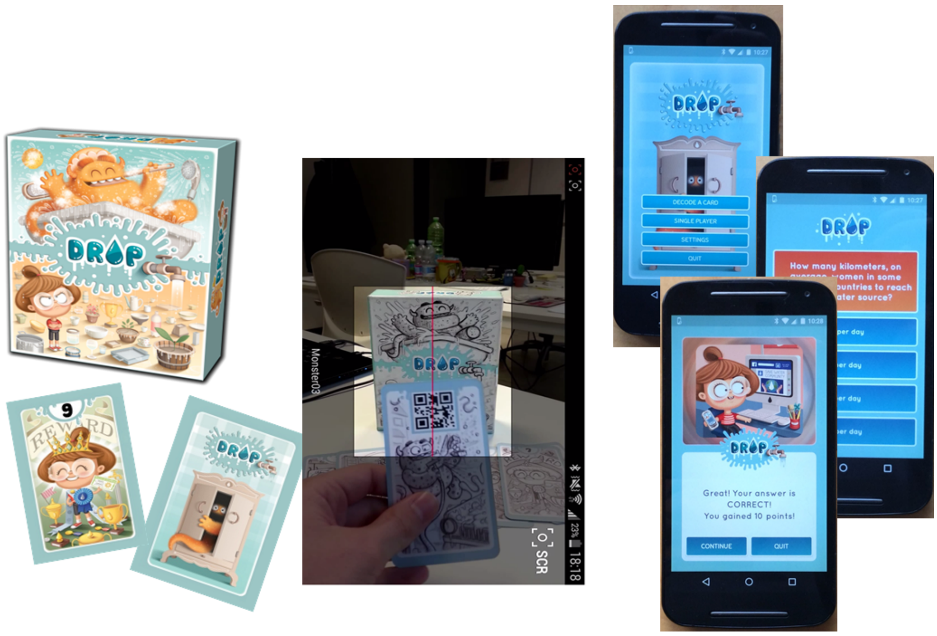

Figure 7. The Drop! game integrated with the SmartH20 gamified application lets the user respond to water saving trivia as part of a card game play [70].

4.3. Algorithms for Implementing Gamified Incentives

Most of the surveyed gamified applications and GWAPs rely on a common algorithmic core for the translation of the behavioural signals coming from the users into behavioural change stimuli. These stimuli act on the user's awareness and promote a behavioural change process, which is retrofitted to the system and generates new stimuli, triggering a virtuous behavioural change loop depicted in Figure 8.

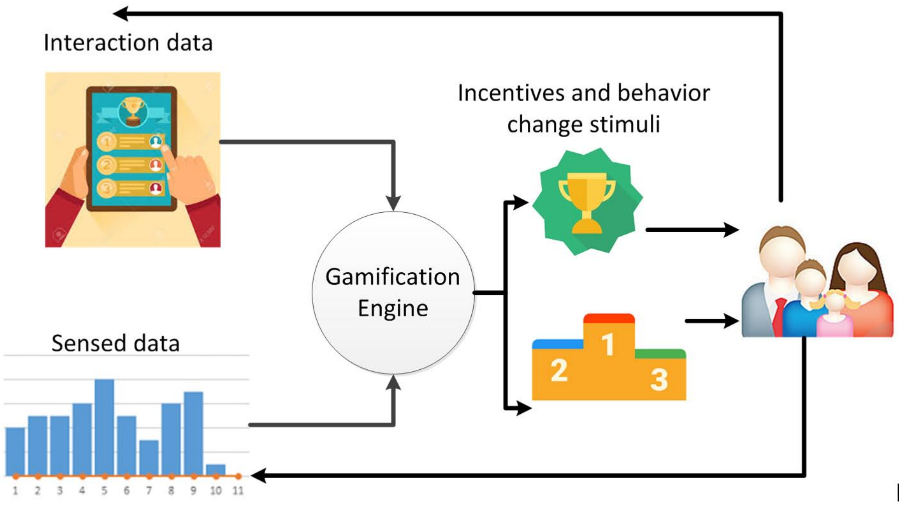

Figure 8. The algorithmic core of gamified behaviour change applications.

The classes of data in input to the incentive-based algorithms can be broadly categorised as:

- *Interaction data*: These data record the interaction of the users, mediated by the (gamified) BCSSs; they can range from the simple login or start of the application, to the accomplishment of articulated tasks in a task-based application or in a sustainability-oriented gameplay.

- *Sensed data*: These data come from the activity of the users in the real world. In the area of sustainable resource usage, such data refer mostly to resource consumption, as recorded by smart meters or manually input by the users into the system. In other types of persuasive systems, e.g., applications for promoting healthy lifestyles, they could represent user's activity traces (e.g., miles run, etc.).

The gamified system "listens" to the user's actions and sensor inputs and transforms them into a variety of incentives for improving activity and participation. It usually works as a rule-based engine, which takes inputs and produces outputs, as illustrated in Figure 8. Its main responsibility is to receive the notification of actions performed by the user and decide if, and to what extent, such actions should be mapped into an incentive, such as a reward or the recognition of some goal attainment or other achievement. The architectural details and rules design for the gamification engine underlying gamified applications have been little exposed in scientific literature, with notable exceptions such as in [73–76]. The algorithms typically rely on a common set of concepts, which can be summarised as follows:

- *Gamified User Interface*: The GUI for end users that allows to explore gamified objects.
- *Monitoring Interface*: The GUI for administrators that allows one (e.g., an utility company operator) to configure gamified objects and monitor users.
- *Gamification objects*: Game concepts composing the gamification mechanics (e.g., Action, Badge, Goal, and Reward).
- *Thematic areas*: Categories in which the gamification objects (action and badge areas) can be grouped to better reflect the different motivations of the users. Examples of such areas are: education, reputation, socialisation and consumption.
- *Credits*: Points that the user (player) can earn performing actions on the platform.
- *Actions*: Rewarded tasks the user can perform (e.g., logging in or using the app, reading a tip, watching an educational video, and inviting a friend to join the community of app users). Actions can be freely executable and always rewarded, or constrained: for example, actions could be rewarded only with a given frequency (e.g., only one login a day) or can be defined as non-repeatable (e.g., watching an educational video should be rewarded only the first time the user sees it). Across such areas, four major categories of actions are normally recognised and classified based on the source where they come from:

  – *Consumption actions*: These actions derive from the smart meter readings or user's declared consumption. When the consumption data are received, they are elaborated to check that some of the resource saving goals has been achieved (e.g., reduction of x% over the baseline average consumption of a period, such as a week, or a month).
  – *Application usage actions*: These actions are generated as consequences of the user activity in the gamified application (e.g., login, access to a specific section of the application, etc).
  – *Gameplay actions*: These actions may be produced by a GWAP connected to the gamified application (e.g., correct answer to a energy or water trivia education game).
  – *External actions*: These actions are produced by external applications, e.g., the pre-existing portal or business system of the water or energy utility.

- *Goals*: Measurable objectives (e.g., energy saving goals) that can be achieved by the user.
- *Badges*: Virtual recognitions assigned to a user and visible to other users in the community, mostly used to demonstrate consumer status and progress. The gamification algorithms map actions to the badge they contribute to attain.
- *Reward*: Physical item that can be redeemed by the user, as a consequence of achieving a determined amount of credits in the persuasive applications.

Most gamified applications and GWAPs for sustainable resource usage group activity and engagement stimuli (e.g., user's actions and badges/rewards) in four broad thematic areas:

- *Resource saving*: Refers to actual resource saving as metered by smart meters or declared by the user.
- *Resource saving Insights*: Refers to learning how to save resources.
- *Engagement*: Refers to activity in the persuasive applications and within the community of reference.
- *Profiling*: Refers to data input about the usage context: household, office, school, or public building.

The algorithms for action recognition and score assignment differ according to the source of the action and the synchronicity between the user's or smart meter input and the rule engine algorithm execution. For example, in a smart metered context, sensed data are typically evaluated synchronously for all users, when the next batch of smart meter readings is acquired. An example of parametric algorithm for weekly consumption action processing can be sketched as in Algorithm 1.

Algorithm 1 Algorithm for asynchronous weekly sensed data processing

```
On Monday at 6am
for all user U_j in the set of resource-metered users MU do
  if reading frequency geq day then
    Compute new weekly average NWA
    for all active weekly resource saving goals WG_k of user U_j do
      if NWA − Weeklybaseline/Weeklybaseline ≥ WG_k then
        SatisfiedWeeklyGoals+ = WG_k;
      end if
    end for
  end if
  AchievedWeeklyGoal = max (SatisfiedWeeklyGoals)
  for all goals G_i in AchievedWeeklyGoals do
    Points_i = G_i.actionType.score
    SendGoalNotification(U_j, G_i)
    U_j.profile.points+ = Points_i
    IncrementPointsInArea(U_j, consumption, Points_i)
    UpdateBadges(U_j);
    UpdateRewards(U_j);
  end for;
  ResetGoals(U_j);
end for
```

This algorithm verifies, on a weekly basis, for every user, if there are saving goals established for the previous week. In such a case, the weekly saving is calculated by subtracting the weekly baseline from the previous week consumption average and dividing the result by the baseline. Then, the result is compared to the established goal: if the goal is achieved, the user is awarded with a defined number of points, a notification is sent about the achievement, badges are awarded if any level is reached, and rewards are awarded, if available for the earned amount of points. The final step of the algorithm is to set new saving goals for the current week.

The other categories of actions of the gamified system that do not depend on the asynchronous processing of smart meter data are treated differently. They are triggered by individual users' events, which are managed by means of asynchronous executions, as exemplified by Algorithm 2. This algorithm executes a series of validations on every action performed by a given user. Validations check: (i) if the action is still active in the system; and (ii) if the action has been executed in the past and, in such a case, if it can be repeated and which is the time span allowed between repetitions. If the action is valid, then the user will be assigned a defined number of points, will be assigned badges if the target levels are reached, and will be offered a reward, if one is available, for the earned amount of points.

Algorithm 2 Algorithm for synchronous weekly sensed data processing

loop
When Action A_j of User U_i is received
if $(A_j.Active = true$ **and** $(A_j.repeatable = trueORCount(U_i, A_j) = 0)$ **and** $(A_j.check_time_elapsed = false$ **or** $A_j.timestamp - A_j.lasttimestamp > A_j.time_elapsed))$ **then**
$Points = A_j.actionType.score$
$U_j.profile.points += Points$
$IncrementPointsInArea(U_i, A_j.area, Points)$
$UpdateBadges(U_j)$
$UpdateRewards(U_j)$
end if
end loop

Algorithms 1 and 2 are parametric with respect to the values of the configuration of the gamification engine objects: actions, badges, and rewards. The values of the configuration parameters dictate how much each action is rewarded and which level of points is necessary to unlock a given achievement (e.g., the attainment of badge or reward); they must be fine-tuned based on the specific characteristics and sustainability objective in each scenario.

5. Design Patterns for Behavioural Change GWAPs and Gamified Applications

The overview in Section 4 reveals that, while there are many different types of applications and approaches to behavioural change for sustainability challenges, they share common design elements aiming at motivating and inducing a change in users' behaviour. This section summarises the different design patterns of behavioural change applications found in several sustainability-oriented GWAPs and gamified applications.

5.1. Visualisation of Behaviour

One key strategy for incentivising behaviour change is the visualisation of behaviour, e.g., providing energy/water consumption feedback, which allows users to self-monitor their saving achievements. Often, this information is provided interactively in the application (e.g., [76]), or as periodic reports that are sent to users (e.g., WaterSmart [77], STEP-BY-STEP [78]). Visualising the behaviour and providing the user with means to analyse it is a first step towards making the user more aware of their behaviour and ultimately changing it [79]. Visualisations can be data-oriented, e.g., bar or pie charts [80,81]; closely connected to the real behaviour context, e.g., floor plans when showing resource consumption in a building [80,81]; metaphorical, e.g., traffic lights and gauges [81–83]; playful and ambient such as shown in BeAware [84] or in [85]; and connected to nature or animal habitats, often termed eco-visualisation [82,86–88]. To effectively visualise resource consumption behaviour and facilitate long-term sustainable behaviour change, the information on the behaviour to be visualised should be broken down, e.g., temporally, by events, per appliance or type of behaviour [80,82,87,89]. Independently of how behaviour is visualised, it is of key importance to present the information in an understandable way and seamlessly embedded into user's context, offering details and comparisons based on the current user context and activity situation [90]. Closing this loop effectively in a user-friendly way is still a challenge.

5.2. Comparison of Behaviour against Historical, Normative, or Social Reference Values

When visualised, behaviour is mostly shown in comparison to a reference value or benchmark, e.g., a historical, goal or social reference. Such references or benchmarks enable the user to better understand whether their behaviour is "normal", excessive, or virtuous [82]. Different references enable different comparisons, e.g., historical references for self-comparison, normative references for comparison with other households or individuals and 'social' comparison for comparison against friends/neighbors [61,80]. Goals as a reference for comparison can be provided by the system, or set and self-adjusted by users (e.g., SmartH2O [80,91]). In their design probe study, the authors of [80] found that goal-comparison was most valued for self-set consumption goals, and least for goals set "top-down" by suppliers or local governments.

Recently, mixed approaches have been tested, and proven to be effective: a system-set goal that can be adjusted by the user, according to his level of ambition and to his/her opportunities for energy saving is presented in [76,92], whereby the default goal that is preset by the system is a crucial factor in the decision of the user which goal to set. This suggests that designers can influence the targets users set for themselves, by providing moderately ambitious goals that the users perceive as a challenge. Although some controversy exists whether social comparison [61] or historical comparison [89] of consumption performance have a greater effect on users, sustaining their interest and motivation once their performance is high (response-relax effect) is an open challenge [89,93,94].

5.3. Action Tips and Personalised Recommendations

In most cases, tips are also provided to show users how to change their behaviour [56,57,83,89,93], sometimes provided in a contextualised [89,93] and even personalised manner [62]. More recent approaches also investigate personalised recommendations, using complex machine learning techniques of different complexity, to be able to present users tips and recommendations that are personalised to their context and specific behaviour: For example, the STEP-BY-STEP project [78] explores the personalisation of recommended actions to suit the household profile and the activity history, even though not adapted to current activity context and not considering collaborative aspects. In addition, the ENTROPY project [95] aims at providing users with recommendations to motivate behaviour change towards a more energy efficient lifestyle. The DEHEMS project [83] also offers personalised recommendations: for example, based on the household size, users are notified if they are consuming significantly more or less than the average of users with the same household size.

5.4. Gamification and GWAPs Elements

As detailed in Section 2, gamified incentives and GWAPS are also a promising tool for computer-mediated behavioural change. Embedding a behavioural change application in a gamified context means e.g., that users can earn points for their actions and get either virtual rewards (e.g., badges), or real-world rewards, (e.g., discounts or gadgets). State-of-the-art persuasive games and applications includes different sustainability areas, such as: energy conservation [87,93,96], environmental awareness [97,98], fossil energy use [99], water [48] and transport (emPOWER project [100]). SmartH2O [76] and enCOMPASS [62] have developed two board games and mobile trivia apps on water and energy sustainable consumption [70], respectively, associated to a gamified web portal.

5.5. Social Interaction

Social interaction can be exploited to motivate users to change their behaviour. Two classes of approaches can be distinguished: competitive and cooperative [57,101]. According to [57], competitive and cooperative approaches can foster better behaviour. Competitive approaches are often gamified, and include, e.g., leaderboards that rank users [61,102], sometimes even introducing prizes at the end of a competition period [76]. Cooperative approaches are not so common yet. Grevet et al. [101] focused on how social feedback can encourage individuals to have a social impact such as increasing their environment-friendly actions. They developed a social visualisation interface, in which e.g., different city districts must work together to uncover a kind of puzzle of a familiar view of the city, in which clear squares are well-performing districts, while dark squares are districts where only a few participants save energy. The more districts engage, the more visible the image. In a small first study by [101] of a dorm competition at a small college, which used the visualisation adapted for the dorm setting, the trend suggested that the addition of social information may lead to increased participation in the site.

Rather than incorporating social aspects into new behavioural change applications, existing social networks have also been leveraged. Foster et al. [61], Mankoff et al. [88] incorporated energy consumption feedback into existing popular social networks. However, in [61], they showed that creating internal support for social interaction within a native behavioural change application was needed rather than making use of existing social networks. Another approach is to enable the sharing of achievements from the SmartH2O platform on existing social networks, e.g., provided by the SmartH2O [76] and enCOMPASS [62] projects.

5.6. Notifications and Reminders

While much research has studied attention triggering in general, e.g., when is the right "opportune moment" to disturb users with a proactive message [103–107], less has been done to investigate the use of notifications and reminders to incentivise behaviour. As one example, Kaptein and van Halteren [108] have explored adaptive persuasive messaging to increase service retention, by using persuasion profiles to increase the effectiveness of email reminders. In their study, Kaptein and van Halteren [108] showed that a main benefit of the persuasion profiles was a lower dropout rate of the service. In a small study, Gabrielli et al. [102] investigated weekly personalised notifications to encourage sustainable travel choices, according to users' profiles and travel behaviour, which were derived from usage logs. Notifications, e.g., concerned invitations to consider carpooling with colleagues for commuting purposes. Results indicated that "personalized notifications were not effective in changing user behaviour in the short term, but contributed together with social and individual motivational strategies to improve user attitudes and behaviour for sustainable mobility in the longer term" [102].

However, these examples do not yet provide sufficient details about user acceptance and design issues, in terms of acceptable and effective frequencies of sending notifications, the content of the notifications, or the design challenge of attracting attention to the notification amidst the abundance of notifications generated by other applications.

6. Conclusions

Games are one of the most ancient means used by humans, and by animals alike, to learn. They have a great potential to engage people not only for entertainment but also for behavioural change. This capability has been recently exploited by a host of research efforts aimed at tackling the problem of making our society more sustainable from a different perspective: managing the consumers' demand. This paper provides a survey on the design of gamified behavioural change support systems for energy and water sustainability. As such systems leverage users' psychological processes to induce long-standing shifts towards environmental-friendly behaviours, their design requires a deep understanding of motivational drivers and behaviour determinants. Therefore, the first part of the paper offers a comparison of several persuasive system design theories. Then, a selected review of recently developed gamified systems is presented, from which general design rules are extracted and elaborated as possible guidelines for further research in the field.

As games and gamified systems for behavioural change towards sustainability approach maturity, the ongoing and future research agenda should concentrate on the analysis of the impact that these systems induce in concrete settings; longitudinal studies over sufficiently long periods of time are required to assess whether these systems are able to modify users' behaviour effectively and durably; the impact of each factor constituting the design should be analysed separately, to better understand the combinations of engagement stimuli that addresses optimally the specificities of each application scenario; and finally, new game mechanics and combinations between traditional (non digital) and digital games and gamified applications should be experimented and their effects reported.

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