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Gamification-based framework for engagement of residential customers in energy applications

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A R T I C L E I N F O

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A B S T R A C T

According to the European Union Third Energy Market package, the roll-out of smart meters in the residential sector can presumably play a key role in reaching the goals of sustainability strategies. However, the deployment of smart meters alone does not necessarily drive residential customers to use energy in a more sustainable manner. Therefore, more attention should be paid to customers energy behavior in order to reach the objectives of the roll-out policy. In this study, we propose an interdisciplinary framework that establishes a behavioral model to identify the main energy-related behavior change requirements necessary to engage residential customers in energy applications. To fulfill the requirements, we first present the technical system architecture that enables energy applications for residential customers. Then, we assess how gamification, which is the employment of game design elements in non-game contexts, can be used to enhance energy applications by driving customer engagement and energy-related behavior change. To do that, the most relevant game design elements are discussed and classified. After that, the expected value streams from using a gamification-based solution for different stakeholders in the energy market are identified. Finally, the study discusses the potential of the proposed framework in different energy applications for residential customers.

1. Introduction

The European Union (EU) has set an ambitious energy policy objective to achieve by 2030 represented by three main targets: a 40% cut in greenhouse gas emissions compared to 1990 levels, a 27% share of Renewable Energy Sources (RESs), and 27% energy savings compared with the business-as-usual scenario. Empowering consumers, as key players in the energy market, is declared as an explicit strategic goal in order to reach these targets [1–3]. This includes improving the provision of information on energy consumption and increasing the awareness of consumers in the metering and billing of energy.

Essential to the achievement of these targets is the transformation of Europe's conventional electricity grids into so-called *Smart Grids* that are characterized by bidirectional flows of electricity and information between power plants and appliances, and all points in between. Smart metering systems roll-out is at the core of this transformation since smart meters are fundamental in monitoring the performance and energy use characteristics of the grid load, and provide the required infrastructure to support energy management services [4–6].

The EU Recommendation 2012/148/EU [7] deeply focuses on the roll-out of smart metering infrastructure stating that at least 80% of residential customers in the EU member states should be equipped with smart electricity meters by 2020, unless a different decision is taken by a member state based on the results of a cost-benefit analysis (CBA) [8]. It is expected that the use of smart meters will create a value proposition for different stakeholders and lead to more participation of residential customers in the electricity supply market. The recommendation explicitly states that active participation of residential customers in the efficient planning and use of electricity is one of the EU main smart meters roll-out policy objectives.

Nevertheless, it is still uncertain whether the deployment of smart meters alone will have a direct impact on residential customers energy-related behavior. It has been discussed in the literature that engaging customers is a critical factor for the success of smart grids [9–11]. Therefore, it is complementary to the roll-out policy to identify what is required for customers energy-related behavior change in order to achieve an active participation and engagement in the energy system. Motivation techniques from the uprising research area of *gamification* can play a key role in achieving this goal. Gamification addresses the features of an interactive system that aims to motivate and engage users through the use of game design elements [12,13]. It has been emerging as a compelling and effective engagement tool in almost every field including education, business, human-computer interaction, technology adoption, sustainability, health care, and transport. One example is the

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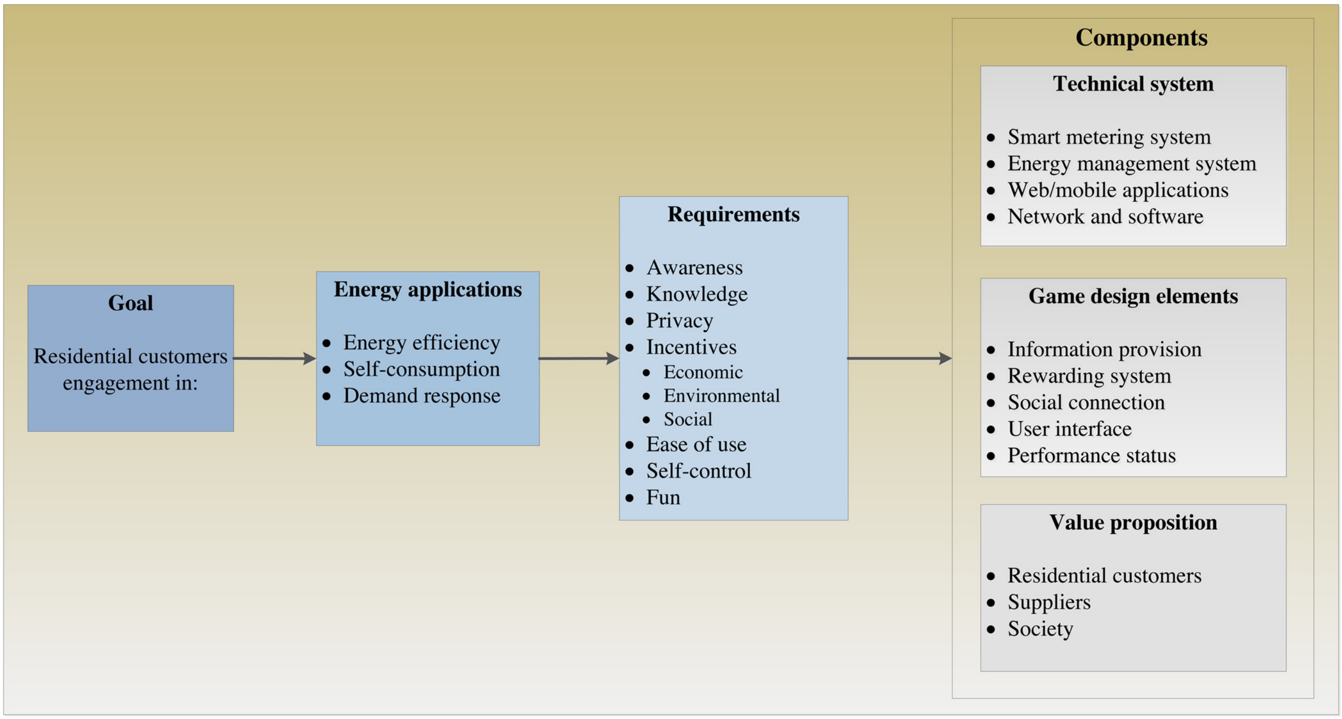

Fig. 1. Conceptual diagram of the proposed framework for gamified energy applications.

social rewarding system used in transport strategies to promote eco-driving [14]. Some major car manufacturers have developed interfaces in this direction. For instance, in Ford's "Ecoguide", green leaves appear on the screen and increase in number as driving behavior becomes more pro-environmental. In Nissan's "Leaf", there is a system of a network of drivers that compares driving styles and offers high-scores for the most energy efficient drivers.

Recently, gamification has also emerged as a tool for increasing residential customers engagement in energy systems through targeting a wide set of motives that a customer may have, including economic and environmental motives, as well as social motives, such as learning and contributing to the community [13,15–19]. For instance, the effect of passive versus interactive, gamified information [18], and the potential of serious games [19] on the antecedents of behavior change have been assessed using the context of solar energy adoption among residential customers. While interesting, some of these gamification-based solutions are designed to run for a limited period of time (e.g., weeks or months) [15–17], or to achieve a certain target (e.g., adopting solar energy production in hosueholds) [18,19]. We argue that when gamified interaction with participants is run for a limited period of time, it is not clear whether the change in participants behavior would be sustained following the completion of the game. For example, in the Energy Battle game [16], only few participants continued to lower their electricity consumption, while others used more electricity than before the game. Other solutions have been developed before the roll-out of smart meters and, thus, the interaction process is not fully automated and/or isolated from the energy system [15–17]. For instance, in [16], residential customers were required to upload their energy consumption data manually to an on-line platform for analyzing their energy consumption behavior.

Based on the above-mentioned observations, this paper introduces a framework that establishes a behavioral model to identify the energy-related behavior change requirements necessary to engage residential customers in the energy applications enabled by smart meters. The proposed framework considers a distinction between the technical, economic and behavioral components that are necessary to fulfill those requirements. It is generic and applicable for any location or country where smart meters are deployed. The main energy applications where residential customers can be engaged and play an active role are: (i) *Energy Efficiency*, (ii) *Self-consumption* and (iii) *Demand Response (DR)*. These applications are all part of the wider term *Demand Side Management (DSM)*. DSM is defined as "the planning, implementation, and monitoring of distribution network utility activities designed to influence customer use of electricity in ways that will produce desired changes in the load shape" [20,21]. In practice, these applications can be offered by energy suppliers to retail customers in the energy market in the form of (optional) programs with voluntary subscription. However, residential customers have limited awareness and knowledge about those programs, and thus their understanding and level of engagement in energy applications is relatively low. The proposed framework presents the technical system architecture that enables these applications, classifies the most suitable game design elements to engage residential customers in each application, and identifies the value streams to different stakeholders in the energy market when using a gamification-based solution, including residential customers, energy suppliers and society in general. It aims to offer different actors, such as suppliers, academic institutions, solution providers and public bodies, a unified view about a gamification-based solution for achieving an active participation and engagement of residential customers in the electricity supply market.

The paper is structured as follows. The methodology of the study is provided in Section 2. In Section 3, the key requirements for energy-related behavior change are identified. The system components needed to fulfill these requirements are presented in Section 4. Section 5 discusses the potential of the proposed framework in each energy application. Finally, conclusions are provided in Section 6.

2. Methodology

The methodology of the proposed framework is divided into three steps. The first step is to identify the main energy-related behavior change requirements that are needed to engage residential customers in energy applications. The second step is to define the components needed to fulfill these requirements, which includes technical, behavioral and economic components. In the third step, we discuss the potential of the proposed framework on how it can satisfy the energy-related behavior change requirements in each energy application. A conceptual diagram of the proposed framework is illustrated in Fig. 1.

For the first step, a brief overview of intervention strategies that focus on residential customers energy use is provided, and the key requirements for energy-related behavior change are identified using a human behavior change model. In the second step, the first component to consider is the technical solution. Smart metering systems and the architecture of the technical system required for residential energy applications are introduced. This includes hardware solutions (i.e., smart meters, Energy Management System (EMS), network, etc) as well as software solutions (i.e., mobile and web applications, data analytics, etc). The second component is game design elements which is considered as an essential component in the proposed framework. The combination of game design elements that are needed to fulfill energy-related behavior change requirements is classified and discussed. The third component, that is important for the realization of an active participation and engagement, is the identification of value streams that result from residential customers participation in those applications when using a gamification-based solution. These value streams are not only restricted to residential customers. Active participation and engagement through gamification can also bring value to energy suppliers and society as a whole. Finally, in the third step we discuss the potential of the proposed framework in different energy application for residential customers including: energy efficiency, self-consumption and demand response. In this step, suitable game design elements are linked to energy-related behavior change requirements for each application.

3. Requirements for energy-related behavior change

Consumer behavior change can be defined as "the act of varying or altering conventional ways of thinking or behaving" [22]. Individual-level factors that govern behavioral choices, such as awareness, beliefs, values, attitudes and knowledge, can be considered as important driving forces behind consumption choices. Various interventions strategies can be found in literature which aim at encouraging consumers to reduce energy use. They are typically classified in two categories: (i) structural and (ii) psychological interventions [23–26]. Structural interventions target the conditions in which behavior takes place. These conditions can be economic measures, physical/technical alternatives and/or legal regulation. Psychological interventions are aimed at changing individual-level variables (e.g., knowledge, awareness, attitudes, norms and values, etc). For instance, providing feedback information and tips about energy-saving practices can lead to an increase in residential customer knowledge and therefore result in the adoption of energy saving behaviors [27,28].

In our work, we identify the key requirements for energy-related behavior change using the Transtheoretical Model (TTM) [29]. This step is important in order to reach the goal of an active participation and engagement of residential customers in energy applications. The TTM model is a comprehensive human behavior change model which classifies the process of behavior change into a number of stages. This model has been applied to achieve behavior change in different areas including: behavioral medicine [29], residential customers water use behavior [30] and residential customers energy-related behavior [31,32]. The TTM stages of changes and the requirement(s) that we identify for each stage in our work are presented in Table 1.

The first stage in this model is the *Precontemplation*. In this stage, it is assumed that a residential customer has no intention to make a change in his/her behavior. The first thing that a residential customer needs in order to contemplate making a change is to be aware of a behavior. This means realizing the consequences of a certain behavior (e.g., the negative impact of an unhealthy behavior or the positive impact of a healthy one). After that, when a customer starts thinking about making a change, he/she needs to find and learn new facts, ideas, and tips that support a healthy energy consumption behavior, which is the second stage of the TTM model. Since the energy use pattern is assumed to be analyzed using the data captured by smart meters, privacy concerns might arise at this stage and transparency on data usage should be ensured in order for a residential customer to accept participating. The knowledge process can also continue to the third stage in order to help the residential customer getting ready for making the change. This includes, for instance, learning how to use and interact with a platform that is used for participating in energy applications. The next stage is when actions related to new energy consumption behaviors take place. If these actions are taken using a platform, this platform needs to be easy to use. It should also allow the customer to observe actions and assess outcomes (e.g., expected rewards). The last stage is when the residential customer has made specific modifications in his/her energy consumption behavior. The focus in this stage is on how to motivate the customer to continue with changes and prevent relapse. The key requirement in this stage is to provide incentives that are of the customer interest by showing, for instance, the social and environmental outcome resulted from a new energy consumption behavior, or by compensating with rewards in proportion to the effort he/she provides in a certain application. The other requirement needed in this stage is self-control. Since the interaction with energy applications is assumed to be automated, the platform used should provide the residential customer a certain level of control and autonomy. In addition, for triggering more engagement, the actions and the platform used need to be playful and fun.

4. System components

4.1. Technical system

4.1.1. Smart metering systems

A smart metering system typically consists of smart meters, communication infrastructure, and load control infrastructure. A smart meter is an advanced digital electric meter that includes sophisticated measurement and calculation hardware, software, calibration and communication capabilities. Basically, it measures and records the consumption of electric power in a household during the day at certain short time intervals (e.g., every 10 s), and communicates that, through a two-way communication system, to the supplier for monitoring and billing processes [33]. Smart metering systems roll-out can bring a considerable number of benefits to the energy system [33–36]. Some of the benefits identified for residential customers include automated meter readings, accurate billings, better accessibility of information about energy use and quality of delivery, and opportunities to save money. Regarding the benefits identified for energy suppliers, smart

Table 1
Energy-related behavior change requirements based on the TTM model.

Stage number	Stage of change	Description	Key requirement(s)
1st stage	Precontemplation	No intention to make a change	Awareness
2nd stage	Contemplation	Thinking about making a change	Knowledge, privacy
3rd stage	Preparation	Getting ready to take the action	Knowledge
4th stage	Action	Doing the action	Incentives, ease of use
5th stage	Maintenance	Keep doing the action and prevent relapse	Incentives, self-control, fun

metering systems provide suppliers with an enhanced knowledge about their customers energy consumption behavior, automated and remote meter readings, real-time decision-making and control, among others. This can help suppliers meet their targets for load management and protect their revenues efficiently.

4.1.2. System architecture

Based on smart metering roll-out policies in the EU and other countries, it is assumed that smart meters will be deployed in every household in the future. In addition to the smart meter, an EMS that receives the meter readings, measures the local renewable energy generation, and possibly controls some flexible appliances (e.g., washing machine and dishwasher) is considered as an essential part of the technical component. The EMS stores the captured data (i.e., either locally or on the cloud), analyses it, and forwards the results to a web-based and/or a mobile-based application that is responsible for data visualization (e.g., per minute, day, week, month, or year). The EMS can be either a hardware installed inside the household and physically connected to the smart meter, or virtually located at the supplier side. In the former case, the EMS need to be connected, either via wired connection or wireless, to the Home Area Network (HAN). For controlling flexible appliances, those appliances need also to be connected to the HAN and identified by the EMS. Some new appliances come with wireless or wired connection capability (i.e., also called smart appliances). However, this solution might not be practical since it requires replacing old appliances with new ones. An alternative solution is through the use of smart plugs that allow appliances to be connected to the network without the need of replacing them. Data security should be guaranteed and applied at the different levels through encryption and authentication. The system architecture of the technical component is illustrated in Fig. 2.

4.2. Game design elements

As mentioned earlier in the introduction, the roll-out of smart meters, even when using a well-designed technical system, does not inevitably lead to energy-related behavior change. This requires something more than the installation of meters and related accoutrements [9,35]. The discussed solution for that is to engage residential customers to take an active role in energy applications enabled by smart meters. This can be achieved through the use of gamification that can make those applications more appealing to residential customers, which can give them the willingness to control their energy behavior and make decisions that can lead, for instance, to cost saving and carbon footprint reduction. In this section, a compilation of the most commonly used game design elements based on the various literature and projects in this area is presented and classified into five categories, which are presented in Fig. 3.

4.2.1. Information provision

Information provision, such as statistics, data-driven messages and tips, can give residential customers a clear view of their energy-related behavior and allow them to understand how their actions impact the amount of electricity they use [13,16]. The consumption data can be provided by their smart meter, processed by their EMS and visualized in

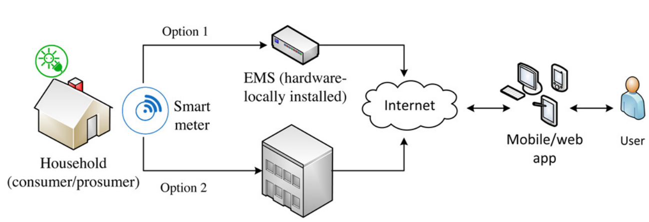

Fig. 2. System architecture of the technical component.

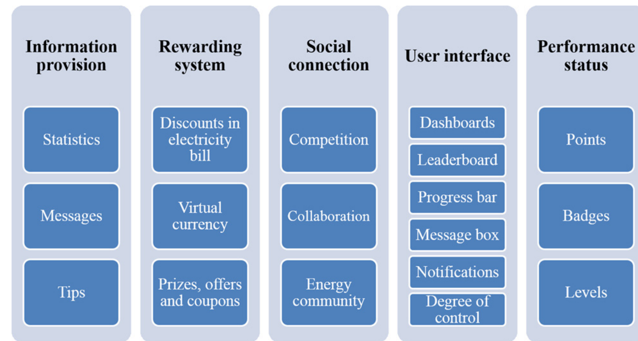

Fig. 3. Game design elements categories for residential energy applications.

their web/mobile applications. Information should be presented using clear and compelling visuals and graphics. Personalized content can help customers better understand their consumption behavior, and educate them about the available options to conserve. Information provision is not restricted to consumption, but it can also visualize information related to energy produced by RESs. Tips and information tailored based on individual needs can result in a better engagement of residential customers and therefore active participation in energy applications. This should be communicated at intervals that customers accept either using their web/mobile applications or via email or text messages.

4.2.2. Rewarding system

Rewarding residential customers based on their energy consumption behavior, effort and impact, can incentivize them to take specific actions and increase satisfaction. This can be practically achieved by assigning a number of credits that is proportional to customer efforts [13]. Residential customers can receive discounts on their electricity bill during, for instance, peaks of electricity production from RESs [37]. The rewarding system could also be designed to award customers virtual currency if they allow, for instance, the EMS to control their flexible load, or if they consume more from their self-produced energy. The rewards can also be prizes, offers and coupons for some leisure activities (e.g., restaurants, concerts, etc). The rewarding system can give potential to residential energy applications, benefit the energy system and give residential customers goals to strive towards.

4.2.3. Social connection

Social connection can make energy applications more fun and appealing to residential customers. This social connection can be in the form of social competition, collaboration or energy community [38]. Competition could be triggered by enabling a residential customer to compare his/her energy performance with another customer of similar household size, with friends, neighbors, and/or with an average household. This can create a normative social influence and bring social aspects into the system. The communication between customers could be linked to social media or using a private web-based or mobile-based platform developed, for instance, by the energy supplier. In addition, there is a trend in on-line gaming, towards collaboration, shared problem solving and on-line connection of players. This is something that gamification can also use in the area of energy. This would mean shift not only from competition to collaboration, but also from solely individual scores and achievements to additional collective scores (e.g., eco-driving applications [14]), and from fixed user roles to user adaptive roles. For instance, collective reduction of energy consumption at peak hours can have great impact on the energy system. In addition, customers can be part of an energy community whose social norms encourage pro-environmental behavior, creating a meaning for their participation in a certain application [39,40].

4.2.4. User interface

The interface of an interactive system greatly influences the motivation of its users. To take a positive effect on customer engagement, the user interface should be designed to not only be perceived as useful or easy to use, but also enjoyable and exciting. This is achieved through an attractive user interface with stimulating visuals and exciting interaction concepts, such as dashboards, message box, notifications, progress bar and leaderboards. Providing residential customers with certain degrees of control and autonomy is also important for gaining customer acceptance and engagement with those systems, such as having different automation settings and allowing residential customers to decide if and when they would like the EMS to control their flexible load [11].

4.2.5. Performance status

Game elements that allow to follow the performance status and progress of customers through, for instance, points, badges and levels, seek to intrinsically change the way they behave and interact with a certain application [13]. As an example, when a residential customer takes an action in an energy application, a specific amount of points can be scored, dependent on its attributes and impact. Badges are visual icons signifying achievements and indicating progress. Levels can refer to ranks acquired by experience and can be related to the amount of points already earned. Each level can be connected to a certain title that virtually describes customer engagement in the application. These titles can also encourage the pro-environmental behavior of residential customers. Further, rewarding systems can be designed as a function of customer performance status (e.g., points).

4.3. Value streams

Using gamification in energy applications can bring significant value streams to residential customers while driving positive and measurable business outcomes for energy suppliers and society as a whole. Therefore, it is important to identify the created value streams and make it clear to the related stakeholders in the energy market. The different value-clusters considered in this section are: (i) value for residential customers, (ii) value for energy suppliers, and (iii) value for society.

4.3.1. Value for residential customers

In order for residential customers to participate and engage in energy applications, they need to be aware of the benefits those applications can bring to them. Literature discussed that economic benefits are considered as a primary interest of residential customers (i.e., mainly through savings in electricity bills) [11,41]. Some game design elements can help increasing customer knowledge about their energy consumption and therefore promote energy conservation. It has been observed in some studies that between 2 and 6% of energy savings can be achieved using only information provision game design element among a sizable number of participants, whereas savings of more than 10% can be achieved in narrowly targeted programs [17]. Gamified energy applications can bring direct benefit to residential customers and compensate them for the inconvenience of, for instance, not being able to use electricity as and when they want. Residential customers are becoming more aware that this inconvenience is providing economic benefits to both suppliers and grid operators, as well as a social benefit through alleviating environmental impact. Therefore, they would expect a fair exchange for their involvement and contribution. This can be achieved through incentives and rewarding systems that compensate customers in proportion to the effort they provide. When the contract is framed this way, residential customers are more likely to trust their suppliers. In addition, this increases the competition between energy suppliers and enables customers to choose from different offers that better adapt to their consumption patterns.

4.3.2. Value for energy suppliers

Since electricity suppliers are generally responsible for the installation of smart meters and the management of metering data, it is important to discuss the benefits they can receive when adopting a gamification-based solution for engaging residential customers in the electricity supply market. Some literature discussed that suppliers can gain considerable benefits from smart meters roll-out by getting closer to their customers, building trust and providing tailored services [4,11,42]. Gamification can help suppliers to enhance their business opportunities by creating new value propositions.

In general, increasing the monetary profit is one of the main goals of energy suppliers. In smart grids, the collaboration between suppliers and grid operators is necessary for reducing the need for grid reinforcement by improving energy efficiency and reducing peak demand that imperil the reliability of the grid. Thus, it is of suppliers' interest to figure out how they can effectively encourage their residential customers to reduce their energy use and be more engaged in energy applications. Some suppliers already promote efficiency directly to customers in messages printed on monthly bills, but those are not exactly game design elements. Behavioral change requires an effective, sustained and smart communication to an engaged audience. When gamification is employed in EMSs, it can help suppliers to analyze customers energy consumption behavior and understand their unique drivers, interests and reactions, which can be used to tailor future communications based on individual needs. This can deliver sustained engagement over time and helps suppliers better understand their customers. Some game design elements (e.g., rewarding system, social connection and performance status) can increase customer flexibility and allow grid operators (i.e., via suppliers) to better manage the distribution networks. For example, if generation capacity were temporarily restricted due to some unforeseen event (e.g., faults or unavailability of RESs), then controlling demand would ensure that those generators available were not overloaded [33,43,44]. To avoid any future problem and increase customer acceptability, agreements and transparency on data usage, honesty and ethical treatment of the data should be ensured.

4.3.3. Value for society

Effective deployment of gamified energy applications can add additional value to societies, leading to a reduced amount of CO_2 emissions which is one of the main EU energy policy objectives. This can be achieved as a result of more efficient use of electricity and higher utilization of RESs [45]. Using the data provided by smart meters, a gamification-based EMS can increase the awareness and knowledge about the environmental outcome of residential customers actions by informing them, for example, about the amount of CO_2 emissions reduction per each kWh of energy saved or consumed from their local RESs. The pro-environmental aspects create a meaning for customers participation in the game, by making them part of a broad initiative towards energy transition and more sustainable world. For instance, one of the gamification elements used in [43] is to assign a title to each energy performance level that virtually describes a user engagement in the system, such as “Consumption newbie”, “Eco Hero”, “Green Mastermind”, etc. Besides, gamification can also help in fostering the diffusion of on-site RESs (e.g., PV systems [19]). This can be done, for instance, by providing credits and rewards for every kWh generated and self-consumed (e.g., the community-based solar electricity reward program SolarCoin [46]).

5. Gamification based energy applications

The main applications where residential customers can be engaged and play an active role, can be classified into three categories: (i) *Energy Efficiency*, (ii) *Self-consumption* and (iii) *Demand Response (DR)*. Fig. 4 provides a graphical illustration of these applications. In the following subsections, we introduce these applications and show the potential of

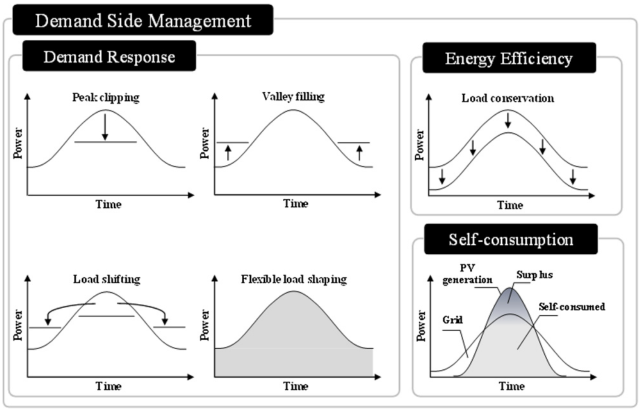

Fig. 4. Energy applications for residential customers.

our gamification-based framework in each application. An overview of recent research activities incorporating gamification for energy-related behavior change in different energy applications is provided in the Appendix and summarized in Table 2.

5.1. Energy efficiency

Energy use in the residential sector accounts for a significant proportion of total greenhouse gas emissions, which makes residential customers an important target group for energy conservation [2,26]. In this context, the European Commission (EC) considers energy efficiency as one of the main driving force for smart metering systems roll-out in residential and commercial buildings [47]. Nevertheless, metering data provided by smart meters, assuming that it is available to customers, is typically generic and it does not provide a tailored insight that can help in engaging customers and increasing their energy efficiency. Using an EMS that employs gamification techniques can provide a meaning for the energy consumption data, and allow to target the different motives that residential customers may have (e.g., economic, social and environmental). This can be achieved at different levels both in the way the electricity is used (i.e., usage behavior), and in the purchase of more energy efficient appliances (i.e., purchase behavior) [48].

Regarding the purchase behavior, using a gamification-based EMS can increase the energy awareness and knowledge of customers by providing insights, possibly in real-time, on the amount of electricity consumed by their electric appliances, comparing their performance with the nominal average demand value of those appliances. A game can recommend the replacement of power-hungry appliances showing the benefit of that on a long run (e.g., replacing light bulbs). In some cases, energy efficiency is not related to the appliance itself. For instance, if the heating, ventilation and air conditioning (HVAC) system is demanding more energy than a normal or an average value, a game can recommend checking the insulation system.

The other way of using gamification is at the usage behavior level. Rather than those major changes, residential customers can be encouraged (e.g., via tips and messages) to use simple tricks and smart practices to lower their energy consumption. This includes actions, such as turning off lights and appliances when not in use (i.e., instead of stand-by mode), reducing the use of ovens, washing at lower temperature, and closing windows and shades on hot summer days [15]. A game can provide incentives by showing the economic and environmental potential resulted from these practices, and encourage good practices (e.g., through a rewarding system and social connection), which can affect customers electricity consumption behavior on the long term.

5.2. Self-consumption

The decreasing cost of photovoltaics (PV) technology has raised the incentives to in-home installation of solar PV panels in many European countries and allowed the EU to set a target of 27% share of RESs by 2030. The idea of self-consumption is that PV-generated electricity is used primarily for local consumption and the surplus electricity is injected into the grid. The injected electricity can be compensated depending on several options that vary between countries or regions [49,50]. Due to the decreasing revenues from the surplus electricity injected into the grid in many countries, as well as the negative effects a large-scale injection of PV energy can cause to the grid, mechanisms promoting self-consumption are becoming increasingly important [50–52]. Storing the surplus PV in energy storage systems (ESSs) or shifting the load from peak periods to periods when local PV energy is available are among the widely used mechanisms for reaching higher self-consumption levels [49,50]. This can provide economic benefits to residential customers and lead to an improved matching between supply and demand at the customer-side which can reduce grid level capacity needs [52].

Storage of electricity can offer important benefits not only to residential customers but also to the energy system. However, equipping each household with an on-site ESS might be economically unaffordable due to the high cost of batteries which are required to buffer sufficient renewable energy for an average household daily energy consumption [53,52]. Load scheduling can be an affordable solution for increasing self-consumption since it is less expensive to intelligently influence a load, than to install an ESS or to expand the distribution network infrastructure in order to cope with the increasing electricity injected into the grid [54]. Load scheduling is typically enabled by an EMS that is connected to the PV system, controllable electric load, and smart meter.

Using a gamification-based EMS can increase customers awareness and knowledge about the importance of self-consumption and give incentives and self-control for increasing their participation. Information provision (e.g., feedback and tips) is a simple yet effective game design element that can raise customers awareness and knowledge of their energy consumption and generation. Other game design elements (e.g., rewarding systems and performance status) can increase customers flexibility in shifting their controllable load to times when their locally produced solar energy is available. A game can set targets and gives incentives to a customer when, for instance, a certain level of self-consumption is achieved. The social influence can also be incorporated in the game either in the form of collaboration (e.g., self-consumption at a neighborhood level), energy community (e.g., by allowing a customer to be part of a community whose social norms encourage pro-environmental behavior), or competition (e.g., by comparing a customer self-consumption level with other customers). This can make the participation more appealing and fun to customers. A gamified user interface that provides different automation settings and allows a customer to decide if and when the EMS is set to control the flexible load (e.g., choosing from full automation to least system control), gives the customer a self-control over the level of automation he/she delegates to the system.

5.3. Demand response

DR programs are designed to incentivize end-users to alter their short-term electricity use patterns [55]. Participants can take actions in response to a DR program by means of load management schemes (see Fig. 4), such as demand limiting, demand shedding, and demand shifting [56]. DR programs are employed by electricity system planners, market parties and operators as resource options for market optimization, balancing supply and demand, increased integration of RESs, and ensuring system security. Recently, an increasing focus of DR is placed on the residential sector motivated by the vision of future homes with

Table 2
Relevant European research and innovation projects.

Project name (Acronym)	Duration	Applications	Game design elements	References
Power Agent	2007	Energy efficiency	Information provision, Rewarding system, Social connection, User interface, Performance status	[59,60]
Power Explorer	2008–2009	Energy efficiency	Information provision, Rewarding system, Social connection, User interface, Performance status	[61,62]
Micro-Request-Based Aggregation, Forecasting and Scheduling of Energy Demand, Supply and Distribution (MIRABEL)	2010–2013	Energy Efficiency, Demand response (residential customers defining their flexibility for demand dispatch)	Information provision, Rewarding system, Social connection, User interface, Performance status	[63]
Energy Battle	2012	Energy efficiency	Information provision, Rewarding system, Social connection, User interface	[16]
Smart Consumer, Smart Customer, Smart Citizen (S3C)	2012–2015	Energy efficiency, Demand response	Information provision, Social connection, User interface, Performance status	[64]
New media for top informed consumers regarding sustainable and energy efficient products (Efficiency 2.1)	2013–2016	Energy efficiency	Information provision, Rewarding system, Social connection, User interface, Performance status	[65]
District Information Modelling and Management for Energy Reduction (DIMMER)	2013–2016	Energy efficiency	Information provision, Social connection, User interface, Performance status	[66]
Gamification in a household energy game (Powersaver Game)	2014–2018	Energy efficiency	Information provision, Social connection, User interface	[15]
ORganizational Behavior improvement for Energy Efficient adminisTrative public offices (OrbEEt)	2015-2018	Energy efficiency	Information provision, Rewarding system, Social connection, User interface	[67]
Energy Game for Awareness of energy efficiency in social housing communities (EnerGAware)	2015–2018	Energy efficiency	Information provision, Rewarding system, Social connection, User interface, Performance status	[68]
Game to promote energy efficiency actions (GreenPlay)	2015-2018	Energy efficiency	Information provision, Rewarding system, User interface	[69]
TRaIning Behaviors towards Energy efficiency: Play it (TRIBE)	2015-2018	Energy efficiency	Information provision, Social connection, User interface	[70]
Design of an Innovative energy-aware IT ecosystem for motivating behavioral changes towards the adoption of energy efficient lifestyles (ENTROPY)	2015–2018	Energy efficiency	Information provision, Rewarding system, Social connection, User interface, Performance status	[71]
Energy Consumption Gamified – Greenely Feasibility Study (ECGGFS)	2016–2017	Energy efficiency	Information provision, Social connection, User interface	[72]
PARticipatory platform for sustainable ENergy management (PARENT)	2016–2019	Energy efficiency, Self-consumption	Information provision, Rewarding system, Social connection, User interface, Performance status	[73]
Personal Energy Administration Kiosk application: an ICT-ecosystem for Energy Savings through behavioral Change, Flexible Tariffs and Fun (PEAKapp)	2016–2019	Energy efficiency, Demand response (dynamic pricing system offering discounts during peaks of electricity production from RES)	Information provision, Rewarding system, Social connection, User interface	[37]
DR in Blocks of Buildings (DR.BOB)	2016–2019	Energy efficiency, Demand response (change the timing of electricity use or reduce energy in order to reduce energy bills)	User interface	[74]
CleAnweb Gamified Energy Disaggregation (ChArGED)	2016–2019	Energy efficiency, self-consumption (use locally produced energy when available and reduce consumption when most power comes from the grid)	Information provision, Social connection, User interface	[75]
Eco-aware Persuasive Networked Data Devices for User Engagement in Energy Efficiency (GREENSOUL)	2016–2019	Energy efficiency	Information provision, Social connection, User interface	[76]

smart appliances that allow their control and integration in EMSs [57]. The Council of European Regulators regards the participation of residential customers in the electricity supply market as essential, and realizing the flexibility potential of the demand-side provides a pathway to enhancing their participation [58]. DR has also been suggested by different studies as one of the important mechanisms for reaching higher self-consumption levels [38,51,50]. In a DR program, customers define their flexibility for controllable load and submit that, through a mobile/web application, to their EMS. The EMS automatically maintains an execution schedule under consideration of the most beneficial exertion of demand flexibility (e.g., balancing demand and supply).

Using a gamification-based solution can encourage residential customers to provide high flexibility and actively participate in DR programs. This can be achieved using different game design elements. Providing information (e.g., statistics, messages and tips) can increase customers awareness and knowledge about the effects of their demand flexibility in enhancing grid efficiency and improving the utilization of RESs at the generation side. Having a high degree of autonomy in defining demand flexibility is important for residential customers to participate in a DR program. However, customers can be incentivized to actively participate and increase their flexibility using a rewarding system, that can be a function of the duration and time of the provided flexibility. Negotiating this flexibility, via suppliers and possibly on a collective base, can be very beneficial to the energy system especially in situations when slight extensions of a flexible period are assumed to allow a better grid optimization. Therefore, customers can be offered to extend or shift their flexibility to a more appreciated position for an extra reward or extra points. A game can also target the environmental motives of residential customers, by informing them about the amount of CO_2 emissions reduction resulted from their demand flexibility. This can be shown in the user interface either on an individual basis, or on a collective basis for a group of customers in a community. For instance, in the DR application presented in [43], titles that have pro-environmental indications are assigned to customers according to their level of participation.

6. Conclusions

This study presents an interdisciplinary framework for residential customers engagement and participation in energy applications. The study starts by establishing a behavior change model for the framework, the Transtheoretical Model (TTM), that identifies the main requirements necessary to achieve the goals of the framework. To fulfill those requirements, the study presents the required technical system architecture. Then, game design elements that can be employed in the technical system are presented and classified into five categories. After that, the study identifies the value streams to different stakeholders in the energy market when using the proposed solution. Finally, the study discusses the potential of the proposed framework in each application, and provides a survey of a number of European research and innovation projects (see Appendix A) that shows the trend of using gamification in this area.

The use of gamification, as a social mechanism, in this area could be justified by two main reasons: (i) the EU recommendations that explicitly mention the importance of residential customers engagement in the efficient planning and use of electricity using smart metering systems, and (ii) the fact that smart metering systems alone do not necessarily drive residential customers to use energy in a more sustainable manner. Therefore, more attention is now being paid to customer engagement in addition to technology. A discussion of the proposed framework in different energy applications shows that, in addition to a well-designed technical system, gamification is a key component for driving customers energy-related behavioral change and increasing their participation.

A survey of the research projects in this area reveals that the main focus of past projects was on applications targeting energy efficiency, whereas DR and self-consumption applications are gaining more attention in recent years. This trend is expected to continue in the future, in parallel with the further development of DR mechanisms and distributed ESSs, as well as with the further integration of RESs at the demand-side which require active control and energy management solutions. Our proposed framework can provide a unified view about the requirements and different components that constitute a gamification-based solution for new projects in this area which focus on residential customer participation and engagement.

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Appendix A. Relevant research and innovation projects

The employment of gamification for residential customers engagement in energy-related applications is getting increasing attention in research and development activities in Europe. A search into relevant databases reveals a significant number of projects related to this area. In this section, a survey of relevant European research and innovation projects is conducted based on the following databases: the CORDIS database [77] (i.e., the EC's primary portal for results of EU-funded research projects), the website of the Joint Programming Initiatives (JPI) Urban Europe [78] (i.e., an instrument designed for the implementation of the European Research Area (ERA) which aims to promote strategic cooperation between EU member states and associated countries), the projects database of the Intelligent Energy Europe (IEE) program [79] (i.e., IEE was launched in 2003 by the EC to support EU energy efficiency and renewable energy policies, and since 2014 it has been integrated into the Horizon 2020 program), and the Utrecht Center for Game Research [80]. An overview of the surveyed projects is provided in Table 2, where the targeted energy applications and the employed game design elements are outlined. The objective of the surveyed projects is mainly focused on achieving residential customers behavioral change towards a more sustainable lifestyle and more active participation and engagement in energy-related applications.

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