Tutorial Serious Game for Demonstrating Demand Response in an Energy Community

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***Abstract*—Energy communities have raised public interest as the world moves toward carbon neutrality. However, many laypeople find the concepts of electricity and energy difficult to grasp. Serious games are games that are designed both to entertain and educate, and they can be used to teach various things, energy among them. This paper describes the design of a prototype serious game where energy communities are tutored for the player. The developed game presents demand response as a game element in a simulated energy community with a shared photovoltaic installation, which suggests that serious gaming can be used to teach people about how energy communities work. When designing a serious game, multiple different gameplay and player engagement elements and intrinsic design should be considered so that different kinds of players can learn best through the game.**

***Index Terms*—Energy community, Solar energy, Smart grid, Serious games, Demand Response**

I. Introduction

Energy saving and ways to cut down on energy costs have become hot topics worldwide. Local energy production methods like photovoltaic (PV) installations have seen an increase in demand, as they can be used to counteract the rising cost of electrical energy by reducing the need for energy purchased from the market. Solar energy has become more affordable as PV technologies have improved [1]. However, a crucial drawback in PV installations is that they only provide energy during high solar irradiance. This happens usually during midday, when domestic energy usage is not at its peak. To utilize this potential, either the energy has to be stored or the consumption has to be shifted to better match the PV generation. Yet, because of the high cost of energy storage systems, it can be argued that the most optimal way to efficiently use a PV installation is to maximize self-consumption by shifting the consumption to times when there is PV energy available.

Successful demand response requires knowledge [2] and active participation of people to gain the most value out of their PV installation. People need to actively monitor the production and consumption values by using smart meters and data visualization tools or have enough knowledge and resources to invest in automation. However, the concepts of electrical energy can be difficult to grasp for laypeople [3], [4]. Many people can find it hard to understand the units of kilowatt and kilowatt-hour [5]. The problem of complexity is emphasized when shared energy resources, such as co-owned PV installations in the form of energy communities, are introduced. Understanding how the produced energy is shared between the owners of the installation can be difficult.

As a possible tool for helping people understand the concepts, *serious gaming* has gained popularity in recent years. According to the definition given in [6], a serious game is *“a digital game created with the intention to entertain and to achieve at least one additional goal (e.g., learning or health).”* In other words, a serious game is a game the purpose of which is not pure entertainment. Serious games can come in many forms, ranging from physical to digital ones. Video games have gained in popularity ever since home computers became available, and especially over the past decade, the availability of smartphones has lowered the threshold for playing different kinds of games. Serious games and *gamification* (adding game elements to something that originally is not a game [6]) are recent growing trends, and they have also been used to train people on energy aspects [7]–[9]. However, in [9], it is shown that there is a research gap on serious games about energy: a game that features demand response and shared energy resources and is based on real-world situations (e.g., employs real-world data) has not yet been implemented. This paper aims to demonstrate that demand response can be used as a game mechanic with a prototype serious game, which can thus be used to educate people on demand response and efficient use of shared energy resources in an energy community. The paper also discusses how different elements of the game can affect the gaming experience of the prototype and how the game could be developed further.

II. Background

Video games can be considered related to television programs, and they can also be argued to be the next step from (educational) television programs [10]. Video games are more interactive than television and allow introduction of new concepts, event recreation, and motivation to learn without being aware of it [10]. Games can have educational aspects even if they are not particularly intended for educational use. As an example, [10] mentions *Cooking Mama*, a game where the player prepares food for fun rather than because of wanting to learn how to cook. This is a common feature in serious gaming: in this case, the player actually learns cooking while being entertained. Serious games come in various forms and

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Fig. 1. Screenshot of the developed serious game. From the screenshot, you can see the avatar needs (1), the current in-game time and score (2), the current in-game date and temperature information (3), the player avatar (4), the current power usage (5), and the total PV installation production (6).

can be categorized by, e.g., educational objective, learning principle, and age of the target audience [11].

Serious games in energy are shown to be an effective method of influencing the players on their domestic energy consumption [7]. They vary from simple energy saving quizzes for children to more complex energy sharing simulators where players must cooperate and use a shared and limited energy source [9]. Demand response itself can be a difficult task to comprehend, and introducing shared PV resources and an energy community makes the system even more complex. Serious games have been made to promote these kinds of arrangements [12]–[15]. However, the kind of serious game where the game involves demand response, an energy community, and real-life data has not yet been developed [9].

A. Design Considerations

The development of digital games can be roughly characterized into three phases: conception, design, and production [16]. The design of a serious game is important because the players of a serious game are said to only be recipients of the gamified project [17], and the success of reaching educational targets thus relies on the quality of the gamified experience. Serious games promote learning in different ways. In [18], the different types of learning in serious gaming are differentiated: learning takes place both in-game by information gathering and reacting to stimuli, and also through playing the game when making decisions in real life by relating to the data the players have collected when playing the game. To achieve the learning aspect of the game, the educational content has to be embedded in it. An arguably low-effort method for this is extrinsic design, where the main game content is interrupted with a learning task [6]. An example of this kind of serious game design is interrupting the gameplay sequence of a controllable character-based game with a quiz session. This kind of content can be seen as annoying and blocking the main content, and intrinsic design is preferred, which means that the gameplay itself is educational (like, e.g., in simulator games) [6] This can also sometimes take the form of *stealth learning*, where the serious content of the game is hidden [6]. Players disliking and rejecting games just because they are labelled educational are also an identified phenomenon [11].

III. Results

A. Game Prototype

Serious games can take various forms, and it may not be self-evident which kind of game would be best to reach the target. Intrinsic design and utilization of stealth learning are shown to be desirable design features, and if the game is targeted to a player who lives in an energy community where shared energy resources are available, the player of the game can learn intrinsically through the game if the scenario in the game is close enough to their own life. Therefore, a *life simulator* serious game prototype titled *EcoDream* (Fig. 1) was developed. In the game, the player takes control of a virtual avatar and experiences the avatar's daily life. To make the world relatable, the apartment should match the player's actual place of residence as closely as reasonably possible. However, making the game world exactly similar to the player's own home is not a viable option, because it would require tailoring the game for each player. Instead, our target was to replicate the most common appliances and features that one may find in a typical Finnish / North European apartment. In this way, the player of the game learns through the game by playing the daily life of a virtual avatar, who does not necessarily have to be a virtual representation of their own life. The possible activities that the avatar can engage in have to be common so that the player of the game knows what each appliance does and what has to be done at a given moment. However, the activities have to be versatile in order to not make the game boring.

The core target of the game is to take care of the player avatar while using as little *money* on energy as possible. Like in *The Sims* franchise, the player avatar has basic *needs* that have to be catered for. These needs indicate the condition of the player and how well they are doing. The needs include *food*, *endurance*, *fun*, *hygiene*, *comfort*, and *social interaction*. The level of the needs will deplete slowly over time at a fixed rate. A few exceptions are that when asleep, the endurance level rises rather than decreases, and an apartment temperature greater than 22 °C causes a fast decrease in comfort. The player has to engage in activities (Table I) to cater for these needs. This requires energy, which causes expenses depending on the amount of energy consumed, the current energy cost, and the current allocated PV energy to the avatar's apartment. The player is free to choose which activities they engage in, except that the avatar is required to go to work every weekday (i.e., not on Saturdays or Sundays). The avatar has to go to work between 8:00 and 9:00 hrs in the morning in order to

TABLE I
INTERACTIVE OBJECTS AND THEIR EFFECTS IN THE GAME. THE AVATAR NEEDS THAT ARE AFFECTED ARE ITALICIZED.

Object/Activity	Effect	Power [W]	Notes
Bed	+ *Endurance*, + *Comfort*; Halt *Food* & *Fun* depletion	0	Available if *Endurance* $< 50\%$
Alarm clock	Allows the avatar to be woken up at a selected time	1	
Computer	+ *Fun* (Internet) or + *Fun*, + *Social interaction* (Game)	$100^a/400^b$	^{a} Internet, ^{b} Gaming
Television	++ *Fun*	125	Requires sitting on the sofa
Sofa	+ *Comfort*	0	
Stove & oven	+/++/+++ *Food*	1000/2000/3000	Power and *Food* increase depend on meal
Refrigerator	Allows selection of the meal to be cooked	20	Requires clean dishes
Dishwasher	Washes dishes	$850^a/50^b$	When ^{a} washing, ^{b} keeping dishes warm
Coffee maker	+ *Endurance*	$900^a/50^b$	When ^{a} brewing, ^{b} keeping pot warm
Washing machine	Washes clothes	250	Available if laundry in the basket
Shower	+ *Hygiene*	0	Available if room in the laundry basket
Air conditioning	Reduces the apartment temperature	1300	If room temperature is above set point
Lights	Illuminates the room if dark	$10–30^a$	^{a} 10 W per room
Vacuum cleaner	Cleans dust	900	
Door	+ *Social interaction* (Friend); + *Fun*, – *Hygiene*, – *Endurance* (Exercise); – *Fun*, – *Comfort* (Work)	0	On weekdays, the avatar has to work

get there in time. If any of the need levels reaches zero, the game session ends in a failure.

B. In-Game Energy Community

The game avatar lives in a single-bedroom apartment that is part of an energy community having a shared PV installation. The apartment consists of a bedroom, a living room with a kitchenette, and a bathroom. The energy community is arranged like in [19]: the energy community is based on a multifamily residential building where the residences are behind a single connection point to the distribution network. They co-own a PV installation, and the intracommunal network service fees are waived (i.e., the transfer of energy from the PV installation to the residences for their own consumption is free). The initial investment in the PV installation is shared between the apartments and can be considered part of the cost of the apartment itself. The system is based on simple energy sharing, where the produced PV energy is first used in the common property of the building (e.g., ventilation and hallway lighting), and the remainder is allocated so that every apartment is given a fixed ratio of their energy consumption as PV energy. The ratio of PV energy R_{PV_i} is calculated by:

$$R_{\mathrm{PV}_i} = \frac{E_{\mathrm{PV}} - E_{\mathrm{C}}}{\sum E_{\mathrm{A}_i}} \tag{1}$$

where E_{PV} is the hourly PV energy production, E_{C} is the hourly energy consumption of the common property of the building, and $\sum E_{\mathrm{A}_i}$ is the sum of the energy consumptions of all the apartments in the building. If $R_{\mathrm{PV}_i} > 0$, there is an excess of PV energy after supplying the common property, and the PV energy allocated to each apartment $E_{\mathrm{PV,A}_i}$ can then be calculated by:

$$E_{\mathrm{PV,A}_i} = E_{\mathrm{A}_i} R_{\mathrm{PV}_i} \tag{2}$$

where E_{A_i} is the hourly energy consumption of each apartment. The billed cost of hourly energy C_{B_i} can then be calculated by:

$$C_{\mathrm{B}_i} = T_{\mathrm{E}}(E_{\mathrm{A}_i} - E_{\mathrm{PV,A}_i}) \tag{3}$$

where T_{E} is the current hourly grid energy tariff (i.e., the cost of energy per kilowatt-hour). In a situation of full surplus where the PV production exceeds the consumption of the building, the remaining energy is sold to the grid. The revenue received from the sold energy can be used, e.g., to fund the maintenance and renovations of the building and its common property. It is worth mentioning that the arrangement described in [19] is, by no means, the only viable option to design an energy distribution and allocation infrastructure. The arrangement promotes simplicity to make it as understandable for laypeople as possible. To ensure the simulation accuracy and to close the research gap identified in [9], a real source of a data is employed for the simulation. The energy consumption data used to simulate the neighbor apartments is from real Finnish homes, and PV production data from the PV installation of the author's university is used to simulate the production of the PV installation of the building in the game world.

C. Demand Response as a Game Mechanic

As the player caters for the avatar, they can observe the power system status screen (Fig. 2), which displays the current electrical energy consumption of the player's apartment and a graph displaying it over time, as well as the cumulative energy consumption and its cost. The other side of the screen displays the hourly solar panel output values and the hourly cost of electrical energy, along with the ratio of energy obtained from the PV installation during the last passed hour. In this way, the player can optimize their energy use.

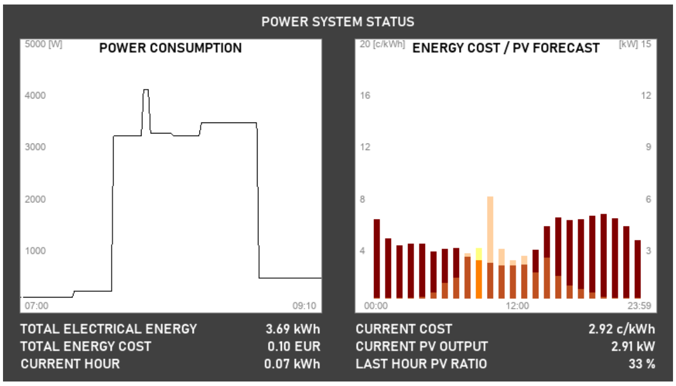

Fig. 2. Power system status screen of the game (screenshot cropped for better viewing). The left-side graph displays the virtual apartment power consumption over time. The right-side graph shows the hourly solar production forecast (orange/yellow) and the hourly energy cost (cyan) for the current day.

Video games can motivate the player by showing them their progression and accomplishments. This can be done by, e.g., visual or auditory feedback. Making progress and getting rewarded by it keeps the player's interest in the game and relieves boredom, if the players are kept motivated to continue playing. This is also true for serious games. In order to keep the player motivated to keep learning and thereby make an effect on real life (e.g., in energy consumption habits), the player should be kept both entertained and rewarded. An advantage of serious games is the opportunity to have an effect on the player's life outside of the game world, and the player can feel rewarded in that way (e.g., by receiving a small electricity bill). However, this effect can be delayed and too slow to act as an engaging reward, suggesting that in-game rewarding is vital for a serious game.

The motivational effectiveness of different kinds of game elements depends on the player, and it is suggested that the elements should be chosen for each game individually to fit the target audience of the game [20]. Virtual collectables, such as achievements, trophies, and badges, are often used to keep the player motivated, and they are said to also have a higher educational impact than, e.g., educational messages [21]. On the other hand, feedback messages in the form of instant positive feedback are identified as valid forms of reward [22]. A classic and sometimes effective way known from arcade video games is a scoring system that the players can use to compare their performance with a baseline or against other players. Achievements and scoring systems are categorized as glory rewards [22], and leaderboards are said to be impactful as they both promote competitiveness and give praise for good performance [23]. Therefore, the main method of player engagement in the prototype game is a scoring system and a leaderboard, where the player score is posted after one in-game week. One real-life minute represents one in-game hour. The player is given points for each in-game hour based on the needs of the player's avatar and the cost of energy used in the past in-game hour. The well-being of the avatar increases the given score, and the money used to cater for the needs reduces it. The amount of points awarded for the passed in-game hour P is calculated after each passed in-game hour by:

$$P = \frac{\min(N_i)}{C_{\mathrm{B}_i} + 0.1} \tag{4}$$

where $\min(N_i)$ is the minimum value of all the avatar needs during the end of the in-game hour, and C_{B_i} is the billed cost of energy used in the in-game past hour calculated using (1), (2), and (3). The constant 0.1 is present in the equation to avoid division by zero error. This kind of scoring system promotes on-demand response by making the energy consumption, energy cost, PV production, and the avatar well-being affect the score. Getting a good score indicates successful demand response, and the player can reflect on the game results and experiences when pondering their energy usage practices in real life. If the scoring system was based to track energy consumption (and avatar well-being) instead of energy cost, the player would then not need to consider the dynamic pricing of the energy. Furthermore, if the scoring was purely based on using as little energy as possible ignoring the avatar well-being, the game would not present as a viable representation of a person's real life, because it is unlikely that people would like to make their lives miserable to reach ultimate monetary and/or energy savings.

Game difficulty by, e.g., introducing punishment features in the game when played poorly, is also shown to have an effect on getting the player into a "flow" state [24]. The game ends when the avatar needs are neglected, which as a punishing game mechanic forces the player to consider their actions. Punishing and rewarding elements in a game guide how the player is encouraged to play the game and show the player what the game is actually about [25]. The rewarding elements have to both incentivize the player to keep playing and also guide the player to make good choices.

IV. Discussion

For a serious game to be effective in teaching its players about energy and how to optimize their energy usage in an energy community, the game has to make concepts that are difficult to grasp easily understandable. It must show the consequences of a player's actions so that they can learn through their mistakes and successes, which is best achieved by intrinsic design and stealth learning. Various game elements can be used to promote player engagement in this (stealth) learning process, but in the case of a life simulator game, a scoring system with a leaderboard can be considered viable. The leaderboard could be complemented with an achievement system to stimulate both competitive and completive players.

Besides individuals who can gain monetary benefit by learning how to save money spent on energy, electric companies and distribution system operators could also be interested in a game that teaches their customers demand response. Although the companies will gladly sell energy and offer distribution services, the customers taking part in demand response by, e.g., peak shaving can be beneficial also for the energy company and the distribution system operator. A lower peak demand ensures that there is reasonably priced energy for both the consumer to use and for the energy company to sell (e.g., by means of the energy company's own production or quotas of purchased low-cost energy). It also results in less stress for the distribution infrastructure.

V. Conclusion

The serious game prototype, EcoDream, is a life simulator game where the player controls an avatar representing a resident in a multifamily residential building. The game uses demand response as a game mechanic so that the player learns through the game and experiments to find out the best thing to do in each situation to optimize their energy usage and expenses. The player is kept engaged in the game by reward mechanics and a scoring system that gives the player points for catering for the needs of their game avatar while using as little money on energy as possible for that purpose. The scoring system is kept motivational by introducing competitiveness with a leaderboard. A poor performance results in a low score, and as a punishing game mechanic, playing very badly will result in the game ending. The game is made to match real-life situations by using an offline database of energy consumption and solar production data of actual residences and a campus PV installation. This feature could be developed further by implementing a more direct link to real life by, e.g., employing real-time temperature and solar irradiance data as a game mechanic. In an ideal situation, even appliance-specific energy consumption data could be used, although this may not be possible in reality. However, even with real-time weather information, the player could have the opportunity to react to the current weather situation. This was, however, left out from this prototype version as it would require tailoring the game to a specific audience. This paper identified the prospective features for a serious game for teaching demand response in energy communities with shared PV installations. As a continuation, further empirical studies will be conducted to assess the effectiveness of the game in detail.

Acknowledgment

We thank the DSO Lappeenrannan Energia Oy for providing the energy consumption data for this research.

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