IEEE Access
Multidisciplinary ⁝ Rapid Review ⁝ Open Access Journal

Received 12 August 2022, accepted 20 August 2022, date of publication 26 August 2022, date of current version 2 September 2022.
Digital Object Identifier 10.1109/ACCESS.2022.3202013

TOPICAL REVIEW

Review of Demand Response and Energy Communities in Serious Games

MIKKO NYKYRI, (Member, IEEE), TOMMI J. KÄRKKÄINEN, (Member, IEEE), SALLA ANNALA, AND PERTTI SILVENTOINEN, (Member, IEEE)
School of Energy Systems, Lappeenranta University of Technology (LUT), 53850 Lappeenranta, Finland
Corresponding author: Mikko Nykyri (mikko.nykyri@lut.fi)

This work was supported in part by the Finnish National Research Funding Organization Business Finland through the Project SolarX.

ABSTRACT Shared energy resources and energy communities are being widely studied and pilots are being implemented in various locations around the world. However, laypeople may find the concepts regarding energy and electricity in general difficult to grasp, and the issue is made more complex by introducing new aspects like demand response and shared photovoltaic (PV) installations. Serious games are proposed as a tool for raising awareness, and this paper presents a systematic literature review on serious games featuring energy and electricity aspects while giving extra attention to whether a serious game has features considering demand response or energy communities. The results are used to determine whether research gaps exist, and if a serious game featuring energy communities and demand response would be meaningful to develop. In total, 34 games were identified, four of which had demand response aspects and five of which had aspects considering energy communities or shared energy resources. None of the games featured both aspects while having a link to real-life events by, e.g., making the energy consumption of the player's home affect the outcome of the game. This emphasizes the fact that the concepts are new, and a serious game covering them could be implemented.

INDEX TERMS Demand response, energy community, energy resources, serious games, solar energy.

I. INTRODUCTION

Energy communities and local energy production are gaining interest worldwide as the demand for fossil-free energy increases and advancements in photovoltaic (PV) technologies make PV installations more efficient [1]. Local energy production, such as different kinds of PV installation implementations are being widely studied to find the most feasible PV arrangements around the world. These include various systems, such as small-scale PV systems in detached households and shared larger installations in, e.g., multifamily residential buildings. However, a major problem with local PV installations is that they produce energy only during high solar irradiance, which happens often during midday when the demand for domestic energy is usually low. In such situations there may be an oversupply of PV production, which will end up being sold to the grid. This is inefficient because of the imbalance of the pricing of bought and sold energy. For instance in the Nordic countries, selling energy to the grid yields approx. one-third of the cost of buying the same amount of energy. To minimize the negative effects of this imbalance, PV installations tend to be dimensioned to be of a low capacity to reduce both the initial investment and the amount of ''wasted'' energy being sold to the grid [2]. To counter this problem, the excess energy from a PV installation would have to be either stored or shared, or the consumption habits would have to be altered with demand response so that more energy is used when more PV energy is available.

As a solution, energy communities have been proposed as a viable technical framework for situations where PV energy is to be shared from a co-owned source. The concept of an energy community is backed by the legislation of the European Union (EU), but energy communities are not yet common due to their novelty; the EU Directives (which are to be implemented in the national legislation of

The associate editor coordinating the review of this manuscript and approving it for publication was Z. G. Zang.

the EU Member States) considering energy communities are from 2018 and 2019 [3], [4]. An energy community allows an energy resource, such as a PV installation, to be shared between people living in different residences. An energy community could be set up, e.g., in a multifamily residential building or other kind of shared housing solution where the locally produced energy is not fully owned by a single residence. Research is also being made on different methods to store the excess energy, but current battery energy storage systems are not always economically viable solutions [5], [6]. Therefore, it can be argued that the easiest way to increase the efficiency of the usage of locally produced solar energy is to maximize self-consumption by engaging in demand response, within or without an energy community.

Despite the improvements in infrastructure and the emergence of new concepts, the technical solutions of how any energy produced by a co-owned PV installation is shared between the residents of the community can be, depending on the situation, rather complex. Many people tend to feel the concepts of energy and electricity difficult to understand properly [7], [8]. Therefore, if people find the concepts complicated in conventional living arrangements where there are no complex or sophisticated energy sharing systems in place, questions are raised of how well the members of energy communities would understand any PV energy sharing and allocation principles. The same goes for demand response: it may prove to be complicated for the residents to understand what demand response is, how it can be performed, and why it is beneficial. People may need to be advised about these subjects to best utilize any shared PV system they have access to. Despite these challenges, consumers are expected to adopt a larger role in the energy system (see, e.g., [9]). Thus, there is a need to increase consumers' awareness of energy issues, and demand response and energy communities in particular.

A. SERIOUS GAMES IN ENERGY

Video games are very popular, and playing digital games has become more and more common ever since home computers became affordable. Over the past decade, the emergence of smartphones has accelerated the demand for video games, as suddenly many people own a gaming-capable personal device. Especially casual, low-threshold mobile gaming has gained immense popularity in recent years. One subtype of video games is *serious games*, which are a prospective and increasingly popular platform for educating people. A serious game is defined in [10] as *"a digital game created with the intention to entertain and to achieve at least one additional goal (e.g., learning or health)."* Another often used term when discussing serious games is *gamification*, which means adding game elements to something that originally is not a game [10]. Gamification is a popular trend and can be seen, e.g., in the language learning platform Duolingo [11]. Serious games that gamify real-life phenomena can be used to teach or coach people, e.g., in their energy consumption habits, and they can be instructed to act in a certain manner while simultaneously being entertained by the digital game. The player could then be rewarded either in real life by a benefit, such as affordable PV energy and a decrease in the electric bill, or in-game while simultaneously teaching the player optimal energy consumption habits to be later adopted in real life, thus indirectly rewarding the player for good choices and playing well.

Serious games in the field of energy are not new, and numerous studies on their effectiveness have been made (e.g. [12], [13], [14]). In [15] it is said that serious games have a great potential to make smart energy tools more effective, but gamification and game design elements are underutilized in real world applications. Furthermore, more specific aspects of electrical energy usage and distribution, such as energy communities and demand response, are more recent and have not reached their full deployment among the general public. As performing demand response and optimizing the value out of an energy community participation requires active involvement and usually requires behavioral change, gamification and serious games are suggested as tools for promoting demand response [16], [17], [18], [19] and energy communities [17]. Because these concepts can be difficult to understand, the motivation for this study is to find out what kind of a serious game for raising awareness of demand response and utilization of shared PV resources in an energy community could be developed. A player of a serious game could, e.g., learn to optimize their energy consumption to happen during the most suitable time of the day, understand better the energy allocation and sharing logic of a shared PV system, and become acquainted with the modern smart grid and distributed energy production infrastructure.

This paper presents a systematic literature review on serious games for demand response and energy communities. The target of the research is to survey the state of the art on the subject, identify and present research gaps in the literature, and conclude what kinds of aspects a serious game covering any possible research gaps should contain and whether it would be meaningful to develop the game or not.

II. METHODS

The review was conducted as a systematic literature review, following the principles of PRISMA described in [20]. A systematic review is performed by systematically identifying records from a database or databases and assessing the records retrieved until relevant studies remain. Although originally developed for medical research, PRISMA is regarded as a valid tool for systematic literature reviews also in other fields of study [20].

For the sources for the records, *IEEE Xplore* and *Scopus* databases were selected. Serious games are a wide field, and thus, in order to retrieve records of studies on serious games and energy or electricity, the search terms were set so that only articles that match both criteria were selected. The database search was performed using the following

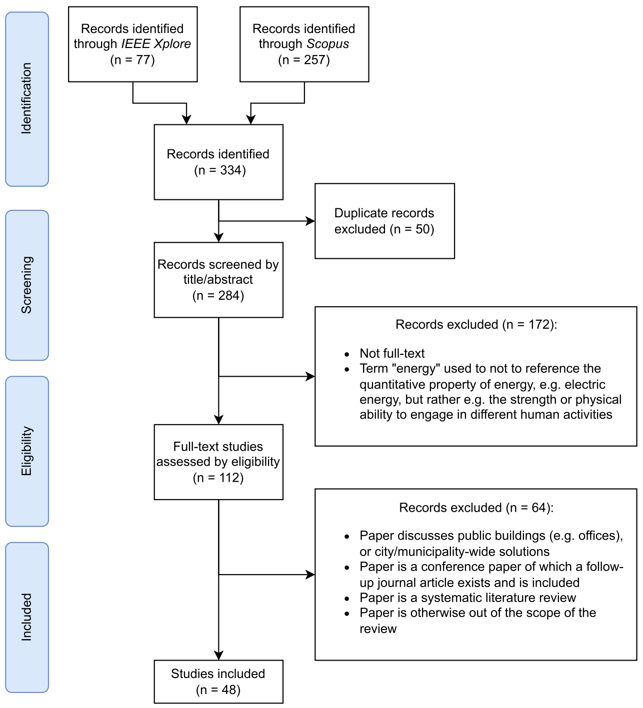

FIGURE 1. **PRISMA flowchart of the systematic review.**

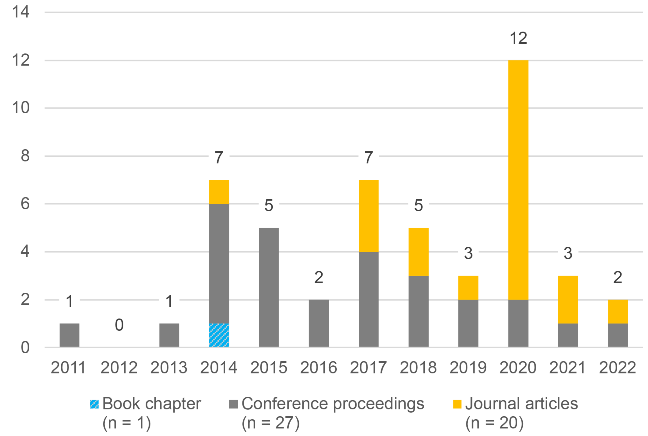

FIGURE 2. **Distribution of years of publication and types of publication. The publication year of the records ranged between 2011 and 2022. Most of the records were published in 2020 (n = 12).**

query to include results with both *serious game* and *serious games*, and either with mentions on *energy* or *electricity*, or both:

```
``serious game*'' AND (energy OR electricity)
```

The search was performed on March 28, 2022, and it resulted in 77 hits in IEEE Xplore and 257 hits in Scopus. After removing duplicate records, 284 unique ones were obtained. The search terms were selected so that they will most likely result in the major proportion of articles within the scope of this review and viable studies will unlikely be left out. On the other hand, as the search terms are broad, the query will likely result in some records that are outside the scope of this review (e.g., considering other forms of energy than electrical energy). These are, however, easy to exclude manually.

The obtained records were screened by title and abstract, and a number of records were excluded (n = 172) on the basis of either being outside the scope of this review or being not full-text papers, such as being index listings of conference proceedings or abstracts only. A common reason for exclusion in this step was that the search term "energy" is also used to refer to a property of something, e.g., strength or ability to engage in various physical activities. Within the scope of this paper, "energy" includes electricity consumed in homes and apartment buildings, which may be complemented by district heating or heating fuels. After this first screening, the remaining articles (n = 112) were assessed for eligibility. Out of these records, a number of articles (n = 64) were excluded, although considering energy and/or electricity and serious games, for being not within the scope of this study. Many excluded papers considered serious games for city- or municipality-wide energy planning including power plant utilization and environmental aspects, such as recycling, and are therefore not within the scope of domestic energy consumption planning. Other reasons for exclusion include the record being a systematic literature review or a follow-up paper from a conference paper, in which case the conference paper was excluded and the journal article was included. In addition, records were also excluded for being otherwise outside the scope, such as focusing more on augmented reality, energy production, and the Internet of Things. The PRISMA flowchart of the record inclusion and exclusion process is presented in Fig. 1.

In total, 48 records were included in the final review. The records consist of journal articles (n = 20), conference proceedings (n = 27), and a book chapter (n = 1). The record years of the papers are distributed between 2011 and 2022, the most common year of publication being 2020 (n = 12). (Fig. 2)

The records were studied for presentations on serious games concerning energy and/or electricity use in domestic environments. Despite [10] defining serious games as digital games, any serious games based on physical media (such as board or card games) that otherwise match the scope of this paper were included. In addition to the records retrieved by the systematic search, some additional references that were used in the included records were employed when studying the presented serious games. The following core aspects were identified for each game:

- The name of the game;
- The main target audience of the game;
- Availability of the game: Is the game effortlessly available for anyone to download and play at the moment of writing of this paper (April–May 2022)?
- The educational target of the game;
- The main gameplay element of the game.

In addition to the core features and specifications, in order to study the state of the art of serious games for domestic demand response and/or energy communities, special attention was paid to detect whether:

- There are any rewards or prizes for playing well in the game, other than in-game awards such as badges;
- The game has any aspects regarding demand response in domestic environments;
- The game features an energy community or any aspects regarding energy communities, such as shared energy resources or shared local energy production;
- The game has a link to real-life events, e.g., real-life energy consumption is presented in the game, and it affects the outcome of the game.

The results of the study are assessed and a conclusion is made as to whether serious games have been used to educate people on demand response and energy communities. The study results are also used to decide on if and what kind of a serious game would be meaningful to develop.

III. RESULTS & DISCUSSION

In total, the records contained mentions of 34 serious games about energy in domestic environments. However, some of the mentioned games (n = 3) were excluded from the final listing (Table 1) because of the lack of information available. The included games varied from simple quiz games to more complex living simulation games, and the target audiences ranged from children to homeowners. A common theme among the records was energy saving or reduction in energy usage, and a serious game was proposed as a viable tool for such a purpose. To promote energy savings, awareness of the subject has to be raised in order for people to understand where energy is being used in their homes, and how each person could reduce their energy consumption. Despite people having a positive attitude to energy conservation and fighting climate change, it can be difficult for many people to identify where electric energy is consumed in their homes [34]. Present-day smart metering is becoming more and more common, but visual presentation of sensor data alone is said not to be enough of an incentive for people to make changes in their consumption [58]. For example, in [59] it is noted that many people find units such as kilowatt and kilowatt-hour difficult to interpret and relate to. Smart metering is said to be a powerful enabler to facilitate behavioral change, but more direct and specifically-timed feedback on user actions are needed to make the use of smart metering more viable [58]. Therefore, instead of plain displays of current energy consumption, more engaging methods are required, and serious games are presented as a possible method for that.

A. CORE FEATURES & GENERAL FINDINGS

The identified games varied considerably in their content and gameplay, and thus, some of the games had a specific target audience and some of the games did not. Notable audiences for games were homeowners, teenagers, and children. The target audience was reflected by the difficulty and depth of the game; more complex games were designed for older audiences, whereas easy, learning-focused games were designed for younger children. The games for children included more exploratory games, where the players learn the general concepts of energy usage. A notable example of such a game is *The Ghost Hunter* [12], where the player attaches an electromagnetic field detection device to their smartphone and uses it to locate energy-consuming appliances in their home. Another game clearly designed for children is *Power Pets* [47], a 2D platformer game, where the player learns the concepts of energy while tending their virtual pet. On the other hand, games designed for more mature audiences include games such as *Social Power Game* [16], a game which is played as an energy saving contest, and *Energy Cat* [12], [13], [26], [27], [28], [29], [30], [31], a life simulator similar to *The Sims* franchise where the player controls how their avatar or avatars called *sims* live and manage their daily lives.

To give an incentive to play well in the game and thus encourage the player to change their behavior in real life, all of the presented games featured some kinds of in-game rewards to give the player a sensation of achievement and progress. These kinds of rewards, such as badges or other virtual collectibles, are said to have a bigger educational impact than educational messages, such as energy saving tips, which were present in some of the games [42]. Games with a direct link to real-life events, such as the current energy consumption of the player's residence, can easily gamify any energy savings made with, e.g., in-game badges and trophies of achievement. Not all the games noted in the study contained this link, and rely on indirect rewarding of the player by providing the player with guidance on how to save energy and thus money. However, some games offer concrete rewards and prizes for the best players. For example, in *ecoGator*, the players are allowed to enter a prize contest after beating a level in the game [16].

A link to real-life events, meaning that the gameplay is affected somehow by the real-life surroundings of the player, was found in 18 of the games. The link in the games usually consisted of energy consumption measurements from the player's place of residence. This data link provides a direct feedback on their actions to the player, and instead of the players only controlling a virtual avatar in the game, the gameplay elements included, e.g., energy-saving activity reporting and energy-saving hints and tips. Games like the above-mentioned *The Ghost Hunter* and *ecoGator* contain exploration of the real world. For example in *ecoGator*, the gameplay is based on scanning of the energy labels on appliances with the player's smartphone camera to find the least energy intensive products. On the other hand, the games that did not feature the link to real-life events had the possibility of more creativity. For example, the players could build their own home and try to be as energy efficient as possible like in *Energy Cat*. The games without a real-life link can also

TABLE 1. Identified serious games concerning energy in a domestic environment.

Game/Framework	Audience	Av.[a]	Target	Prize[b]	DR[c]	EC[d]	RL[e]	Gameplay
Social Mpower [21]–[25]	EC Members	No	Raising awareness	No	Yes	Yes	No	Energy sharing simulator
Energy Cat [12], [13], [26]–[31]	Households	No	Energy saving	No	No	No	No	The Sims-like life simulator
Energy Piggy Bank [12], [32]	Anyone	No	Sustainable energy use	No	No	No	Yes	Activity reporting
Power Agent [12], [29], [33], [34]	Teenagers	No	Energy saving	No	No	No	Yes	Energy saving missions
Power House [12], [16], [25], [33]	Adults	No	Efficient energy use	No	No	No	Yes	Real-life and in-game missions
EnergyLife [12], [33], [35]	Households	No	Raising energy awareness	No	No	No	Yes	Quizzes and eco-feedback
Joulebug [33]	Adults	Yes	Energy saving	No	No	No	Yes	Activity reporting
Power Explorer [12], [29], [33], [36]	Teenagers	No	Behavioral change	No	No	No	Yes	Minigame duels
EcoIsland [12], [33], [37]	Households	No	CO_2 reduction	No	No	No	Yes	Acitivity reporting
The Power Saver [33]	Households	No	Energy saving	No	No	No	Yes	Quizzes
The Ghost Hunter [12]	Children	No	Raising awareness	No	No	No	Yes	Scanning EMFs
Ringorang/Energy Games [12], [38]	Unspecified	No	Raising awareness	Yes[1]	No	No	No	Quizzes
Smarter households [12]	Unspecified	No	Energy monitoring	No	No	No	Yes	Energy tips in 3D home
ecoGator [16], [29]	Consumers	No	Energy saving	Yes	No	No	Yes	Scanning energy labels
Social Power Game [16]	Households	No	Behavioral change	No	No	Yes	Yes	Energy saving contest
ECO ECO [39]	Children	No	Energy saving	No	No	No	Yes	Farmville-like
Dungeon of Conquest [40]	Unspecified	No	Raising awareness	No	No	No	No	Quizzes and puzzles
Green Gang vs Cpt. Carbon [41]	Households	No	Energy saving	No	No	No	No	Quizzes
Reduce Your Juice [14], [42]–[45]	Households	Yes[2]	Energy saving	Yes	No	No	No	Minigames and collecting badges
GAIA Challenge [46]	Students	Yes	Energy saving	No	No	No	No	Quizzes and puzzles
Power Pets [47]	Children	No	Understanding energy	No	No	No	No	2D platformer
Changing the Game – Nbhd. [48]	Adults	Yes[3]	CO_2 reduction	No	Yes	Yes	No	Board Game
Eco Ego [49]	Unspecified	Yes[4]	Efficient energy use	No	No	No	No	Energy usage optimization
Electric City [50]	Unspecified	No	Energy sharing	No	No	Yes	No	Resource management
Apolis Planeta [51]	Unspecified	No	Energy saving	No	No	No	Yes	Energy usage feedback
FunergyAR [16], [52]	Children	Yes	Efficient energy use	No	No	No	Yes	Quizzes (Smartphone camera)
DLT Energy Game [53]	EC Members	No	Understanding of DLT	No	Yes	Yes	No	Peer-to-peer energy trading
NRG Game [54]	Homeowners	No	Rebound effect study	No	No	No	No	The Sims-like life simulator
Sharebuddy [55]	Students	No	Demand response	Yes[5]	Yes	No	Yes	Minigames with demand response
Green my place [56]	Unspecified	No	Energy awareness	No	No	No	Yes	MMO Minigames
Less Energy Empowers You [16], [57]	Households	No	Energy saving	No	No	No	Yes	Real-life monitoring

[a] Available effortlessly for anyone to play in April–May 2022
[b] Real-life rewards for participation or playing well (in addition to energy savings resulting from a possible behavioral change)
[c] Aspects directly concerning demand response or demand management
[d] Aspects directly concerning energy communities or shared energy resources
[e] A direct link to real-life events (e.g. rewards or real-life energy consumption reflected in-game)
[1] Participants received a $10 gift card and entered a raffle for more valuable gift cards
[2] Unofficial download links exist, but no Google Play page
[3] Board game listed but out of stock
[4] Available, but requires Adobe Flash player, which is no longer supported in many web browsers
[5] Gift cards were awarded for the best performer and randomly to participants in the field study of the game

be more universal instead of focusing on specific residences, if the energy consumption of a certain location is a key gameplay factor.

A noteworthy finding of this study is that the vast majority of games presented in the records are not available for anyone to effortlessly download and play during the time of writing this paper (April–May 2022). Only four out of the 31 mentioned and assessed games could be downloaded, which implies that the games are/were available only for a closed audience. In majority of cases, the authors were not able to find the official web pages or download links (in e.g. Google Play) for the games. If a web page associated with a game was available, the game itself was not accessible. An unofficial download link was identified for *Reduce Your Juice*, and *Eco Ego* was still online, but required Adobe Flash player that is no longer supported in many web browsers during the writing of this paper. One of the four downloadable games, *Changing the Game – Neighbourhood*, features a physical game board, which was, at the moment of writing this paper, out of stock with no statement of whether restock was to be expected available or not.

B. DEMAND RESPONSE & ENERGY COMMUNITY ASPECTS

Demand response means shifting the consumer's energy consumption to times when electricity is most available or is at its cheapest. Only four games featured aspects concerning demand response: *Social Mpower, Sharebuddy, DLT Energy game*, and *Changing the Game – Neighbourhood.* The number of demand-response-related games can be considered quite low. Possible reasons for this can be that the energy pricing models in many countries do not follow the dynamic energy spot pricing. The fixed cost of electric energy does not provide any incentives for the regular consumer to engage in demand response, and thus, serious games featuring it are not as popular as games based on more universal themes such as energy conservation.

Five games had aspects regarding energy communities or shared energy resources: *Social Mpower, Social Power Game, Changing the Game – Neighbourhood, Electric City*, and *DLT Energy Game*. Two out of the five games, *Social Mpower* and *DLT Energy Game*, were specially designed for energy community members. The rest are more focused on general shared energy resources instead of energy communities or similarly functioning entities. Energy communities as a concept are even more novel than demand response, which explains the lack of games designed to teach people on them. A problem with serious games for energy communities is also that the case for which the game is designed can be very specific, and therefore, the audience will be very small.

Below, the games with demand response and/or energy community or shared energy resources are described in more detail. The presence of identified key features (demand response, shared energy resources) is also listed with each game.

1) SOCIAL MPOWER

In *Social Mpower* [21], [22], [23], [24], [25], multiple players share a common energy pool, from where only a limited amount of power can be drawn in any moment. The players must coordinate with the in-game chat interface when each player can draw power from the common energy pool, ensuring that every household gets what it needs but does not overload the supply. The game is based on a 3D world where the players live in virtual houses and move their avatars around and perform daily activities. **Identified features:** demand response, shared energy resources.

2) SHAREBUDDY

Sharebuddy [55] is a casual mobile game that features tracking of the electricity and water consumption of the player's real-life apartment. The game presents a timeline displaying the most suitable time to use electricity, and if the player succeeds in demand response, the player will be rewarded with points that can be used to unlock different arcade-style minigames for the player's enjoyment. **Identified feature:** demand response.

3) DLT ENERGY GAME

DLT Energy Game [53] is a game focused on peer-to-peer energy trading or shared energy resources. The game aims to raise the trust and understanding of distributed ledger technologies (DLT) when they are deployed into use in distributed energy production systems. A distributed ledger, such as a blockchain, is proposed. Peer-to-peer trading of energy using cryptocurrency is discussed in the record, and a serious game is proposed to help people better understand how the system works. The game has an emphasis on displaying energy transactions instead of inner workings of the blockchain. **Identified features:** demand response, shared energy resources.

4) CHANGING THE GAME – NEIGHBOURHOOD

Changing the Game – Neigbourhood [48] is a serious board game where the players cooperate in their imaginary neighborhood to arrange their energy supply while trying to minimize their CO_2 emissions. The players set their consumption and emissions target and value their options as the game is played with cards that provide energy saving techniques. **Identified features:** demand response, shared energy resources.

5) SOCIAL POWER GAME

Social Power Game [16] is a mobile serious game that places the players in an energy saving contest. The players are split into teams of their own neighborhoods, each with an own shared energy resource. The players complete tasks on efficient use of the team's energy resources, and the energy consumption history and task completions are displayed to illustrate how everyone and their team is doing. The players are awarded with virtual badges if they manage to do well. **Identified feature:** shared energy resources.

6) ELECTRIC CITY

Electric City [50] is a resource management game designed for Android tablet computers. In the game, each player is placed in a neighborhood on an island, where their goal is to ensure the survival of their house by obtaining and managing resources, one of them being electricity. The players can either build their own production or negotiate deals between other players to get access to their electricity resources. The game allows direct peer-to-peer trading of electricity; however, it does not award or penalize for doing or not doing it. **Identified feature:** shared energy resources.

IV. CONCLUSION

Serious games are widely studied in the literature, and the energy and electricity sector is one of the fields where various serious games are implemented. While engineers may find aspects of the power distribution system self-explanatory, the plain concept of energy can be complicated for laypeople to grasp. Therefore, many serious games focus on universal and simple concepts such as energy conservation and optimal use of electricity in people's homes. These kinds of games include very basic quiz and puzzle games where the player is, e.g., set to pick whether they should use LED or incandescent lighting in their home or whether they should operate their washing machine full or half-full. On the contrary, some of the games go much further than that and focus on, e.g., working together to share a common energy resource pool so that everyone's virtual avatar can live their life without compromising on the quality of life and the sufficiency of the limited common power resource.

As mentioned above, the vast majority of the identified games are no longer available for play. This is most likely because the project in which the game was released has come to an end. Many games were designed to be played for a fixed period of time and/or by a closed audience, and the effect of playing the game was assessed with pregame and postgame surveys or with an analysis of the players' energy consumption habits before, during, and after the game period. These kinds of studies on serious games seem common, but games made for anyone to play regardless of whether the game development project is over or not are not commonplace. Studies conclude that serious games are a viable tool for raising awareness of energy consumption habits, but the viability of the tool is reduced if the game is available for a select group of participants for a limited period of time.

Based on the findings of this review, there are research gaps related to serious games with an emphasis on energy communities with shared energy resources where demand response is taken into effect. Three games, *Social Mpower, Changing the Game – Neighbourhood*, and *DLT Energy Game*, featured both demand response and energy community aspects, but they did not feature a link to real-life events. A serious game where energy community members could practice optimizing their energy usage and engage in demand response where the events of their actual home are reflected in the game has not, to the authors' knowledge, been implemented yet. This kind of a game would suit as a tool to see how different co-owned energy resources could be shared in the best and fairest manner. However, this raises an issue with the availability of the game, as it is difficult to make the game available for anyone to play if the game is focused on real-life homes and what happens in them. Therefore, a middle-ground solution where the game could be played based on a real place of residence or a simulated one could be the most optimal solution. The simulation could be based on e.g. an offline energy consumption database of real residences or on a energy consumption model made using the characteristics of an average apartment or house, depending on the preferred scenario. Based on all this, a novel serious game with the following features could be implemented:

- The game is based on an energy community with shared PV resources.
- The game rewards the player for good demand response actions.
- There is an option between real-life source of data and a simulation.

Meeting these criteria would introduce a novel serious game to the field. The target audience of such a game would focus on the owners of an apartment in a multifamily residential building participating in an energy community, or a detached house with a local energy community. Besides experimenting on possible energy distribution and sharing schemes, this kind of a serious game has the potential to raise awareness of energy communities and promote the spread of PV systems and distributed production of electricity, which is proven to be crucial in the rollout of renewable energy and fighting against climate change.

REFERENCES

[1] Z. Yuan, P. C. Wu, and Y.-C. Chen, "Optical resonator enhanced photovoltaics and photocatalysis: Fundamental and recent progress," *Laser Photon. Rev.*, vol. 16, no. 2, 2022, Art. no. 2100202.

[2] A. Simola, A. Kosonen, T. Ahonen, J. Ahola, M. Korhonen, and T. Hannula, "Optimal dimensioning of a solar PV plant with measured electrical load curves in Finland," *Sol. Energy*, vol. 170, pp. 113–123, Jun. 2018.

[3] *Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the Promotion of the Use of Energy From Renewable Sources*, Eur. Parliament Council, 2018.

[4] *Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on Common Rules for the Internal Market for Electricity and Amending Directive 2012/27/EU*, Eur. Parliament Council, 2019.

[5] J. Mao, M. Jafari, and A. Botterud, "Planning low-carbon distributed power systems: Evaluating the role of energy storage," *Energy*, vol. 238, Jan. 2022, Art. no. 121668.

[6] P. Puranen, A. Kosonen, and J. Ahola, "Techno-economic viability of energy storage concepts combined with a residential solar photovoltaic system: A case study from Finland," *Appl. Energy*, vol. 298, Sep. 2021, Art. no. 117199.

[7] M. R. Herrmann, D. P. Brumby, and T. Oreszczyn, "Watts your usage? A field study of householders' literacy for residential electricity data," *Energy Efficiency*, vol. 11, pp. 1703–1719, Oct. 2018.

[8] K. L. van den Broek, "Household energy literacy: A critical review and a conceptual typology," *Energy Res. Social Sci.*, vol. 57, Nov. 2019, Art. no. 101256.

[9] European Commission, Directorate-General for Energy. (2019). *Clean Energy for All Europeans*. Publications Office. [Online]. Available: https://data.europa.eu/doi/10.2833/9937

[10] R. Dörner, S. Göbel, W. Effelsberg, and J. Wiemeyer, *Serious Games: Foundations, Concepts and Practice*. Cham, Switzerland: Springer, 2018.

[11] D. Huynh, L. Zuo, and H. Iida, "Analyzing gamification of 'Duolingo' with focus on its course structure," in *Proc. Int. Conf. Games Learn. Alliance*, Dec. 2016, pp. 268–277.

[12] X. Wu, S. Liu, and A. Shukla, "Serious games as an engaging medium on building energy consumption: A review of trends, categories and approaches," *Sustainability*, vol. 12, no. 20, pp. 1–16, 2020.

[13] M. Casals, M. Gangolells, M. Macarulla, N. Forcada, A. Fuertes, and R. V. Jones, "Assessing the effectiveness of gamification in reducing domestic energy consumption: Lessons learned from the EnerGAware project," *Energy Buildings*, vol. 210, Mar. 2020, Art. no. 109753.

[14] R. F. Mulcahy, R. McAndrew, R. Russell-Bennett, and D. Iacobucci, "'Game on!' Pushing consumer buttons to change sustainable behavior: A gamification field study," *Eur. J. Marketing*, vol. 55, no. 10, pp. 2593–2619, 2021.

[15] G. Schweiger, L. V. Eckerstorfer, I. Hafner, A. Fleischhacker, J. Radl, B. Glock, M. Wastian, M. Rößler, G. Lettner, N. Popper, and K. Corcoran, "Active consumer participation in smart energy systems," *Energy Buildings*, vol. 227, Nov. 2020, Art. no. 110359.

[16] B. Behi, A. Arefi, P. Jennings, A. Pivrikas, A. Gorjy, and J. P. S. Catalao, "Consumer engagement in virtual power plants through gamification," in *Proc. 5th Int. Conf. Power Renew. Energy*, 2020, pp. 131–137.

[17] P. Makris, N. Efthymiopoulos, D. J. Vergados, E. Varvarigos, V. Nikolopoulos, J. Papagiannis, A. Pomazanskyi, B. Irmscher, K. Stefanov, K. Pancheva, and A. Georgiev, "SOCIALENERGY: A gaming and social network platform for evolving energy markets' operation and educating virtual energy communities," in *Proc. IEEE Int. Energy Conf. (ENERGYCON)*, Jun. 2018, pp. 1–6.

[18] P. Davison, S. Blake, A. Spencer, E. Burton, and S. Lee-Favier, "Activating residential demand side response to relieve network congestion," in *Proc. CIRED Workshop*, 2016, pp. 1–4.

[19] M. A. Zehir, K. B. Ortac, H. Gul, A. Batman, Z. Aydin, J. C. Portela, F. J. Soares, M. Bagriyanik, U. Kucuk, and A. Ozdemir, "Development and field demonstration of a gamified residential demand management platform compatible with smart meters and building automation systems," *Energies*, vol. 12, no. 5, p. 913, 2019.

[20] M. J. Page, J. E. McKenzie, P. M. Bossuyt, I. Boutron, T. C. Hoffmann, C. D. Mulrow, L. Shamseer, J. M. Tetzlaff, E. A. Akl, S. E. Brennan, and R. Chou, "The PRISMA 2020 statement: An updated guideline for reporting systematic reviews," *Systematic reviews*, vol. 10, no. 1, p. 11, 2021.

[21] A. Bourazeri and J. Pitt, "Social Mpower: A serious game for self-organisation in socio-technical systems," in *Proc. Int. Conf. Self-Adapt. Self-Organizing Syst.*, Dec. 2014, pp. 199–200.

[22] A. Bourazeri and J. Pitt, "A game-based approach for collective action in self-organising socio-technical systems," in *Proc. Int. Conf. Self-Adaptive Self-Organizing Syst.*, Dec. 2014, pp. 175–176.

[23] A. Bourazeri and J. Pitt, "Collective awareness for collective action in socio-technical systems," in *Proc. IEEE 8th Int. Conf. Self-Adapt. Self-Organizing Syst. Workshops*, Sep. 2014, pp. 90–95.

[24] A. Bourazeri and J. Pitt, "Collective attention and active consumer participation in community energy systems," *Int. J. Hum. Comput. Stud.*, vol. 119, pp. 1–11, Nov. 2018.

[25] A. Bourazeri and J. Pitt, *An Agent-Based Serious Game for Decentralised Community Energy Systems* (Lecture Notes in Computer Science: Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), vol. 8861. Cham, Switzerland: Springer, 2014.

[26] M. Casals, M. Gangolells, M. Macarulla, A. Fuertes, V. Vimont, and L. M. Pinho, "A serious game enhancing social tenants' behavioral change towards energy efficiency," in *Proc. Global Internet Things Summit (GIoTS)*, 2017, pp. 1–6.

[27] M. Gangolells, M. Casals, M. Macarulla, and N. Forcada, "Exploring the potential of a gamified approach to reduce energy use and carbon emissions in the household sector," *Sustainability*, vol. 13, no. 6, p. 3380, 2021.

[28] M. Gangolells, M. Casals, N. Forcada, and M. Macarulla, "Life cycle analysis of a game-based solution for domestic energy saving," *Sustainability*, vol. 12, no. 17, p. 6699, 2020.

[29] P. Ponce, A. Meier, J. I. Méndez, T. Peffer, A. Molina, and O. Mata, "Tailored gamification and serious game framework based on fuzzy logic for saving energy in connected thermostats," *J. Cleaner Prod.*, vol. 262, Jun. 2020, Art. no. 121167.

[30] R. J. Hafner, S. Pahl, R. V. Jones, and A. Fuertes, "Energy use in social housing residents in the uk and recommendations for developing energy behaviour change interventions," *J. Cleaner Prod.*, vol. 251, pp. 1–12, Sep. 2020.

[31] R. J. Hafner, A. Fuertes, S. Pahl, C. Boomsma, R. V. Jones, M. Casals, and M. Gangolells, "Results and insight gained from applying the EnergyCat energy-saving serious game in UK social housing," *Int. J. Serious Games*, vol. 7, no. 2, pp. 27–48, 2020.

[32] B. Hedin, A. Lundstrom, M. Westlund, and E. Markstrom, "The energy piggy bank—A serious game for energy conservation," in *Proc. 5th IFIP Conf. Sustain. Internet ICT Sustainability*, 2018, pp. 1–6.

[33] J. D. Fijnheer and H. van Oostendorp, *Steps to Design a Household Energy Game* (Lecture Notes in Computer Science: Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), vol. 9599. Cham, Switzerland: Springer, 2016.

[34] A. Gustafsson and M. Bång, "Evaluation of a pervasive game for domestic energy engagement among teenagers," in *Proc. Int. Conf. Adv. Comput. Entertainment Technol.*, New York, NY, USA, 2008, pp. 232–239.

[35] L. Gamberini, N. Corradi, L. Zamboni, M. Perotti, C. Cadenazzi, S. Mandressi, G. Jacucci, G. Tusa, A. Spagnolli, C. Björkskog, M. Salo, and P. Aman, "Saving is fun: Designing a persuasive game for power conservation," in *Proc. 8th Int. Conf. Adv. Comput. Entertainment Technol.*, New York, NY, USA, 2011, pp. 1–7.

[36] A. Gustafsson, M. Bång, and M. Svahn, "Power explorer: A casual game style for encouraging long term behavior change among teenagers," in *Proc. Int. Conf. Adv. Comput. Enterntainment Technol.*, New York, NY, USA, 2009, pp. 182–189.

[37] H. Kimura and T. Nakajima, "Ecoisland: A persuasive application to motivate sustainable behavior in collectivist cultures," in *Proc. 6th Nordic Conf. Hum.-Comput. Interact., Extending Boundaries*, New York, NY, USA, 2010, pp. 703–706.

[38] V. Rai and A. L. Beck, "Play and learn: Serious games in breaking informational barriers in residential solar energy adoption in the United States," *Energy Res. Social Sci.*, vol. 27, pp. 70–77, Apr. 2017.

[39] Y. rock Zou, N. Mustafa, N. A. Memon, and M. Eid, "ECO ECO: Changing climate related behaviors for cellphone-based videogames," in *Proc. IEEE Int. Symp. Haptic, Audio Vis. Environ. Games (HAVE)*, Oct. 2015, pp. 1–5.

[40] M. M. Nadzir and B. Pillay, "A mobile game approach for energy conservation awareness," in *Proc. 16th Int. Conf. Ubiquitous Inf. Manage. Commun. (IMCOM)*, 2022, pp. 1–4.

[41] S. Seebauer, M. Berger, K. Kettl, and M. Moser, "Green gang vs. captain carbon. integration of automated data collection and ecological footprint feedback in a smartphone-based social game for carbon saving," in *Proc. 5th Int. Conf. Games Virtual Worlds Serious Appl.*, 2013, pp. 1–2.

[42] L. Whittaker, R. Russell-Bennett, and R. Mulcahy, "Reward-based or meaningful gaming? A field study on game mechanics and serious games for sustainability," *Psychol. Marketing*, vol. 38, no. 6, pp. 981–1000, 2021.

[43] R. Mulcahy, R. Russell-Bennett, and D. Iacobucci, "Designing gamified apps for sustainable consumption: A field study," *J. Bus. Res.*, vol. 106, pp. 377–387, May 2020.

[44] A. Yam, R. Russell-Bennett, M. Foth, and R. Mulcahy, "How does serious m-game technology encourage low-income households to perform socially responsible behaviors?" *Psychol. Marketing*, vol. 34, no. 4, pp. 394–409, 2017.

[45] T. Swinton, J. Little, R. Russell-Bennett, R. Mulcahy, R. McAndrew, and C. Passion, "Reduce your juice digital social marketing program (LIEEP): Final report," CitySmart, Brisbane, QLD, Australia, 2016.

[46] G. Mylonas, J. Hofstaetter, A. Friedl, and M. Giannakos, "Designing effective playful experiences for sustainability awareness in schools and makerspaces," in *Proc. ACM Int. Conf.*, 2021, pp. 1–9.

[47] M. Bayley, S. Snow, J. Weigel, and N. Horrocks, "Serious game design to promote energy literacy among younger children," in *Proc. ACM Int. Conf.*, 2020, pp. 531–537.

[48] M. Lanezki, C. Siemer, and S. Wehkamp, "'Changing the game-neighbourhood': An energy transition board game, developed in a co-design process: A case study," *Sustainability*, vol. 12, no. 24, pp. 1–18, 2020.

[49] A. Wagner and D. Galuszka, "Let's play the future: Sociotechnical imaginaries, and energy transitions in serious digital games," *Energy Res. Social Sci.*, vol. 70, Dec. 2020, Art. no. 101674.

[50] A. Singh, H. W. Van Dijk, B. O. Wartena, N. R. Herrera, and D. Keyson, "'Electric city': Uncovering social dimensions and values of sharing renewable energy through gaming," in *Proc. Conf. Hum. Factors Comput. Syst.*, vol. 18, 2015, pp. 1519–1524.

[51] T. Csoknyai, J. Legardeur, A. A. Akle, and M. Horváth, "Analysis of energy consumption profiles in residential buildings and impact assessment of a serious game on occupants' behavior," *Energy Buildings*, vol. 196, pp. 1–20, May 2019.

[52] P. Fraternali and S. L. H. Gonzalez, *An Augmented Reality Game for Energy Awareness* (Lecture Notes in Computer Science: Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), vol. 11754. Cham, Switzerland: Springer, 2019.

[53] J. W. Veeningen and N. B. Szirbik, "Using serious gaming to discover and understand distributed ledger technology in distributed energy systems," in *Proc. IFIP Int. Conf. Adv. Prod. Manage. Syst.*, vol. 535, 2018, pp. 549–556.

[54] O. Garay Garcia, C. E. van Daalen, E. Chappin, B. van Nuland, I. Mohammed, and B. Enserink, *Assessing the Residential Energy Rebound Effect by Means of a Serious Game* (Lecture Notes in Computer Science: Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), vol. 10825. Cham, Switzerland: Springer, 2018.

[55] R. S. Brewer, N. Verdezoto, T. Holst, and M. K. Rasmussen, "Tough shift: Exploring the complexities of shifting residential electricity use through a casual mobile game," in *Proc. Annu. Symp. Comput.-Hum. Interact. Play*, 2015, pp. 307–318.

[56] B. Cowley, "The QUARTIC process model for developing serious games: 'Green my place' case study," in *Digital Da Vinci: Computers in the Arts and Sciences*. New York, NY, USA: Springer, 2014, pp. 143–172.

[57] R. N. Madeira, A. Silva, C. Santos, B. Teixeira, T. Romão, E. Dias, and N. Correia, "Ley! Persuasive pervasive gaming on domestic energy consumption-awareness," in *Proc. ACM Int. Conf.*, 2011, pp. 1–2.

[58] P. Fraternali, S. Herrera, J. Novak, M. Melenhorst, D. Tzovaras, S. Krinidis, A. E. Rizzoli, C. Rottondi, and F. Cellina, "Encompass—An integrative approach to behavioural change for energy saving," in *Proc. Global Internet Things Summit (GIoTS)*, 2017, pp. 1–6.

[59] A. Nilsson, M. Wester, D. Lazarevic, and N. Brandt, "Smart homes, home energy management systems and real-time feedback: Lessons for influencing household energy consumption from a Swedish field study," *Energy Buildings*, vol. 179, pp. 15–25, Jun. 2018.

MIKKO NYKYRI (Member, IEEE) was born in Finland in 1993. He received the B.Sc. and M.Sc. degrees from the Lappeenranta University of Technology (LUT), in 2017 and 2018, respectively. He is currently pursuing the D.Sc. (Tech.) degree with the Laboratory of Applied Electronics, LUT School of Energy Systems. His main research interests include utilization of distributed ledger technologies and serious games on solar energy optimization in domestic environments. He has also worked in data analytics, machine learning, and the IoT in industrial predictive maintenance.

TOMMI J. KÄRKKÄINEN (Member, IEEE) was born in Finland in 1987. He received the B.Sc., M.Sc., and D.Sc. (Tech.) degrees from the Lappeenranta University of Technology (LUT), Lappeenranta, Finland, in 2010, 2011, and 2015, respectively.

He is currently a Postdoctoral Researcher with the LUT School of Energy Systems. His main research topic is the reliability of power electronic devices and systems, and the utilization of machine learning algorithms to improve the reliability and productivity of various systems.

SALLA ANNALA received the D.Sc. (Tech.) degree from the School of Energy Systems, Lappeenranta University of Technology (LUT), in 2015. She works as a Postdoctoral Researcher with the School of Energy Systems, LUT. Her research interests include end-users' role in the energy transition, energy communities, and market and regulatory arrangements supporting utilization of demand response and other distributed energy and flexibility resources.

PERTTI SILVENTOINEN (Member, IEEE) was born in Simpele, Finland, in 1965. He received the M.Sc. degree in electrical engineering, the Licentiate of Technology degree in applied electronics and control systems, and the D.Sc. (Tech.) degree with the focus on EMC in electronics from the Lappeenranta University of Technology (LUT), Finland, in 1993, 1997, and 2001, respectively. Since 2008, he has been a Full Professor in applied electronics at LUT. His research interests include analog signal processing and measurement systems, power line communication applications, EMC measurement technology, and power electronic systems in various forms.