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Single player game for decision making in energy communities#

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ABSTRACT

Decentralized energy systems are an integral part of the energy transition toward carbon neutrality. If the energy community manages a decentralized energy system, it becomes a setting where the social dilemma of the tension between individual selfish behavior and collective interest arises. Reaching agreement in this multi decision-makers environment is challenging and complex. A serious multiplayer game can become a deliberation platform for bargaining over solutions. In this study, a dynamic model to simulate energy efficiency measures and on-site renewable energy sources in an energy community located in an urban block of multifamily buildings and a single-player serious game interface to serve as a basis for the multiplayer game is developed. User experience and game mechanics were tested in three user groups. Decisions made by the user were assessed. Results show positive feedback and provide valuable recommendations for further research.

Keywords: urban energy community, simulation game, role-game, system dynamics, serious games

1. INTRODUCTION

Energy systems worldwide are undergoing radical change due to the depletion of fossil fuel resources, climate change, technological, institutional, and political change. The long-term climate action strategy goal in the EU is to reach carbon neutrality by 2050 via the energy transition. It requires a transition of energy systems from centralized to more decentralized [1]. Various technologies are already available to increase energy efficiency and produce energy from renewable energy resources at the building and community level [2,3]. However, state-of-art scientific-technological solutions and policy initiatives are stuck in decision-making chains and conservative behavioral patterns; the diffusion of innovation in society is inert and jeopardizes the climate goals. People are a vital component of the energy community and therefore need to be widely involved in facilitating their participation in sustainable energy systems [4,5]. Today citizens do not identify themselves as part of energy communities - this is instead a normative practice by legislators, the EU, or researchers.

Social sciences and humanities researchers stress the need to shift from perceiving people as passive figures to whom policies and technologies can be applied to active figures taking part in the energy transition. Furthermore, one of the possibilities for engaging people would be to redirect the focus from individuals to communities.

Urban energy communities are facing several challenges. Decentralized energy generation systems, in contrast to traditional centralized energy systems, require investments of local residents, participation, and collaboration [6]. The broader uptake of such systems is still early, and research on the adoption potential of distributed energy sources in existing neighborhood contexts is scarce [7]. In smart neighborhoods, an essential factor is the ability to optimize energy flow at the low voltage grid level; thus, decentralized energy storage systems are a promising means to more effectively match the supply and demand of fluctuating renewable energies. In most countries, the energy storage systems market share is still small and whether or not the technology will attain a critical market share is subject to homeowners' investment decisions.

On the other side of the coin lies energy efficiency improvement and demand-side management, which is used to change consumption patterns to optimize the use of energy supply. A more active role is expected from energy consumers, like changing energy consumption towards higher efficiency, providing flexibility, or taking their role as prosumers. Energy efficiency is not only a technological issue; it is also influenced by household behavior. For decades, researchers have tried to understand the factors that drive or hinder people to move from environmental knowledge to environmentally-friendly behavior.

As a social setting, the energy community faces a social dilemma of the tension between individual selfish behavior and collective interest. Everyone pursuing the former achieves overall lower welfare than cooperation

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would instead ensure. The prisoner's dilemma tends to arise in strategic interactions and emphasizes the effect of the free-rider problem, which arises when considering public and common goods. Theory of social interaction distinguishes social dilemmas and collective decision-making with common interests and conflicting interests.

If participants have common interests, they are faced with collective action and instability of common choice. Bargaining is applied over conflicting interests. One way to promote governance in the energy community is through collective awareness platforms, which offer innovative ways to engage citizens to identify and contribute to solutions to sustainability challenges and solve social dilemmas in a multiplayer environment [8- 11]. However, it is challenging to motivate large groups of people to participate in local communities to address sustainability issues [12]. Unlike traditional top-down approaches, addressing such issues effectively requires flexible solutions that link different individual and collective perspectives to a common challenge [13-15]. Recent studies have confirmed the failure of many climate communication efforts, which has turned audiences into passive consumers of one-way information [16]. The challenges posed to humanity by climate change call for innovative approaches. Well-designed games are powerful tools that can support tackling climate change. [17] Communication tools that are scientifically rigorous and motivate informed action on climate change enables people to learn for themselves through experience and experimentation rather than being told by experts [18].

Gaming is a relatively new area of research, and it is still unclear why some attempts at gaming are more effective in promoting behavior change than others. Little is known about the balance between fun, exciting games, and primarily informative games. As technology continues to evolve and the ability of science to collect behavioral data improves, researchers, continue to explore the use of games as a tool for data collection and analysis of individual behavior. [19] A review on climate change games [20] found that (a) most games are designed for educational purposes, (b) only a few games are designed to have a direct impact on climate change, (c) although climate change requires the involvement from the individual level to the global level, encouraging involvement in collective initiatives, most of the games are at only one level. Climate change games, which focus on individual cooperation at the community level, are relatively rare and are mainly at the global or urban level. However, they are the right platforms for negotiation processes [21].

In East European countries, incl. Baltic countries self-identification with the community is very weak, whether in terms of resource use, sharing, or energy efficiency. 85% of inhabitants live in multi-family buildings in Latvia. Each apartment is owned by a single owner, making building management's common decision process very complicated. Latvia is an aging society where consumption habits are based on inertia, not a choice, and their engagement tools may differ from others, mainly convenience, security, continuity, and fiscal considerations. Consequently, structural changes are not only in the use of energy but also in the social perspective: energy consumption from commodified personalization needs to be transformed into a collective practice, which, moreover, has a historically stigmatized stratification of electricity in Latvia as an unlimited utility.

Previous research on energy efficiency and on-site energy production practices of the population living in multifamily buildings in Latvia shows insufficient knowledge about energy efficiency and renewable energy sources [22]. However, research also reported pre-existing forms of community organization in block housing districts and charted levels of engagement in housing cooperatives among apartment owners.

Research question of this study is: can a serious simulation game based on an integrated model of physical systems and role-play elements be used as a tool for the decision-making process in an energy community located in an urban block of multifamily buildings?

The goal of this study is to develop a dynamic model to simulate energy efficiency measures and on-site renewable energy sources in an energy community located in an urban block of multifamily buildings and develop a single-player serious game interface to serve as a basis for multiplayer game.

2. METHODOLOGY

First, the system dynamics modeling approach is used to build a model structure of physical energy demand and supply systems. Second, the model is supplemented with an Internet-based user interface for role-play of decision-makers involved in the social dynamics. Finally, the game mechanics and user experience are tested in three test groups and the decisions made by different groups are assessed.

2.1 The model

The structure of the energy community's physical energy demand and supply systems was built in Stella Architect software. Each building has a detailed stock and flow structure for heat and electricity demand, including building envelope parameters and energy consumption patterns. On the energy supply side, stock and flow structures are built for heat production on-site from renewable energy sources via heat pumps, district heating, and heat accumulation. Electricity is either produced from on-site renewable energy sources,

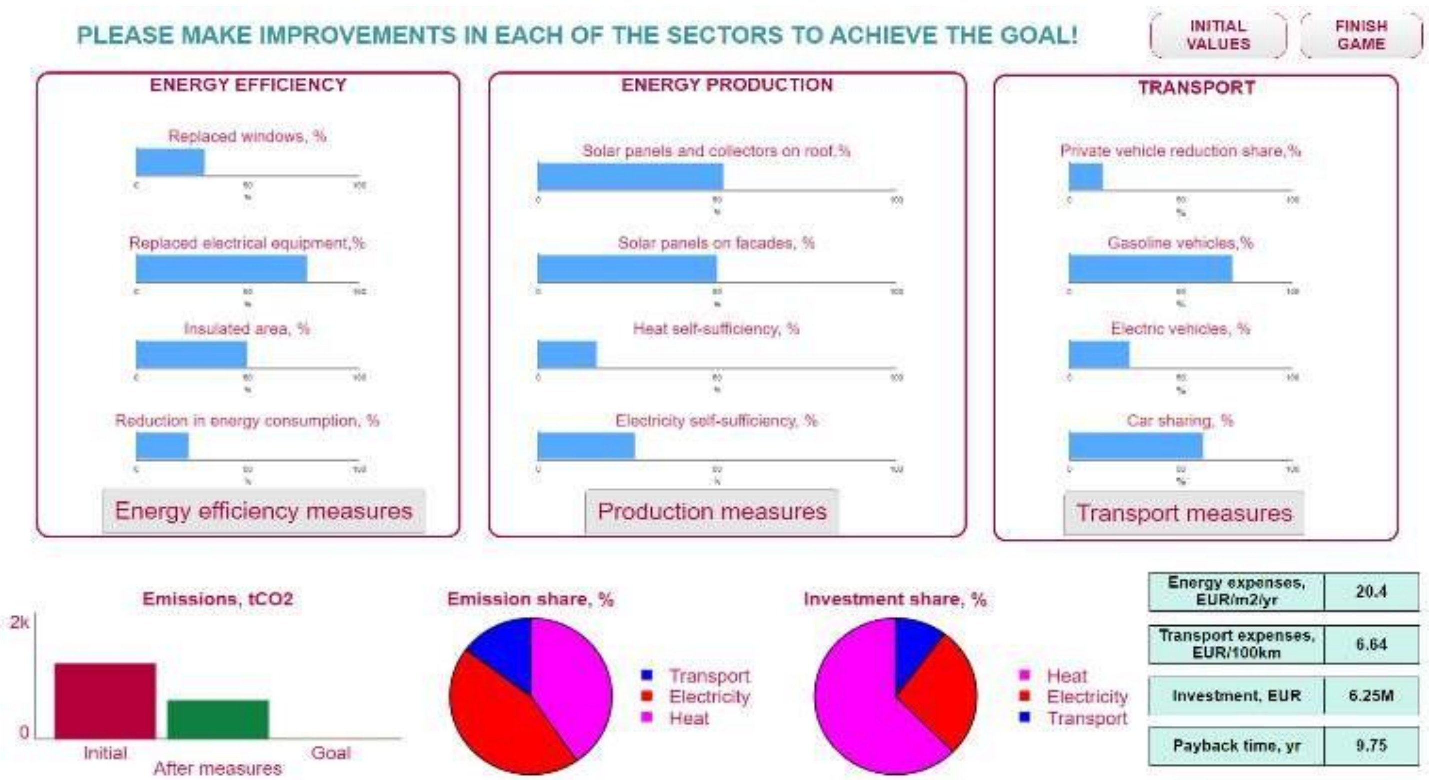

Fig. 1 The main page of single player game's interface

accumulated on-site, or received from the grid. Private transportation means are privately owned or shared in the transportation sector, driven by fossil fuels or electricity. The time step of the model is one day. The structure of the model is described in more detail in other publications [23-25].

2.2 Single player game's user interface

The interface is built on the top of the stock and flow model in the Interface module of Stella Architect. It is developed as a single-player game to be used as a neighborhood energy community laboratory. This experimental single-player game is developed and used to learn about game players' decision-making if various measures can be applied and scenarios developed. The energy transition is a dynamic decision-making process. Decision tasks are dynamic whenever decisions made at a time t alter the state of a system and, thus, the information that conditions decisions that have to be made at time t + 1. Thus, decision-makers monitor their decisions' outcomes and adapt different decisions to the system's current (or an expected future) state. The decision-maker and the system are entwined in feedback loops whereby decisions alter the system's state, giving rise to new information and leading to new decisions.

According to the results of the multifamily apartment owners' survey results [22], the single-player game interface includes three groups of measures (see Figure 1):

- energy efficiency (increasing thermal resistance of building envelope, replacement of equipmentwith more energy-efficient)
- energy production (PVT and PV panels)
- transportation use habits (switching to electric vehicles, sharing, and changing habits, such as average daily mileage and number of car uses per week).

In all three groups the desired volume of subsidies can be changed. Various output performance indicators are used, including the amount of CO2 emissions per energy supply sector, total required investments, distribution of investments, energy costs per year (EUR/m2), transport costs per household (EUR/100 km), and payback period. The results vary depending on the user's choices of variable values. The user can follow the current results throughout the simulation in Stella Live mode and change the values of variables, resetting the initial parameter value if necessary. At the end of the simulation, when the user presses the "Complete task" button, the model records the results, and the user interface shows the final decision.

2.3 Tests and users' decisions

To test game mechanics and user experience, three groups of players were selected:

- group 1: players who are renting their apartments or live with their parents (Environmental Engineering Master level students, age 21 – 30, 32 participants)
- group 2: players who are apartment owners (Business Management Master level students, age 25 – 55, 35 participants)
- group 3: industry professionals in the energy sector (architects, engineers, developers, building owners, municipal representatives, and energy company specialists (63 participants)).

Groups 1 and 2 participated in game mechanics and user experience test, and they filled the feedback in written form. Data about decisions made were obtained from the test sessions. Group 3 was asked to provide (1) feedback about the game mechanics and user experience, including usability of the game and the interface and (2) from the perspective of central planners and policymakers.

Separate test rounds were carried out online for each group. First, the group was introduced to the concept of an energy community and case studies. After that, the group was introduced to the design of the single-player game interface. The following task was assigned to each group: "In the scope of our research project, the project team needs your opinion on the developed online tool. Hence, we invite you to play with the "Positive Energy Quarter in Riga" test tool. You will have the opportunity to find your way to transform a traditional quarter in the historical center of Riga into a quarter of low or positive energy balance using various technology solutions. You have to create a climate-neutral energy community by choosing technology measures, reducing CO2 emissions, and considering costs. No prior knowledge is required to participate in testing. You will have 30 minutes to complete this task. Finally, we will ask you to complete feedback forms."

Stella Architect tracking option is used to track the final decisions made by each player. Each data set is automatically assigned a unique number, and the users are not traceable. Test groups were informed about data collection and were asked for permission. Data sets of all variables included in the interface were collected and processed.

3. RESULTS

3.1 Test results

Although group 1 indicated that they perceive the game as part of their study activities, they see the potential of its application as valuable in a real neighborhood. One explanation can be the difficulty for students from this group to identify themselves with apartment owners who have to make decisions about the renovation and development of a neighborhood. They also stated that the interface and game are helpful for the homeowners to understand the impact of their decisions on reducing CO2 levels.

Group 2 rated the tool positively using the words “convenient,” “fast,” “easy to use,” “interesting,” “understandable,” and “easy to understand”. They also noticed that the explanation and guidance received before playing the game was an essential part of the process. Four users gave a lower grade - one of them indicated that more specific explanatory information would be needed before the game. Two users expressed a desire to see a more intuitive interface, a more modern design (possibly visual), and more user-friendly data input buttons, e.g., a number box instead of a slider. One user admitted that the game captivates him only partly, adding that it was most likely intended for home managers who deal with energy efficiency issues daily.

Both groups provided 22 valuable comments and feedback on the user experience. Comments on game mechanics and interface functionality allowed the research team to identify quality and technical performance shortcomings.

Feedback from group 3 shows that professionals generally support the usefulness of such a simulation tool and encourage its further development. Few users noted that the interface initially looked complex, but it became understandable as soon as they started the game. Industry professionals believe that the game could increase the chances of households collaborating and implementing solutions by highlighting the benefits of implementing collective solutions. According to experts, neighborhood associations are a potential channel to initiate the formation of energy communities. Experts advised including an additional slider to set an interval that limits monthly payments per m2 for investment payback. From the point of view of central planners and policymakers, the experts advised adding more descriptive information about technologies used in the model, investment costs, energy tariffs and other input values, and specific output indicators for each technology. They also suggested starting the game by providing an optimal solution for a given energy community. This would serve as the starting point for further discussions during the multi-player game.

Experts wondered if the game could be adapted to a particular neighborhood and how labor-intensive this process might be.

3.2 Tracking users'decisions

In the energy efficiency sector, both groups replaced electrical appliances with more energy-efficient ones (the difference between both groups is 1%). The main variance is observed in replacing windows (34% higher in group 2) and using subsidies (21% higher in group 2). Group 2 users have selected more improvement of thermal properties of building envelopes (10% higher than group 1). As a result, group 2 users have achieved, on average, 6% more energy savings through their choices.

Group 2 users have made more significant changes in the energy production sector than group 1 users in almost all parameters. The main difference is observed in the choice of subsidies for RES resources (on average by 53%), followed by a greater emphasis on energy production (on average by 31%). The amount of energy produced on-site is higher for group 2.

In the transport sector, group 1 users are more open to transitioning to electric vehicles (100% compared to group 2) and car sharing (40%compared to group 2). Group 2 users decided to use subsidies for electric cars (55% more than group 1).

Key outcome indicators for users from both groups are similar, including investment volume (group 2 by 2% more), CO2 emissions from electricity and heat (group 2 by 4% and 1% more respectively), and total accumulated emissions and costs (group 1 by 5% and 9% more).

4. DISCUSSION

The first version of the single-player game interface for energy communities was built, and user experience and game mechanics were tested. In general, positive feedback on game mechanics and user experience was received. However, several limitations were faced during this research. First, the game is based on a particular urban block located in the historical center of Riga. All input data for buildings and technologies from this block were used during simulations. Test groups were introduced to this urban block by visual means and description of each building prior to the game. Decisions made in a hypothetical energy community may differ from the decisions made in a real community where game players live. This deficiency will be removed in the further development steps by developing a tailor-made energy community by adding input variables where data can be inserted manually.

The second limitation is users' background knowledge about energy efficiency and renewable energy technologies. As test results show, the complexity level of the interface is directly linked to the depth of knowledge of users. Some users found the interface too simple at the expert level and suggested including more input and output variables. Some experts expressed that the interface might be too complex for residents with deficient knowledge levels about energy. This issue will be addressed in the further development stage, and the interface will be adapted to different user groups.

The final limitation of the study is the emphasis on social benefits rather than on the private benefits of residents. More output parameters will be added, including private benefits in terms of money and quality of life in further research.

This study was conducted before the onset of the energy crisis at the end of 2021 and the war in Ukraine. The impact of both events will probably be seen during the next steps of this research.

5. CONCLUSIONS

The study shows that a dynamic model to simulate energy efficiency measures and on-site renewable energy sources in an energy community located in an urban block of multifamily buildings and a single-player interface for a serious game to serve as a basis for the multiplayer game is developed.

The user experience and game mechanics were tested in three different groups. Positive feedback and various valuable comments and recommendations were received in general. They will be further integrated into the subsequent versions of the game. Game users approved that if the single-player game is integrated into a multiplayer game, it will serve as a platform for discussions and bargaining in social dilemma situations faced in energy communities.

Analysis of decisions made by test group users shows that users from the environmental engineering student group were more inclined towards the transportation sector. In contrast, business management students focused more on energy efficiency and energy production.

Further research will focus on adding business models, developing three levels of interface based on the user's knowledge, and adding more output variables and input data to the tailor-made game for any energy community to be further used in any location around the world.

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