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Behavioral Observations of Decision-Making in Energy Sharing Communities From Serious Game Approach#

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ABSTRACT

In the context of decarbonization against climate change, energy management measures including Distributed Energy Resource (DER) is gaining significant social attention. The Ministry of the Environment, Government of Japan, advocates for regional decarbonization and promotes community-wide efforts to increase renewable energy usage. Recent advancement of technologies such as smart metering and blockchain make the implementation of the Peer-to-Peer(P2P) energy trading system, that enables individual buildings to buy and sell energy generated by renewable sources like photovoltaic (PV) and stored in batteries, much easier. Against these backdrops, we expect that energy sharing communities which share the benefits of renewable energy and decarbonization measures will be formed to in the future society. The existing researches which are focusing on the energy trading or energy sharing system mainly aim to evaluate economic benefit for communities through simulation regarding participants in the trading market as agents. However, we point out little consideration has been given whether the results calculated by simulation are truly aligning with participant's behavior and benefit that participants expect in the real world. While simulations can estimate economic benefit, it is crucial to observe actual participant behavior to ensure these results are consistent with the reality. This study will examine how participants behave in the community which shares the benefit from energy management measures through observation of playing the energy sharing game. The results showed that shared funds were distributed equally to players, but players tended to perceive the distribution was equitable. Our findings will be helpful for considering how the energy sharing community will be designed, and how prosumers/consumers behave in a society where the energy sharing is implemented.

Keywords: serious game, peer-to-peer energy trading, renewable energy, decision making, distributed energy system, smart grid

NONMENCLATURE

Abbreviations	
P2P	Peer to peer
PV	Photovoltaic
Li-ion	Lithium-ion
DER	Distributed Energy Resource
ICT	Information and Communication Technology
LED	Light emitted diode

1. INTRODUCTION

Against fierce climate change, over 100 countries are striving to reduce the emissions of CO2 with the goal of achieving carbon neutrality by 2050 [1]. Various ways would be used to contribute the goal, including transition from fossil fuels to the use of the renewable energy, and enhancing energy efficiency technologies. In Japan, administrative bodies advocate for regional decarbonization. For instance, the Ministry of the Environment, Government of Japan, tries to maximize the use of regional resources, including renewable energy, and to address social issues such as improving well-being, revitalizing local economy, and enhancing disaster resilience [2]. The cabinet secretariat of Japan stated that nations and regions should work toward decarbonization as a common goal and formulated the Regional Decarbonization Roadmap [3].

Unlike traditional energy generation such as thermal or nuclear, the renewable energy generation is intermittent, meaning the amount of electricity generated depends on status of renewable energy source. For example, PV batteries can generate energy only when the sun is shining. Thus, the utilization of energy storage like Li-ion batteries is essential to ensure that energy is available whenever it is needed. A system that combines renewable energy with energy storage is

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considered a core component of DER which reduces energy consumption and offers benefits to system owners [4].

Recent advancements in ICT field, like smart contracts, enable the traceability of the renewable energy by connecting individual DER systems through computer networks [5]. DER system owners can buy and sell electricity on a mutually connected P2P energy trading network.

With the above background, the community which shares energy among its members is on the horizon. The concept of "Energy community" where renewable energy, such as generated by solar power, is shared among the citizens and organizations within the community is emerging. According to EU Directive 2019/944 [6], energy community is operated by regional stakeholders, and facilitates efficient energy generation, consumption, supply, distribution and aggregation to provide not only economic but also social community benefits to community members.

We argue that how the benefits are distributed should be determined through consensus among community members. This study shed light on the decision-making process among the members within the coming energy sharing community from the perspective of simulation including human dynamics. Gaining insights into how community members behave thinking the distribution of benefits from shared energy in the simulation environment is essential for understanding future society and making practical policy.

2. RELATAD WORKS

Previous studies have explored to analyze economic benefits of P2P energy trading. Yu et al. conducted simulation to evaluate cost benefits of P2P trading [7]. Energy price was determined following Stackelberg game theory in which energy service provider was the leader, and prosumer was the follower. Their results showed P2P energy trading reduced energy consumption generated by the grid, and energy prices decreased. Li and Ma clarified factors to determine amount and price of energy trading, and revealed that without complicated strategies, P2P energy trading can distribute benefit equitably to community members [8]. Under the continuous double auction, even zero-intelligence strategy that participants bid or ask at completely random prices, can allocate benefits equitably in the long run. Kojima et al. showed that CO_2 emission would decrease if community members could share PV-generated energy [9]. Their results imply that an energy sharing community could contribute the decarbonization and mitigate the climate change.

We point out that the system of energy sharing community should be designed with deep understanding about interaction between community members is essential. However, it is difficult for us to know in advance what they will do in the society with new, unimplemented mechanisms and technologies.

One promising way to tackle this challenge is develop a serious game: simulation environment including human beings. Serious game is game which has the objective other than entertainment, such as training skills, learning or solving social problems [10]. To understand human dynamics, wide variety of research have been conducted using serious games. In the context of decision-making process in the energy community, Brakovska et al. developed multiplayer simulation game to model decision-making process among energy sharing community [11]. Their simulation tool enables to trace the decision-making and behavioral change process among decision makers in an energy-sharing community like apartment owners. But their research did not consider decision-making on how to distribute benefits shared within community members.

This article focuses on decision-making process occurred among decision-makers in an energy sharing community. Specifically, we aim to observe how participants distribute their benefits to achieve their common goals, and whether they perceive the distribution is equitable. If community members perceive the distribution of benefits is inequitable, community will be divided and no longer sustainable [12]. Thus, we emphasize that it is important to identify the relationship between distribution of benefits and equity that community members perceive.

Here, we form our research question: Can participants perceive equity even when shared funds are not equally distributed towards achieving a common goal?

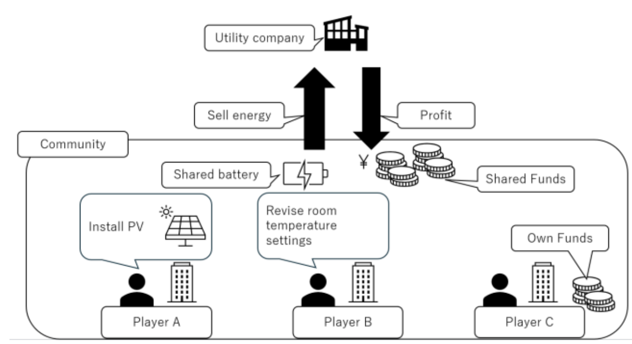

Fig. 1 Outline of community our game assumed

3. GAME FOR EXPERIMENT

3.1 Game outline

We developed an experimental game that can simulate decision-making process among community members who manage their own building. Community has the shared battery, and stored energy will be sold to a utility company. Benefit will be shared among players. Each player will be the owner of a building, and the size of the building is different depends on the player. If player has the small-size building, its contribution to decarbonization would be small, but the cost of measures would be relatively low. Income also depends on the size of the building, larger building gains more. The opposite is true if the building is larger. They can implement measures related to decarbonization and energy management, including installation of LED lighting, new air conditioner, or revision of room temperature. Each energy management measure has a cost and decarbonization score, and options to be implemented are constrained by the player's budgets ; in other words, no more measures can be taken beyond the sum of own funds and shared funds each player has. Players will discuss and select a measure to be implemented. Each player selects one measure at a time. The more measures are implemented, the more benefits will be brought to the community. Fig. 1 shows the overall setting of our game.

3.2 Game implementation

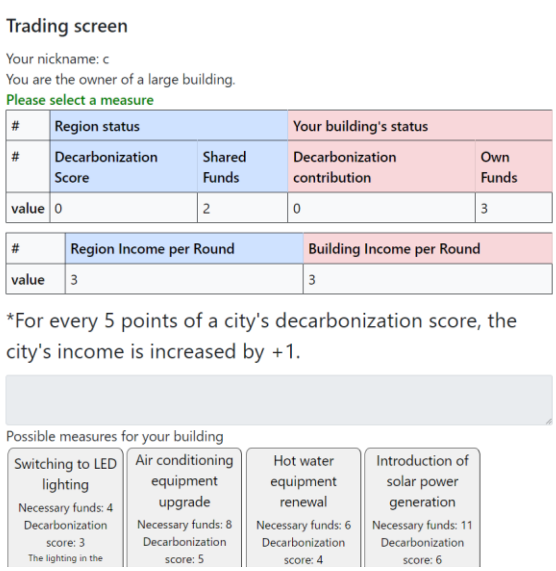

Fig. 2 Example screen of the game

Our game was implemented on oTree, open-source framework to support building multiplayer online game written in python [13]. Players can play the game using web browser. Fig. 2 shows an example screen of the game.

Players can see current region status and own building's status. Region status includes decarbonization score of the region, and shared funds. Own building's status includes their decarbonization contribution and funds. The value of region's decarbonization score and shared funds are common among players. However, each player's building status, decarbonization contribution and funds are unique and different from other players. Each player can select measures which is to be implemented for own building. Each measure has corresponding value of the decarbonization score and required funds. Since the size of the building varies, the value of funds required, and decarbonization score for each measure also different among players, the larger building requires more funds, and can contribute higher decarbonization score. This reflects the relationship between building size and cost for the decarbonization measures [14]. Measures with higher decarbonization scores require more funds, which motivates players to spend shared funds. Type, cost, and decarbonization score of the measures in our game were determined with reference to Regional Energy Management Assistant System [15].

Players need to spend the funds to implement a measure. They can spend own funds freely. Also, all players can use shared funds. The amount of shared funds usage is determined under the unanimous consensus. After selection, the decarbonization score, shared funds, decarbonization contribution, and own funds value on the screen are updated according to players' decision in the real-time manner. When all players finish to select their measures, then a round finishes. Before the beginning of next round, region gains income according to decarbonization score, and each player gains player-specific income according to the size of own building.

3.3 Rule of the game

In our game, players have the common goal to increase the decarbonization score collaboratively as much as they can. Theoretically, the highest decarbonization score that participants can achieve is 25. The detailed procedure is shown in Fig. 3 as a flowchart diagram. Players need to make decisions over several rounds. Once a player selects the measure, the player cannot select the same measure in the subsequent rounds.

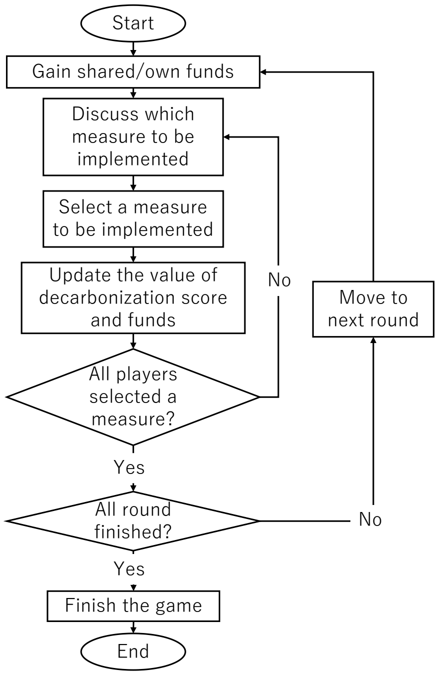

Fig. 3 Flowchart of our game

4. EXPERIMENT

The experiment was conducted according to the following procedure.

1. Experimenter explains the purpose of the experiment and the rule of the game, including how to operate game on web browser.
2. Participants play a practice round.
3. Participants play three rounds.
4. Participants fill out the post-questionnaire.

Experimenter asked participants to play one practice round and familiarize themselves with the operation of our game. We conducted a post-questionnaire to ask participants whether use of shared funds was aligned with players' preference and agreement was asked with a four-point Likert scale, considering individual preferences and agreement can be made the key criterion of the equity [16]. Reflecting regional decarbonization targets have an achievement deadline, experimenter told participants number of rounds in our game. Thus, participants could establish the plan and think strategically what to do by the end of our game.

In our experiment, three groups of three were built. The subjects were six men and three women in their 20s-70s, nine in total. All subjects were randomly assigned to a group.

5. RESULT

5.1 Observations

Only one group reached 25 points of the decarbonization score, which is optimal solution achievable by design. The experiment took a minimum of 760 seconds and a maximum of 1022 seconds. Fig. 4 shows the change in the decarbonization score for each group over rounds.

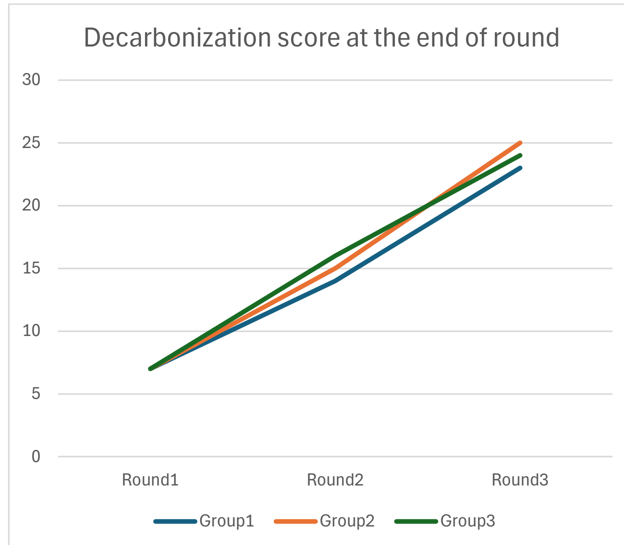

Fig. 4 Decarbonization score at the end of round

We observed that there was common participants' behavior among all groups. Firstly, all groups discussed what measures can be implemented when using only their own funds or combining shared funds at the early stage of each round. Also, members tried to reach a consensus who will use how much of shared funds. Further, members explored various options exchanging information the cost and the decarbonization score of measures, so that they could find the most effective combination. However, the criterion of consensus varies among groups. In Group1 and 3, members selected a combination of measures based on the highest achievable decarbonization score in their current round. In contrast, members of Group2 established the plan considering how to achieve the highest decarbonization score at the end of the final round. They preferred attempting the highest decarbonization score at the end of the final round instead of their current round. As a result, they chose to carry over shared funds rather than using shared funds in earlier rounds.

5.2 *Participants' decisions*

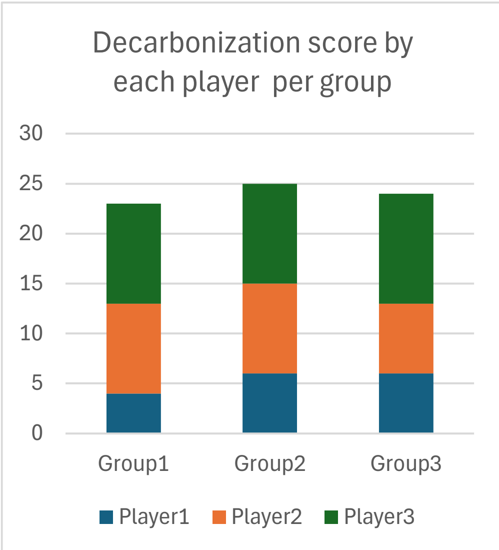

Fig. 5 Decarbonization score by each player per group

Fig. 5 shows the individual decarbonization score that each player contributed to the total decarbonization score of their group. Player1 has the small-size, Player2 has the mid-size, and Player3 has the large-size building.

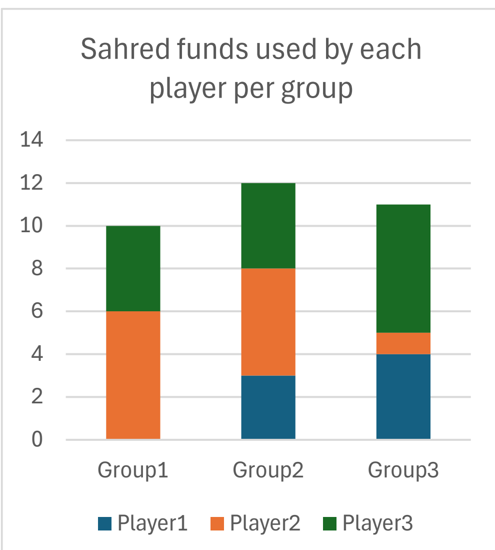

Fig. 6 Shared funds used by each player per group

Fig. 6 shows that individual shared funds usage to the total usage in their group.

5.3 *Questionnaire*

Table 1 Questionnaire

#	Question	Note
Q1	Did the use of shared funds decided during the game match your preferences?	Higher is more positive
Q2	Did you agree with the decisions made during the game on how to use the shared funds?	Higher is more positive

Table 1 shows the questionnaire participants answered, and Fig. 7 shows the average value of each question per group. From the perspective of the degree of preference and agreement, most players answered positively to both of questions.

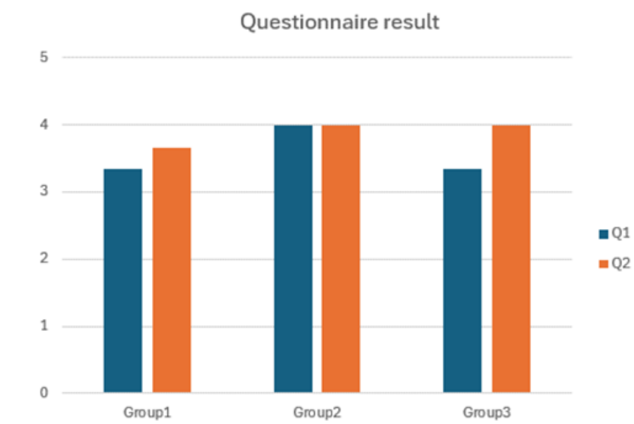

Fig. 7 Questionnaire result

6. DISCUSSIONS

The result showed our game can trace the variety of decisions and adaptation to reach the common goal among players/groups.

According to Fig. 5, trends are similar in all groups, Player3 with the largest building marked the largest decarbonization score, as their decarbonization measures had a large decarbonization score. However, the allocation of shared funds was diverse. Fig. 6 indicates that the usage of shared funds was neither always distributed more to larger building, nor distributed equally. This result implies that how participants adapt themselves towards the target goals differs depending on their decisions. Especially, the result for Group1 was significant because Player1 did not use the shared funds, but used all of Player1's own funds. Considering Fig. 7, since decisions to distribute shared funds were based on members' consensus, even if shared funds usage was biased, players may feel decisions were equitable.

From these insights, we argue that community management should consider not only the increase in economic benefits but also reflect diverse preferences and agreements of community members when distributing shared benefits. Our experiment allows participants' various approaches to reach their common target goals, explores how community members make decisions to distribute shared benefits. Furthermore, it revealed that decisions aligned with participants' preferences and agreements, suggesting that even biased distributions may be recognized as equitable if they are the result of discussion.

7. CONCLUSION

In this study, we focused on distribution of shared benefits, and developed experimental serious game to observe how participants make decisions and shared funds are distributed. Through observations, participants discussed to find out the way to reach the common goal. The results showed their strategies, and the distribution were various, and biased to certain players. Nonetheless, the degree of equity participants had was positive after game play. We emphasize usefulness of our game as the tool to observe decision-making process of distributing shared benefits.

However, it is important to note some limitations. Firstly, this experiment was conducted with only three groups. More experiment sessions need to be conducted to discuss based on stochastic evidence. Secondly, all participants joined this experiment were not actual building owners. Decisions of building owners may differ from those observed in this experiment. Thus, our findings should be interpreted with caution, they may not fully represent the actual building owners' behavior. Lastly, real building owners are not always able to openly discuss their decisions about implementing energy management measures in their buildings. However, for example in Japan, company presidents from neighboring businesses frequently interact at local events, like festival, fostering strongly connected communities with active communication [17]. In such contexts, it is easier to assume that information is shared more openly, meaning that the fidelity of our game may still be maintained. To further explore this, investigating the communication methods through interviews is essential.

Further analyses could be conducted in the future research. For instance, finding out what happens if competitive structure is implemented to our game. Currently, participants do not have any motivations to pursue their own profit. In the reality, the community may have free-rider members who do not want to spend money but want to enjoy the benefits brought by other members. Introducing competitive structure will motivate participants not cooperating towards common target goals, and improve validity of our game. Also, exploring correlation between personality like social value orientation [18] and behavioral patterns in our game. We believe that if there are individualistic members, the process of the decision making will show different pattern from this experiment. These additional experiments will provide valuable insights for policy makers to design the energy sharing system.

8. ACKNOWLEDGEMENTS

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