An Electricity Market Game using Agent-based Gaming Technique for Understanding Energy Transition

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Abstract: The Electricity Market in Japan has been an oligopolistic market since the previous century, but it will be a liberalised competitive market soon due to a policy change. It is supposed to provide wholesale power markets. Therefore, it has high possibilities to become two-sided markets with strong wholesalers. The goal of this study is to clarify decisive factors for making decision of energy selection based on human competitive and collaboration behaviour to be helpful for an incentive design of energy markets. For the purpose, two hypotheses were set in the experiment. First is that energy transition to renewable source is achieved by players while keeping their profit. Second is that aggregators have ability to control the energy market through the share of consumers' power market as well as other two-sided markets. Our experiment confirmed that the energy orientation of electric power consumers could give a significant influence on power generation investment of electric power suppliers, and the risk of nuclear energy was underestimated. And the first hypothesis was adopted and the second was rejected by the experiments through the agent-based gaming.

1 INTRODUCTION

The electricity crisis caused by the huge earthquake in Japan 2011, clarified that traditional electricity systems on a one-sided energy market are inadequate for maintaining safe and stable electricity supply at low cost. Given such an issue, the government of Japan has clearly announced that it would realise liberation for participation of power operators into small consumers such as general households in 2016. It would launch unbundling of power generation and distribution during the period around 2018 to 2020. These policies might bring about advancement of innovation with a wide variety of enterprises participating and increasing the use of renewable energy.

This attempt can encourage a wide variety of enterprises into this market; however, it also entails some risks such as instability of electricity markets and market monopolies or oligopolies. These are due to a two-sided energy-market on a de facto standard platform as well as e-tailer and e-marketplaces.

The purpose of this research is to achieve an efficient market while taking into consideration electricity market liberalisation. Additionally, this research studies incentive mechanisms for a competitive electricity markets for enabling energy transformation from fossil energy to renewable energy. In this research, social systems and infrastructures are referred to as the electricity market platform. Here, the focus is placed on aggregators that bring electricity consumers together as a community. And it is also focused on imbalance settlement which is implemented among power distribution operators and power producers/retailers for the purpose of supply and demand adjustments for renewable energy.

Through this research, by applying the agent-based gaming method, our goal is to propose an incentive design. It promotes innovation such as electricity supply and demand adjustments, stable supply, and dissemination of renewable energy through free decision-making by market participants including consumers and power operators. In a new liberalised energy market old and new energy companies will base their actions and plans on the behaviour of their competitors as well as on the (expected) responses of the consumer market. We propose using an agent based simulation of a market of consumers as a laboratory setting to study the behaviour of human decision-makers in an energy transition game.

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2 RESEARCH BACKGROUND

As clearly demonstrated by examples of the communications and Internet markets, the liberalisation of participation by many enterprises can create new markets while bringing about many benefits such as increase in business opportunities, diversification of services, and lowering of fees. On the other hand, leaving everything to free market competition prevents products and services with higher transaction cost from being transacted. It results in causing market failure. Renewable energy is easily affected by the natural environment, making the supply-and-demand balance difficult to adjust, while power generation cost at the same time is expensive. This increases transaction costs. Therefore, it is overly optimistic to believe that the price mechanisms within the market could for sure promote and disseminate these above-described power sources.

On the other hand, in the ICT market which has two sides, consumers and suppliers, platform competitions are being developed on a global basis. These are attractive on the price side, the supply side, and the service side. This two-sided market mechanism has been analysed by using mathematical models (Boudreau and Hagiu, 2009)(Unno and Xu, 2012). In addition, recently, studies regarding real-time dynamic pricing based on agent modeling and studies regarding incentive mechanisms (Bacon, 2012) have been made.

Smart grid is expected to gain profits from real-time dynamic pricing. This pricing system enables both power consumers and power companies to reflect changes in wholesale prices on the demand side (Samadi et al., 2011). Conversely, auction-based power pricing is not an uncommon concept. However, the demand side which participates in auction sessions is based on renewable energy such as solar energy. Therefore, electricity generated is very variable.

Required studies include those of electricity platform design which maximises social welfare while considering the electricity market as a two-sided market, and those focusing not on a single market, but on multiple competitive electricity markets. Mechanism design in dynamical systems and agent-based gaming models are considered to be the best and suitable in order to optimise participation incentives under such circumstances.

Traditional economic models describing changes in markets are less suitable to understand the dynamics of interaction in a two-sided market. This is because these models do not account for the emergent processes that can happen when multiple actors are interacting. Agent based simulation is a suitable tool to study the dynamics in markets with many interacting actors. When the agent based model is suitable for policy makers to experiment with managing the system, a serious game context can be created to study both the impact of decisional strategies as well as the decision making process of the managers. They can be confronted with different situation, and it can be systematically studied what type of management and which policies are the most effective in guiding such a transition in the energy market.

An important challenge here is the valid modelling of the population of agents in the model. Realistic agent behaviour is important to make an agent based game a tool that provides applicable insights(Jager and Vegt, 2015).

In two-sided markets with consumers and suppliers, platform competitions are being developed on a global basis which are attractive on the price side, the supply side, and the service side. This two-sided market mechanism has been analysed by using mathematical models. However, mathematical models were applied to analyse market mechanisms with only one or two players(Rochet and Tirol, 2003)(Rochet and Tirol, 2006)(Sannikov, 2008). Therefore, mathematical models have limitations in analysing mechanisms with multiple diversified players such as consumers. In addition, studies regarding ABM-based dynamic pricing and incentive mechanisms have been in progress. In these studies, however, the decision-making process of agents was controlled by an algorithm. For this reason, there are limitations in these studies to analyse complicated decision-making processes taking into account movements of actual environments, human behaviour and complex energy consumers markets, and corporate management conditions. Based on these traditional models, in this research, we made an attempt to build a two-sided market model for electricity markets by applying agent-based gaming.

Serious game sessions have been held in recent conferences regarding social simulation (ESSA, 2015). As for the traditional approaches of serious games, however, societies and environments which served as backgrounds were defined by game designers. Therefore, they often tend to have deterministic characteristics. Real societies, where participating agents are actually thrown into interactions with other agents or a non-linear process, have the property of complex adaptive systems. Electricity markets are expected to be such a circumstance as mentioned above. This requires gaming with an assumption of complex adaptive systems.

Afterward, section 3 describes the research objectives, and section 4 explains the outline of the energy conversion model. Section 5 gives a description of experimental environment and section 6 discusses the experimental results, while section 7 summarises this research.

3 RESEARCH OBJECTIVES

The objective is to analyse what players can obtain market ascendancy under what kind of conditions in an electricity market. In order to achieve electricity platform design which maximises social welfare, this research focuses on aggregators and imbalance adjustment. Currently, utilisation of market functions associated with electricity supply and demand adjustment has been considered, with a proposal for establishing a new one-hour-ahead market and a real-time market in order for electricity distribution operators, power producers and retailers to procure the most efficient regulated power supplies from these markets (Ministry of Economy, Trade and Industry, 2013). Use of these market prices in imbalance settlement for renewable energy can secure transparency and fairness. This should have positive influence on the efficiency of electricity markets and the promotion of renewable energy dissemination (Fig.1).

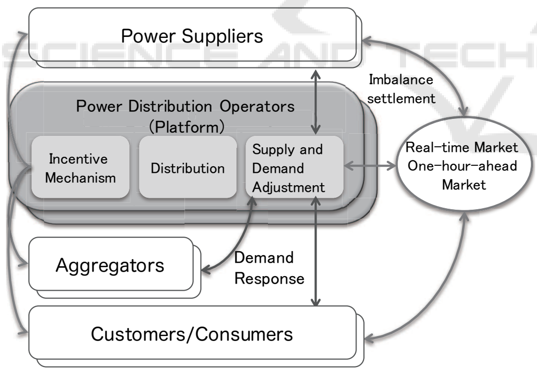

Figure 1: Imbalance settlement and the electricity market.

Market participants are diverse agents and the market itself also consists of multiple competitive platforms; therefore, these things are considered to be multi-agent and multi-purpose optimisation problems. Solving such problems requires a multi-agent incentive mechanism, while an appropriate approach is agent-based modelling (ABM). On the other hand, when the decision-making process of power suppliers and aggregators is left to machine agents, the algorithm's capability could affect the decision-making results. However, a human-agent participatory gaming method which has been used for serious games is more likely to obtain the decision-making results that are close to the actual results when human agents as players organically connect and consider information which they obtain from models. In traditional serious games, however, environmental changes as the background are determined in a deterministic manner. This fact makes it difficult to reproduce the complicated movements of an electricity market.

Given that, through this paper, progress has been made in our present research based on the following two points while connecting ABM and serious games and introducing an agent-based gaming method which makes it possible to design multi-agent and multi-purpose models.

3.1 Analysis of Market Structure which Brings about Energy Conversion

System design in electricity markets have a significant influence on generation of market rulers. Our additional goal is to design a system which is effective for energy conversion to renewable energy. Design of a mechanism for achieving stable electricity supply equilibrium based on utilisation of a wide variety of energy sources needs to play the role of a platform for maximising the utility for both electricity suppliers and consumers. In order to analyse these structures, we use ABM.

3.2 Comparative Analysis of Decision-making Structures

While expanding electricity consumers and power producers to multiple agents, their behaviour is expressed by using a multi-agent model. With that, we conducted comparative analysis on the decision-making results obtained by introducing participatory agent-based gaming. By analysing differences brought by each individual agent, we evaluated strategies of imbalance adjustment incentives for electricity, and government subsidies and tax rate policies. In addition, observing the targeted phenomenon not only from a single viewpoint, but from several different viewpoints, in order that each phenomenon can be expressed accurately by using only one model (Grimm, 2005).

4 ENERGY CONVERSION GAMING MODEL

In energy conversion gaming models based on agent-based gaming models (Fig.2), in an electricity market where power producer players and aggregator players participate, power producers make their decisions based on electricity sale prices, advertising investments, and plans for power-generation facilities. Sale prices are adjusted based on imbalance settlement in supply and demand with electricity distribution operators.

On the other hand, we can expect that marketers, brokers, local public organisations, and non-profit groups which organise electric needs of consumers in order to provide energy management services effectively will participate in electricity markets. They play their roles as aggregators which serve as a bridge between retail players and general households/operators. Aggregators are expected to provide a wide variety of services based on advanced energy management systems by using smart meters, while developing demand responses and negawatt[1] services. This might allow aggregators to dominate market circulation in a two-sided market, and to have the power to determine not only the price, but also to profit allocation. This possibility brings the same structure as IT markets including music distribution and smartphone app markets, where fierce competition for dominating markets can be caused. Therefore, it is extremely important to study on market system design which can promote development of renewable energy and sound market competition.

The proposed agent-based gaming model is based on the government plan of energy market reform in Japan(NRE, 2015).In this gaming model, the actual participants participate in the game playing the roles of power producers, electricity retailers, and aggregators. In addition, computer agents also participate in the market autonomously as a number of consumer agents. The government agents conduct imbalance settlement based on the predetermined market rules. Based on this gaming model, the game participants can experience the complexity of this market and they can design a market system while verifying the effectiveness of the system designed. Our ultimate goal is to verify whether real-time characteristics are satisfied by conducting simulation based on the actual climate data in order to develop further verification.

4.1 Model Outline

According to the ODD protocol, the section below describes the outline of the model. The ODD (Overview, Design concepts, and Details) protocol was proposed to standardise the published descriptions of individual-based and ABMs(Grimm, 2005). The primary objectives of ODD are to make model descriptions more understandable and complete, thereby making ABMs less subject to criticism for being irreproducible.

In this model, 'Entities' are electricity suppliers, aggregators, the government, and consumers. 'State variables' are defined as follows:

- Electricity suppliers
  Sale prices, discount rates for major clients, investments (advertising, thermal, nuclear, and renewable energy), costs (thermal, nuclear, and renewable energy), carbon generation rates (thermal, nuclear, and renewable energy), power generation amounts (thermal, nuclear, and renewable energy), operator attractiveness, carbon gas generated, and rate of power failure occurrences
- Aggregators
  Sale prices, advertising investment, the number of operators that purchase electricity, and energy proportions (thermal, nuclear, and renewable energy)
- Government
  Imbalance prices, business tax rates, carbon tax rates, and renewable energy investments
- Consumers
  Norm effect parameters, information effect parameters, network generation parameters, and the number of consumers

'Process overview and scheduling' are as below. Suppliers generate power, and sell it to consumers and aggregators. While taking into account the environment of consumers and their intentions toward prices, suppliers determine the power generation proportions of thermal power generation, nuclear power generation, and renewable energy, electricity prices (discounts for general/major clients), and advertising investments in order to maximise their own profits. Increase in the proportion of renewable energy increases the power failure probability, resulting in paying the imbalance cost. Additionally, their own competitiveness declines in proportion to the power failure probability.

Aggregators purchase electricity with discounts for major clients from suppliers, while re-selling the electricity to consumers. While taking into account the environment of consumers and their intentions toward prices, aggregators determine the power generation proportions of thermal power generation, nuclear power generation, and renewable energy, electricity prices (for general clients), and advertising investments.

While considering their own preferences for electric power and electric power charges, consumers pur-

[1] Negawatt power is a theoretical unit of power representing an amount of energy (measured in watts) saved.

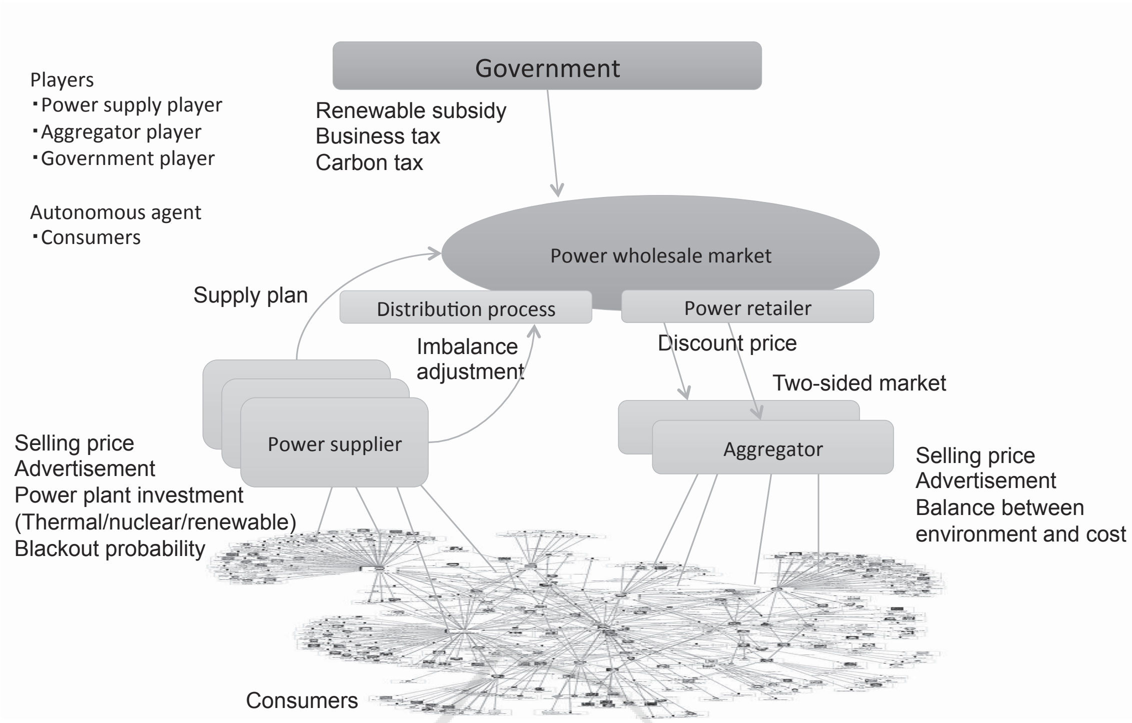

Figure 2: Energy conversion gaming model.

chase electric power from appropriate suppliers. Consumers are network-linked with their acquaintances receiving the norm effect. The government determines imbalance prices, business taxes, carbon taxes, and renewable energy subsidies. Based on these, the total amount of carbon gas generated and the entire probability of power failure are determined. The goal of the government is to optimise these variables.

Within the game, the degree of market dominance by players and decision-making of consumers on neighbouring networks are generated as 'Emergence'.

In gaming models, motivations of players are defined that supplier and aggregator human players make their decisions so that they maximise their profits while referring to decision-making status of other participants as 'Adaptation' processes. Alternatively, their attitudes to their own environment could be reflected. Controlling the amount of CO_2, government players make their decisions so that tax revenues can be secured and the power failure probability is maintained at a lower level. The players in gaming models are expected to discuss and learn as a team.

Agent players interact with other suppliers, consumers, and the government through the market in the following points. Agent players develop competition by receiving orders from consumers, establishing the regulations on CO_2 emission based on carbon taxes with the government, implement environmental measures based on renewable subsidies with the government, establish the restrictions on renewable energy based on imbalance adjustment prices with the government, compete with other companies for attractiveness based on stable electric power supply (power failure probability) with consumers, and secure profits and compete for receiving orders through discounted prices with aggregators.

The initial electric power preferences of consumers are stochastically determined in a uniform distribution, while the environmental preferences vary depending on the period. The electric power proportions are determined in uniform random numbers expressed by the base proportion +/-10%. Based on the synthesised attractiveness of prices and electric power preferences, suppliers and aggregators are determined by using roulette selection. The power failure probability is an exponential function based on the renewable energy proportions.

Decisions made by consumers as realistic agents are determined based on the norm effect of neighbouring market shares on consumer network models(Delre et al., 2007)(Toivonen et al., 2006). As for the norm effect of consumers, the threshold model which is influenced by neighbouring market shares is adopted. Consumers also have information effect functions in which they make decision to purchase electricity from suitable power suppliers stochastically based on price and energy sources such as thermal, nuclear and renewable energy(Kurahashi and Saito, 2013).

5 EXPERIMENT

An electricity gaming model was implemented by the agent programming environments, NetLogo and HubNet, which was operated from each terminal connected to the local network. Fig.3 shows the screen displayed for players, while Fig.4 shows that for operators.

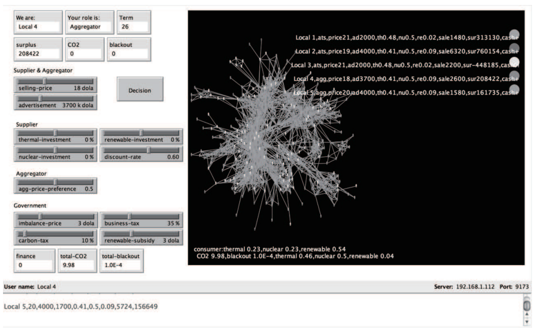

Figure 3: Player Panel: Networks of consumers and market shares are graphically observed. Decision-making and management conditions of other players, including the preferences of consumers, are observed on a panel. Decision-making and management condition of all players are able to be observed on a panel in every period.

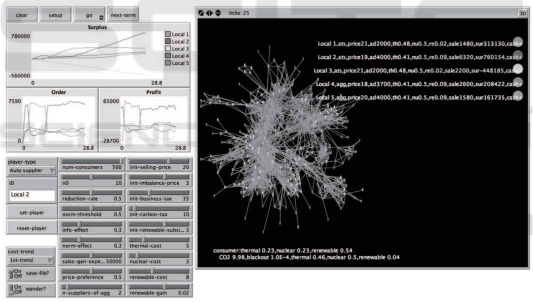

Figure 4: Operator Panel: A game operator could confirm the condition of consumers allocated on the network and the condition of suppliers on the panel.

From any of these screens, the condition of consumers allocated on the network and the condition of suppliers could be confirmed. Consumers were able to identify order destinations in different colours, so that they could intuitively understand the current share condition of suppliers. Electric power prices, investment for power generation facilities, and management information including surplus funds could be confirmed as supplier conditions. From this player screen, each supplier player entered necessary information such as the electric power prices, advertising investments, investments for thermal power generation, investments for nuclear power generation, investments for renewable energy power generation, and the discount rates for major clients. Aggregate players determined the price and the energy source weight, in addition to the electric power price and advertising investments, as factors for deciding order destinations.

In this experiment, four supplier players, one aggregator agent, 500 consumer agents and the government agent made their decisions for 18 periods. The threshold level of norm effect is 0.5. Information effect which indicates price and energy balance of suppliers is 0.3. Business tax rate is 35%. Carbon tax rate is 10%. Thermal energy cost is 10 unit / kW, nuclear energy cost is 5 unit / kW, and renewable energy cost is 8 unit / kW, imbalance price is 3 unit / kW, and a preference level between price and energy source of aggregators is 50%.

The goal of this study is to clarify decisive factors for making decision of energy selection based on human competitive and collaboration behaviour to be helpful for an incentive design of energy markets. For the purpose, two hypotheses were set in the experiment. First is that energy transition to renewable source is achieved by players while keeping their profit. Second is that aggregators have ability to control the energy market through the share of consumers' power market as well as other two-sided markets.

6 RESULTS AND DISCUSSION

The left chart of Fig.5 shows the proportion of each energy source, the amount of CO_2 emissions, and the transition of the power failure probability. In the initial stage, the proportion of thermal power generation exceeded 60%; however, it declined gradually, finally going down to less than 40%. This also reduced the amount of carbon emissions (The right chart of Fig.5). The first hypothesis, which energy transition to renewable source is achieved by players while keeping their profit, has been adopted with this result.

On the other hand, the proportions of nuclear power generation and renewable energy power generation increased. This is because of the influence given by the energy orientation of consumers. In particular, the proportion of renewable energy gradually increased in tune with the orientation of consumers, while it declined in the later stages. This result might be because whereas the power generation proportion of each electric power supplier was inclined toward the use of thermal power generation in the initial stage, the energy orientation of consumers was about 1/3. Therefore, there must have been an incentive that worked where the order volume increased by changing the power generation investment according to this

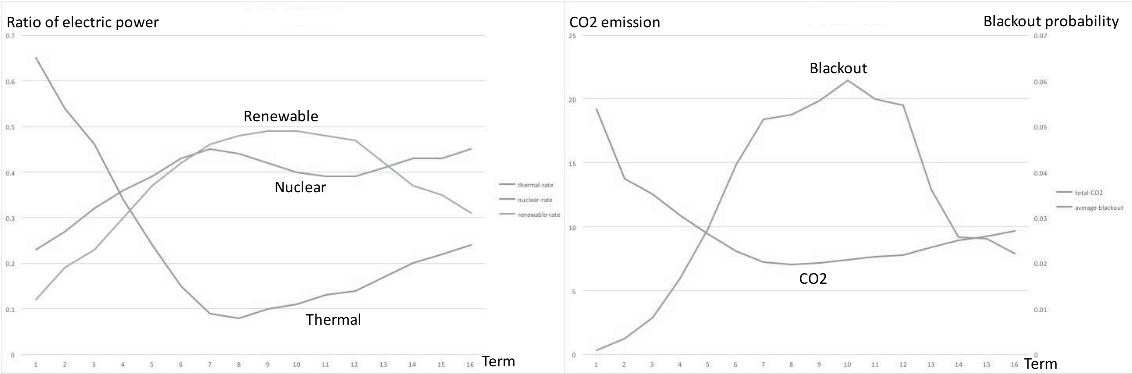

Figure 5: Left: Trend of energy source rate, Right: Trend of CO_2 and blackout rate.

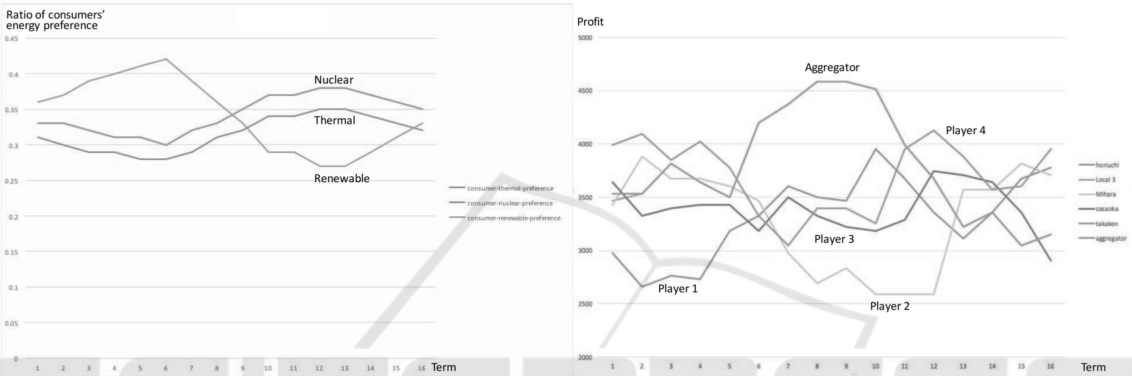

Figure 6: Left: Trend of consumers' energy preference, Right: Trend of players' sales in the power market.

proportion (The left chart of Fig.6).

However, the situation, which was originally expected that the proportion of nuclear power generation decreased, was not observed, while nuclear energy with lower cost and carbon gas emissions continue to be relied on. This result shows that the management of electric power suppliers gave the first priority to maximising their profits, while giving almost no consideration to risks of nuclear power generation accidents. On the other hand, the aggregator agent made profit as well as suppliers players, but it could not monopolise the electric consumer market because one possibility is that the supplier players learnt how to keep their market share in competition from the aggregator(The right chart of Fig.6). The second hypothesis, which aggregators have ability to control the energy market through the share of consumers' power market as well as other two-sided markets, was rejected with the result.

All of the four players participating in this experiment were business people in their 30's, who might have had a custom to make decisions to maximise business profits as corporate managers. They were at the same time consumers, however, this experiment suggests that their concepts of accident risks might significantly change when they play a social role as entities to make corporate decisions.

7 CONCLUSION

In this research, based on agent-based models, serious games, design of electricity market platforms, and social network models, we built a model having the items below as purposes.

1. Feature analysis on electric power imbalance adjustment for achieving new system designs
2. Design of competitive electricity market platforms
3. Design of incentive mechanisms for imbalance adjustment
4. Evaluation and examination of mechanism design based on agent-based gaming models

The goal of this study is to clarify decisive factors for making decision of energy selection based on human competitive and collaboration behaviour to be helpful for an incentive design of energy markets. For the purpose, two hypotheses were set in the experiment. First is that energy transition to renewable source is achieved by players while keeping their profit. Second is that aggregators have ability to control the energy market through the share of consumers' power market as well as other two-sided markets.

Our experiment confirmed that the energy orientation of electric power consumers could give a significant influence on power generation investment of electric power suppliers, and the risk of nuclear energy was underestimated. And the first hypothesis was adopted and the second was rejected by the experiments through the agent-based gaming. These findings enabled us to analyse the decision-making process of people and operators, while being able to obtain effective knowledge regarding social ecosystems which disseminate renewable energy and adaptive behaviour.

In the future, we are going to examine combined models with autonomous and human agents to compare with them. The autonomous agent-based model will show behaviour and attitude as a control group to validate the hypotheses more thoroughly. We will also conduct several games including autonomous agents and human players and compare with other models such as an equilibrium model and so on.

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