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A Study of Integrated Model for Electricity Supply Chain Considering Renewable Energy Fraction and Demand Variation

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ABSTRACT

This paper aims to derive integrated model for electricity supply chain considering renewable energy fraction and demand variation. Currently, attention is being paid to increasing the ratio of renewable energy generation in the electric power market which called Green Energy Coefficient (GEC). This paper aims to derive an integrated model of electricity supply chain considering renewable energy fraction and demand variation using multi-agent reinforcement learning. The subjects of the models are the consumption market model, the electricity market model, and the production market model. Also, the pricing process in electricity supply chain is analyzed using the proposed multi-agent simulations.

Keywords: Green Energy Coefficient (GEC), Electricity Supply Chain, Renewable Energy

INTRODUCTION

With the liberalization of electricity retailing in Japan in April 2016, and the liberalization of the transmission and distribution sectors in April 2020, consumers will be able to freely choose the electricity company they contract with. As a result, more and more companies are offering electricity at lower prices than ever before, increasing the benefits for consumers. On the other hand, power companies need to strategically set appropriate supply volumes and prices based on market prices and electricity demand trends in order to ensure profits in the face of numerous competitors. In addition, it is necessary to consider all aspects of the impact on power companies, power retailers, and consumers. In addition, we are facing many challenges, such as expanding the use of renewable energy, which is generated from natural energy and reusable resources with less impact on the global environment and reducing the number of nuclear power plants. According to data from the Agency for Natural Resources and Energy of the Ministry of Economy Trade and Industry (METI), the goal is to increase the share of renewable energy in total electricity generation to 22-24% by 2030.

Under these circumstances, Koie [1] modeled carbon tax and emissions trading schemes using a multi-agent model and conducted research to analyze their impact on the electricity market. In this model, Q-learning is used as a reinforcement learning method for the agents.

Watanabe.[2] conducted a multi-agent model simulation of the Japanese electricity industry, which is undergoing major changes due to electricity deregulation, and constructed an electricity supply-demand model focusing on dynamic capital investment strategies across multiple time points.

Kanetaka [3] used Q-learning to examine the impact of each pricing strategy of electric power companies based on failures in the pooled market in the United States.

Inagaki [4] found that deregulation was implemented for many utilities, including the electricity market, as the cost of regulation and the inefficiency of regulation itself were pointed out, although it was conventionally believed that regulation was necessary for utilities such as electricity. The dynamic factors such as the entry and exit of different types of power generators into and out of the market were added to the multi-agent model to analyze the movements of power generators and the market.

As described above, there are some studies that model the electricity market under deregulation and some that consider carbon dioxide emissions, but there are few studies that consider the share of renewable energy. Therefore, in a previous study [9], we extended the multi-agent electricity market model of Kanetaka [3] and developed an electricity trading model that takes into account the share of renewable energy.

In a previous study [9], an electricity market simulation model was developed to quantitatively analyze and evaluate price fluctuations in the electricity market for electric power companies. However, in the previous study [9], consumers and electricity retailers were not linked, and the model could not be viewed as a consistent electricity supply system.

Based on the above background, in this study, we first propose an integrated model including consumer market model, production model and electricity market model. After that, using multi- agent simulation we analyze the pricing process in electricity supply chain.

INTEGRATED MODEL DESCRIPTION

In this study section, we propose an integrated model of electricity supply chain considering renewable energy fraction and demand variation using multi-agent reinforcement learning. The subjects of the models are the consumption market model, the electricity market model, and the production market model.

The consumption market model is a simulation model of electricity price plan selection. Due to the liberalization of electricity retailing, consumers are now free to choose new electricity companies and plans and need to select the most appropriate plan depending on the number of household members and their lifestyles. Therefore, this model is designed to provide electricity plans that are suitable for different household characteristics.

The electricity market model is a model that represents the flow of electricity generated at power plants to the market. The production market model is a relative trading model between power generation companies and the electricity market. We perform reinforcement learning on this model to quantitatively analyze and evaluate the price fluctuations in the electricity market considering the percentage of renewable energy.

Furthermore, the amount of demand in each of these three model elements is integrated around an axis to form a single electricity supply model. Figure 1 shows the overall image of the electricity supply model.

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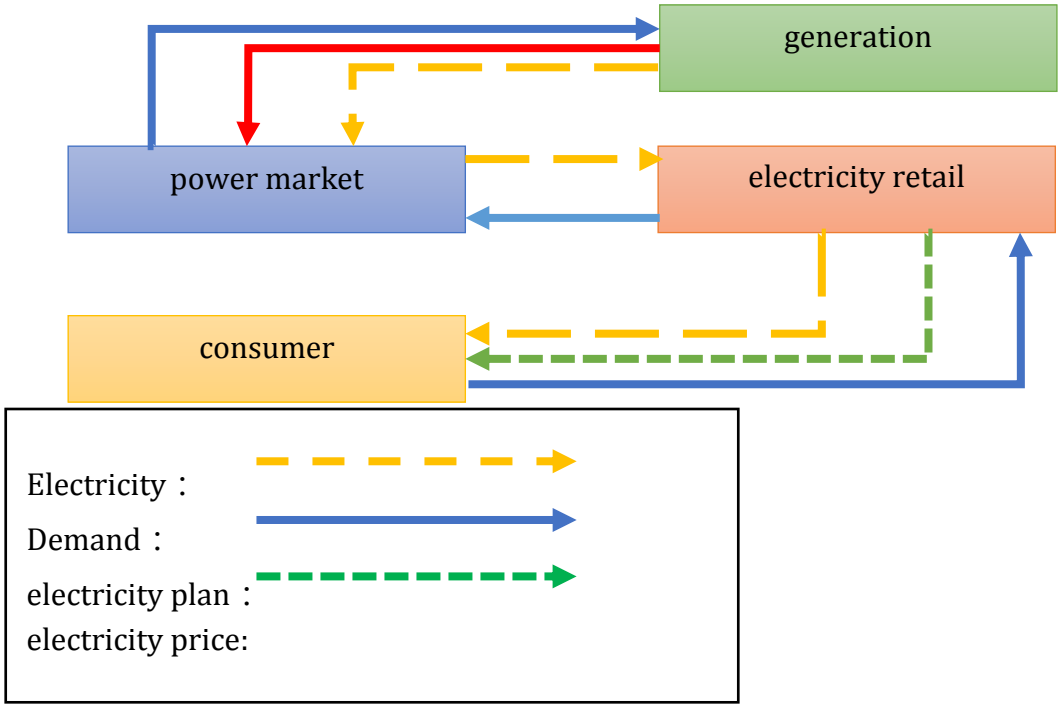


Figure 1 - Diagram of integrated electric power supply

ELECTRICITY MARKET MODEL

A wide variety of liberalization models have emerged in the electricity market transactions in the deregulation of electric power. Among these, there is a model called a pool market, which is not familiar in Japan but is typical in Europe and the United States. In this study, we assume a pool market as the mechanism of the electricity market. In a pool market, the power generation division of an electric power company or an independent power producer (IPP) sends all of its electricity to the market once and then trades in the market to supply electricity.

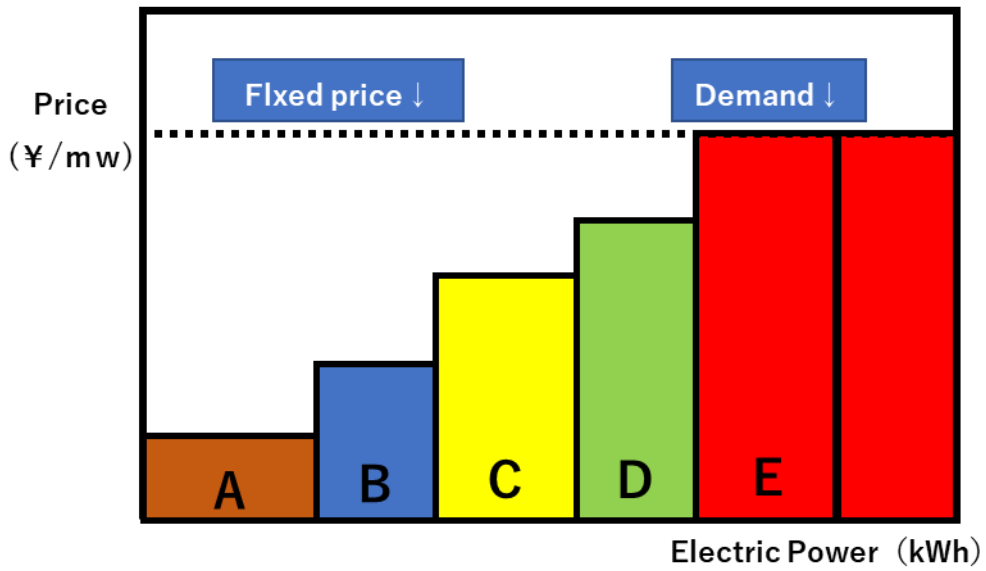


Figure 2 - Example of a transaction in a pool market

The advantage of a pool market is that it enables efficient congestion management, but its disadvantage is that it is vulnerable to the exercise of market dominance. In fact, in the U.S., there have been cases where large companies with control have manipulated prices in the pool market, resulting in supply reductions, frequent power outages, and other problems.

The pricing method is based on a single-price auction, in which power supplies are arranged in order of lowest bid price based on the bids for all power supplies, and power supplies are purchased until total demand is met, at which time the winning bid price becomes the market price.

An overview of the single-price auction scheme in this study is shown in Figure 2. As an example, from Figure 2, the auction is arranged in the order of Company A, B, C, D, and E, with Company E's offer price determined as the market-determined price, since the total demand is satisfied by approximately 60% of the volume offered by Company E.

PRODUCTION MARKET MODEL

Overview of Multi-Agent Simulation

In this study, I treat the four generating companies as agents. The agents put all the electricity they supply into the market. Power generation company agent learns the action that yields the largest profit by evaluating the value of the action.

Q-learning is used in this model as a reinforcement learning method. Equation (1) is a general update formula for Q-learning. α is an appropriate positive value called the learning rate, which adjusts how much the parameters are moved in one update. r is the reward obtained when action a is taken.

The more rewarding the action is, the larger the action value function is. maxQ (s, a) is the Q value when the action with the highest action value function Q is chosen under state S. It means that when moving from the current state to the next state, the Q value is brought closer to the state with the highest Q value.

$$Q(s_{t+1}, a_{t+1}) \leftarrow Q(s_t, a_t) + \alpha\{r_{t+1} + \gamma maxQ(s_{t+1}, a) - Q(s_t, a_t)\} \quad (1)$$

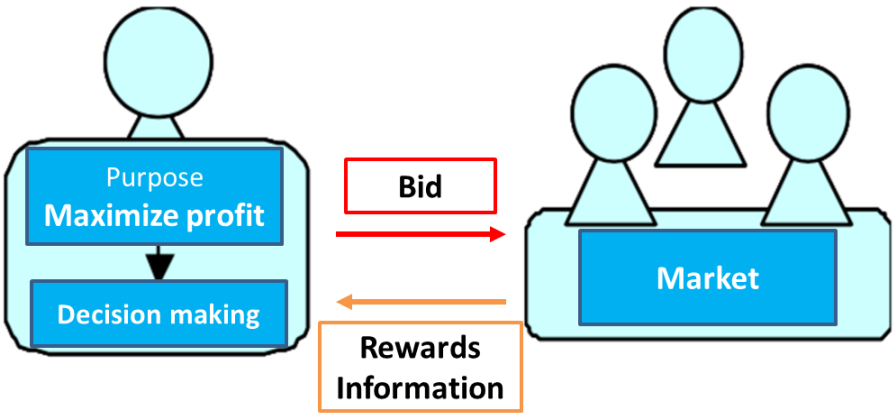


Figure 2 - Reinforcement learning

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In this study, Q-value is used as the asking price for Q-learning.
$Q\ (s_(t+1), a_(t+1))$: Asking price
$Q\ (s_t, a_t)$: Previous asking price
$maxQ(s_(t+1), a)$: Quoted price at historical maximum profit/loss

r: Reward
α: Learning rate
γ: Discount rate

Method for Determining Supply Considering Renewable Energy

Renewable Energy Percentage Adjustment Method

In this study, we defined the share of renewable energy in the total power generation as the renewable energy share ρ. If ρ is not greater than a specified amount, we incorporated a mechanism to keep adjusting the power until it is greater than a specified amount before running the simulation. The mechanism is described below.

If the specified amount of renewable percentage is ρ'

$$\rho = \frac{\sum_{i=1}^{k} E_i}{\sum_{i=1}^{n} E_i} \tag{2}$$

$$\rho < \rho'$$

Then $i = (1,2, \dots, k)$

$$E_i' = 1.01E_i + \frac{0.01 \sum_{a=k+1}^{n} E_i}{k} \tag{3}$$

Then $i = (k+1, k+2, \dots, n)$

$$E_i' = 0.99E_i - \frac{0.01 \sum_{a=1}^{k} E_i}{n-k} \tag{4}$$

$$\rho = \frac{\sum_{i=1}^{k} E_i}{\sum_{i=1}^{n} E_i} \tag{5}$$

Then $\rho < \rho'$ ， This is repeated.

Then $\rho > \rho'$, Start the simulation with Ei as the amount of electricity i generated.

E_i^'：Electricity i generated

ρ：Percentage of renewable energy

i:：Power generation method (i=1,2,…,k,…,n)

However，i=1∼k is renewable energy，

i=k+1∼n is conventional energy

Method of Determining Supply:

Each agent determines the amount of electricity to be supplied by each of the five power generation methods: thermal, nuclear, hydro, solar, and wind. Since the cost of electricity generation differs for each generation method, the total cost is obtained by summing the generation costs using Equation (6), and the overall supply is obtained using Equation (7).

$$C_j = \sum_{i=1}^{n} u_i E_i \tag{6}$$

$$S_j = \sum_{i=1}^{n} E_i \tag{7}$$

C_j: ：Total cost of generating electricity for the company j

S_j：Supply of company j

j: ：Company ($j = 1,2, \dots, m$)

In addition, an adjustment function was added to reflect market trends by using equation (8). ε is a value that varies depending on the previous quantity demanded, and in this study it was set to 101/100 if the quantity demanded increased from the previous period and 100/101 if it decreased.

$$S_j' = \varepsilon S_j \tag{8}$$

S'：Previous Supply

ε：Rate of change in supply

Needs Determination Method

To use this simulator, it is necessary to input demand values. Since there are 12 months of monthly data, the 48 steps in the algorithm were divided into 12 parts, with each partitioned into 4 steps. The adjustment function is added so that the market trend can be reflected by using equation (9) as in the case of supply. θ varies depending on the market-determined price. If the market-determined price in the current period is less than the market-determined price in the previous period, it is set to 101/100; otherwise, it is set to 100/101.

$$D' = \theta D \tag{8}$$

D：Electricity Demand

D'：Previous Electricity Demand

θ：Rate of change in Demand

Offer Price Determination Method

Derived by substituting into equation (9), respectively.

$$P_j = \frac{C_j}{S_j} \tag{9}$$

P_j: Price offered by Company J

ANALYSIS OF ELECTRICITY DEMAND

In order to forecast electricity demand, we took data on electricity consumption by ordinary households and created a simulator to analyze it. In this study, we were able to collect data for 46 students at the Nagoya Institute of Technology. Figure 3 shows a line graph showing the amount of electricity used in a day as a percentage. Although there was no significant seasonal bias, the percentage of electricity use in the morning was low in all seasons, increased as night fell. The main reason for this can be attributed to the fact that the majority of the surveyed

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households are working people living together with college students, who are often out of the house for work in the morning and during the daytime and do not use electricity at home. The average electricity demand for each month can be multiplied by the percentage of time the electricity is used in a day to output the electricity demand transition for each time period. Figure 4 shows this in three-hour intervals. It can be said that the most electricity is consumed from 18:00 to 21:00 throughout the day at all times of the year.

This is basically because families tend to gather at this time and electricity consumption increases. This is especially true during the cold season.

This is presumably because more electricity is consumed due to the use of heating. However, the daytime electricity consumption is relatively high in summer. This is presumably due to the increased use of air conditioning during the hot daytime hours.

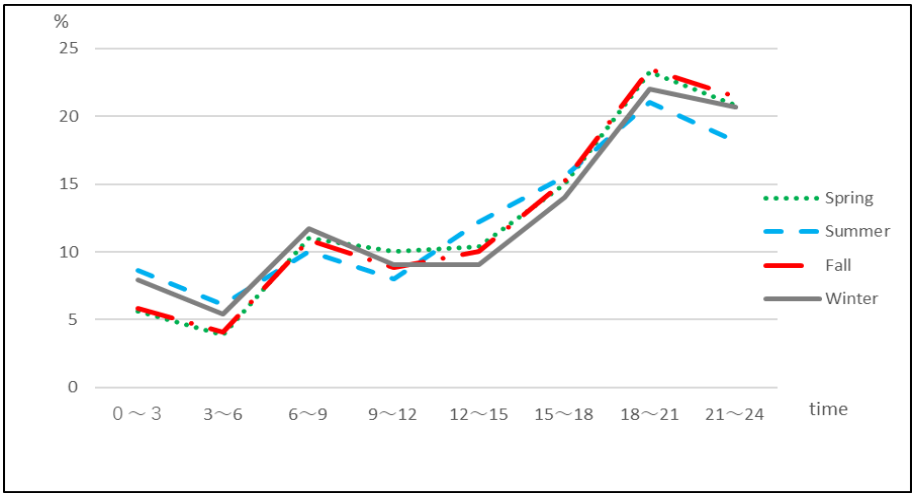


Figure 3 - Percentage of Electricity Used by Hour

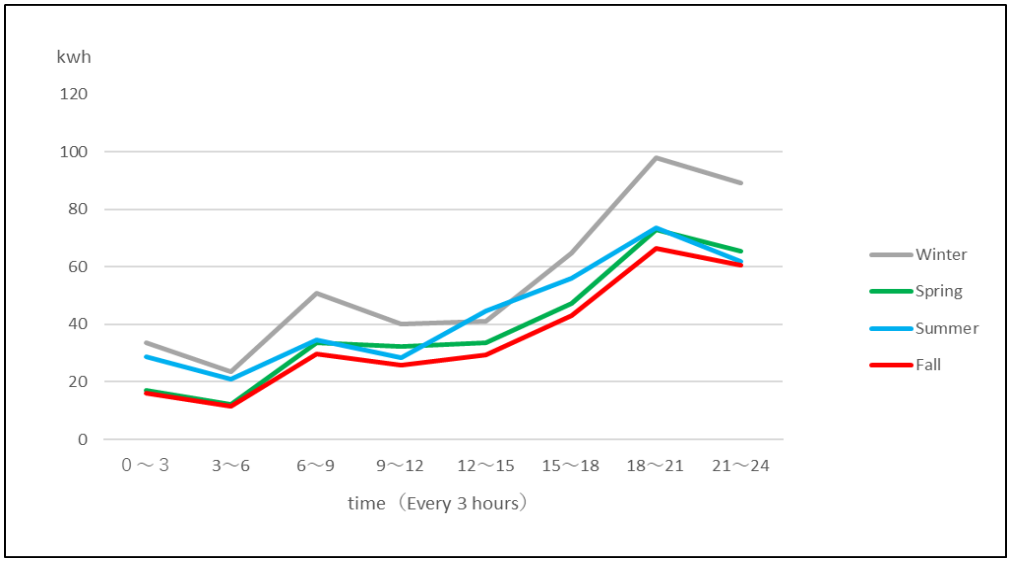


Figure 4 - Electricity Demand by Time Period

NUMERICAL EXPERIMENTS

In this study, we developed a consumption market model for electricity users, a liberalized electricity market model, and a production market model in which electricity companies trade in a pooled market. Then, we proposed an integrated model by linking these three models with the amount of demand. Finally, by using multi- agent simulation, we analyzed the electricity market dynamics considering renewable energy coefficient and demand variation.

Initial Value

Four firms are assumed in this study: firm 1, firm 2, firm 3, and firm 4 are self-generating, renewable energy generating, medium-sized, and large firms, respectively. Two experiments are conducted in this study: the first examines the output results for a change in the percentage of renewable energy ρ, and the second examines the changes in output results generated by changing the supply by generation method for each company. Tables 1, 2, and 3 show the respective initial values [10].

Table 1 - Initial values

Number of Steps	48
Θ	1.01, 0.99
ε	1.01, 0.99
α	0.1
γ	0.9
r	5, -1

Table 2 - Generation Cost by Generation Method (¥/kwh)

thermal	nuclear	hydro	solar	wind
12.3	10.1	11.0	24.3	21.9

Table 3 - Supply by Generation Method of Each Company (kwh)

canpany	thermal	nuclear	hydro	solar	wind
1	0	0	0	5	0
2	0	0	10	20	20
3	80	45	5	5	10
4	130	90	10	10	10

The numerical experiments in this study examine the output results for changes in the renewable energy fraction ρ

RESULTS AND DISCUSSION IN RENEWABLE ENERGY PERCENTAGE CHANGE

In this experiment, we compared two patterns, ρ = 0.19 and ρ = 0.55. When ρ = 0.55, the timing of price competition in the market was earlier than when ρ = 0.19.

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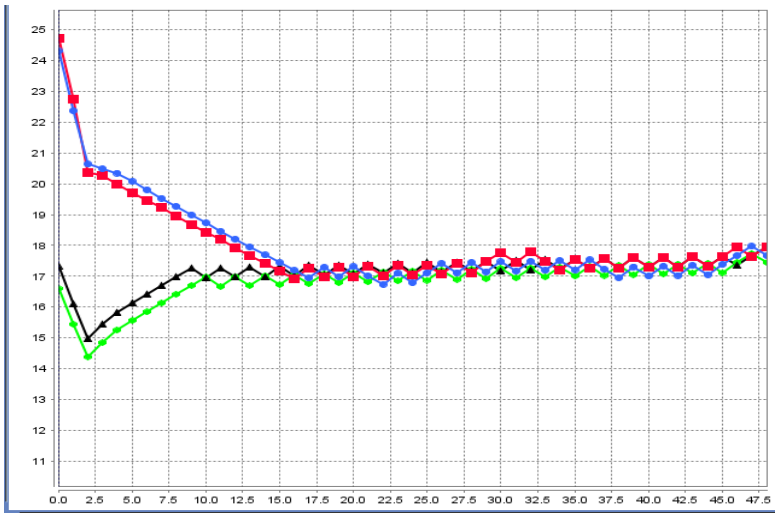


Figure5 - ρ = 0.19 Offered price

This can be attributed to the fact that the initial offer price increased due to the increase in the share of renewable energy with high generation costs. Figures 5 and 6 show the transition diagram of the asking price for ρ = 0.19 and ρ = 0.55, respectively.

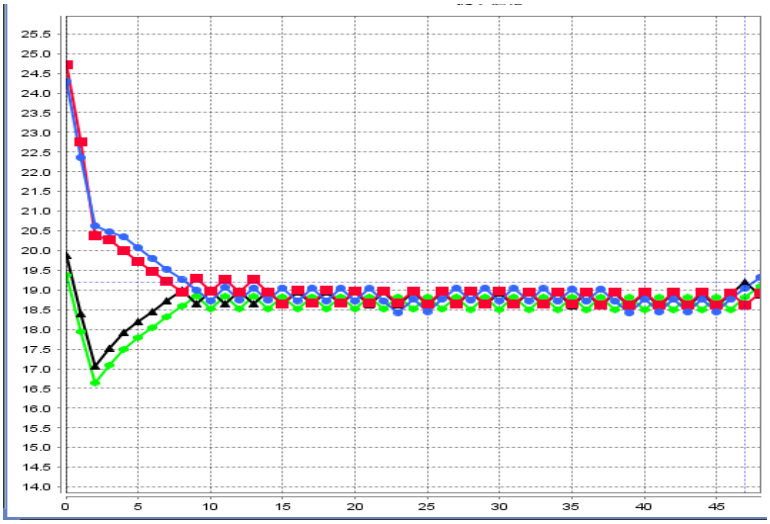


Figure6 - ρ = 0.55 Offered price

CONCLUSION

In this study, we proposed an integrated model that considers the percentage of renewable energy and fluctuations in electricity demand. The results of this study can be used as a reference model to analyze the business strategy of the electricity supply chain.

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