HOW ENVIRONMENTAL POLICIES AFFECT LIBERALIZED ELECTRICITY MARKET: A CASE STUDY OF JAPAN

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Overview

How to mitigate the Greenhouse Gas (GHG) emissions from power sector is critical to a nation's overall environmental achievement. In order to gain insight into the changes of electricity market due to certain environmental policies and to assess the effectiveness of the policies this work employs a multi-agent model based on reinforcement learning to simulate the liberalized electricity market under environmental regulations. In this paper we discuss the Carbon Tax (CT) policy and Emission Trading (ET) policy. By conducting computer simulations we evaluate the impacts of these policies on the wholesale electricity market of and assess their contribution on CO_2 emissions reductions. We also do some discussions on the CO_2 free electricity trading policy which will be introduced to the Japan Electric Power Exchange (JEPX) from April 2009.
The structure of the paper is as follows: After the introduction section we give a brief overview about Japan's electricity market in section two. The third section describes the multi-agent model for the wholesale electricity market. The next is the principles of reinforcement learning method that we use in our model. In section five we show the results of simulations. The last is the conclusion part.

Methods

We use multi-agent model based on reinforcement learning in this work. In our model there are a set of supplier agents $G=\{A_{gi}: i=1,...,n\}$ and one demander agent $D=\{A_{dj}: j=1\}$. The bidding function of a supplier agent is based on its marginal cost as Equaiton (1) shows. The demander agent bids for the market following its marginal utility function expressed by Equation (2). In Equation (2) η is the electricity price elasticity.

$$P_{gi}(q)=MC_i(q)+\alpha_{gi}=2a_{gi}q+b_{gi}+\alpha_{gi} \tag{1}$$

$$p=(P_0 / Q_0^{1/\eta})\times q^{1/\eta} \tag{2}$$

In equation (1), p_{gi} is the bidding price of supplier agent A_{gi}, MC_i is its marginal cost, and α_{gi} is the bias value which indicates the bidding strategy and as we assume constant marginal cost a_{gi} equals to zero. When the market is exposed to no environmental regulations b_{gi} equals to the unit fuel cost. We add environmental cost to b_{gi}. Equation (3) and (4) present the calculation of b_{gi} under the CT policy and the ET policy respectively.

$$b_{gi}=P_{fg}+e_i\times P_{ct} \tag{3}$$

$$b_{gi}=P_{fg}+(e_i-e_{cap})\times P_{et} \tag{4}$$

Where, P_{fg} is the fuel cost, e_i is the emission rate, P_{ct} is carbon tax rate, e_{cap} is the cap for emission rate and P_{et} is the price for CDM credits. We assume that supplier agents with emission rate below the cap can get credits.
The basic unit of the reinforcement learning is called an episode. Within one episode k the supplier agent gets feedback from the last episode and selects the optimal bias value α_{gi} that results the maximum action value $Q_k(s,\alpha)$, which is equal to maximize reward R_k. We use Boltzmann distribution function (Equation (5)) to determine the optimal α_{gi}.

$$\pi(s,\alpha_{gi})=\exp\left[\frac{Q(s,\alpha_{gi})}{T}\right] \Big/ \sum_{j=1}^{N}\exp\left[\frac{Q(s,\alpha_{gj})}{T}\right] \tag{5}$$

Where, $\pi(s,\alpha_{gi})$ is the probability to choose α_{gi}, N is the number of options we have and T is the Boltzmann temperature. A larger $Q(s,\alpha_{gi})$ results a higher $\pi(s,\alpha_{gi})$. Thus, the bias value α_{gi} which makes $Q_k(s,\alpha)$ the largest has the highest probability to be chosen.

Results

Fig. 1~ Fig.15 show how the market share, market price and CO_2 emissions (and also the required CDM credits in the emission trading case) change with the increasing environmental cost (the carbon tax from 1,000JPY/t-CO_2 to 8,000JYP/t-CO_2 and the price of CDM credit from 1,000JPY/t-CO_2 to 8,000JPY/t-CO_2) (JPY: Japanese Yen, 1JPY≒0.01 US dollar).

As environmental cost increases there is a switching from coal to LNG (Fig. 1~Fig.5). The fuel switching causes the PX market price to rise, but the RT market is almost unaffected (Fig. 6~Fig. 10). In the ET case, the PX market price is lower under a higher e_{cap}. Benefit of the fuel switching is that it results in an large progress on CO_2 emissions reduction, but after the switching further CO_2 emissions reductions are difficult (Fig. 11~Fig. 15).

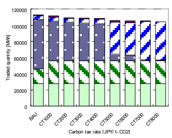

Fig.1 CT case

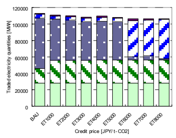

Fig.2 e_{cap}=340E-6

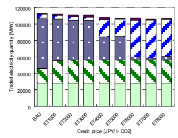

Fig. 3 e_{cap}=400E-6

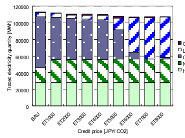

Fig. 4 e_{cap}=450E-6

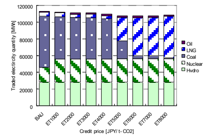

Fig.5 e_{cap}=550E-6

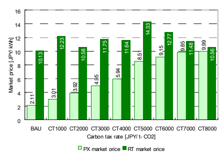

Fig.6 CT case

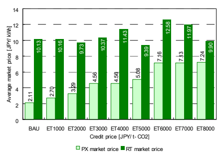

Fig.7 e_{cap}=340E-6

Fig. 8 e_{cap}=400E-6

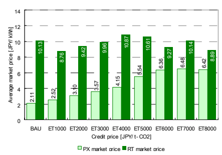

Fig. 9 e_{cap}=450E-6

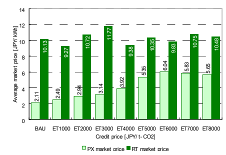

Fig.10 e_{cap}=550E-6

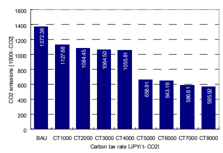

Fig.11 CT case

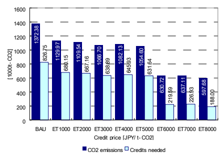

Fig.12 e_{cap}=340E-6

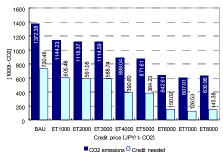

Fig. 13 e_{cap}=400E-6

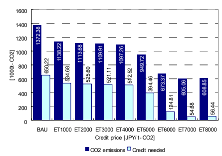

Fig. 14 e_{cap}=450E-6

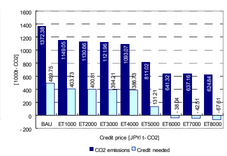

Fig.15 e_{cap}=550E-6

In the CO_2 free electricity market all the eletricity is carbon free, which means that if the electricity is generated from fossil fuel power plants the electricity has to be traded with the CDM credits that offset the CO_2 emissions. In our model, we devide the PX market into a normal market and a CO_2 free market. Supplier agents in one market can not bid for the other market. There is one demander agent who bids for both markets, and then adjusts its bidding quantities for the two markets according to the unit cost of each market. The amount of CO_2 emissions is capped, and the demander agent has to pay penalty for its excessive emissions.

Fig. 16~Fig.18 show the traded electricity quantity and the power source structure in each market in the BAU case. Fig. 19 and Fig. 20 show how the traded electricity quantity in each market changed under differente environmental regulations.

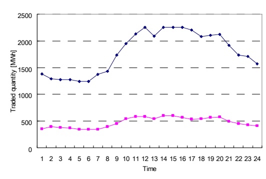

Fig. 16 Traded electricity quantity

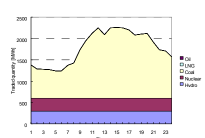

Fig. 17 Normal market

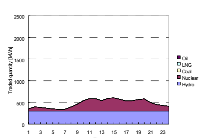

Fig. 18 CO_2 free market

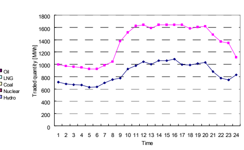

Fig. 19 Strict regulation

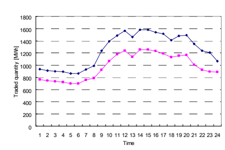

Fig. 20 Not so strict regulation

In the BAU case the demander agent only bid for electricities generated from hydro and nuclear in the CO_2 free market because they are cheaper compared with other types of plants. When the environmental regulation goes stricter, the CO_2 free market becomes more appealing to the demander agent.

Conclusions

In the short term, the increasing environmental cost provides enough economic incentive to cause a switching from coal to LNG. This switching results effective CO_2 emissions reductions. However, the burden of environmental cost will be passed to customers by higher PX market price. Under the CO_2 free electricity trading policy, how the demander agent change its allocation strategy is discussed in the paper.

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