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Allocation of Greenhouse Gas (GHG) Emission for Japanese Electric Utility Post Kyoto Protocol

Jeff Huang, Ken Nagasaka

Abstract—In May 2011, the Japanese Government decided not to participate in the new reduction agreement which will take place after the end of Kyoto Protocol. The Japanese Government believes the new reduction agreement is not capable of tackling the global Greenhouse Gas (GHG) emission problem unless all large GHG emitting countries, such U.S and China, participate. Although the Japanese Government has decided not to participate in this new reduction agreement, it still undertook initiatives to set up its new emission reduction targets. From the latest revision of the Strategic Energy Plan in 2010, Japan has committed to reduce its GHG emission level by 25% compared to its 1990 level, conditional on other industrialized countries making similar reduction effort. Although the target has been established, it did not specify the allocation of the GHG emission reduction target to each General Electric Utility (GEUs) in Japan. In this research we began with an analysis of electricity demand forecasting and relate GHG emission of Japanese Electric Utility Post Kyoto Protocol by Artificial Neural Networks (ANN) methodology. Then based on these forecasting results, we allocated the target emission allowance to each Japanese General Electric Utility (GEUs) in 2013-2016 based on two most common allocation approaches, namely the Grandfathering Approach and the Output-based Benchmarking Approach. In the conclusion, we analyzed the trends and necessary actions that the Japanese electric utility need to undertake to achieve its emission target under different allocation approach.

Index Terms—Allocation, Benchmarking; Forecasting; Greenhouse Gas (GHG) Emission

I. INTRODUCTION

In May 2011, the Japanese Government decided not to participate in the new reduction agreement which will take place after the end of Kyoto Protocol. The Japanese Government believes the new reduction agreement is not capable of tackling the global Greenhouse Gas (GHG) emission problem unless all large GHG emitting countries, such U.S and China, participate. Although the Japanese Government has decided not to participate in this new reduction agreement, it still undertook initiatives to set up its new emission reduction targets.

In this research we began with an analysis of electricity demand forecasting and relate GHG emission of Japanese Electric Utility Post Kyoto Protocol by Artificial Neural Networks (ANN) methodology. Then based on these forecasting results, we allocated the target emission allowance to each Japanese General Electric Utility (GEUs) in 2013-2016 based on two most common allocation approaches, namely the Grandfathering Approach and the Output-based Benchmarking Approach. In the conclusion, we analyzed the trends and necessary actions that the Japanese electric utility need to undertake to achieve its emission target under different allocation approach.

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II. BACKGROUND

A. Emission reduction target for Japanese Electric Utility Post Kyoto Protocol

In 2003, the Japanese Government defined its own medium- (year 2020) and long-term (year 2030) energy targets under the "Strategic Energy Plan". This plan outlines the energy policy in Japan and is required to be reviewed at least every three years. From the latest revision in 2010, Japan has committed to reduce its GHG emission level by 25% compared to its 1990 level, conditional on other industralised countries making similar reduction effort. To do this, the plan outlined the use of zero emission power source (that is, hydroelectric, nuclear energy and renewable energy), to produce up to 70% of National electricity generation by 2030. This includes at least 50% of generation from nuclear energy. In the following figure, it presented the composition of energy sources for electricity generation in Japan between 2010 to 2020 defined under the Strategic Energy Plan. A key component of Japan meeting the 25% reduction target will be this increased dependency on nuclear energy. The proportional of nuclear energy for total electricity generation will expand from 38% in 2010 to 42% in 2020 and 52% by 2030 [1].

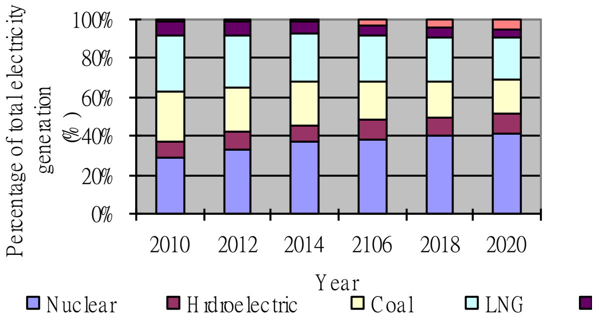

Fig.1. Percentage of total electricity generation by different energy sources in Japan under Strategic Energy Plan

However, the 311 Earthquake has made achieving this target difficult - there was a huge lost in nuclear generation capacity and the safety of nuclear generation was in doubt. The Japanese

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Government has considered the issues and recognized the need for another review on this target. The impact of 311 Earthquake was not considered in this study.

III. MATERIAL

A. *Artificial Neural Network (ANN)*

In this research, we created the electricity demand forecasting model based on Artificial Neural Network (ANN) technique. Artificial Neural Network (ANN) is a very attractive technique in solving engineering problems, especially for the problem including complex non-linear characteristic. ANN has ability by learning from the relationship between input and output pattern to formularize the problem. This feature is especially useful when solving problems in forecasting. The most commonly used architecture of ANN in power system is the feed forward multi layer perception (MLP) with back propagation (BP) learning algorithm. This network architecture has been widely used for different power system applications, in particular load forecasting. Therefore this type of ANN architecture been applied to forecast the electricity demand in Japan during 2013-2016 in this research. Furthermore, based on the forecasting result of the electricity demand, we have calculated the relative greenhouse gas emissions in Japan post Kyoto Protocol.

The structure of an ANN with BP learning algorithm is shown in the following figure (Fig.2). This structure contains three layers: the input layer, hidden layer and output layer. The nodes within each layer are fully connected to the previous layer. For the BP algorithm, the input data is transmitted through the network, layer by layer until output is calculated. The calculated output is compared to the desired output value to generate the error signal, this error signal is then propagated backward through the hidden layers changing or adjusting the weight and biases in each layer in order to reduce the level of the error signal. The network will train continuously until the desired level of error will be achieved. Once the optimum result is achieved the network will be ready to apply for forecasting problem [2].

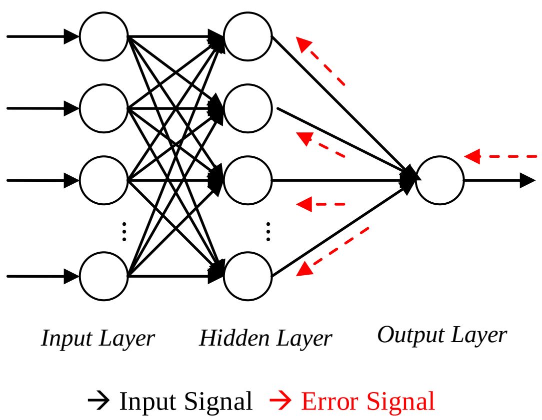

Fig.2. Flow of Signal of ANN with BP Algorithm

B. *Structure of ANN model in this research*

Training is an important process in calibrating the neural network. The accuracy of the forecasted results is heavily dependent on the sufficiency and the relevance of input data for neural network training. From the historical information, we recognized the factors such as Gross Domestic Product (GDP); Index of Industrial Production (IIP), Electricity Price; Population, Number of Household; Weather Data and Past Electricity Demand Data are highly correlated to the level of electricity consumption in Japan [3].

1. **GDP (Gross Domestic Product)**:
   GDP has been used as main indicator to represent the total market value of all final goods and services produced in a country in a given year. From the basic economic theory, an increase in income (GDP) leads to higher purchasing power, and higher purchasing power drives an economic entity to the consumption of superior commodities (such as electricity demand). Therefore the electric demand is expected to increase with the growth of economy (GDP).
2. **Index of Industrial Production (IIP)**:
   IIP Index which indicated the growth of various sectors in an en economy for a given period of time. Same concept as GDP, higher IIP drives an economic entity to the consumption of superior commodities. Therefore the electric demand is expected to increase with the growth of Industrial production index (IPP).
3. **Electricity Price:**
   Under economic theory, price and demand follow opposite direction. An increase in the price of a commodity generally leads to reduced consumption. Therefore the electric demand is decrease to increase with the electricity price*:*
4. **Population**:
   Population is closely related to electricity consumption. For example, with growing population, the total electricity demand in all sectors is expected to rise.
5. **Number of Household:**
   Same fashion as Population. For example, the demand for electric demand expects increase in proportion to the number of household.
6. **Weather Data**:
   Electricity consumption is highly correlated to the level of electricity demand. For example during the summer or winter days, large consumption on cooler/heater which causes a big share of electricity demand.
7. **Past Electricity Demand Data**:
   Historical performance always can give a good indication for the coming trend of electric demand. Therefore, the previous year electricity demand data of forecasting year is used as one of the input of our forecasting model.

In this research, we are not focusing on analysis the detail composition of each factor mentioned above. All the historical or forecasting data on these seven factors are provided directly from associated research center or previous conducted research. In this research, we incorporated the historical data of the above-mentioned factors from 1985 to 2005 in the forecasting model. The proposed neural network models were then trained and tested extensively using different numbers of hidden layers until the most accurate result was achieved.

C. *Emission Allocation Methodology*

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In this research, we adopted two most popular allocation methods, namely the Grandfathering Rule and Output-based Benchmarking Approach. In the following, we presented the structure of these two allocation methods in detail.

1. Grandfathering Rule Approach

Grandfathering Rule is the most basic and straightforward methodology to allocate the GHG emission allowance. It incorporates historical performance data to produce a best estimate for the allocation. Due to its simplicity and ease of understanding, the method was widely used and accepted by most of general public. Under the Grandfathering Rule approach, the allocation of emission allowance for each regulated entity is based on each regulated entity's historical emissions and their entitlements to share of the overall cap. This approach can be generalized by the following formulae: [4]

$$A_x = E_x * Cr \quad -(1)$$
$$Cr = AT / BT \quad -(2)$$

Where:

A_x : Allocation for regulated entity *x* [t-CO_2]
E_x : Baseline emission for regulated entity *x* [t-CO_2]
Cr : Correction factor [Other]
AT :Total allowance cap [t-CO_2]
BT : Sum of baseline emission for all regulated entities

From the above formula, the allocation received by installation *x* is based on a function of its own baseline emission data E_x. For example, if an entity generated Y% of baseline's total emission, then Y% of total cap will be allocated back to this entity accordingly. The "Correction Factor", Cr, in formula (2), is the ratio between the total cap and the total baseline emission data. This factor ensures that the total allocation does not exceed the defined cap value, and each entity will receive less emission allowance than the previous year. Under this approach, entities with historically high level of GHG emissions will receive correspondingly higher allocations of emission allowance.

2. Output-based Benchmarking Approach

The Benchmark Rule Approach for GHG emission allocation consists of one or more reference values in the form of technological performance indicator that is common to the group and/or sector. The reference value enables the comparisons between different scenarios and across all installations. The allocation of GHG emission allowance is based on the benchmarks described above and the entity-specific quantity, such as production output or energy input. The Output-base Benchmarking is the most commonly used benchmarking approach in allocating the GHG emission allowance. It uses the amount of production output to determine the allocation of emission allowance. It can be simplified to the formulae below [5][6]:

$$A_x = P_x * BM * Cr$$
$$Cr = AT/BT$$

Where:

A_x : Allocation for regulated installation *x* [t-CO_2]
P_x : Baseline Production for regulated installation *x* [Unit output]
BM : Emission Benchmark [t- CO_2/unit output]
Cr : Correction factor [Other]
AT : Total allowance cap [t-CO_2]
BT : Sum of baseline emission for all regulated installations

The formulae above demonstrated that the amount of emission allowance allocated to a particular entity is dependent on the amount of output (P_x) of that particular entity. Unlike Grandfathering Approach, the allocation does not depend on the historical emission data. The allocation of emission allowance for a particular entity is the production output of the entity (P_x) multiplied by an emission benchmark (BM) and a correction factor (Cr). The emission benchmark is set according to the relevant peer group for the entity. Whereas the correction factor is used to ensure that the sum of individual allocations is equal to the total allowance to be distributed.

IV. SIMULATION RESULTS

A. Electricity demand forecasting for Japanese electric utility industry in 2013-2016

Based on the slow population and economic development growth, the electricity demand in Japan is expected to decline significantly in the period of 2013-2016 compared to the consumption in the 90's. According to the simulation result, the electricity demand in Japan will reach 957 billion kWh in 2016 with average annual 0.75% increase between the period of 2013-2016. This growth rate is similar to the period of 2000-2010 (0.8%) but much lower compared to the time back in the 90's (2.4% annual average in 1990-2000).

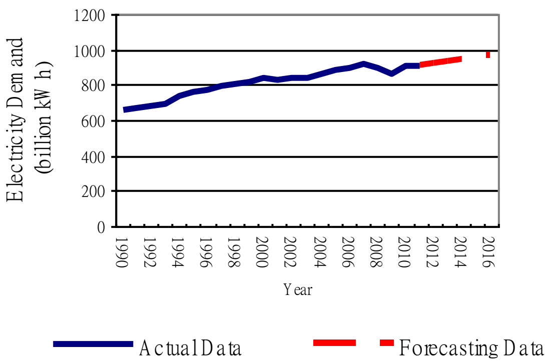

Fig.3. Electricity demand forecasting of Japanese Electricity Utility in 2013-2016

B. GHG emission generated by Japanese electric utility industry in 2013-2016

Emission intensity (kgCO_2-kWh) of electricity generation in Japan is relative low in comparison with most major industrial countries. This achievement is not only result from the Japanese electric utility industry has sought to implement the optimal combination of power sources centering on nuclear energy, also the world top-class thermal efficiency on their thermal power plant. According to the historical data from "Environmental Action Plan" issued by FEPC (The Federation of Electric Power Companies of Japan), Japanese electric utility sector started to upgrade their thermal power plant and achieved a significant effort on thermal efficiency from mid 80's, but this upgrading improvement seems to reach the cap from early 2000. According to many research reports, Japanese electric utility has achieved the world's top level on efficiency of thermal power electricity generation and believed that it will be very costly and highly inefficient to further improve the efficiency level by upgrading its generation unit [7]. Therefore, we assumed the efficiency of thermal electricity generation will be no more major improvement during the forecasting period (2013-2016) and by taking the average of 2008-2010 emission intensity of each energy source for the GHG emission calculation throughout this research. The emission intensity for each energy source generation as following: Coal-fired (0.862 kg-CO_2/kWh); Oil-fired (0.731 kg-CO_2/kWh) and LNG-fired (0.472 kg-CO_2/kWh).

Based on the results derived from the electric demand forecasting and the above assumptions on emission intensity of electricity generation in Japan, the average CO_2 emission generated by Japanese electricity industry was 366.5 million-tons per year in 2013-2016. This amount is used as the emission allowance target for the Japanese electric utility in 2013-2016 for this research.

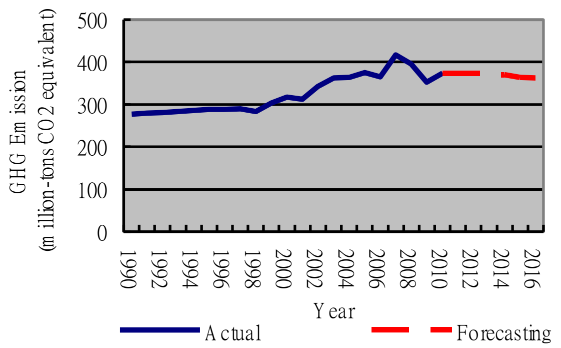

Fig.4. Forecasting on GHG Emission generation generated by Japanese Electricity Utility in 2013-2016

C. Allocation result under Grandfathering Rule approach

In this section, we have used the average value of 2004-2006 GHG emission data and 2008-2010 CO_2 emission intensity of each Japanese GEUs as the baseline year and benchmark value. Then these data were incorporated in the allocation methodologies to determine the emission allowance for each of the GEUs in Japan during 2013-2016.

By applying the Grandfathering Rule Approach as described in section C.1, the allowance allocation to each Japanese GEUs for the period of 2013 through 2016 is as follow:

- Chuden: 60.0 million tons of CO_2 emission per year;
- Hepco : 15.5 million tons of CO_2 emission per year;
- Kepco : 51.4 million tons of CO_2 emission per year;
- Yonden: 10.2 million tons of CO_2 emission per year;
- Chugoku: 40.0 million tons of CO_2 emission per year;
- Kyuden: 29.5 million tons of CO_2 emission per year;
- Tohok : 36.8 million tons of CO_2 emission per year;
- Rikuden: 12.0 million tons of CO_2 emission per year;
- Okiden : 6.9 million tons of CO_2 emission per year;
- Tepco : 104.3 million tons of CO_2 emission per year

In following Table.1, it demonstrated the difference between the allocation result and the average emission level with and without Clean Development Mechanism (CDM) including in 2008-2010 for each GEUs. The number inside the bracket indicated the percentage difference between the calculated allocation and the average emission generation level in 2008-2010. For example, the average emission allocation for Chunden was 60 million-tons CO_2 per year in 2013-2016, which was 0.3% and 19.3% higher then their average emission generation with and without CDM in 2008-2010. Also the red color in Table.1 represented the average emission of utility in 2008-2010 was lower then their calculated allocation.

Utility	Allocation 2013-2016 avg. per year (mts)	Actual Generation 2008-2010 avg. per year (mts)*[a]	Actual Generation 2008-2010 avg. per year (mts)*[b]
Chuden	60.0	59.8 (0.3%)	50.3 (19.3%)
Hepco	15.5	14.6 (6.2%)	14.4 (7.6%)
Kepco	51.4	46.8 (9.8%)	41.2 (24.8%)
Yonden	10.2	10.5 (-2.9%)	9.6 (6.3%)
Chugoku	40.0	41.0 (-2.4%)	30.0 (33.3%)
Kyuden	29.4	32.2 (-8.4%)	29.8 (-1.0%)
Tohoku	36.8	36.8 (0%)	26.7 (37.8%)
Rikuden	12.0	12.7 (-5.5%)	9.5 (26.3%)
Okiden	6.9	7.0 (-1.4%)	6.4 (7.8%)
Tepco	104.3	112.7 (-7.5%)	98.8 (5.5%)

avg. per year: Average per year; mts: million-tons

Table.1.: Allocation of emission allowance for each Japanese GEUs in 2013-2016 by Traditional Grandfathering Approach

According to the calculation results, it indicated the average emission level without CDM including for Chuden, Hepco, Kepco, and Tohoku in year 2008-2010 were lower than the calculated allocation. On the other hand, the remaining power companies have higher average emission in 2008-2010 than the calculated allocation. This result implied that the remaining six companies should further reduce their GHG emission generation in order to keep their emission generation level within the allocation during 2013-2016. Also according to the calculation results, the actual emission level by including CDM for all the utilities beside Kyuden were lower then the calculated allocation. It indicated CDM play a significant role in helping Japanese electric utility industry to achieve its emission reduction target defined under Strategic Energy Plan.

D. Allocation result under Output-Based Benchmarking approach

In this research, we have defined the benchmark value of Japanese electric utility industry as the average of the top 30% most GHG efficient installations.

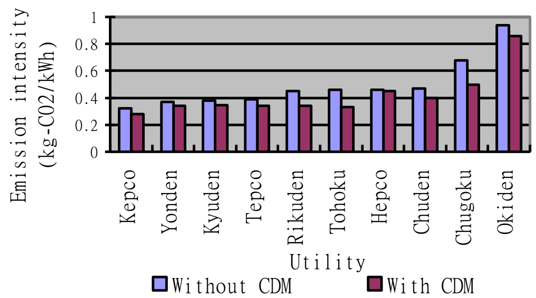

Fig.4. Emission intensity of each Japanese GEUs in 2008-2010

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The benchmark is expressed in term of GHG emitted per unit output generation (kWh electricity), and it is based on the historical performance in year 2008-2010.

The benchmark is then incorporated in the Output-based Benchmarking Rule Approach described in Section 3.2. The results of the emission allowance allocation for each Japanese GEUs are as follow:

- Chuden : 54.2 million tons of CO_2 emission per year;
- Hepco : 12.8 million tons of CO_2 emission per year;
- Kepco : 61.1 million tons of CO_2 emission per year;
- Yonden: 11.6 million tons of CO_2 emission per year;
- Chugoku: 24.9 million tons of CO_2 emission per year;
- Kyuden: 34.4 million tons of CO_2 emission per year;
- Tohoku: 33.1 million tons of CO_2 emission per year;
- Rikuden: 11.5 million tons of CO_2 emission per year;
- Okiden : 3.0 million tons of CO_2 emission per year;
- Tepco : 120.0 million tons of CO_2 emission per year.

In following Table.2, it demonstrates the difference between the allocation result and the average emission level with and without CDM including in 2008-2010 for each Japanese GEUs.

Utility	Allocation 2013-2016 avg. per year (mts)	Actual Generation 2008-2010 avg. per year*[a] (mts)	Actual Generation 2008-2010 avg. per year*[b] (mts)
Chuden	54.2	59.8 (-9.4%)	50.3 (7.8%)
Hepco	12.8	14.6 (-12.3%)	14.4 (-11.1%)
Kepco	61.1	46.8 (30.6%)	41.2 (48.3%)
Yonden	11.6	10.5 (10.5%)	9.6 (20.8%)
Chugoku	24.9	41.0 (-39.3%)	30.0 (-17%)
Kyuden	34.3	32.2 (6.8%)	29.8 (15.4%)
Tohoku	33.1	36.8 (-10.1%)	26.7 (24%)
Rikuden	11.5	12.7 (-9.4%)	9.5 (21.1%)
Okiden	3.0	7.0 (-57.1%)	6.4 (-53.1%)
Tepco	120.0	112.7 (6.5%)	98.8 (21.5%)

avg. per year: Average per year; mts: million-tons

Table.2: Allocation of emission allowance for each Japanese GEUs in 2013-2016 by Output-based Benchmarking Approach

The Table.2 illustrates the difference between the allocation result and the average 2008-2010 emission level for each GEUs. The result indicated the average emission in 2008-2010 for Kepco, Yonden, Kyuden and Tepco were lower than the calculated allocation. Whereas the remaining six power utilities, the average emissions in 2008-2010 were higher than the calculated allocation. This result implied that the remaining six companies (Chuden; Hepco; Chugoku; Kyuden; Tohoku and Rikuden) would be required to further reduce their GHG emission generation level in order to keep their emission generation level within the allocation cap during 2013-2016.

According to the calculation results, it shows that Kepco; Yonden; Kyuden and Tepco were received more allocation for rewarding their good performance on the efficiency of their electricity generation from early action. Extra 14-19% will be rewarded by comparing to the allocation results under the Traditional Grandfathering Rule Approach. On the other hand, the relative poor efficiency performance companies such as Okiden and Chugoku were received less allocation. For example, 40 million-tons of allowance allocated to Chugoku under the Traditional Grandfathering Rule approach. The amount dropped significantly to 24.9 million-tons (37.8% reduced) by including the efficiency of electricity generation into the consideration of allocation. This significant drop will create extra pressure for Chugoku to maintain their pace within the allocation cap during 2013-2016.

V. CONCLUSION

In this research we began with an analysis of electricity demand forecasting and relate GHG emission of Japanese electricity utility industry Post Kyoto Protocol. Then based on these results, we allocated the target emission allowance to each GEU in 2013-2016 based on two most common allocation approaches, namely the Grandfathering Approach and the Output-based Benchmarking Approach.

From the simulation result, we understood the slow population and economic development growth in Japan result the electricity demand and relative GHG emission in Japan is expected to decline significantly in the period of 2013-2016 compared to in the 90's. The electricity demand in Japan will reach 957 billion kWh in 2016 with average annual 0.75% increase between the period of 2013-2016. And the average CO_2 emission generated by Japanese electricity industry was 366.45 million-tons per year in 2013-2016.

The allocation results demonstrated that different allocation approach would yield different outcomes. For example, if both Grandfathering Approach and the Output-based Benchmark Approach were used in the emission allocation, only Kepco was under the allocation cap based on their average emission level in 2008-2010. Furthermore, different methodologies would allocate the emission allowance differently. For example, the power companies such as Chuden, Hepco, Chugoku, Tohoku, Rikuden and Okiden were rewarded with larger emission allocation under Grandfathering Rule approach when compared to the Output-based Benchmark Approach. Under Out-put benchmarking approach, the utilities such as Hepco, Kepco, Yonden and Tepco were rewarded with more emission allowance. This result is mainly due to the reward for the companies' early actions on lowering the emission intensity. The extra allocations could be trade to other utilities and enables the power companies to generate a profit from the carbon trading market. Under the Grandfathering Rule approach, Tohoku is expected to be allocated with an average of 36.8 million-tons of emission allowance per year during 2013-2016. This allocation is higher than the average generation level in 2008-2010. On the other hand, the Benchmarking Rule Approach has allocated 33.1 million-tons of allowance to Tohoku, which is lower than average of 2008-2010 generation level. Similar result applied to Hepco, Kyuden and Tepco. This difference has demonstrated that the different approach will generate different allocation result. Consequently, the choice of allocation approach would have impact on the GHG emission reduction strategy for the power company.

In this research, we only considered the historical data and emission intensity to

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determine the emission allocation for each GEUs. But more factors such as growth rate, limitation on the generation capacity… also are very important factors need to be considered when defined the allocation. How to improve our current allocation model by including all necessary factors are the important issues need to be study in future research.

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