B-14.2 Evaluation of Measures to Cope with Global Warming - Analysis of Carbon Dioxide Emissions from Energy System

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Abstract A method is presented to evaluate countermeasures to the global warming available in the Japanese energy system today and in the near future. The main tool for the method is an ETL version of linear programming software MARKAL, which was developed at Electrotechnical Laboratory to study the Japanese energy system under Energy Technology Systems Analysis Project by IEA . The scope of the MARKAL model covers resource extraction, energy transformation, distribution, storage and utilization in the Japanese energy system from the year 1988 to the year 2032. By minimizing the total CO_2 emission from a future energy system up to the year 2032 to bring annual CO_2 emission per capita in the year 2010 down to the current level, it is shown that the major part of the reduction is achieved in the transformation sector where electricity generation accounts for the most part of CO_2 emission. Technology options in the electricity generation sector are examined from the standpoints of potential to reduce CO_2 emission and of cost-effectiveness both economic and environmental obtained from the results of the analysis by MARKAL. Structural change in the total energy system brought about by the use of a specific countermeasure is closely examined and suitable combination of supply and demand technologies are discussed. Possible reduction of CO_2 emission by the use of imported hydrogen is also discussed.

Key Words Technology evaluation,Systems analysis,Cost-effective,CO_2 emissions reduction

1.Introduction

To develop countermeasures to the global warming has become an international problem. Roughly a half of global warming is caused by carbon dioxide(CO_2), most of which is a by-product of human utilization of fossil fuels. However, there is a strong concern for taking drastic measures to curtail the emissions because it seems to conflict with economic growth of the world. Thus, we must find cost-effective measures to reduce CO_2 emission.

2.Research Objective

The objective of the project is to establish a quantitaive evaluation method of technical options for reducing CO_2 emission from the energy sector, and to search for cost-effective countermeasures to cope with global warming.

3.Research Method

(1)Energy system model MARKAL

Linear Programming is widely used to search for the least cost and the maximum utility strategies. An ETL version of linear programming software MARKAL is used as main tool to evaluate technology options in the energy sector and to search for cost-effective countermeasures. It embodies about eighty types of energy carriers and more than three hundred types of technologies ranging from energy transformation technologies to demand side technologies. Given scenarios of imported fuel prices and final energy demand which is classified into twenty three categories according to its utility, technologies and fuel types are selected over the period from 1988 to 2032 so as to minimize an objective function, which is set to accumulated CO_2 emission during the period in this study.

(2)Evaluation criteria

Technical options to reduce CO_2 emission are evaluated according to the criteria listed below. Necessary information is obtained from the results of analyses by MARKAL.

① Reduction potential To define the reduction potential of a countermeasure installed in a specific year, the accumulated CO_2 emission obtained by installing the countermeasure in the specified year and running it thereafter through its lifetime is compared to the accumulated CO_2 emission obtained without installing it, while the total system cost is the same in both cases. Reduction potential is the difference in accumulated CO_2 emission between both cases, expressed as value per unit installed capacity.

② Emission–reduction ratio Emission–reduction ratio of a countermeasure installed in a specific year is the reduced emission of CO_2 in the total energy system as the result of installing a plant of the countermeasure in the specified year, divided by the direct CO_2 emission from the plant: the sum of CO_2 emitted from its construction, operation and maintenance. It is a kind of cost–benefit ratio taking the direct emission as environmental cost. The numerator is the sum of the direct emission and the reduction potential defined above.

③ Cost–reduction ratio Cost–reduction ratio of a countermeasure installed in a specific year is the reduction potential of the countermeasure in the specified year divided by the lifecycle cost of the plant which is the sum of its construction, operation and maintenance costs.

(3)Scenarios for the analyses by MARKAL

Average growth rate of the total final energy demand is assumed to be about 1.3% /year between 1988 and 2032. Price of imported oil is assumed to rise by about 1.6%/year on average during the same period. Annual nitrogen oxides emission and sulphur oxides emission is assumed to decrease between 1988 and 2000 to the seventy percent of the emissions in 1985, stabilized at the level thereafter. Annual CO_2 emission per capita in the year 2010 is assumed to be curtailed to the current level.

(4)Incorporating hydrogen flows into IEA/ORAU Long Term Global Energy–CO_2 Model(so called Edmonds–Reilly model)

To estimate possible reduction of CO_2 emission in Japan by the use of imported hydrogen, we modified Edmonds–Reilly model to allow for hydrogen flows. Hydrogen is assumed to be produced by electrolysis and then liquefied for transportation. In Japan it is assumed to be used as fuels for electricity production ,road transportation and heating.

4.Results

By minimizing the total CO_2 emission from a future energy system up to the year 2032 with , an optimum path to bring annual CO_2 emission per capita in the year 2010 down to the current level is found and fixed. The results shown below are obtained about the fixed path.

(1)CO_2 emissions by sectors

It is shown that the major part of the reduction is achieved in the transformation sector where electricity generation accounts for the most part of emission.

(2)Evaluation of electricity generation technologies as countermeasures

Quantitative evaluation were performed about electricity generation technologies, most promising countermeasures as stated above. Selected technologies are listed in the following.

i. Fossil fuel power generation
   LNG combined cycle power generation(LNGCC), Integrated coal gasification combined cycle power generation(IGCC)

ii. Non- fossil fuel power generation
   Nuclear power generation(LWR), Hydropower generation

iii. Innovative power generation
   Roof-top type Photovoltaic power generation(3kW/unit), Geothermal power generation, Wind power generation, LNG fuel cell power generation, fossil fuel power generation with CO_2 recovery(Coal,IGCC,LNGCC)

Selected results are presented below.

①Reduction potential The reduction potential and the installed capacity of each technology is illustrated in Figure 1. The area of each rectangular is proportional to the CO_2 emission avoided by installing plants of corresponding countermeasures. The result shows that nuclear power contributes most largely to the reduction of CO_2 emission with the largest potential and the largest capacity installed. The reduction potential of coal fired power with CO_2 recovery is the smallest but it also contributes to the CO_2 emission reduction with a large installed capacity.

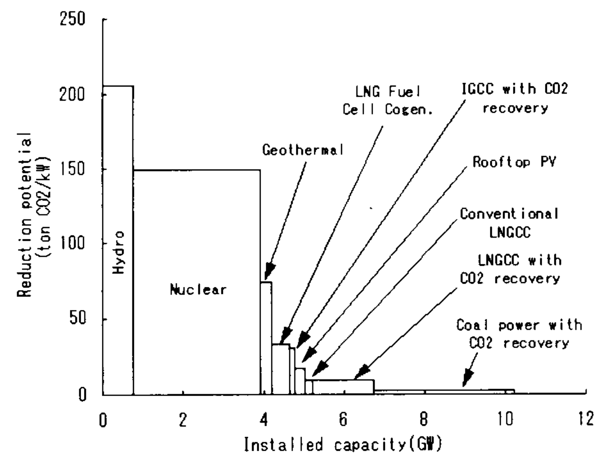

Figure 1 Reduction potential and installed capacity of selected technologies installed in 2010

②Emission-reduction ratio and Cost-reduction ratio The emission-reduction ratio of each countermeasure is plotted against its cost-reduction ratio in Figure 2. Countermeasures positioned in the north-east corner of the figure can be said to be cost-effective economically and environmentally. They are hydropower, nuclear power, geothermal power. Photovoltaic power lies in the south-west corner in the year 2000, when the cost of generated power is about ¥40/kWh and moves to the north-west corner in the year 2010 when the cost of generated power is lowered to about ¥20/kWh, as shown in Figure 2.

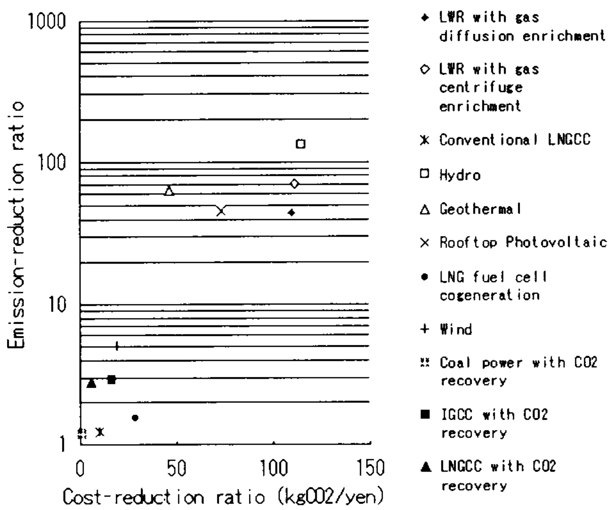

Figure 2 Emission-reduction and Cost-reduction ratios of selected technologies installed in 2010

③Breakdown of reduction potential
To discuss suitable combination of supply and demand technologies, structural change in the total energy system brought about by the use of a specific countermeasure is closely examined. Figure 3 shows the result of breaking down reduction potential of rooftop PV power in 2010. The reduction in the residential sector originates from the combined utilization of heat pumps and photovolta-

ic power and the reduction in the transport sector originates from the combined utilization of electric cars and photovoltaic power. Breakdown of reduction potential concerning IGCC with CO_2 recovery in 2010 is illustrated in Figure 4. Although the installation of IGCC with CO_2 recovery decreases CO_2 emission in electricity generation sector, it increases CO_2 emissions in other sectors at the same time by forcing the extended use of cheaper and more carbon-intensive fuels such as coal in other sectors since its electricity generation cost is rather high.

④Possible reduction of CO_2 emission by the use of imported hydrogen Imported hydrogen is assumed here to be produced by electrolysis using hydropower generation and become available after the year 2025. Effect of imported hydrogen use on annual CO_2 emission in Japan depends on the cost of generated electricity by hydropower abroad. The result shows that annual CO_2 emission doesn't decrease very much even when the cost of generated electricity by hydropower is fairly cheap, in the present framework of analysis.

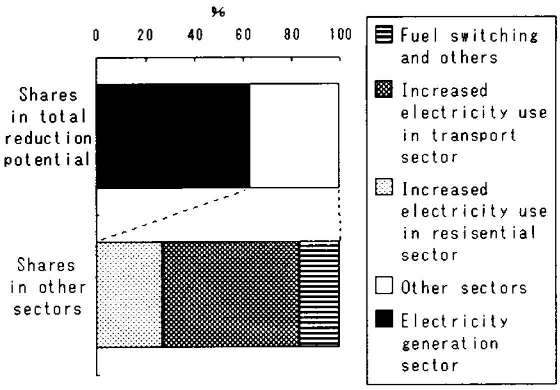

Figure 3 Breakdown of reduction potential of rooftop PV power installed in 2010

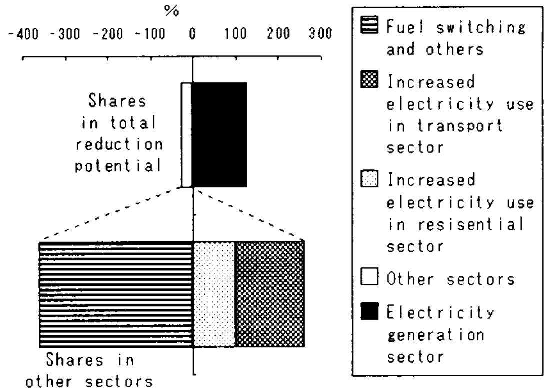

Figure 4 Breakdown of reduction potential of IGCC with CO_2 recovery installed in 2010

5. Discussion

Implications from the results are summerized as follows.

(1) Large potential reduction of CO_2 emission is possible in energy sector. Electricity generation technologies are expected to play an important role.

(2) Electricity generation technologies as countermeasures are grouped into two types. One groupe consists of cost-effective technologies both economically and environmentally and the other consists of cost-effective technologies neither economically nor environmentally. Hydropower and geothermal power are most cost-effective. Nuclear power is less cost-effective environmentally than hyropower and geothermal power, becasue it is more energy intensive than them, especially with gas diffusion enrichment process. But the distinction between the two groups is not decisive. Rooftop photovoltaic power is shown to become cost-effective in the year 2010 if the assumed technical improvement is achieved.

(3) Reduction potential of fossil fuel power with CO_2 recovery is not very large because expensive electricity cost offsets the merit of reducing CO_2 emission.

(4) Non fossil fuel power generation technologies could contribute to reduce CO_2 emissions in residential sector and in transport sector as well as in energy sector if they are used in combination with suitable demand side technologies such as heat pumps and electric vehicles.

(5) The effect of imported hydrogen use on CO_2 emission largely depends on the cost of electricity generated by hydropower abroad. But the effect is shown to be rather small even

if the electricity cost is fairly cheap. The reason is that technologies to utilize hydrogen such as fuel cell and hydrogen vehicles are expensive, too. Cost reduction both on supply side and on demand side is neccesary to make the most of it.

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