“Scenario Analysis for Achieving Carbon Neutrality in 2050 in Japan”

Dr. OZAWA Akito
Senior Researcher, Global Zero Emission Research Center (GZR),
Department of Energy and Environment
National Institute of Advanced Industrial Science and Technology (AIST)

Thank you for your introduction.
I am OZAWA from AIST.

The previous two speakers introduced specific initiatives by companies or regions toward achieving carbon neutrality, but I would like to talk about the transition toward achieving carbon neutrality by 2050, that is, a change to carbon neutrality. Today, I would like to introduce a case study in which we are conducting research on simulating the future using computer simulations regarding scenarios for how to realize changes.

This slide shows the Japanese GHG emission reduction target.
As I am sure you know, reducing CO2 emissions from energy is vital for achieving carbon neutrality by 2050.
Therefore, there is a need to find a way to decrease CO2 emissions, the energy’s source, and to achieve this, various technological developments and social changes, are required.

I would like to talk about three main types of measures to reduce energy-related CO2.
The width of the rectangle shown in a diagram is the energy consumption.
It shows the electricity and non-electricity heat and fuel consumption.
The vertical axis shows the CO2 intensity of electricity and non-electricity, and the total amount of CO2 emissions in Japan is represented by the area of the square, horizontal multiplied by vertical.
Based on these ideas, three measures are organized as follows. First is the reduction of energy consumption or a change in consumption patterns, such as the promotion of energy savings and electrification.
In this diagram, the first measure is to change the direction of the horizontal axis. That is, the promotion of energy savings and electrification.

The second measure is to reduce CO2 intensity. Specifically, this involves the utilization of low-carbon power generation or low-carbon fuels.
This method can reduce CO2 emissions by lowering the vertical axis direction.

The third and last step is to reduce atmospheric CO2 levels by implementing so-called negative emission technologies.

As mentioned earlier, for hard-to-abate industries, in which it is difficult to reduce CO2 emissions, and that will still be emitting CO2 in 2050, negative emission technologies must be applied to offset carbon emissions and achieve carbon neutrality.
Carbon neutrality can only be achieved by combining these three types of measures.

I would like to share the motivation for my research through this slide, 'Scenario Study for Achieving Carbon Neutrality'.
To achieve carbon neutrality, it is important to prepare ahead for pathways to reduce energy-related CO2.
We call this pathway a scenario in our research field.
In considering scenario studies, it is necessary to recognize that there are various possibilities and uncertainties in the future.
The long-term outlook, a forecast with a high level of probability is difficult of technological development and innovation, and social situation.
Consequently, rather than focusing on a single particular image of the future, it is crucial to think through a variety of scenarios and future ideas to prepare.
It is then important to consider the interrelationships between energy systems based on various visions of the future, and to come up with a strategy that can cope with uncertainties.
This approach is called the multiple-target scenario approach or the multiple scenario approach, and many countries have applied a multiple scenario approach for their strategies toward carbon neutrality by 2050.
The slide shows an excerpt from the 6th Energy Basic Strategy, which emphasizes the need for building strategies for multiple scenarios and future visions.

Given this background, we, at AIST use a tool called ‘energy model’ to analyze how various future technological developments and social conditions will affect energy transitions.
This slide shows the analysis flow. First, several future technological developments and social variables are input into the energy model as model calculation conditions.
Based on these calculation conditions, computer simulations are carried out and, as a result of the simulations, various scenarios for technology diffusion are obtained.
Scenarios for future energy consumption or the quantity of technology installed, CO2 emissions at that time, and costs associated with the technology’s adoption can be obtained.
At AIST, research is currently being conducted to examine a route towards carbon neutrality, allowing for all potential outcomes of various assumptions for these computations and the different conditions under which these calculations are performed in order to account for future uncertainties.

AIST is using an energy model, a tool known as MARKAL (MARKet ALlocation), to carry out this research.
MARKAL is an energy model framework which was originally proposed by the International Energy Agency (IEA). Using this framework, AIST is developing a model to analyze Japan's energy system.

We use a mathematical model that optimizes the objective function under assumed constraints.
The objective function is to minimize the total system cost of the future energy system. In other words, the simulation aims to achieve carbon neutrality at the lowest possible cost.
We also analyze the constraints that should be considered at this time, such as constraints related to the energy system or CO2 mitigation target, and the changes in the energy system to the extent that these constraints are met.
Through backcasting from the future, the optimal primary energy sources, final energy consumption, and energy mix transitions that can satisfy future demand in the face of CO2 emission limits can be determined by entering future energy-related condition settings into AIST-MARKAL.

This slide shows the features of the AIST-MARKAL model.
The analysis covers Japan as a whole.
The time period to be analyzed is from 2010 to 2050, and the number of time periods to be analyzed is assumed to be summer, winter, and mid-season, as well as day and night, in two segments. The total of six time periods, three times two, are analyzed in consideration of energy balance.
This slide also shows the structure of the energy system. The analysis is performed considering a series of energy flows from the supply of primary energy sources to its conversion into secondary energy, and finally consumption as demand.

From here, I would like to introduce the 2050 carbon neutral scenario analysis conducted by AIST this time.
Using the AIST-MARKAL model, which I have just introduced, we have analyzed scenarios in which Japan could reduce its overall energy-related CO2 emissions to net-zero in total by 2050.
The results of this research have been published in an academic journal, shown on this slide.
A press release with similar content is also available in Japanese on the AIST website.

I would like to point out three important aspects of this analysis.
First is the additional of negative emission technologies.
To achieve carbon neutrality, the negative emission technologies, which I introduced earlier, are inevitably required.
Therefore, we are analyzing negative emission technology by using technologies called DACCS and BECCS.
Second is constraints on the stable power supply. Specifically, the study scrutinized the constraints on regulating power sources to successfully adjust the supply-demand balance of electricity as renewable energy generation becomes much more widespread in the future.
The third and final point is the consideration of multiple scenarios.
To investigate the multiple-target scenario I previously described, this analysis is based on multiple scenarios of future technological development.
The next slide will show you the specifics of simulation case configurations.

Here, I would like to talk about the six simulation cases, which we configured in this study.
This study has mostly focused on technical factors. The six cases, which include renewable energy, nuclear power generation, CCS, **imported hydrogen**, and others —that are shown on the slide, have been configured using the most recent information available on case settings.
The six cases shown on the slide are analyzed by setting up scenarios in the base case, with different combinations of maximum renewable and nuclear power-generation capacities, the upper limit of annual CO2 storage, and CIF prices of hydrogen.

I will now start to introduce the specifics of the analysis.
First, the transition of energy-related CO2 emissions in the base case scenario is shown.
Please look at the total CO2 emissions shown in the solid line first. Then, you can see the total CO2 emissions decrease almost linearly after 2015 and reach zero in 2050. It means that carbon neutrality will be achieved.
The stacked bar graph shows the CO2 emissions of each sector, and of these, the largest change is in emissions from the electricity sector, shown in yellow.
As you can see here, carbon dioxide emissions from the power sector drop to nearly zero in 2040.
Furthermore, from 2040 onwards, the use of BECCS, a negative emission technology in the power sector, will result in negative CO2 emissions, becoming carbon negative.
While the power generation sector is changing in this way, the CO2 emissions from the industrial sector, shown in red, show that CO2 emissions will remain to some extent in 2050.
CDR technologies are required to offset the residual emissions, and negative emission technologies such as DACC and BECCS have been introduced and calculated to achieve carbon neutrality in total.

Next is the transition of primary energy supply.
It has been gradually falling since 2010, and by 2050, it will have decreased by roughly 30% compared to 2010.
As the breakdown shows, in particular, the supply of coal (shown in black) and oil (shown in red) will decrease significantly.
The proportion of renewable energy supply shown in green will increase significantly, while the proportion of fossil fuels will decrease. It will be 3.5 times higher in 2050 than it was in 2010.
The most significant introduction will be the supply of **imported hydrogen**, shown in orange.
Imported hydrogen is expected to become more common, particularly after 2040, and will account for around 20% of primary energy supply by 2050, according to the calculations.

This slide shows the transition of power-generation by sources.
Total electricity generation remains almost flat between 2010 and 2050.
However, if you look at the breakdown, you will see that there has been a fairly significant change.

Especially after 2045, the result will be solely low-carbon power sources, from power generation that does not create CO_2, such as renewable energy, nuclear power, thermal power with CCS, and hydrogen power generation.
The main role of renewable energy generation is expected to be played by renewable power generation, which will account for approximately 60% of the total power supply mix in 2050.
On the other hand, hydrogen power generation also plays an important role, which will result in the use of hydrogen power generation as a regulating power source in 2050.
By 2050, the share of hydrogen power generation will account for approximately 25% of the total.
The hydrogen used in hydrogen power generation will be mainly imported from overseas, and the increase in hydrogen supply in primary energy supply, as indicated earlier, will be mainly due to hydrogen used for power generation.

So far, I have discussed the result of our analysis in the base case. Next, this slide shows the power generation by source in 2050 for the different case settings for the multiple scenarios.
Although I do not present a full breakdown of the results, we can confirm that in all cases, in 2050, the power generation system will be entirely comprised of low-carbon power generation.
The goal of this analysis is to achieve carbon neutrality, I would like to emphasize that the important issue is how to achieve CO_2 reduction from electricity and not how to breakdown this power supply mix.
And accomplish this, it is necessary to understand how to incorporate power sources such as those shown here.
The breakdown will change depending on the level of future technological development, but the reduction of CO_2 emissions in the power generation sector can be confirmed as an important point from the results of all the case studies.

This slide shows the summary of the carbon neutral scenario analysis.
We found that low-carbon power generation and negative emission technologies are essential for Japan to achieve carbon neutrality.
Using low-carbon power generation, CO_2 emissions in the power sector will achieve full decarbonization by 2040 and will become negative by 2050 using BECCS and other technologies.
Renewable energy generation will also play a major role among low-carbon power sources. On the other hand, hydrogen power generation using **imported hydrogen** as fuel will be particularly important because it plays a role as a low-carbon regulating power source.
In contrast to these measures in the power generation sector, CO_2 emissions will still be emitted in the industrial sector, which is known as a 'hard to abate' industry, and negative emission technologies are being introduced to offset emissions in this area.

This is the last slide. I have given various options for achieving carbon neutrality.
First, we believe that it is important to consider the technical aspects of carbon neutrality, assuming all

possible technological innovations.
Some low-carbon technologies have not yet been examined in the analysis presented today, but they will be in the future evaluations.
Second, I would like to mention two factors that should be taken into account in order to achieve carbon neutrality.
The first is to secure the security of the energy system, which is crucial in addition to reducing CO_2 emissions and reaching carbon neutrality.
From this perspective, renewable energy, e-fuel, and other sources are expected to be technologies that contribute not only CO_2 reduction but also to improved security.
The second factor is the use of the existing energy infrastructure.
Japan already has an abundance of infrastructure to store and transport energy.
By utilization of these facilities, it is expected that carbon neutrality can be achieved while limiting additional investments in energy costs, i.e., increased cost.
From these aspects, we would like to explore the possibilities of various technologies in the future.

That concludes my presentation. Thank you very much.