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World Energy Supply/demand Outlook and Climate Change Scenario Analysis Considering Technological Progress Impacts♦

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CO_2 reduction policies lower damage caused by climate change while mitigation costs sharply increase as the CO_2 reduction amount increases. We developed four scenarios to estimate the impacts of the decreased costs of innovative technologies on costs and temperature changes using a climate change model up to 2300. The Standard Scenario assumes that abatement costs decrease with technological progress under current model assumptions. The Technological Innovation Scenario assumes that future technological innovation moderates a sharp increase in the marginal abatement cost at high CO_2 reduction rates. For a comparison, we developed the Baseline Scenario and the 50% Reduction by 2050 Scenario. The 50% Reduction by 2050 Scenario assumes global GHG emissions decrease by 50% from 2014 by 2050 and the trend continues afterwards. Although the 50% Reduction by 2050 Scenario moderates a temperature rise, the costs become much higher. Although the Standard Scenario moderates mitigation costs, the temperature rise exceeds 3°C above pre-industrial levels. The Technological Innovation Scenario moderates mitigation costs and the temperature rise is nearly 2°C above pre-industrial levels if the climate sensitivity is 2.5°C. Collaborating and investing on innovative technologies is important for countries to prevent a high temperature rise.

Keywords ：CO_2 Reduction Policies， Climate Change Model， Technological Innovation， Temperature Rise

1.Introduction

According to The Fifth Assessment Report by the Intergovernmental Panel on Climate Change, mitigation scenarios in which it is likely that the temperature change caused by anthropogenic GHG emissions can be kept to less than 2 °C relative to pre-industrial levels are characterized by atmospheric concentrations in 2100 of about 450-500 ppm CO_2eq. Scenarios reaching 400 ppm by 2100 are characterized by 40% to 70% lower global GHG emissions in 2050 compared to 2010, and emissions levels near zero $GtCO_2$eq or below in 2100.

The Paris Agreement on climate change took effect on November 4, 2016. Learning lessons from the Kyoto Protocol, the Paris Agreement shifts to a bottom-up framework in which all countries participate and submit Intended Nationally Determined Contributions, known as INDCs, representing their respective voluntary GHG emission reduction targets. These targets can contribute to cutting emissions below the past trend but fall far short of halving emissions by 2050. This is mainly because the marginal abatement cost rises in line with an increase in the emission reduction amount. The technologies that are unavailable or restricted at present could become available at a lower cost if technological innovation is promoted through accelerated technology development. Technological innovation substantially lowers the marginal abatement cost, contributing to expanding the emission reduction amount of each country.

When considering emission reduction scenarios, we must take into account not only mitigation costs but also adaptation costs and damage caused by climate change from the long-term viewpoint. This is because emission reduction actions contribute to lowering damage caused by climate change and adaptation costs while excessive actions cause a rapid increase in mitigation costs. Given that a temperature change leading to climate change depends on the GHG concentration, future damage depends not only on annual GHG emissions but also cumulative emissions.

In this paper, we apply a climate change model based on dynamic optimization to project GHG emissions and a temperature change when total costs covering damage, adaptation and mitigation are minimized under technological innovation by developing the Standard Scenario where technology development continues as assumed at present and the Technological Innovation Scenario where technology development accelerates. We also develop a Baseline Scenario and a 50% Reduction by 2050 Scenario where GHG emissions are halved in 2050, projecting total costs, a CO_2 concentration

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and a temperature rise through 2300 for each scenario.

2. Analytical approach

2.1 Econometric energy supply and demand model

In this paper, we use the IEEJ's bottom-up technology assessment model to project emission reduction investment costs through 2050[1]. Based on the Baseline Scenario where the present energy and environment policies continue through 2050, we accumulate investment stocks and flows for energy conservation, fossil fuel-fired power generation efficiency improvement, nuclear energy, renewable energy, power transmission and distribution, fossil fuel production and transportation, carbon capture and sequestration and others, with realistic technology penetration rates taken into account, to project the marginal abatement cost (Figure 1). The CO_2 emission reduction costs are shown in Equation (1).

$$A(\mu) = I(\mu) - EC(\mu) \quad (1)$$

A stands for the CO_2 reduction costs, I for the investment costs in CO_2 emission reduction actions, EC for energy costs fall from the Baseline Scenario and μ for a CO_2 emission reduction rate from the Baseline Scenario.

The CO_2 emission reduction costs are negative as far as an emission cut from the Baseline Scenario remains below a certain level, because energy costs decline accompanying energy conservation exceeds additional emission reduction costs. However, the emission reduction costs gradually rise as the reduction makes progress. After the emission reduction from the Baseline Scenario exceeds 60%, the costs sharply increase. This is because substantial emission cut from the existing stocks is difficult.

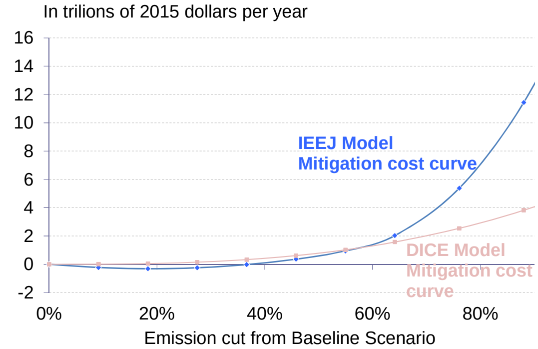

Figure 1 Mitigation cost curve for 2050 (reduction from the Baseline Scenario)

2.2 Climate change model

We apply a climate change model based on dynamic optimization to project CO_2 emissions, damage caused by climate change and adaptation costs and mitigation costs. An equation in the DICE-2013R model is applied to estimate damage and adaptation costs[2)3)]. The costs are given in Equation (2).

$$R(t)/Q(t) = \frac{\Omega(t)}{\left[1+\Omega(t)^{\theta}\right]} \quad (2)$$

R stands for damage and adaptation costs, Ω for climate change damage function, θ for damage and adaptation cost adjustment factor and t for time. Ω represents a quadratic function for the global average temperature change and is given in Equation (3).

$$\Omega(t) = 0.0026 T_{AT}(t)^2 \quad (3)$$

T_{AT} represents a temperature rise. The damage covers agriculture, a sea level rise's impacts on coastal areas, energy use changes, climate-related diseases and pollution, lost outdoor recreation opportunities, coastal communities' relocation and impacts on biodiversity.

Gross product Q covering damage, adaptation and mitigation costs is indicated in Equation (4).

$$Q(t) = A(t)K(t)^{\gamma} L(t)^{1-\gamma} - R(t) - A(\mu) \quad (4)$$

A stands for total factor productivity, K for capital, L for labor and γ for capital share. Damage and adaptation cost cuts from the Baseline Scenario through climate change actions are treated as benefit, with a mitigation cost rise considered as cost, a cost-benefit analysis is conducted in Equation (5).

$$\sum_{t=1}^{Tmax}\left(\frac{Q_a(t)}{(1+\delta+\eta g_a)^t} - \frac{Q_b(t)}{(1+\delta+\eta g_b)^t}\right) \quad (5)$$

Q_a stands for gross product for each scenario with emission reduction actions, Q_b for gross product for the Baseline Scenario, δ for pure time preference rate, η for marginal utility's elasticity to consumption, g_a for growth of Q_a, g_b for growth of Q_b and $\delta+\eta g$ for the discount rate. If the equation is positive, benefits exist in each scenario with emission reduction actions. This paper uses the pure time preference rate at 1.5% and marginal utility's elasticity to consumption at 1.45 in reference to DICE-2013R model .

3. Scenarios

This paper develops the Baseline Scenario, the Standard Scenario, the Technological Innovation Scenario and the 50%

Reduction by 2050 Scenario. In the Baseline Scenario, emissions per gross product are projected to improve in line with the past trend, and present energy and environment policies in a period between 2010 and 2300 to maximize the utility in the period. In the 50% Reduction by 2050 Scenario, energy-related CO_2 emissions are halved from 2014 by 2050 and reduced at the same pace later to zero by 2080.

In the Standard Scenario, the annual cost reduction through technological progress from 2050 is assumed at 0.5% in line with the DICE-2013R model to calculate optimized GHG emissions.

In the far future from 2050, innovative technologies beyond existing sophisticated ones could be introduced to reduce mitigation costs additionally and substantially. Given that effects of uncertain next-generation technologies are difficult to accumulate, however, this paper assumes a case in which innovation will make progress for the presently available CO_2 recovery technology among CO_2 capture technologies. The U.S. Department of Energy has set three categories to indicate the advancement of CO_2 recovery technologies -- First Generation, Second Generation and Transformational (or Third Generation)(4). The First Generation represents the currently commercially available technologies that can capture CO_2 at a cost of \$60/ton. The cost is expected to fall to \$40/ton for the Second Generation and \$20/ton for the Transformational (or Third Generation). In the Technological Innovation Scenario, the Second Generation is assumed to penetrate into the market by 2100 and Transformational (or Third Generation) by 2150. For the case where GHG emissions cut from the Baseline Scenario are more than 60%, costs are assumed to decline to two-thirds of the Standard Scenario level in 2100 and to one-third in 2150. Costs of other technologies categorized for the emission reduction rate more than 60% are similarly assumed to decline so that optimum GHG emissions are calculated.

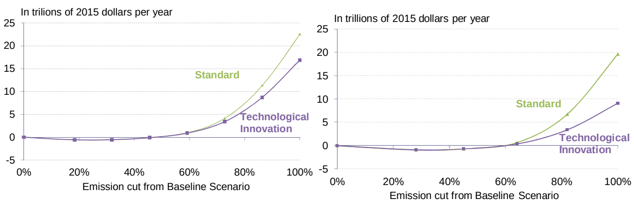

Figure 2 Mitigation cost curve (emission reduction from Baseline Scenario (left for 2100, right for 2150)

It is controversial how to set the climate sensitivity when projecting a temperature rise from CO_2 concentration changes. The climate sensitivity represents how much temperature rises if CO_2 concentration remains at twice the level until the atmosphere and the ocean come into temperature balance. The climate sensitivity is put at 3℃ in the MAGICC climate model used at the Working Group 3 in the Fifth IPCC Assessment Report. The average climate sensitivity in energy models ranges from 2.0℃ to 2.6℃. It was put at 2.5℃ in the First to Third IPCC Assessment Reports. Given these precedents, this paper gives results for both 3℃ and 2.5℃ of the climate sensitivity levels.

As other GHGs' influences on the temperature, this paper uses values that are set exogenously in the DICE-2013 model. Given that the feasibility and impacts of bio-energy with CCS and other CO_2 removal technologies are highly uncertain, we do not assume any negative emissions for each scenario.

4. Results

4.1 Energy-related CO_2 emissions

In the Baseline Scenario, energy-related CO_2 emissions persistently increase until 2200 and decrease gradually owing to the improvement of emissions per gross product (Figure 3). In the 50% Reduction by 2050 Scenario, cumulative emissions between 2100 and 2300 total 268 $GtCO_2$. In the Standard Scenario and the Technological Innovation Scenario, emissions gradually decrease from 2010. As a higher climate sensitivity leads to greater damage, emissions are reduced earlier. In the Standard Scenario, emissions fail to fall close to zero irrespective of the climate sensitivity as the marginal abatement cost increases in line with a higher emission reduction rate. In the Technological Innovation Scenario, however, emissions fall to zero after 2180 at the climate sensitivity of 3℃ and after 2200 at the sensitivity of 2.5℃. Cumulative emissions between 2010 and 2300 total 1,239 $GtCO_2$ in the Standard Scenario and 812 $GtCO_2$ in the Technological Innovation Scenario at the climate sensitivity of 3℃. At the sensitivity of 2.5℃, they total 1,369 $GtCO_2$ in the Standard Scenario and 938 $GtCO_2$ in the Technological Innovation Scenario.

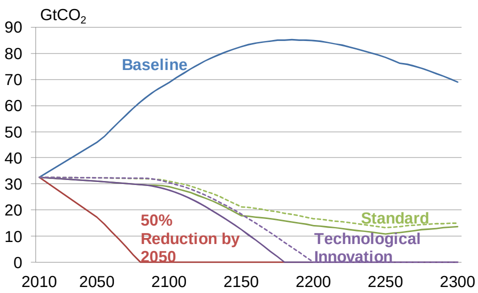

Figure 3 Energy-related CO_2 emissions through 2300 in each scenario (solid line for climate sensitivity of 3℃ and dotted line for climate sensitivity of 2.5℃)

4.2 Atmospheric CO_2 concentration

The atmospheric CO_2 concentration in the Baseline Scenario persistently increases, reaching 1,400 ppm in 2300 (Figure 4). In the 50% Reduction by 2050 Scenario, however, the concentration peaks out in 2050. It slowly decreases after slipping below 400 ppm after 2100.

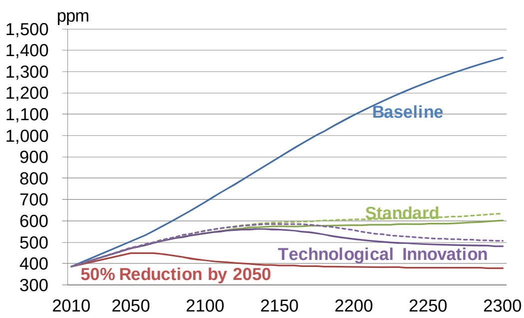

Figure 4 Atmospheric CO_2 concentration (solid line for climate sensitivity of 3℃ and dotted line for climate sensitivity of 2.5℃)

In the Standard Scenario where CO_2 continues to be emitted to some extent, the concentration exceeds 600 ppm in 2300. In the Technological Innovation Scenario where CO_2 emissions are zero after 2080, the concentration peaks out around 2130 at the climate sensitivity of 3℃ and around 2150 at the sensitivity of 2.5℃ and falling close to 500 ppm by 2300 irrespective of the climate sensitivity. Given that there are other GHGs, the atmospheric GHG concentration remains above 450 ppm over a long term under an optimum solution based on the current damage, adaptation and mitigation cost estimation, even if technological innovation reduces the marginal abatement costs at high reduction rates after 2100.

4.3 Costs and benefits

Figure 5 shows cumulative benefits of mitigation, damage and adaptation cost cuts from the Baseline Scenario from 2010 to 2150, to 2200 and to 2300 for each of the other scenario. At 0, costs are equal to benefits, with a positive value indicating benefits excess over costs.

In the 50% Reduction by 2050 Scenario, although the CO_2 concentration is suppressed substantially, over a long term costs are higher than in the Baseline Scenario even if climate change damage and adaptation cost cuts taken into account. In the Standard Scenario and the Technological Innovation Scenario where emission reduction actions are taken after a substantial decline in mitigation costs, the cost-benefit performance is higher than in the Base Scenario. While the CO_2 concentration in the Technological Innovation Scenario is lower than in the Standard Scenario, benefits are the same in the two scenarios.

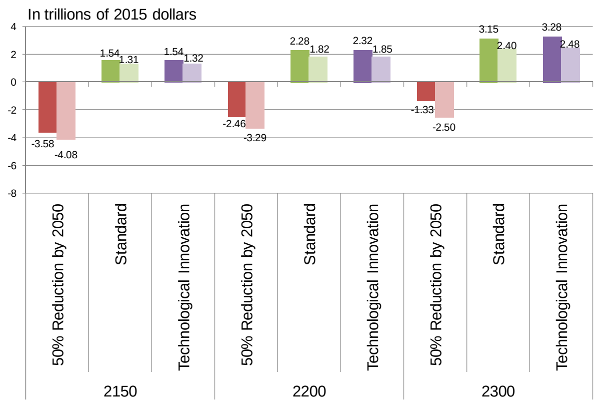

Figure 5 Sum of cumulative costs and benefits from 2010 (left for climate sensitivity of 3℃ and right for climate sensitivity of 2.5℃)

4.4 Temperature rise from 2nd half of 19th century

A temperature rise from the second half of the 19th century ranges from 1.3℃ to 1.5℃ in the 50% Reduction by 2050 Scenario, achieving the 2℃ target (Figure 6).

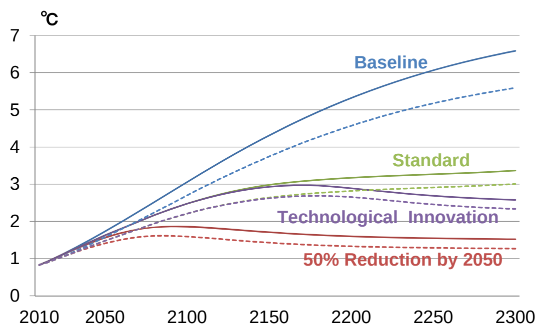

Figure 6 Temperature rise from 2nd half of 19th century (solid line for climate sensitivity of 3℃ and dotted line for climate sensitivity of 2.5℃)

In the Standard Scenario where CO_2 emissions continue increasing, the temperature rise from the second half of the 19th century to 2300 is 3.0℃ to 3.4℃. In the Technological Innovation Scenario, the temperature rise from the second half of the 19th century peaks out around 3℃ at the climate sensitivity of 3℃ or 2.7℃ at the climate sensitivity of 2.5℃ around 2180 and narrow later to a 2.3-2.6℃ range. In the Technological Innovation Scenario where benefits are more than in the Baseline Scenario, the temperature rise from the second half of the 19th century is limited to around 2℃ over a long term at the climate sensitivity of 2.5℃.

5. Conclusion

In the 50% Reduction by 2050 Scenario where CO_2 emissions are reduced substantially to limit the temperature rise, costs are higher than in the Baseline Scenario. If the current pace of technological advancement continues in the future, benefits will be more than in the Baseline Scenario but the atmospheric CO_2 concentration will continue increasing, with the temperature rising persistently. If further technological development limits costs of technologies for expanding emission cuts, the CO_2 concentration may be reduced at a lower cost to limit the temperature rise from the second half of the 19th century to around 2℃ depending on the climate sensitivity. In near term, we apply available energy conservation and low-carbon technologies and over a very long term in order to substantially reduce global CO_2 emissions close to zero to cut emissions, technologies have to be developed to limit a sharp rise in the marginal abatement cost when the emission reduction expands beyond a certain level. Countries have to cooperate in promoting investment in innovative technology development to narrow a temperature rise globally.

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