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ECONOMIC ANALYSIS OF ZERO-EMISSIONS STABILIZATION
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1. Introduction
At the Group of Eight (G8) Summit of 2009, the powerful industrialized countries that attended
the summit declared that the global mean temperature must not exceed 2 °C above pre-industrial
levels, a decision made in recognition of the scientific findings of the Intergovernmental Panel on
Climate Change (IPCC). However, maintaining temperature rises within 2 °C of pre-industrial
levels is quite a stringent target, considering the prospect of future emissions increases from devel-
oping countries. Practical strategies to keep temperature change below this limit remain in the
planning stage. However, the mere fact that a target has been agreed upon amounts to progress.
During negotiations on greenhouse gas (GHG) emissions reductions, the international commu-
nity failed to reach any such agreement. The Kyoto Protocol, which was initially adopted in
1997, obliged industrialized countries to reduce their total emissions of six GHGs by at least
5 percent for the 2008–2012 period relative to emissions levels in 1990. However, the Kyoto
Protocol did not establish mandated targets for GHG emissions reductions for developing coun-
tries, despite the predictions that future emissions from developing countries would be larger than
those from industrialized countries. This contradiction later led to a severe altercation between
the industrialized countries and developing countries over their respective obligations with
respect to GHG emissions reductions. For example, at the 15th Conference of Parties (COP-15)
of the United Nations Framework Convention on Climate Change held in Copenhagen in
2009, industrialized countries demanded that legally binding targets for GHG emissions reduc-
tions be imposed on developing countries, resulting in a fierce confrontation between the two
groups. Furthermore, although industrialized countries largely had agreed on the direction of the
GHG emissions reduction policy since 1990, differences of opinion became apparent at COP-15.
In short, practical policies on climate change mitigation have not been fully established, particu-
larly because of tensions between industrialized and developing countries.

In this study, we note that the IPCC’s climate change mitigation scenarios all presuppose the
stabilization of GHG concentrations. Proposals for large emissions reductions in the near future
are based on the IPCC’s concentration stabilization scenarios. For example, one IPCC plan calls
for maintaining CO₂ concentration levels below 450 ppm.

Other researchers, however, have sought approaches that avoid this potentially difficult-to-attain
prerequisite. Matsuno et al. (2012) proposed a “Z650 scenario” that approaches climate change
mitigation from a different perspective than the concentration stabilization scenarios. Matsuno et al. (2012) referred to the IPCC’s concentration stabilization scenarios as “emissions-keeping stabilization (E-stabilization),” wherein GHG concentrations become stable at some future time. By contrast, in the Z650 scenario, GHG emissions are reduced to zero at some future time; thereafter, GHG concentrations decrease via natural removal processes, finally reaching an equilibrium state that Matsuno et al. (2012) termed “zero-emissions stabilization (Z-stabilization).” The “Z” in Z650 comes from the “Z” in zero-emissions stabilization, and the “650” comes from the assumption under the Z650 scenario that cumulative CO₂ emissions in the 21st century will be 650 GtC.

If zero emissions are required in the medium- to long-term future but a feasible emissions reduction rate is allowed, then greater quantities of emissions remain permissible in the near future. Thus, we can infer that Z-stabilization is more advantageous than E-stabilization for minimizing long-term risks while meeting short-term needs for high emissions levels. Given that post-Kyoto Protocol negotiations have reached a stalemate and that GHG emissions in developing countries continue to increase, the Z650 scenario is more realistic because its emissions path is close to that of the current “business-as-usual” scenario. However, as businesses have failed to adapt and countries have failed to enforce even the relatively modest changes required by past climate change reduction policies, it is clear that attempting to achieve even a slight change from “business as usual” can present significant problems, especially in an economic climate that prioritizes short-term profits over increased spending on environmental policies that yield only long-term benefits. Therefore, to be feasible for widespread adoption, climate change policies must also make economic sense. This chapter examines Z650’s potential advantage in that respect.

Although meteorological and atmospheric studies of the Z650 scenario have been conducted, this study adopts a fresh approach in conducting an economic analysis to assess the economic efficiency of the Z650 scenario. In this study, we employ the DICE and RICE models, which are the most widely used models to simulate the economic effects of climate change. Assessing the adequacy of the Z650 scenario is more easily and accurately achieved by comparing its economic efficiency with that of other scenarios than by investigating the economic efficiency of the Z650 scenario alone. Thus, we compare the economic efficiency of the Z650 scenario with that of two traditional E-stabilization scenarios: 500-ppm stabilization and 450-ppm stabilization.

The structure of this chapter is as follows. Section 2 presents a brief overview of the simulation models that are used in this study. Section 3 presents the simulation results for climate change and the global economy obtained using the DICE model. Section 4 presents the simulation results for regional economies obtained using the RICE model and shows how the economic figures differ by region. Section 5 focuses on the Asian region, presenting an analysis of the effects of CO₂ emissions reductions on the economies of China, India, Japan, and other developing Asian countries. Section 6 presents an evaluation of the economic efficiency of CO₂ emissions reduction scenarios using two analytical methods. Section 7 summarizes the findings of this study and the main conclusions.

2. Model description

2.1 Overview of the models

The DICE and RICE models were used in this study, with a novel improvement. First proposed by William Nordhaus in 1991, DICE is an acronym for “Dynamic Integrated Model of Climate and the Economy,” and it treats the world as a unified single region. By contrast, RICE, which is an acronym for “Regional Dynamic Integrated Model of Climate and the Economy,” divides the
world into multiple regions. In this study, the RICE model is used to analyze the world divided into 12 regions. The equations used in RICE and DICE are the same; thus, we can regard RICE as a regionally disaggregated companion model for DICE. We employ the DICE and RICE models in this study because these models are the most widely used models for simulating the economic effects of climate change (Hatase and Managi, forthcoming).

The DICE model, which is an improved version of the model that preceded it (Nordhaus, 1991), was given the name DICE in 1992 (Nordhaus, 1992). Nordhaus has continued to develop and improve DICE. The latest version at the time of conducting this research is DICE-2010 (Nordhaus, 2010a). The RICE model appeared as a reconstructed version of DICE in the mid-1990s (Nordhaus and Yang, 1996). The latest version at the time of this study is RICE-2010 (Nordhaus, 2010b). In this study, DICE is used for simulations covering the world as a whole, and RICE is used for simulations in which the world is divided into multiple regions. In short, we use the DICE and RICE models in a complementary manner.

The DICE and RICE models consist of an economic sub-model, a CO₂ accumulation sub-model, a temperature change sub-model, and a climate damage sub-model. The economic sub-model is a standard dynamic economic model of the Ramsey type that maximizes the total utility over the entire simulation period. We first present an overview of the equations for the DICE model. The objective function (which maximizes the total utility) of DICE is as follows:

\[
\max \sum_{t=1}^{T} U[c(t)](1 + \rho)^{-t}
\]

where \(U_c\) is a utility function, \(\rho\) is the pure time preference rate, and \(c\) is consumption per capita. The production function of DICE follows the form of the Cobb-Douglas function:

\[
Q(t) = \Omega(t)\left[1 - \Lambda(t)\right]A(t)K(t)^{\gamma}L(t)^{1-\gamma}
\]

where \(Q\) is the gross world product with net abatement and damage, \(\Omega\) is a climate damage function, \(\Lambda\) is a function of CO₂ abatement costs, \(A\) is the total factor productivity, \(K\) is capital, \(L\) is the population and labor inputs, and \(\gamma\) is the capital’s value share. DICE uses the following standard capital accumulation equation:

\[
K(t) = \left(1 - \delta_k\right)K(t-1) + I(t-1)
\]

where \(I\) is investment and \(\delta_k\) is a capital depreciation rate. The CO₂ abatement costs \(\Lambda\) in Equation (2.2) are calculated using the following function:

\[
\Lambda(t) = \theta_1(t)\mu(t)^{\theta_2}
\]

where \(\theta_1\) and \(\theta_2\) are the parameters of the CO₂ abatement cost function and \(\mu\) is the reduction rate of CO₂ (relative to the business-as-usual scenario). The economic sub-model of DICE is closed by the following identity of the macro economy:

\[
Q(t) = C(t) + I(t)
\]

Next, DICE assumes that CO₂ emissions \(E\) consist of industrial emissions \(E_{IND}\) and emissions from land use change \(E_{LIND}\).
Economic analysis of zero-emissions stabilization

\[ E(t) = E_{\text{IND}}(t) + E_{\text{LAND}}(t) \]  

(2.6)

The industrial CO₂ emissions in Equation (2.6) are calculated as follows:

\[ E_{\text{IND}}(t) = \sigma(t) \left[ 1 - \mu(t) \right] A(t) K(t) \gamma L(t)^{1-\gamma} \]  

(2.7)

where \( \sigma \) is the CO₂ emissions intensity. The emissions from land use change \( E_{\text{LAND}} \) in Equation (2.6) are given exogenously. DICE’s CO₂ accumulation sub-model is a box model consisting of a single atmospheric layer and two ocean layers (dividing the ocean into upper and lower oceans). In the CO₂ accumulation sub-model, CO₂ emissions \( E(t) \) are added to the atmosphere as follows:

\[ M_{\text{AT}}(t) = E(t) + \phi_{11} M_{\text{AT}}(t-1) + \phi_{21} M_{\text{UP}}(t-1) \]  

(2.8)

where \( M_{\text{AT}} \) is the CO₂ concentration of the atmosphere, \( M_{\text{UP}} \) is the CO₂ concentration of the upper ocean, and \( \phi_{11} \) and \( \phi_{21} \) are the parameters of carbon circulation.

Finally, we calculate the climate damage in Equation (2.2) using the simplest damage function employed by Ackerman and Finlayson (2006):

\[ \Omega(t) = \frac{1}{1 + \pi_{2} T_{\text{AT}}(t) \gamma} \]  

(2.9)

where \( T_{\text{AT}} \) is the temperature increase in the atmosphere and \( \pi_{2} \) is a parameter. Because of space limitations, we do not show the CO₂ accumulation sub-model and temperature change sub-model of the DICE model, but readers may refer to Nordhaus (2008) for details on these sub-models.

The equations for the RICE and DICE models are essentially the same, but the models diverge at the point at which RICE calculates Equations (2.2)–(2.7) by region. However, DICE and RICE use the same CO₂ accumulation and temperature change sub-models. Readers interested in the equations of the RICE model may refer to the supporting information found in the work of Nordhaus (2010b).

### 2.2 Adaptation of the models

The latest versions of the DICE and RICE models mentioned previously are not entirely suitable for use in evaluating the Z650 scenario. Thus, we adapted DICE-2010 and RICE-2010 in the following ways.

First, the CO₂ accumulation and temperature change sub-models in DICE-2010 and RICE-2010 cannot recreate the CO₂ concentration and temperature increases in the Z650 scenario described by Matsuno et al. (2012), which uses a more detailed climate change model. Therefore, we used the CO₂ accumulation and temperature change sub-models in an older DICE model, DICE-2007 (Nordhaus, 2008). In fact, these sub-models of DICE-2007 can rather accurately recreate the CO₂ concentration and temperature increases of the Z650 scenario in Matsuno et al. (2012).

Second, DICE-2010 and RICE-2010 incorporate temperature increases and sea level rises as elements of the climate damage sub-model. However, the Z650 and 450-ppm stabilization climate mitigation scenarios do not reduce the estimated damage associated with sea level rise to the same degree, and as a result, the benefits of CO₂ emissions reductions are small if we
use the default climate damage sub-model in DICE-2010 and RICE-2010. Therefore, we regard the climate damage sub-model of DICE-2010 and RICE-2010 as premature and instead use the simplest climate change model proposed by Ackerman and Finlayson (2006). Note that the actual damage function that we use is Equation (2.9) in the DICE model and Equation (2.10) in the RICE model.

2.3 Parameter settings and other calculation conditions

The simulations are conducted for ten-year increments beginning in 2005. The simulation period is 600 years (60 periods) in the DICE model and 300 years (30 periods) in the RICE model. We shortened the simulation period in the RICE model to 300 years because of the computation times required (note that RICE consumes more computational resources because it analyzes multiple regions rather than the world as a whole). We established three simulation scenarios: the Z650 scenario, which is the main focus of this study, and two E-stabilization scenarios, one for the E500 scenario and one for the E450 scenario. In the work of Matsuno et al. (2012), the Z650 scenario is compared with the E450 scenario because these two scenarios are similar from the perspective of atmospheric science; for example, the Z650 and E450 scenarios consider similar degrees of climate change mitigation in the next 150 years. Although this study primarily compares the Z650 scenario with the E450 scenario, we can also draw comparisons with the E500 scenario. Although it is difficult to view the E500 scenario as a practical climate mitigation policy from the perspective of atmospheric science (note that the E500 scenario may cause dangerous climate changes), the Z650 and E500 scenarios are anticipated to have similar economic effects in the first half of this century; thus, the E500 scenario is a convenient referential scenario for economic analysis. This study primarily focuses on comparing the Z650 and E450 scenarios, as in Matsuno et al. (2012). Table 2.1 explains the calculation conditions for the three scenarios.

The parameter settings differ among the economic, CO₂ accumulation, temperature change, and climate damage sub-models. First, in the economic sub-model, the DICE-2010 and RICE-2010 default parameter settings are applied in the DICE and RICE models, respectively. In the CO₂ accumulation and temperature change sub-models, the DICE-2007 default parameter settings are applied in both the DICE and RICE models. In the climate damage sub-model, the parameter settings differ slightly between DICE and RICE. In the DICE model, we apply the default parameter settings of the DICE-2007 climate damage sub-model. In the RICE model, however, we adjust the parameters of the climate damage function as described in the following equation.

The RICE model estimates climate damage by region, and we apply the following damage function, consistent with Equation (2.9) in the DICE model:

\[
\Omega(t,n) = \frac{1}{1 + B[\pi_2(n)T_{AV}(t)]}
\]  

(2.10)

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<th>Table 2.1 Simulation scenarios</th>
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<td><strong>Scenario</strong></td>
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where $n$ is a region of the world, $\Omega$ is the rate of climate damage per gross domestic product in each region, $T_{at}$ is the temperature increase in the atmosphere, and $\pi_2(n)$ and $B$ are parameters. In the parameter settings, we use the default parameter values of RICE-2010 for $\pi_2(n)$ which determines the regional allocation of climate damage, and we adjust the values of parameter $B$ such that the climate damage estimated by DICE and RICE approximately correspond to the business-as-usual scenario.

3. Simulation of climate and global economy

This section presents the simulation results for both climate change and the global economy according to the DICE model. We first show the climate mitigation paths for the three mitigation scenarios considered, including Z650. We then present the results for the global economy. Note that all monetary values are shown in 2005 US dollars.

3.1 Simulation of climate change mitigation

The Z650 scenario assumes that zero emissions are achieved in the year 2160 (i.e., the middle of the next century). Under the E-stabilization scenarios proposed by the IPCC, large emission reductions from the early 21st century levels are imperative for avoiding dangerous climate change. In contrast, under the Z650 scenario, higher levels of emissions in the near future are permissible as a result of zero-emissions stabilization, which leads to sufficient climate change mitigation in the future. First, we show the simulation results for climate change mitigation under three mitigation scenarios according to the DICE model.

Figure 2.1 shows the CO2 emissions for each scenario. Note that the legend “BaU” denotes the business-as-usual scenario. In the climate change mitigation path, we focus particular attention on the difference between the E450 and Z650 scenarios, following Matsuno et al. (2012). In the E450 scenario (450-ppm stabilization), substantial CO2 emission reductions are achieved beginning in the early 21st century, whereas the Z650 scenario permits some increase in CO2 emissions. By contrast, in the Z650 scenario, emissions are reduced more than in the E450 scenario by 2075, before becoming roughly zero in 2155. Incidentally, the emissions paths

![Figure 2.1 Global CO2 emissions](image-url)
of the Z650 and E500 (500-ppm stabilization) scenarios are similar in the first half of 21st century.

Figure 2.2 shows the atmospheric CO$_2$ concentration for each scenario. The concentration paths of the E-stabilization and Z-stabilization scenarios follow different trends: CO$_2$ concentrations become stable at some point in the E450 and E500 scenarios, whereas CO$_2$ concentration first peaks and then begins to decline in the Z650 scenario. In addition, in the Z650 scenario, CO$_2$ concentration reaches a peak at approximately 500 ppm in the middle of the 21st century and then begins to decline, becoming smaller than in the E450 scenario after 2135. Incidentally, the CO$_2$ concentration levels before 2045 are similar in the E500 and Z650 scenarios. The simulation results shown in Figure 2.2 reveal the outcome of the DICE model. Figure 2.3 compares the CO$_2$ concentration in the Z650 scenario according to DICE with that of Matsuno et al. (2012), which uses a more detailed climate model. Figure 2.3 demonstrates that the simplified climate module in DICE can reproduce the results of Matsuno et al. (2012) fairly well.
Figure 2.4 shows projected atmospheric temperature changes since 1750 (during the pre-industrial era). The trends of the temperature change paths between the E-stabilization and Z-stabilization scenarios differ as follows: temperatures continue to increase after CO₂ concentration stabilization is achieved in the E450 and E500 scenarios, whereas temperatures initially peak and then begin to decline under the Z650 scenario. In the Z650 scenario, temperatures increase with respect to the pre-industrial level peaks at approximately 2.2 °C at the beginning of the 22nd century and then begin to decline until temperatures finally become lower in the Z560 scenario than in the E450 scenario after 2155. The results shown in Figure 2.4 clearly indicate that Z-stabilization is more effective than E-stabilization for long-term climate change mitigation. Figure 2.5 compares temperature changes in the Z650 scenario, as calculated by DICE and Matsuno et al. (2012). In the DICE scenario, temperature increases begin slightly sooner; the
temperature decreases in the 22nd century also begin slightly earlier compared with that found by Matsuno et al. (2012), but the peaks in the temperature increases match in the two models.

To summarize the climate change mitigation simulation results, we first confirmed that zero-emissions stabilization is more effective than “emissions-keeping” stabilization for long-term climate change mitigation. For instance, the E450 scenario is an ambitious climate mitigation scenario requiring drastic CO₂ emission reductions beginning in the early 21st century. However, from the perspective of long-term climate change mitigation, the Z650 scenario, which permits some CO₂ emission increases in the early 21st century, has a greater effect on climate mitigation than the E450 scenario. Second, we confirmed that a simplified DICE climate module can reproduce the results of Matsuno et al. (2012) fairly well, thus demonstrating that the adapted DICE and RICE models are fully applicable for use in simulations comparing the E500, E450, and Z650 mitigation scenarios.

### 3.2 Simulation of the global economy

We next focus on simulating the global economy under the same three mitigation scenarios. If zero emissions are achieved in the middle of the next century, then some increase in emissions is permissible in the near future, and economic losses associated with CO₂ emissions reductions are expected to decrease in the Z650 scenario. We also observe the shadow price of carbon (which reflects the amount of carbon tax) and the amount of climate damage in this section. Note that we evaluate the economic efficiency of all three mitigation scenarios in Section 6.

Figure 2.6 shows the GDP loss predicted for each scenario as a result of CO₂ emissions reductions, expressed as a percentage of GDP for the business-as-usual scenario. The GDP loss in the first half of the 21st century is roughly proportional to the level of CO₂ emissions reduction; thus, the GDP loss in the E450 scenario is substantial, whereas the GDP losses in the E500 and Z650 scenarios are relatively small. Conversely, the GDP losses in the 22nd century are fairly consistent among the three scenarios. For the DICE parameter settings used in this study, the GDP losses in the E500 and Z650 scenarios are roughly the same throughout the simulation period, but the outcome depends on the parameter settings and other calculation conditions. For example, the simulation results obtained with the RICE model in Section 5 show that the

![Figure 2.6 GDP loss caused by CO₂ reduction (% of BaU)](image-url)
GDP loss in the Z650 scenario is significantly larger than that in E500 in the 22nd century (see Figures 2.17 (a)–(d)). In any case, as the GDP loss in the first half of the 21st century is roughly proportional to the level of CO2 emissions reduction, the GDP loss in the Z650 scenario is much smaller than in the E450 scenario, although the Z650 scenario has a greater long-term climate mitigation effect than the E450 scenario.

Figure 2.7 shows the shadow price of carbon in each scenario. The shadow price of carbon is the marginal abatement cost of carbon (the cost of reducing one additional ton of carbon) and the amount of carbon tax in each scenario. The shadow price of carbon in the Z650 and E500 scenarios remains roughly the same until the middle of 21st century, but the shadow price of carbon in Z650 continues to increase, and the Z650 shadow price of carbon outpaces that in E450 in 2075. As noted previously, the GDP loss in each scenario is roughly proportional to the level of CO2 emissions reduction only in the first half of 21st century, but the shadow price of carbon is roughly proportional to the level of CO2 emissions reduction throughout the calculation periods. In the E500 and E450 scenarios, the increase in the shadow price of carbon slows in the middle of the 21st century when CO2 concentrations are stabilized, whereas in the Z650 scenario, the shadow price of carbon continues to increase through the middle of 22nd century when zero emissions are achieved.

Figure 2.8 shows the amount of climate damage in each scenario. The estimated climate damage in the business-as-usual scenario in 2095 is $13 trillion, a value that is similar to that predicted by Nordhaus (2010b), who used a different damage function than that used in the current study. Because climate damage, according to the function used in this study, is proportional to the square of the temperature increase (see Equation (2.9)), climate damage reductions are proportional to the square of the temperature decrease with respect to the business-as-usual scenario, and the estimated climate damage in the Z650 scenario decreases to $5.2 trillion in 2095. The estimated climate damage in the Z650 scenario is close to that in the E500 scenario in the 21st century, but the estimated damage in the Z650 scenario becomes smaller than that in the E450 scenario after 2155. In the E500 and E450 scenarios, the climate damage amounts continue to increase exponentially, rising to $20 trillion by the end of the 22nd century in the E500 scenario; by contrast, in the Z650 scenario, climate damage increases become smaller with
time, rising to merely $10 trillion by the end of the 22nd century. Thus, we can confirm that from an economic perspective, Z-stabilization is more effective than E-stabilization in climate damage mitigation.

We summarize the simulation results for the global economy as follows. First, GDP losses and the shadow price of carbon are roughly the same for the E500 and Z650 scenarios in the first half of this century. Thus, economic losses for Z650 in the near future will be much smaller than those for E450, the scenario often recommended by the IPCC. Second, the level of climate damage estimated for the Z650 scenario is similar to that for the E450 scenario in the middle of the 22nd century, but in the longer term, the level of climate damage estimated for Z650 is smaller than for E450. Thus, in comparison to the two E-stabilization scenarios, the Z650 scenario results in less long-term climate damage while also producing relatively small GDP losses.

4. Simulation of regional economies

RICE is a regionally disaggregated companion version of DICE, as explained in Section 2. Following Nordhaus (2012b), this study utilized 12 regions of the world. The RICE economic sub-model parameter settings used in this study are the same as those in the RICE-2010 model. For information regarding the regional partitions, readers should refer to the legends in the figures showing the simulation results (the following abbreviations are used: US: United States; EU: the European Union; MidEast: the Middle East; LatAm: Latin America; OHI: other high-income countries; and OthAsia: other developing Asian countries).

Figures 2.9 and 2.10 show the CO₂ emissions for each region in the E450 and Z650 scenarios, respectively. Because of space limitations, we do not show the regional CO₂ emissions for the E500 scenario, but the regional emissions paths for the E500 scenario are similar to those for the Z650 scenario for the first half of this century. As is evident in Figure 2.9, large reductions in CO₂ emissions beginning in the early 21st century are essential, and emissions reductions must be particularly substantial in China and the US. Thus, in reality, it will be difficult for the global community to agree to the CO₂ emissions reductions required based on the E450 scenario. Compared with the E450 scenario, however, the Z650 scenario permits some emissions increases.
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in developing countries in the near future, as shown in Figure 2.10; thus, the Z650 scenario will be more agreeable for the global community. However, we must emphasize that increases in CO₂ emissions are permissible only until 2025, and substantial emissions reductions are required beginning in the middle of this century, even in the Z650 scenario. Thus, in any case, we must prepare for high levels of emissions reductions in the future.

Figure 2.11 shows the GDP loss from emissions reductions in each region in the E450 scenario, expressed as a percentage of the emissions associated with the business-as-usual scenario. Figure 2.12 shows the GDP loss in each region in the Z650 scenario. Because of space limitations, the GDP loss in the E500 scenario is not shown, but it is similar to that in the Z650 scenario in the first half of this century. Concerning Figure 2.11, GDP losses in the E450 scenario are large in developing countries, particularly in China, Russia, and Eurasia, up to 3 percent compared with

Figure 2.9  CO₂ emissions by region of the world (E450 scenario)

Figure 2.10  CO₂ emissions by region of the world (Z650 scenario)
BaU levels. By contrast, the EU suffers a maximum GDP loss of only 1 percent from BaU in the E450 scenario. Differences in GDP loss of this magnitude between industrialized and developing countries may hamper agreement on CO₂ emissions reduction levels. However, GDP losses in the Z650 scenario, as shown in Figure 2.13, are significantly smaller than those in the E450 scenario in the early 21st century, although the paths have similar shapes in both the E450 (Figure 2.11) and Z650 (Figure 2.12) scenarios. For example, in 2025, GDP losses of more than 1 percent from BaU levels occur in some regions in the E450 scenario, whereas GDP losses in the same period increase to 0.3 percent in the Z650 scenario. However, we must emphasize that GDP losses after the middle of the 21st century are considerably large even in the Z650 scenario; for instance, GDP losses in China and Russia increase by up to 2.4 percent from BaU levels. As noted previously,
there are differences in the level of GDP losses between industrialized and developing countries even in the Z650 scenario, which may hamper international agreement on a CO₂ reduction policy. However, it should be noted that the advancement of new energy technologies and carbon capture and storage (CCS) may reduce GDP losses, thus facilitating international agreement.

Figure 2.13 shows the estimated climate damage in each region in the business-as-usual scenario. The estimated damage amounts are large in developing countries, especially in Asia and Africa. The estimated damage amounts also are large in the US and in EU countries, but these countries have large GDPs and the damage as a percentage of GDP is not as large. Climate damage amounts as a percentage of GDP are larger for Africa, India, and other developing Asian countries.

Figure 2.14 shows estimated climate damage amounts for each region in the E450 scenario, whereas Figure 2.15 shows estimated climate damage amounts in the Z650 scenario. In the business-as-usual scenario, the estimated climate damage amounts are 4.2 percent to 7.1 percent of GDP in 2155. In the E450 scenario, the estimated damage amounts are 0.9 percent to 1.5 percent of GDP in 2155. In the Z650 scenario, the estimated damage amounts are only 0.8 percent to 1.4 percent of GDP in 2155. In both the E450 and Z650 scenarios, the percentage of climate damage reduction is roughly the same for all regions, at approximately 80 percent of the business-as-usual level in 2155. In fact, the estimated climate damage amounts do not differ greatly between the E450 and Z650 scenarios in terms of long-term climate damage mitigation, despite the fact that the estimated damage amounts for Z650 are slightly larger than those for E450 during the 21st century. It should be noted that regions that suffer greater climate damage would experience larger reductions in climate damage with the E450 and Z650 scenarios; thus, developing countries with high levels of climate damage will have an incentive to reduce CO₂ emissions to mitigate climate damage.

We summarize the simulation results for regional economies as follows. First, the Z650 scenario permits developing countries to have some increases in CO₂ emissions until 2025. Thus, the global community is likely to attain agreement on Z650 easier than agreement on the E450 scenario. However, large reductions in emissions are necessary after 2025 even in the Z650 scenario. Second, the GDP losses from emissions reductions in some developing countries are relatively larger than those that industrialized countries would experience even in the Z650 scenario, and this difference may hamper international agreement on a CO₂ reduction policy. Third,
regions with greater climate damage have higher levels of damage reduction under the Z650 scenario, which will incentivize CO₂ emissions reductions in developing countries with greater climate damage. These findings indicate that the factor that hampers international agreement on a CO₂ reduction policy will be the differences in GDP losses across world regions. Thus, efforts will be needed to overcome such differences in GDP losses.

5. Simulation of the Asian economy

Following the analysis of regional economies in the previous section, this section focuses on the analysis of the Asian economy using the RICE model. The previous section showed the simulation results for 12 world regions, whereas this section focuses on four Asian regions: China, India,
Japan, and other developing Asian countries (this category, referred to as “other developing Asian countries,” is the same as the “OthAsia” category mentioned in the previous section). The parameter settings used for RICE are the same as those described in the previous section. We show the simulation results for CO2 emissions, GDP loss, and climate damage, which are the same categories of data discussed in the previous section. However, this section analyzes those results from different perspectives.

Figures 2.16 (a), (b), (c), and (d) show CO2 emissions in China, India, Japan, and other developing Asian countries, respectively. First, Figure 2.16(a) shows that China’s CO2 emissions increase steeply in the early 21st century in the business-as-usual scenario. Such a steep increase in CO2 emissions, which is permitted until 2025, influences the emissions reduction paths of the E500 and Z650 scenarios. However, in both the E500 and Z650 scenarios, China is required to reduce...
emissions drastically beginning in the middle of the 21st century. In the E450 scenario, China is required to reduce emissions beginning in the early 21st century, but such a requirement is not realistic. Second, Figure 2.16(b) shows that India’s CO₂ emissions increase gradually throughout the simulation period in the business-as-usual scenario. In the E500 scenario, India is allowed to increase CO₂ emissions until 2035, as opposed to 2025 in the Z650 scenario, after which emissions must be gradually reduced. Third, Figure 2.16(c) shows that in the business-as-usual scenario, Japan’s CO₂ emissions will increase only slightly until 2025 before beginning to decline. This decline in Japanese emissions will result from population shrinkage and technological advancements. In all three mitigation scenarios (E500, E450, and Z650), Japan is required to reduce emissions by approximately two-thirds by the middle of the 21st century. Incidentally, the difference in emissions reduction paths between E500 and E450 is smaller in Japan than in the
other three regions. Finally, Figure 2.16(d) shows that CO₂ emissions in other developing Asian countries follow a trend that is similar to that observed in India: in the business-as-usual scenario, CO₂ emissions increase gradually throughout the simulation period, whereas in the Z650 scenario, gradual emissions reductions are required beginning in 2025. On the whole, the Z650 scenario requires drastic emissions reductions after 2025 for China and after 2010 for Japan and gradual emissions reductions after 2025 for India and other developing Asian countries. Compared with the E450 scenario, the Z650 scenario is considered more realistic for Asian nations, but drastic CO₂ emissions reductions are required from China and Japan, as noted previously.

Figures 2.17(a), (b), (c), and (d) show the GDP losses associated with CO₂ emissions reductions in China, India, Japan, and other developing Asian countries, respectively. First, Figure 2.17(a)
shows that China’s GDP loss could reach up to 3.1 percent in the E450 scenario, up to 2.4 percent in the Z650 scenario, and up to 1.9 percent in the E500 scenario, compared with the business-as-usual scenario. China’s GDP loss is among the largest in the world’s regions, as noted in Section 4. Second, Figure 2.17(b) shows that India suffers only moderate GDP loss: up to 2.1 percent in the E450 scenario, up to 1.7 percent in the Z650 scenario, and up to 1.4 percent in the E500 scenario. Third, Figure 2.17(c) shows that despite Japan being required to reduce emissions drastically, its GDP loss is relatively small: up to 1.3 percent in the E450 scenario, up to 1.1 percent in the Z650 scenario, and up to 0.9 percent in the E500 scenario. Finally, Figure 2.17(d) shows that the GDP losses of other developing Asian countries could reach up to 2.2 percent in the E450 scenario, up to 1.8 percent in the Z650 scenario, and up to 1.5 percent in the E500 scenario. These values are similar to those for India; because India and other developing Asian countries...
have similar economic situations, they also have similar simulation results. Although the specific values for GDP loss are quite different, as shown previously, the trends in GDP loss are fairly similar among the four Asian regions. For example, the GDP losses in the E500 and Z650 scenarios are similar in the first half of the 21st century, and the GDP loss in the Z650 scenario becomes larger than that in E500 in the latter half of the 21st century. In any case, the difference in GDP loss among the four regions is likely to be problematic for policy decision-makers in Asia.

Figures 2.18 (a), (b), (c), and (d) show the climate damage estimates for China, India, Japan, and other developing Asian countries, respectively. The figures show that the climate damage estimates for the countries in the “other developing Asian countries” group are the largest of the four Asian regions, and those for India are the second largest. Although the climate damage
estimate for China is similar to that for India, China’s climate damage as a percentage of GDP is relatively small compared with that of other regions of the world because China has a large GDP. Thus, in terms of estimated climate damage, India and other developing Asian countries fare the worst of the four Asian regions considered. In fact, the climate damage estimates for other developing Asian countries are the largest of all 12 world regions considered in this study, as shown in Section 4. The trends in climate damage are similar for the four Asian regions, despite the differences in the values of climate damage among the regions. For example, in all four regions, the climate damage estimates for the E500 and Z650 scenarios are similar in the 21st century, but the estimates for the Z650 scenario are smaller than those for the E450 scenario in 2155. As already discussed in Section 4, regions with higher levels of climate damage have greater degrees of damage reduction in the Z650 scenario. Accordingly, both India and other developing Asian countries will have incentives to reduce CO₂ emissions.
We briefly summarize the findings of this section in Table 2.2. We summarize the simulation results for the Asian economy as follows. First, the CO₂ emissions paths in the business-as-usual scenario differ among the four Asian regions because of differences in their socioeconomic situations that significantly affect their CO₂ reduction paths. In the Z650 scenario, gradual emissions reductions after 2025 are required for India and other developing Asian countries, drastic emissions reductions after 2025 are required for China, and drastic emissions reductions after 2010 are required for Japan. The Z650 scenario permits CO₂ emissions to increase until 2025 for China, India, and other developing Asian countries but not for Japan. Second, GDP loss is not always proportional to the level of CO₂ emissions reductions. For example, the Z650 scenario requires Japan to undertake drastic emissions reductions, but Japan’s GDP loss is small relative to that experienced by the other world regions. In the Z650 scenario, China’s GDP loss is one of the largest of the world regions, India and other developing Asian countries experience moderate GDP loss, and Japan’s GDP loss is small compared with that of other regions. Third, the climate damage estimates also are quite different for the four Asian regions. India and other developing Asian countries are predicted to experience more severe climate damage than other regions. Thus, India and other developing Asian countries will have incentives to reduce their CO₂ emissions. In general, the four Asian regions are quite heterogeneous in terms of CO₂ reduction paths, GDP loss, and climate damage.

### Table 2.2 Rough summary of climate and economy in Asian regions

<table>
<thead>
<tr>
<th></th>
<th>China</th>
<th>India and other developing Asian countries</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ emissions in the BaU scenario</td>
<td>Steep increase in the early 21st century</td>
<td>Gradual increase throughout the simulation period</td>
<td>Emissions begin to decline in 2025</td>
</tr>
<tr>
<td>CO₂ emissions reduction in the Z650 scenario</td>
<td>Drastic emissions reduction beginning in 2025</td>
<td>Gradual emissions reduction beginning in 2025</td>
<td>Drastic emissions reduction beginning in 2010</td>
</tr>
<tr>
<td>GDP loss from CO₂ emissions reduction</td>
<td>Large</td>
<td>Medium</td>
<td>Small</td>
</tr>
<tr>
<td>Estimated climate damage</td>
<td>Large in amount, small in % of GDP</td>
<td>Large in amount, large in % of GDP</td>
<td>Small in amount, small in % of GDP</td>
</tr>
</tbody>
</table>

6. **Evaluating the economic efficiency of climate change-mitigation scenarios**

This section evaluates the economic efficiency of the three climate-mitigation scenarios using two analytical methods. The first method is a cost-benefit analysis in which we evaluate the net present value of benefits minus costs. The second method is a damage-mitigation analysis in which we evaluate the net present value of mitigation costs plus climate damage. The analyses described in this section focus primarily on a comparison of the Z650 and E450 scenarios, as Matsuno et al. (2012) demonstrated that these two scenarios are competitive from the perspective of atmospheric science.

### 6.1 Cost-benefit analysis

We have already discussed the economic effects of CO₂ emissions reductions in the previous sections. This section presents an evaluation of the economic efficiency of the three climate-mitigation scenarios. First, we conduct a cost-benefit analysis in which we evaluate the net
present value of benefits minus costs. In the cost–benefit analysis, a project is assessed as follows: if the net benefit (net present value of benefits minus costs) is positive, then the project is worth undertaking; by contrast, if the net benefit is negative, then the project is not worth undertaking. When we compare a number of projects, we use the guideline that the project with the largest net benefit is most worthy of undertaking. In this section, we assess three proposed projects for climate change mitigation (CO₂ emissions reduction): the E500, E450, and Z650 scenarios.

In the cost–benefit analyses that are presented in this section, we use the following formula:

\[
\sum_{t=2005}^{T_{\text{max}}} \left[ \frac{\text{Benefits of reduction}(t) - \text{Costs of reduction}(t)}{(1 + r)^t} \right] \quad (6.1)
\]

where “\(r\)” is the discount rate for which we use the shadow price of GDP (which is the same as the interest rate of the global economy). Note that the “benefits of reduction” in Formula 6.1 is the climate damage avoided as a result of CO₂ emissions reduction.

Figure 2.19 shows the net present value of benefits minus costs for each scenario, as calculated by the DICE model. When \(T_{\text{max}}\) in Equation (6.1) is within the 21st century, the net benefit remains a negative value for all three scenarios. By contrast, when \(T_{\text{max}}\) is in the middle of the 22nd century, the net benefit is a positive value for all three scenarios, and the project (CO₂ emissions reduction in each scenario) is judged to be worth undertaking.

The Z650 scenario has the largest net present value of benefits minus costs under the calculation conditions of the DICE model used in this study. However, because the net benefit of the Z650 scenario is barely larger than that of the E500 scenario in the 21st century, the net benefit of the E500 scenario actually could be larger than that of the Z650 scenario, depending on the parameter settings and other calculation conditions. The E450 scenario has the smallest net present value of the three scenarios because of the high costs of CO₂ emissions reduction in the 21st century. To reiterate, the comparison of the Z650 and E450 scenarios is the main focus of the cost–benefit analysis in this study, and the results of this analysis confirm that the Z650 scenario is more advantageous than the E450 scenario.

Figure 2.19  Net present value of benefits minus costs
Figure 2.20 shows the net present value of benefits minus costs in the Z650 scenario for the four Asian regions (China, India, Japan, and other developing Asian countries) as well as for the US and EU. The calculation was performed using the RICE model, with the same calculation conditions as those used in the preceding calculations. The figure shows that India, other developing Asian countries, and the EU have relatively high net benefits, whereas China has a low net benefit. The time when the net benefit becomes positive varies among the regions. The net benefit becomes positive in the 21st century for some regions, but in China, the net benefit remains negative throughout the calculation period. These results indicate that undertaking the Z650 scenario will result in disagreement between the global and local levels. On the global level, the Z650 scenario is worth undertaking; however, at the regional level, the Z650 scenario is not worth undertaking for China. Thus, we must take measures to ensure a positive net benefit for China. Accordingly, persuading China to participate in a GHG reduction scheme will be crucial.

### 6.2 Damage-mitigation analysis

We now turn to evaluating the three scenarios according to the second method. In this method, we calculate the net present value of mitigation costs plus climate damage for each project using the following formula:

\[
NPV_{\text{mitigation + damage}} = \sum_{t=2005}^{T_{\text{max}}} \left( \frac{\text{Costs of reduction}(t) + [\text{climate damage}]}{(1+r)^t} \right)
\]  

(6.2)

where climate damage is calculated from the damage function in Equation (2.9). In this second method, we use the guideline that the project with the smallest net present value of costs plus damage is most worthy of undertaking. Using this method, we evaluate the three scenarios at the global and regional levels.

Figure 2.21 shows the net present value of mitigation costs plus climate damage for each scenario at the global level, as calculated by the DICE model. The Z650 scenario has the smallest net present value of mitigation costs plus climate damage for the calculation conditions of the
DICEM model that is used in this study. As Figure 2.19 shows for the cost-benefit analysis, the net present value of costs plus damage for the Z650 scenario is only slightly more advantageous than that for the E500 scenario, especially in the 21st century. However, our main focus is the comparison of the Z650 and E450 scenarios, and we can confirm that the Z650 scenario is more advantageous than the E450 scenario in this analysis based on the DICEM model.

Figure 2.22 shows the net present value of mitigation costs plus climate damage for the Z650 scenario for the four Asian regions, the US, and the EU. The figure shows that the US, the EU, Japan, and other developing Asian countries have relatively low net present values of costs plus damage, whereas China and India have relatively high net present values of costs plus damage. India has a relatively high net benefit and is in an advantageous position in the cost-benefit analysis, but in the damage-mitigation analysis, India is in a disadvantageous position. Japan ranks particularly low in the net present value of costs plus damage, but this result is largely a reflection

![Figure 2.21](image1.png)  
**Figure 2.21** Net present value of mitigation costs plus damage

![Figure 2.22](image2.png)  
**Figure 2.22** Net present value of mitigation costs plus damage by region (Z650 scenario)
of the country’s size. As in the first cost-benefit analysis method, China is in a disadvantageous position in terms of its net present value of costs plus damage.

Figures 2.23 (a)–(f) compare the Z650 and E450 scenarios in terms of net present values of costs plus damage for the six regions. For China, the Z650 scenario drastically reduces the net present value of costs plus damage, compared with that for the E450 scenario. The US would experience a moderate degree of reduction in the net present value of costs plus damage with the Z650 scenario compared with the E450 scenario. For the other regions, the differences in the net present values of costs plus damage between the Z650 and E450 scenarios are small. Relative to the E450 scenario, the Z650 scenario drastically improves China’s economic efficiency, although China is in a disadvantageous position compared with the other regions.

To summarize the results of this section, we found that the Z650 scenario is more advantageous than the E450 scenario in terms of two criteria: the net present value of benefits minus costs and the net present value of costs plus damage. In the cost-benefit analysis, the Z650 scenario is found to be worth undertaking at the global level, but the net benefit varies by region;
(c) China

(d) India

(e) Japan
for China, we found that Z650 is not worth undertaking. Therefore, a conflict exists between the outcomes at the global and regional levels, and we must take measures to ensure a positive net benefit for China. Compared with the E450 scenario, the net present values of costs plus damage decrease drastically in China in the Z650 scenario; this result suggests that although the Z650 scenario drastically improves China’s economic efficiency, China is in a disadvantageous position compared with the other five regions.

7. Summary

In conclusion, we summarize the main findings of this study. CO₂ emissions reductions in the Z650 scenario are small in the first half of the 21st century, but the long-term climate change mitigation of the Z650 scenario eventually exceeds that of the E450 scenario. This finding suggests that zero-emissions stabilization is more effective than “emission-keeping” stabilization in the long term. With regard to the economic effects of CO₂ emissions reductions, in the first half of the 21st century, GDP losses and the shadow price of carbon in the Z650 scenario are similar to those in the E500 scenario, in which emissions reductions are small. The economic effects of CO₂ emissions reductions on the world’s regions in terms of GDP losses are significantly larger for some developing countries than for industrialized countries. Thus, agreement on CO₂ emissions reductions among the countries will be difficult to obtain even based on the Z650 scenario. Meanwhile, given the projections for the amount of climate damage, developing countries in which high damage levels are expected also tend to have expected benefits (in terms of reductions in climate damage) in the Z650 scenario, which may incentivize emissions reductions in developing countries. The evaluation of the economic efficiency of the three climate change mitigation scenarios using two analytical methods (cost-benefit analysis and damage-mitigation analysis) shows that the Z650 scenario is the most advantageous of the three scenarios.

The Z650 scenario has a large climate change mitigation effect, and its economic effect is relatively small, making it the most advantageous scenario. Given the current situation, in which post-Kyoto Protocol negotiations are at a stalemate, the Z650 scenario may break through the
current deadlock of international negotiations. However, the differences in the economic effects among the world’s regions (particularly the relatively large GDP losses for some developing countries and the negative net benefit for China) remain a problem, and efforts are needed to reduce regional differences in GDP losses.

The four Asian regions considered in this study differ in terms of the economic influence of CO₂ emissions reductions on their economies, and it is difficult to regard them as an economically unified region. One noteworthy finding is the contrast between China and Japan: China’s GDP loss from emissions reductions is heavy, and climate damage as a percentage of GDP is relatively small, whereas Japan’s GDP loss is small, and its climate damage as a percentage of GDP is relatively large. Thus, in theory, China is reluctant to undertake emissions reductions, while Japan has an incentive to undertake such reductions and wants China to reduce emissions. In such a situation, the transfer of new energy technologies and CCS from Japan to China may be the solution.

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