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ORIGINAL ARTICLE

National implications of a 50% global reduction of greenhouse gases, and its feasibility in Japan

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Abstract This paper considers three questions concerning a low-carbon society. The first is the implication of a 50% reduction in greenhouse gases (GHGs) by 2050. In the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, released in 2007 (IPCC 2007b; http://www.gtp89.dial.pipex.com/chpt.htm), the suggested limit of increase in average worldwide temperatures is 2–3°C above the current level, but is this consistent with a 50% reduction by 2050? Second, when a 50% reduction in global emissions is envisioned, what is the level of reduction needed in Japan? Should the 50% reduction be uniform for advanced industrial countries and developing countries, or differentiated based on a country's emissions? Third, how feasible are emission reduction targets in Japan? Even if the emission reduction target set for each country takes into account climate change impact and equity, whether the target is technically, or socially and economically, acceptable is another matter.

Keywords Climate change · Long-term target · Burden sharing · Low-carbon society · Innovation

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The trend toward a low-carbon society

On 24 May 2007, Shinzo Abe (Prime Minister of Japan at the time) gave a dinner speech at the International Conference on the Future of Asia entitled "Invitation to 'Cool Earth 50': Three Proposals, Three Principles." The speech proposed (1) a long-term target of cutting global emissions of greenhouse gases (GHGs) to half the current level by 2050 as a common goal for the entire world, (2) three principles for establishing an international framework to address global warming from 2013 onwards, and (3) the launching of a national campaign for achieving the Kyoto Protocol target. In particular, the first proposal for cutting GHG emissions by half included the specific suggestions of developing innovative technologies and building a low-carbon society. Furthermore, at the G8 Summit held in early June 2007 in Heiligendamm, Germany, there was agreement among leaders to give serious consideration to reductions of at least 50% by the year 2050.

In Japan, interest in a low-carbon society is growing rapidly. However, this is not merely a recent trend. Various European countries have been considering drastic reductions in their own emissions since about 2000. This has resulted in the release of an energy white paper in the United Kingdom (February 2003) and a report by the research agency of the German government, the German Advisory Council on Global Change (October 2003). Nor has this movement been limited to the national level. In June 2005, the state of California in the United States announced a target of an 80% reduction in CO_2 emissions by 2050 compared with 1990 levels. Moreover, the movement to give these targets legal binding force has grown stronger.

This paper considers three questions that arise from these trends pertaining to a low-carbon society. The first is the implication of a 50% reduction by 2050. In the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, released in 2007 (IPCC 2007b), the suggested limit of increase in average worldwide temperatures is 2–3°C above the current level. But is this suggestion consistent with a 50% reduction by 2050? The second question addressed is, if a 50% reduction of global emissions is envisioned, what is the level of reduction needed in Japan? Should the 50% reduction be uniform for advanced industrial countries and developing countries, or differentiated based on a country's historical or per capita emissions, carbon intensity or other indexes? Third, how feasible are the emission reduction targets in Japan? Even if the emission reduction target set for each country takes into account climate change impact and equity, whether the target is within the range of what is technically, or socially and economically, acceptable is another matter.

Model and calculation of the impact on climate change with a 50% reduction in GHG emissions

To evaluate the mitigating effect on climate change brought about by a 50% reduction in worldwide GHG emissions, this paper uses the AIM/Impact (Policy) model (Hijioka et al. 2005). This model combines GHGs and climate change mechanisms with one regional world macroeconomic model and an energy supply and consumption model, calculating a number of variables so as to maximize the present value of economic welfare. However, Hijioka et al. (2005) take into account only a portion of carbon cycle feedback, so this paper adds the following improvement. First of all, in the AIM/Impact (Policy) model, atmospheric carbon balance is expressed by formula (Eq. 1):

$$\Delta M(t) = \int_{\tau=1850}^{t} E(\tau)G(t-\tau)\mathrm{d}\tau \qquad (1)$$

Here, $\Delta M(t)$ is the change in atmospheric carbon storage in the period t years since the base year (1850), $E(t)$ is carbon dioxide emissions, and $G(t)$ is the impulse response function estimated by Maier-Reimer and Hasselmann (1987). This formulation was established through experiments with oceanic general circulation models and, although it can reflect the increase in the ocean's absorption of CO_2 that occurs with increases in atmospheric CO_2, it cannot reflect the fertilization effect of CO_2 on terrestrial vegetation, or the feedback effects of climate change. Friedlingstein et al. (2003) have proposed the following formula (Eq. 2) as a comprehensive expression of these feedback effects:

$$\begin{aligned} \Delta M(t) &= \int^{t} E(\tau)\mathrm{d}\tau - \Delta F_{\mathrm{L}}(t) - \Delta F_{\mathrm{O}}(t) \\ \Delta F_{\mathrm{L}}(t) &= \beta_{\mathrm{L}}\Delta M(t) + \gamma_{\mathrm{L}}\Delta T(t) \\ \Delta F_{\mathrm{O}}(t) &= \beta_{\mathrm{O}}\Delta M(t) + \gamma_{\mathrm{O}}\Delta T(t) \end{aligned} \qquad (2)$$

Here, $\Delta F_{\mathrm{L}}(t)$ and $\Delta F_{\mathrm{O}}(t)$ are changes in land or ocean storage of CO_2, respectively, β_{L} and β_{O} are land or ocean carbon sensitivity to atmospheric CO_2, γ_{L} and γ_{O} are land or ocean carbon sensitivity to climate change, and $\Delta T(t)$ is temperature increase. Utilizing this method of estimation, $G(t)$ in Eq. 1 roughly indicates ocean carbon feedback caused by atmospheric CO_2 increase. Therefore, combining the feedback mechanism expressed by Eq. 2 with Eq. 1 results in Eq. 3:

$$\Delta M(t) = \frac{1}{1+\beta_{\mathrm{L}}} \int_{\tau=1850}^{t} E(\tau)G(t-\tau)\mathrm{d}\tau - \frac{\gamma_{\mathrm{L}}+\gamma_{\mathrm{O}}}{1+\beta_{\mathrm{L}}}\Delta T(t) \qquad (3)$$

The values for β_{L} and $\gamma_{\mathrm{L}} + \gamma_{\mathrm{O}}$ are taken from experiments using coupled carbon cycle climate model intercomparison project (C4MIP) models (IPCC 2007a). Accordingly, β_{L} is in the range of 0.1–1.2 ($\mathrm{GtC} \cdot \mathrm{GtC}^{-1}$), while the median is 0.6 ($\mathrm{GtC} \cdot \mathrm{GtC}^{-1}$). In addition, $\gamma_{\mathrm{L}} + \gamma_{\mathrm{O}}$ is in the range of -199 to -36 ($\mathrm{GtC} \cdot {}^{\circ}\mathrm{C}^{-1}$), while the median is -96 ($\mathrm{GtC} \cdot {}^{\circ}\mathrm{C}^{-1}$). Figure 1 shows the impact on climate change that will occur with a 50% reduction in CO_2 by 2050, with the median value $\beta_{\mathrm{L}} = 0.6\ \mathrm{GtC} \cdot \mathrm{GtC}^{-1}$ and $\gamma_{\mathrm{L}} + \gamma_{\mathrm{O}} = -96\ \mathrm{GtC} \cdot {}^{\circ}\mathrm{C}^{-1}$ as the reference value for carbon feedback, and 3°C, the best estimate value (IPCC 2007a), as the reference value for equilibrium climate sensitivity. The gases to be reduced are the six gases specified in the Kyoto Protocol and, if 1990 is taken as the baseline year for calculating emissions, the rise in temperature by 2050 will be roughly 2.0°C compared to pre-industrial times (case 2 in Fig. 1). Although this is considerably lower than the 2.7°C of BaU (business as usual), it nevertheless constitutes continued warming. In this calculation, the reductions from BaU begin in 2010, but their effect on limiting temperature does not occur until around 2025. Figure 1 shows the changes only up to 2100, but Table 1 shows temperature increases over the longer term (up to 2200). The table shows that, even with a 50% global reduction in emissions by 2050, we must expect a rise in temperature to about 3°C by 2200 unless further reduction efforts are made thereafter.

What should the emission reduction target be to achieve the objective of climate change mitigation?

The previous section analyzed the effect of a 50% reduction in emissions by 2050 on controlling increases in

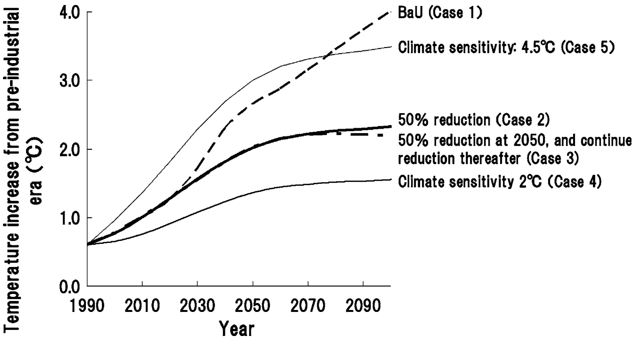


Fig. 1 Impact of a 50% reduction in emission of greenhouse gases (GHG) by the year 2050 on temperature change in the twenty-first century; details of cases are summarized in Table 2

Table 1 Effects of a 50% reduction in emission of greenhouse gases (GHG) by the year 2050 on long-term temperature change

Case	Temperature change (°C)[a]
Case 1 BaU, climate sensitivity 3°C	5.7
Case 2 50% reduction of 1990 emission levels after year 2050, climate sensitivity 3°C	2.8
Case 3 Continuation of case 2 emission reduction speed until year 2100, thereafter 25% of year 1990 emission maintained	2.0
Case 4 Same as case 2 except climate sensitivity is 2°C	1.9
Case 5 Same as case 2 except climate sensitivity is 4.5°C	4.2

Using same socio-economic assumptions as SRES B2. Compliance with Kyoto target in year 2010 is assumed, and reduction will start after year 2010. Controlled gases are those denoted in Kyoto Protocol

BaU Business as usual

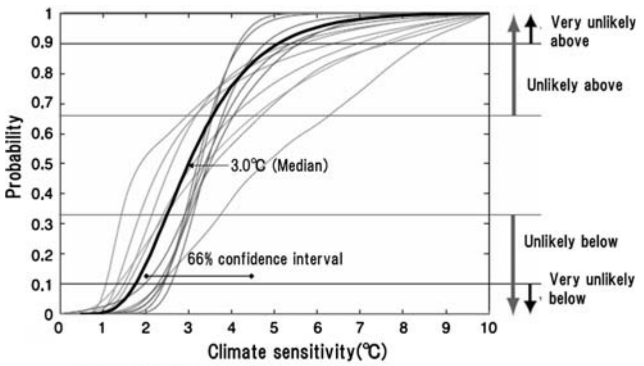
[a] Temperature increase in year 2200 above pre-industrial period

temperature. At the same time, the IPCC Fourth Assessment Report (IPCC 2007b) states: “It is very likely that all regions will experience either declines in net benefits or increases in net costs for increases in temperature greater than about 2–3°C,” taking 2–3°C above 1990 levels as the upper limit of temperature increase in terms of impact. So what is the upper limit for emissions when viewed in terms of this target? This problem is accompanied by a number of uncertainties.

The first is the relationship between emissions and temperature increase. Stated simply, this relationship is as follows. Firstly, (a) GHG emissions increase in concentration in the atmosphere, and (b) these increased concentrations cause radiative forcing. Radiative forcing (c) then causes climate change. Furthermore, (d) climate change exerts an impact on the generation, absorption, and decomposition mechanisms of GHGs, thereby changing the effects of (a) and (b). At each of these stages, uncertainties arise. Of (a) through (d), the stages with the greatest uncertainty are (c) and (d). This article considers the implications of variations in climate sensitivity concerning (c). With regard to (d), we will consider the implications of uncertainties in the carbon feedback parameters of the C4MIP experiments mentioned above.

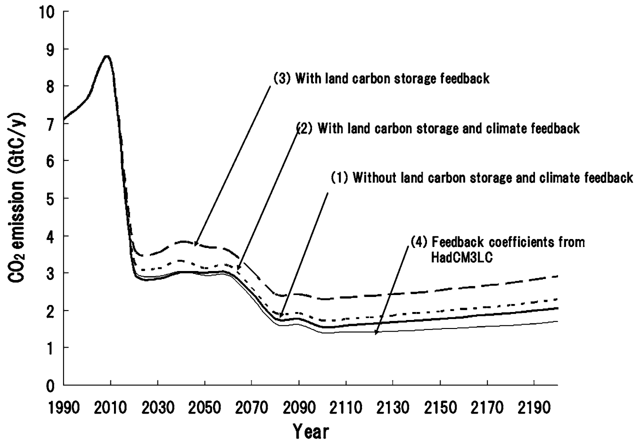
As for the variability in equilibrium climate sensitivity, Fig. 2 shows the probability of climate sensitivity suggested by previous research (IPCC 2007a). Based on this information, the IPCC contends that the sensitivities are likely to be in the range of 2–4.5°C higher, with a most likely value of about 3°C. Figure 2 shows that 3°C is roughly the median, and 2–4.5°C corresponds to a 66% confidence interval. Nevertheless, the question of whether the temperature increase caused by a doubling in CO_2 levels is only 2°C, or whether we must be prepared for 4.5°C, significantly changes the emission reduction target, and how to handle the final uncertainties in setting targets is a major problem. As for the uncertainties of carbon cycle feedback, we examined the influence exerted by the path of CO_2 emissions, changing the values of the parameters of feedback in Eq. 3 with reference to IPCC (2007a, Table 7.4) as mentioned in the previous section. Figure 3 shows the results when the target temperature increase is set at 2°C above the pre-industrial period and equilibrium climate sensitivity is set at 3°C. In Fig. 3, (1) is a calculation where the effects of feedback from terrestrial vegetation and climate feedback are not taken into account ($\beta_L = 0, \gamma_L + \gamma_O = 0$); (2) is a calculation using the median values $\beta_L = 0.6\,\text{GtC·GtC}^{-1}$ and $\gamma_L + \gamma_O = -96\,\text{GtC·°C}^{-1}$; (3) is a calculation where feedback from terrestrial vegetation only is taken into account ($\beta_L = 0.6$ GtC·GtC^{-1} and $\gamma_L + \gamma_O = 0$); and (4) is a calculation using the HadCM3LC parameter values with the strongest positive feedback among the 11 C4MIP models ($\beta_L = 0.6$ GtC·GtC^{-1} and $\gamma_L + \gamma_O = -199\,\text{GtC·°C}^{-1}$). The CO_2 emission path gets smaller in the order (3) > (2) > (1) > (4).

In these calculations, the concentration of atmospheric CO_2 is, at most, 450 ppm and the change in temperature is 2°C or less, explaining why the difference in permissible emissions stays at about 10–20%. However, this range is the result when climate sensitivity is fixed at 3°C. When seeking to determine permissible emissions while taking into account the uncertainty of climate sensitivity when the objective is to stabilize the concentration of atmospheric CO_2, a larger variation arises from climate—carbon cycling feedback. There is only one major drop in the profile of the paths of CO_2 emissions, especially by 2030, due mainly to the current large energy-saving potential coupled with relatively cheap emission reduction costs in



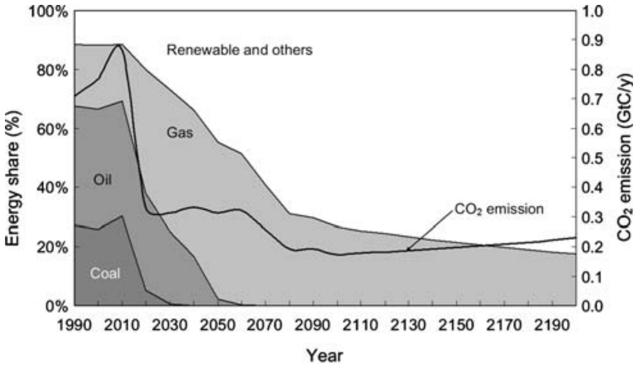
Heavy solid line: adopted probability curve in this paper
Gray line: reported probability in IPCC (2007a)

Fig. 2 Probability of climate sensitivity, added to Box 10.2, Fig. 2 of IPCC (2007a)



Target temperature = 2℃, Climate sensitivity =3℃, Discount rate = 1%/y
Land carbon storage sensitivity = 0.6 GtC·GtC^{-1}(=1.3 GtC/ppm) in (2), (3) and (4)
Carbon storage sensitivity to climate = -96 GtC/℃ in (2), -199 GtC/℃ in (4)

Fig. 3 Impact of carbon cycle feedback on CO_2 emission paths



Target temperature = 2℃, Climate sensitivity = 3℃, Discount rate = 1%/y
Land carbon storage sensitivity = 1.4 GtC/ppm
Carbon storage sensitivity to climate = 96 GtC/℃

Fig. 4 Energy supply share of 2°C target case

developed countries. We cannot expect this rapid decrease in global emissions to continue after 2030. Emissions increase slightly from around 2040–2060, to fall again as a result of economic rationality factored into the model, which causes a drastic change in the energy mix during this period as shown in Fig. 4. A gradual increase in CO_2 emissions after 2100 appears with a time lag of several decades due to the effect of reduced emissions of long-lived GHGs such as chlorofluorocarbons during the twentieth and twenty-first centuries.

Bearing these factors in mind, this article examines the validity of the emission reduction targets by (1) stochastically expressing emission reductions by 2050, and their effects on suppressing temperature increase over the long term, focusing on the uncertainties at stage (c) indicated above; and (2) comparing these effects with the proposed values for the upper limit of increased temperature. Compared with climate sensitivity, little information is available about the uncertainties involved in carbon cycling feedback; therefore, taking into account that, even when $\beta_L = 0$ and $\gamma_L + \gamma_O = 0$, there is no significant difference from emissions with a median value, this paper bases its calculations only on $\beta_L = 0$ and $\gamma_L + \gamma_O = 0$. Figure 5 shows the results for (1). Using the AIM/Impact (Policy) model mentioned above, this shows emissions trajectories with the value for temperature increase above pre-industrial levels up to 2200 below a fixed value with a certain nonexceedance probability (shown on the horizontal axis). The necessary rate of reduction by 2050 calculated from the trajectory is shown on the vertical axis, with 1990 as the baseline. The rate of reduction in this figure is the rate of reduction of the six gases specified in the Kyoto Protocol, and the uncertainties (b) concerning climate sensitivity are expressed by the probability function indicated by the thick line in Fig. 2. Therefore, in order to keep the temperature increase to 2°C or less with a nonexceedance probability of 90% or more, it will be necessary to make reductions of 80% or more by 2050. With a nonexceedance probability of 50% or more, the reduction rate is 60% or more, and with a nonexceedance probability of 10% or more, emissions must be kept below 1990 levels. As an extension of (2), Table 2 shows the nonexceedance probability corresponding to the proposed values for upper limits of temperature increase based on this figure. The upper limits for comparison are 2.6 and 3.6°C above pre-industrial times, corresponding to 2 and 3°C above the present, and 2°C above pre-industrial times as consistently advocated by the EU. Table 2 shows that, to tolerate 2°C (at which broad changes begin to occur in ecosystems) with a nonexceedance probability of 33–66% or more, reductions of 40–80% compared to 1990 are necessary and, in order to achieve a nonexceedance probability of 66% or more for 2–3°C above the current level cited by the IPCC, reductions of 53% or more are called for. In other words, a 50% reduction by 2050, with a baseline of 1990, can be interpreted as a rate of reduction at which temperature rise

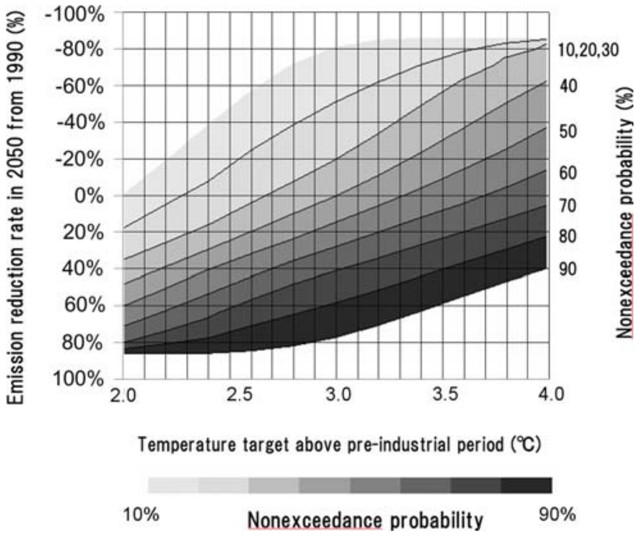


Fig. 5 Relation between probability of temperature target compliance and emission reduction rate in the year 2050

can likely be kept to less than 2–3°C above the current level ("likely" is the expression used in the IPCC Fourth Assessment Report). However, dependence on the nonexceedance probability of the required rate of reduction is extremely high, and the possibility that these values may change significantly with future advances in science must be borne in mind.

Japan's emission reduction target

So far we have discussed a target of reducing worldwide emissions by half. But how are these reductions to be allocated to each country? This problem is referred to as "burden sharing," and it is the subject of intense debate from the standpoints of equity, responsibility for emissions, reduction capability and so on (e.g., IPCC 2007c). In stressing the importance of equity, there have been proposals for allotting emissions per capita so that the value is the same irrespective of the individual's country or region (Meyer 2000). In that case, the permitted emissions for each country after attainment of the allotted targets will be worldwide emissions multiplied by the ratio of population (national population/world population). However, there are many problems with the per-capita method; for example, countries with growing populations have an advantage, and there is no direct incentive to improve energy efficiency. In complete opposition to this approach are allocation indexes based on emission intensity and the concept of improvement velocity, which takes the (GHG emissions/GDP) ratio of each country in the target year (2050) as an index. These may become common values for all countries.

Table 2 Probability of temperature target compliance and emission reduction rate in the year 2050

Temperature target (°C)[a]	Probability of compliance				
	10%	33%	50%	66%	90%
2.0[b]	0	40	60	78	86
	−4	43	64	87	97
2.6	−56	10	32	53	85
	−64	8	34	56	95
3.6	−85	−54	−13	16	55
	−79	−63	−21	15	59

[a] Temperature targets are increases above pre-industrial period and reduction rates are based on 1990 emissions

[b] Upper row corresponds to six gases in Kyoto Protocol, lower row is CO_2

Table 3 shows the necessary rates of reduction, calculated using these methods, for Japan and the other main countries and regions of the world. For Japan, with the equal per-capita emissions method the rate of reduction is 85% with a 1990 baseline; with the equal emission intensity method it is 35%, and with the equal velocity of emission intensity reduction method it is 91%. The emission intensity method depends heavily on estimates of the GDP of each country in 2050. This paper uses a SRES scenario and nine types of estimate for GDP made by a number of agencies thereafter; 35% and 91% are the respective median values for Japan, with ranges (in parentheses) of −23 to 44% and 87 to 93%. For other countries, according to the per-capita emissions method the rate of reduction is 89% for America, 74% for Western Europe, 34% for China, −97% (i.e., a 97% increase) for India, 87% for all countries in Annex B, and −2% for other countries. There are conspicuous differences between the values for developed countries and for developing countries. On the other hand, with equal emission intensity the differences are not so big, with Annex B countries at 63% and other countries at 35%. With either method, the variation in the rate of reduction differs for each country and region, but can be roughly divided into six groups (Fig. 6). These are: (1) CIS and Eastern Europe with an 80% rate of reduction regardless of the method used, (2) Western Europe, North America, etc., with a lower rate under equal emission intensity but still a 40% or higher rate of reduction, (3) Japan and Korea, with a 40% or lower rate under equal emission intensity and 75% or more with equal per-capita emissions, (4) China and the Middle East with a rate of about 30% regardless of the method used, (5) Central and South America with an equal per-capita emissions rate of 20% or less, but a rate 10% higher with equal emission intensity, and (6) India, Africa, etc., which can increase emissions under equal per-capita emissions.

Table 3 shows the results of calculations based on a simple allocation index, which envisions the smoothing of unfair burdens in reductions by 2050 or before. The significant feature of these estimates is that whatever the country or region of the world, whether current emissions are heavy or light, they impose common permissible emissions either per capita or per unit of economic activity. While this approach is simple and, to an extent, persuasive, it has significant problems from the standpoints of economic efficiency and ethics. Furthermore, some countries do not meet permissible emissions levels because it is likely that significant unfairness will arise concerning the cost of reduction. At present, many amendments are being proposed to ameliorate these problems, and will have to be taken into consideration in applying this method in future.

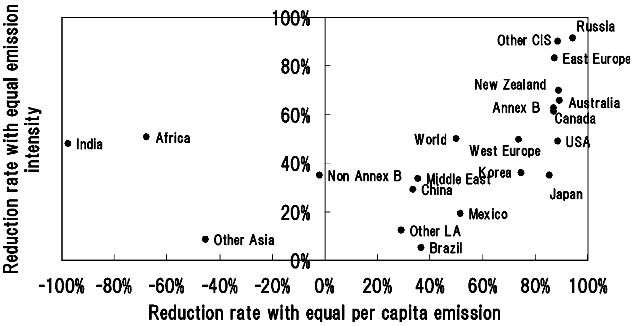


Fig. 6 Relation of reduction rates between different sharing schemes

Design for a low-carbon society

Table 3 shows 35% and 85% (1990 baseline) as the rates of reduction by 2050 for Japan according to the equal emission intensity and equal per capita methods, respectively. This section examines the possibility of achieving a low-carbon society in Japan with reference to these rates. As a working index, and taking as a reference studies in Europe and elsewhere, a 70% reduction was set as a median value between 35 and 85%.

A reduction of 70% is by no means a simple objective to attain. The speed of transformation of social systems and energy systems must be increased several times over. To put this in perspective, we will look at some examples of reductions in CO_2 emissions. A 70% reduction with a 1990 baseline is equivalent to a 73% reduction with a 2000 baseline. Thus, to achieve such as reduction in 50 years requires a speed of reduction of $1-(1-0.73)^{1/50}=2.6\%/$year or more. We will call this speed of reduction

Table 3 Reduction rates by country for world 50% emission reductions in the year 2050. Based on projections of GDP in 2050. We used six SRES scenarios of AIM (Hijioka et al. 2005), A2r scenario (Grubler et al. 2007), Wilson and Purushothaman (2003), and Poncet (2006)

Country/region	Equal per capita		Equal emission intensity	Equal velocity of intensity reduction
	Emission (million tC/year)	Reduction ratio based on 1990 (%)	Reduction ratio based on 1990 (%)	Reduction ratio based on 1990 (%)
United States	207	89	49 (2–63)	85 (75–88)
Canada	22	87	61 (33–65)	87 (77–89)
Japan	53	85	35 (−23 to 44)	91 (87–93)
Australia	14	89	66 (44–73)	80 (65–83)
New Zealand	3	89	70 (51–75)	83 (70–87)
Western Europe	343	74	50 (37–62)	88 (87–92)
Eastern Europe	49	87	83 (75–92)	72 (64–82)
Russia	55	94	91 (75–94)	69 (60–77)
Other CIS	72	89	90 (87–93)	59 (49–67)
South Korea	22	75	36 (−104 to 75)	68 (62–78)
China	728	34	29 (−69 to 46)	−1 (−46 to 12)
India	852	−97	48 (−168 to 66)	−36 (−57 to 2)
Other Asia	644	−45	8 (−27 to 49)	−8 (−15 to 22)
Mexico	68	52	19 (−13 to 59)	57 (44–60)
Brazil	130	37	5 (−23 to 80)	40 (33–49)
Other Latin America	197	29	12 (−12 to 71)	40 (38–44)
Middle East	232	35	34 (20–84)	26 (22–48)
Africa	1,028	−68	51 (17–92)	−18 (−49 to 37)
World	4,719	50	50 (50–50)	50 (50–50)
Annex B	705	87	63 (37–67)	82 (78–84)
Non-annex B	4,014	−2	35 (29–66)	12 (9–16)

a ($<-2.6\%$, with increase as a positive value). The value a can be shown as the sum of the rate of change in the effectiveness of reducing carbon intensity through carbon capture and storage (CO_2 emissions/CO_2 production) (b), the rate of change in carbon intensity (CO_2 production/primary energy) (c), the rate of change in energy intensity (primary energy/activity) (d), the rate of change in activity per capita (e), the population rate of change (f), and confounding factor (g). As a mathematical equation, this identity is written as follows:

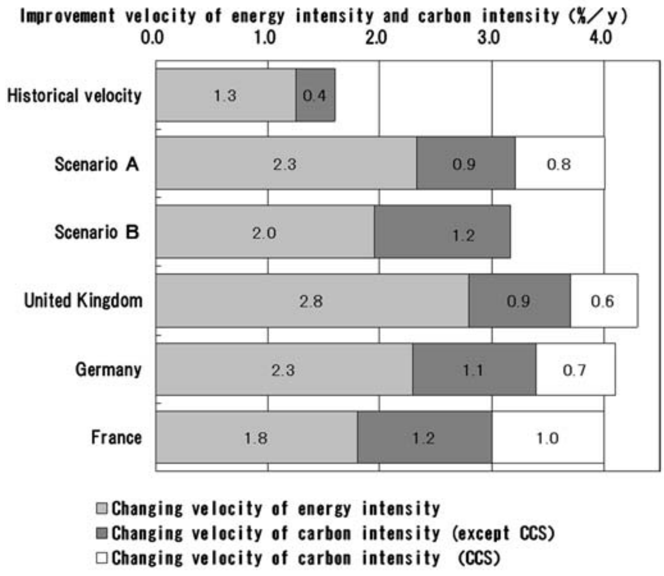
$$a = b + c + d + e + f + g \tag{4}$$

Taking GDP as the index of activity, if the GDP growth rate per capita in the 50 years to 2050 is 1–2% (=e), and the rate of population change is −0.5% per year (=f) then, based on the relationship described above, with $-2.6 > b + c + d + 1\text{–}2 \quad -0.5 + g$, and $g = 0$, the result is $b + c + d < -4.1$ to -3.1 (%/year). However, Japan’s record for the last 40 years and for the last 10 years has been about −1%/year. To put this another way, in addition to the earlier pace of reduction, it is necessary to accelerate the pace of reduction by a further ~2–3%/year. Figure 7 shows both Japan’s low-carbon scenario described below and examples of various European countries mentioned at the beginning of this paper, and it indicates that $c + d + e + f = 3\%$/year or more, plus about ~0.5–1%/year through the introduction of carbon capture and storage, is required.

If the effects of implementing carbon capture and storage are excluded, improvement in carbon intensity (c) depends on how far it is possible to replace energy with low-carbon sources. This is a question of how quickly technological innovation in new energy options, and replacement infrastructures to supply them, can progress. As can be seen from Fig. 7, this is about 1%/year. Thus, a significant issue is whether there is scope for accelerating the improvement velocity (d) of energy intensity. The definition of energy intensity used above is (primary energy/GDP), but this is a product of (energy services/GDP) and (primary energy/energy services). The first term is concerned exclusively with the efficiency of energy services, while the second term is concerned with the efficiency of energy technology (facilities and equipment). The former depends on transformations in industrial structure, land use and urban structure, and lifestyle, while the latter depends on the development and adoption of energy conservation technologies. Thus, in order to achieve sweeping reductions, it is necessary to improve the efficiency of energy services as far as possible, including a wide range of social reforms. A plan must be designed that can achieve intensity reductions of 2–3%/year in total (efficiency improvements of 3- to 5-fold in 50 years) with the development and adoption of energy-saving technologies to cover deficiencies.

As a signpost for different social trends, and with the goal of reducing CO_2 emissions by 70% by 2050 compared to 1990, we designed two social scenarios (“2050 Japan Low-Carbon Society” Scenario Team 2007). For this task we first used a multi-sector computable general equilibrium model, quantitatively depicting a social and economic macroframe that takes into account changes in envisioned social trends, demand and supply of goods and services, advances in production technology, final demand, trade structure and so on. Next, with an

Fig. 7 Improvement velocity for realizing a low-carbon society (from 2000 to 2050)



(Historical velocity) IPCC, 2001
(United Kingdom) Dept. of Trade and Industry (DTI) in UK, 2003; Future Energy Solutions: Options for a low carbon future, DTI. Economic Paper No. 4., DTI, London.
(Germany) Deutscher Bundestag in Germany, 2002; Enquete Commission on Sustainable Energy Supply Against the Background of Globalisation and Liberalisation: Summary of the Final Report.
(France) Interministerial Task Force on Climate Change (MIES) in France, 2004; Reducing CO2 emissions fourfold in France by 2050 - Introduction to the debate.

engineering bottom-up model, we calculated the energy services, the amount of energy, and the stock of equipment and facilities required to maintain these social and economic systems. We based the outlook for technological progress on information taken from various future technological scenarios and hearings with experts. Table 4 is an outline of the social and economic indicators, energy consumption and CO$_2$ emissions in these two scenarios. Scenario A is a technocentric and urban-centered scenario (nicknamed "Doraemon"), while Scenario B is a slower, more ecocentric scenario (nicknamed "Satsuki and Mei"). In both scenarios, reductions of 70% are achieved, but the specific means of reduction differ for each. As shown in Table 4, the average economic growth rate in Scenario A is 1.5% per year, higher than the 0.6% for Scenario B. The amount of energy services, such as energy-intensive goods production and freight transport, is affected by the trend toward dematerialization and hence does not change as much as the GDP, although in Scenario A the amount of energy services increases (whereas it decreases in Scenario B). In both scenarios, there is an active movement toward a highly energy-efficient urban structure and low-carbon energy, with widespread adoption of energy-saving equipment, but Scenario A involves faster technological innovation and adoption, whereas Scenario B is designed to depend on carbon intensity improvements through a switch to biomass. In order to achieve the emissions target, Scenario A envisions the capture and storage of carbon dioxide (CCS) emitted in thermal power generation and in the production of hydrogen.

In Fig. 7, energy intensity is expressed as a single item. However, if items related to energy service efficiency and to technology are calculated separately, the results for energy service efficiency and technology efficiency in Scenario A is 1.4%/year and 0.9%/year, respectively, while in Scenario B they are 0.8%/year and 1.1%/year. It is clear that both scenarios depend on social and structural transformations such as changes in industrial structure, land use and urban structure, and lifestyle, resulting in improvements in energy service efficiency of about 1%/year.

Table 4 Seventy percent reduction societies in the year 2050 (percentages compared with the year 2000 in parenthesis)

Indicator	Unit	2000	2050	
			Scenario A	Scenario B
Population	Million	127	94 (74%)	100 (79%)
Households	Million	47	43 (92%)	42 (90%)
Number of average households	Person	2.7	2.2	2.4
GDP	Trillion yen	519	1,080 (208%)	701 (135%)
Share of gross domestic product				
Primary industry	%	2%	1%	2%
Secondary industry	%	28%	18%	20%
Tertiary industries	%	71%	80%	79%
Floor space of business office	Million m^2	1,654	1,934 (117%)	1,718 (104%)
Passenger transportation volume	Billion passenger km	1,297	1,045 (81%)	963 (74%)
Private car	%	53%	32%	51%
Public transportation	%	34%	52%	38%
On foot/bicycle	%	7%	7%	8%
Volume of freight transportation	Billion tonne km	570	608 (107%)	490 (86%)
Industrial production indicator		100	126 (126%)	90 (90%)
Iron and steel production	Million tonne	107	67 (63%)	58 (54%)
Ethylene production	Million tonne	8	5 (60%)	3 (40%)
Cement production	Million tonne	82	51 (62%)	47 (57%)
Paper production	Million tonne	32	18 (57%)	26 (81%)
CO$_2$ emission	Million tonne			
Generation		311.5	127.7 (41%)	85.2 (27%)
Carbon capture and storage			42.4	0.0
Emission (compared with 1990)		311.5	85.3 (27%)	85.2 (27%)
Energy	MTOE		−30%	−30%
Primary		523.5	334.1 (64%)	264.0 (50%)
Final consumption		380.2	225.8 (59%)	209.3 (55%)
Fossil energy dependency ratio		80.0%	59.8%	51.0%

Whatever the scenario, serious and systematic initiatives must be started immediately

The analysis above shows that making a sweeping reduction of 70% in Japan's emissions by 2050 is impossible through technological improvements alone. Nonetheless, the direct costs required, calculated at about ¥10 trillion per year ("2050 Japan Low-Carbon Society" Scenario Team 2007), are not beyond the bounds of economic possibility.

However, in order to undertake serious initiatives toward a low-carbon society, in addition to the social and energy visions depicted in Scenarios A and B, it is necessary to draw up a roadmap for achieving this society. While we must make adaptive improvements to this vision in response to relevant scientific developments and advances in technology, we must also take the following initiatives promptly and systematically:

1. Structural changes in industry, land, and cities; infrastructure upgrades and development; investment, adoption and use of energy conservation and low-carbon energy technologies
2. Economic and systemic measures in support of these transformations

Since this is a long-term issue, there is a tendency to view it as non-urgent, but the longer the actions are delayed, the lower the possibility of solving the problem. A coordinated response is necessary across all sectors of society under strong leadership, based on a firm recognition of the necessity of establishing a low-carbon society. In order to achieve this, more research of the kind presented in this paper is required.

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