How to Approach Asian Low-Carbon Societies?

Yuzuru MATSUOKA[1*], Mikiko KAINUMA[2], Junichi FUJINO[2] and Tomoki EHARA[3]

[1]*Graduate School of Engineering, Kyoto University*
Kyoto daigaku-Katsura, Nishikyo-ku, Kyoto 615-8540, Japan
[2]*National Institute for Environmental Studies (NIES), Japan*
[3]*E-KONZAL, Japan*
**e-mail: matsuoka@env.kyoto-u.ac.jp*

Abstract

In order to achieve global climate stabilization targets, it is an urgent task to develop low-carbon societies in Asia, as Asian countries will account for almost half of both the global population and GHG emissions by 2050 in the business-as-usual scenario. It is necessary to identify leapfrog development pathways to realize a shift to low-carbon emissions and low resource consumption while simultaneously improving people's daily lives through economic growth.

This paper presents the GHG reductions in Asia required for achieving climate stabilization based on three different GHG emission allocation schemes to reduce global emissions by half by 2050 compared with the 1990 levels. Next, it describes the current climate change mitigation targets and actions proposed by individual countries in Asia, as well as the GHG emission reductions required in order to achieve these national targets. The gaps between the emission reduction requirements and the current targets proposed by each country are then identified. In order to bridge the gaps between the situation of the present national targets and the global GHG reduction targets for 2050, it will be necessary to make significant changes to society itself. Finally, the paper outlines the approach taken by the authors' team to design pathways towards low-carbon societies in Asia.

Key words: AIM, Asia, climate change, low-carbon society, mitigation

1. Introduction

The Copenhagen Accord adopted at COP15 confirmed in accordance with the 4th IPCC Assessment Report that, in order to avoid dangerous anthropogenic interference with climate systems, it will be necessary to limit the global temperature increase to within 2°C compared with the pre-industrial level (UNFCCC, 2010a). Subsequently, the Cancun Agreements at COP16 explicitly referred to the importance of a paradigm shift towards building a low-carbon society that offers substantial opportunities and ensures continued high growth and sustainable development (UNFCCC, 2010b). In these latter agreements, emphasis was also placed on 'Equitable Access to Sustainable Development'. In accordance with this viewpoint, in the present study we examined some of the consequences of equitable access to allowable GHG emission capacity.

In order to achieve the global climate target, it is an urgent task to develop low-carbon societies in Asia, as Asian countries will account for almost half of both the global population and GHG emissions by 2050 in the business-as-usual (BAU) scenario. It is therefore necessary to identify leapfrog development pathways in order to realize a shift to low-carbon emissions and low resource consumption while simultaneously improving people's daily lives through economic growth. Moreover, the following two specific characteristics of this region's scenarios should be taken into account: (1) the diversity of the Asian region, and (2) the multiple transitions (*e.g.*, demographic, income, technological, infrastructural and institutional) that Asian countries will have to pass through. Based on these viewpoints, the linkage to sustainable development and the transition to a low-carbon society are both feasible and essential.

What is a low-carbon society? Skea and Nishioka (2008) define such a society as one that takes actions that are compatible with the principles of sustainable development, ensuring that the development needs of all groups within the society are met and that an equitable contribution is made towards global efforts to stabilize the atmospheric concentration of CO_2 and other greenhouse gases at a level that will avoid dangerous climate change, through deep cuts in global emissions.

Many studies have been carried out to analyze the feasibility of meeting climate stabilization targets. The IEA released a message in *Energy Technology Perspectives* in 2008 stating that to meet the challenges of energy security and climate change as well as the growing energy needs of the developing world, a global energy technology revolution would be essential. Then, in 2010, it presented more practical information and tools to help kick-start the transition to a more secure, sustainable and affordable energy future (IEA, 2008 and 2010). Many other studies have also analyzed portfolios to meet climate stabilization targets (IEA, 2011; Akashi *et al*., 2012; Fujimori *et al*., 2013; Kainuma *et al*., 2013). The Energy [R]evolution scenario and the Advanced Energy [R]evolution vision developed by Greenpeace (Krewitt *et al*., 2010), as well as the WWF's ECOFYS scenario (Deng *et al*., 2011), explore the feasibility of achieving the global target by introducing renewable energy.

Although stabilization pathways and their feasible mitigation roadmaps can be proposed, without initiatives by stakeholders, including national and local governments, business communities and citizens, climate stabilization will not be achieved. There are still wide gaps between the required GHG reductions to meet the 2°C target and the consequences of emission reduction targets being considered in each country in Asia (Kawase & Matsuoka, 2013).

This paper presents the required GHG reductions in Asia to achieve climate stabilization based on three different GHG emission allocation schemes to reduce global emissions by half by 2050 compared with the 1990 level. The three allocation schemes are described in Section 2. Next, current climate change mitigation targets and actions proposed by individual countries in Asia are described, followed by the GHG emission reductions required to reach these national targets. The gaps between the emission reduction requirement and the current target proposed by each country are then identified. In order to bridge the gap between the present efforts and the global GHG reduction targets for 2050, it will be necessary to make significant behavioural and institutional changes in society. Finally the approach taken by the authors' team to designing pathways towards low-carbon societies in Asia is outlined.

2. Required GHG Reductions in Asia to Meet Global Mitigation Targets

Participants at the COP16 UNFCCC conference in Cancun in 2010 recognized that countries should take urgent action to limit the increase in global average temperature to a maximum of 2°C relative to the pre-industrial level (UNFCCC, 2010b), although the policy-makers in Cancun did not specify a reduction target for each country to achieve such climate stabilization.

There are many uncertainties in estimating the volume of anthropogenic GHG emissions that could be released into the atmosphere while limiting the temperature increase to within 2°C, including the time trajectories of emission pathways, the composition of GHG emissions, the climate system, the carbon cycle response to emissions, and many other factors. Such uncertainties can be specified in terms of the probability of the temperature remaining below a given target (Matsuoka *et al*., 2008). Rogelj *et al.* (2011) have reported that total global GHG emissions in 2050 with a 'likely' (greater than 66% probability) chance of limiting the temperature rise to below 2°C indicate a median reduction of 45% (range 35%-55%) below the 1990 level.

The G8 leaders at Heiligendamm, Germany, in 2007 confirmed that GHG emissions should be reduced to half the current levels by 2050 and agreed to seek to share and adopt this goal with all Parties to the UNFCCC at the Toyako G8 Summit in Japan in 2008.

In this paper, the target for global GHG reduction is set at half the 1990 level by 2050. The GHG species considered are restricted to the gases specified in the Kyoto Protocol (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6). It is assumed that countries can achieve their reduction targets by 2020 if they have submitted their targets to the UNFCCC following the Copenhagen Accord. After 2020, it is assumed that countries will aim to reduce their emissions by the amounts specified in their respective allocation schemes to achieve half the 1990 level of global emissions by 2050.

The following three allocation schemes are considered (Kawase & Matsuoka, 2013):

(a) Per capita emissions to be the same after 2050 across countries (pCAP).
(b) Per GDP emissions to be the same after 2050 across countries (pGDP).
(c) Cumulative national emissions from 2020 to 2050 divided by the national population to be the same across countries (pCUM).

The required emission reductions by the year 2050 are estimated based on these three schemes, which reflect equity considerations.

In the case of pCAP, the allocated emissions of a country would be equal to global emissions multiplied by the population ratio of the country in question. Countries expected to have population increases would have a less severe emissions target than countries where the population is decreasing. As this scheme does not take economic activity into account, it lacks economic rationality.

pGDP is a measure that equalizes emissions per unit of GDP. While it significantly lessens economic partiality, it has drawbacks from the standpoint of fairness of per capita emissions, and there is a problem of the allocation varying significantly according to future GDP estimations, which are more difficult to quantify than population.

As pCUM considers cumulative emissions, it may be more acceptable than pCAP, which only takes population into consideration when determining emissions allocations, and pGDP, which only takes economic activity in 2050 into consideration. However, it is more difficult to estimate pCUM than the other schemes, as it has a larger number of factors requiring clarification such as the starting year of accumulation and the population to be considered as the denominator. In this paper, pCUM is calculated as the cumulative emissions from 2020 to 2050 divided by the cumulative population in the corresponding period; *i.e.*, from 2020 to 2050. The year 2020 is taken as the starting year. This is because, if the starting year is set at before 2020, some countries will have to curtail their emissions immediately and start absorbing GHGs, or buy a larger amount of emissions allowances than the amount of emissions, which is neither realistic nor recommended as a first choice.

Table 1 shows the required GHG reduction ratios in 2050 compared with the 2005 level in several countries in Asia and some regions of the world. The assumptions behind Table 1 are described in Kawase and Matsuoka (2013). This table shows the required ratio of reduction in 2050 compared with the 2005 level, so the global ratio of GHG reduction in 2050 is 58%, which is somewhat higher than the 50% target compared with the 1990 level. The reduction ratios of the Annex I countries in 2050 increase in the order of pGDP, pCAP, and pCUM, to 46%-58%, 83%, and 95%, respectively, while those of the non-Annex I countries increase in the order of pCUM, pCAP, and pGDP, to 34%, 42%, and 57%-65%, respectively.

Although the ratios of the Asian region excluding Japan show a similar tendency to those of the non-Annex I countries in the case of pCAP and pGDP, Asia has a higher ratio of pCUM than the non-Annex I countries, with values of 43% and 34%, respectively. This is mainly because the economic growth rates of Asian developing countries, especially China, are projected to be higher than those of other developing countries over the next few decades, necessitating higher reduction ratios to equalize cumulative emissions per capita by 2050.

Under the pCAP scheme, Japan and Korea have to make reductions of more than 80%. They are followed by Malaysia, China, and Thailand, with reduction ratios of more than 60%. The reduction ratios are estimated to be 12% and 15% for Vietnam and Indonesia, respectively, while India is allowed an increase of 51%. Overall, these are very severe reduction requirements for emerging countries such as China, Malaysia and Thailand as well as developed countries such as Japan.

The reduction ratios under the pGDP scheme differ from those under the pCAP. The reduction ratios under pGDP decrease for countries and regions with high GDPs per capita and increase for low-income countries and regions compared with those under pCAP. Although there are some differences among regions and countries, most countries would have to prepare for reductions of about 60% (*e.g.*, 58%-63% for the Asian region excluding Japan).

The reduction ratios under the pCUM scheme are very high for countries with high expected per capita emissions in 2020 and low population growth rates from 2020 to 2050 such as Korea, China, Japan and Malaysia, whereas that of India is very low, reflecting the lower economic growth rate and higher population growth rate of India in comparison with, for example, China.

Whichever reduction scheme is adopted, the conditions for achieving the goal are very severe. For example, Japan's required reduction ratio would be 83% under pCAP and that of Asia, about 60% under pGDP, both of which are very stringent targets. Will such large reductions be possible? In order to clarify this, emissions are decomposed using the Kaya identity as shown in Equation (1). GHG emissions are decomposed by the emissions intensity of energy, energy intensity of GDP, per capita GDP, and population. Taking the logarithmic derivative of both sides, the rate of emissions change (ΔEmissions / Emissions) is expressed with the sum of the changes in the factors as shown in Equation (2). The use of this identity (summing equation) makes it easier to explain the contribution of emissions increases than the use of a multiplication equation.

$$\text{Emission} = \frac{\text{Emission}}{\text{Primary energy consumption}} \times \frac{\text{Primary energy consumption}}{\text{GDP}} \times \frac{\text{GDP}}{\text{Population}} \times \text{Population} \tag{1}$$

$$\underbrace{\frac{\Delta\text{Emission}}{\text{Emission}}}_{(-e)} = \underbrace{\frac{\Delta\left(\frac{\text{Emission}}{\text{Primary energy consumption}}\right)}{\left(\frac{\text{Emission}}{\text{Primary energy consumption}}\right)} + \frac{\Delta\left(\frac{\text{Primary energy consumption}}{\text{GDP}}\right)}{\left(\frac{\text{Primary energy consumption}}{\text{GDP}}\right)}}_{(-x)} + \underbrace{\frac{\Delta\left(\frac{\text{GDP}}{\text{Population}}\right)}{\left(\frac{\text{GDP}}{\text{Population}}\right)}}_{(g)} + \underbrace{\frac{\Delta\text{Population}}{\text{Population}}}_{(p)} + \text{Residual} \tag{2}$$

Based on Equation (2), the meaning of an 83% reduction in Japan can be explained as follows. The left-hand side of the equation, (–*e*), shows that a rate of change of $(1 - 0.83)^{1/45} - 1 = -3.9\%$ per year would be necessary as an annual percentage rate to achieve a

Table 1 Required GHG reduction ratios in 2050 compared with the 2005 level.

Burden sharing scheme	Required GHG reduction ratio compared with the 2005 level											
	World	Annex I	Non-Annex I	Asia except Japan	China	India	Indonesia	Japan	Korea	Malaysia	Thailand	Vietnam
pCAP	58	83	42	42	68	-51	15	83	85	67	61	12
pGDP	58	46-58	57-65	58-63	59-61	41-53	67	18-43	49-57	57-60	54-65	60-74
pCUM	58	95	34	43	97	-100	49	94	99	93	85	32

Negative values show an increase of allowable emissions compared with the 2005 level.
Values of Indonesia and Malaysia exclude emissions/sinks of LULC sectors.
Ranges of pGDP correspond to the ranges of GDP projections in the references (Kawase and Matsuoka, 2013).

reduction of 83% compared with the 2005 level over the 45 years from 2006 to 2050. On the right-hand side, the fourth term of the equation, (p), indicates the population, which is estimated to be 108.5 million in Japan in 2050. Its annual rate of decrease is about 0.3% (UN, 2011). The GDP per capita, (g), which is the third term of the equation, is estimated to increase by 0.7% to 0.9% annually (Kawase & Matsuoka, 2013).

Using these numbers, the sum of the first and second terms of the equation, ($-x$), becomes -4.2 to -4.4, which signifies that the annual decrease in the emissions intensity of GDP (the emissions intensity of energy multiplied by the energy intensity of GDP) will be 4.2% to 4.4%.

As Japan's annual rate of decrease (x) has been at most 1% over the last few decades, the rate of 4.2% to 4.4% would be a difficult target to achieve with only a slight improvement in the efforts to date. A reduction in the first term on the right-hand side, the carbon intensity of energy, would require low-carbon energy sources if the introduction of carbon capture and storage is not considered. Historical data show that the likely rate of reduction will be no more than about 1% per year and it will take time to introduce low-carbon energy sources, considering the availability of new supply technologies and the timing of replacement of energy infrastructure. This means that improving the energy intensity of GDP, which is the second term of Equation (2) (energy consumption/GDP) is important in the early stages of planning for a low- carbon society.

If the energy intensity of GDP is divided by the energy service intensity of GDP (energy services/GDP) and the energy intensity of services (energy consumption/energy services), the former is concerned with the efficiency of energy services, while the latter is concerned with the efficiency of energy technology (facilities and equipment). The former depends on industrial structure, land use, urban structure and lifestyles, while the latter depends on the development and deployment of energy conservation technologies. When this factor is broken down in this way, the roles of energy services and technologies become clear. Generally, it is difficult to speed up the development and widespread deployment of energy conservation technologies by more than about 1% to 2% per year. The remainder should be accomplished by improving the efficiency of energy services, including wide-ranging social reforms and the construction of low-carbon infrastructure. Moreover, these efforts must be assiduously continued for the next 40 years.

Table 2 shows the required annual reduction rate of emissions (e), annual per capita GDP growth (g), annual population growth (p), and required annual reduction rate of emissions intensity of GDP (x) in Japan, China and India under the pCAP scheme and in Asia, excluding Japan, under the pGDP scheme. According to Equation (2), the required annual reduction of the emissions intensity of GDP is calculated by $x = e + g + p$. The values for the required annual reduction of emissions (e) are taken from Table 1. The annual changes in GDP (g) and population (p) are estimated based on past studies. The last column of Table 2 shows the historically observed reduction rates of emissions intensity of GDP (x_0) from 1990 to 2008. These numbers show that reformation of energy systems, including reorganization of social and economic structures, is required at an extraordinary rate, ranging from 7%-9% in China and 4%-6% even in India. These rates of improvement in energy systems are far from what has ever been achieved anywhere. The realization of low-carbon societies poses such a challenge in emerging countries.

3. Present Climate-change-mitigation Targets and Actions in Asia

The importance placed on climate-change-mitigation actions has been increasing in many countries in Asia. Although each country has different priorities in terms of sectors and technologies to achieve the target, most Asian countries have set their own targets for GHG emissions or relevant indicators including emissions intensity or energy efficiency. In this section, Asian targets and actions towards low-carbon transitions are reviewed and summarized.

Japan, the only Annex I country in the Asian region, has pledged to reduce its GHG emissions by 25% by 2020 compared with the 1990 level under the conditions of the appropriate international framework (UNFCCC, 2009a). Since the emissions target is set in reference to the level of emissions in 1990, the maximum emissions from Japan in 2020 can be fixed. Japan has also indicated its long-term reduction target of an 80% reduction in domestic emissions by 2050 (Ministry of Foreign Affairs, Japan, 2009); however, in this case, the reference year is not explicitly stated.

Some countries apply the GHG emissions intensity of GDP as an indicator for their mitigation action target. For example, China has announced a 40%-45% reduction of

Table 2 Required annual rates of change in some Asian countries for a 50% global GHG reduction.

%/year

Country	Burden sharing scheme	Projection : 2005-2050				Historical 1990-2008
		Required reduction rate of emissions	Per capita GDP growth	Population growth	Required reduction rate of emission intensity of GDP	Observed reduction rate of emission intensity of GDP
		e	g	p	x	x_0
Japan	pCAP	3.9	0.7～0.9	-0.3	4.2～4.4	0.6
China	pCAP	2.5	4.8～6.0	-0.02	7.3～8.5	4.0
India	pCAP	-0.9	4.0～5.6	0.9	4.0～5.5	1.1
Asia except Japan	pGDP	1.9～2.2	3.7～5.0	0.6	6.4～7.4	-1.0

CO_2 emissions per unit of GDP by 2020 compared with the 2005 level as a voluntary target. China has also set a legally binding target of a 17% reduction of CO_2 emissions per unit of GDP in its Twelfth Five Year Development Plan (2011-2015), a key national economic planning document. Similarly, Malaysia also intends to reduce its emissions intensity by 40% compared with the 2005 level by 2020. India's emissions target is to reduce the emissions intensity of its GDP by 20%-25% by 2020 compared with the 2005 level, except in the agricultural sector. In order to achieve this target, an expert group was organized and pathways towards low-carbon inclusive growth were analyzed in detail. The interim report of the expert group pointed out that India could reduce its emissions intensity by 33%-35% compared with the 2005 level with aggressive efforts (Planning Commission, Government of India, 2011). The report also indicated that 'low- carbon inclusive growth' would be a key pillar of India's Twelfth Five Year Plan (2012-2017).

Other countries such as Indonesia, Singapore, and Korea have chosen to set their own targets in comparison with the BAU case. The Indonesian target is a reduction of 26% from the BAU case by 2020. This target can be further strengthened to 41% if international support is put in place (UNFCCC, 2009b; Ministry of Environment, Republic of Indonesia, 2010). Since Indonesia has unique features in terms of GHG emissions, countermeasures in sectors related to deforestation and land use are predominant in the mitigation policy portfolio.

Singapore aims to reduce its GHG emissions by 16% from the BAU level in 2020 if all countries implement their commitments. As a country with limited resources, Singapore emphasizes energy efficiency improvement as a key action for achieving the target. Apart from this international commitment to mitigation, Singapore is also targeting an energy efficiency improvement of 35% from the 2005 level by 2030 (National Environment Agency, Singapore, 2010).

Korea is actively engaging in industrial development through green growth. In 2008, President Lee Myung-bak released the 'Low-Carbon Green Growth' concept as the country's new vision for the next 60 years (Green Growth Korea, 2012). Under the aegis of green growth, Korea's emission reduction target is set at 30% from BAU in 2020.

Thailand and Vietnam have not pledged to reduce their GHG emissions. However, Thailand has an energy intensity target specifying a 25% reduction by 2030 (Ministry of Energy, Thailand, 2011), and Vietnam has presented a study of climate change mitigation scenarios in its Second National Communication (Ministry of Natural Resources and Environment, Socialist Republic of Vietnam, 2010).

Table 3 summarizes the climate change mitigation targets of selected Asian countries. Although their approaches towards low-carbon societies are diverse, Asian countries have put increasing emphasis on climate change issues as well as energy issues and taken relevant actions towards low-carbon transitions. However, these current actions and pledges are insufficient to achieve the global 50% reduction target by the year 2050, as seen in the conclusion reached by UNEP (2012). The right-hand column of Table 3 shows each country's reduction rate calculated with the proposed target, and when these values are compared with the corresponding required rates shown in Table 2, it becomes clear that the rates must be doubled or tripled in order to reach the global 50% reduction target.

4. Research towards Achieving Low-carbon Societies in Asia

This paper first outlines the global target to stabilize climate change, then describes efforts to reduce the GHG emissions of individual countries in Asia to equitably contribute to the mitigation of climate change. Next, it summarizes the reduction targets currently set for each country in Asia and identifies the gaps between these targets and the required reductions.

Below, we consider how to close these gaps. The discussions in the previous sections are based on a prescriptive, top-down approach. This approach is useful for

Table 3 Summary of climate change mitigation targets of selected Asian countries.

Country	Indicators	Compared with	Reduction target	Target year	Reduction rate, %/y
China	CO_2 intensity of GDP	2005	-40 to -45%	2020	3.1-3.7
	Share of non-fossil fuels in primary energy		15%	2020	
	Forest coverage		+40 million ha	2020	
	Forest stock volume		+1.3 billion m^3	2020	
India	GHG intensity of GDP	2005	-20% to -25%	2020	1.4-1.8
Indonesia	GHG emissions	BAU	-26%	2020	
			-41%	2020	
Japan	GHG emissions	1990	-25%	2020	0.9
	GHG emissions	N/A	-80%	2050	
Korea	GHG emissions	BAU	-30%	2020	
Malaysia	GHG intensity of GDP	2005	-40%	2020	3.1
Singapore	GHG emissions	BAU	-16%	2020	
	Energy intensity of GDP	2005	-35%	2030	1.6
Thailand	Energy intensity of GDP	2005	-25%	2030	1.1

considering what needs to be implemented over the next 50 years or so at a global or national level, but it is also necessary to design a feasible roadmap in order to achieve the required emission reductions identified by a top-down approach. In addition, to realize low-carbon societies, it will be crucial to take actions at the city or regional level with a time scale of the next 10 to 20 years in addition to national-level actions.

This means that it will be necessary to integrate the top-down global approach with bottom-up national, regional and city-level approaches, and by combining these two types of approaches, to design feasible roadmaps towards the realization of low- carbon societies. Several studies have been carried out to integrate these two approaches by the participants in the development and dissemination of the Asia-Pacific Integrated Model (AIM), including authors and collaborators. Tables 4 and 5 introduce some of these low-carbon society studies <http://2050.nies.go.jp/LCS/>.

Several papers included in this volume also present some of the outcomes of regional, national, and/or local-level mitigation approaches under the framework of the Asia Low-Carbon Society project (Kawase & Matsuoka, 2013; Fujimori *et al*., 2013; Ashina & Fujino, 2013; Namazu *et al*., 2013a and 2013b; Gomi *et al*., 2013). The Japanese AIM team is conducting cooperative research on low-carbon societies with research institutions in each region of Asia at the national level (including China, India, Indonesia, Thailand, Vietnam and Malaysia) (Table 4) and at the regional/city/local level (including three provinces and cities in China, two cities in India and three cities in Malaysia) (Table 5).

The partners in the joint research presented in Tables 4 and 5 include the relevant regional research institutions and local governments, with whom collaborative studies have been carried out to develop scenarios and roadmaps for low-carbon societies. At the start of research collaboration, in all cases, the policymakers and stakeholders lacked a clear conception of low-carbon societies, or any idea of targets or a unifying vision. In such a situation, researchers in the counterpart country play an important role in facilitating discussions between the policymakers and stakeholders and helping them to understand the significance and importance of developing scenarios that can lead to a low-carbon society. Rather than negotiating with the stakeholders, the role of Japanese researchers has been to undertake capacity building with local researchers and government officials for the development of scenarios and to provide support for improvement of the models for scenario development.

Steps towards low-carbon societies should be accelerated to achieve the reduction target of 50% by 2050 in the countries shown in Table 3. From this point of view, for the past 15 years or more members of the Japanese AIM team have exchanged joint research findings with researchers in Asian countries and held international workshops and training workshops for capacity building once or twice a year for researchers and government officials recommended by the collaborating research institutes. The training workshops are held for a period of one or two weeks.

The AIM model has a variety of different sub-models such as CGE, end-use, and extended snapshot and back-casting models. At the training workshops, the core models are explained first, then basic knowledge for understanding the models is provided, including energy statistics and social accounting matrixes. Next, one of the AIM sub-models is selected and detailed explanations are given on how the model works and how to interpret the results obtained from it.

The regions and types of analysis covered depend on the interests, needs, and capabilities of the participants. After the participants return to their countries, the Japanese AIM team follows up appropriately by organizing exchange visits with the institutions involved, holding web conferences, and exchanging e-mails, as well as validating the results of estimates, conducting reproducibility activities, and so on.

Some of this joint work has reached the level of implementation by government authorities, while some remains at the research and proposal stage. Although this originally started as joint research, in some cases the local research institutions have developed their independent findings into proposals to their own governments for low-carbon society scenarios, with a focus on ambitious reductions (2050 China Energy and CO_2 Emissions Report Commission, 2009).

Table 4 AIM national low-carbon society studies.

	Progress up to now	Collaborating research institutes
China	Extending ERI's national study (low-carbon development, China) with AIM models. Preparing provincial energy, industrial, and economic database in order to integrate national level and provincial level	Energy Research Institute(ERI), National Development and Reform Commission
India	Constructing Indian national scenarios with 'Conventional mitigation' and 'Sustainable development' corresponding to global 2 C	Indian Institute of Management, Ahmedabad
Thailand	Thailand national study using coupled CGE and enduse model and applying Thailand NAMA process	Thammasat University
Indonesia	Indonesia national study using coupled Energy/enduse model and AFOLU model	Institut Teknologi Bandung Bogor Agriculture University
Vietnam	Preliminary analysis of Vietnam energy related and AFOLU related GHG emission reduction completed	Institute of Strategy and Policy on Natural Resources and Environment (ISPONRE), Institute of Meteorology, Hydrology and Environment, Ministry of Natural Resources and Environment
Bangladesh	Preliminary analysis of Bangladesh LCS with energy ExSS completed	Department of Environment, Bangladesh
Malaysia	Extending the reduction plan of the 2nd National Communication with ExSS and AFOLU models	Universiti Teknologi Malaysia

Table 5 AIM regional/local low-carbon society studies.

	Progress up to now	Collaborating research institutes
Iskandar, Malaysia	1. Started full scale collaboration with related governmental institutions 2. Preparting a draft of 'Blueprint to Low-carbon Iskandar' including 12 acions 3. Started assessment study on cobenefits by 3R policies and air quality management 4. Developing Regional Diffused Energy Supply System Model 5. Developing a systematic methodology of Consensus Building towards LCS	Universiti Teknologi Malaysia (UTM) Iskandar Regional Development Authority (IRDA) Federal Department of Town and Country Planning Malaysia (JPBD) Malaysian Green Technology Corporation (MGTC)
Putrajaya, Malaysia	Completed preliminary design of 'Actions towards Putrajaya Green City 2025.' Conducted Focus Group Meeting with regional stakeholders	Universiti Teknologi Malaysia (UTM) Putrajaya Corporation Malaysian Green Technology Corporation (MGTC)
Cyberjaya, Malaysia	Started Cyberjaya Digital Green City 2025 (Cyber DGC 2025) project with four pillars: 'Low-carbon Cyberjaya' for climate change mitigation, 'Smart 3R Cyberjaya' for solid waste management, 'Livable & Vibrant City' for a good living environment, 'Smart Digital Network City' for an ICT-based society	Universiti Teknologi Malaysia (UTM) Multimedia Development Corporation Sdn. Bhd. (MDeC) Cyberview Sdn. Bhd.
Ratchaburi, Thailand	Preliminary analysis of energy related part almost completed with ExSS, now adding AFOLU part	King Mongkut's University of Technology
Guangzhou, China	Completed preliminary design of '4. Actions for Guangzhou Low-carbon Social development' including 5 actions: Action 1: Convenient Transport, Action 2: Green Building, Action 3: Decarbonation of Industry, Action 4: Fuel Switch, Action 5: Low-carbon Electricity	Guangzhou Institute of Energy Conversion
Ahmedabad, India	Preliminary analysis of energy related part completed with ExSS	Indian Institute of Management, Ahmedabad
Bhopal, India	Completed 1st phase study on 'Low-Carbon Society Scenario Bhopal, 2035' with 7 actions; Held symposium with regional policy makers and stakeholders to stimulate Actions, in Sept. 2011	Maulana Azad National Institute of Technology, Bhopal School of Planning and Architecture, Bhopal
Kyonggi Province, Korea	Preliminary analysis of energy related part conducted with ExSS, completed	Seoul National University

5. Final Remarks

Considering the effects of climate change, action to reduce GHG emissions by half by 2050 has become an urgent task. Many studies have been carried out to develop scenarios in order to show the feasibility of this goal.

Taking an operations-research approach to long-term social and economic planning design and control is nothing new. However, to refocus this approach from the standpoint of realizing low-carbon societies requires additional research. This includes multilayered and dispersed interactions from the global to the community level, the use of ICT in information control and coupling with the innovation and diffusion of new energy technologies.

Furthermore, considering the size of the anticipated emission reductions, this problem is not a matter of making certain changes in existing societies, which has been the assumption of most environmental plans to date. Rather, it is an issue for which no solution will be found unless we endogenize the entire social and economic framework and set a planning horizon of several decades or more. We believe this issue is a good opportunity to re-examine and re-enhance earlier environmental research methods and to contribute to the realization of low-carbon societies.

Acknowledgements

This research was conducted jointly by the National Institute for Environmental Studies, Kyoto University, Mizuho Information & Research Institute, and the research institutions shown in Tables 4 and 5. It received support from the Environment Research and Technology Development Fund for S-6-1, 'General research concerning the development and widespread adoption of methods for drafting, forecasting and evaluating mid- to long-term policy options towards low-carbon societies in Asia,' and A-1103, 'The effects and impact of Japan's global warming policy considering worldwide measures against global warming using a comprehensive assessment model,' and the Science and Technology Research Partnership for Sustainable Development (SATREPS), 'Development of scenarios for low-carbon societies in the Asian region.'

References

2050 China Energy and CO_2 Emissions Report Commission (2009) *2050 China Energy and CO_2 Emissions Report*. Scientific Press, Beijing. (in Chinese)

Akashi, O., Y. Hijioka, T. MasFui, T. Hanaoka and M. Kainuma (2012) GHG emission scenarios in Asia and the world: The key technologies for significant reduction. *Energy Economics*, 34(3): S346-S358.

Ashina, S. and J. Fujino (2013) Methodology for designing quantitative roadmaps towards low-carbon societies using a backcasting approach. *Global Environmental Research* 17, 99-107.

Deng, Y., S. Cornelissen, S. Klaus, K. Blok and C.J. van der Leun (2011) *The Energy Report*. WWF International, Gland, Switzerland; Ecofys, Utrecht, the Netherlands; and OMA, Rotterdam, the Netherlands.

Fujimori, S., T. Masui and Y. Matsuoka (2013) Global low-carbon society scenario analysis based on two representative socioeco-

nomic scenarios. *Global Environmental Research* 17, 79-87.
Gomi, K., A. Deshpande and M. Kapshe (2013) Aligning low-carbon society scenario with city development goals in Bhopal, India. *Global Environmental Research* 17, 129-138.
Green Growth Korea <http://www.greengrowth.go.kr /english/>.
IEA (2008) *Energy Technology Perspectives, 2008: Scenarios & Strategies to 2050*. OECD/International Energy Agency, Paris.
IEA (2010) *Energy Technology Perspectives, 2010: Scenarios & Strategies to 2050*. OECD/International Energy Agency, Paris.
IEA (2011) *Global Energy Outlook*. OECD/International Energy Agency, Paris.
Kainuma, M., K. Miwa, T. Ehara, O. Akashi and Y. Asayama (2013) A low-carbon society: global visions, pathways, and challenges. *Climate Policy*, 13(S01): 6-22. doi:10.1080/14693062.2012.738016.
Kawase, R. and Y. Matsuoka (2013) Global GHG 50% reduction and its feasibility in Asia. *Global Environmental Research* 17, 11-18.
Krewitt, W., T. Pregger, S. Simon, T. Naegler, S. Schmid, W. Graus, E. Blomen, P. Baer, D. Urge-Vorsatz, J. Rutovitz and A. Atherton (2010) *Energy [R]evolution: A Sustainable World Energy Outlook*, 3rd Edition. Greenpeace International, Amsterdam, the Netherlands and the European Renewable Energy Council, Brussels, Belgium.
Matsuoka, Y., J. Fujino and M. Kainuma (2008) National implications of a 50% global reduction of greenhouse gases, and its feasibility in Japan. *Sustainability Science*, 3:135-143.
Ministry of Energy, Thailand (2011) *Thailand 20-Year Energy Efficiency Development Plan (2011-2030)* <http://www.eppo.go.th/encon/ee-20yrs/EEDP_Eng.pdf>.
Ministry of Environment, Republic of Indonesia (2010) *Indonesia's Second National Communication to the United Nations Framework Convention on Climate Change* <http://unfccc.int/resource/docs/natc/indonc2.pdf>.
Ministry of Foreign Affairs, Japan (2009) *Japan-U.S. Joint Message on Climate Change Negotiations* <http://www.mofa.go.jp/region/n-america/us/pv0911/climate.pdf>.
Ministry of Natural Resources and Environment, Socialist Republic of Vietnam (2010) *Viet Nam's Second National Communication to the United Nations Framework Convention on Climate Change*. <http://unfccc.int/resource/docs/natc/vnmnc02.pdf>
Namazu, M., S. Fujimori, K. Jiang and Y. Matsuoka (2013a) Feasibility of low-carbon development in China. *Global Environmental Research* 17, 109-118.
Namazu, M., S. Fujimori, P.R. Shukla and Y. Matsuoka (2013b) Two low-carbon development pathways in India. *Global Environmental Research* 17, 119-128.
National Environment Agency, Singapore (2010) *Singapore's Second National Communication to the United Nations Framework Convention on Climate* Change <http://unfccc.int/resource/docs/natc/sinnc2.pdf>.
Planning Commission, Government of India (2011) *Interim Report of the Expert Group on Low-Carbon Strategies for Inclusive Growth*.
Rogelj, J., W. Hare, J. Lowe, D. van Vuuren, K. Riahi, B. Matthews, T. Hanaoka, K. Jiang and M. Meinshausen (2011) Emission Pathways Consistent with a 2°C Global Temperature Limit. *Nature Climate Change*, 1: 413-418.
Skea, J. and S. Nishioka (2008) Policies and practices for a low-carbon society. *Climate Policy*, 8: S5-16.
UN (2011) *World Population Prospects, the 2010 Revision*. Department of Economic and Social Affairs <http://esa.un.org/unpd/wpp/index.htm>.
UNEP (2012) *The Emissions Gap Report 2012, A UNEP Synthesis Report*. 50 pp.
UNFCCC (2009a) *Appendix I – Quantified economy-wide emissions targets for 2020* <http://unfccc.int/meetings/copenhagen_dec_2009/items/5264.php>.
UNFCCC (2009b) *Appendix II – Nationally appropriate mitigation actions of developing country parties* <http://unfccc.int/meetings/cop_15/copenhagen_accord/items/5265.php>.
UNFCCC (2010a) *Report of the Conference of the Parties on its fifteenth session, held in Copenhagen from 7 to 19 December 2009*. FCCC/CP/2009/11/Add.1 <http://unfccc.int/resource/docs/2009/cop15/eng/11a01.pdf>.
UNFCCC (2010b) *Report of the Conference of the Parties on its sixteenth session, held in Cancun from 29 November to 10 December 2010*. FCCC/CP/2010/7/Add.1 <http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf#page=2>.

Yuzuru MATSUOKA

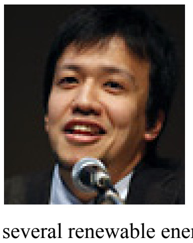
Yuzuru MATSUOKA is a Professor at the Graduate School of Engineering, Kyoto University. He specializes in environmental engineering. He started researching global environmental issues in the late 1980s. He has developed various kinds of integrated models, including bottom-up and top-down models. Recently he has been leading projects for development of Asian low-carbon societies.

Mikiko KAINUMA

Dr. Kainuma received her B.S., M.S., and Ph.D. degrees in applied mathematics and physics from Kyoto University in Kyoto, Japan. She joined NIES in 1977, and since 1990, she has been engaging in the development of Asia-Pacific Integrated Model (AIM), which assesses policy options for stabilizing the global climate, particularly in the Asian-Pacific region, with the objectives of reducing greenhouse gas emissions and avoiding the impacts of climate change. From 2006 to March, 2011, she headed Climate Policy Assessment Research Section at the Center for Global Environmental Research in NIES. Currently she is a Fellow at the Center for Social and Environmental Systems Research in NIES, and serves as an adjunct professor at Japan Advanced Institute of Science and Technology.

Junichi FUJINO

Junichi FUJINO is a Senior Researcher at NIES, Japan, in the Sustainable Social Systems Section, Center for Social and Environmental Systems Research. He is also a Visiting Associate Professor at the Japan Advanced Institute of Science and Technology (JAIST). His fields of research include environmental modeling analysis, especially for energy-economy system modeling and bioenergy studies. He is involved in the development of the Asia-Pacific Integrated Model (AIM) to estimate climate change impact and to assess policy options for stabilizing the global climate. He has been fully engaged in the "Japan Low-Carbon Society Scenario Project" since 2004 and the "Asia Low-Carbon Society Scenario Project" since 2009. He received his B.S., M.S and Ph.D. in Electrical Engineering from the University of Tokyo, Japan. He has been working in his current position since April 2000.



Tomoki EHARA

Tomoki EHARA is a founder and Representative Executive of E-konzal, a Japanese consulting firm with expertise in energy and environmental policies. He has been a member of the Japanese Low-Carbon study since 2004. He is also an expert on renewable energy (mainly photovoltaic) and has been a member of IEA PVPS Task8 as well as several renewable energy committees in Japan.

(Received 9 July 2012, Accepted 25 January 2013)