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Tsuneyuki Morita, Nebosja Nakicenovic and John Robinson

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Center of Global Environmental Research (CGER)
National Institute for Environmental Studies

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Tsuneyuki Morita[1), Nebosja Nakicenovic[2) and John Robinson[3)

1) National Institute for Environmental Studies of Japan
16-2, Onogawa, Tsukuba, 305-0053 Japan
phone: +81-298-50-2541, fax: +81-298-50-2572, email: t-morita@nies.go.jp
2) International Institute for Applied Systems Analysis
A-2361 Laxenburg, Austria
phone: +43-2236-807-411, fax: +43 2236 807 488, email: naki@iiasa.ac.at
3) Sustainable Development Research Institute, University of British Columbia
B5 2202 Main Mall, Vancouver V6T 1Z4 Canada
phone: +1-604-822-8198, fax: +1-604-822-9191, email: johnr@sdri.ubc.ca

Contributors:

Junich Fujino (Japan), Kejun Jiang (China), Shunsuke Mori (Japan), Hugh Pitcher (USA), Keywan Riahi (IIASA), R. Alexander Roehrl (IIASA), Kenji Yamaji (Japan)

Abstract

This paper compares technological development paths that determine future mitigation scenarios aimed at stabilizing atmospheric CO2 concentrations. Future social and economic development paths have already been compared in relation to their impact on climate mitigation by Morita, Nakicenovic and Robinson (2000). This paper is an expansion of that earlier comparison. Forty stabilization scenarios are reviewed, and all use as their baseline the new scenarios by the Intergovernmental Panel on Climate Change (IPCC) published in the Special Report on Emission Scenarios (Nakicenovic et al, 2000).

Several common tendencies and characteristics can be observed across the scenarios. First, the different technological development paths described in the baseline IPCC scenarios require

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that: CO2 emissions be reduced by different levels; different schedules for the reductions be adopted; and, different technology/policy measures be chosen to stabilize atmospheric CO2 concentrations - even to achieve the same stabilization level. Second, no one single measure is sufficient for the development, adoption and diffusion of mitigation options to achieve stabilization within the accepted time-frame. Third, the level of technology/policy measures needed to achieve stabilization toward the end of the 21st century or beginning of the 22nd century will be greatly affected by the choice of technological development paths over next decades. The paper also identifies some characteristics in technological measures across the different technological development paths to achieve the stabilization targets.

1. Introduction

Future social and technological development paths will have a significant influence on global climate change because these paths will determine levels of emissions of greenhouse gases (GHG), such as CO_2, and aerosols, such as SO_2, and also strongly affect climate impacts, adaptative capacity and mitigative capacity. Therefore, the policies and technologies to be implemented to stabilize the future atmospheric GHG concentrations will depend on the paths chosen for future development. This suggests that there is a wide range of policy/technology options available to mitigate global climate by stabilizing GHG concentrations at a chosen level.

To assess GHG stabilization technologies and policies, it is necessary to consider carefully the range of possible assumptions about social and technological developments that underlie the baseline scenarios of future economic development. The policy/technology options designed to stabilize concentrations in a future world with reference to high baseline GHG emissions are entirely different from those for a world with low baseline emissions. Also, it is necessary to assess what packages of technology/policy measures are robust against different world development paths.

The Intergovernmental Panel on Climate Change (IPCC) developed a set of new emission scenarios based on a wide range of social and technological development paths. A range of emission scenarios was quantified based on different future paths for economic social and technological development, but they did not include any climate policy or mitigation measures additional to those already in place. These scenarios are published in the "Special Report on Emission Scenarios" by the IPCC (Nakicenovic et al., 2000) and are called SRES scenarios for short.

The authors of this paper coordinated a special project to establish mitigation scenarios based on these SRES scenarios. Nine modeling teams participated in the project and more than 70 mitigation scenarios were quantified based on the SRES scenarios. These are called 'post-SRES' scenarios.

A description and comparison of the post-SRES scenarios has already been published as a special issue of the journal "Environmental Economics and Policy Studies", and it focuses on the differences in social development paths (Morita, Nakicenovic and Robinson, 2000). In that paper, more than 40 stabilization scenarios, based on different social and economic development paths, were compared and robust technology/policy measures were discussed in relation to different future worlds and different stabilization targets. A key finding of this work was that the future direction of technological development has significant implications for future GHG emissions and aerosol emissions as well as future technological mitigation.

This paper extends the earlier work by providing an overview and comparison of the post-SRES scenarios from the perspective of long-term technological development. First, the technological development paths in the post-SRES are presented and compared to those in the IPCC SRES baselines scenarios. Second, 41 post-SRES scenarios are compared. Third and finally, several findings are summarized.

2. Quantification of new stabilization scenarios that use different technological development paths.

The outline of SRES scenarios is summarized in Appendix 1. SRES scenarios comprise four scenario families. One of the four families - the A1 family - contains very high economic growth scenarios. It is characterized by a strong commitment to: education; high rates of investment; various technology innovations; increased international mobility of people;

promotion and implementation of ideas; and, a general use of technology that has been accelerated by advances in communication technologies.

With its high rate of economic growth, futures in the A1 family generate great pressures on the energy resource base. As a result, this set of scenarios has a particularly large level of uncertainty with regard to the future directions of technological progress in the energy field. Thus, the A1 scenario family is divided into 3 groups that are each based on alternative directions of technological change in the energy system.

The three A1 groups are distinguished by their technological emphasis: A1FI is a fossil fuel intensive scenario, incorporating, for example, clean coal technologies and new technologies for unconventional oil and gas; A1T has an emphasis on non-fossil fuel energy sources, such as solar, wind, fuel cell, and nuclear technologies; and, A1B is balanced across all energy sources. 'Balanced' is defined as not relying too heavily on one particular energy source and incorporates the assumption that similar improvement rates apply to all energy supplies and end-use technologies.

The first stage of the post-SRES project to quantify mitigation scenarios based on SRES focused on the differences in social and economic development paths among the four scenario families. An outline of the first stage of the project is provided in Appendix 2.

In the second stage of the post-SRES project, additional comparisons among technological development were conducted. Table 1 shows the 41 scenarios that enable a comparison of different development paths.

Five modeling teams - AIM, LDNE, MARIA, MESSAGE-MACRO and MiniCAM - prepared additional mitigation scenarios based on A1FI and A1T technology development paths. These paths are compared with A1B scenarios for different stabilization targets. The technical methodologies used to quantify the stabilization scenarios are explained in Appendix 2.

Table 1: Post-SRES Participants And Quantified Scenarios for A1-based scenarios (indicated by stabilization target in ppmv)

Baseline scenarios	A1B	A1FI	A1T
AIM **(NIES and Kyoto University, Japan)**	450 550 650	550	
ASF **(ICF Corporation, USA)**			
IMAGE **(RIVM, Netherlands)**	550		
LDNE **(Tokyo University, Japan)**	550	550	550
MARIA **(Science University of Tokyo, Japan)**	450, 550, 650		450, 550, 650
MESSAGE-MACRO **(IIASA, Austria)**	450 550 650	450(*), 550(*) 650(*), 750(*)	450 550
MiniCAM **(PNNL, USA)**	550(*)	450, 550, 650, 750	
PETRO **(Statistics Norway, Norway)**	450 550 650 750		
WorldScan **(CPB, Netherlands)**	450 (**) 550(**)		

Notes: (*) High and low baselines were used. (**) An early action and a delayed response were quantified**.**

3. Comparison of stabilization scenarios

Figure 1 shows CO2 emission scenarios used as the baselines for stabilization scenarios. LDNE shows exceptionally high emissions, but it carries a great deal of uncertainty because of a lack of time to harmonize all quantitative scenarios. As a result, the technological development path of A1FI is considered to show the highest emission path and A1T is considered to show the lowest emission path. The main conclusion from this comparison is that technology developments determine to a large extent future CO2 emission trajectories.

These differences between the baseline scenarios imply differences in the amount by which the concentration of atmospheric CO2 must be reduced to achieve stabilization. In turn, this results in a selection of different technology/policy measures, and as a consequence it means different financial costs to stabilize the CO2 concentration even at the same level in different scenarios. Technological change is a key component in bringing down the cost of mitigation options and their contribution to emission reductions.

Figure 2 shows stabilization scenarios based on different A1 development paths. It is clear that stabilization targets at low levels require low emission trajectories and high stabilization levels require high emission trajectories. This range of trajectories is caused by several factors, in particular model structures that determine trajectory patterns, baseline emissions that determine technology and policy options, and a carbon cycle model that determines the cumulative emissions.

Figure 2 shows emissions paths of stabilization scenarios and thus does not directly indicate the differences in technology development paths among stabilization scenarios. Figure 3 compares the times when the stabilization scenarios achieve a 20% reduction in relation to the global baseline emissions. This figure compares not only technology development baselines but also stabilization targets and illustrates in this way the difference among the technological development paths across stabilization scenarios. As shown, the higher the level of baseline emissions caused by the selected technology development path, as well as the lower the stabilization level that is required, the earlier the emission reduction from the baseline level. It must be stressed that technology/policy measures need to be introduced earlier if a fossil fuel intensive technological development path is chosen.

Figure 4 was prepared to respond to a key policy question related to 'reduction levels' in the first quarter of the 21st century. The 'reduction level' is the amount by which Annex 1 countries have to reduce their CO_2 emissions from the 1990 level for the atmospheric CO_2 concentration to be stabilized at 450 ppmv, 550 ppmv and 650-750 ppmv. In order to identify a range of middle course scenarios, the figure shows the range between the 25th and 75th percentile of frequency distribution. If an A1 world is selected over the next 100 years, the Kyoto target becomes the minimum required to stabilize concentrations at 450 ppmv and 550 ppmv. If 450 ppmv is required, Annex 1 emission levels after 2010 have to be reduced much more than the 2010 level. In the 550 ppmv stabilization scenario, the Kyoto commitment may be adequate to achieve stabilization.

Figure 5 illustrates mitigation options for developing countries. It shows the times when per capita CO_2 emissions in Annex 1 countries fall below per capita CO_2 emissions in non-Annex 1 countries based on the assumption that all CO_2 emission reductions necessary to achieve stabilization occur in Annex 1 countries while non-Annex 1 countries emit CO_2 without any controls. Most of the post-SRES scenarios based on A1 world indicate that per capita Annex I emissions would fall below per capita non-Annex I emissions in the 21^{st} century. This situation occurs before 2050 in quarter of the scenarios. The times at which stabilization is achieved is significantly affected by future technology development paths as well as stabilization targets. As a result, the selection of technology development paths will strongly influence the time at which developing countries will need to begin to diverge from baseline emissions.

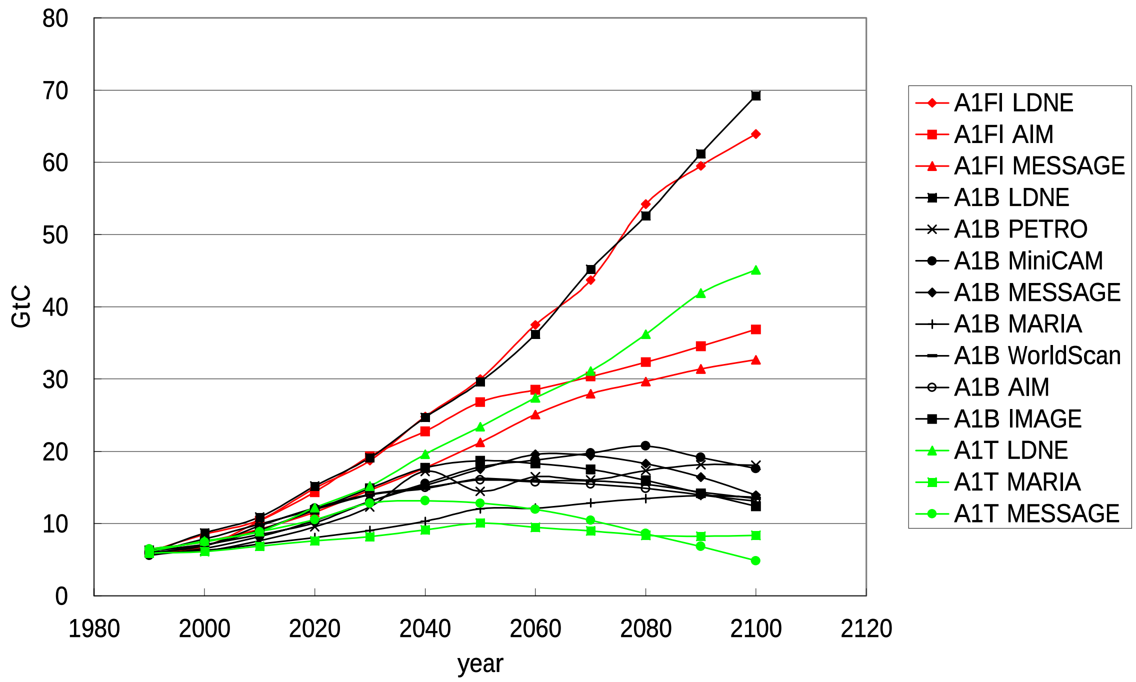

Figure 1: Baseline emission scenarios in A1 family as quantified by all modeling teams. (red line: A1FI; black line: A1B; green line: A1T technology development path)

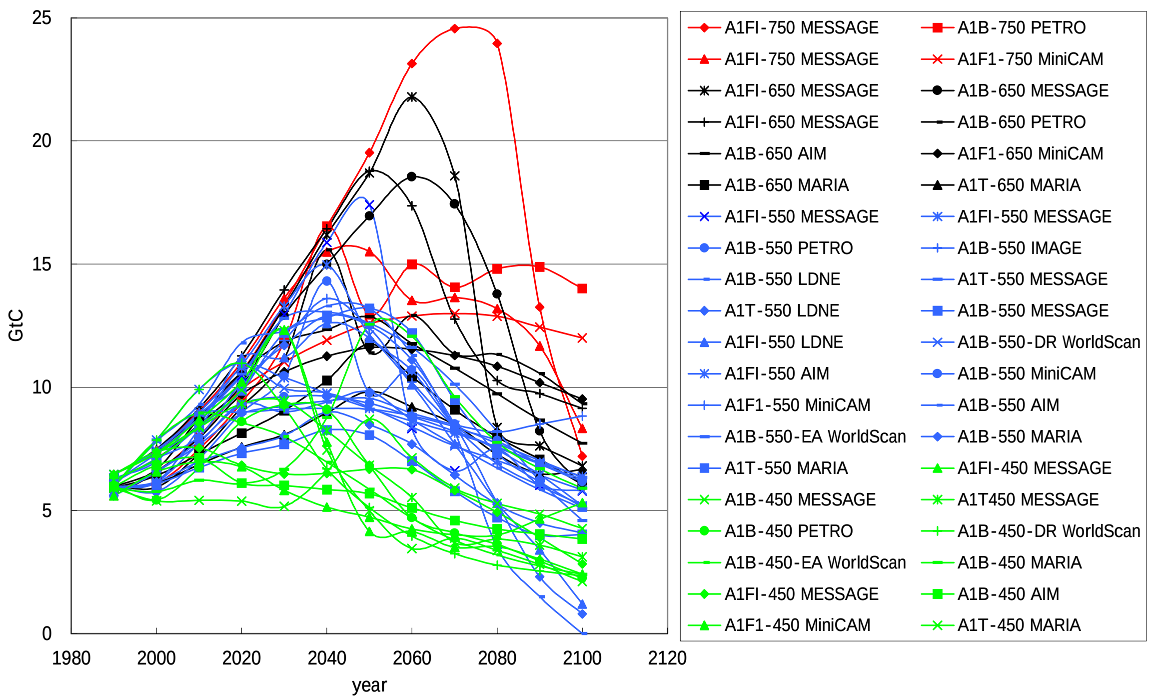

Figure 2: Stabilization scenarios based on A1 family as quantified by all modeling teams. (red: 750 ppmv; black: 650 ppmv; blue: 550 ppmv; green: 450 ppmv stabilization level)

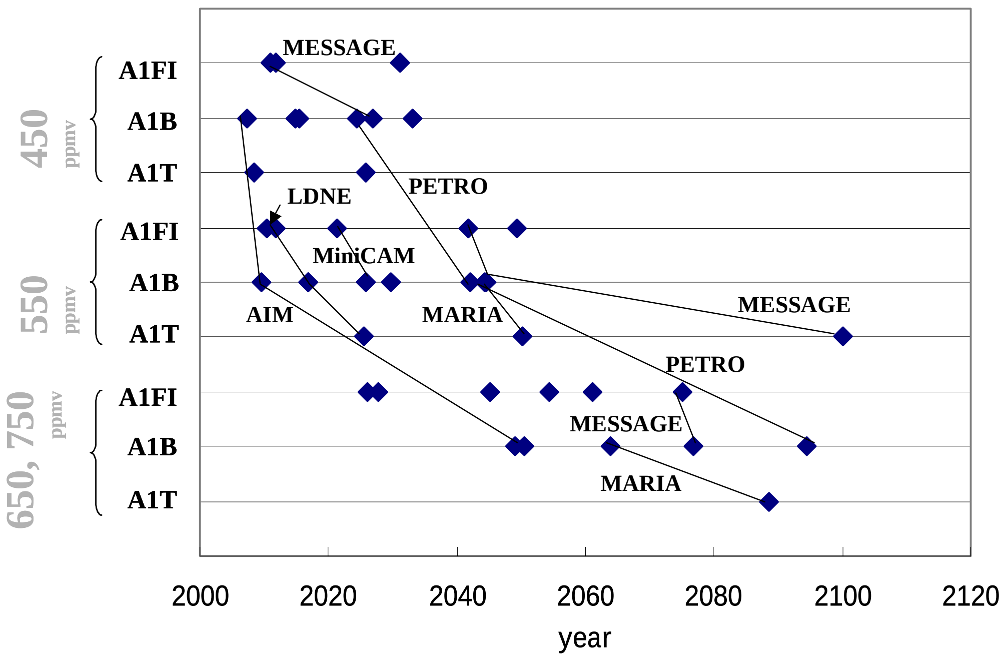

Figure 3: Times when the stabilization scenarios in A1 family achieve a reduction of a 20% reduction of global energy-related CO_2 baseline emissions, compared across stabilization targets as well as baselines. Sloping lines join scenarios quantified by the same model.

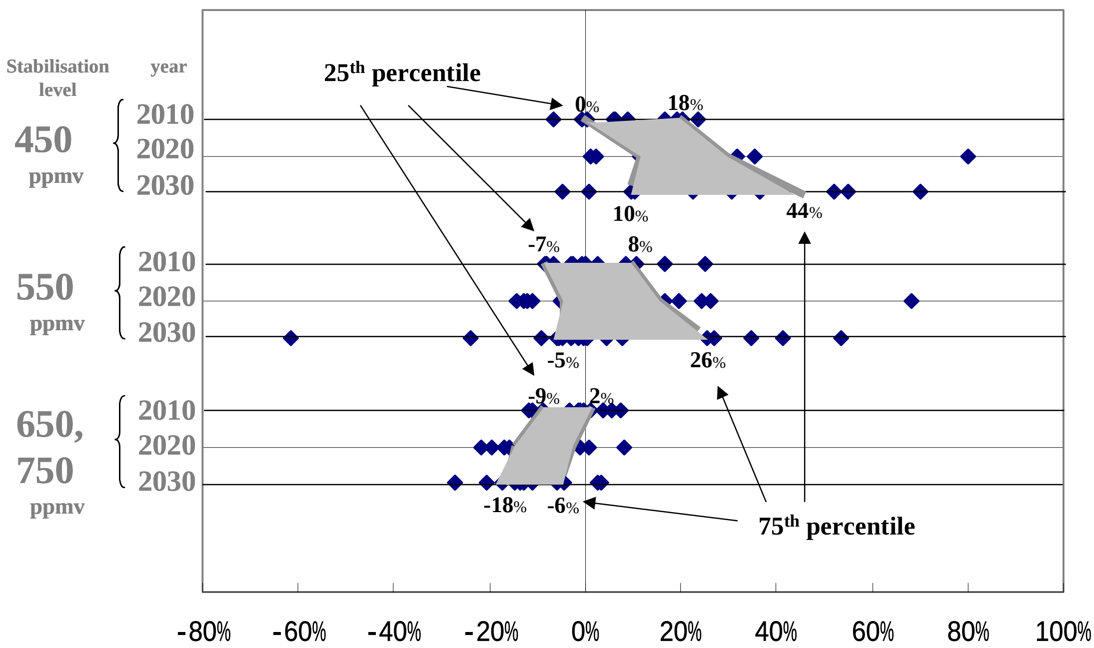

Figure 4: The reduction of energy-related CO_2 emissions in A1 family from 1990 level in Annex I countries for stabilization at 450 ppmv, 550 ppmv and 650-750 ppmv. The upper line of each set shows data for 2010, the middleline shows data for 2020, the lower line shows data for 2030. Hatched areas show the range between 25th and 75th percentile of frequency distribution.

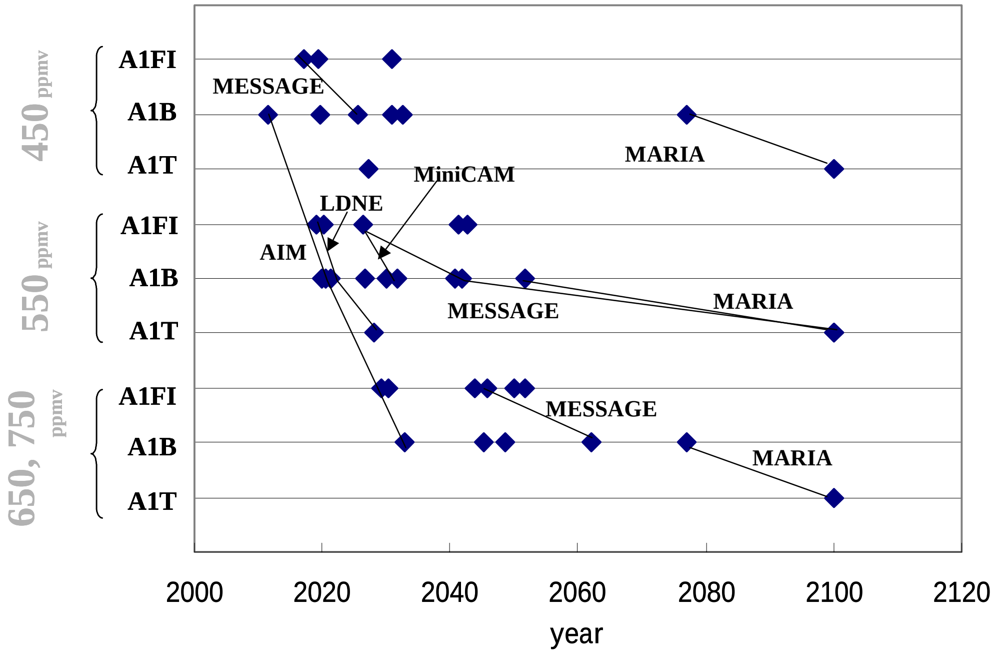

Figure 5: The times when per capita CO_2 emissions for Annex I countries would fall below per capita CO_2 emissions for non-Annex I countries, if that all CO_2 emission reductions necessary for stabilization occur in Annex I countries but non-Annex I countries continue to emit CO_2 without any controls

4. Comparison of technology/policy measures and assessment of robustness

As discussed in the previous sections, the technology/policy measures required to achieve stabilization are significantly affected by future technological development paths. To compare the differences in technology/policy measures, the sources of emission reductions are estimated in Table 2. This summarizes the contribution of several mitigation options and/or measures for the post-SRES scenarios. The numbers represent the emission reduction (in Giga tons of Carbon, GtC) between the baseline and the stabilization cases. For simplicity, the table only shows the range from the maximum to the minimum as well as the medium value in 2100 for the 550 ppmv stabilization case. In the table, the demand reduction includes technological efficiency improvements for both energy use technology and energy supply technology, social efficiency improvements such as public transport introduction, dematerialization promoted by lifestyle changes and the introduction of recycling systems

The following conclusions can be drawn from this table:

1) No single measure will be sufficient to stabilize atmospheric CO2 concentrations, even if a specific technology development path is selected;

2) If a fossil fuel intensive technological development path is selected, the reduction in end-use energy demand should become a very important countermeasure otherwise CO2 scrubbing and removal technology needs to be deployed. Substitution of fossil fuels is more effective in conjunction with carbon removal and storage; and,

3) The contribution of energy demand reduction, substitution among fossil fuels and switching to renewable energy are all relatively large. The contribution of nuclear energy and CO2 scrubbing and removal differ significantly among the models and also across technology development paths.

Table 2: Sources of emissions reductions for 550 ppmv stabilization across the nine Post-SRES models. Minimum-Maximum and (Median) at 2100 (GtC)

Baseline scenarios	A1B	A1FI	A1T
Substitution among fossil fuels	-0.1 – 2.2 (0.97)	0.2 – 11.8 (1.82)	0.1 – 0.1 (0.09)
Switch to nuclear	0.3 – 6.4 (0.55)	-2.4 – 1.9 (1.20)	0.0 – 2.0 (1.03)
Switch to biomass	-0.8 – 1.5 (1.03)	-0.2 – 5.5 (2.50)	-0.2 – 0.3 (0.07)
Switch to other renewables	0.1 – 2.5 (1.51)	0.6 – 15.1 (2.70)	-0.1 – 0.0 (-0.05)
CO2 scrubbing and removal	0.0 – 4.7 (0.00)	0.0 – 23.8 (0.39)	0.5 – 1.6 (1.06)
Demand reduction	0.5 – 6.6 (0.94)	1.9 – 17.7 (10.4)	0.0 – 0.2 (0.11)
TOTAL reduction	*7.1 – 11.9 (9.16)*	*21.7 – 30.5 (21.1)*	*0.3 – 4.4 (2.31)*

Note: Emission reductions are estimated by subtracting the mitigation value (in GtC) from the baseline value (in GtC) of each scenario.

5. Concluding remarks

Several main conclusions emerge from this review.

First, because the technological development paths are different, the CO_2 emissions produced by following each path must be reduced by different amounts. Each path requires the adoption of different technology/policy measures and different financial expenditures to stabilize the concentration of CO_2 - even where the same concentration is achieved in different scenarios.

Second, the higher the level of baseline emissions and the lower the required stabilization level, the earlier must the emission reduction from the baseline level must be achieved. It must be stressed that technology/policy measures need to be introduced earlier in the first half of the 21st century if a fossil fuel intensive technological development path is chosen.

Third, the selection of technology development paths also determines the time at which developing countries need to begin to diverge from the baseline emissions. Most of the Post-SRES scenarios based on A1 world suggest that developing countries need to prepare to diverge from baseline emissions in the first half of the 21st century.

Fourth, no single measure is sufficient to stabilize atmospheric CO_2 concentrations, independent of which specific baseline technology development path is selected. Therefore, policy integration across an array of technologies, sectors and regions is essential if climate policies are to be successful.

Fifth, energy demand reduction, substitution among fossil fuels and switching to renewable energy sources make a relatively large contribution to the success of climate mitigation policies across all different technological paths.

Finally, if a fossil fuel intensive technological development path is selected, the reduction in end-use energy demand should become a very important countermeasure, otherwise CO_2 scrubbing and removal technologies need to be developed.

This paper represents the early stages of systematic studies on the relationships between technological development paths and climatic policy/technology measures. The potential for more valuable work on this globally important topic is large. Analysis is needed of more consistent relationships between technological development paths and technology options for climatic stabilization. Mitigation scenarios in developing countries should be examined in relation to the choice of future technological development paths. Also, studies are needed of the effects of technological development paths on mitigation technologies to reduce non-energy and non-CO2 gaseous emissions.

Most importantly, the feasibility and/or applicability of various technology options as well as technological development path have to be examined more systematically in relation to the socio-political assumptions underlying the different SRES baseline worlds. For example, the choice of future development paths will influence or even determine some aspects of future social structures. In turn, social structures will influence or determine whether a particular technological development path is followed and/or a technology option accepted. In this respect, a key area for future research lies in examining the degree of choice that exists with respect to achieving different development paths, and the types of decisions and policies that can be expected to reinforce or contribute to the achievement of such paths. It is more difficult to provide clear answers to such qualitative issues. However as the analysis presented in this paper suggests, the SRES and post-SRES approach of combining narrative storylines and model quantifications opens the door to new approaches to considering of these critical questions.

Appendix 1. Outline IPCC SRES scenarios

For baseline estimates of GHG and sulfur emissions, IPCC has so far developed three sets of emission scenarios. The first two were developed in 1990 and 1992 (IPCC, 1990; Leggett et al., 1992). In 1996, after evaluating the usefulness of the 1992 scenarios (Alcamo et al 1995), the IPCC decided to develop a third set of GHG scenarios, the SRES scenarios (Nakicenovic et al.,., 2000), which are used in this paper as baseline scenarios. The SRES writing team developed 40 individual scenarios based on an extensive literature assessment, based on six alternative modeling approaches, and an "open process" that solicited wide participation and feedback. They cover a wide range of the main demographic, technological and economic driving forces for GHG and sulfur emissions. These scenarios do not include explicit mitigation measures or policies (additional climate policy initiatives), although they necessarily encompass various policies of other types, some of which have the effect of reducing emissions.

Each scenario links one of four narrative "storylines" with one particular quantitative model interpretation. All the scenarios based on a specific storyline constitute a scenario "family". The following Box shows four narrative storylines which describes driving forces of SRES scenarios and their relationships. Each storyline represent the playing out of different social, economic, technological and environmental developments (or paradigms), which may be viewed positively by some people and negatively by others. Possible "surprise" and "disaster" scenarios were excluded.

Box: The main characteristics of the four SRES storylines and scenario families.

- The A1 storyline and scenario family describes a future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology. Major underlying themes are convergence among regions, capacity building and increased cultural and social interaction, with a substantial reduction in regional differences in per capita income.
- The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, resulting in high population growth. Economic development is primarily regionally-oriented, and per capita economic growth and technological change are more fragmented and slow compared to other storylines.
- The B1 storyline and scenario family describes a convergent world with rapid change in economic structures toward a service and information economy, reduction in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.
- The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with less rapid, and more diverse technological change, but with a strong emphasis on community initiative and social innovation to find local and regional solutions. While policies are also oriented towards environmental protection and social equity, they are focused on local and regional levels.

In addition, scenarios in the A1 family were categorized into three groups according to their technological emphasis -- on coal, oil and gas (A1FI), non-fossil energy sources (A1T) or a balance of all three (A1B). The last group, a balanced A1 is simply noted here as “A1”.

Six different models, AIM, ASF, IMAGE, MARIA, MESSAGE-MACRO and MiniCAM were used that are representative of different modeling approaches and different integrated assessment frameworks in the literature. One preliminary scenario from each family, referred to as a “marker,” was posted on the SRES web site, and the markers were intensively tested for reproducibility using different modeling approaches with “harmonized” common assumptions of population growth, GDP growth, and final energy use. Table 1 summarizes the main demographic, technological, social and economic driving forces across the maker scenarios in 2050 and 2100. These drive the energy and land-use changes that are the major sources of GHG emissions.

The 40 SRES scenarios cover most of the range of carbon dioxide, other GHG, and sulfur emissions found in the recent scenario literature. Table 1 summarizes main driving forces and GHG and sulfur emissions of the maker scenarios at 1990, 2020, 2050, and 2100 year. CO2 emissions in A1 are highest in growth rate in the first quarter of the 21^{st} century, peak at the middle of the century in terms of absolute emission levels, and then decrease toward 2100. In A2, CO2 emissions are in the middle of the range of scenarios in the first half of 21 century, but become very high in the latter half of the century. In the B1 world, CO2 emissions decline after the second quarter of the 21^{st} century even without any climate policy, and this scenario family has the lowest emission levels in the latter half of the century. CO2 emissions in B2 world are lowest in the first half of the 21^{st} century, but continue to increase in the second half, and the emissions reach a similar level to that in A1 in 2100.

Table A-1 Overview of main driving forces and GHG emissions in marker scenarios

Scenario group	(1990)	A1	A2	B1	B2
Population (billion)	**5.3**				
2020		**7.4**	**8.2**	**7.6**	**7.6**
2050		**8.7**	**11.3**	**8.7**	**9.3**
2100		**7.1**	**15.1**	**7.0**	**10.4**
World GDP (10^{12} 1990US$)	**21**				
2020		**56**	**41**	**53**	**51**
2050		**181**	**82**	**136**	**110**
2100		**529**	**243**	**328**	**235**
Primary energy (1018 J/yr)	**351**				
2020		**711**	**595**	**606**	**566**
2050		**1347**	**971**	**813**	**869**
2100		**2226**	**1717**	**514**	**1357**
CO_2 (fossil fuels: GtC/yr)	**6.0**				
2020		**12.1**	**11.0**	**10.0**	**9.0**
2050		**16.0**	**16.5**	**11.7**	**11.2**
2100		**13.1**	**28.9**	**5.2**	**13.8**
CO_2 (land use: GtC/yr)	**1.1**				
2020		**0.5**	**1.2**	**0.6**	**0.0**
2050		**0.4**	**0.9**	**-0.4**	**-0.2**
2100		**0.4**	**0.2**	**-1.0**	**-0.5**
CH_4 (MtCH4/yr)	**310**				
2020		**421**	**424**	**377**	**384**
2050		**452**	**598**	**359**	**505**
2100		**289**	**889**	**236**	**597**
N_2O (MtN/yr)	**6.7**				
2020		**7.2**	**9.6**	**8.1**	**6.1**
2050		**7.4**	**12.0**	**8.3**	**6.3**
2100		**7.0**	**16.5**	**5.7**	**6.9**
SO_2 (MtS/yr)	**70.9**				
2020		**100**	**100**	**75**	**61**
2050		**64**	**105**	**69**	**56**
2100		**28**	**60**	**25**	**48**

Appendix 2. Outline of Post-SRES Scenarios

The new mitigation and stabilization scenarios developed in the Post-SRES effort are based on the four SRES scenario families as baselines. A "Call for Scenarios" was sent by the authors of this paper to more than one hundred researchers in March 1999, and modelers from around the world were invited to prepare quantified stabilization scenarios for two or more concentration levels of atmospheric CO_2 in the year 2150, based on one or more of the four SRES scenario families. Alternative concentration ceilings include 450, 550 (minimum requirement), 650, and 750 ppmv, and harmonization with the SRES scenarios was required by tuning reference cases to SRES GDP, population and final energy trajectories.

Responding to the call, nine modeling teams participated in the comparison program, included six modeling teams that originally developed the SRES scenarios and three other teams: the AIM team (see article by Jiang, Morita, Masui & Matsuoka in this special issue), the ASF team (see article by Sankovski, Barbour & Pepperin this special issue), the IMAGE team, LDNE team (Yamaji, Fujino & Osada), the MESSAGE-MACRO team (Riahi & Roehrl), the MARIA team (Mori), the MiniCAM team (Pitcher), the PETRO team (Kverndokk, Lindhot & Rosendahl) and the WorldScan team (Bollen, Manders & Timmer). The analyses of eight of these teams are summarized elsewhere in this Special Report Table A-2 shows all the modeling teams and stabilized concentration levels, which were adopted as stabilization targets by each modeling team. Most of the modeling teams analysed more than two SRES baseline scenarios, and half of them analysed more than one stabilization case for at least one of these baselines. This allows a systematic review to be conducted to clarify the relationship between baseline scenarios and mitigation policies/technologies. In total, fifty[1] Post-SRES scenarios were analysed by the nine modeling teams.

Because of time constraints, the modeling teams focused their analyses mostly on the energy-related CO2 emissions. However, half of the modeling teams, including AIM, IMAGE, MARIA and MiniCAM, have also tried to quantify mitigation scenarios in non-energy CO2 emissions. The modeling teams that did not estimate non-energy CO2 emissions, introduced exogenous scenarios for these emissions from outside of their models.

In order to check the performance of CO_2 concentration stabilization for each post-SRES mitigation scenario, a special "generator" (Matsuoka, in this Special Issue) was used by the modeling teams to convert the CO_2 emission into CO_2 concentrations trajectories. , In addition, the generator was used by them to estimate the eventual level of atmospheric CO2 concentration by 2300 based on the 1990 to 2100 CO_2 emissions trajectories from the scenarios This generator is based on the Bern Carbon Cycle Model (Joos et al 1996), which was used in the IPCC Second Assessment Report (IPCC 1995). Using this generator, each modeling team adjusted their mitigation scenarios so that the interpolated CO_2 concentration reach one of the alternative fixed target level at 2150 year within 5% error. Further constraint was that the interpolated emission curve should be smooth also after 2100, the end of the time-horizon of the scenarios. This adjustment played an important role in the post-SRES for harmonizing emissions concentrations levels across the stabilization scenarios. The key driving forces of

[1]Forty-four scenarios are listed on Table 2, but the MiniCAM team quantified two mitigation scenarios for B2-550 ppmv and the WorldScan team did also two scenarios for A1-550, A2-550, B1-450, B2-450 and B2-550 ppmv.

emissions such as population, GDP and final energy consumption were harmonized in baseline assumptions specified by the four SRES scenario families.

Table A-2 Post-SRES participants and quantified scenarios

Baseline scenarios	A1	A2	B1	B2
	Stabilization targets in ppmv			
AIM (NIES and Kyoto University, Japan)	**450 550 650**	**550**	**550**	**550**
ASF (ICF Corporation, USA)		**550 750**		
IMAGE (RIVM, Netherlands)	**550**		**450**	
LDNE (Tokyo University, Japan)	**550**	**550**	**550**	**550**
MARIA (Science University of Tokyo, Japan)	**550**		**550**	**450 550 650**
MESSAGE-MACRO (IIASA, Austria)	**450 550 650**	**550 750**		**550**
MiniCAM (PNNL, USA)	**550**	**550**	**550**	**550 (*)**
PETRO (Statistics Norway, Norway)	**450 550 650 750**	**450 550 650 750**		
WorldScan (CPB, Netherlands)	**450 550(**)**	**450 550(**)**	**450(**)**	**450(**) 550(**)**

Notes: (*) High and low baselines were used.
(**) An early action and a delayed response were quantified.

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Data Statistics

(1) World baseline scenarios of energy related CO2 emissions (GtC)

Scenario	Model	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
A1B	AIM	5.96	6.92	9.70	12.14	14.03	15.00	16.03	15.74	15.46	14.86	13.96	13.12
A1FI	AIM	5.96	6.85	10.36	14.37	19.32	22.76	26.82	28.53	30.35	32.34	34.53	36.87
A1B	IMAGE	6.30	7.00	9.10	11.90	14.90	17.70	18.70	18.30	17.50	16.00	14.20	12.40
A1B	LDNE	5.96	8.70	10.90	15.20	19.10	24.70	29.60	36.20	45.20	52.60	61.20	69.20
A1FI	LDNE	6.14	8.50	10.50	14.90	18.70	24.80	30.00	37.50	43.70	54.20	59.50	63.90
A1T	LDNE	6.14	7.60	8.90	12.20	15.20	19.60	23.40	27.40	31.10	36.20	41.90	45.10
A1B	MARIA	5.90	6.28	7.15	8.07	9.04	10.32	12.04	12.13	12.84	13.46	13.87	13.62
A1T	MARIA	5.90	6.11	6.88	7.61	8.19	9.13	10.06	9.48	8.99	8.39	8.23	8.37
A1B	MESSAGE	6.23	7.09	8.49	10.12	13.05	15.27	17.52	19.56	19.40	18.29	16.42	13.92
A1FI	MESSAGE	6.46	7.49	9.20	11.56	14.64	17.70	21.24	25.10	27.96	29.65	31.39	32.66
A1T	MESSAGE	6.46	7.45	8.89	10.55	12.81	13.15	12.84	11.96	10.46	8.60	6.82	4.87
A1B	MiniCAM	5.59	6.57	8.18	10.42	13.08	15.55	17.85	18.79	19.75	20.73	19.13	17.61
A1B	PETRO	6.00	6.22	7.61	9.54	12.32	17.24	14.47	16.49	16.02	17.34	18.15	18.07
A1B	WorldScan	6.00	7.86	9.91	11.95	13.96	14.83	16.18	15.91	15.93	15.43	14.37	13.46

(2) World stabilization scenarios of energy related CO2 emissions (GtC)

Scenario	model	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
A1B-450	AIM	5.96	6.83	7.13	6.11	6.02	5.84	5.67	5.10	4.59	4.24	4.04	3.84
A1B-550	AIM	5.96	6.18	7.73	9.33	9.00	9.40	9.82	8.67	7.66	6.72	5.85	5.09
A1B-650	AIM	5.96	6.67	8.74	10.61	11.84	12.34	12.86	11.77	10.78	9.73	8.67	7.73
A1FI-550	AIM	5.96	6.15	8.31	10.79	10.39	9.74	9.14	8.62	8.14	7.57	6.95	6.37
A1B-550	IMAGE	6.30	7.00	8.90	10.10	11.90	13.60	12.40	10.20	8.40	6.90	6.00	5.20
A1B-550	LDNE	5.96	7.80	9.30	11.80	12.30	13.30	13.20	11.30	8.20	3.50	1.50	0.00
A1FI-550	LDNE	6.14	7.30	8.50	11.20	11.20	12.60	12.00	10.10	7.70	5.30	3.40	1.20
A1T-550	LDNE	6.14	7.10	8.00	10.20	11.70	12.90	12.50	11.10	8.50	5.30	2.30	0.80
A1B-450	MARIA	5.90	5.76	6.22	6.08	6.66	8.77	12.56	12.07	9.62	7.76	6.70	5.89
A1B-550	MARIA	5.90	6.16	6.98	7.54	8.03	8.99	8.48	7.69	6.43	5.25	4.48	4.09
A1B-650	MARIA	5.90	6.41	7.29	8.13	9.05	10.27	11.76	10.43	9.08	7.98	7.07	6.05
A1T-450	MARIA	5.90	5.38	5.41	5.38	5.17	6.56	8.70	7.14	5.90	5.28	4.85	4.27
A1T-550	MARIA	5.90	6.08	6.74	7.32	7.68	8.26	8.05	7.00	5.78	4.72	3.99	4.02
A1T-650	MARIA	5.90	6.10	6.86	7.57	8.07	8.96	9.83	9.20	8.49	7.27	6.49	6.66
A1B-450	MESSAGE	6.23	7.08	8.42	9.89	12.30	7.45	4.99	3.46	3.87	3.37	2.81	2.12
A1B-550	MESSAGE	6.23	7.06	8.38	9.85	12.21	12.83	13.20	12.21	9.48	7.31	6.15	5.14
A1B-650	MESSAGE	6.23	7.09	8.49	10.07	12.91	15.00	16.96	18.53	17.43	13.79	8.23	5.97
A1FI-450	MESSAGE	6.46	7.38	7.53	6.83	6.48	6.50	6.67	6.65	5.81	4.93	3.89	2.83
A1FI-450	MESSAGE	6.46	7.34	8.68	10.22	12.32	7.77	4.15	4.15	3.50	3.53	3.02	2.41
A1FI-550	MESSAGE	6.46	7.43	8.97	10.88	13.29	14.96	12.12	10.66	8.46	7.47	6.46	5.19
A1FI-550	MESSAGE	6.46	7.36	8.77	10.47	12.96	15.88	17.40	8.32	6.61	7.49	6.01	5.79
A1FI-650	MESSAGE	6.46	7.49	9.14	11.27	13.95	16.43	18.77	17.37	12.76	10.27	9.74	9.14
A1FI-650	MESSAGE	6.46	7.36	8.81	10.59	13.26	16.19	18.70	21.78	18.59	8.37	7.61	6.81
A1FI-750	MESSAGE	6.46	7.45	9.03	11.02	13.60	15.49	15.51	13.53	13.65	13.19	11.67	8.33
A1FI-750	MESSAGE	6.46	7.36	8.83	10.62	13.37	16.52	19.52	23.14	24.56	23.96	13.25	7.20
A1T450	MESSAGE	6.46	7.32	8.37	9.33	9.45	8.23	6.84	5.53	3.69	3.84	3.59	3.12
A1T-550	MESSAGE	6.46	7.45	8.88	10.54	12.80	13.05	12.60	11.61	10.13	8.21	6.21	4.59

Scenario	model	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
A1B-550	MiniCAM	5.59	6.57	7.80	9.28	9.62	9.64	9.35	8.81	8.21	7.56	6.89	6.26
A1F1-450	MiniCAM	5.59	6.56	6.96	6.77	5.82	5.14	4.72	4.25	4.01	4.00	4.66	5.31
A1F1-550	MiniCAM	5.59	6.56	7.67	8.91	9.23	9.45	9.55	8.94	8.48	8.18	8.51	8.83
A1F1-650	MiniCAM	5.59	6.56	7.94	9.70	10.63	11.26	11.60	11.54	11.29	10.85	10.19	9.53
A1F1-750	MiniCAM	5.59	6.56	8.01	9.91	11.03	11.92	12.59	12.89	12.99	12.88	12.44	12.00
A1B-450	PETRO	6.00	5.42	6.73	8.60	9.29	9.09	6.81	4.71	4.08	3.62	2.94	2.24
A1B-550	PETRO	6.00	5.76	7.10	8.97	10.46	14.31	9.77	10.70	8.51	7.83	6.89	6.17
A1B-650	PETRO	6.00	5.94	7.30	9.18	11.15	15.58	11.40	12.91	11.35	11.33	10.56	9.32
A1B-750	PETRO	6.00	6.11	7.48	9.39	11.82	16.53	12.95	14.99	14.06	14.81	14.88	14.01
A1B-450-DR	WorldScan	6.00	7.86	9.91	10.97	9.18	6.69	5.12	3.96	3.24	2.77	2.55	2.34
A1B-450-EA	WorldScan	6.00	7.86	8.96	8.56	7.99	6.95	5.86	4.69	3.78	3.19	2.74	2.41
A1B-550-DR	WorldScan	6.00	7.86	9.91	10.97	9.96	9.77	9.18	8.39	7.62	7.02	6.42	5.82
A1B-550-EA	WorldScan	6.00	7.86	8.96	8.98	9.11	9.15	9.10	8.83	8.40	7.71	7.03	6.34

(3) Annex I stabilization scenarios of energy related CO2 emissions (GtC)

Scenario	model	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
A1B-450	AIM	4.08	4.03	3.11	2.77	2.59	2.22	1.91	1.59	1.33	1.16	1.08	1.00
A1B-550	AIM	4.08	3.24	3.05	3.01	2.98	2.79	2.61	2.14	1.76	1.47	1.23	1.04
A1B-650	AIM	4.08	3.82	3.92	4.05	3.97	3.80	3.64	3.18	2.78	2.46	2.20	1.98
A1FI-550	AIM	4.08	3.41	3.39	3.09	3.03	2.56	2.17	1.98	1.81	1.72	1.69	1.65
A1B-550	IMAGE	4.60	4.20	4.60	3.70	3.00	2.70	2.00	1.60	1.50	1.50	1.50	1.50
A1B-550	LDNE	4.08	4.40	4.40	4.60	4.30	3.50	2.90	2.40	1.80	0.90	0.20	-0.20
A1FI-550	LDNE	4.08	4.20	4.20	4.30	3.90	3.40	2.80	2.40	2.00	1.30	0.40	-0.20
A1T-550	LDNE	4.08	6.40	6.60	6.60	6.60	6.20	4.80	3.80	2.80	2.00	1.40	1.00
A1B450	MARIA	4.21	3.96	3.96	3.71	3.77	4.25	5.35	5.44	4.91	4.32	4.12	3.90
A1B-550	MARIA	4.21	4.14	4.11	4.18	4.34	4.47	4.22	4.13	3.94	3.50	3.26	3.21
A1B-650	MARIA	4.21	4.36	4.36	4.52	4.76	4.99	5.03	4.90	4.93	5.07	5.03	4.62
A1T450	MARIA	4.21	3.71	3.40	3.27	3.26	3.66	4.11	3.88	3.53	3.49	3.43	3.12
A1T-550	MARIA	4.21	4.03	3.86	3.77	3.89	3.96	3.95	3.87	3.59	3.18	2.92	2.76
A1T-650	MARIA	4.21	4.04	3.91	3.87	4.07	4.27	4.29	4.46	4.61	4.44	4.51	4.59
A1B-450	MESSAGE	4.38	4.25	4.37	4.34	4.59	2.23	0.94	0.61	0.35	0.00	0.00	0.02
A1B-550	MESSAGE	4.38	4.25	4.38	4.37	4.59	4.05	3.44	2.44	1.63	0.86	0.72	0.70
A1B-650	MESSAGE	4.38	4.26	4.40	4.42	4.87	4.76	4.57	4.18	3.19	1.72	0.62	0.50
A1FI-450	MESSAGE	4.48	4.46	4.08	2.89	2.02	1.74	1.55	1.29	1.09	0.86	0.70	0.56
A1FI-450	MESSAGE	4.48	4.39	4.46	4.37	4.05	1.99	0.55	0.40	0.35	0.26	0.12	0.01
A1FI-550	MESSAGE	4.48	4.50	4.84	5.12	5.55	5.16	2.75	2.33	1.96	1.65	1.39	1.22
A1FI-550	MESSAGE	4.48	4.40	4.51	4.57	4.49	4.42	3.29	1.07	1.04	0.96	1.12	1.25
A1FI-650	MESSAGE	4.48	4.52	4.87	5.23	5.70	5.60	5.44	2.91	2.34	2.12	1.95	1.91
A1FI-650	MESSAGE	4.48	4.40	4.53	4.64	4.67	4.59	4.41	4.41	2.70	1.46	1.47	1.65
A1FI-750	MESSAGE	4.48	4.51	4.87	5.18	5.69	5.41	3.65	2.25	2.24	2.06	1.87	1.70
A1FI-750	MESSAGE	4.48	4.40	4.54	4.65	4.74	4.78	4.94	5.21	5.30	5.03	3.16	1.82
A1T-450	MESSAGE	4.48	4.32	4.19	3.88	2.83	2.09	1.39	0.70	0.11	0.35	0.67	0.78
A1T-550	MESSAGE	4.48	4.39	4.48	4.46	4.46	3.88	3.35	3.11	2.74	2.43	1.87	1.47
A1B-550	MiniCAM	3.98	4.16	4.32	4.46	4.21	3.55	3.20	2.92	2.66	2.42	2.18	1.95
A1FI-450	MiniCAM	3.98	4.16	4.01	3.52	2.76	2.20	1.84	1.55	1.38	1.32	1.50	1.68
A1FI-550	MiniCAM	3.98	4.16	4.31	4.42	4.04	3.72	3.46	3.10	2.84	2.67	2.75	2.82

Scenario	model	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
A1FI-650	MiniCAM	3.98	4.16	4.42	4.75	4.53	4.31	4.11	3.90	3.70	3.51	3.28	3.05
A1FI-750	MiniCAM	3.98	4.16	4.44	4.84	4.67	4.52	4.41	4.30	4.20	4.12	3.98	3.83
A1B-450	PETRO	4.10	3.00	3.27	3.59	4.07	2.03	1.58	0.91	0.74	0.63	0.49	0.36
A1B-550	PETRO	4.10	3.36	3.66	4.00	4.47	5.07	2.29	2.06	1.60	1.38	1.15	0.98
A1B-650	PETRO	4.10	3.54	3.87	4.23	4.71	5.64	2.70	2.55	2.17	2.04	1.78	1.48
A1B-750	PETRO	4.10	3.70	4.05	4.45	4.95	5.92	3.09	3.02	2.74	2.71	2.56	2.26
A1B-450-DR	WorldScan	4.10	4.45	4.78	3.74	2.14	2.51	1.63	1.08	0.73	0.55	0.47	0.41
A1B-450-EA	WorldScan	4.10	4.45	3.74	0.89	1.33	2.62	1.90	1.31	0.88	0.65	0.52	0.42
A1B-550-DR	WorldScan	4.10	4.45	4.78	3.74	2.63	3.58	3.05	2.55	2.05	1.74	1.54	1.34
A1B-550-EA	WorldScan	4.10	4.45	3.74	1.42	2.08	3.41	3.03	2.70	2.30	1.95	1.72	1.50

(4) Non-Annex I stabilization scenarios of energy related CO2 emissions (GtC)

Scenario	model	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
A1B-450	AIM	1.88	2.80	4.02	3.34	3.43	3.55	3.76	3.50	3.25	3.08	2.95	2.83
A1B-550	AIM	1.88	2.93	4.68	6.32	6.02	6.56	7.21	6.52	5.89	5.25	4.61	4.05
A1B-650	AIM	1.88	2.85	4.82	6.56	7.86	8.51	9.22	8.58	7.99	7.27	6.47	5.75
A1FI-550	AIM	1.88	2.74	4.92	7.71	7.36	7.15	6.97	6.63	6.31	5.84	5.24	4.72
A1B-550	IMAGE	1.70	2.70	4.20	6.40	8.90	11.00	10.40	8.40	6.80	5.40	4.50	3.80
A1B-550	LDNE	1.88	3.40	4.90	7.20	8.00	9.80	10.30	8.90	6.40	2.60	1.40	0.30
A1FI-550	LDNE	1.85	3.10	4.40	6.90	7.20	9.20	9.20	7.70	5.60	4.00	3.00	1.50
A1T-550	LDNE	1.85	2.80	3.90	6.10	7.60	9.00	9.50	8.70	6.90	4.10	1.40	0.40
A1B450	MARIA	1.69	1.80	2.26	2.37	2.89	4.51	7.21	6.63	4.70	3.45	2.58	2.00
A1B-550	MARIA	1.69	2.01	2.87	3.36	3.69	4.52	4.25	3.55	2.49	1.74	1.22	0.88
A1B-650	MARIA	1.69	2.04	2.93	3.62	4.29	5.28	6.73	5.53	4.15	2.91	2.04	1.43
A1T450	MARIA	1.69	1.67	2.00	2.11	1.90	2.91	4.60	3.25	2.37	1.79	1.42	1.14
A1T-550	MARIA	1.69	2.05	2.88	3.55	3.79	4.29	4.10	3.13	2.19	1.54	1.08	1.26
A1T-650	MARIA	1.69	2.06	2.95	3.71	4.00	4.69	5.55	4.75	3.88	2.83	1.98	2.07
A1B-450	MESSAGE	1.85	2.84	4.05	5.55	7.71	5.22	4.05	2.84	3.53	3.37	2.81	2.10
A1B-550	MESSAGE	1.85	2.81	4.00	5.49	7.62	8.78	9.76	9.77	7.85	6.45	5.43	4.44
A1B-650	MESSAGE	1.85	2.84	4.09	5.65	8.04	10.24	12.39	14.35	14.24	12.07	7.60	5.47
A1C450	MESSAGE	1.98	2.92	3.44	3.94	4.46	4.76	5.12	5.37	4.72	4.07	3.20	2.26
A1FI-550	MESSAGE	1.98	2.93	4.13	5.77	7.75	9.80	9.37	8.33	6.50	5.82	5.07	3.97
A1FI-550	MESSAGE	1.98	2.96	4.26	5.91	8.47	11.46	14.11	7.25	5.57	6.54	4.90	4.53
A1FI-650	MESSAGE	1.98	2.97	4.27	6.04	8.26	10.84	13.34	14.45	10.42	8.15	7.79	7.23
A1FI-650	MESSAGE	1.98	2.96	4.28	5.95	8.58	11.59	14.29	17.38	15.89	6.91	6.15	5.15
A1FI-750	MESSAGE	1.98	2.95	4.16	5.84	7.91	10.08	11.86	11.27	11.41	11.13	9.81	6.64
A1FI-750	MESSAGE	1.98	2.96	4.29	5.97	8.63	11.73	14.59	17.92	19.26	18.93	10.09	5.38
A1G450	MESSAGE	1.98	2.94	4.22	5.84	8.27	5.79	3.60	3.75	3.15	3.27	2.90	2.40
A1T450	MESSAGE	1.98	3.00	4.18	5.44	6.61	6.14	5.45	4.83	3.59	3.49	2.92	2.33
A1T-550	MESSAGE	1.98	3.06	4.40	6.07	8.33	9.17	9.25	8.51	7.38	5.78	4.34	3.11
A1B-550	MiniCAM	1.61	2.41	3.48	4.82	5.65	6.09	6.15	5.88	5.55	5.14	4.71	4.30
A1F1-450	MiniCAM	1.61	2.41	2.95	3.25	3.06	2.94	2.89	2.70	2.63	2.68	3.16	3.63
A1F1-550	MiniCAM	1.61	2.41	3.37	4.49	5.20	5.73	6.08	5.84	5.65	5.51	5.76	6.01

Scenario	model	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
A1F1-650	MiniCAM	1.61	2.41	3.52	4.95	6.10	6.95	7.49	7.64	7.59	7.34	6.91	6.48
A1F1-750	MiniCAM	1.61	2.41	3.56	5.07	6.36	7.39	8.17	8.59	8.79	8.76	8.46	8.17
A1B-450	PETRO	1.90	2.42	3.46	5.01	5.22	7.07	5.23	3.80	3.34	3.00	2.45	1.88
A1B-550	PETRO	1.90	2.41	3.44	4.96	5.99	9.24	7.48	8.64	6.92	6.45	5.75	5.19
A1B-650	PETRO	1.90	2.40	3.43	4.95	6.44	9.94	8.70	10.36	9.18	9.30	8.78	7.84
A1B-750	PETRO	1.90	2.40	3.43	4.94	6.87	10.62	9.85	11.97	11.33	12.10	12.33	11.75
A1B-450-DR	WorldScan	0.00	3.41	5.13	7.23	7.04	4.18	3.49	2.88	2.51	2.23	2.08	1.94
A1B-450-EA	WorldScan	0.00	3.41	5.22	7.67	6.66	4.33	3.96	3.38	2.90	2.54	2.23	1.99
A1B-550-DR	WorldScan	0.00	3.41	5.13	7.23	7.32	6.19	6.14	5.84	5.57	5.29	4.89	4.48
A1B-550-EA	WorldScan	0.00	3.41	5.22	7.56	7.03	5.74	6.07	6.13	6.09	5.76	5.30	4.84