Global Greenhouse Gas Emissions Scenarios: Integrated Modeling Approaches

Nebojša Nakićenović

RR-00-19
August 2000

Reprinted from *Technological Forecasting and Social Change*, **63**:105–109, 2000.

International Institute for Applied Systems Analysis • Schlossplatz 1 • A-2361 Laxenburg • Austria
Tel: (+43 2236) 807 • Fax: (+43 2236) 71313 • E-mail: publications@iiasa.ac.at • Web: www.iiasa.ac.at

Reprinted from *Technological Forecasting and Social Change*, **63**:105–109, 2000.

NORTH-HOLLAND

INTRODUCTION

Global Greenhouse Gas Emissions Scenarios: Integrated Modeling Approaches

NEBOJSA NAKICENOVIC, Guest Editor

This special issue of *Technological Forecasting and Social Change (TF&SC)* reports on the findings of an international and interdisciplinary study that developed a new set of greenhouse gas (GHG) emissions scenarios with different modeling approaches. Long-term GHG emissions scenarios are an indispensable tool for the analysis of possible climate change and its impacts, as well as for crafting strategies to adapt to or mitigate against undesirable consequences. The challenges such analyses pose are enormous. They include dealing with planetary processes and highly non-linear systems, such as the global climate; addressing time scales of up to a century; dealing with the inherent uncertainties of the pervasive social, economic, and technological transformations that can be expected over such long time scales; analyzing the multitude of sources of a large variety of different GHG "species" and devising scenarios of how they might evolve in the future.

The study started with an extensive review of the scenario literature in general and the assessment of emissions scenarios and their driving forces in particular. Some of the results of these initial activities have been documented in the special issue of *Mitigation and Adaptation Strategies for Global Change* Journal [1]. Next, a set of four alternative narrative descriptions or storylines of possible future developments were formulated by the study group that were consistent with the range of emissions and driving forces from the literature assessment. Finally, the four storylines were interpreted through quantifications of the main driving forces and the resulting emissions by six different modeling teams. Together this multi-model approach resulted in 30 distinct emissions scenarios. Each is based on one of the four storylines.

Dr. NEBOJŠA NAKICENOVIC is Project Leader of the Transitions to New Technologies Project at the International Institute for Applied Systems Analysis, Laxenburg, Austria.

Address correspondence to Dr. N. Nakicenovic, IIASA, A-2361 Laxenburg, Austria. Tel: +43-2236-807-411; Fax: +43-2236-71313; E-mail: <naki@iisa.ac.at>.

Technological Forecasting and Social Change 63, 105–109 (2000)

655 Avenue of the Americas, New York, NY 10010
0040-1625/00/$–see front matter
PII S0040-1625(99)00117-1

A part of this overall research effort will be submitted for consideration to the Special Report on Emissions Scenarios (SRES) by the Intergovernmental Panel on Climate Change (IPCC). This special issue of *TF&SC* documents one part of the supporting research conducted by individual modeling teams that resulted in the new emissions scenarios. Most authors of the nine papers that constitute this special issue have contributed to SRES and have benefitted enormously from the interaction and contributions of the other members of the SRES writing team. Indeed, this special issue is a product of a closely collaborating, interdisciplinary, and international team as well. Consequently, the individual authors of the articles have, to an extent, drawn on the discussions and the material assessed and analyzed by the whole SRES writing team. However, it should be noted that this supporting material has been prepared by the individual research groups for consideration by the IPCC, but it has not been subject to the formal IPCC review process. Thus, although some of the analysis and findings presented in the article might be used as the background and supporting material for SRES, they have been subjected to the review process of this Journal and not to that of the IPCC, nor will they be submitted to the IPCC for approval.

In this issue the first article by Jung et al. presents the analysis of possible structural changes in developing countries as one of the main driving forces of future emissions. The article examines historical development patterns and common features of developed countries to analyze both developed and developing countries adaptation processes and response strategies to the concerns surrounding possible climate change. Further development in the world will require the provision of adequate energy services, land availability, and other essential natural endowments, including climate and natural resources. The concept of "sustainable development" is discussed as a way of reconciling the seemingly conflicting objectives of further development needs and preservation of natural endowments for future generations.

The following six articles present the emissions scenarios developed by the five modeling teams that contributed towards the development of the 30 scenarios presented in this special issue. All of the scenarios presented in the six articles were developed in collaboration with many groups and individuals over the last three years. Each of the 30 scenarios is rooted in one of the four narrative storylines that describe alternative developments relevant for emissions and their driving forces. Some of the articles provide more detail about the storylines. All scenarios based on one storyline constitute a scenario "family." Each of the four scenario families is based on one prototype scenario for that storyline, called marker. Marker scenarios were developed first by one modeling team and then modeled by other teams sharing common scenario assumptions. Together, the scenarios cover a wide range of the main driving forces of future emissions from demographic to social and economic developments. For example, the scenarios encompass different future developments that might influence GHG sources and sinks, such as alternative structures of energy systems and land-use changes. By design, jointly the scenarios cover most of the GHG emissions range in the published scenario literature. The emissions scenarios encompass all relevant species of GHGs and emissions of sulfur dioxide.

The first of these six articles by de Vries et al. presents an emissions scenario that was used as a marker scenario for one of the four scenario families. The scenario was formulated with two models, WorldScan and IMAGE, developed by the Dutch Central Planbureau (CPB) and the Dutch National Institute of Public Health and the Environment (RIVM), respectively. This scenario describes a future world that chooses collectively and effectively to pursue service-oriented economic prosperity while taking into account equity and environmental concerns without policies directed at mitigating climate change.

The second article by Riahi and Roehrl presents another marker scenario used to develop the second family within the 30 scenarios. It was developed by an integrated modeling framework consisting of three models, SG, MESSAGE, and MACRO, at the International Institute for Applied Systems Analysis (IIASA). The scenario describes a world in which the emphasis is on local and community solutions to economic, social and environmental sustainability. This scenario, which excludes any policies directly addressing climate change is then used to develop a change case that includes emissions mitigation measures and policies directed at stabilizing the atmospheric concentrations of greenhouse gases after the end of the next century.

The third article by Jiang et al. describes a set of scenarios developed at the National Institute for Environmental Studies in Japan with the AIM integrated modeling framework. The set includes also the marker scenario used for the third of the four scenario families that constitute the set of 30 scenarios. The paper focuses on the developments in the Asia-Pacific region within the global context. It also presents variations of these scenarios that include mitigation measures and policies directed at stabilizing the atmospheric concentrations of greenhouse gases.

The fourth article by Roehrl and Riahi presents four scenarios based on a world with very rapid rates of economic and technological development that were developed with the IIASA modeling framework. These four scenarios explore different future structures of energy systems based on the same marker scenarios presented in the Jiang et al. article. The four scenarios with different energy systems structures are then used as alternative reference cases to analyze possible mitigation measures and policies that would lead to the stabilization of atmospheric concentrations of greenhouse gases at different levels. The article illustrates that technological uncertainty in the baseline emission scenarios has a far greater influence on the costs of meeting alternative CO_2 concentration targets than the magnitude of these targets themselves. With continued uncertainty in what these targets might look like, technology policy moves to the forefront of contingency planning and precautionary policies.

The fifth article by Sankovski et al. presents a set of scenarios developed by the ASF integrated modeling framework at ICF Consulting in the United States. The article presents the fourth marker scenario along with ASF versions of the other three presented in the previous five articles. It provides the quantitative descriptions of these four alternative future worlds described by the scenarios, as well as corresponding brief narrative scenario descriptions. They offer stylized "stories" of how these scenarios could unfold to complement the model quantifications and facilitate scenario interpretations.

The last article of this set, by Mori, presents scenarios developed by the integrated assessment model MARIA at the Science University of Tokyo. Three reference scenarios are based on the three marker scenarios presented in the previous articles. They are, in turn, used to elaborate six scenarios with mitigation policies and measures that lead to stabilization of atmospheric concentrations of greenhouse gases after the end of the next century.

This special issue concludes with two articles that review the emissions of the whole set of 30 scenarios in greater detail than the preceding six articles by individual modeling teams. The article by Fenhann describes the emissions of all GHGs, other than CO_2 and for all sources other than energy activities, for the four marker scenarios in a much greater detail than the previous articles. Emissions of these GHGs have an important role in future contributions toward global warming but are difficult to integrate in the formal modeling approaches that describe the emissions from other GHGs sources such as energy and land use. The article focuses on emissions of three groups of GHGs that include perfluorocarbons, sulfur hexafluoride, and hydrofluorocarbons; on emissions of ozone-depleting substances covered by the Montreal Protocol; and on the emissions of nitrous oxide from the production of adipic acid. It also describes the assumptions about the main driving forces of these emissions.

The last article in the issue, by Kram et al., summarizes the global and regional GHG and sulfur emissions of the 30 scenarios presented in the previous articles. First, it briefly presents the narrative stories behind the four families of scenarios and the ranges of the main driving forces that determine future emissions at global and regional levels — population growth, economic development, and energy requirements. It then presents global and regional emissions by main sources of carbon dioxide, methane, nitrous oxide, halocarbons, other halogenated gases, and sulfur dioxide. The study concludes by presenting derived characteristics of the set of scenarios, such as energy and carbon intensities and per capita levels.

Three more papers based on this collaborative study will be published in a future issue and are previewed here. The first of these three papers by Nakicenovic gives an overview of the emissions scenarios and summarizes the findings of the whole study. The paper outlines the motivation behind the development of the set of 30 emissions scenarios. It discusses the reasons why a whole set of scenarios was developed and why it would have been inappropriate to consider only one emissions scenario. The paper presents the ranges of greenhouse gas and sulfur emissions across the scenarios, the ranges of the main underlying driving forces, and concludes with a discussion of the implications for climate change.

The other two consider the climate change implications of the emissions scenarios in much greater detail. The article by Schlesinger et al. assesses the geographical distributions of articles temperature change that are related to the emissions of greenhouse gases and sulfur dioxide in the scenarios. The emissions of GHGs lead to global warming while the emissions of sulfur dioxide result in regional cooling. The geographical and time evolution of the changes in global-mean surface temperature and sea level are calculated for each of the four marker scenarios, presented in this special issue, by the modeling approach developed at the University of Illinois at Urbana-Champaign in the United States. The main conclusions are that the global-mean surface-air temperature changes are not distinguishable among the four prototype scenarios until the middle of the next century, that by 2100 the warming and sea-level rise range for the four scenarios from 1.2° C and 27 cm to 4.9° C and 72 cm, and that the uncertainty of future emissions across the scenarios results in large uncertainties about the geographical distribution of warming.

The last of the articles by Smith et al. also assesses the global climate change implications of the four marker scenarios with the reduced-form climate systems models used in the 1995 IPCC assessment [2, 3]. Total anthropogenic temperature change by the year 2100 ranges from 1.3 to 4.0° C for the upper and lower bounds on emissions from the scenarios and low and high values for the climate sensitivity, respectively. Thus, both of these papers indicate significant future climate change for all scenarios in the set, demonstrating that emissions mitigation and adaptation to climate change need to be considered as an important component of possible response strategies. It is noteworthy that this conclusion also applies to the scenario with the lowest emissions and with the assumption of low climate sensitivity to future increases in atmospheric concentrations of GHGs.

The authors of all 12 articles have benefitted enormously from the interaction and scientific contributions of the other members of the SRES writing team to the research

effort presented in this special issue and a later issue this year. Thus, the authors share the credit for the work described in this special issue with the whole SRES writing team, but they alone are responsible for the views and findings presented in this special issue and the 12 individual articles. The authors have also benefitted from the suggestions and comments received from the anonymous reviewers of these manuscripts.

Last but not least, thanks are due to Katalin Kuszko for helping with the production of this special issue, to Devin Wolfe for editing six of the manuscripts and other colleagues at IIASA for their support and assistance.

References

1. Alcamo, J., and Nakicenovic, N. (eds.): Long-term Greenhouse Gas Emission Scenarios and Their Driving Forces. *Mitigation and Adaptation Strategies for Global Change* 3(2–4), Special Issue, 1998.
2. Kattenberg, A., et al.: in *Climate Change 1995: The Science of Climate*. J. T. Houghton, et al., eds., Cambridge University Press, Cambridge, UK, 1996, pp. 285–357.
3. Harvey, D., Gregory, J., Hoffert, M., Jain, A., Lal, M., Leemans, R., Raper, S. C. B., Wigley, T. M. L., and de Wolde, J.: *An Introduction to Simple Climate Models Used in the IPCC Second Assessment Report*. IPCC Technical Paper II, J. T. Houghton, et al., Eds., IPCC, Geneva, Switzerland, 1997.