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A FRAMEWORK FOR SCENARIO GENERATION FOR CO2 GAMING

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PREFACE

The Resources and Environment (REN) Area Task on Global Climate and the Management and Technology (MMT) Area activities on risk management and operational gaming are cooperating in the investigation of societal responses to the possibility of CO2-induced climatic change through a gaming approach. The carbon and climate gaming effort began in March of 1980 and is expected to culminate with gaming experiments in the latter part of 1981. Three working papers describing the effort have been published previously. "Carbon and Climate Gaming" (J. Ausubel, J. Lathrop, I. Stahl, and J. Robinson, WP-80-152) offers the basic arguments in favor of a gaming approach and outlines briefly the two proposed games. "CO2: An Introduction and Possible Board Game" (J. Ausubel, WP-80-153) sketches the CO2 issue in non-technical terms, describes the objectives and a possible design for the board game, and includes a tentative listing of spaces for the game. "An Interactive Model for Determining Coal Costs for a CO2-Game" (I. Stahl, WP-80-154) explains further the reasons for emphasizing coal mining, combustion, and world coal trade in CO2 gaming, and presents a model which begins the incorporation of the coal economy into the computer-based game. This Working Paper develops a framework for the generation of integrated scenarios of carbon use and climatic impacts in the computer-based game and for strengthening the design of the board in the board game. The paper also seeks the assistance of readers in the further elaboration of several aspects of game design.

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Jennifer Robinson and Jesse Ausubel

INTRODUCTION

The basic structure of the issue of carbon dioxide and climatic change has been apparent for a long time. A generation ago Revelle and Suess (1957) recognized that,

> During the next few decades the rate of combustion of fossil fuels will continue to increase, if the fuel and power requirements of our world-wide industrial civilization continue to rise exponentially...(H)uman beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future. Within a few centuries we are returning to the atmosphere and oceans the concentrated organic carbon stored in sedimentary rocks over hundreds of millions of years.

In the past two decades the experiment has continued as Revelle and Suess foresaw.

Is mankind making a wise decision in continuing this global experiment? Will we accelerate it, or will it not occur for one reason or another? The carbon dioxide question has remained a vexing one through recent years in spite of considerable research to estimate better its seriousness. Partly this is because of large scientific uncertainties, but it is equally because of inadequate efforts to explore more thoroughly the character of a greatly expanded carbon economy (particularly coal) and because of an inability to assess the impacts of climate on human activity and the environment. Not least, it is because of failures to link these

these various aspects of an assessment together.

Information on the CO_2 question and climatic change remains widely scattered. Efforts to integrate, to describe plausible sequences of how climatic change or CO_2 related events will unfold have not been very successful (d'Arge et al. (1975), MITRE (1977), SRI (1977), National Defense University (1978) Aspen (1980)). Yet, research which gathers and synthesizes information and puts both findings and uncertainties in perspective is greatly needed, when there is a broad and confusing expanse of possible physical states associated with CO_2 increase and designing research on constructive societal responses to possible physical changes is in a formative stage. As long as the basis for a more definitive method of assessment of the CO_2 issue is lacking, there may be an irreplaceable role for analysis of "scenarios," or reasonable, coherent, sometimes qualitative depictions of projected developments (Epple and Lave, 1980). However, development of a single detailed scenario may be as misleading as illuminating (AAAS, 1979). Too often the single scenario is treated as a prediction.

Gaming appears to offer a flexible way to generate and explore CO_2 scenarios. A play of a game can constitute a CO_2 scenario by creating a sequence of possible events associated with development of the carbon economy and climatic change. Arguments for the use of a gaming approach have been presented in fuller form elsewhere (Ausubel et al., 1980), and only the broad rationale will be repeated here.

To judge from our initial experience, gaming offers three broad categories of benefits. One is that the construction of the games is enlightening as an exercise in model building and scenario generation. Game development stimulates advances in the collection and organization of information, for example, on impacts of climatic change. Moreover, gaming requires an attempt to integrate formally the carbon economy, the scientific issues of the carbon cycle and climatic change, and the impacts on society of increased concentrations of CO_2 and altered patterns of climate. A major opportunity for research into the CO_2 issue lies in looking at the non-climate implications which are consistent with the assumptions which also create a CO_2-induced climate problem. The gaming approach encourages consideration of the implications of a greatly expanded carbon economy which will come along with the focal issue of climatic change; for example, questions about employment, transportation, and technology in the coal industry naturally arise.

The second category of benefits is that the playing of the games offers insights into strategic and behavioral aspects of the question. To illustrate further, the proposed gaming begins with incorporation of mechanisms for the generation of CO_2, so one can explore at what rates of growth CO_2 becomes a serious problem and what sources, by both fuel and national origin, are crucial to its coming into existence. The presence of actual human players in this process allows inquiry into the possible strategic behavior of nations with respect to their carbon wealth and carbon demand. For example, will coal cartels tend to form? The gaming also allows one to test hypotheses about the importance of scientific uncertainties for societal response. "States of nature" relating to, for example, the size of the airborne fraction or the extent of climatic change associated with different levels of atmospheric carbon can be used to assess the sensitivity of societal response to the resolution of these uncertainties in various ways. Similarly, which aspects aspects of climatic change are perceived as posing serious risks?

The third type of benefit is educational. Along with what the game designers learn from the construction and play of a game, the players learn about the issues at hand. While gaming will also not produce an "answer" to the CO2 question, it can assist the development of plausible expectations with respect to how CO2-induced climatic change may unfold. It appears to offer a fruitful approach to the generation and exploration of scenarios of carbon dioxide and climatic change. One hopes that such exercises will be a useful tool in the evolution of prudent policies for long-term management of the earth's carbon resources.

THE TWO PROPOSED GAMES

Games with various purposes, levels of complexity, and substantive emphases can be envisioned. IIASA's carbon and climate gaming activity is concentrating on the development of two complementary games. One is a relatively simple board game, with emphasis on educational objectives through identification in discreet form of events and processes related to climatic change and societal responses to it. The second game, which is computer based, will attempt to describe more continuously and with more quantitative accuracy the economics and geopolitics of carbon combustion, as well as the impacts of CO2 emissions on climate and society. The computer game is being designed to yield tentative answers to several outstanding CO2 issues and to be useful in improving research design in a complex and confusing research environment.

The board game is intended as a tool to spread understanding of the CO2 issue within and beyond the technical community. Such a tool appears desirable because of the interdisciplinary nature of the CO2 issue and because of the potential importance of the issue to global development. To be an effective educational device, the board game should be of a form that can be distributed on a wide scale. It must be transparent and self-explanatory, so that it can be played without a professional game leader. It must be interesting, so that people will want to play it. Its content need not be highly detailed, but it should serve to organize images of the future in a way that is consistent with scientific understanding.

A preliminary version of the board game (Ausubel, 1980) has been constructed and played several times at IIASA and elsewhere. Even now the board game shows promise of going beyond its intended educational functions and serving a useful research function as well. It is quite effective as a tool for integrating the widely scattered literature on the CO2 issue. It moves from fragmented discussion of impacts on specific crops or sectors, or in diverse geographical areas, toward a comprehensive listing of relevant events and phenomena, organized in a chronological sequence. Such listings are conspicuously absent from the literature.

In addition to identification of basic elements of the CO_2 issue, it is desirable for the gaming to educate people on several dynamic aspects of the CO_2 question. These include:

- how much carbon wealth various nations have to sell or burn;
- how much CO_2 different nations may emit each year;
- how the volume of emissions can be expected to change over time, particularly under conditions of exponential growth;
- how much of the carbon which is emitted remains airborne;
- what magnitudes of climatic change are to be expected with different increases in atmospheric carbon.

The preliminary version of the board game, however, falls short in some of these areas, partly because it is difficult to use real physical units consistently within a completely manual format. Because of the limitations of the manual format of the board game, it is important that the computer game treat these questions in a more sophisticated fashion.

Both the board game and the computer game can be thought of as consisting of essentially two modules, one a "carbon economy" module and one a "CO_2 impacts" module. A simplified form of the overall structure of the games can be pictured this way:

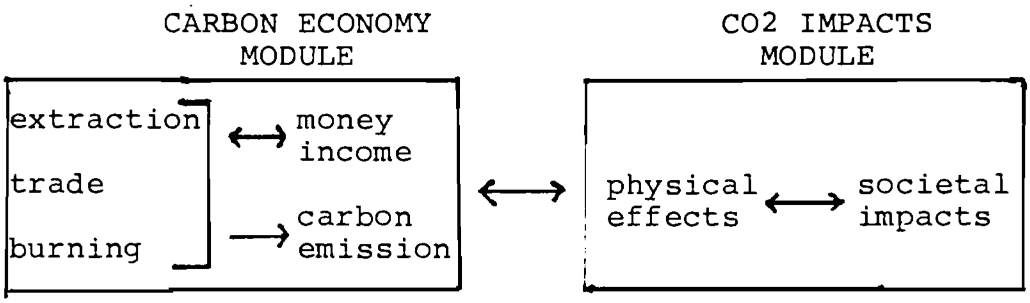

Figure 1: Overall structure of the games

In the board game the carbon economy module is embodied in a simple device to generate economic growth and in "chance" type cards whose appearance in each round may offer players an opportunity to reshape their energy strategies. Impacts, which appear as event spaces on the board that "happen" when players land on them, receive the bulk of the attention.

In the computer game, both the carbon economy module and the CO_2 impacts module will be made more detailed and realistic than they are in the board game. The carbon economy module will be extended to carbon extraction, trade, and emissions for several countries. The impacts module will also be much more specific with respect to timing, levels of atmospheric CO_2, and estimates of costs and benefits related to CO_2. For each country represented, the computer game will keep simple accounts, designed in a way that monetary impacts of climatic change (calculated in the impacts module) can be registered, along with the costs of expenditures made to avert or compensate for the CO_2 problem.

The two modules are being developed separately and will eventually be linked. When this is done, the resulting configuration will probably be along the lines shown in Figure 2. In such a full configuration the carbon economy module passes information on carbon usage to the CO2 impacts module, which calculates an increase in atmospheric carbon. Increase in atmospheric carbon advances play. Events, including CO2-induced impacts, resolution of scientific uncertainties, exogenous events, and opportunities to prevent, adapt to, and compensate for CO2 effects ensue according to the level of atmospheric CO2 arrived at. These feed back to the carbon economy module as factors that increase or decrease national wealth and as stimuli to alter energy strategy.

In the computer game, the extraction, trade, and burning of carbon and the societal impacts areas will receive considerable attention, because these are heretofore insufficiently developed in regard to CO2 research. Development has so far focused on the coal aspect of the carbon economy and the origins of a potential CO2 problem. Improvement in understanding of the role of coal in the CO2 issue is a major emphasis of the computer game effort. An interactive routine for estimating coal costs for the computer game has been demonstrated (Stahl, 1980) and will be refined. Questions of income, carbon emissions (carbon fractions and so forth), and physical (climatic) effects are modeled in considerable detail elsewhere and will be dealt with in the computer game in simplified form based on review of existing work. Most of this paper deals with the development of the representation of the impacts of CO2-induced changes and societal responses to them and with the integration of these into a workable overall structure.

A FRAMEWORK FOR SCENARIO GENERATION

The method used here to advance the game design is the construction of a framework for scenario generation. The framework is a transitional device. It is not expected to be fully dynamic or "playable" in the sense that the board game and computer game will be. Rather, it is a device for interactive simulation which will allow convenient development of components for the games. The framework described below builds from the base already developed in the preliminary board game toward a computerized formulation that uses real units and has the potential to organize a larger amount of information in a more powerful fashion. Out of this framework, the CO2 impacts module for the full computer game should develop. At the same time, the concepts developed below will serve to strengthen the underlying rationale of the board game and improve its design. The key problem is to move toward greater realism and consistency, without establishing a structure which is unwieldy.

The framework needs to be formulated in such a way that it can accept information about physical quantities of coal and other carbon fuels burned from the carbon economy module. In return, it must be able to give to the carbon economy module monetary estimates of the costs and benefits of climatic change, as well as certain other information implied by changing levels of CO2.

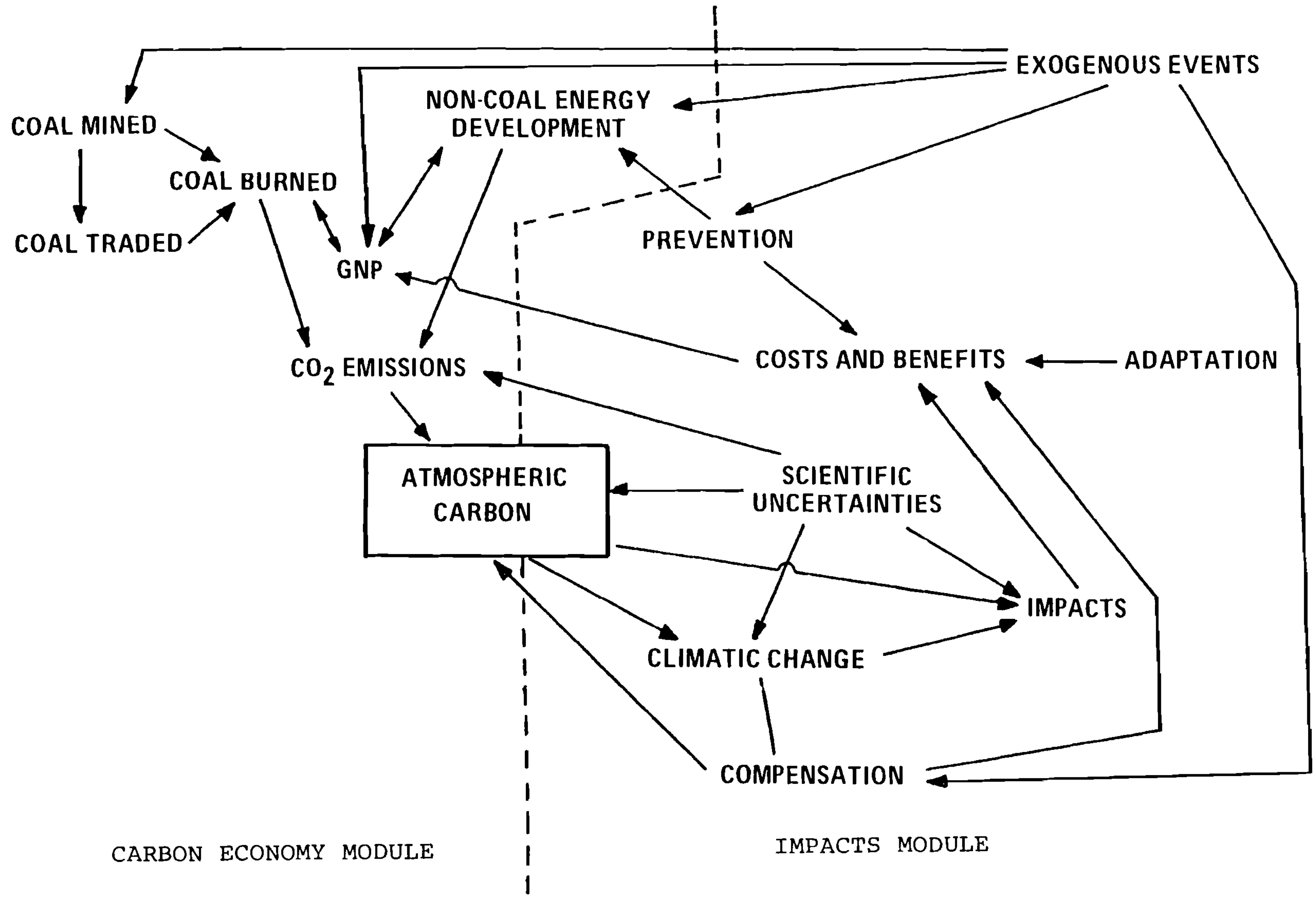

Figure 2: Full configuration of CO_2 issue.

The framework is derived from the preliminary board game by:

[1] changing its ambiguously scaled event spaces (spaces somewhat akin to the spaces in a game like "Monopoly") to spaces corresponding to specific levels of atmospheric carbon; and

[2] scaling the fictitious units the board game uses for players' costs and benefits to correspond to real data from national accounts and projected costs and benefits of carbon economy related events.

The eventual carbon economy module will use realistic money units, and will contain a rough accounting of national income and wealth. Counting costs and benefits in actual money terms in the impacts module should allow a reasonable link with the carbon economy module. For example, in the situation where increased CO_2 improves photosynthetic efficiency, the impacts module could pass hypothetical figures for increased agricultural income to the accounting section of the carbon economy module. (After some initial estimates of impacts, the preliminary version of the board game will be revised to reflect better the findings about probable magnitudes of costs and benefits.) The carbon economy module will track extraction, trade, and burning in physical quantities of carbon. Indexing the framework in physical terms allows linking of specific physical states with projected events.

The framework is built around atmospheric carbon, measured in gigatons of elemental carbon (gigaton = billion metric tons, abbreviated gT C). Atmospheric carbon has been chosen as the main index because it is the central physical parameter of the CO_2 question. The position of atmospheric carbon is an important feature of the framework. Neither our forecasts nor our scientific undertanding of the CO_2 question is secure enough to specify at exactly what *time* various events will occur. While still uncertain, it may be reasonable to link certain events to certain levels of CO_2, more so than it is to link them directly to time. For example, impacts of climatic change (thawing of permafrost, changing growing seasons, possible collapse of the West Antarctic Ice Sheet) and policy measures that might be used to prevent, compensate for, or adapt to CO_2-induced climatic change (reforestation, restrictions on fossil fuel use) might be tentatively indexed to levels of CO_2. For example, some events may seem likely to occur around a 50% increase, some around a doubling, some around a tripling.

Using cumulative carbon emissions as an index was also considered. This would link play more closely to carbon resources and world energy demand, but it was decided against on the grounds that CO_2 impacts are more directly related to atmospheric carbon values. A board calibrated in units of atmospheric carbon permits easier translation from the board location to changes in temperature and other climatic parameters, as predicted by physical models of the atmosphere. (Using temperature as the main physical index is tempting because of the extensive literature, but it is obviously too limited for our purposes.) Moreover, atmospheric carbon is an actual measurable physical quantity, while cumulative emissions is a mathematical concept for which measurements remain imprecise. Atmospheric carbon in gT is chosen rather than parts per million (ppm), the measure of atmospheric carbon most often used by atmospheric scientists, because carbon weights are a common denominator for stocks of fossil fuel, the biosphere, and carbon dioxide. It will be easy, in the computer game, to present ppm's and gT C simultaneously, thus conferring upon the game an incidental benefit of familiarizing players with the conversion rate.

BOARD LAYOUT

The framework is visually centered on a representation of the atmosphere gradually holding more and more carbon. For practical purposes, this can be pictured as a board or screen. As play progresses, players emit carbon into the atmosphere, and the atmosphere board fills up with marks or chips representing carbon. Events are triggered by the arrival of play at different levels of atmospheric carbon.

The board is a common. Each player, when taking a turn, registers the emissions of one period of economic activity on the board and thus changes the state of nature for all players. The structure is a variant of the "Tragedy of the Commons," in which potential costs and benefits are not known in advance and are unevenly distributed among players.

The following section describes the atmosphere board, how it is scaled, what is on it, and how it operates in game play. It is followed by a sample exercise. Board details will almost certainly change during the course of implementation of the computer game; not everything stated below will remain true in later versions of the impact module. However, the main structure should carry over.

SPACES AND BLOCKS

Our first version of the board consists of 1600 numbered "spaces," each representing 1 gT C. These spaces are numbered from 600 gT, the estimated weight of atmospheric carbon before the industrial revolution, to 2199 gT C, about a tripling of current (1981) values. Thus, the board shows a range of atmospheric carbon values which imply a significant warming. A doubling over present atmospheric carbon values suggests an increase in global mean temperature of about 2 to 3.5 degrees centigrade. Even with relatively conservative assumptions, a tripling seems likely to lead to a warming which could be associated with significant changes in the Antarctic ice cover and possible changes in sea level. The *game* begins at the current level of a little over 700 gT C; the *board* begins at 600 gT C in order to suggest the consequences of economic activity of the past century and to contrast the past rate of emissions with that in the present and future. That is, if exponential growth continues, the board will graphically show the rapidity with which the absorbtive capacity of the atmosphere is used.

If the board is to represent 1600 gT C, a 40 x 40 square matrix is convenient. As indicated, each cell of this matrix is referred to as a space. Referring to 1600 spaces can be clumsy, so the spaces are organized into 16 "blocks" of 100 spaces each. We will refer to these by gT values of atmospheric carbon, the first being the 600 gT block, the next the 700 block, and so forth. Using this convention, one would say that at present the earth is in the 700 block; a doubling of atmospheric carbon will advance us to the 1400 block. This division gives the board a layout as shown in figure 3.

*1 600	*2 700	800	900
1000	1100	1200	1300
*3 1400	1500	1600	1700
1800	1900	2000	*4 2100

Figure 3: Block layout of atmosphere board. *1 indicates the pre-industrial level of atmospheric CO2, *2 the current level, *3 the doubling level, and *4 a tripling.

The size of units within a block should be sufficiently small to describe the amounts players can be expected to be emitting. It could be varied, depending on whether players were representing the globe, regions, or nations, and whether game decisions are made on a one, five, or ten year basis. As a first experiment, we have adopted a resolution of one space per gT C. This is simple and provides fine enough resolution to show carbon added under various situations interesting for simulation. For example, it would be adequate to show one global player making decisions on an annual basis. (Current global carbon emissions are estimated at a little over 5 gT C per year, of which about half appears to remain airborne.) This resolution would also be appropriate for a gaming situation with large and medium sized nations making emissions calculations on a 10 year basis. For later development of the module for more players and different time periods the number of blocks can be changed or the spaces can be rescaled or subdivided.

TYPES OF SPACES

Each of the spaces is associated with what we shall refer to for purposes of convenience as an "event." In fact, these may be not only events, but also various kinds of opportunities, processes, or trends. An event "happens" when the number of gT C in the atmosphere equals the number of the space on the board. Based on Meyer-Abich (1980) and Ausubel (1980a, 1980b), six kinds of events are distinguished. These are:

[1] *Impacts of climatic change* (I). These spaces describe the impacts of climatic change and increased CO_2 concentrations. They include impacts on agriculture, water resources, health, and so forth. These can be positive or negative, according to the player's location on the board and a chance variable. Impact spaces may affect one or all players (i.e., nations), and may affect different players differently. While called "impacts," the role of these spaces in the game is not unidirectional, as the costs and benefits arising from them interact with the economic base from which other decisions are made.

[2] *Opportunities for adaptation* (A). On these spaces players can purchase adaptive measures that will mitigate later adverse impacts of climatic change. Early on there are opportunities to purchase assessment reports and sponsor CO_2 research. Later there are opportunities to make agricultural systems more resilient by developing drought resistent crop strains, to redesign hydrologic systems so as to buffer against changes in precipitation, and the like.

[3] *Opportunities for prevention* (P). On these spaces players are offered means for reducing carbon emissions by preventing them at the origin, that is, by changing economic activity so less CO_2 is generated in the first place. For example, there are opportunities to invest in conservation, nuclear, solar, and hydro energy, and to explore for natural gas (which emits less CO_2 per unit energy than other carbon fuels). Eventually in the computer game these will be linked to the coal decisions in the carbon economy module, so that in effect one of these will come up every round. It is an open design question whether a prevention opportunity should be included in every turn in the board game.

[4] *Opportunities for compensation* (C). Here players, having allowed generation of CO_2, can take measures either individually or cooperatively to reduce levels of atmospheric carbon or other measures which physically compensate for climatic change. These include, for example, planting trees to increase biotic CO_2 removals and engaging in weather modification.

[5] *Resolution of scientific uncertainties* (S). On these spaces more conclusive findings are provided for various natural and physical questions. For example, answers are offered about:

- how precipitation change associated with CO_2 increase will be distributed;
- how much heat and carbon the oceans can absorb; and,
- to what extent other trace gases such as N_2O and chlorofluorocarbons will compound the greenhouse effect;

Resolution of these uncertainties may have political, strategic, or economic ramifications.

It should be noted that the precise ways in which the resolution of scientific uncertainties will be represented in the game remains an open question. Realistically, what they should affect is the players' *knowledge* of the rules by which the game is being played, not the rules themselves. By affecting players' knowledge, the resolution of the scientific controversies may have various effects. These need not be prescribed in the event spaces. For example, if resolution of scientific uncertainty shows that a player's agricultural lands will become arid, the player may then perceive that he has an increased interest in reducing global emissions. How he uses this information is up to him.

This approach will require thoughtful examination of the set of scientific uncertainties in terms of their character in both the real world and a gaming simulation. For example, the fraction of emissions remaining airborne is a critical system parameter about which there is currently great uncertainty. As the framework stands, players can estimate the atmospheric fraction simply by dividing the known global fossil emissions by the amount added to the atmosphere in the period. In this case, a way for the game directors to introduce scientific uncertainty may be to add some undisclosed amount of emissions to the atmosphere by sources other than known fossil fuel emissions, and let this number be better defined as play progresses; this would be a fairly realistic representation.

[6] *Exogenous events* (X). On these spaces events occur which are not directly part of the carbon cycle or climatic change, but which can significantly impinge on the well-being and policies of the players. They include, for example, depression, war, strengthening of international institutions, technological breakthroughs, and so forth.

A sample listing of around 80 events grouped into the six above categories is presented in the Appendix of this paper. A major task is to expand the information on the events with respect to relevance to specific countries which will be represented by players in the game, in terms of appropriate frequency of appearance at various levels of atmospheric carbon, and in terms of magnitude (in monetary or other terms). The catalogue of events in the computer game could be larger and more detailed than that developed for the board game, and the functions describing costs and benefits can be more refined and complex. For instance, with help from a computer, delayed impacts and interactions among impacts could be represented. Assistance from readers is sought on elaborating the events to an appropriate degree.

DISTRIBUTION OF EVENT CATEGORIES

It is clear that a key issue in the construction of the games (or any scenario oriented exercise) is the sequence of events and types of events to be faced in each period. It is extremely difficult to associate events or opportunities directly with time periods (e.g. the decade 2020-2030), because we do not know in advance of playing the game at what rate emissions will occur. (The same holds true in the real problem.) However, as suggested above, it may be possible, though highly speculative, to associate different events and opportunities with different levels of carbon in the atmosphere. From a practical point of view, this question may be seen as deciding on the distribution of event categories within any block of the atmospheric carbon board. In a sense, this judgement also establishes the basis of the probabilistic model proposed in Ausubel et al. (1980). While recognizing that not every space will be encountered, one should be able to propose tentatively that each given block might be characterized by, for example, a preponderance of impacts spaces or of spaces where scientific uncertainties are resolved. What follows are some arguments for overall distribution patterns for each category of event and possible relative shares of spaces over the proposed range of atmospheric carbon.

Both the distribution of events and the costs and benefits associated with them will vary as atmospheric carbon increases. For example, in the 700 block, where play begins (at present, in 1981, there are around 710 gT C in the atmosphere), impacts are few and inconsequential, while opportunities for prevention are relatively abundant. By the 1400 block, with double present values of atmospheric carbon, impacts should be prominent: deserts may be turning to cropland, cropland to desert, tundra to boreal forest, and icefields into open ocean. Clearly, a varity of changing distributions of spaces might be proposed. What follows are some opening arguments for overall distribution patterns for each category of event and possible relative shares of spaces over the proposed range of atmospheric carbon.

> *Impact* spaces barely appear before the 900 block. Before that time climatic phenomena are of "normal" dimensions, and in any case human-induced effects can hardly be distinguished from natural variation, as the CO_2 signal-to-noise ratio is low. Around the 1000 block, with roughly 50 percent more carbon in the atmosphere than at present, impacts begin to become more pronounced and attributable to CO_2. Their frequency and the amount of attention given to them increase until around the 1400 block (a doubling over present levels). Thereafter, society is accustomed to anticipating climatic change, and attention to the CO_2 problem levels off. After this, the number of impact spaces declines slightly, under an assumption that the magnitude of impacts may increase, but the kinds of impacts will not. However, at very high levels of atmospheric carbon it may be that the frequency of impact spaces should again increase, as new possibilities like an ice free Arctic and a collapse of the West Antarctic Ice Sheet increase in probability.

Adaptation spaces exist at a steady level at the beginning. These early spaces would mostly consist of opportunities for research and building resilience. As the level of atmospheric carbon rises and impacts begin to occur, ways to adapt become more apparent, and more opportunities for adaptation appear. As the level continues to rise, the possibilities for adaptation remain quite high but tend to lag behind the multitude of impacts. When the problem has been around for a long while, societies become more attuned to changing climatic regimes, and new opportunities for adaptation diminish. The overall pattern of adaptation bulges, as an indication of transition or adjustment costs.

Prevention spaces are common in the beginning of play, while the successor to the oil economy is being nominated and built into social and economic infrastructures. Once new energy sources gain momentum, the pattern becomes less flexible, and there are fewer options for averting CO_2 buildup by relinquishing fossil fuel usage. Given the long market penetration times of energy systems, it seems reasonable to assume that if choices are not made by the time the level of atmospheric carbon increases by about 50%, fewer opportunities for prevention will arise, and they will be less effective.

Compensation spaces are always present, but never common, due to constraints on this strategy. Initially lack of mechanisms for international cooperation and pressures for use of the biosphere for food, firewood, and fiber limit opportunities. However, as the CO_2 question becomes more serious, new chances for biospheric (especially terrestrial) solutions appear. These are no longer on an appropriate scale once the level of atmospheric carbon becomes high, so the spaces again become infrequent. At very high levels of carbon emissions and atmospheric carbon new opportunities arise, as technological solutions (gigamixer, methane capture) gain greater consideration.

Resolution of *scientific uncertainties* is extremely important in the first 300 gT increase in atmospheric carbon. In the 700, 800, and 900 blocks, the signal-to-noise ratio increases, and scientists are able to answer questions they are now asking about atmospheric and carbon cycle behavior. At around the time the signal to noise ratio improves, the frequency of this category of event diminishes drastically. At the doubling level the climate behaves about in accord with the "state of nature" set by these early resolutions. At very high levels, new uncertainties arise, particularly in relation to the West Antarctic Ice Sheet.

Exogenous event spaces are most frequent early on, as at the beginning of the game the CO_2 problem is relatively unimportant for national and global development and easily dominated by other events. As atmospheric carbon increases, and the physical situation departs more and more from recent history, the relative importance of CO_2 related events and decisions grows. At high levels of atmospheric carbon, exogenous events become infrequent in the game.

Figures 4 and 5 offer a graphic representation corresponding to these arguments of the hypothetical frequency of occurrence of the game event categories as CO2 concentration increases. *The authors sincerely request readers to consider this distribution of event categories. The distribution is critical to which hypotheses the game is capable of testing and what the results of play will be, that is, what scenarios will be generated and explored. Figures 6 and 7 have been left blank, and readers are invited to fill them in according to their own judgement. Please send us your comments and ideas.*

TOWARD USING THE FRAMEWORK

To begin to test the framework, we propose an extremely simple model of CO2 emissions and economic growth, which can be linked to the impacts module through the atmosphere board. Once the carbon economy module is developed, it will replace the crude treatment of the question offered below.

Emissions of CO2 are calculated by assuming that players' carbon emissions are proportional to GNP. The relationship is variable and subject to modification by deliberate measures to reduce emissions, as well as through exogenous events (X spaces). While GNP growth is assumed to be exponential, GNP is also increased or reduced by costs and benefits arising from policy expenditures (P, A, and C spaces), impacts of climatic change (I spaces), and exogenous events (X spaces). We will initially incorporate one uncertainty about the "state of nature," that relating to the fraction of carbon emissions which remains airborne. Estimates of this parameter range widely (World Climate Programme, 1980). The range for the game might be 0.43 to 0.65, and it can be set within that range by the game directors to look at implications for the way the game develops. This rudimentary model is described below in a mixture of English and algebra:

$$GNP(t) = (GNP(t-1) - nb(t-1)) * eg(t)$$

GNP(t) = gross national product in given time period
nb(t) = net of costs and benefits from events (I spaces, etc.) of time period
eg = economic growth factor (for example, 1 + growth rate in percent)

$$CE(t) = GNP(t) * cr(t)$$

CE = carbon emissions (gT)
cr = carbon to real GNP ratio in gT C emitted per trillion dollars

$$cr(t) = cr(t-1) * pe(t) * f[tb(t)]$$

pe = prevention effect
tb = technological breakthrough from exogenous event (X) spaces

HYPOTHETICAL FREQUENCY OF OCCURRENCE
OF GAME EVENT CATEGORIES

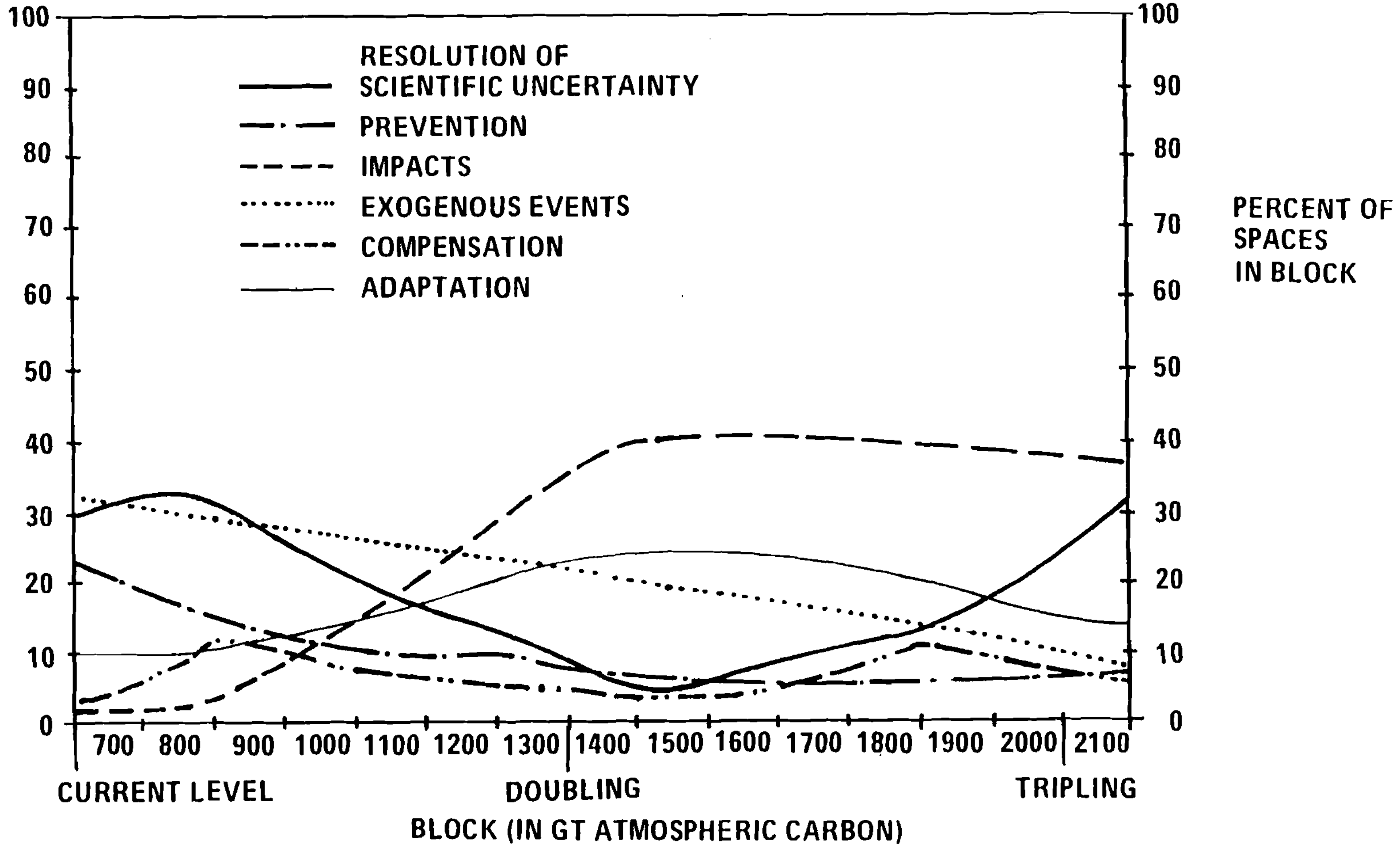

Figure 4

HYPOTHETICAL FREQUENCY OF OCCURRENCE OF GAME EVENT CATEGORIES
(CUMULATIVE SHARES)

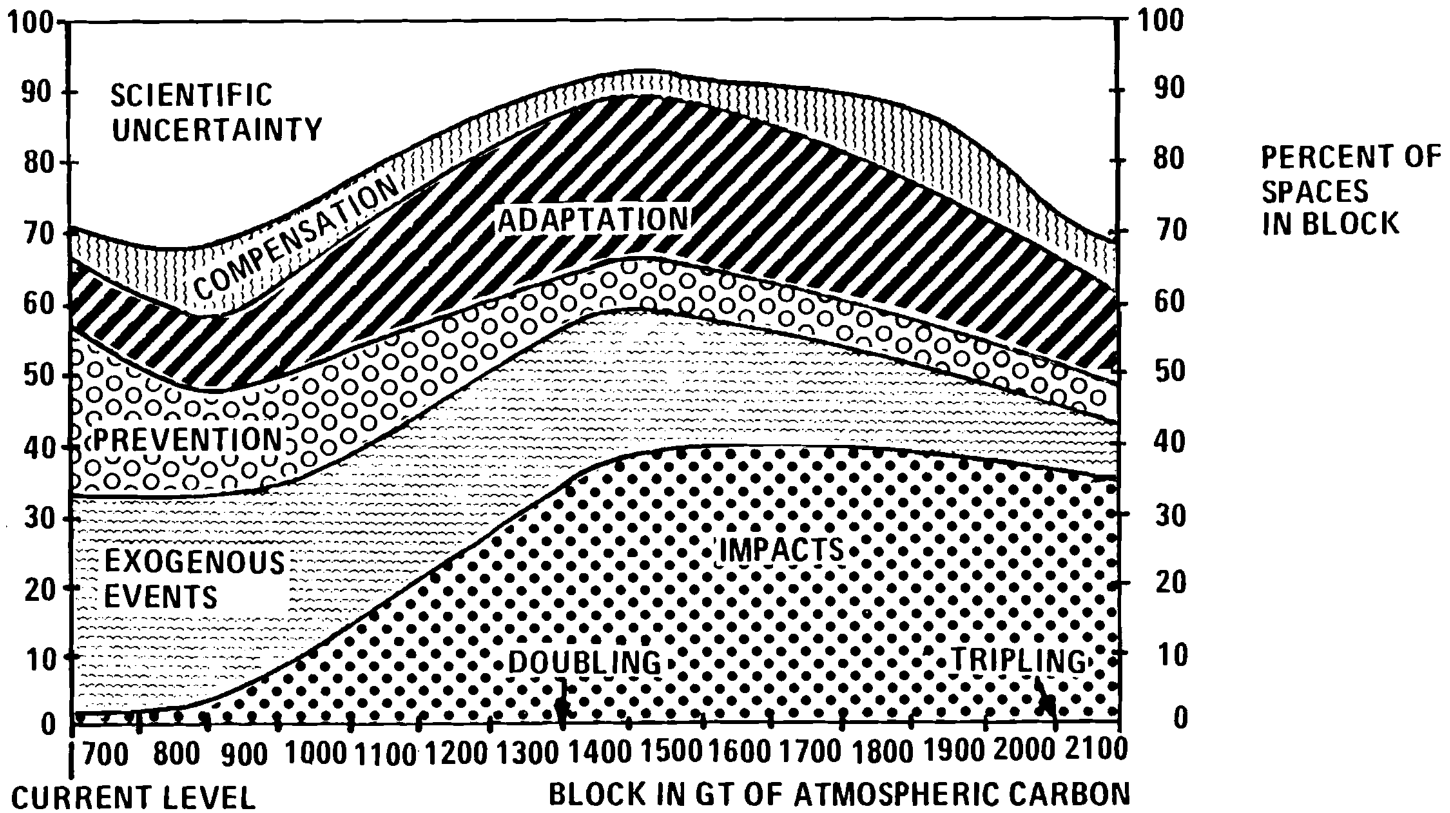

Figure 5

HYPOTHETICAL FREQUENCY OF OCCURRENCE
OF GAME EVENT CATEGORIES

IMPACTS (I)

ADAPTATION (A)

PREVENTION (P)

COMPENSATION (Ç)

SCIENTIFIC (S)
UNCERTAINTIES

EXOGENOUS
EVENTS (X)

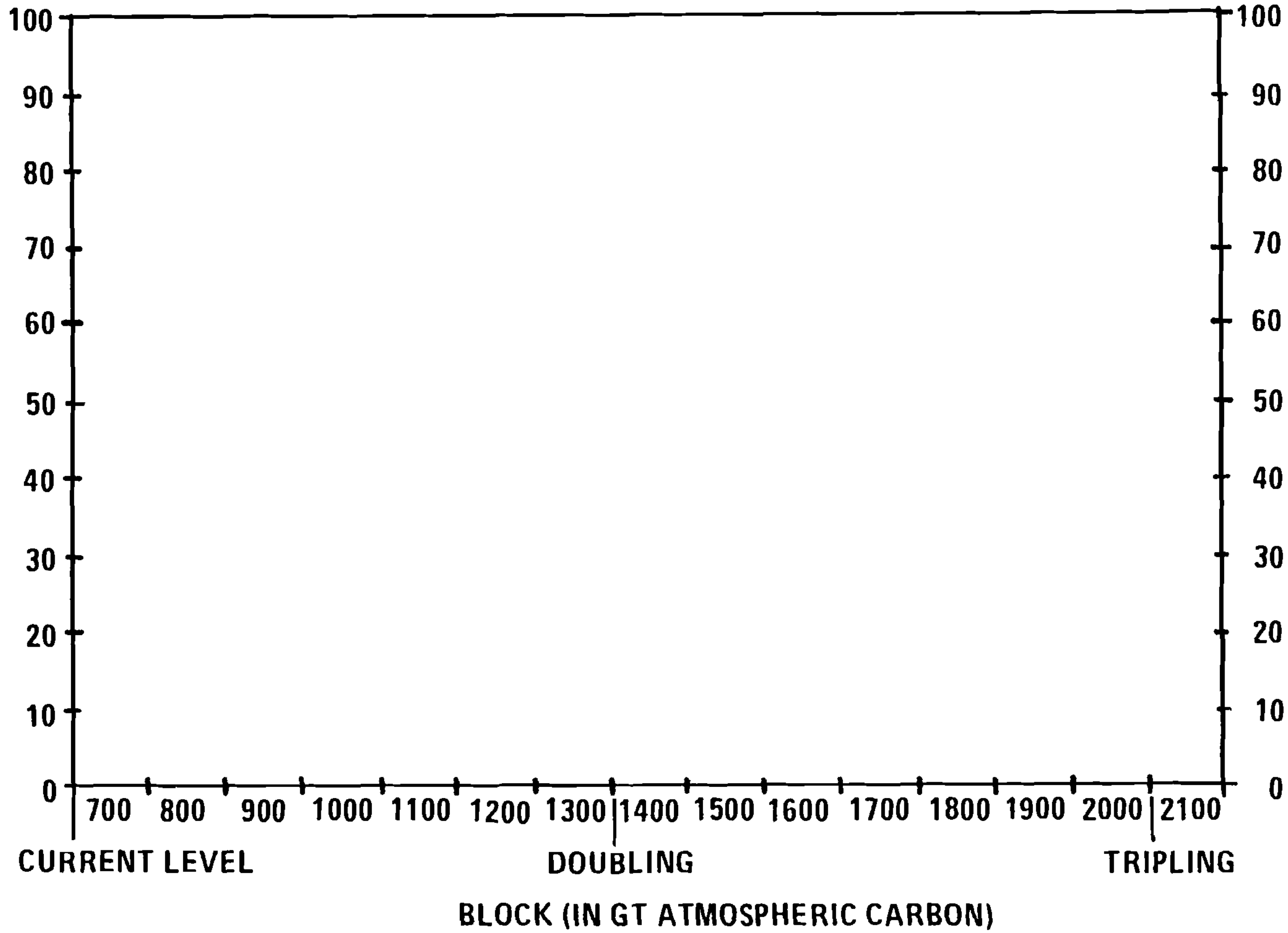

Figure 6

HYPOTHETICAL FREQUENCY OF OCCURRENCE OF GAME EVENT CATEGORIES
(cumulative shares)

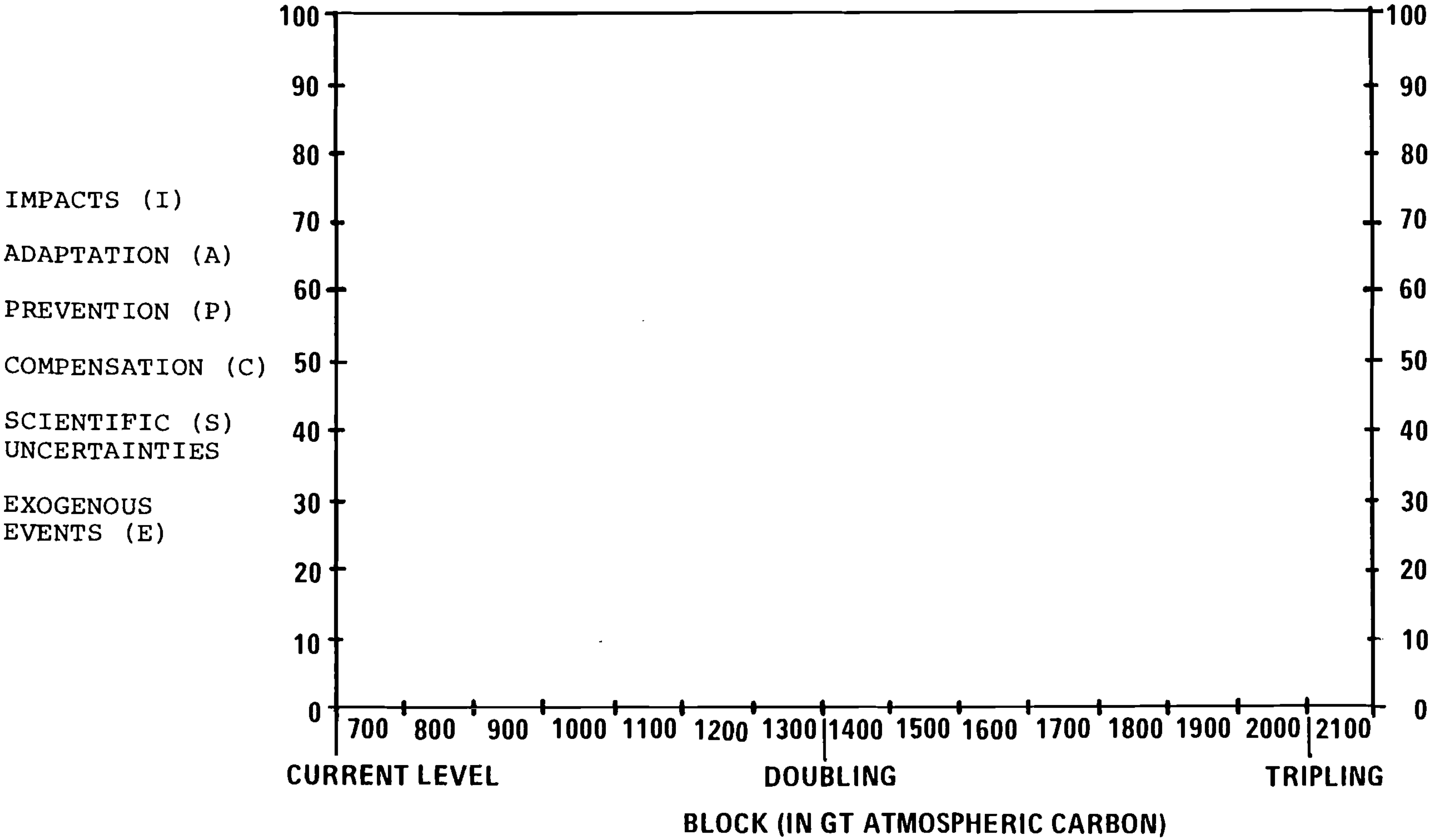

Figure 7

$pe(t) = g[pe(t-1), pp(t-1)]$

pp = prevention purchases from P space opportunities

$AC(t) = AC(t-1) + (CE(t) * a)$

AC = atmospheric carbon (gT)

a = fraction of emissions remaining airborne

As indicated above, the ratio of carbon emissions to GNP may vary from historically existing values through prevention measures, such as adoption of non-fossil fuel strategies (P space purchases) or through technological breakthroughs coming from X spaces. Prevention effects and effects from technological breakthroughs are carried over into the next time period. (A lifestyle change representing shift of values to less energy intensive goods and services might also be entered here as an X space outcome.) How to establish GNP growth rates remains a question. The rates of change could be held constant; they could be changed by players' decisions; they could take a random form, obtained by spin of a wheel or, in computerized version, by use of a random number generator. A multiplier needs to be devised to represent increasing costs and benefits for impacts spaces as the atmospheric carbon level increases.

A SAMPLE EXERCISE

This section presents an example of how the framework might operate using the extremely simple carbon emissions model described above. The results of what is sketched here are obviously not valid research findings; rather, the immediate effort is undertaken primarily for identifying what structural improvements need to be made, what data are desired, and for acquiring experience in scenario generation and exploration.

The exercise uses one of the framework's sixteen blocks, the 1000 block, which corresponds to an atmospheric CO_2 level about 50% higher than today. A tentative board layout for this block is shown in Figure 8. The letters and subscripts in the 100 spaces on the board refer to the events listed in the Appendix. For example, S_2, the last space in the block, refers to Scientific Uncertainty #2, anthropogenic effects on climate other than CO_2. The frequency of types of spaces (I, A, P, C, S, X) corresponds to that shown in Figures 5 and 6. Of course, not all the events listed in the appendix are included in the 1000 block. For example, because there are no serious predictions that the West Antarctic Ice Sheet will collapse because of a warming induced by this level of CO_2, the impact space representing this event does not appear in the block. The order of events within the block is largely random. For example, S2 could equally be in the first or the fifty-second space, as in the last.

P_{10}	S_1	A_2	C_1	I_{10}	S_6	P_5	C_2	X_1	I_9
S_6	X_2	C_1	P_3	X_3	I_4	S_5	P_2	X_{13}	S_2
X_9	X_5	A_2	S_1	C_2	P_7	P_1	A_6	A_3	S_5
S_4	C_3	X_{16}	I_1	X_6	S_3	A_7	X_{12}	C_1	I_5
X_{18}	S_8	A_1	P_9	S_2	C_1	P_6	X_7	S_7	S_2
S_4	P_4	X_{13}	S_3	X_8	S_1	A_7	I_{18}	P_7	A_5
A_4	I_3	A_6	P_3	X_9	S_7	C_5	X_{13}	P_1	A_8
P_2	X_{10}	A_5	X_{11}	I_6	I_7	X_{12}	A_1	S_4	S_1
S_3	A_7	X_{14}	S_2	X_{10}	X_{15}	A_4	I_2	X_{17}	A_8
P_8	S_4	I_6	X_6	S_3	I_{11}	X_2	C_4	X_9	S_2

Figure 8: Example of possible layout for the 1000 block of the atmosphere board. 12 percent impacts (I), 25 percent exogenous events (X), 24 percent scientific uncertainties (S), 14 percent prevention (P), 9 percent compensation (C), and 16 percent adaptation (A).

For simplicity of presentation and accounting, the exercise is conducted with only one "player," who represents a single global decision-maker. One year time periods are used. The economic growth factor is determined by spin of a hypothetical dial and may range from 1% to 4%.

For the sake of starting calculation, let us assume that the year is 2005, gross world product (GWP) in 2004 was 16 trillion dollars, the carbon emission to GWP ratio (cr) is at .75 gT per trillion dollars, and the fraction of emissions remaining airborne (a) is 0.53. (For comparison, in 1975 GWP was around 6 trillion dollars and the carbon emission to GWP ratio was around 0.8.) Let's say that net costs and benefits (nb) from 2004 to 2005 were +.25 trillion dollars (between 1% and 2% of GWP), and a spin of a dial indicates that GWP growth (eg) is 3%.

Using the equations from the previous section:

$$GWP(2005) = (GWP(2004) - nb(2004)) * eg = (16 + 0.25) * 1.03 = 16.74$$

$$CE(2005) = GWP(2005) * cr(2005) = 16.74 * 0.75 = 12.55$$

$$AC(2005) = AC(2004) + (CE(2005) * a) = 1000 + (0.53 * 12.55) = 1006.65$$

With rounding to the nearest gT C, this puts the counter on space 1007, where card P7, an opportunity to prevent emissions by instituting a carbon tax, turns up. Say the player decides to purchase reduction of the carbon emission ratio (cr) of 0.5 percent per year for five years at a cost of 50 billion dollars per year. Say also that the next spin of the economic growth dial gives a factor of 2%. The next round of calculations goes as follows:

$$GWP(2006) = (GWP(2005) + nb(2005)) * eg = (16.74 - 0.05) * 1.02 = 17.02$$

$$cr(2006) = cr(2005) * pe(2006) = 0.75 * 0.995 = 0.74625$$

$$CE(2006) = GWP(2006) * cr(2006) = 17.02 * 0.74625 = 12.70$$

$$AC(2006) = AC(2005) + (CE(2005) * a) = 1007 + (0.53 * 12.70) = 1013.73$$

The counter thus moves to space 1014, where the player draws card P3, an opportunity to reduce carbon emissions by searching for new sources of natural gas. Say the global player decides to invest 100 billion dollars and finds that the investment permitted reduction of the carbon ratio by only 0.02%. (If the results of drilling are uncertain, there should be a range of outcomes possible for spaces like this.) The next spin of the dial shows an economic growth factor of 4%. Including the costs and reductions in emissions ratio from the carbon tax instituted in the year 2006, calculations proceed:

$$GWP(2007) = (17.02 - 0.05 - 0.10) * 1.04 = 17.55$$

$$cr(2007) = 0.74625 * 0.995 * 0.998 = 0.7410$$

$$CE(2007) = 17.55 * 0.7410 = 13.00$$

$$AC(2007) = 1014 + (13.00 * 0.53) = 1020.89$$

The board is now filled to space 1021, where card X5 is found. X5 informs the player that there has been a significant breakthrough in generation of electricity through fusion, with a capability to reduce the carbon emissions ratio by 1%. Spin of the dial indicates economic growth at 2%. Thus, still carrying over the costs and benefits of the carbon tax:

$$GWP(2008) = (17.55 - 0.05) * 1.02 = 17.85$$

$$cr(2008) = 0.7410 * 0.995 * 0.99 = 0.730$$

$$CE(2008) = 17.88 * 0.730 = 13.03$$

$$AC(2008) = 1021 + (0.53 * 13.03) = 1027.91$$

This moves play to space 1028, where A6, the card for offensive contingency plans comes up. This card permits the player to invest in order to take advantage of market dislocations caused by climatic change. In a multiple player situation, this might allow the player whose turn is taking place to profit the next time a negative CO2 impact appears for another player. It may be inapplicable to the global player situation.

Clearly this brief exercise is unrealistic. Much work lies ahead, for example, obtaining more reliable estimates of costs. It is also clear that situations will arise in play which we have not yet anticipated and for which rules will have to be set. However, it is hoped that this exercise does show how the framework may begin the generation of scenarios, ones which will be more consistent as research continues.

FURTHER DEVELOPMENT AND PLAY

As mentioned above, to make the framework operational, events need to be assigned to the spaces of the atmosphere board, and approximations must be made of their probable ranges of costs and benefits to different players. This will take thought, research (but the literature will not yield much information), and a lot of guessing. We will have to be satisfied with being plausible and should use the research effort as an exercise that will raise important questions more than as a means of arriving at firm estimates or irrefutable arguments. As the games are developed, expert opinion on general and specific parameters will be solicited from people who participate in the gaming experiments.

Several major design questions remain open, and others will appear as work proceeds. Might some other format be better? Should the board the players see be blank, should they see only the designation of space categories, or should the exact nature of the spaces ahead be revealed? For example, should they be able to see that space 1027 holds a powerful technological breakthrough, should they only know that it is an exogenous event, or should they be given no clues at all as to what is there? Is a player confronted with policy decisions every turn, or only when his carbon emissions land him on a P, A, or C space?

To look at such questions, experiments such as that shown above have begun with single blocks. To keep play feasible with a hand calculator, we are experimenting initially with a single (global) player situation. As work proceeds, further blocks will be added and experiments will begin looking at what happens when multiple players are considered.

In addition to the several issues for game development raised already, at least one more should be mentioned. This is the question of which countries ought to be considered for early inclusion in the computer game. Play is initally envisioned with players representing 4-7 countries. It is necessary to begin collecting data on these countries, with regard to the coal industry, costs of alternative energy sources, and climatic impacts.

Individual countries might be valuable to include in the gaming experiments (and in study of the CO2 issue in general) for several reasons. First, the carbon giants (USSR, US, China) must be considered, both because of the potential level of their emissions and because of the key roles they can play in a world coal trade. Indeed, for the carbon economy module, countries representative of several different supply and demand characteristics are interesting. (See Ausubel, 1980a) On the one hand, there are countries with high demand and low supply (for example, Japan and Italy); there are countries with low demand and high supply (for example, Australia, Canada, Botswana, and South Africa); and countries with high demand and high supply (West Germany and India, for example).

From the point of view of impacts of climate, countries most susceptible to the disaster scenario, like the Netherlands and Bangladesh, are interesting. Countries, like Sweden, in the high latitudes where climatic change is expected to be greatest, may be interesting players, as well as countries like the US and Brazil which can play very large roles in world agricultural products trade. Representation of both industrialized and developing countries is crucial to exploring political aspects of the issue.

Which of these countries will eventually be playable in the computer game will probably become a question of data availability as much as anything else. It is hoped that collaborators in several countries might be found to help develop the necessary information for their own countries and thereby enlarge the potential of the game. It might be mentioned that such research should be broadly useful for study of the CO2 issue, not only as a contribution to the gaming approach.

Meanwhile, the game can begin to be computerized so that programs take care of assigning random values; performing the accounting relating to economic growth, carbon emissions, and atmospheric carbon; and giving players descriptions of the impacts and opportunities for decisions ensuing from their carbon emissions in the last time period. Further programming can be made to produce an interesting display of the board and of players' movement across it. However, it is desirable to experiment further with the proposed format using manual calculation and a paper board display before investing much time in programming.

It is clear that we must avoid making the computer game excessively complicated and ambitious. Our intent is not to undertake a large basic CO2 research program. Rather, the idea is to use the gaming approach to organize what is known, to educate people about what is known, to gain tentative answers to some questions for which a gaming approach is uniquely suited, and to assist in the design of future research. We hope this paper, as well as the earlier papers on the gaming effort, already illustrate that the gaming approach may yield insights into the CO2 question.

APPENDIX

This appendix offers a listing of about 80 topics which might be represented in the six event categories. The assistance of readers is sought in the elaboration of these spaces to a degree appropriate for use in the games and in suggesting additional topics for inclusion. With respect to each topic one or more of several questions might be asked.

1) *What role* should this have in the game? Is the event in the proper category? Is it properly formulated?

2) *For which countries or regions* is this relevant? As Meyer-Abich (1980) has pointed out, the different options may in many cases turn out to be options of the different parties involved, so that, for instance, the question is whether country A takes a step for prevention, or whether country B takes a step for adaptation. International activities for compensation may also be viewed differently by the different parties involved. For some countries (or biomes) reforestation may be relevant; impacts in northern ecosystems are important for certain countries and not others, and so forth.

3) *Over what range of atmospheric carbon* is this event likely to become important or prominent? After small increases? Around a doubling? A tripling? Can other comments about timing be made? Is the event a sudden one? Or is it a process occurring over a long span of time?

4) *What costs or benefits* may be involved with this event? Can this be formulated in monetary terms (for example, as percent of GNP) or in some widely applicable physical quality of life indicator?

5) *How effective or powerful* is the event or measure? This might be assessed in potential reduction of carbon in the atmosphere (in gT C) or in monetary terms.

In the following listing we have occasionally begun to sketch in answers to some of these questions. These are highly subjective. They are merely meant to be suggestive, by no means conclusive or exhaustive. Readers are encouraged to keep in mind a sample group of countries and check off which areas are relevant to which countries as they read. Similarly, we hope readers will develop their own chronologies and tentative answers to other questions. Please send us your ideas.

IMPACTS

I1: Estuaries and Salt Marshes

Small changes in climatic conditions over continental areas may manifest themselves in coastal areas, due to the delicate marginal nature of estuaries and salt marshes. The impacts could include changing biological productivity and community structure along the coastline.

Which countries?	Coastal, for example, US, Canada, Bangladesh.
When?	Possible early impact
How costly?	Likely to be perceived negatively

I2: Northern Ecosystems

The greatest temperature change is expected to be at the poles, so northern ecosystems may change considerably and in advance of equatorial systems. This could provide agricultural opportunities, but the soils may be poor and the ground swampy.

Which countries?	USSR, Canada, Sweden and other high latitude countries
When?	Possible early impact
How costly?	Considerable costs and benefits possible

I3: Weather Stress on Economic Crop Plants

One of the ways climatic change is likely to manifest itself is through changing occurrences of extremes and "weather stress." There could be record floods and hail, but there could also be fewer frosts.

Which countries?	Many consumers, some producers
When?	Possible early impact
How costly?	Quite costly or beneficial

I4: Fresh Water Ecosystems

Shallow water bodies are particularly sensitive to variability and change of climate. Lake shores may expand or contract, and certain streams and rivers may also change dramatically in character.

Which countries?	US, Canada, Sweden, USSR
When?	Possible early impact
How costly?	Likely to be more costly than beneficial

I5: Tundra and Terrestrial Cryosphere

Engineering problems could increase or decrease in areas with permafrost on land and ice offshore. Mineral extraction, transportation, and tourism may be affected.

Which countries?	USSR, Canada, US, Denmark (Greenland)
When?	Possible early impact
How costly?	Some costs, high benefits possible

I6: Water Resources

The quantity and quality of water resources could improve or worsen.

Which countries?	All countries, highly regional
When?	Depends very much on degree and kind of climatic change
How costly?	Potentially very high costs, benefits

I7: Grazing Land and Animal Husbandry

Pastures may improve; animals may suffer from higher temperatures.

Which countries?	US, Australia
When?	Could be early, if animals subject to extremes
How costly?	Costs moderate and should precede benefits, which would depend on recognition of new opportunities

I8: Forest Ecology

Geographic shift in species, faunal migration, and the frequency of drought and fire could affect the character of forest areas. National forests and protected areas may no longer serve the functions they have been set aside for.

Which countries?	Countries with forest areas not used only for timber
When?	Forest ecosystems may be relatively conservative
How costly?	Could be costly, hard to see short-term benefits

I9: Competing Environmental Systems and Conservation

The biosphere is adapted to the climate of the recent past. Decisions about environmental preservation have been made on the assumption that the environment will only change very slowly. Climatic change may mean a whole new set of decisions are needed with respect to species preservation, national parks, and so forth.

Which countries?	Countries with greatest environmental heritage
When?	Timing and suddenness of transition may depend on biome
How costly?	Dependent on values, could be very high

I10: Broad Climatic Impacts on Agriculture

Production may be dramatically altered in many areas.

Which countries?	Most countries, e.g., India, China, US, USSR, Canada
When?	Increasing frequency as atmospheric carbon rises
How costly?	Very high and increasing, both costs and benefits

I11: Plant Protection from Pests and Pathogens

There may be significant increases in the magnitude of problems associated with the protection of plants from pests and proliferation of weeds. Colder weather and frosts may have offered protection.

Which countries?	All agricultural producers; consumers
When?	May be difficult to predict
How costly?	Potentially very costly, few benefits

I12: Ocean Biota

There could be more or fewer fish and beneficial or harmful impacts on the marine food chain. The shifts in location of stocks may be advantageous to some and not to others.

Which countries?	Japan, USSR, Canada, other major fishing countries
When?	Difficult to predict but ocean may be slower to react
How costly?	Locally high costs

I13: Soil Organic Matter

Temperature rise accelerates oxidation of soil organic matter, especially under intensive soil cultivation practices and in regions with fragile soils.

Which countries?	USSR, Canada, Finland, some tropical areas
When?	Will wait until temperature change is quite strong
How costly?	Potentially quite costly, no benefit

I14: Managed Forests

Rotation time in forests may be shortened, enabling higher production of wood and pulp products. New pests or water deficiencies may outweigh this.

Which countries?	USSR, Canada, US, Brazil, Sweden
When?	Relatively long time before this effect is certain
How costly?	Potentially high cost, high benefit

I15: Photosynthesis and Productivity of Crop Plants from CO2 Increase

There should be increased growth fom CO2 fertilization, and a variety of impacts on species' life cycles, phenologies, and yields of usable product. (Combines with I21.)

Which Countries?	
When?	Gradual increase, with possible leaps allowing for different limiting factors
How costly?	Strong potential benefits, fewer costs

I16: Heating and Air Conditioning

Space heating and air-conditioning requirements may increase or decrease.

Which countries?	US, Canada, Sweden, USSR
When?	Relatively direct function of climatic change
How costly?	Strong regional distribution of benefits and costs

I17: Arctic Sea Ice

The Arctic Sea Ice may be reduced, and it may begin to disappear seasonally or even on a lasting basis. This may increase the possibility of mineral extraction in the Arctic and its usefulness for transportation. However, this is a major environmental shift, and the consequences are hard to foresee.

Which countries?	USSR, Canada, US
When?	Requires high temperature (atmospheric carbon) change
How costly?	Potentially very high benefits, costs are a question

I18: Migration

There could be large climate-induced population movements, both internally and between nations, and the adjustment costs and political stresses arising from these may be great.

Which countries?	India, Canada, Australia, China, USSR
When?	Probably quite distant, but could be triggered by regional extremes
How costly?	Potentially very costly, few benefits

I19: Problems of Location

Some facilities will no longer be located in appropriate places. Relocation, capacity expansion, new industrial development may involve added costs because of climatic change. Since infrastructure is adapted to the present climate, benefits seem less likely than costs.

Which countries?	USSR, Canada, US
When?	Probably requires high temperature (carbon) change
How costly?	Quite costly, few benefits

I20: Visibility and Other Air Quality Issues

Changing the climate may alter many other attributes of the atmosphere at the regional and local level. Areas famous for limpid skies may become hazy, while areas formerly with sluggish circulations may have fresh winds to blow their pollution away.

Which countries?	Most countries
When?	Regionally variable, increasingly widespread
How costly?	High at local level

I21: Efficiency of Water Use in Plants

CO_2 Enrichment increases ratio of photosynthesis to transpiration. A 10 percent increase in water use efficiency could come wth a doubling of atmospheric CO_2. (Combines with I15.)

Which countries?	Important agricultural producers
When?	Requires high levels of CO_2
How costly?	Potentially beneficial, few costs

I22: Human Health

Climate may become more pleasant, or higher temperatures and greater frequency of extreme episodes may have negative impacts. Extended exposure to higher levels of CO2 may have a variety of biomedical consequences.

Which countries?	All countries
When?	Very high levels of atmospheric carbon and climatic change
How costly?	Potentially very costly, few benefits

I23: Imminent Collapse of the West Antarctic Ice Sheet

The sea level could rise five or more meters within a few centuries. Low-lying coastal areas, including many of the world's major cities and major river deltas, would be submerged.

Which countries?	Netherlands, Bangladesh, US, Japan, Egypt, Vietnam
When?	Beyond doubling of atmospheric carbon
How costly?	Extremely costly

I24: Hydropower Systems

The yields of watersheds may change so that hydroelectric plants end up working well below capacity.

Which countries?	USSR, Canada, US
When?	Precipitation changes hard to predict in timing
How costly?	Moderately costly; beneficial if adaptive investment made

I25: On Solar Systems

The timing and percent of cloud cover may change and affect solar potential.

Which countries?	Australia, Italy, US, West Germany
When?	Could be long time before trend is clear
How costly?	Moderately costly, moderately beneficial

I26: Non-CO2 or Climate
Health Effects of Coal

Substantial increases in mining and burning of coal may have strong consequences for occupational safety and health and for air quality.

Which countries?	Heavy coal miners and users
When?	Function of increasing use and technological improvements
How costly?	Also depends on level of use and technology

ADAPTATION

A1: Sponsor Research on CO2 and Climatic Change

This is a reasonable step to take regardless of whether one's eventual strategy is adaptive or otherwise; it is already underway in some countries. Having some information about the future is better than none. Purchase an assessment report and be better prepared for your next impact.

Which countries?	Those with research capacity
When?	Especially important early
How costly?	Inexpensive
How effective?	

A2: Grain Stockpiles

Stockpile grain as protection against adverse impacts on agriculture. Next time an adverse agricultural impact appears, you receive payment equal to all the other players' losses.

Which countries?	US, Canada, other grain surplus countries
When?	All periods
How costly?	Increasing costs and benefits
How effective?	

A3: Insurance

Use monetary means to buffer yourself against costs imposed by climatic change. You have resources so that the next negative impact has no cost to you.

Which countries?	Those who can afford it, probably the richer
When?	All periods
How costly?	Low, increasing
How effective?	

A4: Defensive Contingency Plans

For example, increase your civil defense preparedness for natural hazards like severe storms. Invest now and skip the next negative impact.

Which countries?	Relevant to most
When?	Extreme events may be an early
How costly?	Check literature

A5: Investment in Strategies to Mitigate Agricultural Disruption

For example, develop more drought resistant crop strains or be ready for new attacks of pests and pathogens. Protection against I3, I10, I11 and I13.

Which countries?	Richer, important food producers
When?	Early action particularly valuable
How costly?	Increasing cost
How effective?	

A6: Offensive Contingency Plans

You foresee that climatic change will create market disruptions and invest in capacity to produce goods and services that will be in short supply. Collect on others losses, for example, on I10, I16, and I19.

Which countries?	Flexible industrial structure
When?	All periods
How costly?	Steady investment cost
How effective?	

A7: Hydrological Management

Reinforce dams for flood production, increase irrigation potential to protect against drought. You become immune to I6 and I24.

Which countries?	Most countries
When?	After new climatic patterns become likely or evident
How costly?	Could be costly

A8: Climate Extension Work

Enhance institutions which work with agriculturalists and climate sensitive industries so that they are better prepared to adapt to changes in climate and weather. Reduce all costs of impacts of climate by x percent.

Which countries?	Most climate sensitive
When?	As types of impacts become clear.
How costly?	Could be costly
How effective?	

PREVENTION

P1: Solar

Give greater emphasis to solar technologies for heating, generation of electricity, and production of fluid fuels for transportation. Note interaction with I25 and X18.

Which countries? US, Italy, India, Australia
When?
How costly?
How effective?

P2: Conservation

Incentives for energy conservation are increased, partly through deliberate policies, and partly because of high capital costs of energy development. Note interaction with X18.

Which countries?
When?
How costly?
How effective?

P3: Natural Gas

Natural gas emits less CO2 per unit of energy than other carbon fuels. Provide assistance in exploration for and exploitation of natural gas reserves, especially in less-populated regions where modern geological and geophysical methods have just begun to be used.

Which countries?
When?
How costly?
How effective?

P4: Conventional Nuclear Power

Pursue rapid expansion of conventional (non-breeder) nuclear power. (It is likely that the computer game will initally explore the case of a nuclear moratorium.)

Which countries?
When?
How costly?
How effective?

P5: Carbon Tax

Institute a carbon tax to encourage a shift to non-fossil and cleaner fossil fuels.

Which countries?
When?
How costly?
How effective?

P6: Improve Land Use

Slow down expansion of agriculture into forested lands and introduce improved sylvicultural practices. Note interaction with S6, S7.

Which countries?
When?
How costly?
How effective?

P7: Breeder Reactors

Encourage development of nuclear power, especially breeders. (It is likely that the computer game will initially explore the case of a nuclear moratorium.)

Which countries? Developed, more advanced developing
When?
How costly?
How effective?

P8: Hydro

Subsidize capital for development of hydroelectric power. Note interaction with I24.

Which countries?
When?
How costly?
How effective?

P9: Biomass

Encourage development of biomass fuels. Note interaction with I10, I15.

Which countries?
When?
How costly?
How effective?

P10: Local Generation

Substitute small scale dispersed generation of electricity, using locally available sources, for large-scale centralized generation.

Which countries?
When?
How costly?
How effective?

P11: Carbon Residuals Permits

Create a market in CO2 permits to limit use of coal and other fossil fuels and make emission much more costly.

Which countries?
When?
How costly?
How effective?

P12: Liability

Your government and judicial systems accept the principle of assigning liability for damages on account of climatic change. Everyone dreads litigation except the lawyers, so it is a way to reduce emissions. Note interaction with X4, X13.

Which countries?
When?
How costly?
How effective?

P13: Ambient CO2 Standards

You can adhere to the Global Environmental Protection Agency which has just set the standard. Note interaction with X2, X3.

Which countries?
When?
How costly?
How effective?

COMPENSATION

C1: Decrease Atmospheric Carbon through Reforestation

Plant millions of trees to transfer carbon to the biosphere pool.

Which countries?	Large land area where trees may grow quickly (Brazil)
When?	Before pressures for agricultural use overwhelm
How costly?	Costly
How effective?	

C2: Decrease Atmospheric Carbon through Soil Carbon Banks

Grow short-lived plants for conversion to humus to be stored in artificial peat bogs.

Which countries?	Humid tropics, other areas of rapid biomass accumulation
When?	Could be all periods if
How costly?	Costly
How effective?	

C3: Limit Atmospheric Carbon by Biospheric Transfer to Deep Ocean

Supply phosphates and nitrates to surface waters to fertilize growth of marine organisms. These will incorporate carbon and eventually sink and settle safely at the ocean floor.

Which countries?	Black Sea (USSR)
When?	When slow removal is still useful rate
How costly?	Costly
How effective?	

C4: Weather Modification

Weather and climate modification (cloud seeding, changing albedo) and other human actions outside the carbon cycle may become a way to compensate for the increased level of atmospheric CO2.

Which countries?	High technology, international consortium
When?	Not likely soon
How effective?	
How costly?	Bigger problems are physics and politics

C5: Limit Atmospheric Carbon
by Physical Transfer to the Deep Ocean

Build pipelines to deliver CO_2 to the Straits of Gibraltar where currents will take it safely down to the abyssal depths.

Which countries?	West Europe, other highly concentrated carbon emitters
When?	Well into the future
How costly?	Costly
How effective?	

C6: Extract Carbon from the Atmosphere
and Convert to Methanol

Use solar or nuclear-generated electricity to extract carbon from the atmosphere and convert it to a liquid hydro-carbon.

Which countries?	Technically sophisticated, low carbon wealth
When?	Distant future, high CO_2 concentrations
How costly?	Costly
How effective?	

SCIENTIFIC UNCERTAINTIES

S1: Clouds and Cloud Dynamics

Cloud feedback and other processes may increase or decrease the magnitude of the CO_2 effect. (Affects impacts multiplier.)
When?

S2: Non-CO_2 Anthropogenic
Influences on Climate

Chlorofluorocarbons, N_2O, and other trace gases and climatogenic factors may increase or decrease the CO_2-induced climatic change. (Affects impacts multiplier.)
When?

S3: Ocean Thermal Buffering

The oceans may or may not absorb heat at calculated rates, and this could alter the timing of climatic change by decades. (Affects impacts multiplier.)
When?

S4: Ocean Chemical Buffering

The oceans may be a much better chemical buffer than is currently estimated, and the buffering may be non-linear. Or, the oceans may absorb a smaller fraction of CO_2 than currently estimated, and as the atmosphere gets warmer the oceans may become a less and less effective carbon sink. (Affects impacts multiplier.)
When?

S5: Natural Climatic Change

Apart from human-induced shifts, the climate is always varying and changing. It may be that in coming years the climate will be warming, adding to the CO_2 effect, or perhaps the climate will be cooling, and the greenhouse effect will have to counteract it. (Affects impacts multiplier.)
When?

S6: The Biosphere Has Been a Sink

This implies that the fraction of CO_2 remaining airborne from fossil fuel burning is larger than previously estimated. Hence, accumulation of atmospheric carbon is fast. (May affect play in several ways.) Possible interaction with reforestation/biomass spaces.
When?

S7: The Biosphere Has Been a Source

This suggests that the fraction of carbon remaining airborne from fossil fuel burning is smaller than previously estimated. Accumulation of carbon in the atmosphere is slow. (This may affect play in several ways.) Possible with deforestation/biomass spaces.
When?

S8: Reliable Scenarios of Future
Climate Are Developed

Models and historical analogues produce scientifically reliable maps of the climate of future periods. The problems looms more or less seriously. This may affect play in several ways. For example, those who stand to benefit may seek to increase their carbon to GNP ratios.
When? 50-150 gT C increase

EXOGENOUS EVENTS

X1: Technological Breakthrough

There is a loosening of carbon emissions/energy production relationship. Reduce appropriate factor in carbon emission calculating procedure. How much should it be reduced? How many times can this occur?
When?

X2: Strengthening of International
Agencies and Institutions

The cost of compensation and adaptation might be reduced, if cooperative international efforts are possible.
When? Cyclic?

X3: Weakening of International
Agencies and Institutions

The cost of compensation should probably be raised when the means to organize cooperative international efforts is lacking.
When? Cyclic?

X4: Scenarios of Future Climatic
Change Are Published

Models and historical analogues produce maps of the climate of the future, and arguments develop over who will benefit and who will be harmed. Distributive issues are heightened. A mechanism is needed to determine whether you give to or receive mollifying transfer payments from other players. How large are payments?
When? Next 100 gT C

X5: Fusion

This may be considered a special case of a technological breakthrough.
When? Appropriately far in the future.

X6: Limited War

A portion of GNP or principle should be destroyed. One (civil) or more (international) players participate.
When?
How costly?

X7: International Monetary System in Crisis

It is difficult to get bank loans to finance carbon imports. GNP growth rate is lower than expected.
When?
How costly?

X8: Political Chaos in Carbon Producing Areas

If you are a carbon importer, you are forced to endure temporary cutbacks in carbon fuels usage. Higher costs of domestic or other substitution reduce growth.
When?
How costly?

X9: Natural Disaster

There is a severe earthquake in your country.
When?
How costly?

X10: Acid Rain

If you are a heavy user of coal. you are probably also an acid rain producer. To reduce sulfate emissions, you try to reduce coal burning, but emission control makes you less energy efficient, so CO_2 release remains unchanged. However, players who have not adopted a heavy coal strategy receive reparations from you.
When?
How costly?

X11: Nuclear Disaster

It is a cost for the period, and it also turns the public against nuclear energy, so the nuclear prevention options become unavailable for the next two time periods.
When?
How costly?

X12: Prolonged Unrest in Coal Mining Unions

You unexpectedly have to import to meet domestic carbon demand. This results in increased costs for you for the period and a benefit for another player.
When?
How costly?

X13: Evidence of Climatic Change

There is dramatic evidence of human-induced change, and in the news disasters dominate positive turns of events. Public pressure for preventive and compensatory measures increases, no matter what the cost. Each player must pay and the rate of investment in prevention increases in the next time period.
When? 900-1000 gT C
How costly?

X14: Drought in the Sahel

There is another terrible drought in the poor arid lands bordering the southern Sahara. This time the affected countries attribute the drought to human-induced climatic change brought about by heavy energy use in the rich countries. The richest player makes payment to the poorest player.
When?
How much?

X15: Foreign Exchange

Lacking foreign exchange to buy carbon fuels, you are forced to an alternative energy strategy in the next period. (For carbon importers.)
When?
How costly?

X16: Cleaner Carbon Fuel

Natural gas emits less CO_2 per unit of energy than other carbon fuels, and it turns out that there is much more natural gas underground than traditional geological explanations have forecast. (Increased role for gas might be reflected in several ways.)
When?
How effective?

X17: Depression

There is a decrease in economic activity, which can lead to reduced CO_2 emissions, but mostly players shift to cheaper, dirtier fuels. Reduce GNP growth for the period, and you are too poor to maintain preventive or adaptive measures--environmental protection is a luxury--reduce a prevention or adaptation factor, if you can.
When?
How costly or powerful?

X18: Lifestyle Change

Materialism is going out of fashion in the industrialized countries. Consumption patterns shift toward low energy services (music, video networks, mystic religions). The carbon/GNP ratio is decreased.
When?

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