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CO2: An Introduction and Possible Board Game

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IIASA Working Paper

WP-80-153

October 1980

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PREFACE

There are growing concerns that human activities may lead to global climatic changes. Particular concern is associated with the release of carbon dioxide into the atmosphere, in the future above all from the burning of coal. Questions of the physical effects of different energy policies on climate have been investigated during the last few years under IIASA's Energy Systems Program. More recently, research in the Resources and Environment (REN) Area of IIASA has focused on the relationships of short-term climatic variability and longer term climatic change to human activities, for example, in the agricultural sector.

In March of 1980, informal discussions among Jesse Ausubel, and Ingolf Ståhl, John Lathrop and Jennifer Robinson of the Management and Technology (MMT) Area led to the idea that gaming might offer an integrative method for study of the overall problem, from causes, through physical changes, to environmental, economic, and societal effects. At present, a collaborative effort is underway among REN and MMT to develop two prototype games, one a board game with primarily an educational purpose, and one an interactive computer game which is seen primarily as a research tool. The board game is intended to be useful for an audience which is non-technical or begins with quite limited familiarity with the CO_2 issue. In view of this objective, the following Working Paper sketches the overall CO_2 question in simple terms, describes some basic elements of a board game, and offers an annotated bibliography. Another Working Paper, "An Interactive Model for Determining Coal Costs for a CO_2-Game," (WP-80-154) describes the logic and a possible framework for parts of the computer game. The project as a whole is described in a Working Paper entitled "Carbon and Climate Gaming" (WP-80-152).

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CO_2: AN INTRODUCTION AND POSSIBLE BOARD GAME

Jesse Ausubel

1. A SKETCH OF THE CO_2 ISSUE*

The carbon atom is obviously very valuable. Carbon has a rare capacity to be stored in forms whose transformation releases energy. At the broadest, and also the profoundest, level the question of carbon dioxide and climatic change is the problem of the prudent long-term management of the Earth's carbon wealth.

Of course, carbon is abundant on the Earth. Indeed, there is carbon everywhere (see Figure 1). There is a vast reservoir of carbon in the oceans. There are two large reservoirs of carbon in the biosphere, one in the biota, primarily in forests, and one in the soil. There are enormous reservoirs of carbon concentrated in the form of fossil fuels: oil, gas, and especially coal. There is also a large, diffuse, but quite sensitive reservoir of about 700 Gigatons of carbon in the atmosphere in the form of carbon dioxide.

There is a natural or extra human circulation of carbon among these different reservoirs, particularly through photosynthesis and oxidation. Tracing the flows between the different reservoirs opens a biogeochemical perspective on the cycle of carbon. Such a biogeochemical perspective takes a kind of corporate view of the Earth. The various chemical reservoirs of the Earth are observed as comparable to the organs in a person's body. The problem being addressed here is that human activities are apparently feeding carbon into the circulation faster than the ability of the Earth's

*It should be emphasized that this is a simplified account of the issue. There is uncertainty, controversy, and disagreement about each aspect of the CO_2 question and how the aspects fit together.

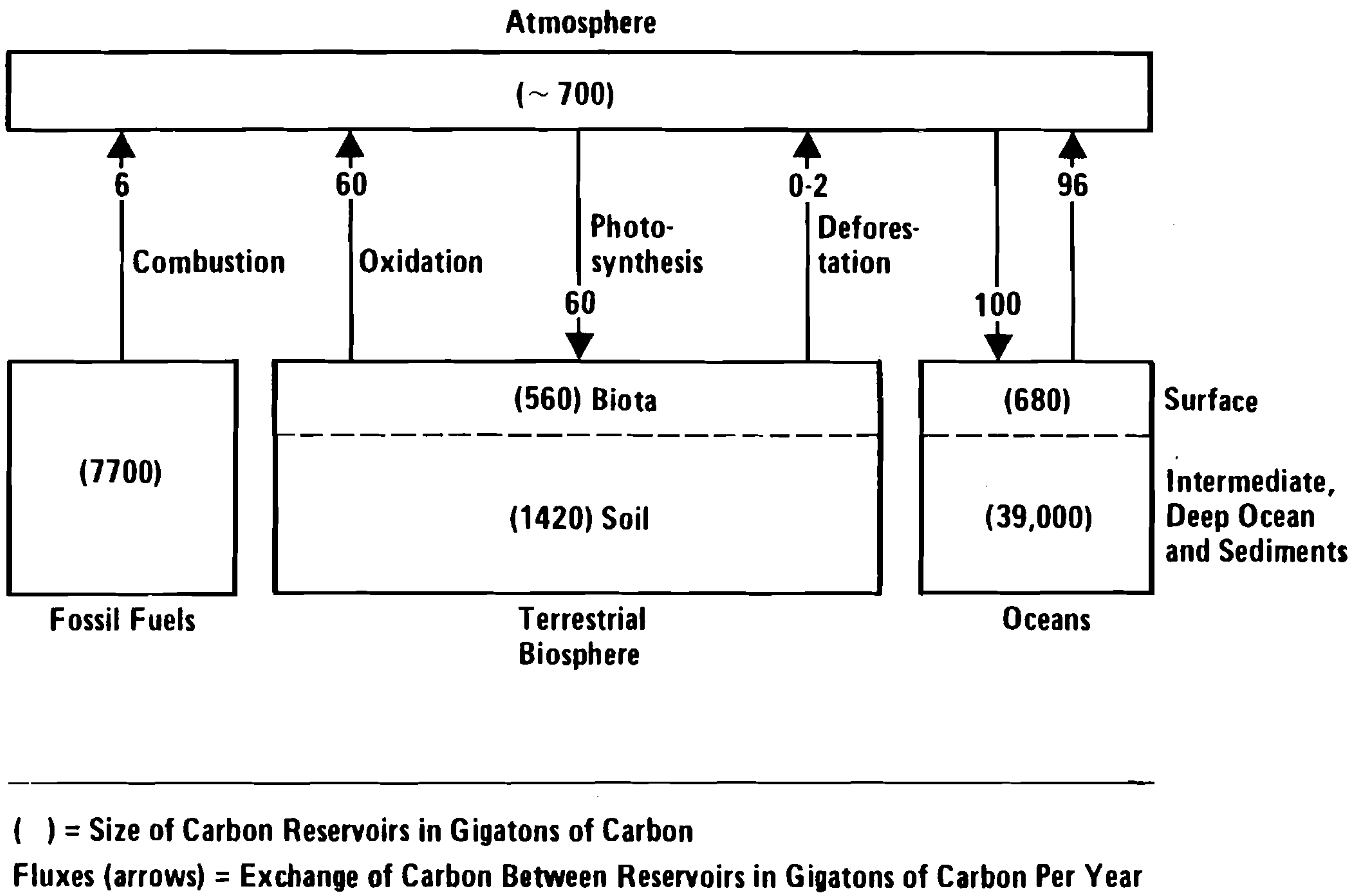

Figure 1. Exchangeable carbon reservoirs and fluxes. (Source: After U.S. Department of Energy, 1980, adjusted with estimates by Hampicke, 1980, and Ausubel, 1980.)

organs to digest or metabolize it. Normally, the atmosphere receives carbon and passes it along to the biosphere and the oceans at rates which maintain a relatively constant chemical composition for the atmosphere. With the existence of large-scale transformations of carbon by human activities, the size of the atmospheric reservoir is growing. Once it grows, it can only diminish again slowly, because of the limited metabolic rates of the biosphere and oceans. In fact, the atmospheric reservoir has been growing more and more rapidly.

This growth is something which is directly measured, in contrast to many other aspects of the CO_2 question. For example, Figure 2 shows the trend in atmospheric concentration of CO_2 at a clean air station in Hawaii. The short cycle indicates the annual uptake and release of carbon by the plants and forests of the northern hemisphere. Since 1958, the average concentration has risen by more than 20 parts per million. When one thinks of the size of the atmosphere, this increase is quite staggering. Indeed, CO_2 is perhaps the most prominent case of pollution* or emissions on a truly global scale. The class of global environmental problems in fact remains quite small.

We are all too accustomed to the presence of severe local pollution, for example, in cities, but it is often possible to avoid by a short move to a new location. In recent years, long-range transport of pollutants like sulfur dioxide has caused concern at the regional level. Similarly, dumping of wastes and residuals in the oceans has begun to cause vexing problems at the regional level, for example, in the Mediterranean. Few individuals or nations are now escaping the effects of such regional problems. With CO_2 the additions of residuals are potentially so large and the mixing in the atmosphere so thorough that we face the prospect of a global environmental change, one which will inevitably affect all nations, although in a variety of different ways. CO_2 is an issue of the global commons. Because it may be representative of a growing class of problems, CO_2 becomes of even more interest than it otherwise might be.

To return to the physical background of the problem, the reason the atmospheric reservoir has been growing more and more rapidly is simple: more and more carbon is being burned and thus released into the atmosphere as CO_2. This is largely because of increasing demand for energy from fossil fuels. Figure 3 shows how rapidly fossil fuel consumption has increased over the past century. In 1880, combustion was about .2 Gigatons (Gt = 10^9, or billion, metric tons) of carbon, in 1920 1 Gt, in 1950 2 Gt, and in 1980 over 5 Gt. Combustion of carbon through burning of forests and clearing of land for agriculture may also have been an important contributor, but it cannot account for the potential drastic atmospheric changes about which we are most concerned. The carbon wealth in the biosphere available for transformation to carbon dioxide is ultimately quite limited. The forecasts by

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*It is not altogether correct to speak of CO_2 as a "pollutant," because its effects are not necessarily destructive.

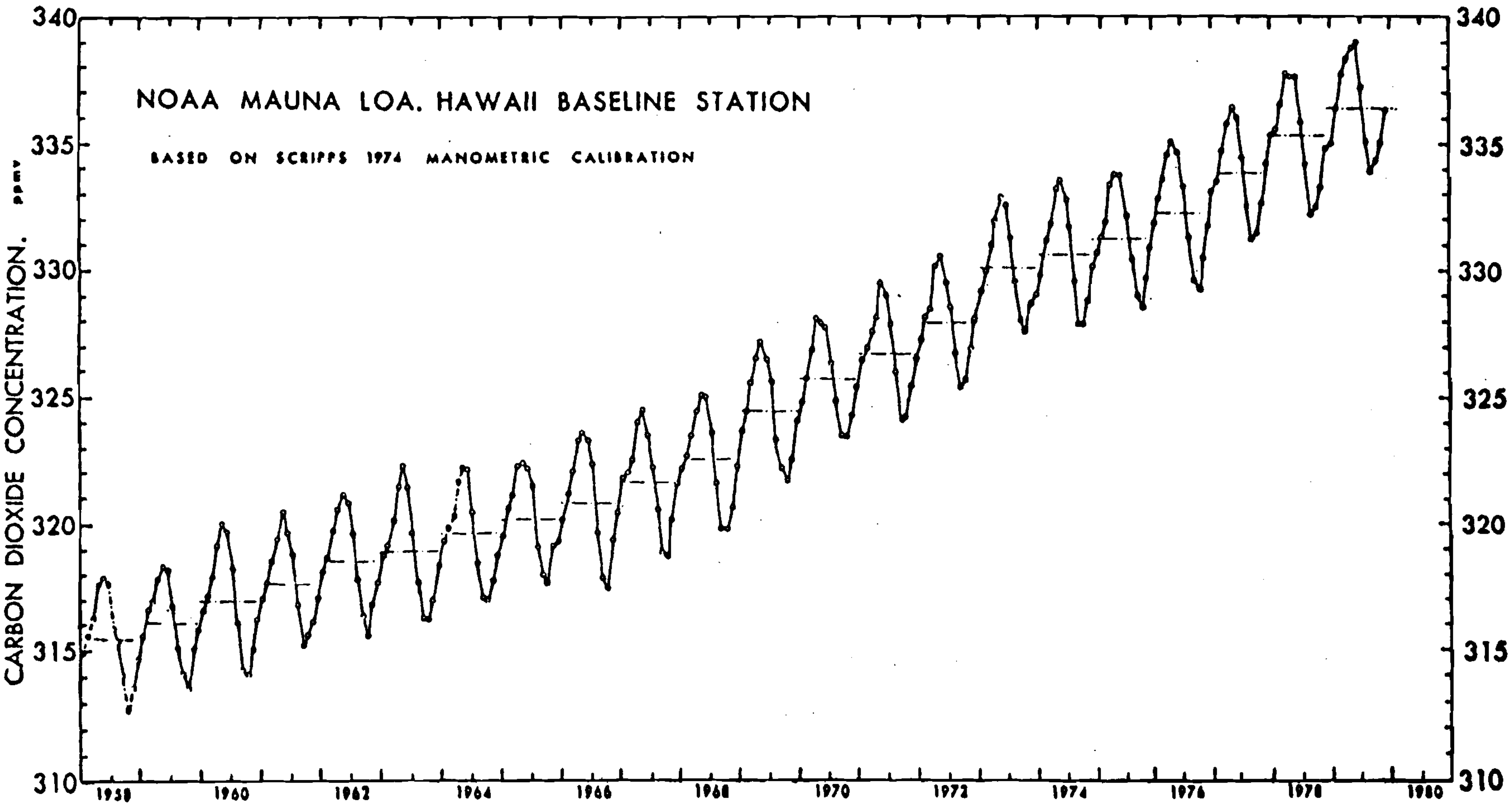


Figure 2. Trend in atmospheric CO_2 concentrations.

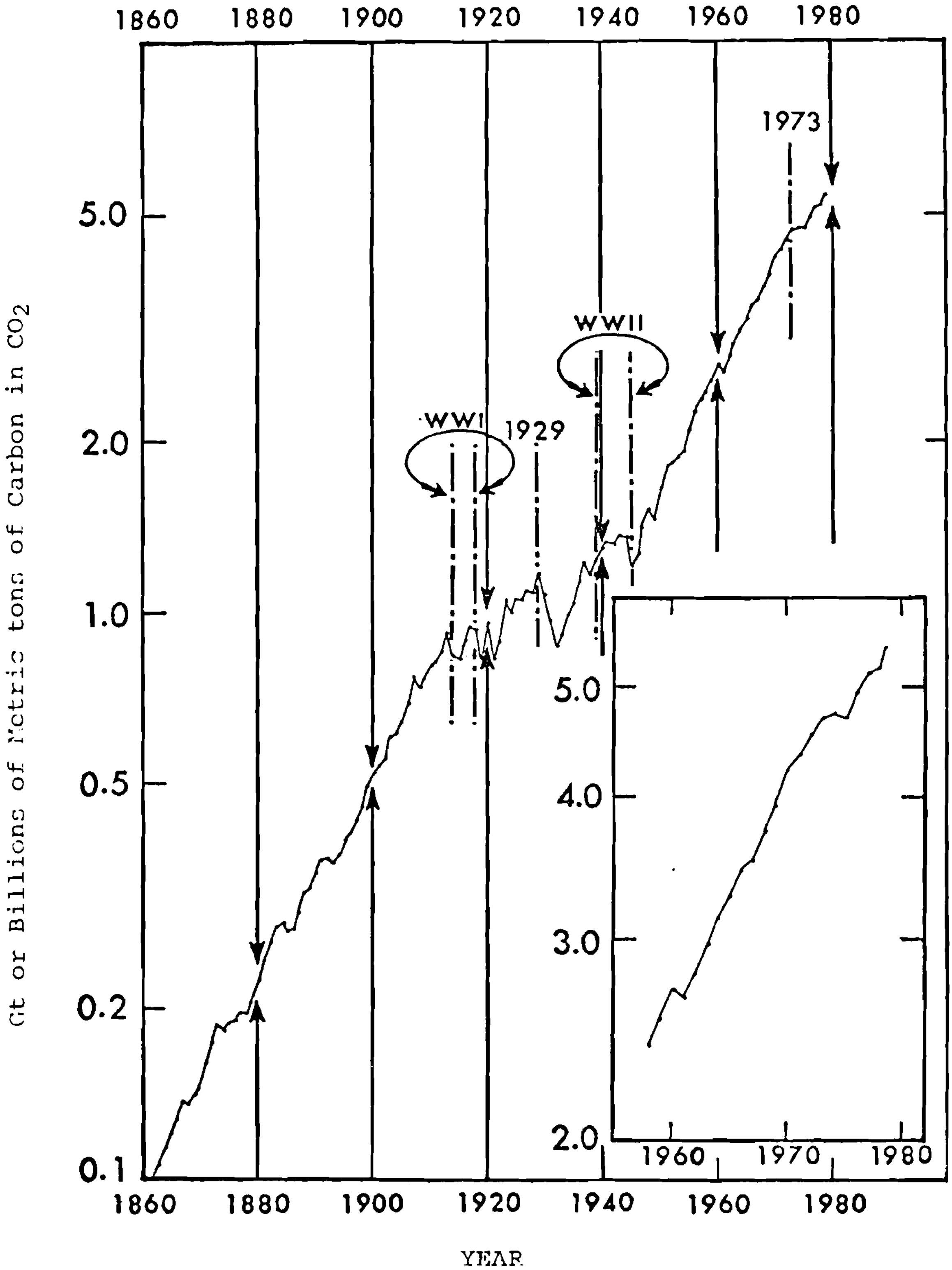


Figure 3. CO_2 production from fossil fuel combustion. (Source: U.S. Department of Energy, 1980.)

several groups, from IIASA, the US Academy of Sciences, and Oak Ridge National Laboratories, which show a doubling of the CO_2 in the atmosphere in the next 50-100 years do so on the basis of continuing increases in fossil fuel use. It should be pointed out that groups which do not forecast increased fossil use, for example, Friends of the Earth, also do not anticipate a CO_2 problem.

How more precisely would a doubling come about? Table 1 shows a hypothetical carbon economy projected for the next hundred years. Keep in mind there are now about 700 Gt of carbon in the atmosphere. According to this projection, sometime before the year 2060 human activities will have resulted in the addition of a roughly equal amount of carbon which remains in the atmosphere. Because the fraction of carbon remaining airborne is only about 50%, a gross consumption of about 1500 Gt of carbon is needed to achieve such a doubling. Some of this very large amount of carbon may come from forests and other biospheric sources, but the overwhelming portion will come from fossil fuels. Indeed, the level of exploitation required of carbon from fossil fuels over the next 80 or so years is somewhat more than 1000 Gt. In other words, the CO_2 problem projected here requires that we use fossil carbon in the next 80 years which would last about 200 years at present consumption rates.

While the numbers involved are imposing, it can be seen from Table 2 that there is an ample supply of fossil carbon, seven times the demand suggested above. From a global perspective, when one considers growth in population and demands for industrial development, it is certainly plausible that a CO_2 problem will accompany the economy many seek for the next century. However, the potential role for various fuels and regions is dramatically different. A carbon dioxide problem, should it occur, will be brought about only if there is large scale exploitation of coal in a few regions, above all, in the USSR, US, and China. It should be noted that addition of estimated unconventional gas and oil resources does not change this situation. They are still relatively small in quantity, and, moreover, tend to be found in the already coal-rich regions.

Why is there anxiety about carbon dioxide in the atmosphere? There are two parts to the answer. First, carbon dioxide is a so-called "greenhouse" gas. It is nearly transparent to visible light, or incoming radiation from the sun. However, it is a strong absorber of infrared radiation in the wavelengths where a considerable proportion of the outgoing radiation from the Earth's surface is transmitted back to space. Thus, CO_2 has the capacity to trap heat and raise the temperature of the lower atmosphere. In other words, changing the concentration of CO_2 can change the climate.

Secondly, it should be noted that CO_2 has direct biological effects. Changing concentrations of CO_2 can alter the productivity of agricultural crops, forests, weeds, and other biota regardless of whether the climate changes. From an optimistic perspective, elevating the concentration of CO_2 may fertilize the atmosphere.

Table 1. Hypothetical carbon economy to 2080.

	Gt of Carbon			
Year	a) Cumulative fossil fuel production	b) Cumulative land clearing production	Total carbon wealth consumed (a + b)	Carbon added to atmosphere
1860	0	0	0	0
1950	62	42	103	43
1970	115	70	185	76
1980	155	88	243	100
2000	279	131	410	171
2020	489	177	666	286
2040	827	220	1047	471
2060	1328	253	1581	750
2080	1987	271	2262	1123

SOURCE: After Revelle and Munk (NAS 1977:155).

Table 2. Carbon wealth.

Fuel form/ Region	I	II	III	IV	V	VI	VII	World	World reserves[a] plus resources[b]
CARBON WEALTH IN RESERVES IN GT									
Coal	126	100	99	7	31	–	69	432	
Oil	4	9	3	5	5	45	2	73	
Gas	4	12	3	1	2	11	–	33	
Total reserves	134	121	105	13	38	66	71	538	
CARBON WEALTH IN RESOURCES IN GT									
Coal	1,760	3,500	520	23	120	–	1,000	6,900	7,300
Oil	23	38	13	19	17	89	10	209	282
Gas	23	31	8	8	6	41	5	122	155
Approximate total resources all fuels	1,810	3,600	540	50	140	130	1,000	7,200	7,700
Approximate total reserves and resources	1,940	3,700	650	63	180	200	1,100	7,700	

Region I (NA) North America
Region II (SU/EE) Soviet Union and Eastern Europe
Region III (WE/JANZ) W. Europe, Japan, Australia, New Zealand, S. Africa, Israel
Region IV (LA) Latin America
Region V (Af/SEA) Africa (except N. Africa & S. Africa), S. & S.E. Asia
Region VI (ME/NAf) Middle East and Northern Africa
Region VII (C/CPA) China and Centrally Planned Asian Economies

[a] "Reserves" are geologically and geographically identified resources that are economically and technically recoverable and producible under present conditions or under conditions that are expected to prevail in the near future.
[b] "Resources" can be of two types: identified resources that are presently considered nonproducible for economic reasons; or those portions of a given resource that are not identified but surmised to exist.

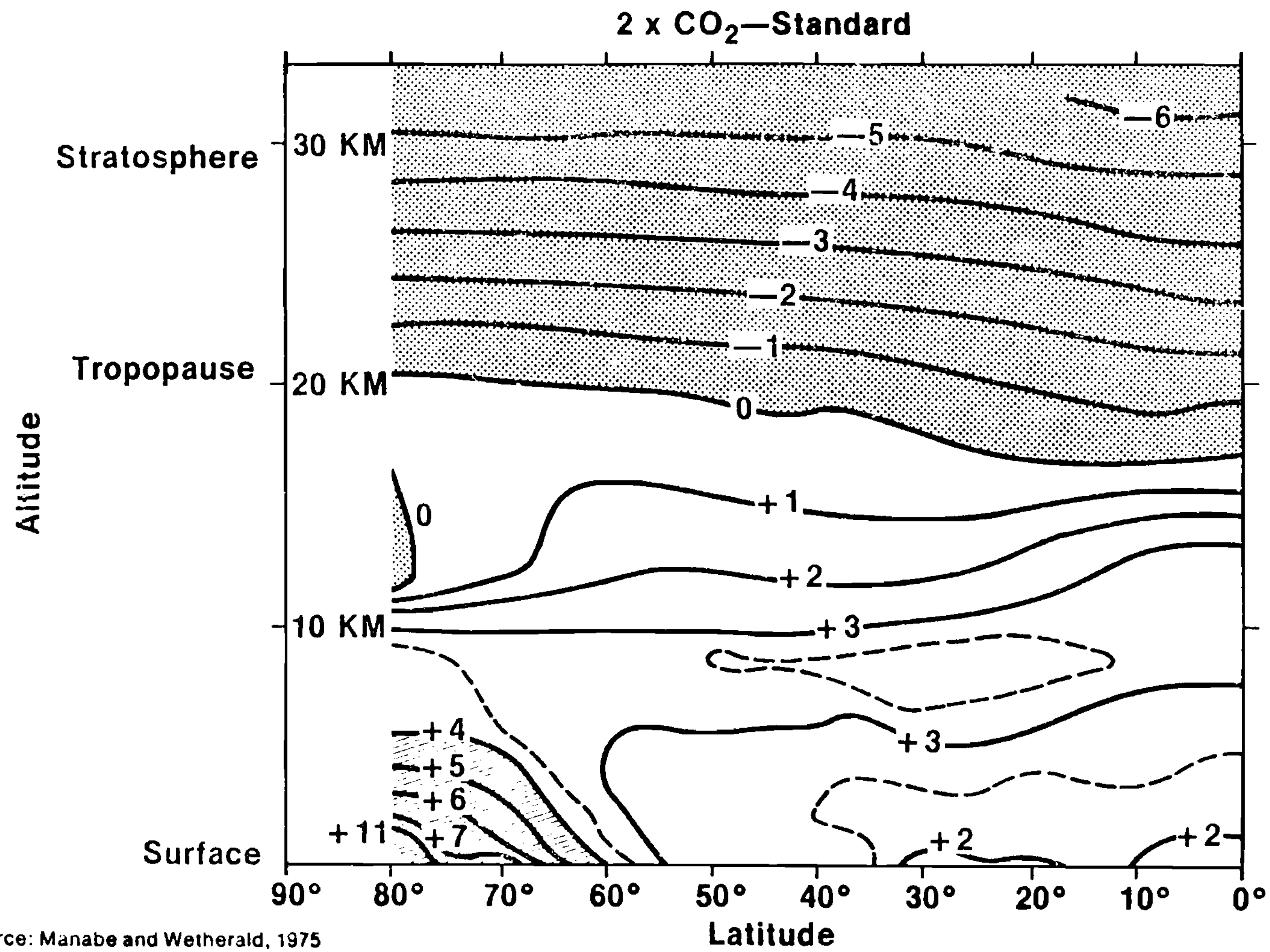
SOURCE: Ausubel (1980).

While concern about CO_2 can be easily understood, why does this concern often focus on a doubling of CO_2? Partly this level is arbitrary, just a convenient number. Partly this level is chosen because it appears to be clearly above the threshold of natural variability of climate during human history. In some periods of our history the global climate has been slightly warmer, and in some slightly cooler. A doubling of CO_2 appears likely to take us out of the usual range of variability on human time scales of about $1^{o}C$ global average. With a doubled concentration of CO_2 the average surface temperature has most often been calculated to rise between 2^{o} and $3.5^{o}C$. The full range includes estimates of warming which are more drastic as well as ones which are milder. A warming of 2^{o} or $3^{o}C$ may still sound small in absolute terms, or when compared to the change between seasons. However, on a long-term basis such an alteration of the climate system is enormous. It might, for example, involve dissolution of the sea ice in the northern polar regions, ice which has been present for millions of years. So, with a doubling major changes are in prospect, at least from an environmental or geophysical standpoint.

Can the climatic changes be specified in more detail than a 2^{o} or $3^{o}C$ global average warming? There are many researchers around the world studying this question, some using numerical models of the climate system, others using primarily historical climatology. The results of even the most sophisticated approaches are always described as highly tentative. They should not be taken as more than illustrative of the magnitude of changes which are possible. For physical reasons, the results about temperature change seem more reliable than those about shifts in rainfall.

Various kinds of maps are being produced. The first map (Figure 4) shows temperature changes associated with a doubling of atmospheric CO_2. It is the result of a computer simulation with a general circulation model of the atmosphere by a numerical modeling group at Princeton University. While the model does not have realistic geography, it does give estimates of average changes according to latitude. The changes are relatively small at the equator and dramatically large at the pole. The average annual change near the North Pole is $11^{o}C$. At the latitude of northern Norway, it is about $7^{o}C$. At the latitude of Stockholm, Helsinki, and Leningrad it is about $4^{o}C$. At the latitude of Vienna the warming is about $3^{o}C$. One may speculate whether people from Nordic or alpine areas will find the thought of such a warming appealing. Some Swedes might like to have the climate of Italy, and as many Austrians may enjoy the added warmth as regret diminished skiing opportunities. Alas, at the latitude of Cairo it is still warming by $2^{o}C$, and most Egyptians seem likely to say it is already hot enough.

The next Figure (5) is a map of rainfall changes constructed using analogue methods by Sergin of the Institute of Geography in Vladivostok. While this map is for a warm period in comparison with recent times, it is not based on an atmospheric response specifically to an increase in CO_2. One commonly displayed map of precipitation changes (by Kellogg) shows rather frightening



Source: Manabe and Wetherald, 1975

Figure 4. Temperature change (^{o}C) due to doubling CO_2 concentrations. (Source: Manabe and Wetherald, 1975.)

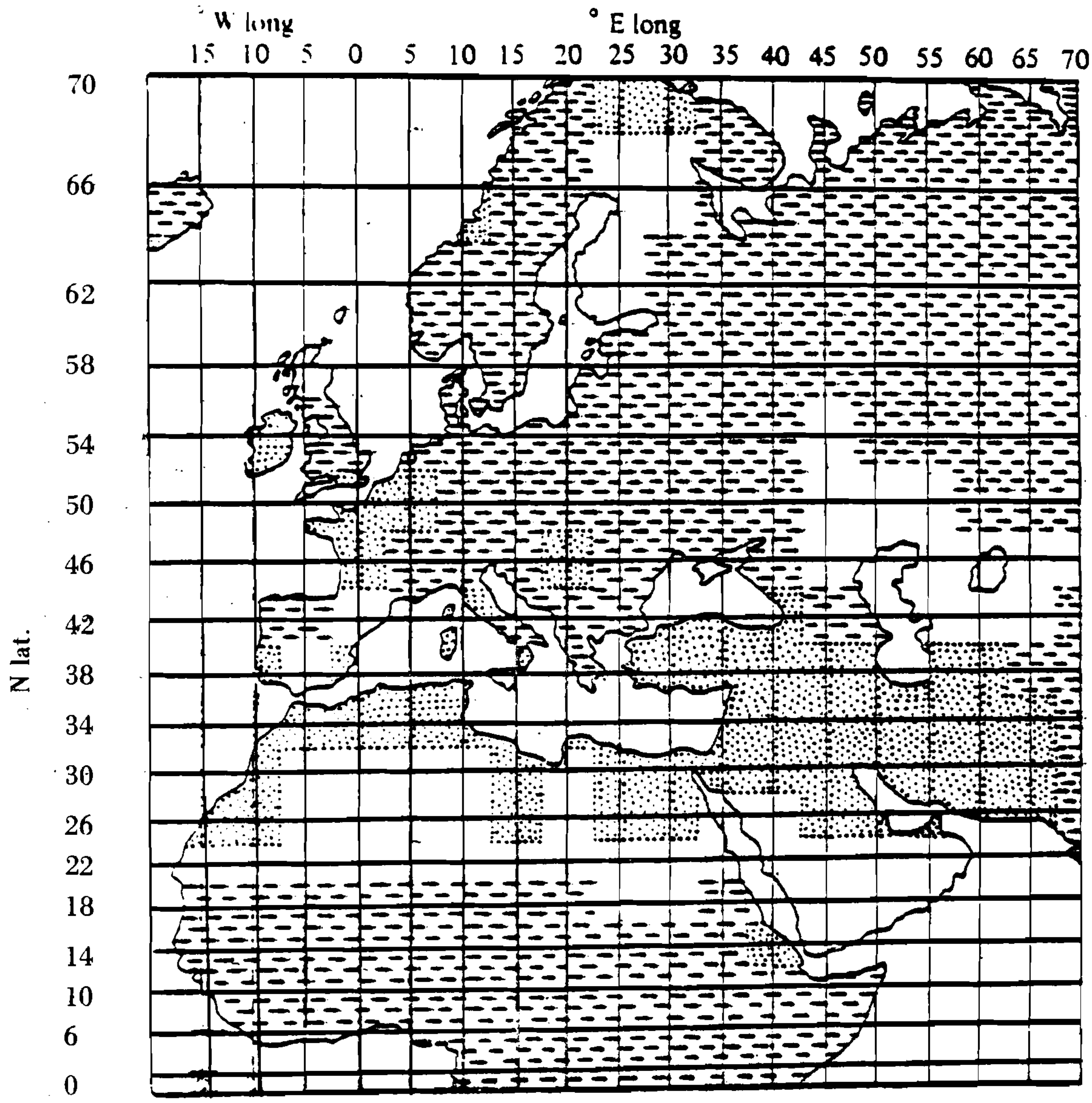


Figure 5. Estimate of the average annual precipitation field for a warm climatic period, in comparison with recent times. In areas marked with broken lines, the amount of precipitation increases; in areas marked with dots, the amount of precipitation decreases; and in areas which are blank, the amount of precipitation is unchanged. (Source: Sergin, 1980.)

decreases in rainfall in several major grain producing areas. Sergin's results are more sanguine. For example, there is an increase in rainfall in the Ukraine. In the Sahel, the southern edge of the Sahara, one of the world's most drought-stricken areas, there is also an increase in rainfall. In contrast, many already arid areas, for example, Iran and Egypt, become drier. It also becomes drier in parts of Hungary, in Ireland, and in the Bordeaux and Loire regions of France.

As the casual speculations above begin to suggest, there is no well-defined process for translating climatic changes into effects on agriculture and economy and into societal responses. The point of maps with the level of uncertainty that these have is largely that climatic change is likely to have important distributive implications. Some regions will find themselves with more favorable climates, others with less favorable climates. Indeed, distributive issues could well be of great importance, both among regions and nations and among groups within a geographical area. In the same area, for example, one can easily imagine some industries flourishing because of climatic change and others stagnating. At the same time that the possibility of benefits must be emphasized, it should also be stressed that areas or sectors in which major changes take place will probably face considerable adjustment costs, regardless of whether the new situation appears ultimately to be more favorable.

In the context of these general comments and with a reminder that many unexpected consequences may follow from environmental changes, it is still possible to identify several sectors for major impacts with some confidence. Agriculture is obviously most prominent. There could be significant changes in the production potential of many areas as a result of climatic shifts. At the same time, CO_2 enrichment of the atmosphere increases the ratio of photosynthesis to transpiration; a 10% increase in water use efficiency could come with a doubling of CO_2. CO_2 may also affect the yield of usable product from plants. While the last two factors mentioned may be favorable, climatic change seems likely to create significant risks with respect to protection of plants from pests and pathogens. Absence of frosts and cold winters could mean proliferation of pests. The net effect of CO_2 and climatic change on agriculture and the dynamic response through time are extremely difficult to foresee.

With respect to quantity and quality of water resources, effects are again very likely, but difficult to specify in a credible way. The situation is similar for forests and fisheries. One may expect effects on migration, on human health. For example, one recent hypothesis is that very large increases in CO_2 accelerate the process of aging. (This seems a particularly appropriate and intuitively correct fate for mankind!) Will the various effects interact and increase world conflict? Will they be a negligible addition to the already enormous problems of world development? Will they be beneficial? Arguments are made for all these possibilities.

While the overall outlook with regard to the impacts of climatic change is mixed and extremely uncertain, it must be mentioned that there is one catastrophic possibility associated with a large warming. This is a collapse of the West Antarctic Ice Sheet, leading to a rise in sea level of about 5 meters. Some experts argue that such a collapse could occur in a few centuries. A sea level rise of the amount mentioned would probably mean the elimination through submergence of the Netherlands and Bangladesh, and the inundation of much of the Nile valley, Florida, and Washington D.C. While there may be ambivalence to several of the impacts of climatic change, many people are likely to regard the disappearance of a country as an unacceptable outcome for world energy policy, even if it is a dozen generations in the future.

Before concluding this sketch, it is necessary to reiterate that these are the pieces of a puzzle which may--or may not--fit together. Among others, there are major uncertainties with respect to:

-- future rates of introduction of CO_2 into the atmosphere from fossil fuel combustion;

-- the global carbon cycle, and prediction of levels of CO_2 remaining in the atmosphere for various amounts injected;

-- the timing and geographical distribution of climatic changes due to increased atmospheric CO_2-levels;

-- the effects of climatic changes and increased CO_2 levels on the environment and human activities, in particular, agricultural production;

-- economic and political responses to possible climatic effects.

What does seem certain is that the CO_2 issue raises a fundamental question of the responsible management of the Earth's carbon wealth. The burning of carbon clearly has benefits in the form of energy release. However, carbon concentrated in fossil fuels, as well as carbon stored in the form of trees and soil, also form an important part of the Earth's endowment. Altering the distribution of carbon among the reservoirs, particularly by reducing the amount underground and in the biosphere and transferring it to the atmosphere, appears to be an inevitable aspect of man's economic activity. However, the rate at which this is done is not inevitable. It appears prudent now, when we are still potentially at the beginning of the age of massive carbon exploitation, to consider carefully the rate at which carbon resources should be transformed. Whether climatic change appears to be costly or beneficial, from this perspective CO_2 is a challenging item for consideration on the agenda of global development.

The picture presented here has been intended primarily as an introduction to the game approach which follows. Indeed, this approach may be a more effective way of conveying the same information. Readers interested in pursuing particular aspects of the issue in more detail are referred to the annotated bibliography at the end of the paper.

2. A CARBON AND CLIMATE BOARD GAME*

2.1 An Educational Tool

From the previous discussion of the CO_2 question it is clear that the issue is a complex one. There are many aspects of the physical problem which must be grasped; there are inherent strategic factors in the creation of the problem, if it should come to be; there are important behavioral questions in assessing risk and response. Is there a method of familiarizing people with such a complex issue, a method more sympathetic and effective than trying, for example, to make students read government reports, or make government officials read academic papers? One possible device for accomplishing this is a board game, a format known to most people through games such as "Monopoly."

Shortcomings of education and misunderstanding in both the public and the technical community are often among the reasons cited for the absence of broadly acceptable solutions with respect to nuclear energy. At present, CO_2-induced climatic change does not seem likely to arouse the concern that nuclear risks do. However, it is clear in recent years from books, magazines, and television programs that alarm can quickly arise about possible human modification of climate and weather. It seems desirable to encourage responsible consideration of the carbon dioxide issue now, rather than in an atmosphere of polarization and anger. It is easy to imagine such an atmosphere in 5 or 10 years (if not sooner) at a moment when an unusually severe drought somewhere in the world might coincide with reports of the finding of a "CO_2 signal" in the climate. Thus, development of a sound board game which might be widely disseminated in high schools and universities, as well as in the communities more directly involved in research or policy related to CO_2, could be a constructive contribution to the public debate on energy.

There are three basic objectives which an educational board game can fulfill. It can:

-- organize an issue with a complex structure in a simple, efficient, and readily comprehensible format;

-- inform people about a relatively large and diverse body of specific information in a short period of time;

-- serve as an attractive basis for structured discussion.

With respect to the first objective, a variety of basic concepts relating to CO_2 might be embodied successfully in a board game. These structural concepts include the following.

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*The underlying logic for a gaming approach to the CO_2 issue is described in the Working Paper entitled "Carbon and Climate Gaming" (WP-80-152).

-- The CO_2 situation is a potential tragedy of the commons, a problem of abuse of common property resources. Use of the atmospheric common for waste disposal by many nations may collectively lead in the extreme case to widely shared, climate-induced tragedy.

-- There is great uncertainty. There are uncertainties in the carbon cycle, in climate modeling, in assessing the impacts of climatic change, in linking these together. No single credible estimate of the risk of CO_2 will be forthcoming.

-- There is likely to be a mixture of effects, some good, some bad. It is extremely hard to predict for any group, region, or the world as a whole, what the net effect will be. Indeed, it appears that the distribution of effects may be of greater importance than the net global effect.

-- There are long delays and a question of irreversibility. Decisions about energy policy leading to CO_2 emissions are taken decades before the emissions accumulate. Steps to prevent or diminish the environmental changes probably need to be taken well before the effects become prominent. If we wait a long time to evolve a policy, the only option we may have is adaptation.

-- It is a multidisciplinary research problem. It is not a problem which atmospheric scientists, or ecologists, or economists can successfully analyze in isolation.

These themes will determine the structure of the board and the rules of the game and should become clear to the player in the course of play. Other specific information will be imparted directly through verbal or graphic means. The reader is referred to the list of board spaces which follows to gain a sense of some potential areas which might be dealt with. It is clear that the board format allows for very limited presentation of written information, and this introduces a danger of oversimplification. Great care will have to be taken in offering information which is significant and not misleading.

While certain concepts and information will be conveyed directly as a result of the structure and specific contents of the board, there is a third, indirect benefit which arises from the gaming approach. This relates to eliciting discussion on the basis of the actual playing of the game. One of the needs in the CO_2 question is a flexible method of scenario generation and exploration. As has been suggested, many futures, many resolutions are possible with the CO_2 question. It seems premature with the current level of uncertainty to try to elaborate in great detail one or two particular futures. If it becomes apparent that the number of paths nature may follow is being reduced, then it may be worthwhile to invest a large effort in describing thoroughly some particular outcome. At present, it is more appropriate to try to develop frameworks for integrating the issue and lay out the wide range of possible outcomes.

While a flexible method of looking at CO_2 futures is called for, it is also clear that some formal, organizing method is needed. One of the difficulties (and opportunities) with a subject like climatic change is that everyone is immediately ready to speculate about it. It is not a topic with an intimidating technical sound, a topic which quiets an audience, about which most of an audience readily assumes that the speaker understands more than they and has some knowledge to impart. Now, of course, it is true that the knowledge of so-called experts on climatic change is quite limited and uncertain. Still, some basic concepts and a variety of possibilities can valuably be brought to people's attention, before wild conjecture begins. The board game may be a stimulating and effective way of bringing structure to discussions of a CO_2 world.

Finally, it should be mentioned that the board game is intended to be complementary to the computer-based game which is also being developed. The board game should offer a simple, clear portrayal of the overall problem. The computer-based game will focus in depth on a few of its most crucial aspects, particularly the development of a greatly expanded world coal trade which is the prerequisite for the existence of a CO_2 problem. A full gaming experiment might involve during the course of a day the playing of both games, as well as discussion and analysis. In such an experiment, the board game may be a good means of introducing people to the issue, of providing a framework for the decisions players will be asked to make in the computer-based game.

2.2 A Possible Design

Several arrangements for the board game have been explored, and experiments will continue in coming months. What follows should not be taken as a rigid structure but as an indication of design possibilities and the opportunity for representation which the format offers.

At the most general level, the board game attempts to depict a plausible sequence of events and trends between the present and a time when serious climatic change may have occurred. It is tentatively structured in the following way. There is a path of accumulating emissions of CO_2 along which the Earth is moved on the basis of the rate of economic growth of the various players, who represent undefined world regions. Individual players receive more wealth, the higher is their rate of economic growth. This usually means the amount of their CO_2 emissions is also higher because the game assumes players use large amounts of fossil fuels unless they make decisions in the game not to do so. From the monetary viewpoint, emitting more CO_2 can be a positive economic indicator in the game, a reflection of increasing fossil energy consumption, which in the absence of alternative energy policies is normally associated with rising domestic product.

While the players are gaining wealth individually, a variety of opportunities arise for them, and various things can happen to the Earth, as 6 different categories of spaces on the board are encountered. These are:

Effects Spaces -- where the effects of climatic change and increased CO_2 concentrations are felt. These can be positive or negative, according to the rolls of a cost-benefit die. These spaces may affect one or all of the players; that is, the effects can be either regional or global. They include effects on agriculture, water resources, health, and so forth.

Adaptation Spaces -- where players can purchase adaptive measures which will mitigate later negative effects. Indeed, the first space in the game is an adaptation space, where players have the opportunity to purchase an assessment report. (One of the biases of the game is that research is cheap.) Later adaptation spaces involve opportunities like development of more drought resistant crop strains.

Prevention Spaces -- where players can adopt strategies which later enable them to reduce CO_2 emissions. Thus, there are opportunities to invest in conservation, or solar energy, or nuclear energy, or to explore for more natural gas, which is a cleaner form of fossil fuel from the point of view of CO_2. One of the interesting behavioral aspects of the board game may be to see which particular alternative policies players are willing to adopt on account of concern about climatic change.

Compensation Spaces -- where players individually and cooperatively can take measures to reduce levels of CO_2 in the atmosphere or take other measures to compensate for climatic change through physical means. These spaces thus offer the opportunity to plant trees to absorb the CO_2, to pipe it into the deep oceans, or to engage in compensatory weather modification. To be more than marginally effective, these measures become very costly.

Scientific Uncertainty Spaces -- where scientific controversies important to the seriousness of increased CO_2 are resolved. It turns out in the game, for example, that the oceans can absorb more or less heat than expected, or that other residuals like oxides of nitrogen and aerosols either counteract or increase the warming effect of CO_2. The consequence of the resolution of these uncertainties is either to advance or retard the Earth's movement along the path of accumulated emissions. In different plays of the game, these uncertainties can be resolved in different ways, helping display the sensitivity of the CO_2 issue to the resolution of these questions.

Exogenous Event Spaces -- where events occur which are not directly part of the carbon cycle or climatic change, but will significantly impinge on the well-being and policies of the players. The events include economic depression, war, technological breakthroughs, strengthening of international institutions, and so forth.

In the early portion of the board, more and better opportunities exist for preventive or compensatory measures. Gradually, prevention becomes more costly, and effects come to dominate the later portion of the board. If players do not adjust their energy strategies, or cooperate in certain ways, or have good luck with some of the uncertainties, the game can end with the imminent collapse of the West Antarctic Ice Sheet.

It is hoped that a Board Game may prove a stimulating method of informal scenario analysis, suitable for a variety of audiences. Such an educational activity would seem to have a useful place in exploration of the CO_2 question, given the uncertainties associated with the issue and its potential importance. This kind of gaming will not, of course, answer our many questions about a CO_2 world, but it can serve as a good description of the overall issue, showing where individual problems fit and how they must be integrated. It may, thus, help define and order inputs that subsequent more detailed analyses will require. Finally, it may help players explore their own values and preferences with respect to policies related to preventing a CO_2 problem, and with respect to what is important (or not important) about climatic change.

2.3 Listing of Tentative Spaces

Some spaces which have been used in experimental plays of the board game follow. The full instructions relating to the spaces and the devices used in play are not explained here. A fuller explanation of the rules will be prepared when the game is in a version which is less likely to undergo significant revision. For the present, the spaces should be regarded primarily as indicative of the possible categories and specific contents of a board game. Comments and suggestions are most appreciated.

3. LISTING OF POSSIBLE SPACES FOR A CO_2 BOARD GAME

EFFECTS SPACES (In possible chronological sequence)

E_1 -- ON ESTUARIES AND SALT MARSHES OF CHANGES IN CONTINENTAL CONDITIONS

A possible early effect, because of the delicate nature of coastal areas. Look for changing biological productivity and community structure along the coastline. You are a "coastal" player and this will probably be perceived negatively. Roll to find out how negatively you are affected.

E_2 -- ON NORTHERN ECOSYSTEMS

You are a high latitude region. The greatest temperature change is at the pole, so northern ecosystems may change well before change is evident at the Equator. Will this provide agricultural opportunities? Or will the soils be poor and the ground too swampy? Roll to find out.

E_3 -- OF STRESS FROM CLIMATE ON ECONOMIC CROP PLANTS

One of the early ways climate change is likely to manifest itself is through changing occurrence of extremes or "weather stress." Will there be record floods and hail, or will they diminish? Roll. Everyone.

E_4 -- ON FRESH WATER ECOSYSTEMS

You have lots of lakes in your region. Shallow water bodies may be among those aspects of the environment where climatic change first manifests itself. Neither expanding nor shrinking lake shores are likely to be popular. Roll to find out how much of a problem it is.

E_5 -- ON TUNDRA AND TERRESTRIAL CRYOSPHERE

You are an arctic region. Will your problems of engineering ease or increase? What will be the impacts on mineral exploitation, transportation, and tourism? Roll the die.

E_6 -- ON WATER RESOURCES

What will happen to the quantity and quality of your water? Roll the die. Everyone.

E_7 -- ON GRAZING LAND AND ANIMAL HUSBANDRY

These are important to your region. Is there better pasture, or are your animals dying of the heat? Roll the die to find out.

E_8 -- ON FOREST ECOLOGY

Geographic shift in species, faunal migration, and the frequency of fire and drought could all effect your large forest areas. Roll the die to find out whether it is beneficial or costly.

E_9 -- ON COMPETING ENVIRONMENTAL SYSTEMS

We are adapted to things the way they are. "Conservative" attitudes towards environmental change suggest an initial negative reaction. But how serious? Roll the die. Everyone.

E_{10} -- BROAD EFFECTS ON AGRICULTURE

Production may be dramatically altered in some areas. Roll the die and double the face value to find out whether it is good or bad for you. Everyone.

E_{11} -- ON PLANT PROTECTION FROM PESTS AND PATHOGENS

There may be significant increases in the magnitude of problems associated with protection of plants from pests. Roll the die to find out how serious it is. Everyone.

E_{12} -- ON OCEAN BIOTA

Fisheries are important to your region. Will there be more or fewer fish? Beneficial or harmful effects on the marine food chain? Are the shifts in location of stocks advantageous or awkward? Roll the die to find out.

E_{13} -- OF CLIMATE CHANGE ON SOIL ORGANIC MATTER

Your region has fragile soils. Temperature rise accelerates oxidation of soil organic matter, especially under intensive soil cultivation practices. Pay the bank. Roll the die to find out how much.

E_{14} -- ON MANAGED FORESTS

All regions want wood. Rotation time in forest management may be shortened. But will new pests or water deficiencies outweigh this? Roll the die to find out. Everyone.

E_{15} -- ON PHOTOSYNTHESIS AND PRODUCTIVITY OF AGRICULTURAL PLANTS FROM CO_2 INCREASE

There should be increased growth from CO_2 fertilization, and a variety of effects on species' life cycle, phenology, and yield of usable product. Experts think the result will be positive, but how much? Roll the die. Everyone.

E_{16} -- HEATING AND AIR-CONDITIONING

Your region uses lots of it. Space heating and air-conditioning requirements may increase or decrease for you. Roll the die to find out.

E_{17} -- ON ARCTIC SEA ICE

Will there be reduction? Disappearance? Will this increase for your region the possibility of mineral extraction in the Arctic and its usefulness for transportation? Roll the die to find out.

E_{18} -- MIGRATION

The adjustment costs and possible political stresses arising from climate-induced population movements may be great. All players roll the die to find out.

E_{19} -- PROBLEMS OF LOCATION

Some of your facilities are no longer located in appropriate environments. Relocation, capacity expansion, new industrial development may involve added costs because of climatic change. You are not likely to benefit since your infrastructure is adapted to the present climate. Everyone rolls to find out how much to pay.

E_{20} -- BROAD EFFECTS ON AGRICULTURE (second time)

Production may be dramatically altered in some areas. Everyone rolls the cost-benefit die and doubles the face value to find out whether it is good or bad for them.

E_{21} -- ON EFFICIENCY OF WATER USE IN PLANTS

CO_2 enrichment increases ratio of photosynthesis to transpiration. A 10% increase in water use efficiency could come with a doubling of atmospheric CO_2. This is a benefit for your region, but roll the die to find out how much.

E_{22} -- OF INCREASED CO_2 AND CLIMATIC CHANGE ON HUMAN HEALTH

Will there be more pleasant climates? Will higher temperatures and greater frequency of extreme episodes have negative effects? Will CO_2 accelerate the aging process? Roll the die to find out. Everyone.

E_{23} -- THE COLLAPSE OF THE WEST ANTARCTIC ICE SHEET IS IMMINENT

The sea level will rise 5 to 10 meters within a few centuries. All players give their money to the bank to start buying boats or building shelters to accommodate all the new immigrants.

ADAPTATION SPACES (in proposed game sequence)

A_1 -- PURCHASE OF ASSESSMENT REPORT

The first measure people are taking is to study the problem. It costs money, but not much, and you are prepared for your first effect.

A_2 -- STOCKPILES

Save for mitigation of a future effect. But you have to pay the bank a little now.

A_3 -- INSURANCE

Buy some from the bank. It will cancel out your next negative effect.

A_4 -- CONTINGENCY PLANS

You are prepared for demographic shifts, for example. Buy from the bank and you can skip your next negative effect.

A_5 -- INVESTMENT IN STRATEGIES TO MITIGATE DISRUPTION

For example, you have developed more drought resistant crop strains and flexible water supply systems.

PREVENTION SPACES (in proposed game sequence)

P_1 -- SOLAR

Give greater emphasis to research on solar technologies for generation of electricity and production of fluid fuels for transportation.

(3 prevention units may be purchased at 1 chip/unit)

P_2 -- CONSERVATION

Incentives for energy conservation are increased, partly through policies, and partly because of high capital costs of energy development.

(2 prevention units may be purchased at 1 chip/unit)

P_3 -- NATURAL GAS

Provide assistance in exploration for and exploitation of natural gas reserves.

(1 prevention unit may be purchased at 1 chip/unit)

P_4 -- NUCLEAR

Rapid expansion of nuclear power in developed countries with less coal reserves than the United States and the Soviet Union.

(3 prevention units may be purchased at 2 chips/unit)

P_5 -- CARBON TAX

Instituting a carbon tax encourages shift to non-fossil and cleaner fossil fuels.

(2 prevention units may be purchased at 2 chips/unit)

P_6 -- IMPROVE LAND USE

Slow down expansion of agriculture into forested lands and introduce improved sylvicultural practices.

(1 prevention unit may be purchased for 2 chips/unit)

P_7 -- BREEDERS

Encourage development of nuclear power, including breeders, in the more advanced less-developed countries such as Brazil and India.

(2 prevention units may be purchased at 3 chips/unit)

P_8 -- HYDRO

Subsidize capital for development of hydroelectric power.

(1 prevention unit may be purchased at 3 chips/unit)

P_9 -- BIOMASS

Encourage development of biomass fuels in tropical less-developed countries.

(1 prevention unit may be purchased at 3 chips/unit)

P_{10} -- LOCAL GENERATION

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

(1 prevention unit may be purchased at 3 chips/unit)

P_{11} -- CARBON RESIDUALS PERMITS

Create a market in CO_2 permits to limit use of coal and other fossil fuels, and make the emissions much more costly.

(1 prevention unit may be purchased at 4 chips/unit)

P_{12} -- LIABILITY

Your government and judicial systems accept the principle of assigning liability for damages on account of climatic change. No one wants to be blamed, so it is a way to reduce emissions.

(1 prevention unit may be purchased at 4 chips/unit)

P_{13} -- AMBIENT CO_2 STANDARDS

You can adhere to the Global Environmental Protection Agency which has just set the standard.

(1 prevention unit may be purchased for 5 chips/unit)

COMPENSATION SPACES (in proposed game sequence)

C_1 -- DECREASE CO_2 IN THE ATMOSPHERE THROUGH REFORESTATION.

Plant millions of trees to transfer carbon to the long-term biosphere.

C_2 -- DECREASE CO_2 IN THE ATMOSPHERE BY DEPOSITING IN SOIL CARBON BANKS.

Grow short-lived plants for conversion to humus and artificial peat bogs.

C_3 -- LIMIT ATMOSPHERIC CO_2 BY BIOLOGICAL TRANSFER TO THE DEEP OCEAN

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

C_4 -- WEATHER MODIFICATION

Intentional weather and climate modification and other human actions outside the carbon cycle may become a way to compensate for the increased level of atmospheric CO_2.

C_5 -- LIMIT ATMOSPHERIC CO_2 BY PHYSICAL TRANSFER TO THE DEEP OCEANS

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

C_6 -- EXTRACT CO_2 FROM THE ATMOSPHERE AND CONVERT TO METHANOL

Use solar or nuclear-generated electricity to extract CO_2 from the atmosphere and convert it to a liquid hydrocarbon.

CARDS FOR SCIENTIFIC UNCERTAINTY SPACES (not to occur in this order)

CLIMATE MODEL IMPROVEMENT

Cloud feedback and other processes are better incorporated into models. Roll the die to find out whether this increases or decreases the CO_2 effect.

NON-CO_2 ANTHROPOGENIC INFLUENCES ON CLIMATE

Roll the die to find out whether chlorofluorocarbons, NO_x and other factors add to or subtract from the CO_2 effect.

OCEAN THERMAL BUFFERING

The oceans may or may not absorb heat at the calculated rates. Roll the die to advance or go back.

OCEAN CHEMICAL BUFFERING

The oceans may absorb a larger fraction of CO_2, or the oceans may absorb a smaller fraction of CO_2, and as it gets warmer they may even start to bubble it out into the atmosphere! Roll the die to find out for the Earth which way this uncertainty is resolved.

NATURAL CLIMATIC CHANGE

It's getting warmer. It's getting cooler. Roll the die to find out whether the Earth should advance or move back.

THE BIOSPHERE HAS BEEN A SINK FOR CO_2

Unfortunately, this implies that the fraction of CO_2 remaining airborne from fossil fuel burning is larger, and this means the accumulation of emissions occurs faster. Roll the die to find out how many spaces to advance the Earth. But it also means the biomass is growing, so collect a chip from the bank.

THE BIOSPHERE HAS BEEN A SOURCE OF CO_2

Fortunately, this suggests that the fraction of CO_2 remaining airborne from CO_2 inputs is lower and the accumulation of emissions will occur more slowly. Roll the die to find out how many spaces to send the Earth back. Alas, it also means you have suffered severe regional problems from deforestation, for which you pay the bank one chip.

CARDS FOR EXOGENOUS EVENT SPACES (not to occur in this order)

TECHNOLOGICAL BREAKTHROUGH

Decoupling of carbon emission-energy production relationship. From now on the Earth advances one less space than the dial indicates, but collect the indicated chips. For stimulating the breakthrough you collect 2 GDP chips from the bank.

STRENGTHENING OF INTERNATIONAL AGENCIES AND INSTITUTIONS

The players collectively receive one prevention card to play when they all agree.

WEAKENING OF INTERNATIONAL AGENCIES AND INSTITUTIONS

Next time the Earth lands on a compensation space, the means to organize cooperative international efforts is lacking, so the Earth cannot move more than one space backwards.

SCENARIOS OF FUTURE CLIMATIC CHANGE ARE DEVELOPED

Models and historical analogues produce maps of the climate of the future. The distributive issues are heightened. Roll the die to find out whether you give to or receive from the player on your left. Every player takes a turn.

FUSION

Collect wealth but do not advance Earth for next 2 spins of the economic growth dial.

LIMITED WAR

Pay half your accumulated wealth to the bank and pick another player to do the same.

INTERNATIONAL MONETARY SYSTEM IN CRISIS

You can't get bank loans to finance your carbon imports. You advance one space less than planned (go back one space), and pay the bank one GDP chip for premium interest rates.

THERE IS POLITICAL CHAOS IN CARBON PRODUCING AREAS

Temporary cutbacks in carbon fuels usage. Advance the Economic Growth counter one time period, while the Earth stands still.

NATURAL DISASTER

There is an earthquake in your country. Roll the die to find out how big it is, and pay the bank.

ACID RAIN

You are a "producer" of acid rain. To reduce sulfate emissions, you try to cut back on burning of coal, but emission control makes you less energy efficient, so CO_2 release remains the same. But pay the player on your right one GDP chip for the damage you have caused.

NUCLEAR DISASTER

It's costly, so pay the bank one GDP chip, and it necessitates greater use of fossil fuels, so advance the Earth two spaces.

UNREST IN YOUR COAL MINING UNIONS

You unexpectedly have to import to meet domestic carbon demand. Give one GDP chip to the player on your left.

EVIDENCE OF CLIMATIC CHANGE

There is dramatic evidence of human-induced change. Public pressure for preventive and compensatory measures increases, no matter what the cost. Every player pays the bank one GDP unit to move the earth back one space.

DROUGHT IN THE SAHEL

There is another terrible drought in the poor arid lands bordering the Southern Sahara. Only 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 gives one GDP unit to each of the two poorest players.

FOREIGN EXCHANGE

You don't have the foreign exchange to buy carbon fuels. You are forced to an alternative energy strategy. Go back to where the Earth started the turn. Do not collect GDP chips. In fact, pay the bank 2 for extra investment costs.

CLEANER FOSSIL FUEL

There is discovery and exploitation of large natural gas resources in your less-developed region where modern geological and geophysical exploration methods for hydrocarbons have just begun to be used.

DEPRESSION

There is a decrease in economic activity, which can lead to reduced CO_2 emissions, but mostly you just shift to cheaper, dirtier fuels. Do not collect your GDP chips. And you are too poor to maintain preventive or adaptive measures--environmental protection is a luxury--give up a prevention or adaptation card, if you have one.

MISCELLANEOUS SPACES

CARTEL

The US, USSR, and China are estimated to hold over 80% of the world's available carbon wealth. When the Earth lands here, it means they form a cartel to limit the world coal trade. This effectively controls CO_2 emissions. As long as the cartel survives, the Earth stays within a controlled range. Enter the loop.

ECONOMIC PERFORMANCE

All players count up their wealth. Any player who has not accumulated chips at least equal to the number of times he has spun the economic growth dial is not meeting the expectations of the people. You have been spending too much on environmental protection and not enough to meet the needs of the present. Or maybe it is just bad luck. In either case, your government is overthrown, and you lose your voice as a decision-maker.

ANNOTATED BIBLIOGRAPHY

Ausubel, J.H. and A.K. Biswas, eds. 1980. Climatic Constraints and Human Activities. Oxford: Pergamon Press.

See for discussions of impacts of climate on agriculture and analysis of societal responses to possibility of climatic change.

Bach, W., J. Pankrath, and W. Kellogg, eds. 1979. Man's Impact on Climate. Amsterdam: Elsevier.

Comprehensive review of physical problem.

Bolin, B., E.T. Degens, S. Kempe, and P. Ketner. 1979. The Global Carbon Cycle. SCOPE 13. New York, Chicester, Brisbane, and Toronto: John Wiley and Sons.

Best comprehensive treatment of carbon cycle.

Environmental and Societal Consequences of a Possible CO_2-Induced Climate Change. 1979. Annapolis, Maryland. Workshop conducted by the American Association for the Advancement of Science, sponsored by the Carbon Dioxide and Climate Research Program, U.S. Department of Energy, Washington, D.C.

Broadest and most innovative treatment to date of impacts on society and environment of CO_2-induced climatic change.

IIASA. 1981. Energy in a Finite World. Volumes 1 and 2. Cambridge, Massachusetts: Ballinger.

See especially for projected world energy consumption, climate model experiments with increased CO_2, and discussions of implications of CO_2 for coal option.

National Academy of Sciences. 1977. Energy and Climate. Washington, D.C.

Particularly valuable for sections on projected world energy consumption, impact of gases on climate, and carbon cycle in relation to biosphere.

National Academy of Sciences. 1979. Carbon Dioxide and Climate: A Scientific Assessment. Washington, D.C.

See especially for review and critique of range of estimates of climatic change associated with CO_2 increase.

Williams, J., ed. 1978. Carbon Dioxide, Climate and Society. Oxford: Pergamon Press.

Particularly valuable for comprehensive treatment of physical problem and for statement on relation of CO_2 to energy policy.

World Meteorological Organization (WMO). 1979. Proceedings of the World Climate Conference, Geneva.

Contains a number of useful papers on physical problem, especially paper by Hare on natural variability of climate, and a variety of papers on impacts by region and sector, including excellent synthesis by Kates.