CARBON AND CLIMATE GAMING

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PREFACE

The issue of carbon use and possible associated climatic change has received growing attention in the last few years as an important aspect of assessing the impacts of various energy options. At IIASA that attention has been reflected in the Energy Systems Program and in the Global Climate Task of the Resources and Environment (REN) Area. As explained in this paper, the problem of climatic change can be viewed both as a problem of societal risk management and as a problem in strategic gaming behavior of the various decision makers involved. It is natural, then, that a joint working group at IIASA has formed, quite spontaneously, from representatives of the IIASA climate task (REN), the IIASA risk management project (Management and Technology Area, MMT), and the IIASA gaming project (MMT and Systems and Decision Sciences Area, SDS). This research group benefits from the multidisciplinary character of IIASA, which, along with its neutral scientific stance and long-standing interest in climate and energy, puts IIASA in an excellent position to increase our understanding of the problem of carbon use and climatic change. A list of IIASA papers and publications relating to climate is included here.

This paper describes an effort which began in March of 1980 and is expected to continue for another year or more. The paper consists primarily of material developed for a research proposal intended to assure continuation of the project. Two other working papers describing the project are also available. The paper entitled "An Interactive Model for Determining Coal Costs for a CO_2-Game" (WP-80-154) describes in more detail the logic and a possible framework for parts of the proposed computer game. The paper "CO_2: An Introduction and Possible Board Game" (WP-80-153) offers a non-technical sketch of the question and a description of the second proposed game. The development of the carbon and climate games described in these papers is being carried out at IIASA, while the actual gaming experiments are expected to take place both at IIASA and at other locations convenient for interested groups.

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SUMMARY

The Problem

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. The question of carbon dioxide and climatic change is a complex one, distinguished by several key features:

-- Exploitation of common resources. It is a tragedy of the commons problem where the common resources are the climate and the capacity of the atmosphere for waste disposal. It is to the short-run, individual gain of a country to burn carbon and release CO_2 to the atmosphere. Yet, if many countries burn large amounts, a drastic climatic shift may result.

-- Large uncertainty. The current state of scientific knowledge is such that no one knows for sure what the physical or societal effects of releasing large amounts of CO_2 are. Such a release could be a human and financial disaster, it could be beneficial, or it could be a mixture of both.

-- Large delays and irreversible effects. Important uncertainties could be resolved, given enough time, but the environmental effects of energy policy decisions made in the 80's may not be understood until later, when it may be much more costly or impossible to reverse those effects to the extent that they turn out to be

adverse. Yet there could be tremendous social and financial costs involved in delaying, for example, increased coal use until CO_2 effects are better understood. In fact, it may be the case that the effects cannot be adequately understood without actually releasing the CO_2.

-- Multidisciplinary research needs. Relevant study ranges from basic geophysics to applied economics.

The Objectives of the Gaming

It is desirable to have an overall systems analysis which integrates and displays in a meaningful way the numerous aspects of the problem of carbon dioxide and climatic change. There are several reasons to believe that a gaming approach to such an analysis, by capturing the uncertainties in the issue and its strategic and behavioral aspects, will accomplish this better than other methods. Research is needed to collect and present estimates of carbon wealth, coal extraction costs, and information on the possible effects of climatic change, and synthesize this information through a game format. Two prototype games are envisioned. These might be developed and tested with scientists and representatives of government and industry. Playing of the games and their documentation and evaluation could serve to inform researchers and others concerned about the CO_2 issue as to the overall character of the problem. It could also help establish priorities for future research on climate and CO_2 by better defining plausible scenarios regarding future CO_2 emissions and societal responses to increasing atmospheric CO_2 levels and associated environmental change.

THE CO_2 QUESTION AND IDENTIFICATION OF RESEARCH NEEDS

In the last decade the possibility that a variety of human activities may be responsible for future long-term shifts in the climate has become increasingly prominent. Using the atmosphere on a massive scale as a receptacle for waste, for example, for oxides of nitrogen, chlorofluorocarbons, and carbon dioxide seems particularly likely to have serious consequences for the climate and thus for our economy and the environment. At the moment our most uneasy state of blended interest, uncertainty, and apprehension exists with respect to carbon dioxide. The earth harbors enormous reservoirs of carbon in the forms of biomass, oil, gas, and especially coal. As these are burned, primarily to produce energy for human uses, their carbon content is released for disposal into the atmosphere, oceans, and biosphere. The apparent inevitability of the exploitation of the earth's carbon wealth and concomitant transfer of huge volumes of carbon dioxide to the atmosphere pose important questions for policy toward resource development.

This situation has been recognized at high levels of government. For example, the Declaration of the Summit Conference of the Heads of State of Canada, the Federal Republic of Germany,

France, Italy, Japan, the United Kingdom, and the United States held in Tokyo in June 1979 included the following statements:

> "We pledge our countries to increase as far as possible coal use, production, and trade, without damage to the environment....
> We need to expand alternative sources of energy, especially those which will help to prevent further pollution, particularly increases of carbon dioxide and sulphur oxides in the atmosphere."

Political and economic decisions (for example, with regard to synthetic fuels) and scientific findings during the past year have reiterated the need to improve our understanding of the CO_2 question and its policy implications.

This need for improving our understanding of the CO_2 question stems more specifically from the great uncertainty that prevails in many areas of research related to CO_2 and climate. Among others, one may mention uncertainties with respect to

- present and future rates of introduction of CO_2 into the atmosphere from fossil fuel combustion, deforestation, and changing land use practices;
- the global carbon cycle, and prediction of levels of CO_2 remaining in the atmosphere for various scenarios of input;
- 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;
- the political responses to possible climatic effects, especially in regard to North-South relations;
- the possibility of measures being taken on a national or international scale for prevention of emissions or compensation for emissions once they have taken place;
- the comparative evaluation of risks from various energy sources.

Research is now underway on most of these problems; for example, there is extensive research with general circulation models to explore the sensitivity and predictability of the atmosphere.

There are, however, reasons to believe that the research underway might not be sufficient. In particular, there appears to be a need for an overall systems treatment of the CO_2 question, one which incorporates explicitly the uncertainty of information and the political choices in a situation with a multitude of countries pursuing independent energy strategies. While from the

point of view of decisions about industrial development, it appears possible to wait the 5 or 10 years which some researchers mention as the time necessary to achieve a good integrated treatment of the CO_2 question, there are also strong reasons to undertake preliminary efforts at this time, even before additional detailed results about various aspects of the problem become available.

At the most general level, it must be recognized that it is by no means certain that individual uncertainties will be resolved within the next decades. For example, considerable uncertainty is likely to remain regarding how accumulated CO_2 emissions and climatic change will affect well-being in various countries. It is quite possible that part of this uncertainty will be resolved first when the effects are directly felt. It might then, due to irreversible effects of CO_2 emissions, be impossible to carry out policies to remedy some of the problems created by the emissions. By the time certainty nears, adaptation could well be the only option left.

If societies decide to try to prevent or physically compensate for CO_2-induced climatic change, it is quite likely that this must begin well before there are clear "carbon dioxide signals" in the climate. That is, decisions about climatic change will have to be made under great uncertainty, whether in this decade or in following ones. We will learn faster as the problem looms larger, but it is not clear how much we will learn. We cannot be confident that there will be some definitive set of information ten years from now, so we need to seek innovative ways for societies to assess the problem. In fact, because there will almost certainly not be a definitive result to research on the CO_2 question, it is important to begin to develop decision-making aids which do not depend on secure findings but rather support decisions that must be made in the face of extreme uncertainty.

It should be noted further that there is an issue about the effect that the uncertainties may have on the actions of various policy bodies. A particular problem may arise in the dynamics of the reaction of the political process to new technical information. It seems quite likely that during the next decades there will be different research reports at different times with different main conclusions, sometimes stressing the danger of CO_2, sometimes playing it down. Too optimistic forecasts about CO_2 emission effects might encourage excessively large emissions, while too pessimistic forecasts might possibly put an unmotivated hindrance on an economically rational use of the world's large coal resources. Thus, it is desirable to develop methods of assessment which allow people to experience responding to the problem and which can familiarize them with the several states of nature which may occur, before real choices must be made.

Even if one believes that climate research will resolve the major portion of uncertainties within the next decades, it would still be desirable to obtain a better overall systems view of the CO_2 problem within the next few years. Such systems studies are

desirable for several reasons. First, they could possibly improve future research by helping put in focus the most critical issues, so that the uncertainties in these areas may be researched with a higher priority. Furthermore, there will most probably be a lag between the time when better information about the effects of CO_2 is available and the time when political bodies can act on this information. This time lag could be reduced, however, by prior efforts to inform both political decision-makers and the larger interested community about the general nature of the CO_2 problem. These information efforts should come at an early date, in an atmosphere which encourages responsible consideration, rather than polarization and alarm.

Finally, there is, as mentioned, a need for studying explicitly the geopolitical and strategic aspects of the CO_2 problem. This can be accomplished by viewing the problem as an international game situation. This game situation arises as follows. The combustion of carbon, in the future mostly from burning of coal, has a positive influence, at least in the short term, on the welfare of a country. It will, by increasing the total CO_2 content of the atmosphere, probably change the global climate, and hence could negatively affect the long-term welfare of many countries. Some countries might be better off from such a climatic change. This situation is a form of "The Tragedy of the Commons,"* with many countries pursuing national energy policies which involve free use of the atmosphere for waste disposal, until potentially severe climatic changes result. How likely is it that there will be the kind of cooperation which will allow nations to avoid pursuing possibly short-sighted policies which may lead to a common long-term disaster? Most research on carbon dioxide and climatic change is looking at specific physical aspects of the question and not exploring this crucial issue.

THE GAMING APPROACH

We have argued the need for studies of the CO_2 problem which are more holistic and which focus on international interdependence and the problem of uncertainty, with the uncertainty possibly being resolved slowly and in an irregular fashion. The kinds of questions one wants to ask in such studies are, of course, exceedingly difficult to answer, and certain commonly used methods appear unsuitable for such an effort. For example, economic models of the general equilibrium type, assuming pure competition, fail to incorporate the strategic aspects of the situation. Ordinary simulation, with only the researcher interacting with the computer, has the great drawback that it presupposes that one already has answers to the most difficult questions regarding the functioning of the system, namely the behavior and the expectations of the players.

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*Garret Hardin. 1968. "The Tragedy of the Commons," Science 162:1243-1248.

Although game theory, the purely theoretical mathematical analysis of game situations, deals explicitly with the strategic aspects of a situation, it is not very useful for analysis of the CO_2 problem as outlined. Such analysis relies on either "cooperative game theory," which gives the answer that cooperation will follow, or "non-cooperative game theory," which in our case would find that massive increases of CO_2 will not be prevented. The presence of "players" of different sizes in the creation of CO_2 emissions, incomplete and changing information, and long time delays between actions and effects create a problem of far greater complexity than can be handled by ordinary game theoretic models.

Due to the restrictions of other methods, we have turned to gaming, that is, the actual playing of games. Gaming is an interactive simulation involving real human beings as the most important players, in this case facing and coming to decisions about various situations with respect to the carbon economy and consequent environmental change. Gaming offers the advantage from the point of view of research that one can obtain a broader spectrum of behavioral responses than a model builder can conveniently assume. Moreover, both the researchers and those who play the games can explore various scenarios in a flexible, non-deterministic manner. It is also important that gaming forces us as researchers to put the CO_2 problem into the decision maker's perspective. As analysts, we tend to see the problem in terms of probability distributions over outcomes, gradually revealed states of nature, long-delayed feedback, irreversible costs, and so forth. The decision makers actually faced with CO_2 policy options, however, may view the problem very differently. The gaming approach forces us to consider the problem in terms of the observables available to the decision maker, the policy levers at his disposal, and the incentives he faces.

TWO PROPOSED GAMES

While fruitful games of several different degrees of sophistication might be envisaged, we initially envision the development of two specific games:

1) a simple board game

2) a more elaborate computer game which will involve coal extraction and coal trade among many countries.

The board game would primarily serve a pedagogical function: to demonstrate the characteristics of the overall systems aspects of the problem in an easily comprehensible format. The CO_2 issue is a complex one, where familiarity with a wide variety of information is desirable. As mentioned earlier there are uncertainties with respect to the carbon cycle and climate, strategies for prevention or compensation, effects on the economy, and so forth. There is also a wide range of possible events exogenous to the carbon cycle and climate which may dramatically shift the importance of this particular issue. Finally, there is the difficulty

that people are unfamiliar or unaccustomed to the units of measurement of the CO_2 issue; people usually think in terms of barrels of oil, not gigatons of carbon, and in time horizons of a few months or years, not decades and generations.

It is the objective of the work on the board game to produce an educational device that could be distributed on a wide scale. The game should be simple and self-contained, so that it can be played, without professional instruction, by many people. In such a way, a board game could aid in improving the understanding of the many aspects of the CO_2 problem among concerned government and industry groups, students, and the interested public. The board game will also generate insights which will be helpful for the development of the more complex computer game.

Conventional articles and lectures tend to present only partial pictures of the CO_2 question, generally limited by discipline and failing to convey the strategic aspect of the issue to the audience. In contrast, a board game may be a promising technique for broadly structuring and illustrating the issue. It offers wide scope for representation: of emissions of CO_2; purchase of adaptive, compensatory, or preventive measures; various resolutions of scientific uncertainties about the carbon cycle and climate; possible intervention of factors exogenous to the carbon cycle and climate; and effects on society and economy. These various aspects can change and combine to produce different scenarios. The board game will also help increase understanding of CO_2 as a potential "Tragedy of the Commons" in which certain benefits are associated with increasing use of the atmospheric common for waste disposal while potentially negative effects accumulate and distribute themselves somewhat independently of those who in a sense cause them.

The design of the computer game will emphasize different purposes than the board game. In this case, the educational aims are secondary. At least in its final stages, the computer game will be a research tool intended to raise and to give some very preliminary answers to specific questions about the CO_2 issue. For example, will the interactions of the decision makers be such that potentially threatening levels of CO_2 will be created? What range of amounts of accumulated CO_2 is likely to result from the interactions of the decision makers? If created, what kind of a global carbon (coal) market does a CO_2 problem presuppose? Will it be possible for the big coal-producing nations to form and enforce some sort of a cartel? Will those favored by geographic endowment or technological capability act unilaterally to accelerate the carbon economy in a potentially dangerous way? Will those who cannot exploit the capacity of the atmosphere for carbon waste disposal seek to obtain rent from those who can? Will they try to forestall use of the resource until they can develop their own exploitation capacity? As the atmospheric CO_2 content increases, will the interest become stronger in control strategies and will strategies of reducing carbon extraction, trade, or emissions be preferred? An important question is whether there are institutional scenarios (treaties, cartels, and so forth) which will help avoid the "Tragedy of the Commons" outcome of the CO_2 problem.

Obviously the answers to these questions will be dependent on the specific character of the game, including the data base used. However, the game will be oriented toward indicating what scenarios are more likely given various information and institutional arrangements. The questions and the tentative answers will be intended mainly to serve as a basis for future discussions both with regard to what kind of research is most urgently needed and which outcome scenarios are acceptable to various interested groups. For example, what are acceptable outcomes of the CO_2 issue for the US or the Netherlands, and what suitable objectives for the coming decade can be deduced from them?

As mentioned earlier, the computer game will focus on coal, trade, and many countries.

Why Coal?

The key long-term question in the release of carbon dioxide is the burning of coal, which is likely to account for two-thirds or more of the emissions in a scenario of serious climatic change. In fact, present estimates of total resources of oil, gas, coal, and other forms of carbon indicate that atmospheric carbon dioxide levels regarded by some experts as critical (for example, a doubling of the present level within the next century) can only be reached by very substantial burning of coal. Other carbon resources are simply not available in large enough quantities. Because coal plays this critical role in the CO_2 issue, it is logical to begin game development with emphasis on coal.

Why Trade?

About 80% of the coal deposits of the world are in the hands of three big countries: the USSR, the USA, and China. Thus, in discussing possibly dangerous levels of CO_2, one can conclude in theory that if these three large players do not export any coal and also keep their own coal combustion low, a severe CO_2 emission problem will not arise. However, by far the largest part of future potential coal combustion lies in the world outside of these three players. Much of this coal would come from imports over a long period of time. Hence, the main CO_2 emission threat arises from scenarios, like the one that can be projected from the recent MIT World Coal Study,* where a ten-fold increase in world coal trade is envisaged. The trade in coal is also of interest in connection with different schemes of international cooperation to reduce or prevent CO_2 emissions. The possibility for the larger countries to limit supplies of coal on the world market or to specific countries can give "teeth" to attempts at enforcing international cooperation. Finally, study of international trade in coal is important for discussing whether coal prices will be cartelistic and thus high, discouraging the use

*World Coal Study Group. 1980. Coal--Bridge to the Future. Ballinger.

of coal, or more formed by competition and thus cost-based, possibly leading to a rapid increase in combustion. We will attempt to capture the essential aspects of a world coal market as it relates to the CO_2 problem, while avoiding the considerable complexities of a detailed market simulation.

Why Many Countries?

The computer game will try to represent a world where many countries, acting independently, affect the problem. The first reason for this is that a major portion of energy consumption will be taking place outside of the three big countries in a great many smaller countries, which can act independently and use this independence to their own advantage. Secondly, even if the three big players account for around 80% of total coal resources, the resources of some smaller holders are large from an absolute point of view. Around a dozen countries, including, for example, Poland and the FRG, have probable resources that alone could lead to a level of emissions of the same size as total global emissions during the whole of the last decade. Ultimately one would probably wish to include about twenty countries of different sizes to catch fully the strategic problem. If we limit ourselves to only a handful of actors in all phases of development of the game, we would exclude certain possibly crucial scenarios where international cooperation is impeded by the actions of several relatively small countries. It is possible to include twenty or more countries in the game without requiring such a large number of human players, as is explained later.

STRUCTURE OF GAME DEVELOPMENT

The research to meet the needs and objectives described above can be divided into seven mutually supportive tasks.

Task 1: Improvement of estimates of carbon wealth

It is often mentioned that there are many times the amount of carbon necessary to create a CO_2 problem stored in the form of fossil fuels. However, the regional and national origin of this and other carbon wealth is important. By following the flows from carbon mining, through carbon trade, to carbon dioxide emissions, one can obtain an initial picture of the geopolitical and economic structure of a world characterized by a serious CO_2 problem. This may help narrow the bounds of plausible CO_2 injections. Choice among possible preventive, compensatory, and adaptive strategies will also be crucially affected by the distribution of carbon wealth.

Preliminary attempts have been made at IIASA to gather and analyse data on carbon wealth and use this information to establish the broad strategic basis of the CO_2 issue. However, the strategic aspects can be better understood only if more refined estimates are made of the physical and economic geography of that carbon which may be available for transformation to atmospheric

carbon dioxide. Information on carbon fractions in various fuels has been applied broadly but should be explored with reference to more specific areas and time scales to help in the selection of countries for the computer game. Techniques are available to do this using the IIASA WELMM* data base. A detailed study of the carbon wealth of certain key countries might be undertaken. This information will not only help in the development of the computer game, but also offer a first estimate of the long-term potential accountability of a country for a CO_2 problem.

Task 2: Data collection on coal extraction costs**

While a broad picture of the carbon situation forms the foundation for carbon-climate games, it is necessary to have somewhat more detailed information on coal because of the long-term dominance of this form of carbon. In particular, estimates of coal extraction costs for various countries are needed in order to open the estimation of future supply of coal on the international market and the ensuing coal trade and consumption pattern. Data might be sought from two sources:

1) The available data base at IIASA on coal extraction costs, gathered by the WELMM group in connection with IIASA's Energy Systems Program.

2) Collection of expert "guesstimates" by computer dialogue system. Some forecast needs are more long-term and more country specific than the data already gathered at IIASA. This new information can be collected from experts independently (possibly via teleconferencing), but also in connection with the playing of games, thus ensuring that the participants in the game regard this important aspect of the game as realistic.

On the basis of these two types of information, coefficients can be calculated for a simple model which would make it possible to produce cost tables suitable for gaming which show for different countries how coal extraction costs for various years change with production quantities.

Task 3: Develop probabilistic model of effects

As previously mentioned, there is great uncertainty over what economic and environmental effects will result from a given level of net CO_2 accumulation and accompanying climatic changes. Moreover, even where one can expect effects, for example, in forestry and agriculture, it is not clear where and when they will be beneficial or harmful. Decision makers taking this uncertainty into account may behave quite differently in a resource

*Water, Energy, Land, Materials, and Manpower.

**This question is discussed in greater detail in "An Interactive Model for Determining Coal Costs for a CO_2-Game," (WP-80-154).

allocation situation than decision makers acting on confident expectations. It follows that the global CO_2 question is best approached by a method where decision makers are faced with uncertainties in outcomes similar to the uncertainties decision makers face in real world problems. In the literature reviewed to date CO_2 and climatic impacts are usually assembled in a rather incoherent listing; a gaming approach allows a more flexible and consistent presentation.

This task thus involves a review of the growing literature of the relationship of CO_2 and climate to, for example, crops, forests, fisheries, and ecosystems. For the two games the catalogue of effects derived from the review can be presented in different ways. For example, in the interactive computer-based game, players would be presented with projections of consequences of some decisions that represent an appropriate degree of uncertainty. Actual consequences obtained in each run of the game would be consistent with a particular set of assumptions about the real world, a particular "state of nature." That state of nature will be revealed to the players at the rate that actual decision-makers would discover them: by observing outcomes of past actions. With several runs of the game, it might be possible to gain a sense of how players would act in each of several possible states of nature, with, for example, various climatic shifts or CO_2 effects on crop production.

Clearly, the development of a model incorporating probabilistic estimates for a thorough catalogue of effects would be an extremely ambitious effort. Given the scale of the proposed research, it is appropriate for the model for this work to be simple in structure. However, even an extremely simple model of this sort should provide improvements in realism over the deterministic efforts on climatic change offered so far.

Task 4: Development of the board game

The board game will be a game of the Monopoly type to be run completely by the players themselves, something which necessitates a far simpler game than is possible with a game led by a game director. The design of the board game will utilize experience from similar educational games, so that questions of importance are emphasized and the game is playable and has outcomes of a logical kind. Appropriate use of probabilistic features will be made. Also, a good deal of attention will go into the production and presentation of the game, so that the maximum feasible amount of information about the CO_2 issue is imparted through playing. This requires attention to both verbal and visual conveyance of information.

Much care has to be devoted to the construction of the game so that it can be played in a time of about one hour. During that time, the game should be stimulating, not only for good play at the moment, but also as an incentive for further examination of the CO_2 problem. The construction of unambiguous and yet simple rules is another important part of this task.

Task 5: Development of the computer game

Although the computer game is of a more complex nature than the board game, it must still have a simple structure from the point of view of the players. In order to have the game played frequently, preferably with persons engaged in energy policy (see task 7), it must be playable in a convenient amount of time, for example, 3 hours. This again requires a game that will be easy for players to learn, understand, and play.

Allowing for about ten rounds in a game, each round must therefore call for only a small number of decisions by each player. The actions of each player at each round of the game will probably include a coal extraction decision, a coal trade decision (supply or demand), a decision on total amount of energy consumed (implying a certain level of CO_2 emission), and a decision relating to emission control, possibly in the form of international agreement. After market clearing calculations at the end of each round, players would be informed about the price of coal, their status as regards coal extraction and coal trade, their own CO_2 emission in the world, as well as their present "welfare," measured in the form of an index.

With regard to the welfare index, players would be informed about changes due to individual energy consumption, as well as changes due to total CO_2 in the atmosphere. The welfare index would be calculated on the basis of the probabilistic model developed in Task 3. As explained in that task, the model would be set to represent a particular state of nature on any given run, though that state would only be revealed to the players through observations of past outcomes. In the early stages of the game, welfare would be largely a function of size of the coal combustion economy. In the later stages of the game, however, effects of global environmental change would begin significantly to affect in varying ways the welfare of individual players, depending on the accumulated level of atmospheric CO_2.

The construction of the computer-based game is expected to take place in several stages, of which the most advanced may lie beyond the present research plan (see task 7). First, a primarily manual version of the game is foreseen. In this there would only be human players involved. Since the game has to be administratively simple to be run in, say, three hours, only a limited number of human players can be used. Thus, less than ten countries can be studied in such a manual game.

This limitation causes an important problem since, as noted above, we are ultimately interested in studying a world with many more independently acting countries. It is not reasonable to resolve this conflict between many countries and few players with a game using instead a small number of regions, lumping into regions a great many countries of different sizes and characteristics. Such a game would deprive the gaming exercise of one of its most important capabilities, namely to study the effect of policies of fairly small, independently acting countries.

A preliminary plan for taking care of this problem is to design a game which can take advantage of the computer's capacity to simulate additional players. This computer-based game might thus have the following form. It would include the three big countries (USSR, USA, China) and four smaller countries (for example, FRG, Botswana, India, and Italy). The roles of these seven countries would be played by humans. Besides this, the playing of some ten or more countries would be simulated by the computer. These "robot players" would act partly in the way that the four smaller-country human players acted earlier in this game or in previous games. The important thing is that the action of each small player will, at the moment, seem to him not to be significant to the total outcome.

Task 6: Experimentation with the games

The playing of the games would take place both at IIASA and outside of IIASA. Experimentation would take place first with IIASA scientists, and then with visitors and in connection with IIASA workshops on related topics, such as energy policy, environmental protection, and so forth. Outside of IIASA, the game would be played with interested groups of people from the government, industrial, and academic communities of various countries, as well as at conferences which bring together relevant groups. It should be noted with respect to this task that what players learn from playing the games must be considered one of the most important results of the proposed project. It is expected that the games even at this stage will be useful to players, for example, by better explaining the overall nature of the question of carbon dioxide and climatic change and by helping identify research priorities.

A full experiment involving a couple of plays of the board game and one run of the computer game mixed with discussions about the CO_2 problem and the gaming approach is expected to last one or one and half days. It should also be possible to arrange for shorter simple experiments, for example, a single evening session with the computer game.

Task 7: Evaluation and further gaming

Analysis of the games is necessary during and especially following the initial experiments. The experiments will be evaluated from several points of view: what has been learned about the question of carbon dioxide and climate, how the current games can be improved, and what the prospects are in general for further gaming approaches to the carbon dioxide and similar questions. There are several ways in which one might want to develop the games further. Since the CO_2 problem does not only refer to coal but also other fossil fuels such as oil, gas, and wood, as well as to carbon released from soil or biomass for non-energy purposes, one might want in later phases of game development to depict, for example, independent decisions regarding non-coal fossil fuels. Alternatively, one might include activities for reduction of emission levels more explicitly.

The process of making the game more complex should, however, proceed cautiously, because the value of gaming diminishes as it becomes unwieldy with respect to playing time.

CONCLUDING COMMENTS

The proposed research has several interesting aspects which bear pointing out in closing. The research represents a creative approach to an important and intriguing problem. While essentially exploratory in nature, the project is designed to yield concrete and useful results. The board game effort is notable for making the object of the research itself an effective instrument for dissemination of results. The computer game effort addresses the classic problem of investigating a phenomenon under extreme uncertainty. More traditional research typically takes one of two approaches to the problem: developing scenarios or developing probabilistic models. The proposed research combines those two approaches in the computer game, using each to its best advantage. Each run of the game generates a scenario, a particular interaction of a set of decision makers who are observing the results of a probabilistic model which is set to represent a particular state of nature. The probabilistic model is used to represent the uncertain effects of CO_2 emissions on the welfare of the decision makers, while the scenario approach is used to represent interactions of decision makers, a process not amenable to probabilistic modeling. In combining these approaches in this way, the proposed research represents a promising avenue for investigating a complex and important problem.

LIST OF IIASA PAPERS AND PUBLICATIONS
RELATING TO CLIMATE

CARBON DIOXIDE

Book, 1978 Carbon Dioxide, Climate and Society. Edited by Jill Williams. Published by Pergamon Press.

RR-75-45 The Carbon Cycle of the Earth--A Material Balance Approach. R. Avenhaus and G. Hartmann.

RM-76-17 On Geoengineering and the CO_2 Problem. C. Marchetti.

RM-78-63 Dynamic Standard Setting for Carbon Dioxide. E. Hoepfinger.

WP-75-63 Can We Control Carbon Dioxide? W.D. Nordhaus. Later revised and published in Nordhaus (1979) The Efficient Use of Energy Resources.

WP-80-75 Climatic Change and the Carbon Wealth of Nations. J.H. Ausubel.

WP-80-153 CO_2: An Introduction and Possible Board Game. J.H. Ausubel.

WP-80-152 Carbon and Climate Gaming. J. Ausubel, J. Lathrop, I. Ståhl, and J. Robinson.

WP-80-154 An Interactive Model for Determining Coal Costs for a CO_2-Game. I. Ståhl.

RM-76-035 A Non-Linear Eight Level Tandem Model to Calculate the Future CO_2 and C-14-Burden to the Atmosphere. F. Niehaus.

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