SOLAR AUSTRALIA

AUSTRALIA AT THE CROSSROADS

A REPORT ON A PROJECT FOR

THE FOUNDATION FOR AUSTRALIAN RESOURCES

EVALUATING AUSTRALIA'S SOLAR ENERGY POLICY ALTERNATIVES

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He initiated the post-graduate course in Operations Research. His main interests are in the application of Operations Research to Australian Resource problems.

THE FOUNDATION FOR AUSTRALIAN RESOURCES

World Governments have at various times been forced by wars and other events to look closely at their country's resources. But never before have these studies been carried out in such detail as they are today. In October 1973 the Arab nations decided to restrict oil output and to embargo oil deliveries to certain countries. The short-term supply crisis focused attention beyond the immediate future. It gave the industrialised nations a taste of a world in which energy was permanently short.

Natural resource wealth has always been associated with national power. The abundance of resources had been a key reason for the rise to industrial might of the United States. Inexpensive and plentiful resources were a cushion which allowed organisations often to indulge in wasteful practices without obvious bad effects. This has now changed in dramatic fashion and the United States is finding itself in a new type of situation along with Japan and Western Europe.

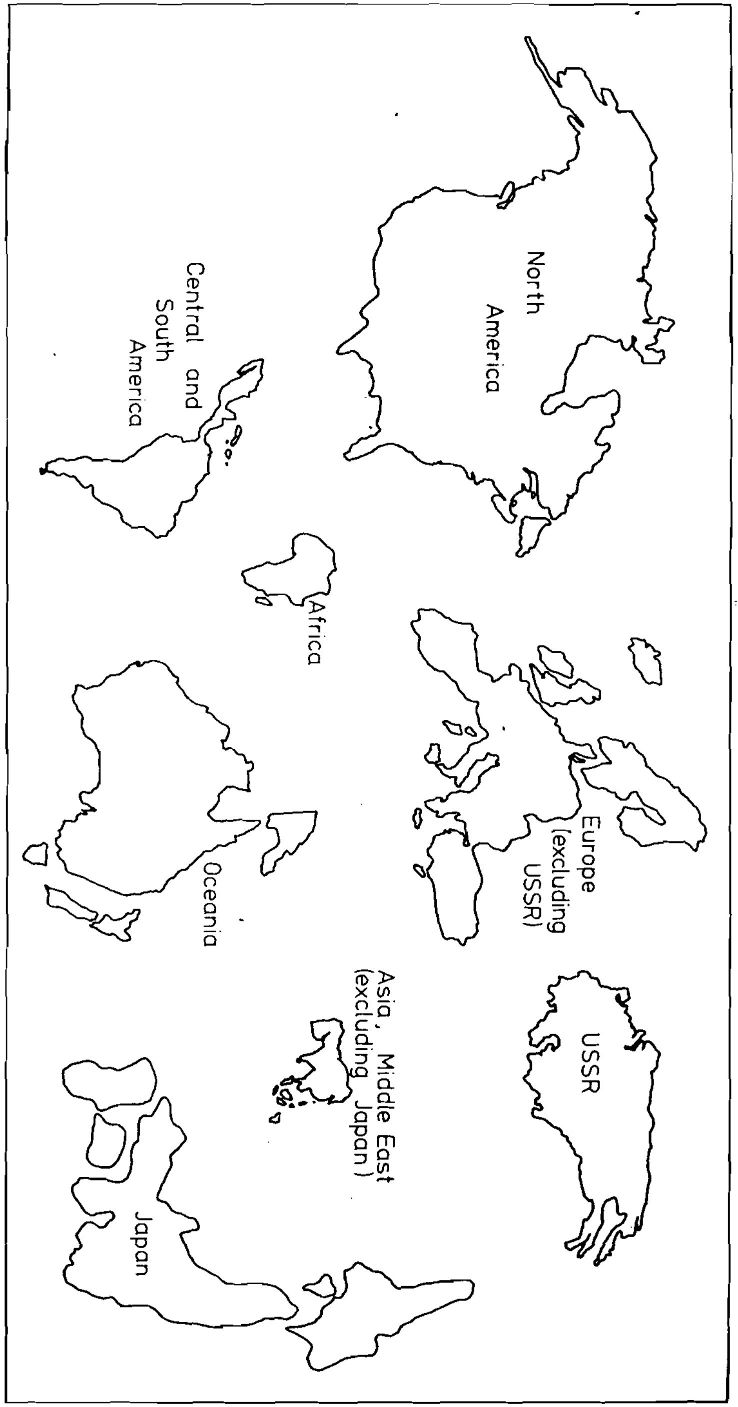
Australia is a resource rich country — "The Lucky Country". It is favoured with naturally occurring mineral, energy, agricultural and other wealth. These resources are complemented and exploited by a small but skilled population and a steadily accumulating framework of manufacturing industry.

Australia is one of the world's richest countries measured in terms of gross national product per capita, and its resources are very great. Some idea of our worth can be seen in the accompanying map of countries of the world drawn in proportion to their gross national product per capita. The growing gap between the world's rich and poor nations, and the manner in which our natural, physical and human resources are used in the future will affect our role with the rest of the world.

In Australia we have not made full use of vital information concerning the extent and potential utilisation of our resources. We search, discover and exploit natural and physical resources. We give birth, educate and employ our human resources. But we know little about the overall intermeshing picture. Although it has been predicted that Australia's energy requirements will quadruple by the year 2000, we have scant quantified information on where our weaknesses lie and to which areas our research and education should be directed.

The Foundation for Australian Resources is a non-profit, voluntary foundation, conceived to foster evaluation of Australia's natural, physical and human resources against the needs of our time. It is sponsoring "defined objective" research at Australian Tertiary institutions, initial work being done at The New South Wales Institute of Technology. It is fostering

COUNTRIES OF THE WORLD SHOWING EACH REGION IN A SIZE PROPORTIONAL TO ITS G.N.P. PER CAPITA



Source: World Bank Atlas, 1974.

community awareness of the importance of resource optimisation. It is developing processes which can profitably maximise utilisation of resources.

The problem of Australia's resources is, of course, too enormous for any one organisation to solve. F.A.R. does intend, however, at least to stimulate interest and hopefully to assist in the development of this country's human, physical and natural resources. In addition to the "Solar Australia" project, other projects which are nearing completion include a new method for assessing underground water resources, a new procedure for optimising solar absorber design and a method for determining the optimal planning of hospital and health services with respect to centralisation versus decentralisation.

The affairs of the Foundation are administered by a Council. Its Patron is His Excellency the Governor-General, Sir John Kerr. Council Members are:

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Mr. J. Latimer, Solicitor,
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(Secretary to the Foundation).

Dr. B. S. Thornton,
Head, School of Mathematical Sciences,
New South Wales Institute of Technology.

Sir Robert Norman,
Director and former Chief General Manager,
Bank of New South Wales.

Close relationship with industry in Australia is progressively being achieved and Mr. F. M. Dobbs, former Managing Director of the Honeywell computer company in Australia is the Director of Corporate Liaison. The Foundation's work is currently supported from a (presently) small number of member companies including Alcoa of Australia Limited, The Bank of New South Wales, Resource Analysis Pty. Ltd., Honeywell Pty. Limited and E. Sachs and Company Limited, and donations from a number of organisations.

Companies or organisations interested in possible membership of the Foundation, to enable them to participate and support its work by funds or through their resources or facilities, are invited to contact the Secretary, Mr.

John Latimer, c/- C. R. Potts Latimer and Company, 181 Elizabeth Street, Sydney, 2000, Australia.

or

Mr. F. M. Dobbs, Director of Corporate Liaison, 23/54 Darling Point Road, Darling Point, N.S.W. 2027, Australia.

or

Any member of the council.

His Honour Mr. Justice C. L. D. Meares,
Chairman,
Foundation for Australian Resources.

ACKNOWLEDGEMENT

The Council of the Foundation for Australian Resources wishes to thank Dr. R. L. Werner, President of the New South Wales Institute of Technology for his interest in the Foundation and its projects, most of which are being conducted at the Institute as part of research programmes and post-graduate studies.

Appropriate aspects of the research are being incorporated into undergraduate courses or in some instances used as case studies.

Although funded by the Foundation, publication of the present report has been greatly assisted by the interest and co-operation of Mr. W. Anthes, Assistant Registrar and Head of the Information and Publications Unit of the New South Wales Institute of Technology.

FOREWORD

The purpose of computing is insight, not numbers.

Dr. Richard Haming,
Bell Telephone Research Laboratories

This is not another "doomsday report" of the type which have emerged over the past few years. The "Club of Rome's" *The Limits to Growth* and similar publications stimulated a widespread anti-growth movement. Although the systems dynamics programmes of the "Club of Rome" have been the basis of the work herein, two very important changes were part of the extensive modification made for focusing on Australia and its role with the rest of the world.

The first is that we have removed the seeds of destruction inherent in earlier world models, by breaking the non-renewable sector into energy and minerals (which are distinctly different in both availability and use). If anything is limiting it is energy, not minerals. The application of capital to extract lower and lower grades of minerals is of no avail if there is no energy to power the equipment which becomes more energy intensive as lower grades are extracted.

Also we removed the physically limiting assumption of an absolute limit to non-renewable resources but of course remain within sensible boundaries. Therefore a renewable energy sector was introduced — solar energy — so that there is the possibility of continuing the process of using whatever in the future can be considered as resources. Perhaps we are too limiting in our thinking at present as to what we regard as our future non-renewable resources. The second is that provision for solar energy as a resource has been included, which has not been done before.

The reason for the inclusion of a solar energy potential for an Australian-oriented study is obvious since this country is best situated in terms of the supply of sunshine and has energy needs at a level of technology and of a type consistent with our way of life and Australia's level of development. However, the fallacy of so-called finite resources needs some further comment. On the face of it, it does seem to have plausibility and it also gained support from events such as the 1973 "oil crisis". Many people cannot see any possible answer to the problem of how to reconcile continued rapid economic growth with finite resources. It would seem logically insoluble. Yet as Wilfred Beckerman, Professor of Political Economy at University College, London, explains in his paper *The Fallacy of Finite Resources* (Bank of New South Wales Review, April 1975), the finite resources problem is *"the least of the problems that the human race needs* *to face in the foreseeable future — or even beyond that".* This illuminating article should receive the same attention as the "doomsday" and "alarmist's" reports. For this reason the article is reproduced in an appendix of this book.

Professor Beckerman's comments on the oil crisis are of particular relevance to our energy scenarios for Australia. *"In fact, the rise in the oil price, far from proving that the finite-resources school of thought were right all along, happens to be a change in the situation that will help prove them wrong. For it was probably true that the price of oil had been artificially low during the previous 20 years, so that demand had been rising faster than was optimal given the longer-run price prospects. It was already known that the equilibrium price of oil would have to rise over the long run. The recent quadrupling of its price is an over-correction and will do more than anything to slow down the rise in demand and to stimulate the development of substitute sources of oil or of other forms of energy."*

For Australia, one of these "other forms of energy" which needs proper consideration to allow informed public discussion is obviously solar energy. But how can we implement these human concepts into a practical procedure which will help us see what the possible outcomes would be in a quantitative form, yet where human insight can be applied. Economic modelling of the complex interactions and the use of a computer quickly come to mind. In many ways too much reliance is often placed solely on results produced by computers. However the results can provide insight into a problem. Sometimes the insight that computing gives leads to better application of the human mind to the solution of a problem. The following comments from the editor of the Honeywell Computer Journal illustrate the point — "Some fifteen years ago many people were sure that the computer could be applied effectively (at that time) to translating Russian text into English. Some of the results are now folklore. 'Out of sight, out of mind' translated into Russian and back becoming 'blind and insane'. Nevertheless it seems that more has been learnt about the nature and structure of language in the past fifteen years than over the past fifteen centuries. Why? Because the computer experiments pointed out what we did not really know, although we thought we did. The problem was substantially more difficult than ever imagined and then more study and less computer time was applied to it."

Our economic and social systems belong to a class called multi-loop non-linear feedback systems and we have only been required to understand these systems in recent times.

As J. W. Forrester, author of *World Dynamics* stated in *Technology Review*, Volume 5 No. 3 (Massachusetts Institute of Technology) *"Evolutionary processes have not given us the mental skill needed to properly interpret the dynamic behaviour of the systems of which we have now become a part".*

The approach used in the Solar Australia World Study by the Foundation for Australian Resources, used computer models in a way which combines

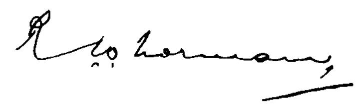
the perception of the human mind with the ability of today's computers.

There is nothing new in the use of models to represent economic and social systems. In fact our mental image of the world around us is a model, but this mental model is fuzzy and incomplete. Also our mental model changes even during the flow of a single conversation — the human mind assembles relationships to fit the context of a discussion and as the subject shifts, so does the model. Forrester again explains —

> *"When only a single topic is being discussed each participant in a conversation employs a different model to interpret the subject. Fundamental assumptions differ, but are never brought into the open. Goals are different and left unstated. It is little wonder that compromise takes so long, and it is not surprising that consensus leads to laws and programmes that fail in their objectives or produce new difficulties greater than those that have been relieved. . . ."*
>
> *"The key to success is not in having a computer; the important thing is how the computer is used. With respect to models, the key is not to computerise a model, but instead to have a model structure and relationships which properly represent the system that is being considered."*

The various skills of the contributing authors and the many sources of information used, we hope, have combined to meet this requirement.

Dr. B. S. Thornton



Sir Robert Norman

CONTENTS

FIGURES

TABLES

INTRODUCTION

. . . in the big matters in which new scientific knowledge and technology are the major component, and which now affect human destiny, wise decisions for today cannot be safely taken unless we realize that those same decisions determine the shape of tomorrow and the day after.

Sir Solly Zuckerman, as Chief Scientific Adviser to Her Majesty's Government

In the early 1950s, energy supplies, particularly oil, seemed inexhaustible. In fact, the consumers entered a period where energy sellers were cutting prices to sell their products and this price war led to the industrialised nations becoming dependent on oil and natural gas.

In 1973 members of the Organisation of Petroleum Exporting Countries surprised the world by cutting off supplies and subsequently increasing prices. The oil crisis of 1973 rapidly focused the world-wide attention of politicians and scientists on to the need for obtaining energy from alternative sources so that dependence on non-renewable fuel supplies could eventually be overcome.

In Australia, apart from the increase in the cost of goods imported from Japan, America and Western Europe, we were reasonably insulated from the oil crisis. At that time Australia produced about 65% of its oil needs. However, if Australia's self-sufficiency in oil were to fall significantly by 1985 as some estimates indicate, then the nation could face an oil import bill of between $2-3.2 million per day (even at 1976 prices) based on figures given by Mr. K. Richards, Exploration Manager of ESSO Australia to the ANZAAS Conference in May 1976. Other estimates are even higher, often double or treble, if 1976 dollars and prices are not used.

Against the background of world events and increasing concern for the energy future for almost every country, it must be asked whether Australia has a national energy policy. An energy policy is not as simple a matter as it might at first seem.

As stated by Mr. Fife, M.H.R., in the House of Representatives on March 22, 1977, in the debate on the speech of Her Majesty The Queen: "Balanced energy policies have been in great demand throughout the world since 1973, and to a lesser extent also in Australia. One of the problems is that opinions as to what constitutes an energy policy are extremely vague. Unfortunately, energy usage is an essential part of the economic nature of the community; hence the development and final implementation of an energy policy require decision making at top levels of government. Basically there is a dichotomy between demand-consumption and traditional economic growth on the one hand and conservation of non-renewable energy sources and generation of alternative sources on the other. An energy policy is a compromise between these two forces, imposed of course by government."

The Sydney Morning Herald on February 11, 1977, reported that the Minister for National Resources, Mr. Doug Anthony, considered that "the development of a national energy policy was a matter for expert analysis". The report added that a high level energy advisory committee had been set up to help formulate a national policy.

There seems every case to argue that Australia should have information upon which to consider its possible energy future in a quantitative manner, giving regard to alternative courses of action. In the past our good fortune perhaps was suitably summarised by the statement in the 1974 Organisation for Economic Co-operation and Development Examiners report on "Science and Technology in Australia": "With regard to its energy resources, Australia has a privileged position in the world. The country possesses important domestic resources in coal, petrol, gas and uranium, which will probably protect it over a long period from the direct repercussions of the world energy crises."

Since that report, another great reservoir of energy available to Australia has burst into prominence in the public eye — Solar Energy. Recently, Mr. Russel T. Madigan, OBE, an executive director of Conzinc Riotinto of Australia Limited, in his paper "Energy — An Overview" presented to the 9th General Meeting of the Pacific Basin Economic Council held in Vancouver, Canada in May 1976 stated that this source is "of the order of *20,000 times* the present world consumption of energy from all sources". This is supported by table 1 which is based on a paper "Towards a Global Vision of Human Problems" by Y. Kaya presented at the "Club of Rome" Symposium in Tokyo, October 1973, and data from Professor C. N. Watson-Munro, OBE, of the University of Sydney from a paper entitled "A New Look at Solar Radiation as an Energy Source" published in *Search*, Vol. 4, April 1973.

This table shows that solar energy can play an important role in supplementing non-renewable energy sources. The calculations carried out by Professor Watson-Munro indicate that Australia's potential solar energy per annum could be 1500 billion tonnes of coal equivalent, compared with the same figure for U.S.A., and 30,000 billion tonnes for the world.

Only a small fraction of the available Solar Energy, if harnessed, would be required to meet Australia's future energy requirements. Although the potential of this energy resource is enormous there are two aspects which require answers before its utilisation can be achieved even at the small percentage required. The first is the technical problem of capturing the energy in an efficient and economical manner. The present study does not

concern itself with this technological aspect. The second is the socio-economic manner in which the introduction of Solar Energy into Australia can be achieved. What would be required in economic and social terms if a significant Solar Energy Policy were implemented and what would be the resulting effect on the many other aspects of Australia's economic and social life?

TABLE 1 RELATIVE ENERGY RESOURCES AND POTENTIAL
(1Q = 3 × 10^{10} tonnes of black coal equivalent)

	OPERATING RESERVES		POTENTIAL RESOURCES	
	WORLD	AUSTRALIA	WORLD	AUSTRALIA
	Q	Q	Q	Q
Coal	30	3.3	321	8.75
Oil	6	0.01	12	~ 0.01
Natural Gas	6	0.04	8	~ 0.8
Total Fossil	42	3.35†	341	~10
Hydro per annum	0.1	0.0001	6	small
Geothermal				
- Natural	small	small	small	small
- Hot Rocks	small	small	1000	small
Fission				
- Thermal	2	0.2	*200-300	20-30
- Fastbreeder			200	10-20
Fusion - D-D	—	—	10^{10}	10^{8}
Solar per annum	—	—	1000	50
		† plus 0.02 for LPG	*by year 2000	

Also, how long would it take to achieve any worthwhile overall effect in Australia even if all the technological problems could be overcome? In other words, just how much effort would be required to produce any sort of helpful contribution and when would we be likely to see the effects in the Australian way of life?

In order to answer these types of questions the Foundation for Australian Resources undertook a major study on the effects of alternative scenarios in which Solar Energy was given various emphasis and degrees of urgency ranging from apathy to rescue from an energy crisis. Experience on this type of study on a world basis had been achieved in the "Club of Rome's" projects *The Limits to Growth* and *Mankind at the Turning Point* using socio-economic models in which the complex relationships and interactions necessarily required the use of large scale computers to simulate the processes. This approach has been used by F.A.R. where an Australian, Mr. J. M. Mula, spent two years modifying the "Club of Rome" programs to adapt them for specific application to Australia and its role with the rest of the world. This included the time to collect the vast amount of statistical data needed for the background information from many different sources in Australia, and the introduction of potential solar energy resources missing from earlier "Club of Rome" models. The Council of the Foundation commissioned several scenarios to be set up and run using this model and giving particular relevance to the way in which Solar Energy would contribute to Australia's requirements in the future.

The work was carried out with the assistance of Mr. R. A. Ward and associates of the Thames Polytechnic, London, and Mr. J. M. Mula in Australia, under the direction of Dr. B. S. Thornton and Mr. C. Malanos of The New South Wales Institute of Technology, Australia. Consultation was maintained with the members of the Council of the Foundation during the progress of the work. A description of the scenarios and the results obtained are given in the following chapters of this report. These results are the answers to the questions "What would happen if . . . ?" and therefore are not necessarily recommendations. They do, however, for the first time provide a basis for policy guidelines where the information has a more credible foundation compared with many of the often emotional comments that have been made in the past, generally based on an incomplete consideration of the many interacting factors involved.

The overriding advantage of working with a broad analytic model of this type is that it tries to hold together the actions and interactions which are associated with Australia's social, trading, demographic, productive and resource-consuming activities. In this way, specific searches for more information and understanding are set within a wider context. Also the essential compromises in a multi-objective situation tend to emerge more clearly. Thus this study allows solar energy to be viewed in proper perspective with respect to Australia's future, and not necessarily as the new panacea for the nation's future energy problems.

We note the comment of the Chairman of the Senate Standing Committee on Solar Energy, Senator Andrew Thomas, who is quoted in *The National Times,* December 1976, as saying:

> *"We can't see solar energy making a contribution to Australia's energy requirement until the end of the century. Unlike the anti-nuclear people, we don't see solar energy being the complete answer."*

However, as the Editorial in *The Sydney Morning Herald,* April 6, 1977, stated:

> *"The case for solar energy research and development is strong; and in few places more so than in well-sunned Australia."*

Just what will be required to be done now to bring this about, and what other effects there will be on Australia is precisely the subject of our report.

CHAPTER 1

AN APATHY POLICY — WHAT FUTURE? THE STANDARD RUN (STD)

More good things in life are lost by indifference than ever were lost by active hostility.

— Sir Robert Gordon Menzies,
The Measure of the Years

THE MODEL

A full description of the model is given in J. M. Mula's thesis, *Exploring Conflicting Views of Australia's Future Using a Systems Dynamic Model.* The model is based on the "Club of Rome" study described in *The Limits to Growth.* However, in the light of criticisms levelled at the Meadows' model it was necessary to change the model structure particularly with respect to the assumption that resources are "finite". A technical note outlining the modifications made is given in Appendix B for interested readers.

A brief and non-quantitative impression of the model can be gained from figures 1 and 2. Despite the descriptive nature of these two diagrams, the inputs to and the outputs from the model are quantitative. Some confidence in its calculations can be gained by comparing historic data about events in Australia with the model's performance over the same period. This process is referred to as calibration and forms part of the validity tests.

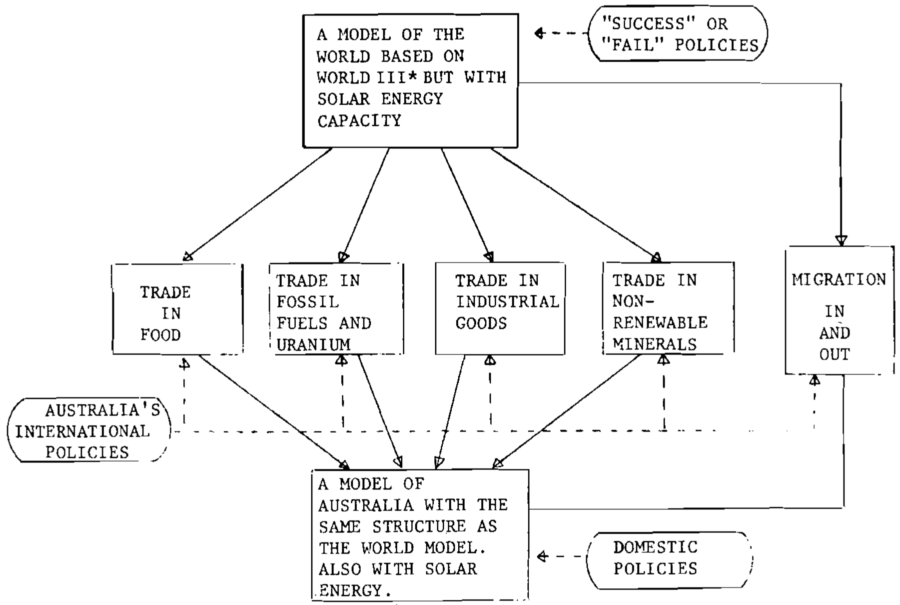
There are about 400 relationships in the model, a few of which are indicated by the connecting links in figure 2.

The input data provide a formal statement of the remaining assumptions which have been made. There are nearly 260 items of such data, and the reader must necessarily refer to the original thesis if details at this level are required.

CALIBRATION

Eighteen self-explanatory figures are given in Appendix A. Each shows some facet of Australian life — for example, its population, birth rate, consumption of energy or its trading activities. The horizontal scales run

FIGURE 1 THE OVERALL STRUCTURE OF THE WORLD— AUSTRALIA SOLAR MODEL



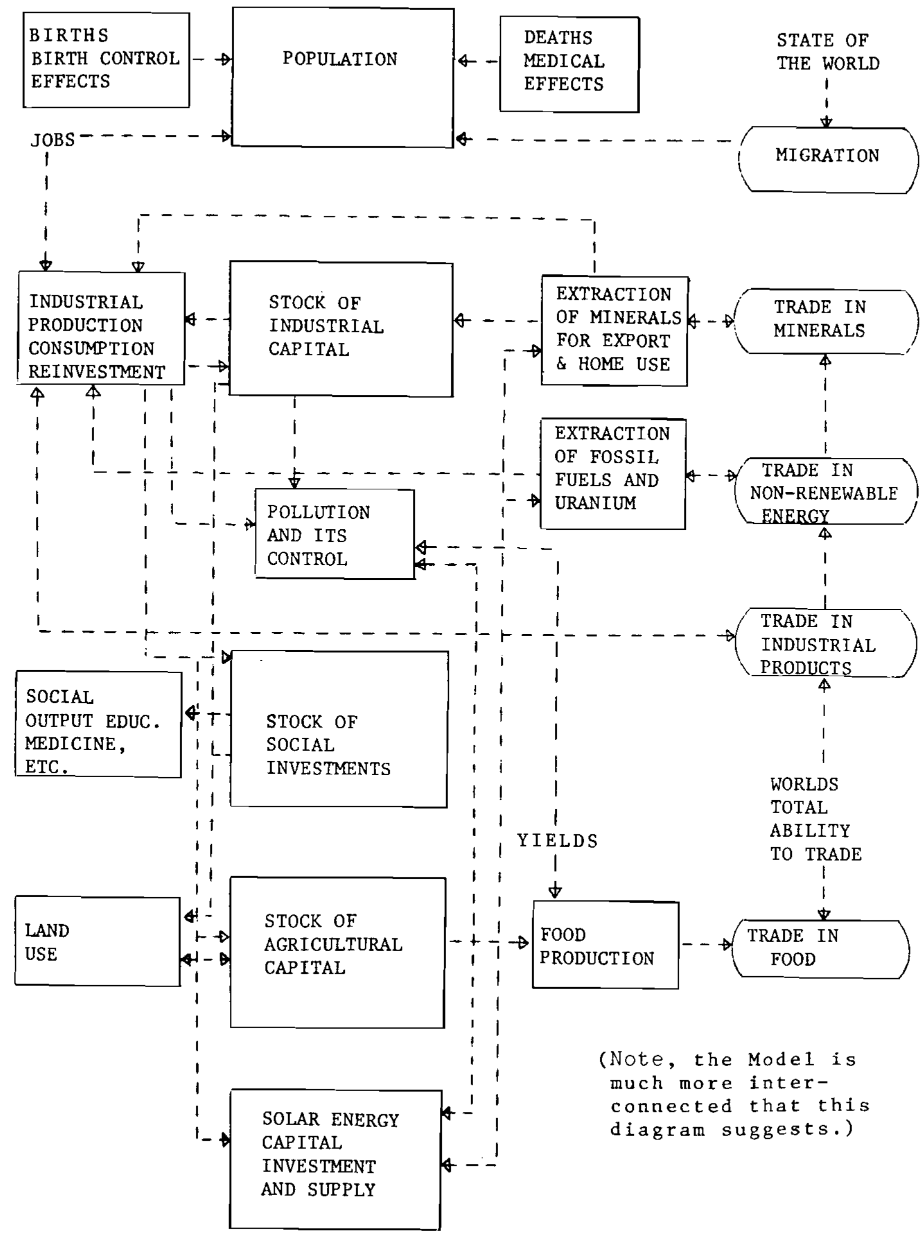
(Note, in the Model, Australia is affected by the state of the World, but not vice versa.)

* MEADOWS D.L., MEADOWS D.H., RANDERS J., BEHRENS III W.W. Dynamics of Growth in a Finite World - Technical Report First Draft. M.I.T. PRESS 1972.

from years 1900 to 2100. In each figure the line should be compared with the plotted points. The points represent the best statistical data we have available, while the line gives the results which the model produced for the same period. Naturally the comparison can only cover the approximate period 1900-1975. From 1975 onwards the line (model output) is extended indicating the "model's view of the future". However, Australia's future cannot be viewed in isolation from events in the rest of the world.

Two possibilities might be considered. The first is that the world does not cope with the problems arising from exponential growth of population and from shortages of food and resources (the solid lines in the figures). The

FIGURE 2 OUTLINE OF THE WORLD AND THE AUSTRALIAN COMPONENTS OF THE MODEL



(Note, the Model is much more inter-connected that this diagram suggests.)

model suggests inexorable growth of world population to a limit of 18 billion under conditions in which all the social and medical advances of the last 100 years would be lost with food below subsistence level. In material terms the undeveloped world would never get the benefits to which it aspires (the "Fail" policy option of figure 1).

The second is that the world does cope with these problems and would move towards a stable and moderately affluent condition. With a world population 2¼ times larger than at present, i.e. 9 billion, everyone would be well fed. The benefits of medicine and social progress would be secured in perpetuity, whilst in material terms the average man eventually would acquire the standards of the Australian in the 1970s (the "Success" policy option of figure 1).

This optimistic view of the world's future certainly warrants further exploration, but we have concentrated on the pessimistic possibility. We stress that the presentation of this work should be seen only as a beginning. If it provokes useful questions and helps to sort out possible important policy issues then this type of study should be continued.

RESULTS — THE STANDARD RUN (STD)

We must stress at the outset that the Standard Run (STD) is simply a continuation of present policies with no changes whatsoever and it is necessary in order to provide us with a basis for evaluating the effects of alternative policies. It enables us to project a picture of the type of future Australia could expect if it adopted a policy of complete apathy. In short, it indicates the outcome of the "She'll be right, mate" philosophy.

The comments which now follow are expressed in terms which seem to imply that in some way it has become possible to see into the future. However, we have merely preferred to adopt phrases such as "population would become . . ." so as to avoid continuous repetition of the phrase "the model suggests that . . .".

Of course, all the scenarios must be read with the clear understanding that they are generated by our model of Australia, which is subject to the many assumptions fed into it.

Associated with this study, there are computer print-outs of the model results which show how every variable changes its value between 1900 and 2100. It is therefore possible for some specialised readers to enlarge these images of the future by further analysis of these print-outs.

Three scenes will now be portrayed — life, industry and trade as they might be in the years 2000, 2050, and 2100. Figures referred to in these scenes for the Standard Run may be found in Appendix A.

AUSTRALIA 2000

Population

Although the restriction of 50,000 net migration per year is still in operation (figure A2), the population would increase from the 1976 figure of 13.5 million to 18.6 million (figure A1). This population increase would principally be an urban phenomenon being brought about by a natural increase in which about 76,000 new families would need homes, schools and jobs each year together with 13,000 (net) immigrant families. Although the drift from the country to the towns continued it would constitute a comparatively small effect amounting to approximately 1000 families leaving the countryside per year. The natural increase would have been much larger if the already declining birth rate had not continued to fall. In 1975 there were 18 births per year per 1000 people, and this would decrease to 14 per 1000 (figure A4). Coupled to a small decrease in the death rate (figure A3), the year 2000 would give Australia a slightly older age profile arising from the natural increase. We have not considered the extent to which selective migration policies might be used to offset this trend although of course humane immigration policies would not have any significant effect on age distribution.

Food and Agriculture

As cities and towns grew so the land normally used for agricultural purposes would be turned over to urban and industrial use. The increase would force marginally more land to be brought into agricultural use elsewhere. However, agriculture itself would not expand (figure A5) and in fact would decrease by about 6% from the peak years of the mid 1970s. This does not mean that Australia would be eating less well, but rather on the contrary, the meat-eating habits would continue to grow (figure A6). What did change was the major role played by wool and food in Australia's exports. These exports, which amounted to 1.5 billion in 1975, would fall to 0.6 billion (in 1970 prices) by the turn of the century (figure A8). Food imports would show the opposite trend and increase substantially (figure A7). Note that this contradicts the short term effects which the declining food imports of the 1960s and 1970s would have suggested. However, the principal reason would appear to be the very favourable trade balances which Australia was maintaining throughout the period thus making imported food quite cheap.

Industry

The rapid growth of Australia as an industrial nation would continue at about 4% per annum after 1975 and would lead to a level of industrial output three times greater in 2000 (figure A9). However, this does not mean that Australia would become a major exporter of industrial goods. There had already been signs prior to 1975 that the rate of growth of industrial exports was falling. This effect would have continued but would quickly reverse (figure A11). By 1980 exports would no longer be increasing year by year but would start to fall. By 2000 the total industrial exports per year would be approximately the same as they had been in the 1970s and would be falling annually at about 2%. Industrial imports on the other hand would not show this trend, but would continue to grow (figure A10). Again the principal reason was the relative cheapness of imported goods and equipment. From the standpoint of the consumer, however, the use of material goods both to support industry and for direct consumption would continue to rise. The rate in real terms would be nearly 3% per annum. This means that for the average Australian in the year 2000, his material standard of living would be twice as good as it was in 1975, thus continuing the growth of material well-being associated with the period 1945-1975.

Since the turn of the century (1900), public expenditure on health, education, roads and public transport has grown faster than the population. This investment in social facilities would continue (figure A18), and would grow at the same rate as industrial consumption so that by the year 2000 the average Australian would also be twice as well-off in the facilities which he would have available communally. However, in the 1990s the first signs of a possible national labour shortage would begin to be felt.

Minerals

During the 1960s the developed world's increasing demand for minerals led to Australia expanding both its search for new reserves and its mineral extraction activities. During the period 1961 to 1971 mineral extraction activities grew in real terms by 13% per annum (figure A12). This massive expansion rate would continue for another decade but while annual production would still be increasing in the year 2000, the rate of growth would have slowed down to about 4% per annum. During the period 1975-2000, 14 times more tonnage of minerals (metal content) than had ever been mined before would be extracted. Naturally, a large proportion of this would be for export — about 90% of all production leaving the country. This differs little from the state of affairs in 1975 except, of course, that the scale of activities would have become 6 times greater (figure A14).

Although there is widespread optimism that more mineral deposits would be found, it cannot be denied that the grades of ore would fall as the best deposits were worked out. Offsetting this effect there would be progressively smaller investments in capital per tonne extracted being made each year to sustain growth in the industry. We assume that an implicit improvement in technology would account for this phenomenon.

During the 25 year period, mineral imports would also continue to grow. However, the scale of these imports would be of an order of magnitude lower than that of the exports, and mineral imports would grow more slowly so that by the year 2000 they would be only 1/30th of the mineral exports (figure A13).

Home consumption of minerals would follow home industrial production, expanding by about 300% during the last quarter of the century.

Thus the exploitation of Australia's natural mineral resources would emerge as the dominating feature of its economy during the period. The overseas income earned in this way would grow so large that it would become impossible for Australians to consume the riches to which a strict balance of trade entitled them. By the year 2000, the recipients of the profits from the sale of minerals (and fuels) to other countries would be able to

acquire overseas investments equivalent to 11 times the total industrial capital in use in Australia in 1975. Put another way, it would amount to owning parts of the productive capacity of the rest of the world which would be nearly as large as all Australian productive capacity in the year 2000.

Energy

The pattern of energy production, consumption and trade would have much in common with that just described for minerals. However, there is one important distinction. Unlike mineral imports, energy imports (probably oil) would form a large part of home consumption. This had been a growing tendency since 1900 with both imports and exports expanding faster than home production and consumption (figure A16). By 1975 imports of oil were approximately equivalent in energy terms to the exports of coal and stood at 50 million tonnes of coal equivalent per year (figure A17). At the same time, production and consumption stood at about 90 million tonnes per annum (figure A15). However, 1975 was a time when energy production, consumption and trade were all increasing at their highest rates. For example, production of coal and oil was growing at about 13% per annum. By the year 2000, the annual production of fossil fuels of all types together with uranium would have reached 500 million tonnes of coal equivalent per year. Significantly, however, home consumption would have reached only 250 million tonnes by the year 2000, nearly all of which would be met by imports. Such a pattern was the result of selling fuels which Australia did not wish to use (coal and uranium) in exchange for fuels which it did want (petroleum).

The net contribution to trade would be that energy exports would earn more than was being spent on energy imports. Thus the picture would remain the same, with Australia in the year 2000 earning its living in overseas markets by its mining activities and the sale of physical resources.

Solar Energy

Despite the debate about conservation of fuel reserves, economic considerations would prevail and fossil fuels and uranium would all be freely exported thus stimulating a large technological expertise in these extraction industries. One consequence would be that solar energy remains relatively costly. Investment would grow in solar energy plant and at a relatively rapid rate. However, the scale of use would always remain relatively small compared with that of other fuels. Although we have no record of the form these investments would take, we might interpret it to mean that conventional hydro-electric schemes would develop and alongside those for power generation from fossil fuels and uranium in similar proportion to their pre-1975 development. In short, there would be no dramatic breakthrough of the social and economic barriers talked about in the late 1970s. However, because solar energy could not be exported directly, it would contribute more to the home consumption of energy.

AUSTRALIA 2050

Let us now put the clock forward a further 50 years in our Standard Run in order to see what new factors might, by then, have entered the scenario which we have just drawn.

Population

The birth rate of 9 per 1000 per year and the static death rate of 8.5 per 1000 would mean that by the year 2050 the population would have risen to 24 million. With a net migration policy still set at 50,000 per year, the population growth rate would be only 1/5% per annum. In some ways life had been remarkably static for the previous half century. Peoples' expected life span would be the same as it was in 1975. They would still be eating far above subsistence levels in contrast with the eating habits of large numbers of people outside of Australia. There would be little movement from country to town, although a few people would be planning to move out of the growing cities.

There would be some changes, however, such as a higher proportion of childless couples and a higher proportion of women in the work force. In terms of material goods consumed per annum, people would be eight times better off than they had been in 1975 (in 1970 prices). The community spending per head on shared services would be seven times larger than in 1975. There would be small reductions in the age of retirement, with the school leaving age being slightly higher. However, because of the large number of women in the work force, there would be a small increase in the fraction of the population employed. And yet, industry would still require more labour than it could get.

Food and Agriculture

Agriculture had remained almost unchanged for half a century. Yields per hectare would not have risen and neither would the area of land under cultivation, although the growing towns would continue to push farming outwards. Yet a bigger population would be eating as well as ever. Two factors combined to produce this effect. For all practical purposes food exporting would have stopped and the production sold at home. Also imports would rise appreciably until almost one-third of the nation's food would be imported. As we show later, this trend is not surprising. Note, however, that the food eaten per head would be richer in protein than in 1975 so that in the event of an emergency, Australians would not be in danger of starvation, even if all imports suddenly stopped.

Industry

Industrial production continued to grow at 3½% per annum. However, there would be a decline in exporting activities in order to serve the home market. This would be achieved despite an abundance of cheap imported industrial goods. These imports which stood at $2,000 million in 1975 would reach $14,000 million in 2050. This seven-fold increase (in 1970 prices) would none-the-less constitute a decreasing proportion of all industrial production. In 2050, imports would become 6% of consumption. Thus Australia's ability to be industrially self-sufficient would not be in jeopardy.

Minerals

The reason Australia could import so freely lay in the continued expansion of her mineral exporting activities during the preceding 50 years. For every tonne of metal content in the minerals being exported in 1975, 20 tonnes would be exported in 2050. But the year 2050 will mark the turning point. For the first time in nearly 100 years the mining industry would stop growing. The progressive working out of rich ores in favour of poorer quality would have begun to make its mark. Not only would it cost five times as much in annual capital outlays to extract the minerals, but marketing would become more difficult. The rest of the world would be struggling to feed a population of 8,000 million without success, while at the same time industrial expansion would have dropped to ½ % per annum.

Despite the country's mineral riches, Australia would not have everything her expanded industry would require, so mineral imports would have to grow to meet special needs. However, as had been the case in the year 2000, mineral imports would now be much smaller than exports — about 1/20 of the tonnage. Thus up to and beyond the year 2050, the mining and export of minerals would become Australia's method of paying its way in world trade.

The balance of payments resulting from this lucrative activity would produce for the mineral owners overseas investments worth another *four* "1975 Australias". At the same time everyone else would have benefited because of the array of cheap goods in the shops. The farmers and the industrialists would have progressively given up trying to export because they would have found themselves outpriced in overseas markets.

Energy

By 2050 Australia would have built a large industrialised society both demanding energy and making it available as an export to the rest of the world. On balance, imports would be less than exports so that the fuel industry would closely follow the pattern of the massive mineral producers. In so doing, it would experience both the same rapid expansion and the same difficulties, the key difference being that large imports of fossil fuels would now be part of the overall situation. Our records do not distinguish between coal, oil and uranium as basic fuels and thus it is not possible to specify the form of the trade-off which would take place between imported and exported fuels. If pre-1975 is any guide then the probability is that in 2050 Australia would be offering coal and uranium in exchange for oil.

The existence of large imports together with large exports implies an industrial infrastructure which is not in keeping with a policy of short term self-sufficiency.

No significant breakthrough in the use of solar energy would have occurred by the year 2050.

Pollution
Brief mention must be made of this potential social and ecological hazard. Our records show that by 2050 pollution would be making 24 times as much impact on people and the environment as it had in 1970. Pollution takes such ill-defined and subjective forms that only an impression can be suggested. Twice as many people with eight times the material goods, the industry producing these goods, a massive mining industry, and an energy consumption per head 9 times the 1975 level clearly imply that there would be significant matters to be dealt with.

In 2050, sums equivalent to 10% of all industrial production would have to be spent to control the effects of pollution.

AUSTRALIA 2100

We now put the clock forward a further 50 years. The population would now have reached 26 million; the birth rate still being low at 8.5 per 1000 per year and the death rate having risen slightly to 9 per 1000.

People would be richer in material terms than they had ever been before although they would have adjusted to a lower annual rate of material improvement.

Social investment would also continue to grow at ½ % per annum, a significantly lower rate than before.

Thus life will have changed very little from its condition in 2050. There would be, however, a different outlook in society arising from two main causes. For the past 25 years international trade in all sectors had been declining and home consumption of energy from fossil fuels had been constant.

Australia would therefore be learning to cope with a near stable economy following a century of very rapid growth. Declining food imports per head of population would have induced a return to the land philosophy.

Thus in the five years between 2095 and 2100, 2½ million more hectares of land would have come under cultivation, accompanied by a slow trickle of people back to the countryside.

In the year 2100 Australia would therefore be a very rich nation indeed compared with most of the rest of the world. The problem of how to stay that way would seem to offer no alternative solution, but to adopt an isolationist policy and self-sufficiency drive for as long as these could be maintained. The key to this would be energy supply and demand.

NOTES ON USE OF THE MODEL

The Standard Scenarios we have just portrayed lead to two broad types of reaction.

The first is concerned with questions of the type "What would happen if . . .?". Such questions are stimulated by possible dissatisfaction with the projected images and a desire to see policies introduced which would change the undesirable outcomes. Thus experiments on the model which suggest answers to such questions provide a method of exploring possible policies and defining satisfactory objectives.

The second reaction challenges the model assumptions, and rightly so. Most specialists with detailed knowledge of subjects such as mining, agriculture, energy generation, etc., will find the model to be crude and unrefined in relation to their specialist knowledge. However, if they can be persuaded to express their knowledge in terms which can be integrated into the model then further experiments can be carried out. In due course these experiments will give an even better understanding of the competing forces which influence the outcome of various policies.

In this way those priority areas can be defined in which more understanding is needed to aid the formulation of policies which have both a high chance of success and a strong controlling influence.

In the remainder of this report we intend to respond only to the first type of question. Thus we will now proceed to examine the first of the scenarios proposed, namely, "What might the future be like for Australians if new policies towards the development of Solar Energy resources were adopted?"

However, before we do so, let us dispel possible doubts which may have arisen in the reader's mind about the credibility of our model, particularly when one attempts to interpret the results produced by the Standard Run in isolation from those of the subsequent scenarios.

At first sight the "apathy" policy seems to suggest such an optimistic future that there would appear to be little reason for wanting to take any course other than one of "apathy". However, some readers at this stage will no doubt, be bristling with arguments as to why the "apathetic" Australian would almost certainly be deprived of the opportunity of experiencing a future such as projected by the Standard Run. Some of these arguments are considered in chapter 5 after the reader has had an opportunity of assessing the alternative scenarios.

At this stage, therefore, it is necessary to re-iterate our earlier warning that the Standard Run should be regarded merely as a basis for evaluating possible alternative policies. With this in mind, we can now consider the first of these, namely, a Solar Energy Policy.

CHAPTER 2

A SOLAR ENERGY POLICY (SEP) (WITH RESTRICTIONS ON FOSSIL FUELS AND URANIUM)

And we should do it now — not wait until the world's dwindling resources force us into panic action which we might find hard to afford.

Editorial —
"Pushing into the Solar Energy Age"
The Australian, March 26, 1977

BACKGROUND

Even before the oil crisis of 1973, there had been a growing awareness among industrial nations that they would eventually have to overcome their dependence on non-renewable fuel supplies by developing alternative sources of energy.

Throughout the centuries, the possibility of harnessing solar energy has always had the greatest intuitive appeal to man. For example, the ancient Greeks lit the temple fires at Delphi by concentrating the sun's rays with concave mirrors. Perhaps this pioneering use of solar energy was motivated by answers given by the Oracle itself to early questions posed by the enlightened ancients who may have anticipated man's ultimate need for alternative sources of energy. Unfortunately this early solar energy policy was apparently only partially implemented, although Archimedes is reported to have successfully burned the Roman fleet at Syracuse by using polished shields to focus the sun's rays on the enemy fleet.

However, it is really only during the last 100 years that man has actively been engaged in extracting and consuming fossil fuels to any significant extent. Industrial development and low labour-intensive farming owe everything to the availability of these natural stocks. Two other requirements have been man's intellectual ability or knowhow and his capacity to co-operate with other men.

In the last decade we have been stocktaking. The facts which have emerged are these:

(1) A simple extrapolation of the world's energy consumption rate points to a 300-fold increase in less than 50 years.
(2) The most optimistic opinions define available stocks of fossil fuels in terms of a few centuries, while pessimists speak in terms of decades.
(3) Nuclear energy poses massive technological problems concerned mainly with the disposal of radio-active waste.
(4) There is an upper limit on the amount of extra heat man can risk generating before severely disturbing the world climatic system.

However, to talk of man's history and indeed, his future, in terms of only one or two centuries clearly misses out on some vital factor, for man's history and hopefully his future is on a time scale of tens of thousands of years at least. The missing factor is solar energy — the source of energy which has enabled life to grow on this planet, and which is 20,000 times greater than the present world energy generation from fossil fuels.

The essential difference between capturing solar energy to provide heat, electricity and fuel and its generation from natural stocks is that the former can continue indefinitely while the latter is bounded in the ways we have just indicated.

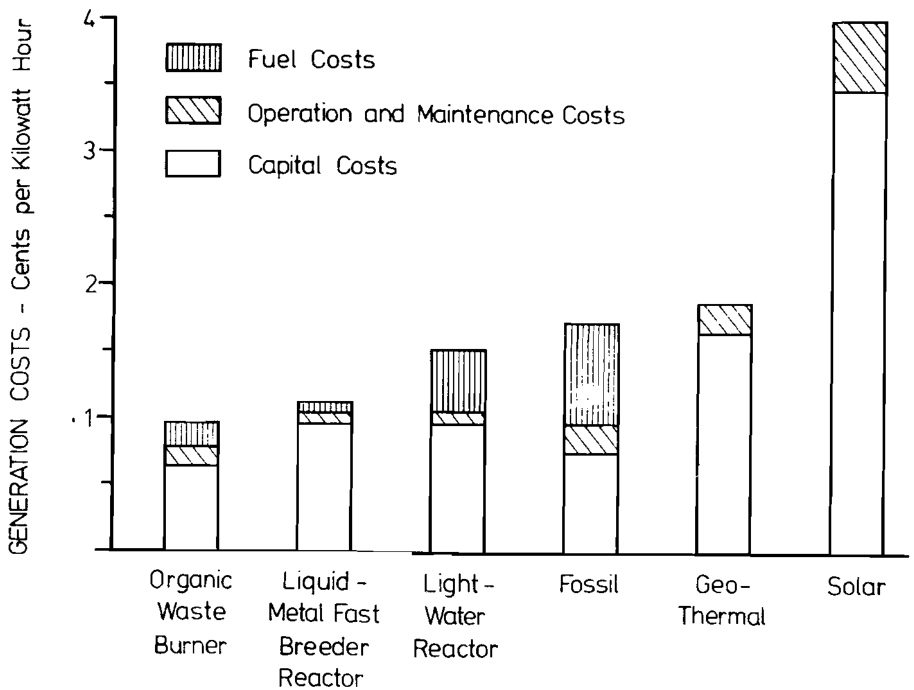
There are many ways of capturing solar energy for the three types of supply we need. For example, sunlight can be directly absorbed on solar panels to heat water, or, as in France, reflected on large mirrors to melt metals. Silicon cells can be used to generate electricity, while wind, wave and tidal movements can also be converted to electricity. Fuels can be obtained by electrolysis of sea water, by anaerobic decomposition of organic materials and, of course, by directly growing crops, possibly followed by fermentation. Suffice it is to say that the study and development of many such techniques are now popular research themes in universities throughout the world. In all cases, however, the processes are more costly than the established technologies of power generation from coal, oil, gas and uranium. This is well illustrated by figure 3 taken from a report by the U.S. Energy Research and Development Administration.

The universal aim is to develop these technologies so that 10% of the sunlight which falls on a square metre can be captured for a capital outlay of less than $16, according to calculations made by J. O'M. Bockris in his paper "Solar Power and the Coming Energy Shortage", *Search,* Vol. 5, No. 8, August 1974.

Bockris has also calculated figures for supplying energy requirements for Australia, U.S.A. and Japan from solar energy. He based his figures on a 10% conversion factor with a diminishing factor of 3 to cover problems such as dust and cloud, for an 8 hour sunlight day. For Australia with a population of 15 million (1976 population was 13½ million) and a possible energy requirement of 10 kW per person per year, the necessary area would be a square with a side of 100 kilometres. For the U.S.A. with a population of 200 million at the same requirement (1966 requirement was 8.3 kW per person), it would be about 350 km^2, and for Japan with 100 million people about 250 km².

We should point out at this stage that our use of the term Solar Energy involves all forms ranging from the low grade heat for domestic appliances through the next range of heat for residential and commercial heating and cooling, to high grade heat for industrial use such as required for steam turbines.

FIGURE 3 UNIT POWER COST COMPARISON



Source : U.S. Energy Research and Development Administration.

The relative proportions of these requirements over the next 25 to 30 years are well illustrated in figure 4 from *Fortune,* September 1972, for the U.S.A. It is interesting to note that the biggest increase in energy consumption has been for residential and commercial use which is of about the same magnitude as for industrial use.

THE BURNING QUESTION

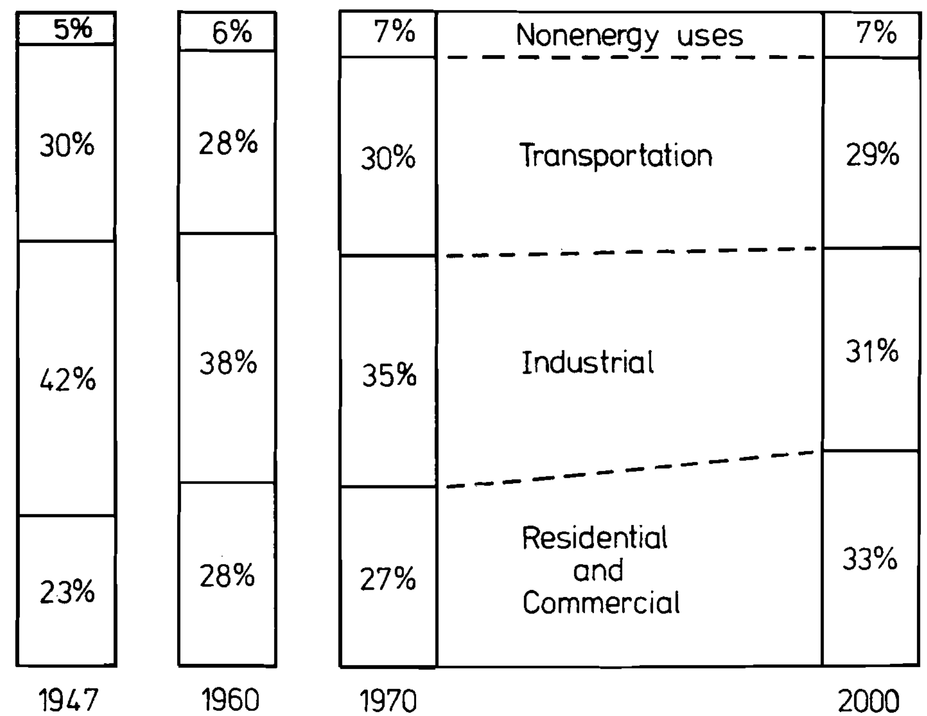
In order to ascertain whether a Solar Energy Policy might be worth pursuing in the hope of providing us with the "ultimate power-house", or whether Solar Energy is destined to remain for a long time as just another "ray of hope", we were prompted to formulate the specific questions "What would be the effect if Australia increased its investment in Solar Energy supplies by 100%-300%-500%, and what are the implications of delay in doing so?".

The relative crudeness of the model with which we are working, and the limited quality of the data upon which it rests has forced us, in the first instance, to pose a less precise question. Our next scenario therefore explores the general proposition that Australia now institutes a large-scale Solar Energy development policy. It must be stressed that we are not concerned here with a technical examination of the issues involved, but with a much broader consideration of the impact that such a policy might have in the long run on various aspects of the nation's life style and its economy.

Thus we will firstly examine just what we mean by a Solar Energy Policy. We will then explain how such a policy is introduced into the model. We will see that the preliminary results induced us to modify these inputs and led us to some tentative conclusions which we offer as the next more detailed set of questions which need attention.

Just as for the Standard Scenario, we have interpreted the numerical output of this model. But, in order to make this report more readable, we have not repeated here, in the text, the many reservations and alternative interpretations which are needed.

FIGURE 4 WHERE THE ENERGY GOES IN THE U.S.A.



Source : FORTUNE, September, 1972.

A SOLAR ENERGY POLICY (SEP)

We can now state what we mean by a Solar Energy Policy.

Despite its extra cost, a mixture of heat-generating systems, electricity supplies and fuel sources should be developed based on solar energy, and these should expand in the next 20 years to become industries on the same scale as those of the fossil fuels.

This would require a distortion of the free market in energy supplies which was assumed in the Standard Run. Necessarily this would mean government intervention in the form of taxes on fossil fuels or of subsidies for solar energy systems.

Thus the demand is a social one, essentially ecological and conservationist in origin, presuming a public reaction in favour of this form of energy. This could be likened to the widespread desire to own a car rather than use public transport (i.e. an expensive item which comes into vogue is valued more highly than its cheaper alternative). At the moment, such a change in social attitudes seem highly unlikely and would have to be "sold" to the public. The obvious issues in the argument are the possible risks associated with nuclear energy and the long term conservation of fossil fuels.

Nevertheless, the policy and its effects can only be explored with the model by assuming the technical, social and political feasibility of such an investment.

A Solar Energy Policy is likely to have associated with it significant economies in the use of energy and also of minerals. This effect is already programmed into the model and the economies occur if and when solar energy consumption increases.

This social and economic response would mean reversing the attitudes which have been a feature of industrial societies for many decades. It would, for example, involve the use of more public transport, sharing and hiring cars, restricting the use of electricity for heating and cooling buildings, and the development of longer-life products.

Thus the assumptions we are making are bold ones.

MODEL CHANGES

Figure 5 provides a qualitative description of the portion of the model which determines the behaviour of the solar energy sub-sector. In the Standard Run the solar energy sub-sector was functioning, but at a much lower level than the fossil fuel sub-sector. Thus even when the capital cost of producing each tonne of fossil fuel energy had reached 8.7 times its 1975 level (in 1970 prices), solar energy production was still only 4% of the total home energy production.

This suggests that the model's assumptions in the Standard Run were "holding back" solar energy development, when, in all probability, economic considerations alone would have stimulated a larger scale of development.

To reproduce the proposed policy in the model, it was necessary to "switch on" solar energy development with a social mechanism. This we

did by ensuring that the demand for solar energy became strongly influenced by the run-down of fossil fuels as soon as usage began to exceed present levels (see (1) on the influence diagram of the model — figure 5).

In the model this demand for solar energy was not responded to instantly, but was delayed on average by 20 years. This delay represented the development time for laboratory achievements to be turned into full-scale supply systems. (In fact the model started "switching on" the demand in 1965 but we allowed this early start to remain.)

We also modified the input conditions to ensure that solar energy development was paid for in real terms (see (2) in figure 5). The cost of developing solar energy is an output from the model and will be considered later.

NECESSARY EXTENSIONS TO THE POLICY — CONSERVATION

The results of experimenting with the above policy produced an outcome which made it clear that we had forgotten a possible response of the system.

The fossil fuel and uranium producers could be expected to pursue policies of growth while their costs of production were low (see (3) in figure 5).

On depriving the producers of their home market by subsidies and/or taxes, the model reacted by expanding the export of fossil fuels. If the long term conservation of fossil fuels and uranium was the purpose of the policy, then the continuation of large scale exporting was clearly in conflict with that aim. We therefore extended the "meaning" of a Solar Energy Policy to include the enforced conservation of fossil fuels and uranium. The restriction which we introduced was that from 1980, the industry would only be able to plan for an export growth rate of half the 1975 figure. This proved to be more constraining than might at first have seemed likely, because it was later found to reduce the competitive value of fuel exports in relation to mineral exports which were not so restricted. We also restricted imports of fossil fuels, because without such a constraint, home demand would have used this as a relatively cheap source of energy thus tending to thwart the growth of the solar energy development.

THE OUTCOME OF THE SOLAR ENERGY/CONSERVATION POLICY (SEP)

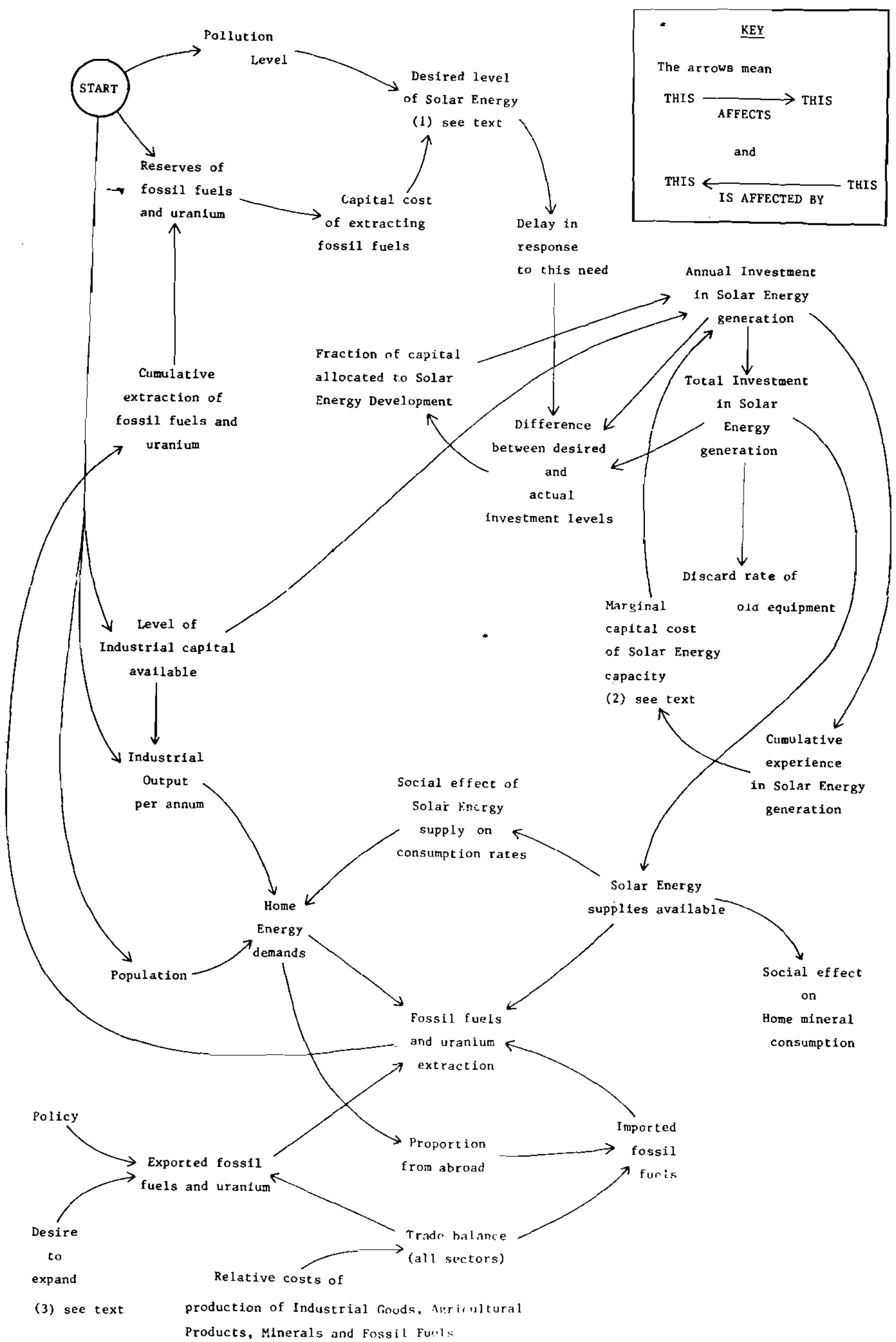
We will now consider the changes to the Standard Scenario results (given in chapter 1), which this broader policy would produce if implemented. Unless otherwise stated comparisons are between these new policy outcomes and the Standard Run results for the same variables at the same date.

AUSTRALIA 2000

Population

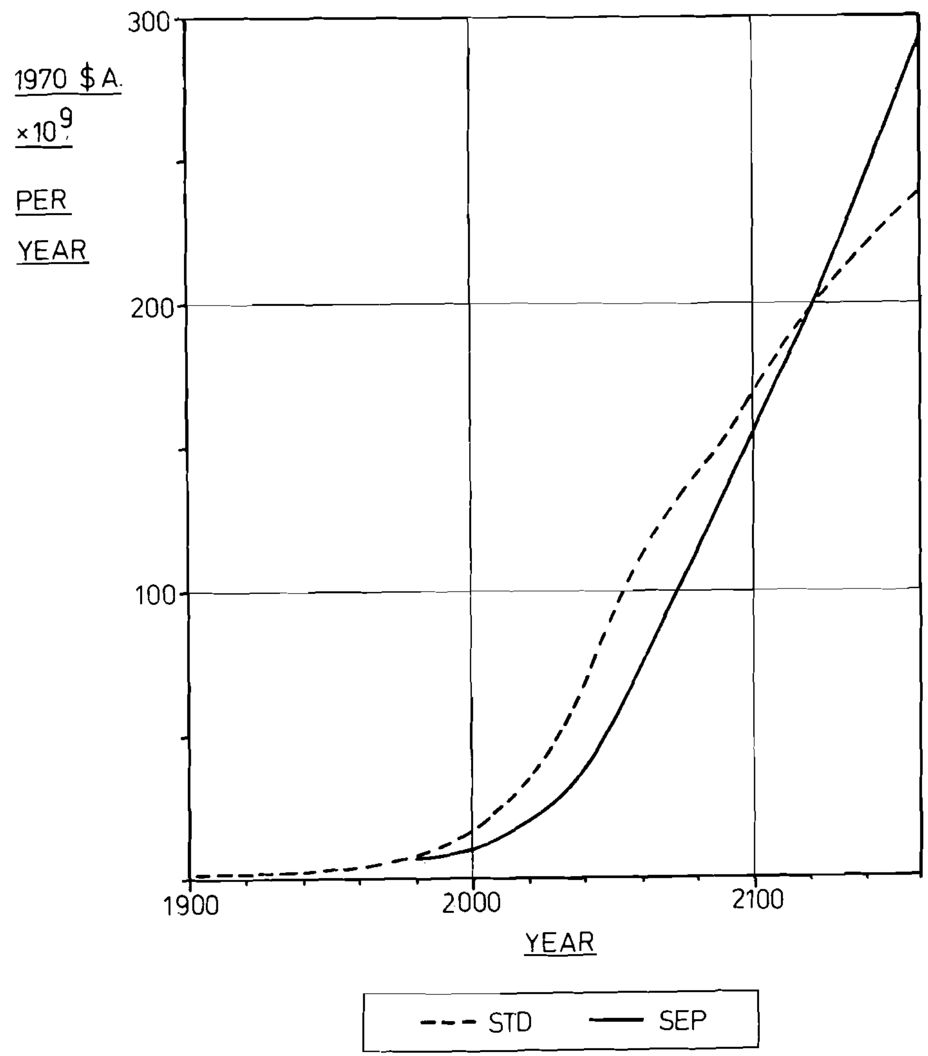
By the year 2000, the population has increased to 19.1 million compared

FIGURE 5 THE ENERGY SECTOR INFLUENCE DIAGRAM



with 18.6 million. The explanation lay in the existence of a slightly higher birth rate. That, in turn, was based on the model's assumption that less material affluence tends to be associated with a slightly larger family size. No change in migration was involved because the restriction of 50,000 net migration per year was still retained.

FIGURE 6 ANNUAL CAPITAL INVESTMENT IN INDUSTRY



Food and Agriculture

Food standards continued to grow as they did in the Standard Run. By the year 2000 eating habits were not quite so indulgent, with each person consuming an average 6% less, although consumption was still far above substinence levels.

The Standard Run suggested that agricultural exports would be cut back and eventually cease because large scale mineral exporting would so dominate the terms of trade that selling agricultural products overseas would become unprofitable. This effect was not altered significantly by the Solar Energy Policy. It should be mentioned that we did not introduce into this run changes of the type which might be associated with solar energy farming, that is to say, more labour-intensive methods and a reversion to lee farming to reduce the inputs of fertiliser. It is likely, however, that a solar energy development policy would find some of its energy capture incorporated in the agricultural sector. Our results did not allow for increased pressure on the use of land.

Industry

The Solar Energy Policy was more costly. This was reflected throughout the economy by the smaller amounts of industrial capital which could be made available each year for growth as is shown in figure 6.

All sectors of economic growth were held back to some extent with food and mineral production being the least affected.

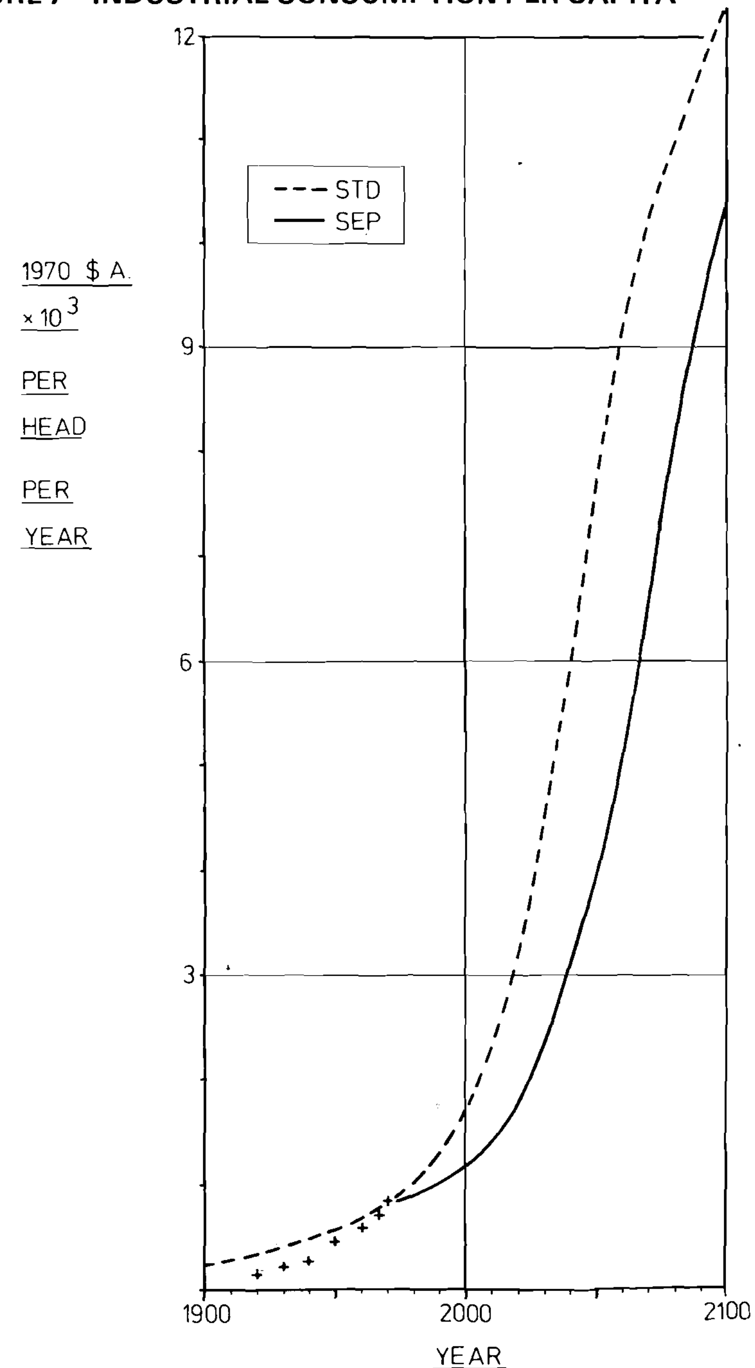
Industrial output per capita grew less rapidly so that instead of its doubling by 2000 it rose by only 50% (see figure 7). The consumption of home-produced industrial goods was even more severely held back for it rose by only 39% in the 24 years. A similar result occurred for the service sector so that it too grew more slowly. Thus shared services such as roads, education and health services increased by 36% compared with the doubling which had been achieved in the Standard Run. Looking further forward, however, the emphasis is not so much on reduced growth as on delayed growth.

Trade in industrial goods showed little change from the Standard Run. There was a short-lived increase in imports triggered off by the solar energy investment, after which industrial imports were the same as for the Standard Run. However, by 2010, when solar energy was established, industrial imports grew less rapidly than they had in the Standard Run (see figure 8). Industrial exports followed the pattern of the Standard Run by levelling out and returning to the 1970 level of $900 million per year. Note that imports were about twice as great as exports in this sector and thus had to be paid for by some exporting activity.

Minerals

Less industrial production, combined with materials and energy conserving attitudes, reduced the home demand so that by the year 2000, mineral consumption was half of what it had been in the Standard Run. Mineral imports

FIGURE 7 INDUSTRIAL CONSUMPTION PER CAPITA



were also reduced. They too were only half what they had been in the Standard Run. However, as figure 9 shows, the dominant activity of the minerals sector was that of exporting. Up to the year 2000, adjustments to production levels were therefore marginal. To compensate for the loss of home production a small increase in exporting took place.

The central fact was the continuing dominance of the mineral exports in Australia's international trade pattern. Indeed it was more marked than in the Standard Run, for the combined exports of fossil fuels and uranium reverted to their 1975 levels, and mineral exports were now filling the gap.

FIGURE 8 INDUSTRIAL IMPORTS

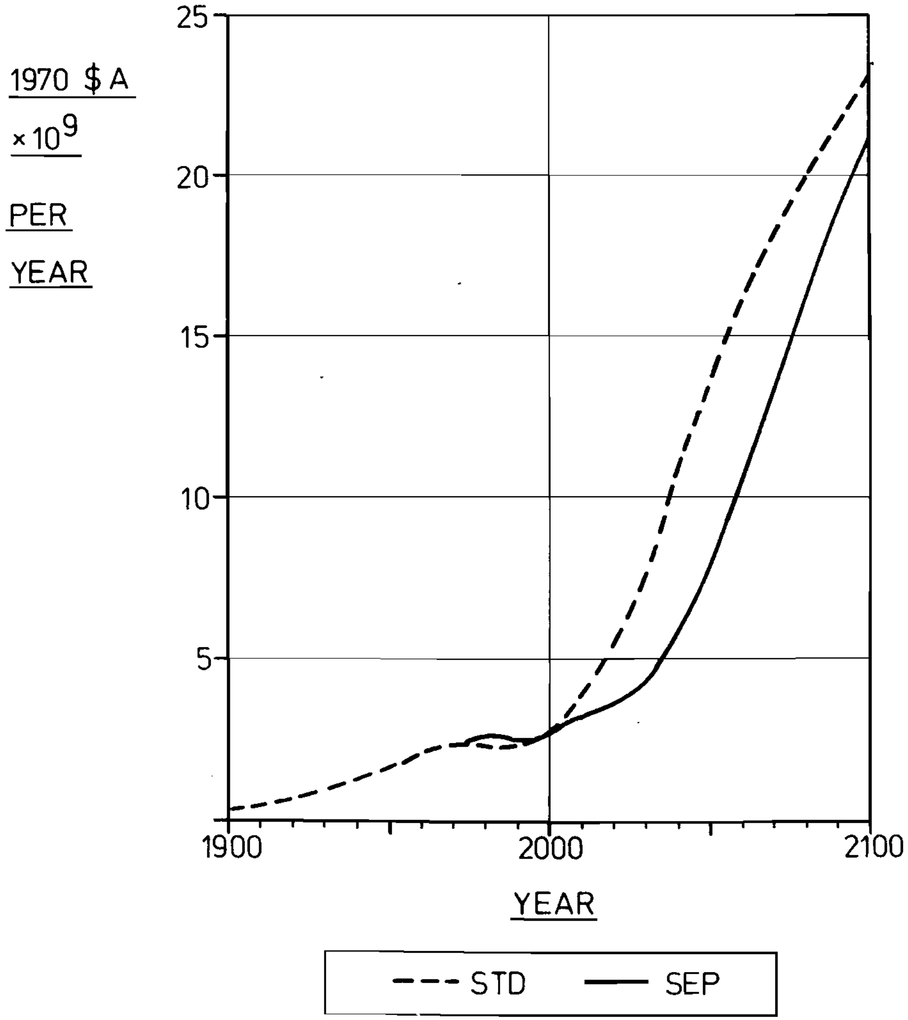
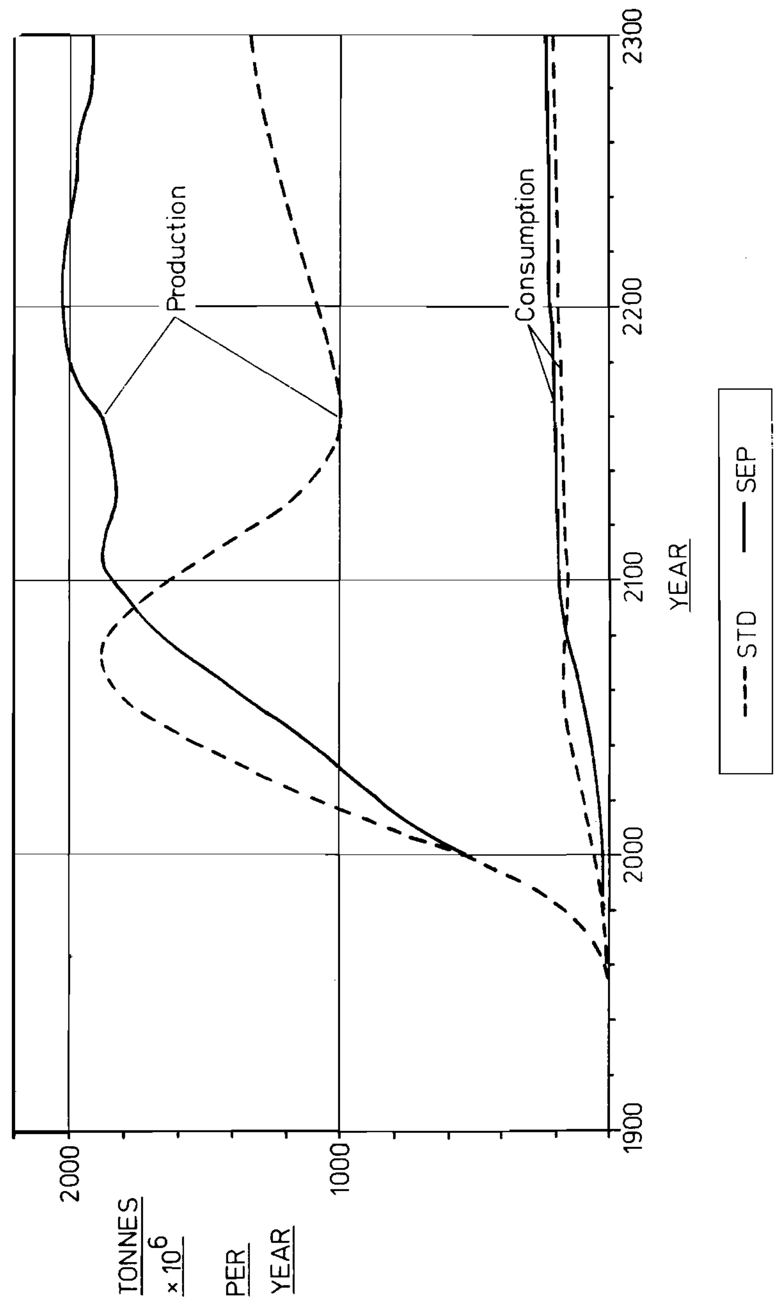


FIGURE 9 MINERAL PRODUCTION AND CONSUMPTION



The disadvantageous position of agricultural and industrial exporters remained. Mineral exports continued to be the easiest way of earning overseas currency.

Nevertheless, Australia as a whole was importing less food, less industrial goods and less energy (oil). This fact was taken up by a gradual change in the cumulative capital investment overseas (see table 2).

TABLE 2 CUMULATIVE CAPITAL INVESTMENT OVERSEAS (1970 $ Billion)

DATE	STANDARD RUN	SOLAR ENERGY POLICY
1975	12	12
2000	111	90
2025	326	170
2050	539	186
2075	660	206
2100	601	227

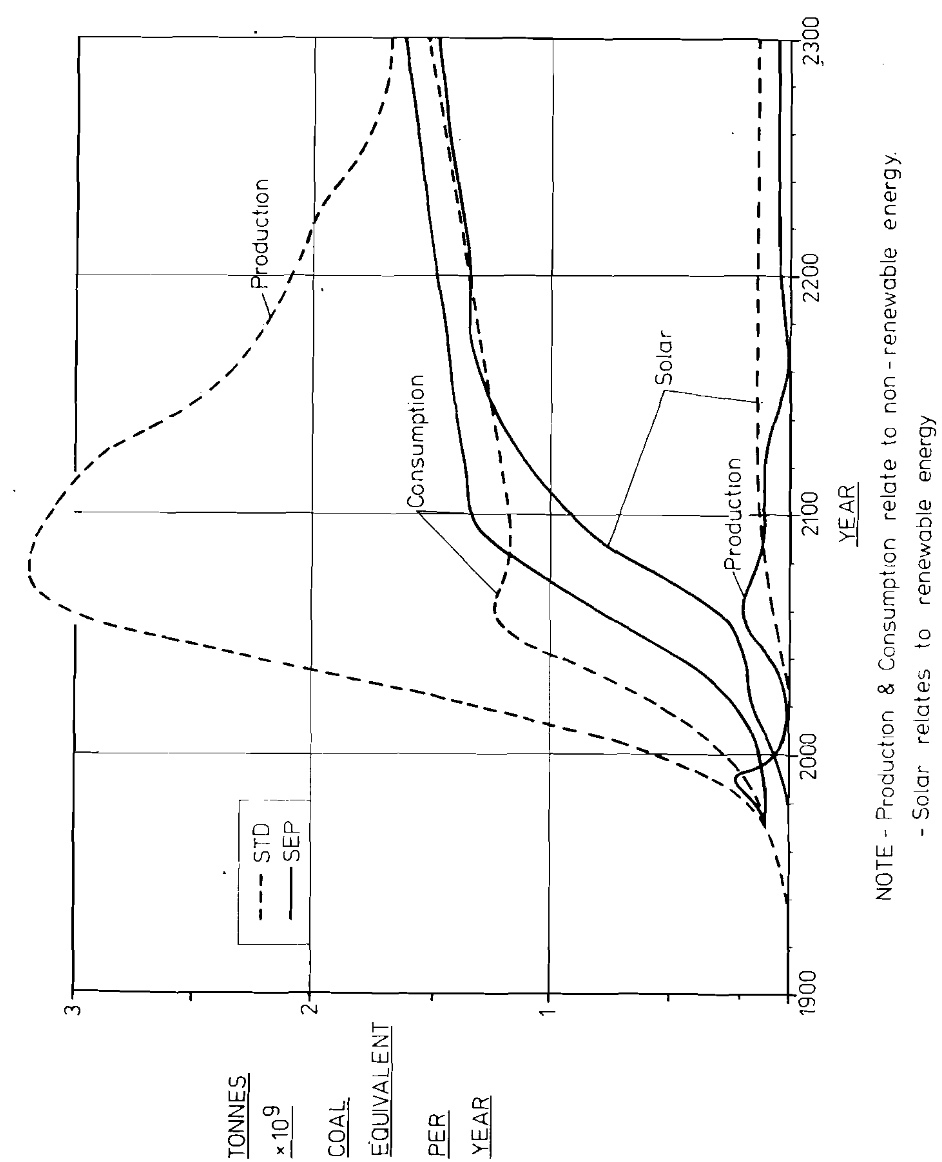
Energy

The records show that the production of fossil fuel energy first exceeded home consumption in 1965. In the Standard Run this was the start of an export-led expansion of the industry (including uranium) which continued for 100 years before it began to decrease (see figure 10).

Thus at its peak, annual production of non-renewable energy resources was 2½ times greater than home consumption. In addition, large imports of fossil fuels were being refined and re-exported. Australia was functioning as a major provider and refiner of energy supplies for the rest of the world. Eventually, this trading activity was to collapse leaving Australia supplying only its home needs with a small amount of support from imports and solar energy.

Under the Solar Energy Policy, Australia took quite a different path. During the 1970s interest in renewable energy supplies led to a development plan for solar energy designed to meet the nation's home requirements by the year 2010. By 1985, the development of these alternative

FIGURE 10 ENERGY PRODUCTION AND CONSUMPTION



supplies was being felt by the fossil fuel producers. There were also other factors at work inhibiting the growth rate of the industry. One of these was the increasing economy in the use of primary fuels with the result that home energy consumption grew slowly for 30 years.

The second effect was that non-renewable fuels lost their international commercial viability to minerals. By 2010, Australia was once again a net importer of energy (see figure 11). The massive international trading operation in fossil fuels and uranium never materialised. Instead, effort and industrial capital were being directed into the development of solar energy.

FIGURE 11 TRADE IN NON-RENEWABLE ENERGY

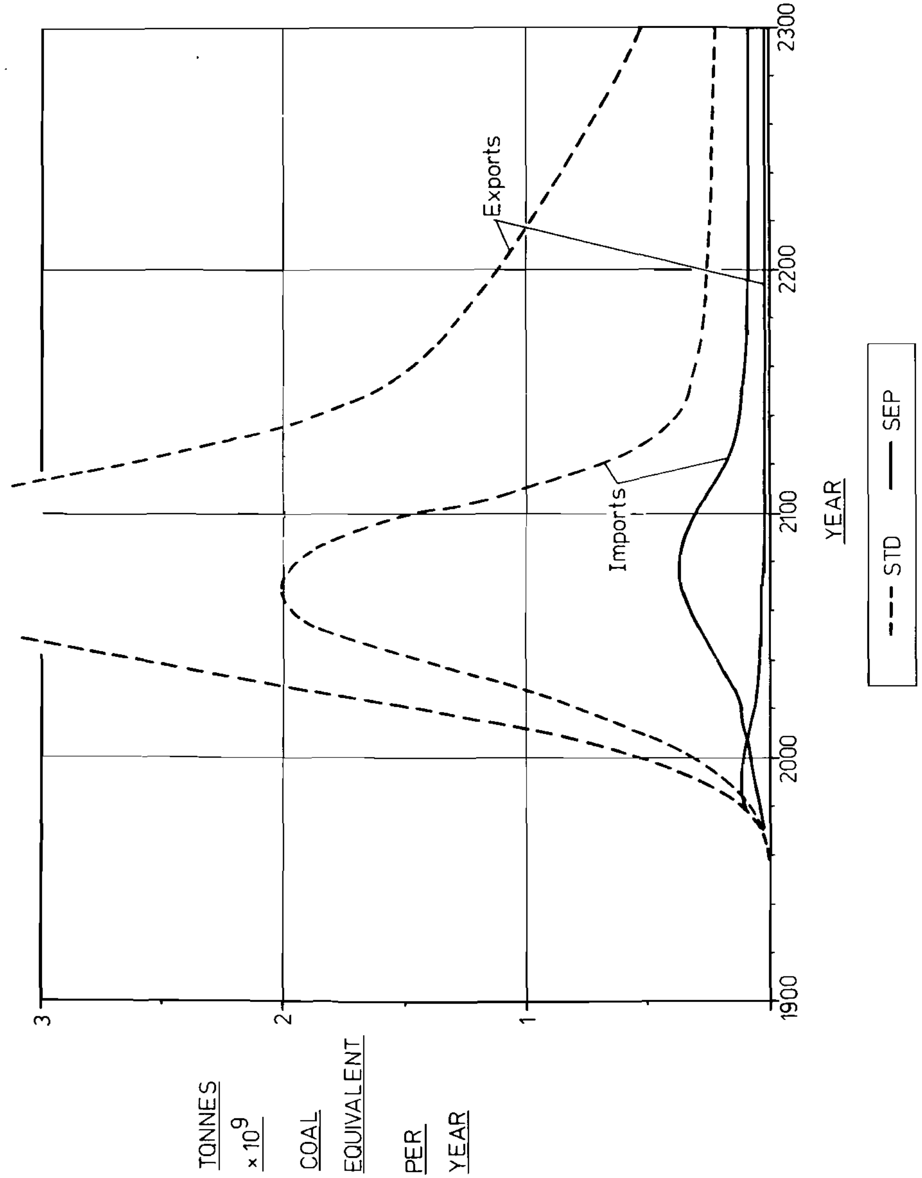
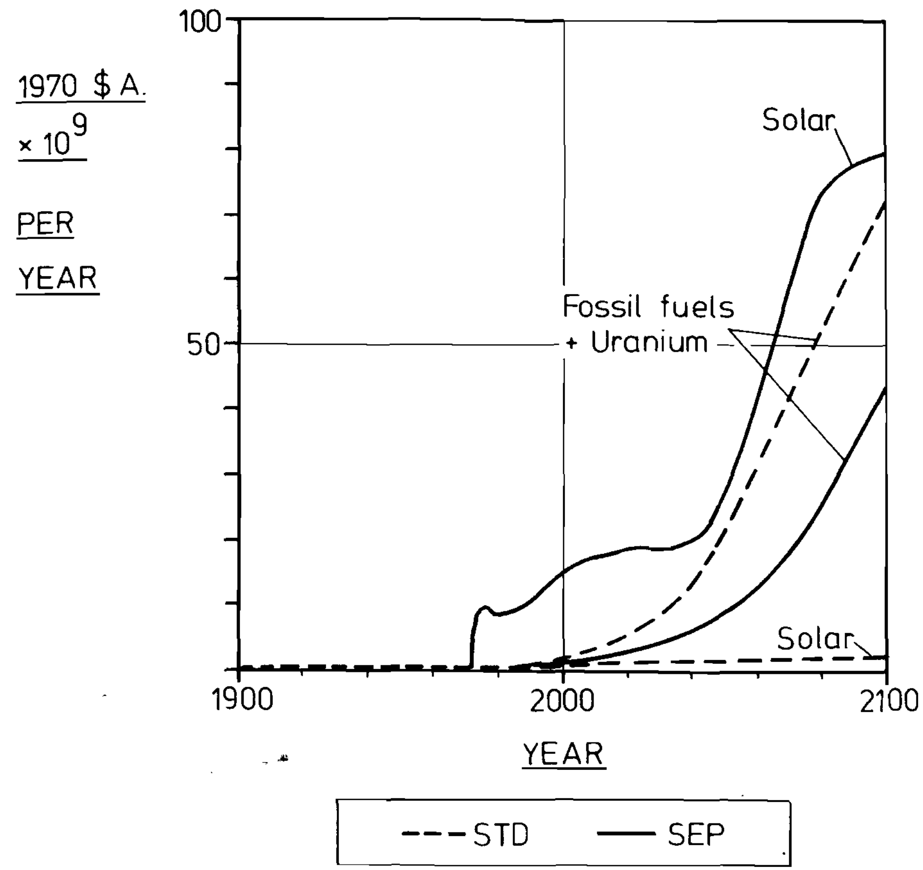


FIGURE 12 ANNUAL CAPITAL INVESTMENT IN ENERGY SUPPLIES



The scale of annual capital investment in solar energy generation is indicated in figure 12, which also shows the capital which continued to be expended on non-renewable energy within the same policy. We should note the very significant "switch on" of solar investment. In the year 2000, *seven* times as much capital was being spent annually on energy production as in the Standard Run. Moreover, these investments remained in excess of those in the Standard Run beyond 2100. Also, it should be noted that this investment was providing only half as much energy for home consumption by the year 2000, and for another 50 years (see figure 10). The Solar Energy Policy was very demanding, requiring not only large investments but also new attitudes towards the use of energy.

In one respect, the Solar Energy Policy had succeeded in its aim, namely to conserve fossil fuels and uranium. By way of summary, the energy situations under the Standard Run and the Solar Energy Policy for the year 2000 are compared in table 3.

TABLE 3 THE ENERGY SITUATION IN THE YEAR 2000

POLICY	STANDARD RUN	SOLAR ENERGY POLICY
	Millions of tonnes of Coal Equivalent	
PRODUCTION		
Fossil Fuels & Uranium	505	54
Solar Energy	2	73
TOTAL PRODUCTION	507	127
EXPORTS	586 (†)	88 (*)
IMPORTS	314	71
CONSUMPTION	235	110
Consumption per head (Tonnes per year)	12.7	5.8
$ of industrial output per tonne of coal equivalent	148	209

(*) Exporting of Solar Energy Fuels
(†) Re-exporting of imported energy

The last two rows of figures in table 3 not only indicate the reduced energy consumption but also show that it is in part, due to the more efficient use of energy.

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Pollution

Obviously a Solar Energy Policy will reduce pollution. However, energy generation and fossil fuel extraction are not the only polluting agents. Table 4 provides a comparison of the model outputs in the two modes.

TABLE 4 RELATIVE STATE OF POLLUTION

DATE	STANDARD RUN	SOLAR ENERGY POLICY
1975	1.0	1.0
2000	2.2	1.3
2025	5.9	1.9
2050	19.8	6.4
2075	34.5	19.9
2100	34.8	12.1
1.0 - The state of pollution perceived in 1975		

BEYOND 2000

Enough has been said of the output of the model with the Solar Energy Policy in operation to indicate that the first 25 years would simply impose economic setbacks compared with the unrestricted use and exporting of non-renewable energy resources. Moreover, there were no significant benefits except those of conservation of energy stocks for some undefined future eventualities.

In order to evaluate the Solar Energy Policy in a meaningful way, it is therefore necessary to switch to a new time horizon with the aim of exploring the possibility that the Solar Energy Policy might include a longer term pay-off which had not been reached. We therefore carried out two experimental runs on the model.

These were for extended time periods from 1900 to 2300. The first was a direct continuation of the model run which provided the scenario just described under the heading "Australia 2000". The second run was a continuation of the Standard Run over the same period. It will have been noted already that figures 9, 10 and 11 cover this extended period.

The results we derived beyond the year 2100 showed a marked reversal of the situation which the model had shown up to the year 2000 (see table 5).

TABLE 5 THE LONG TERM BENEFITS OF THE SOLAR ENERGY POLICY (Model values at year 2300)

VARIABLE	STANDARD RUN	SOLAR ENERGY POLICY
Industrial consumption per person $/year	14,190	17,279
Service Output per person $/year	14,840	15,239
Cumulative Australian Capital invested overseas $	13×10^{10}	13.3×10^{10}
Pollution compared with 1.0 in 1975	51	34
Energy Exports Tonnes Coal Equivalent	495×10^{6}	1.6×10^{6}
Total Imports $ per year	3.8×10^{10}	4.7×10^{10}
Population	32.6×10^{6}	39×10^{6}
Food per capita Kilograms of crop equivalent per person per year	3212	3319

It will be seen that all the disadvantages arising from the Solar Energy investment have been overcome, and in most cases there is a relative improvement over the Standard Run.

It is useful to allow industrial consumption per capita to serve as a proxy for all the other variables. Figure 13 gives meaning to the idea of trading short term losses for long term gains.

In terms of industrial consumption per head, the model shows the Solar Energy Policy to be a straight choice between less material affluence up to the year 2150 in exchange for a higher long term stability in the years that follow.

As table 5 indicates, this choice is reflected in many other variables including service output per person, food and pollution. Those who advocate solar energy policies generally do so because they believe that

their implementation would also involve significant changes in the industrial way of life. Many people consider that the "throwaway" philosophy of modern industrial societies damages man intellectually and socially, and that there are large subjective gains to be achieved from a change to a life style which is more communal and more labour-intensive. The savings of energy and minerals on the scale the model assumed could only be achieved through radical changes of the type just suggested. The Solar Energy Policy may therefore be misrepresented if it is interpreted solely in terms of explicit variables of the model and ignores these qualitative considerations.

Two other effects of the Solar Energy Policy warrant mention. The first occurred in the energy sector. As the Solar Energy Policy became established, the initial holding back in the rate of industrial capital investment was overcome and by the year 2020 the growth of industrial investment was as great as it had ever become in the Standard Run (see figure 6). This led to an increased demand for energy. The earlier assumption that it would take 20 years for the new technology of solar energy to respond was still present. As a result, fossil fuels made a comeback because they were able to meet the increased demand more quickly. As figure 10 shows, the recovery was sustained only until the new solar energy system had responded to the demand. At no time were fossil fuels more than a secondary source of energy.

The second effect has a deeper significance. It will be seen from figure 9 that mineral production eventually became much greater under the Solar Energy Policy than it was in the Standard Run. This was because it emerged as the only large scale export sector supporting Australia's international trade.

The magnitude of the revenue earned by minerals can be seen in table 6 (*The Bulletin*, January 22, 1977, p. 56, "Special Survey on Mining"). This aspect raises the thought that the whole Solar Energy Policy was indirectly dependent on mineral exporting activities. In short, in order to conserve fossil fuels and uranium, it was necessary to dissipate the stocks of non-renewable minerals at an even faster rate.

At this point let us summarise our interpretation of the changes and the effects of those changes, resulting from the introduction of a Solar Energy Policy.

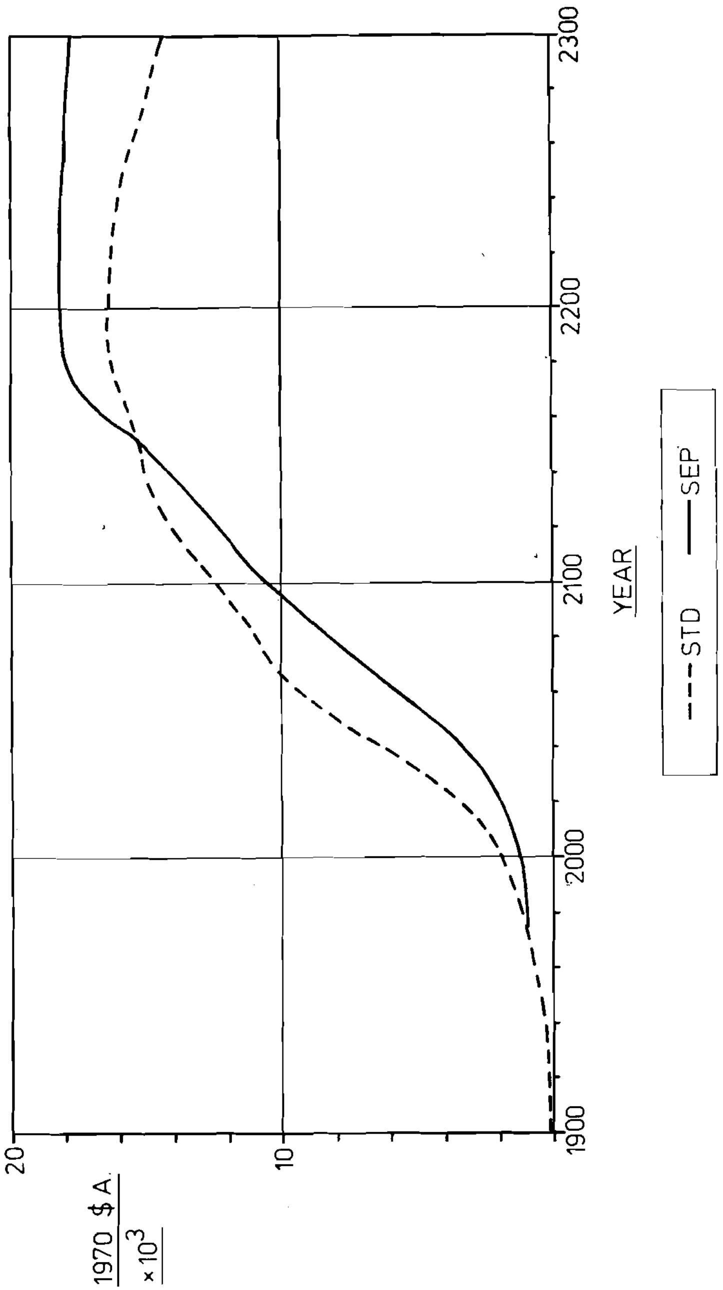
SUMMARY OF SOLAR ENERGY POLICY

To interpret the scenario for the advancement of Solar Energy in Australia only data changes were made to the model in the following areas:

(a) The cost of obtaining non-renewable energy forms was marginally increased as more and more of this form of energy was consumed — the magnitude of this increase can be seen in figure 14.

(b) In an endeavour to make solar energy more attractive economically, the efficiency of the capital invested was increased

FIGURE 13 INDUSTRIAL CONSUMPTION PER CAPITA



by a factor of 10, and the utilisation of this energy form was made 20% more effective; i.e. technology had progressed considerably.

(c) The remaining stimulus was of a social awareness and change with respect to the desirability of solar energy, thus producing a demand while still retaining a delay in meeting that demand.

Included in the Solar Energy Policy was the restriction on the export and import of fossil fuels and uranium. These trade rates were halved from 1980.

FIGURE 14 CAPITAL REQUIRED TO EXTRACT NON-RENEWABLE ENERGY

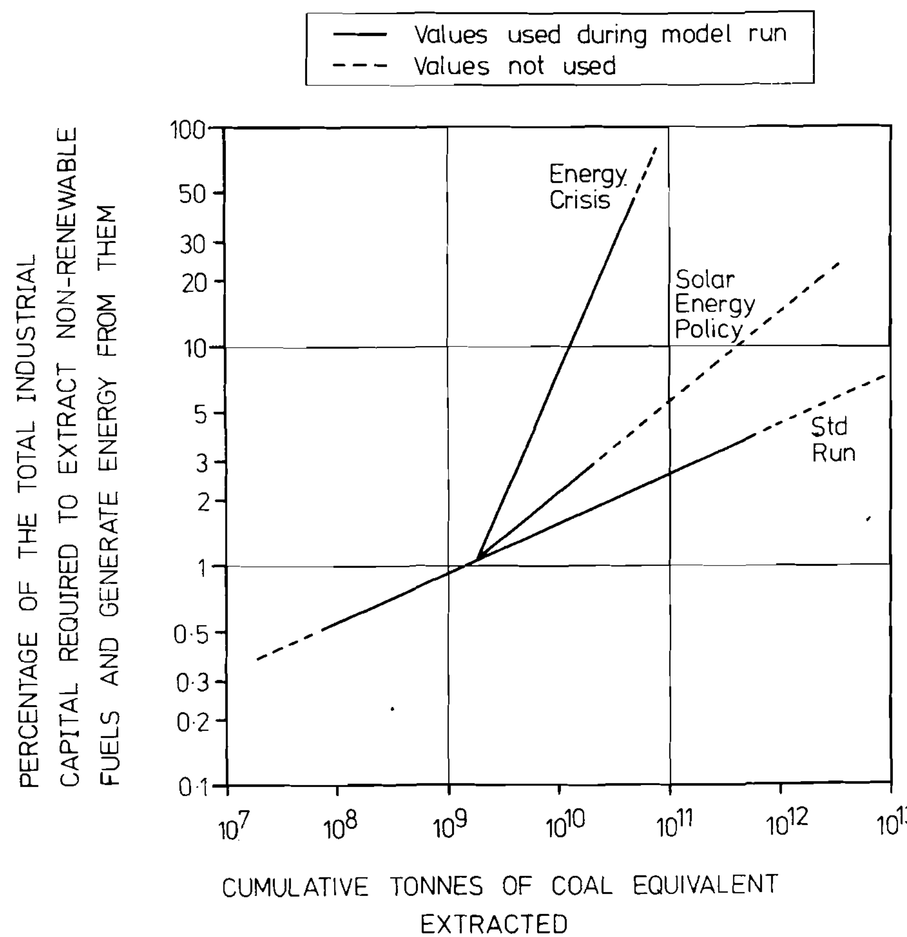


TABLE 6 WHAT THE MINERALS EARN

	1974-75 Millions $'s	1975-76 Millions $'s
METALLICS*		
Aluminium ***	375	515
Copper	161	139
Gold	11	30
Iron	871	891
Lead	145	130
Manganese ***	43	58
Mineral sands	122	128
Nickel	131	150
Silver	18	10
Tin	37	26
Tungsten	11	15
Zinc	137	135
Other	15	17
	2077	2244
FUELS		
Coal, coke	673	981
Petroleum products **	272	272
	945	1253
NON-METALLICS		
Asbestos	-	12
Precious stones	18	22
Salt	17	23
Other	13	13
	48	70
TOTAL	3070	3567

* Includes ores, concentrates and primary refined metals.

*** Bauxite and manganese estimated. Official statistics confidential, only combined total of $93 million.

** Includes $100 million estimate for L.P.G. and L.N.G. gas exports.

SUMMARY OF EFFECTS OF SOLAR ENERGY POLICY

Our conclusions are:

1. The policy would have a *substantial* effect on Australian energy patterns resulting in a switch from a reliance on imports to the use of "home grown" energy in both renewable and non-renewable forms.
2. The renewable portion of total energy would not constitute a major part even by the year 2100. However, by that year we would be consuming per head more solar energy than energy from fossil fuels and uranium, and in fact, would be consuming *six times more* total energy per head than we did in 1975 (see figure 15).
3. Although the Solar Energy Policy would have a great effect on the Australian energy pattern, this would be achieved at a very high cost. We would have to spend per annum, *five times more* than we would have under our Standard Run policy. Thus solar energy plant would *cost five times more* than conventional hydro-electricity plant. However, in the latter part of the twenty-first century, solar energy would *cost less* to produce per unit than would fossil fuels and uranium (see figure 16).
4. There are a number of favourable results associated with the Solar Energy Policy, particularly lower pollution effects and conservation of resources. Under this policy annual total consumption of energy per head would be 70% of that indicated by present policy extrapolations by the year 2100.

In summing up, if we had implemented our Solar Energy Policy in 1975, we would have seen some impact by the year 2000, and a greater impact around 2065. Delays of this magnitude may be intolerable to some, but the very high cost of achieving even this result may be equally intolerable to others.

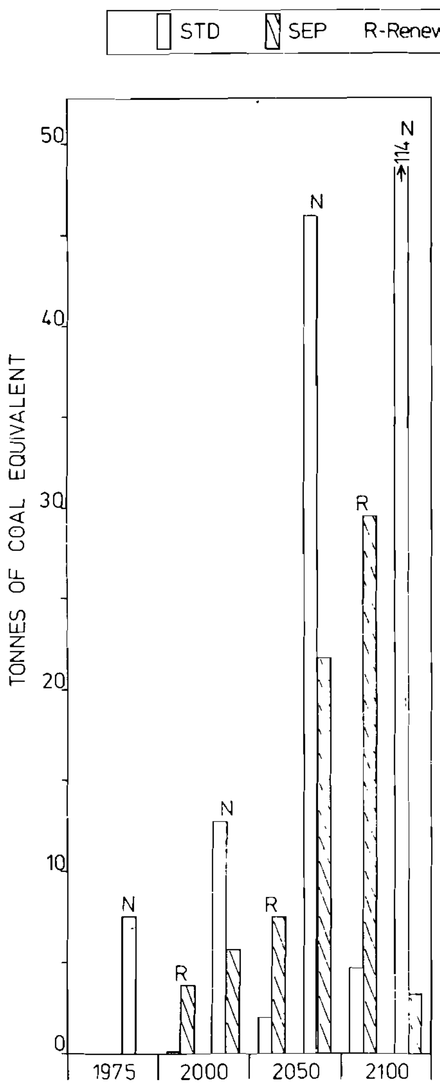
FURTHER QUESTIONS

At this point it is necessary to pause and examine some of the questions that the Solar Energy Policy has provoked. There are two broad questions we should consider.

1. What would Australia be like if it ran into an Energy Crisis? How would it cope with the situation? Could Solar Energy come to the rescue?
2. If we had an Energy Crisis situation how could Solar Energy be used as an alternative? Would we be able to afford it without detrimentally affecting our standard of living?

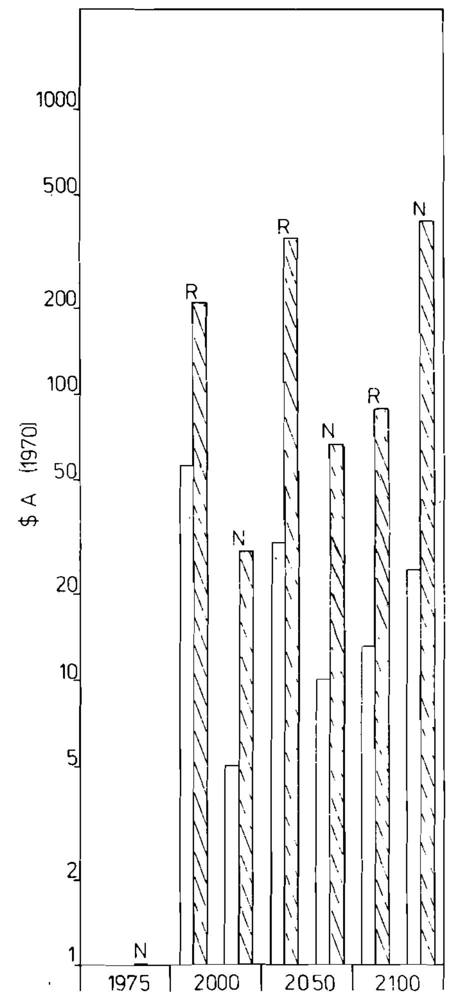
We attempt to answer these questions in the following chapters.

FIGURE 15



ANNUAL CONSUMPTION OF ENERGY PER HEAD

FIGURE 16



ANNUAL CAPITAL INVESTMENT PER ENERGY UNIT PRODUCED

CHAPTER 3

AN ENERGY CRISIS IN AUSTRALIA (ECA)

In an effort to teach Aboriginal women in South Australia the advantages of contraception, family planners taught them a song with lyrics detailing the subject. But the experts have given up the musical approach. As one of them explained, "The women imagined that they could avoid pregnancy merely by singing the song."

Quotation from *Reader's Digest*, April 1977.

THE TIME HORIZON

Although most individuals are philosophically concerned about the next 200 years or more, looking so far ahead is largely irrelevant to practical politics. This is because the forecasting uncertainties are too great to justify any committing action, other than undertaking to review the situation.

Thus it became apparent that the delay time and the resulting "switching on" of solar energy was an important factor in determining the rate of investment and the desire to invest. Of course this was not the only factor as we have seen earlier.

However, what if we had no say in the "switch on" and in fact it was determined for us? To explore this possibility, a radical experiment was run on the model by reversing the normal approach. Instead of introducing "sensible" assumptions into the model and interpreting the resulting output, we decided on the types of output which we required. We then introduced various new assumptions until those outputs were obtained.

INTRODUCING THE ENERGY CRISIS

The theme we adopted was to create a short term energy crisis. Our understanding of a crisis is one of a drastic cut in the availability of imported energy, and even if we were willing to pay a high price for it no one would be interested in taking any of our exports as payment. This could result from our exports becoming very expensive (particularly minerals) and/or the necessity to retain our energy resources (in particular uranium) for home use although the rest of the world needed them. In addition, a Solar Energy Policy was not pursued.

In order to create such a crisis we returned to our present policy model (the Standard Run) as described in chapter 1 and introduced two changes. The first was to alter drastically the rate at which the extraction costs of fossil fuels and uranium increased with the cumulative amount extracted. Thus as more and more of our fossil fuels were used up at lower and lower grades, they would cost exponentially more to extract. Consequently there was a switch to uranium as an energy source which, per unit, was much more expensive to produce (see figure 14). The second was to remove the independent motivation to expand industrial, mineral, energy and food exports. This did not stop exports but restricted international trade to the level required to pay for the imports which Australians demanded. This step was necessary so that our nation would not be able to get non-renewable energy by acquiring ownership of external resources. This would have provided an artificial escape from the crisis situation. The restrictions were instigated in 1980 and the model allowed to run to see what Australia would be like under these crisis conditions.

OUTCOME OF THE ENERGY CRISIS

AUSTRALIA 2000

Population

By the year 2000, population still constrained by a net migration of 50,000 people per year, would reach 18.6 million as in the Standard Run. However, the first signs of the energy crisis would start to have an effect by increasing the birth rate through a lowering of the material standard of living.

Food and Agriculture

As a result of the restrictions on exports and their consequential influence on imports (see figures 17-4 and 18-4), Australians' food intake per head would be reduced by 10%. Lack of energy to produce the necessary ingredients for modern day farming (e.g. fertilizers, machinery, etc.) would induce a 6% drop in agricultural production. The crisis had started to hit the Australians where it hurt most although they were still eating well above the level of the rest of the world. Thus the agricultural industry was allowed to run down and our cheap imported food markets were being lost.

Industry

In order to maintain some balance of trade, industrial exports would enter a growth period and in fact would constitute the main export earner up to the year 2000 (see figure 17-1). Although this was the case, Australians were

materially worse off as capital was ploughed into high-cost energy plant. There was a drop of 6% in the consumption of industrial products per head and a drop of 4% in public expenditure per head, compared with the Standard Run. Annual capital investment dropped because of the demands of the resource sector.

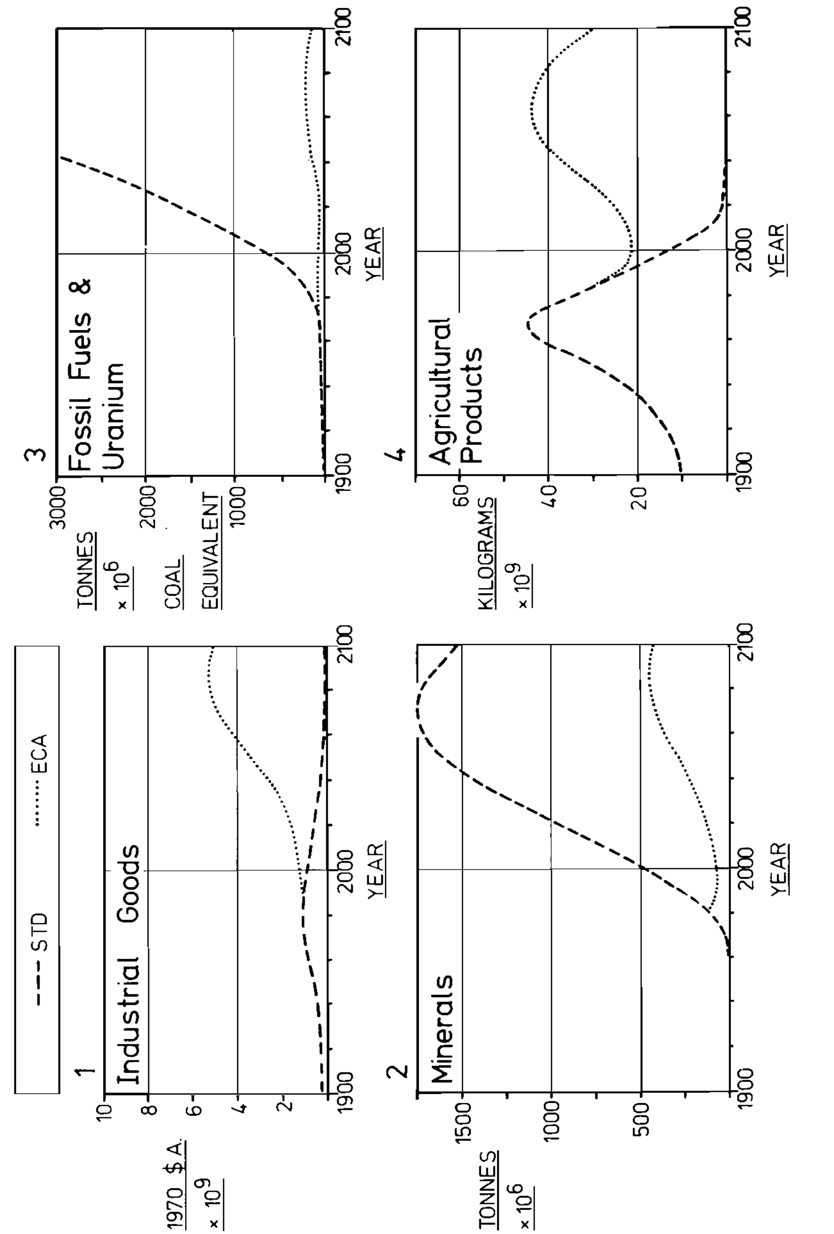


FIGURE 17 EXPORTS

Minerals
The great export earner of the 1970s would be severely curtailed and in fact would have dropped to 1/5 of the Standard Run level by the year 2000. Cumulative production of minerals would be only half that of the Standard Run figure by the year 2000, thus leaving Australia with twice the mineral reserves it had under the Standard Run. The main contributor to this factor was the reduction in exports (see figure 17-2), but home consumption fell as well being 10% less per head (see figure 19).

Energy
Figure 17-3 shows that under the Standard Run policy heavy reliance was placed on mineral exports paying for energy imports. As a result of the energy crisis, mineral exports would be curtailed and thus energy imports would suffer. By the year 2000 the pinch was already being felt. The amount of capital being allocated to extracting fossil fuels and uranium had doubled (see figure 20) while the consumption per head had fallen (see figure 21a).

While the export embargo was being enforced its effect was further enhanced by the non-exporting of uranium. It was necessary, even at a high price, to import the essential energy form (petroleum), but the economy was forced to reduce imports to 1/3 of the Standard Run level by the year 2000 (see figure 18-3).

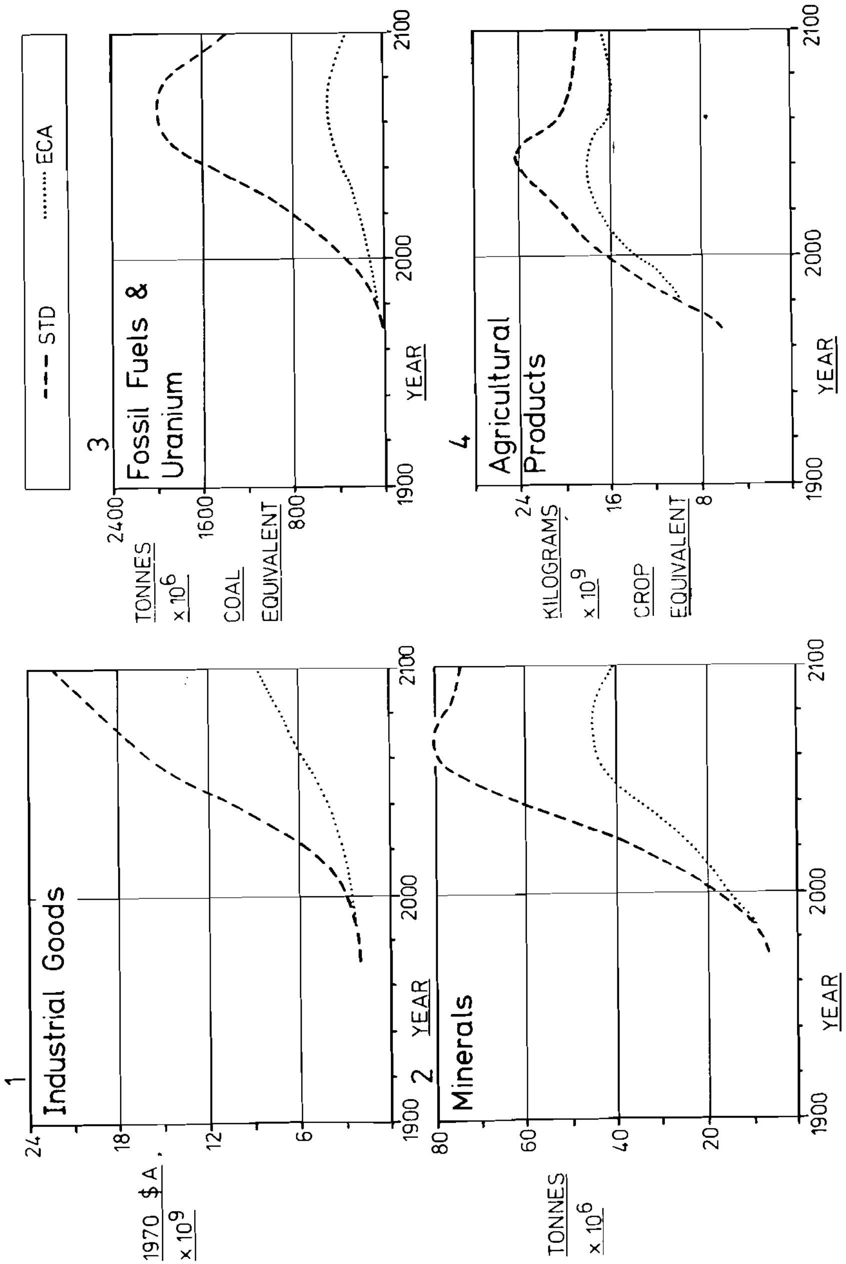
Under the conditions of reduced capital spending, high cost of non-renewable energy extraction and diminished production of fossil fuels and uranium, solar energy would not have the background against which to flourish and in fact it hardly survived. All attention was turned towards the relatively cheaper energy forms, actually 6 times cheaper per unit (see figure 21b).

BEYOND 2000

After the year 2000 the greatest impact of the energy crisis would be felt when capital and resources suffered from an insufficient supply of the required energy forms (see figure 22). A graphical example of the impact of the energy crisis can be seen in figure 23 in which the industrial consumption per head peaks around the year 2040 at about $5800 and then declines. This peak is well below the Standard Run value of $12,500 for the year 2100.

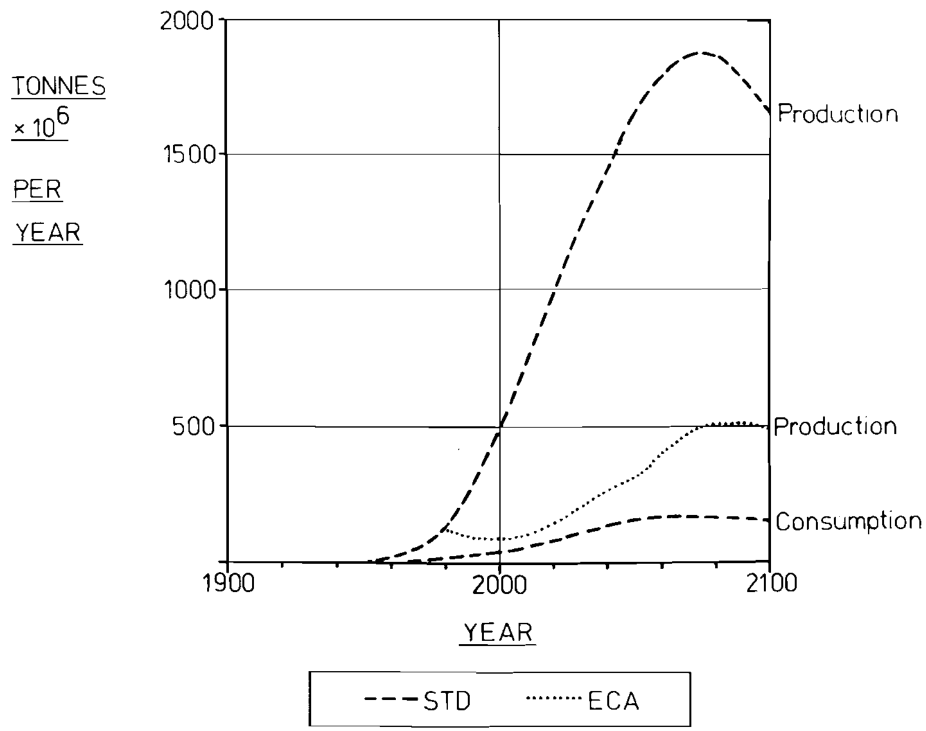
Trade would continue but there would be a change in its mix. Industrial goods produced would be exchanged for overseas goods, the net effect being in the negative direction (imports exceeding exports). There would be pressure on farmers to return to the land once cheaper foods were no longer available. This would produce a favourable swing towards exporting of food and agricultural products (see figure 17-4) which was a reversal of the Standard Run situation. In this way food and agricultural products returned to their original role of being major trade earners for Australia and helped to pay for the deficits in the other traded commodities.

FIGURE 18 IMPORTS



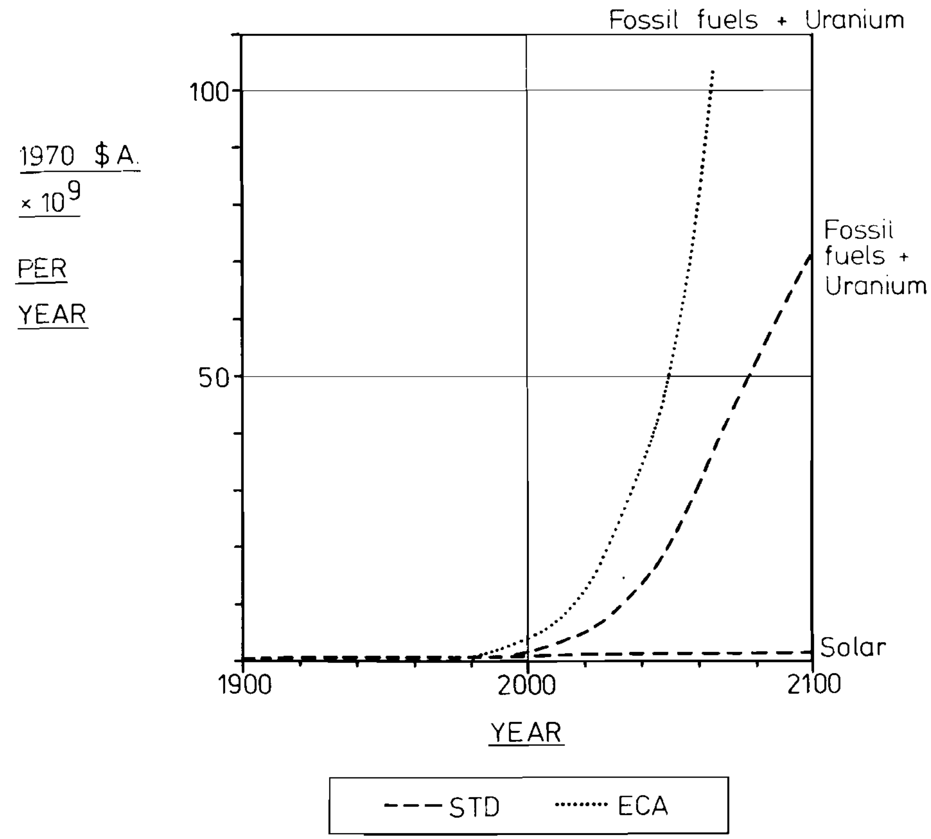
Although mineral exports were severely curtailed they would still be used in part to pay for the necessary industrial imports. In this way too, we would continue to finance imported energy while retaining our own energy production with very little of it being exported. Generally Australians were worse off materially, socially, in their eating habits and in their international relationships. Under the energy crisis the cost of producing fossil fuels and uranium (i.e. the annual investment per unit of non-renewable energy) would have to be *10 times greater* than under our present policy (the Standard Run) and *4 times greater* than under the Solar Energy Policy. The consumption per head was reduced by a factor of 10 in comparison with that indicated by extrapolation of the present policy. Solar energy does "not even get a look in" and in fact plays the same role as in the Standard Run.

FIGURE 19 MINERAL PRODUCTION AND CONSUMPTION



NOTE - Consumption under ECA is insignificant on this scale.

FIGURE 20 ANNUAL CAPITAL INVESTMENT IN ENERGY SUPPLIES



QUESTIONS ANSWERED

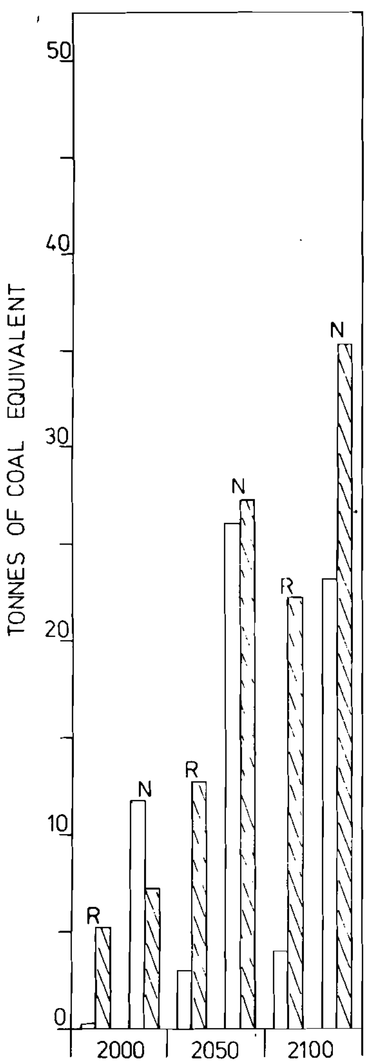
In response to the first set of questions asked at the end of the last chapter, we see that if there were to be an energy crisis of this nature, Australia would be in a rather poor state if the crisis continued for an appreciable time — even 10 years. It can also be seen that we would *not* be able to cope, and that without the necessary investment and desire to set into motion a solar program, this form of renewable energy would not be able to help rescue the crisis.

We are not concerned with the unlikely event of an energy crisis being allowed to develop unchecked, since no nation would retain the same policies under these conditions. However, what we are interested in is if we did have a short term energy crisis, how could Solar Energy be used as an alternative?

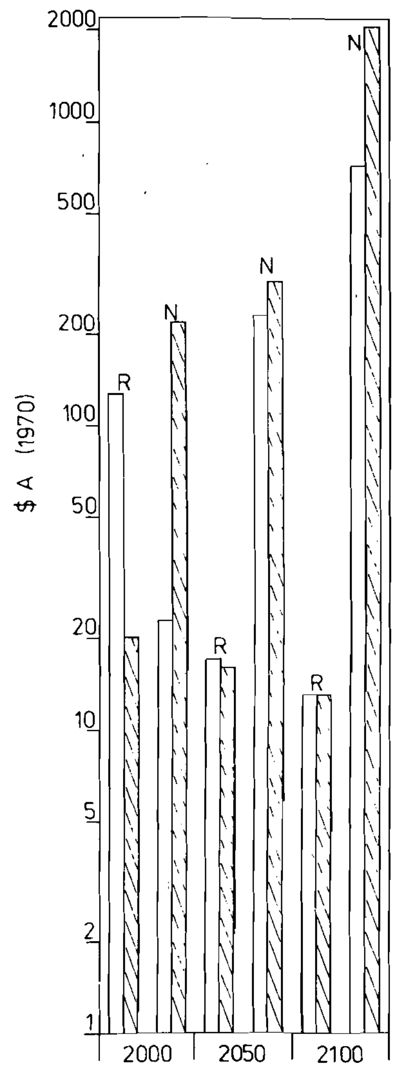
In the next chapter we will explore this theme.

FIGURE 21a **FIGURE 21b**

ECA SER R - Renewable energy N - Non renewable energy



ANNUAL CONSUMPTION OF ENERGY PER HEAD



ANNUAL CAPITAL INVESTMENT PER ENERGY UNIT PRODUCED

FIGURE 22 ENERGY PRODUCTION AND CONSUMPTION

NOTE - Production & Consumption relate to non-renewable energy.
- Solar relates to renewable energy.

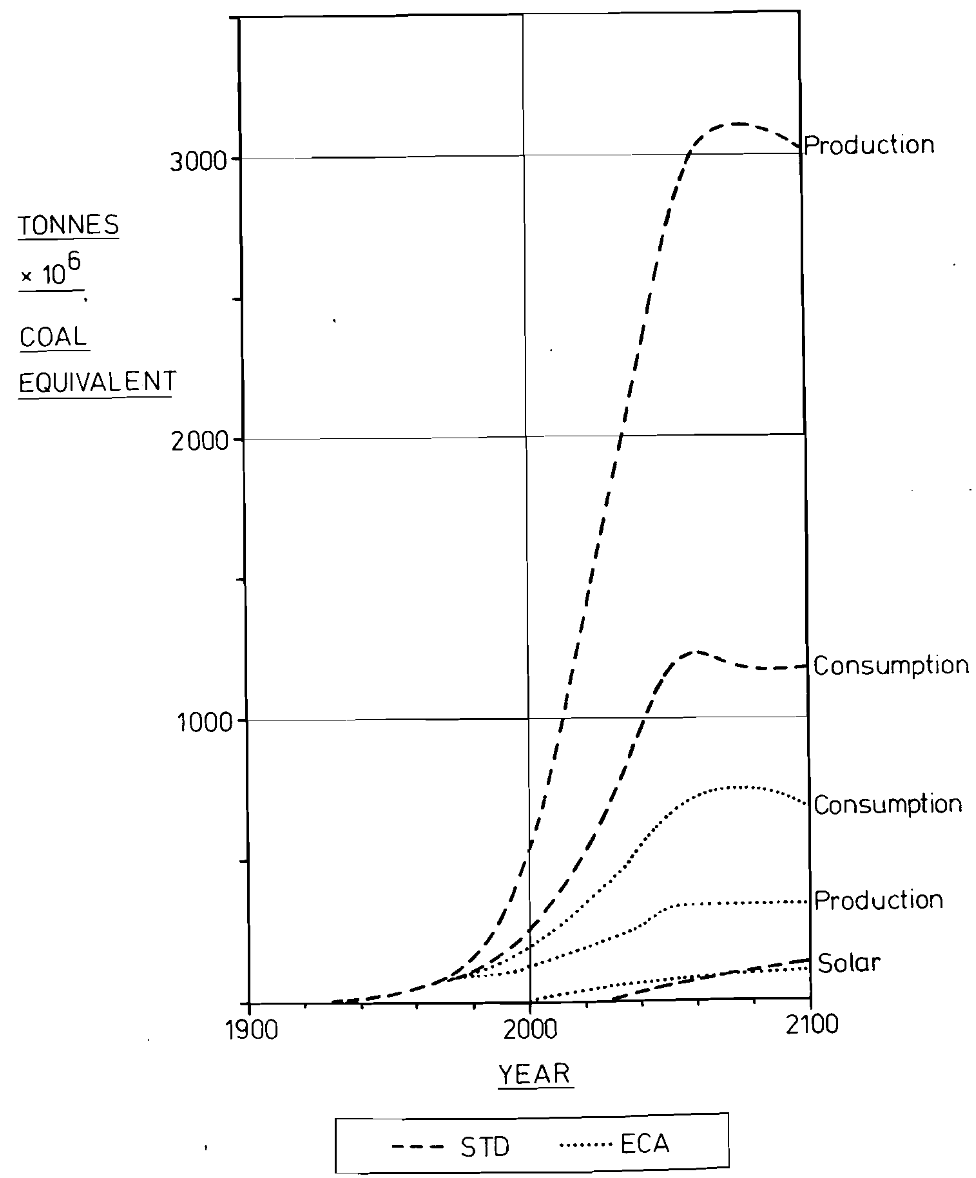
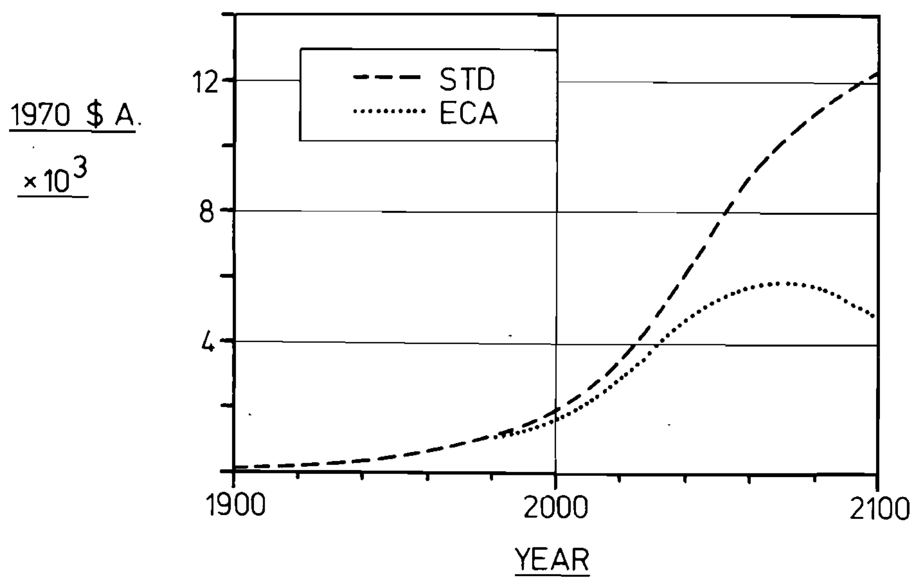


FIGURE 23 INDUSTRIAL CONSUMPTION PER CAPITA



CHAPTER 4

AN URGENT SOLAR ENERGY RESCUE OPERATION (SER)

If you can read this, get help and rescue me.

Message printed on the underside of a beginner's skis at Thredbo, N.S.W.

DELAYS — TECHNOLOGICAL OR ECONOMIC?

Earlier we were questioning the delay in the "switching on" of solar energy and we were looking for the "switching on" mechanism. One of the reasons for the delay is purely technological and this has been built into the model to cover our present "state of the art". Another delay is to be found in our social attitude towards the use of energy and in particular, solar energy. This too will take time to overcome, but today we are seeing signs of a reduction of these delays. New technologies are being found and the papers are full of announcements about "breakthroughs" in absorber efficiencies and the like. People are increasingly concerning themselves with alternative forms of energy. This is mirrored in both the public debate which is taking place about energy and the increasing number of people actually using solar absorbers to harness the sun.

In view of the growing inroads being made into overcoming the technological and social delays, the question which must necessarily follow from our earlier discussion is, would the economics of a Solar Energy Policy cause hidden delays in its development? Would this type of delay be the downfall of an attempted solar policy especially in a crisis situation, since all our effort and monetary resources would then be concentrated on overcoming the crisis? This chapter explores this question.

INTRODUCING THE SOLAR ENERGY RESCUE (SER)

One of the purposes of the crisis scenario described in chapter 3 was to set up conditions in which solar development would be relatively urgent and critical. However, unlike the Solar Energy Policy, we reduced the technological and social delays by an appreciable breakthrough in these areas.

The necessary model changes to incorporate both the crisis and rescue policies were mainly those we used in previous chapters.

Firstly we retained the model conditions described in chapter 3 which gave us a potential crisis in 1980. Then we re-introduced our Solar Energy Policy from chapter 2 to give us our determined development program. However, as we stated earlier, this policy had a rather long inbuilt delay period of 20 years before effects of the solar policy actually came to fruition. To remove the effect of the social and technological delays we reduced the time down to a nominal 1 year, possibly sufficient time to build solar stations and become operational.

OUTCOME OF THE SOLAR ENERGY RESCUE

AUSTRALIA 2000

Population

The effect of a more affluent society produced a population of 18.4 million by 2000 which was ½ million less than under the Solar Energy Policy. However, as we have mentioned earlier signs of a labour shortage started to appear by 1980.

Food and Agriculture

Our eating habits progressively increased until by the year 2000 we were eating better per head than we did under any of the other policies. However, the first signs of an export revival began to appear, while imports remained at the levels reached during the energy crisis (see figures 24-4 and 25-4).

Industry

Without the great need for capital by the mineral and energy sectors, the material standard of living climbed to surpass that reached by the Solar Energy Policy, and was only slightly less than that reached during the crisis by the year 2000 (see figure 30). The annual capital investment in industry grew at a much faster rate (see figure 26), as did industrial exports which were 25% greater than for the Solar Energy Policy while imports were 15% less by the year 2000 (see figures 24-1 and 25-1). Again industrial exports pointed to an upsurge along with agricultural exports.

Minerals

Not so much pressure was placed on this sector as some of the other sectors were providing more export dollars to pay for imports. This had a dramatic effect on the depletion of reserves, so much so that cumulative output was only *half* that produced by the Solar Energy Policy by the year 2000 (see figure 27).

FIGURE 24 EXPORTS

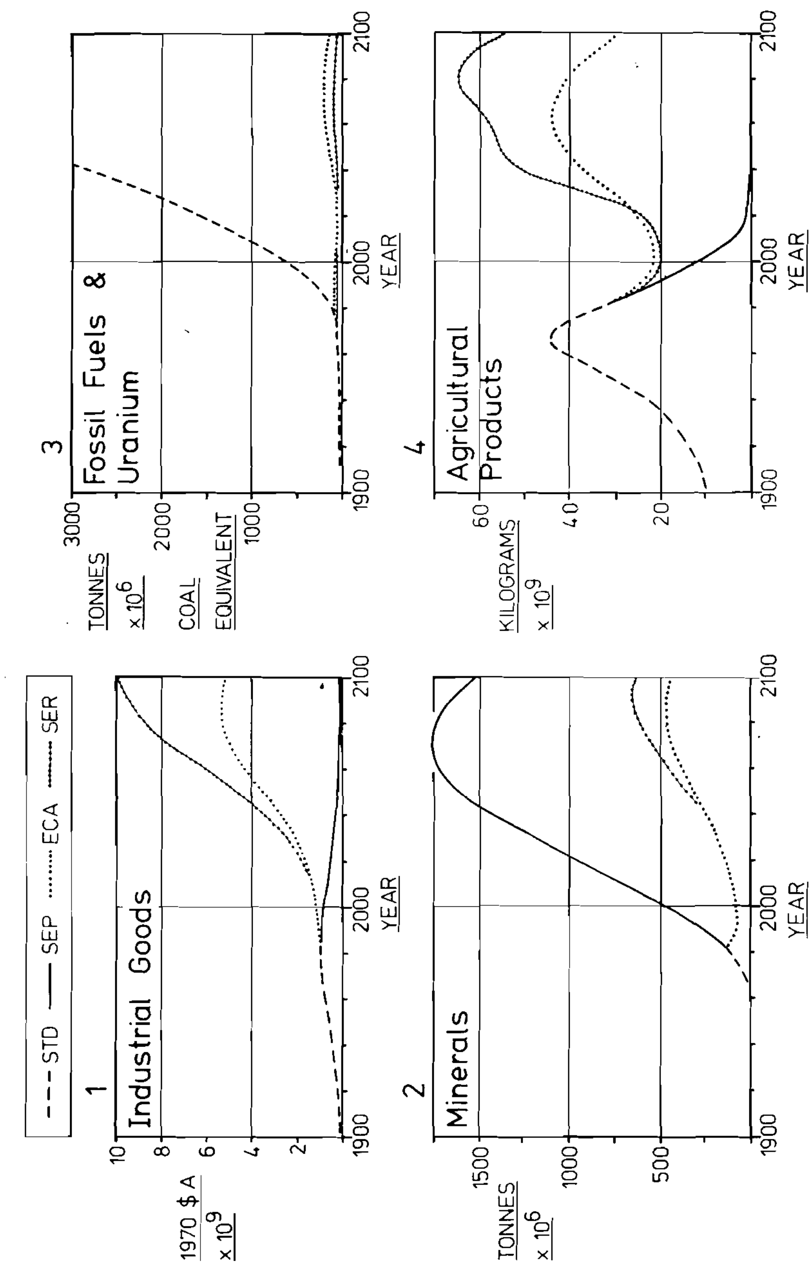


FIGURE 25 IMPORTS

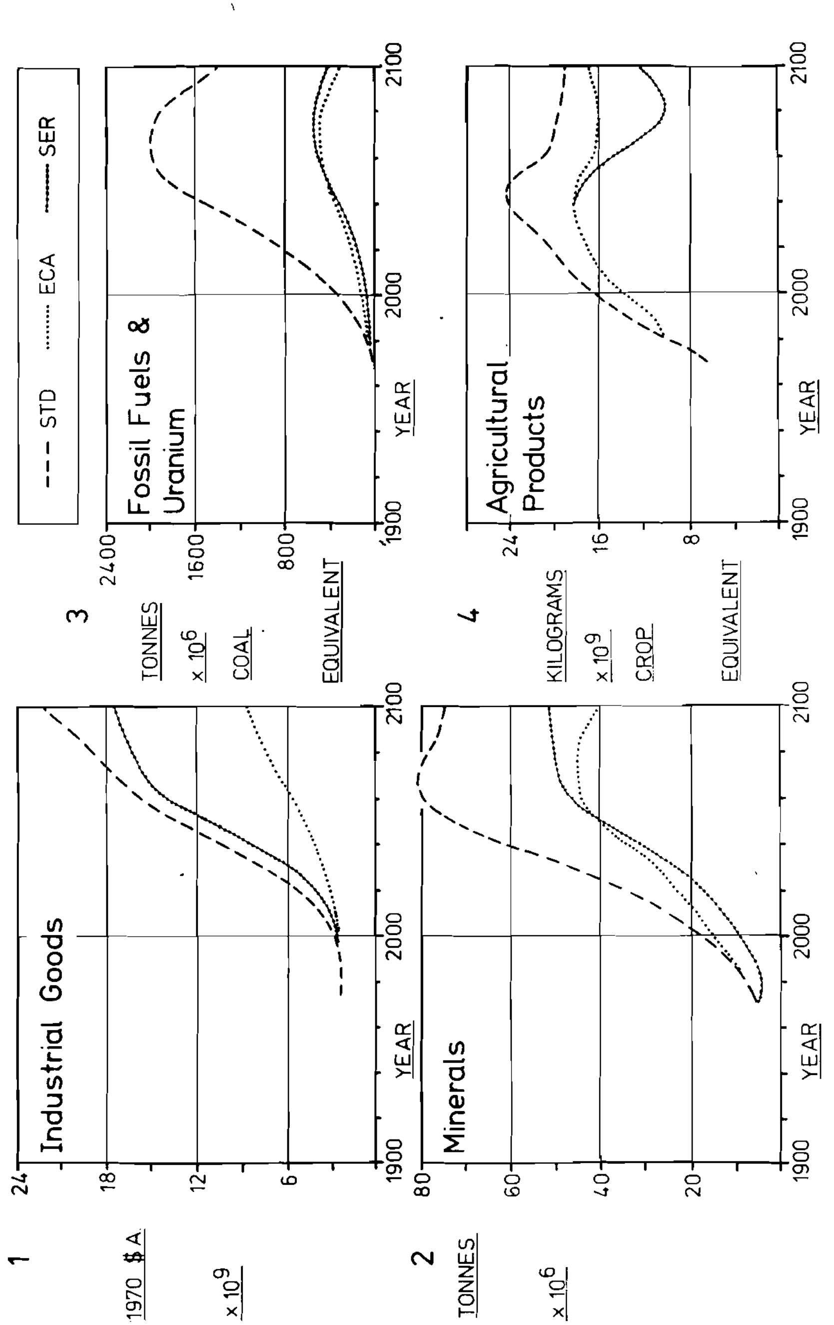
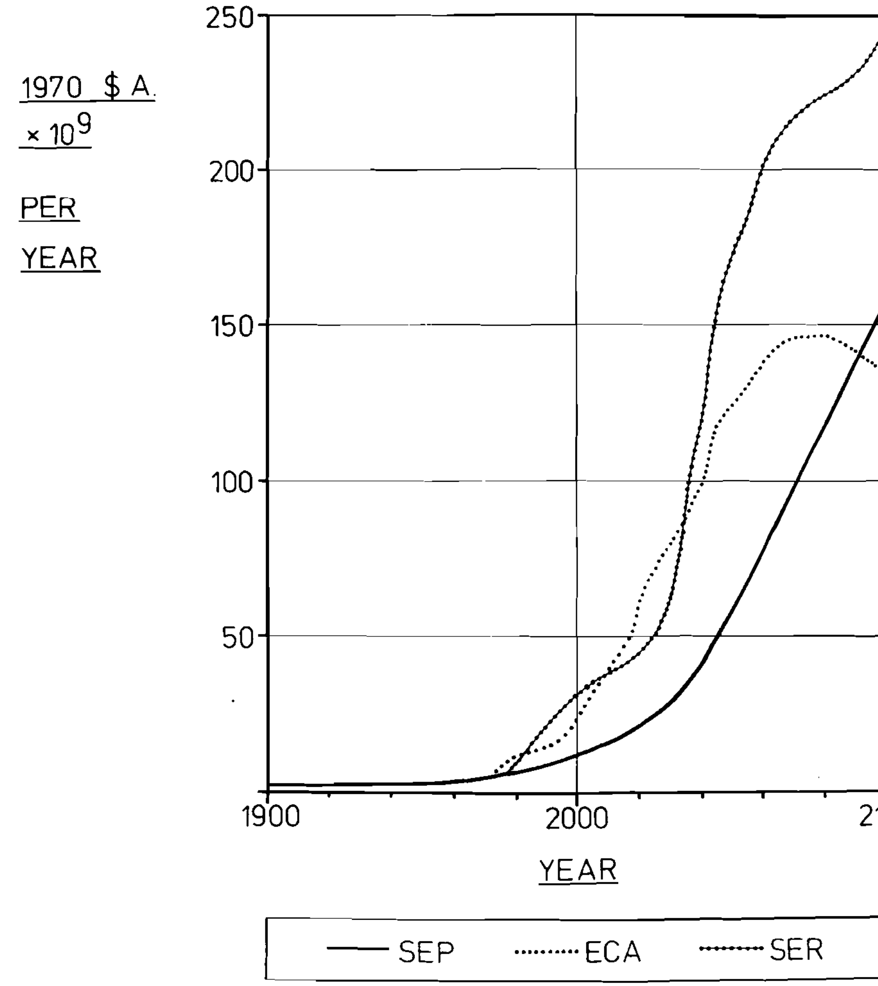


FIGURE 26 ANNUAL CAPITAL INVESTMENT IN INDUSTRY



Energy

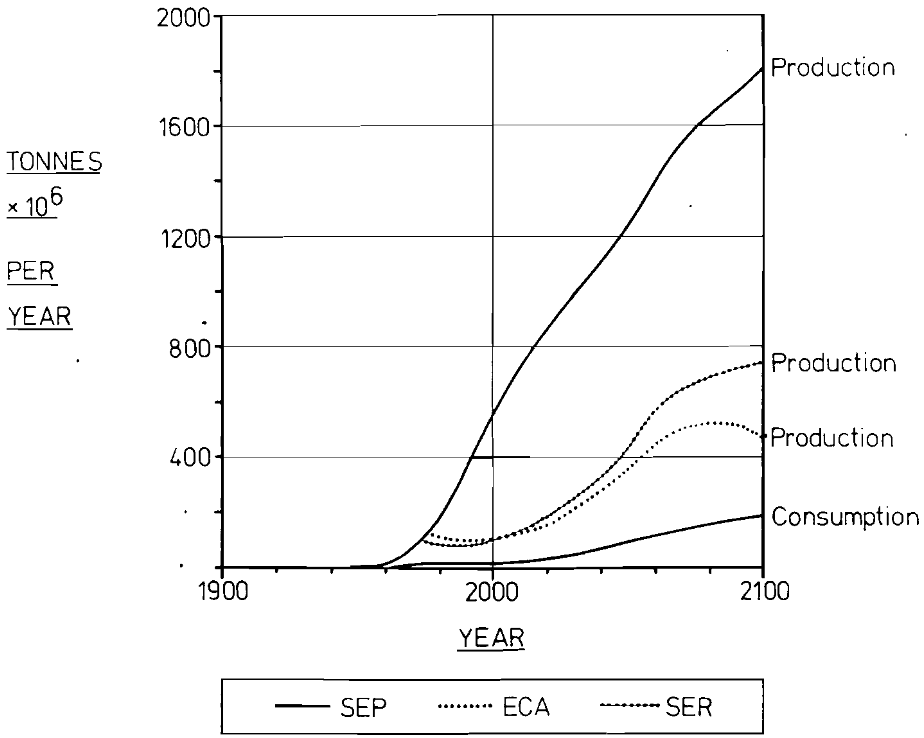
The big question lay in this area. Did we rescue the crisis or did we fail? Well, not only did we rescue the crisis but we actually prevented it from happening. We must remember that our Solar Energy Policy was implemented in 1975 and the crisis was not due to hit until 1980. The other interesting phenomenon which occurred was that solar energy cost us less per year in investment than did fossil fuels and uranium (see figure 28).

Not only were our exports of fossil fuels and uranium appreciably less (60% less than the Solar Energy Policy and half the Energy Crisis levels by the year 2000) but also our imports were less (see figures 24-3 and 25-3). This had an effect on total cumulative production of this energy form and the amount of capital that was necessarily drawn away under the energy crisis.

In this environment solar energy was able to shine. Supplies were 1/3 greater than those of the Solar Energy Policy by the year 2000 (see figure 29), while as was stated above, the investment requirement was much less. Under this policy we would consume 1.3 units of fossil fuels and uranium for each unit of solar energy by the year 2000. The corresponding ratios were 1.5:1 under the Solar Energy Policy and 2.8:1 under the Energy Crisis.

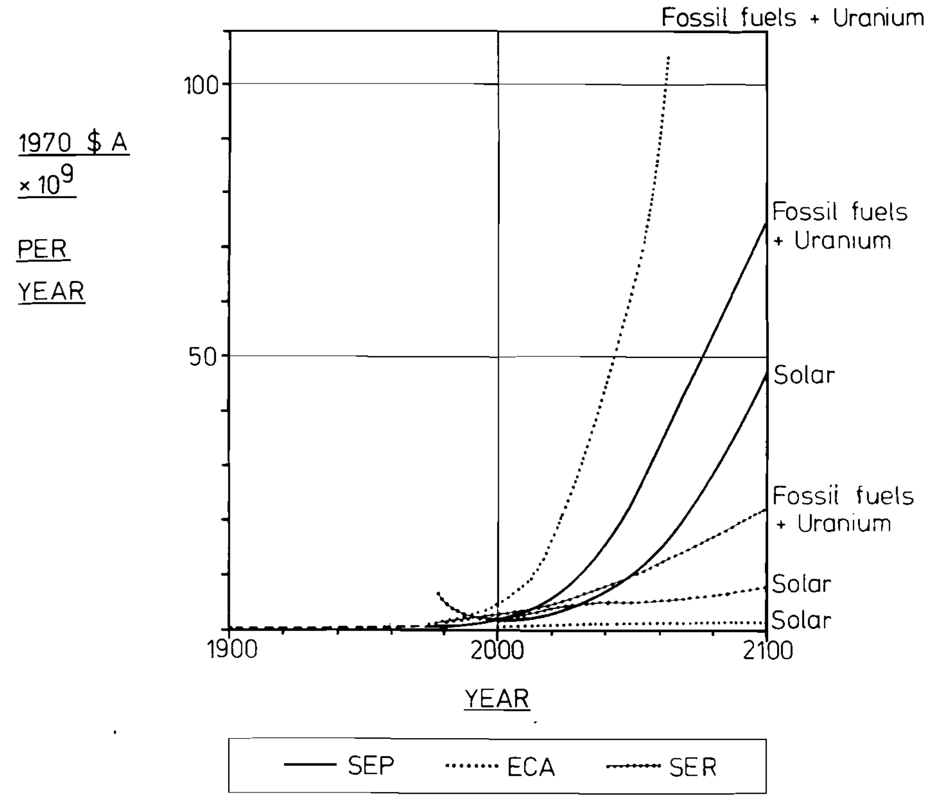
Thus the crisis would not have been able to get a hold of the situation if a Solar Energy Policy had been instigated in 1975 with appreciable reductions in the technological and social delays, and if the incentives to export, especially minerals, had been removed.

FIGURE 27 MINERAL PRODUCTION AND CONSUMPTION



NOTE - Consumption under ECA & SER is insignificant on this scale.

FIGURE 28 ANNUAL CAPITAL INVESTMENT IN ENERGY SUPPLIES



BEYOND 2000

It is very difficult to put into words the description of Australia beyond the year 2000. We can only say that Australians would become more prosperous, more well-fed and more conscious of the need for conserving minerals and energy.

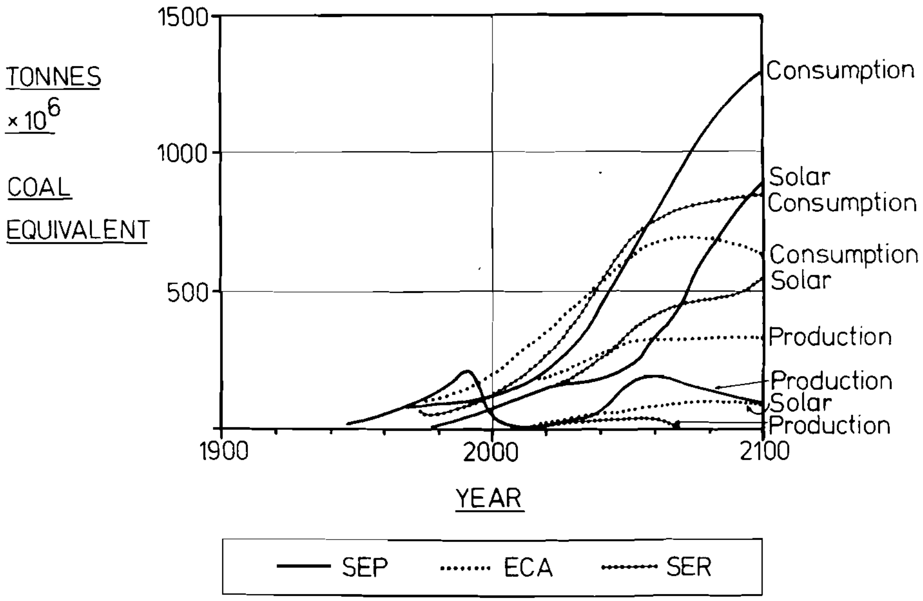
The population growth would be slower due to the lower birth rate. However, this has its repercussions in the shortages in the labour force which become increasingly worse. In terms of international trade the combination of a Solar Energy Policy and a potential crisis produces a boom period for industrialists and farmers. The massive distortion in trade induced by the exporting of minerals, fossil fuels, and uranium in the Standard Run would no longer take place. Instead Australia would pay for its necessary imports by exporting food and industrial goods on an expanding scale at least up to the year 2100. However, the total imports would duly be about half what they had been in the Standard Run. These changes in trade patterns are summarised by figures 24 and 25.

Table 7 provides a summary of the international trade situation showing that the large scale acquisition of overseas investment which was a feature of the Standard Run has now been reversed. Instead of mineral exports dominating the situation, a more even balance between exports of food, industrial goods and minerals would be achieved. Of course, energy would not be exported because fossil fuels and uranium are extremely costly and solar energy would now be needed at home. It is noteworthy that in seeking to understand the sensitivity of the pay-off date of the original Solar Energy Policy, we have been led to a consideration of international trade.

QUESTIONS ANSWERED

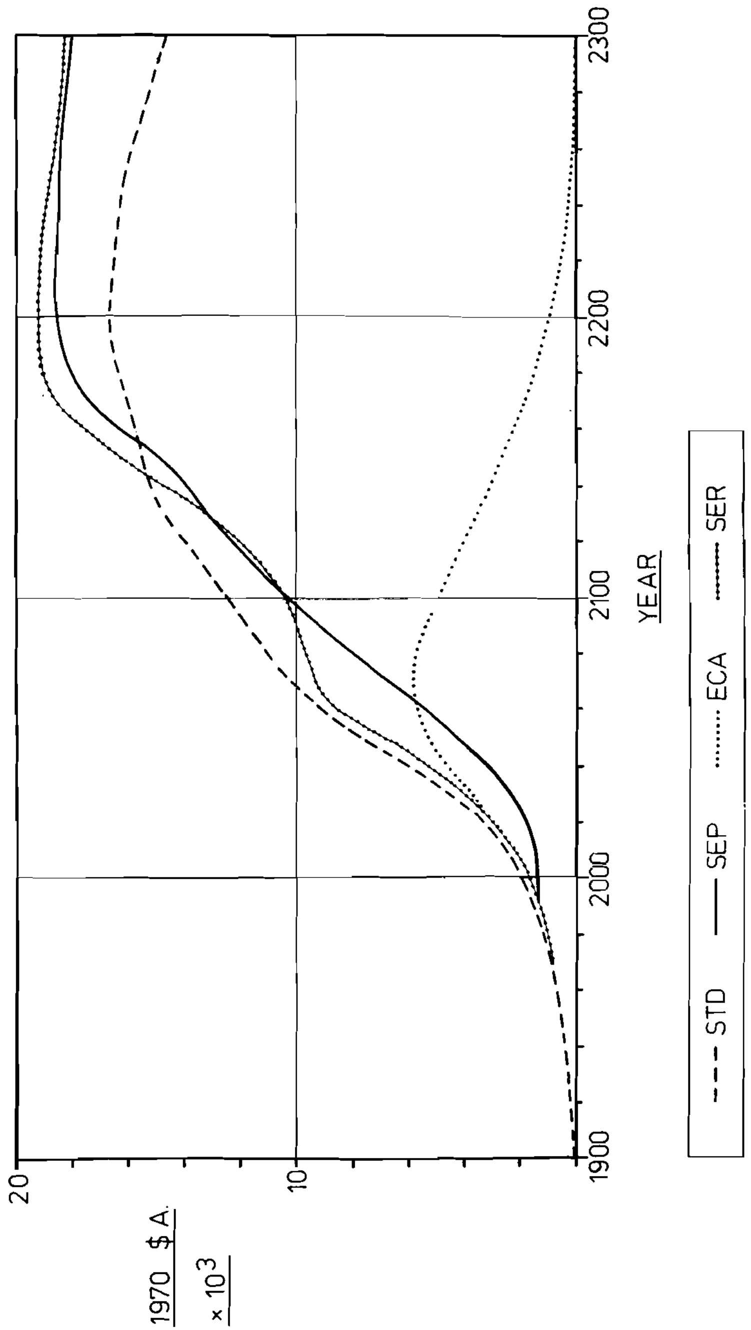
From the above discussion we can see that the feasibility of a Solar Energy Policy is well within our economic ability. However, the necessary conditions under which this would occur must be present. The Solar Energy Rescue was achieved by a breakthrough in the technological, social and economic delays which were inherent in both the present policy (Standard Run) and the Solar Energy Policy extrapolations. Constraints were also

FIGURE 29 ENERGY PRODUCTION AND CONSUMPTION



NOTE - Production & Consumption relate to non-renewable energy.
- Solar relates to renewable energy.

FIGURE 30 INDUSTRIAL CONSUMPTION PER CAPITA



placed on the export of our resources. However, this purely reversed the trend from exporting minerals to one of exporting food and industrial goods, and essentially produced many more favourable conditions under which the economy would flourish. A graphical representation of the economy can be seen in figure 30.

Fossil fuels and uranium would become prohibitively expensive; so much so that by the year 2100 the annual investment per unit would be *2000 times* greater than it is today. On the other hand solar energy would become less costly per unit. In fact, it would become *10 times cheaper* than fossil fuels by the year 2000, and *150 times cheaper* by the year 2100 (see figure 21b). As a result, consumption per head of solar energy would rise dramatically and would form an appreciable percentage of total energy consumption, although not the dominant percentage, so that by the year 2050 it would contribute 32%, and by 2100 it would contribute 40%. Under this policy total annual energy consumption per head by the year 2100 would be 50% of the present policy extrapolations (Standard Run) and some 80% more than that for the Solar Energy Policy.

The exploration of these possibilities creates pictures of possible Australian futures which provoke even more questions. These are set out in the final chapter.

TABLE 7 INTERNATIONAL TRADE
(All values in $ Billion (1970))

YEAR	TOTAL IMPORTS PER ANNUM	TOTAL EXPORTS PER ANNUM	CUMULATIVE AUSTRALIAN INVESTMENT OVERSEAS	CUMULATIVE OVERSEAS INVESTMENT IN AUSTRALIA
			*	*
	STANDARD RUN			
1975	4	7	12	3.8
2000	118	347	110	0.1
2050	61	145	539	-
2100	59	139	601	-
	SOLAR ENERGY POLICY			
2000	6	22	90	0.1
2050	18	45	186	-
2100	32	65	227	-
	ENERGY CRISIS			
2000	7	8	13	0.1
2050	22	22	0.2	2.2
2100	19	26	47	1.3
	RESCUE BY SOLAR ENERGY			
2000	5	6	14	-
2050	23	22	-	10
2100	29	38	56	-

* These investments depreciate at 7½% p.a.

CHAPTER 5

CONCLUDING QUESTIONS

If you can look into the seeds of time,
And say which grain will grow and which will not,
Speak then to me. . . .
— Shakespeare, *Macbeth*

CONCLUDING QUESTIONS

We have stressed at the start of chapter 1 that this type of modelling was not a predictive mechanism but rather served as a question provoker. The conclusions which can be drawn are therefore essentially more questions, but hopefully questions which have the advantage of being posed with the *total* picture in mind.

While it is helpful for the authors to state the questions which the analysis has brought to their minds, it is even more important that the reader should pose his own questions. The remarks which follow are but illustrative.

GOALS

Four different futures for Australia have been generated. All but one portrayed a materially affluent society for at least 200 years. They were based on:

A. The massive exploitation of fossil fuels, uranium and minerals as a prime supporter of international trade (Standard Run).

B. Preservation of fossil fuels and uranium by expensive solar energy development but with massive support from international trade based on exported minerals (Solar Energy Policy).

C. Preservation of non-renewable energy resources by solar energy development but with international trade supported by agricultural, industrial and some mineral exports (Solar Energy Rescue).

D. A collapse of economic and industrial society in Australia (Energy Crisis).

Clearly the question to be asked is:

WHICH (IF ANY) OF THESE FUTURES DOES AUSTRALIA WANT?

By considering each of these futures in turn, further questions can be generated.

FUTURE A

This is the future defined in chapter 1 and called the Standard Run. Certain key features emerge which raise the following doubts:

A1. Are the reserves of fossil fuels, minerals and uranium such that expansion of exports could be sustained on the scale indicated? More specifically, how fast will extraction costs rise? Is the model value of 1.5% per billion tons extracted reliable?

A2. Is the world likely to provide an effective market for mineral exports on this scale? The magnitude of the revenue currently earned is given in table 6. A recent study at the Stanford Research Centre reported in *Aviation Week and Space Technology*, April 19, 1976, shows how the raw material dependence of the United States, the European Economic Community and Japan ranges over various metals at the present time. The results are shown in figure 31. The future profile of this market could be changed by events of both technological and political natures.

A3. If mineral and energy exports are indeed possible does Australia wish to expand this trade on a scale which substantially exceeds its import capacity? (This would involve something like economic colonisation.)

A4. Would the massive expansion of minerals and non-renewable energy resources inhibit the exporting activities of agriculture and industry as the model suggests? If so, would this imbalance in international trade be acceptable?

A5. Would a 2% industrial growth rate be sustained for 140 years or would social reactions inhibit this growth as personal affluence grew? (How would you behave if your income was 14 times its present level?)

A6. Would trading with the richer material-consuming nations while neglecting the food needs of the poorer hungry nations produce any side effects? (e.g. internal or external violence)

A7. Who is likely to want such a future?

FUTURE B

This is the future described in chapter 2 of this report and referred to as the Solar Energy Policy.

B1. Would the costs of developing solar energy be as punitive as the model suggests? (i.e. up to 14 times as much capital investment per tonne of coal equivalence)

B2. Would the suggested lengthy delay before the benefits of solar energy are obtained still apply if its development costs were say only double the capital costs of non-renewable energy supplies?

B3. Would a Solar Energy Policy require large areas of land, and where would it be required?

B4. Is it politically realistic to stop the exports and extraction of cheap energy resources while spending large sums on more expensive energy supplies? How might this be achieved?

B5. What are the implications for the stability of Australia's international trade if the only significant exports are minerals?

B6. Questions A1, A2 and A4 would also be posed if this Solar Energy future were envisaged.

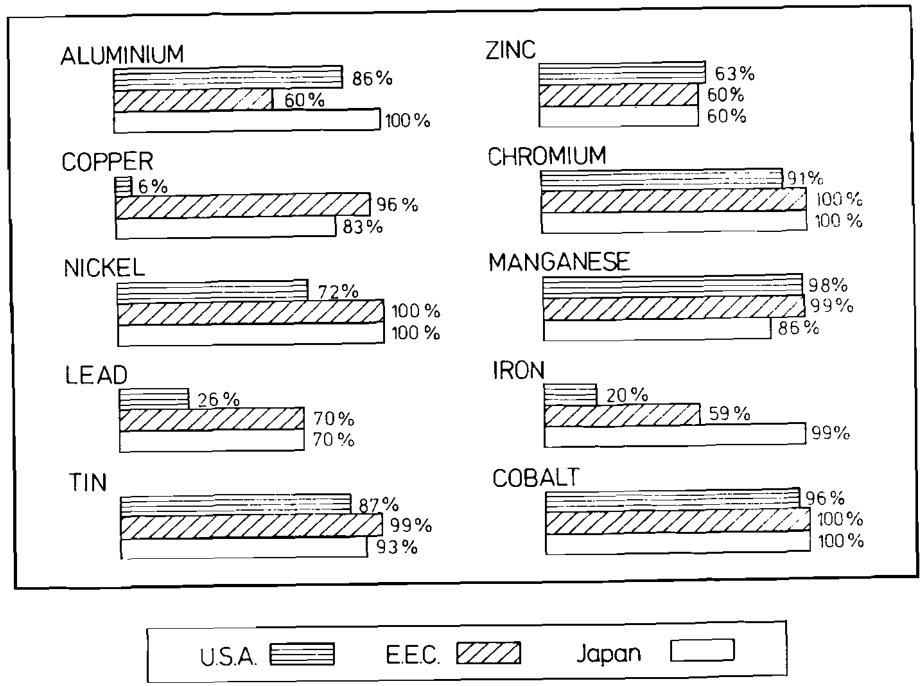
B7. Would Australia be obliged to sell its minerals relatively cheaply in the world markets or would it join with other mineral producers in maintaining high prices?

B8. If mineral exporters were to compete in world markets, should they be allowed the privilege of using low cost fossil fuels?

B9. What forms of solar energy capture would prove viable and desirable on a large scale? What social side-effects would they produce?

B10. Would the economies of energy and mineral use associated with expensive solar energy development be brought about solely by the impact of more costly fuel?

FIGURE 31 RAW MATERIAL DEPENDENCE OF U.S.A., E.E.C. & JAPAN



Source: Aviation Week & Space Technology, April 19, 1976.

FUTURE C

This scenario was the result of investing in solar energy to offset the effects of an energy crisis. It is the Solar Energy Rescue described in chapter 4.

C1. How quickly could a solar energy development policy be "switched on"?

C2. How could the propensity to grow by exporting be controlled by Government in all sectors so that only Australia's import needs were balanced?
That is to say, trade would be based solely on revenue and not used for capital investments in other countries?

C3. If solar energy is developed, what should be the planned rate of use of fossil fuels and uranium?

C4. What would be the technology for exporting solar energy?

C5. Would the rest of the world be willing to send fossil fuels to Australia in exchange for food and industrial goods while Australia limited the use and export of its own fossil fuels and uranium?

FUTURE D

This is the Energy Crisis described in chapter 3, and was generated by:

(a) making non-renewable energy resources very expensive to secure;

(b) restricting trade to revenue activities; and

(c) doing nothing about Solar Energy.

No one wants this future for Australia. There are three key questions to ask, and if this future is to be avoided all the answers need to be NO.

D1. Is the STD curve in figure 23 close to the truth?

D2. Will the growth in world trade be constrained in the next 20 years by policies of resource conservation and nationalisation, price cartels, and the stagnation of the non-industrial nations?

D3. Will a breakthrough into large scale solar energy capture prove impossible?

FUTURE E — A Possible Scenario

This is the future that most Australians could agree about. Clearly we have not defined it by using the model but we have at least made it possible to talk about it more explicitly. It would probably contain the following main elements:

(a) Economic growth in both industry and public sector services rising to a plateau at least 8 times richer than at present, and possibly 16 times richer (which would be morally indecent if the world were very poor).

(b) Maintenance of that state of affairs in a stable condition for centuries.

(c) Birth rate equalling death rate at approximately 9 per 1000 per annum.

(d) Self-sufficient in food if need be but at the same time exporting generously to help feed the world, and importing in order to enjoy variety and to stimulate trade.

(e) Running modern labour-efficient, energy-efficient and mineral-efficient industries, and also importing and exporting.

(f) A mining industry which is always looking 200 years ahead so that there is plenty of time for the next generation to solve the problems that "finite" resources might bring. Trade with other nations but with respect for their conservation needs or their shortage problems.

(g) An energy generation policy based on the same 200 year philosophy.

(h) Solar energy used extensively and in a continuous state of technological and economic improvement.

(i) Trade in balance, without trying to own other nations' resources or having its own resources owned by others.

This possible scenario has been portrayed because it could be given sensible numbers by engaging in a series of model experiments designed to find out just how it might be achieved. However, it too provokes some questions, and the model experiments would provoke even more questions. We thus conclude by posing three such questions:

E1. What population would Australia need in order to make the above future both possible and probable?

E2. What balance do Australians on average want to effect between work and leisure?

E3. How can a small rich nation that secures such a future stay out of violent conflict with those who envy her?

APPENDIX A: THE STANDARD RUN

The following figures provide two sources of information:

(i) The best data we had available for the period 1900-1975. These are indicated by the points marked '+'.

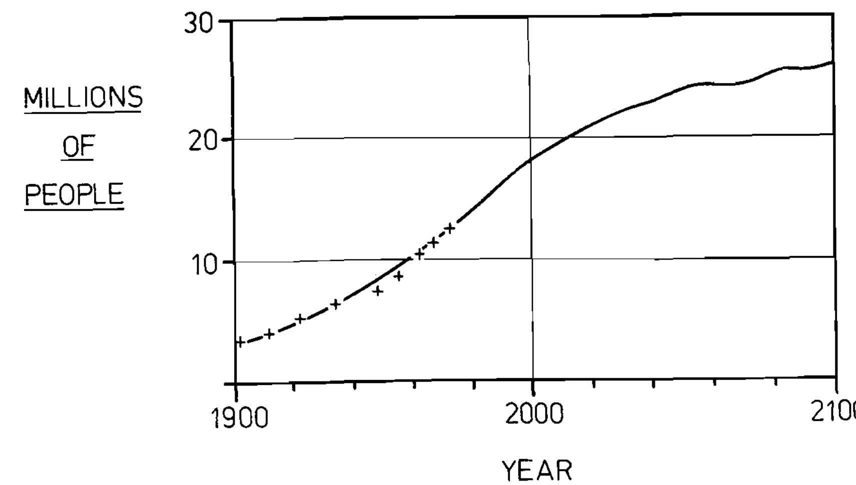
(ii) The results generated by the model in its Standard Run. These are shown as continuous lines for the period 1900-2100.

Note that in most cases the figures are drawn on logarithmic scales.

LIST OF FIGURES

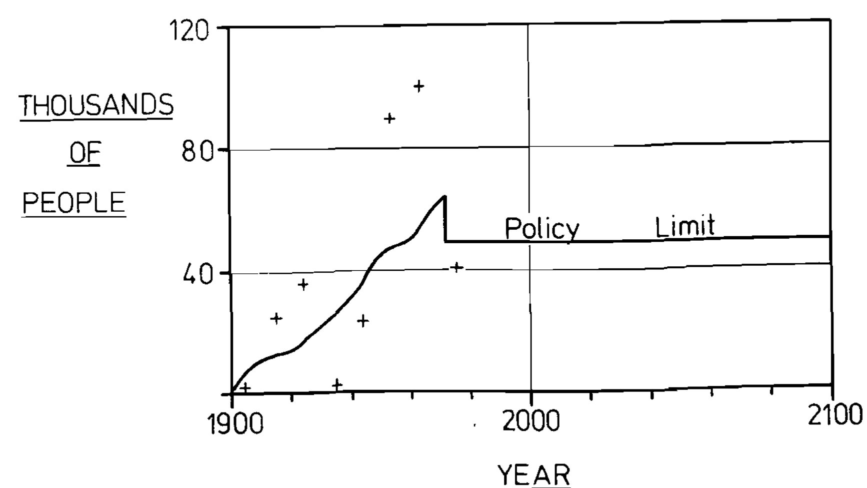
A1

POPULATION

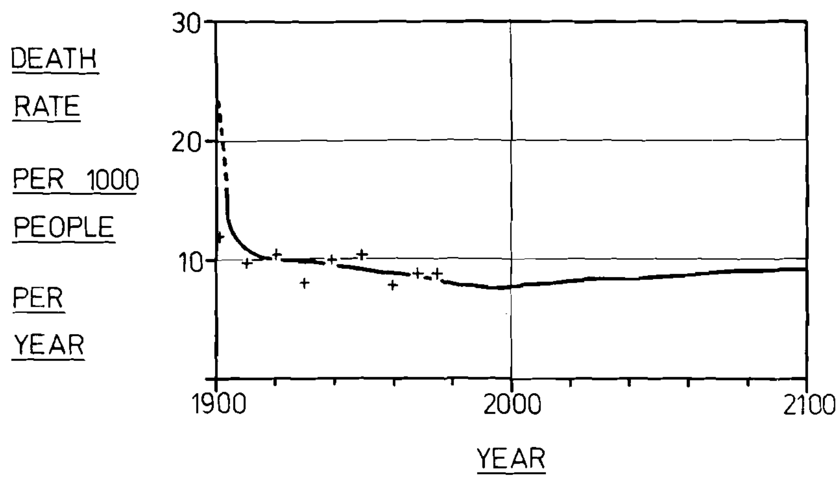


A 2

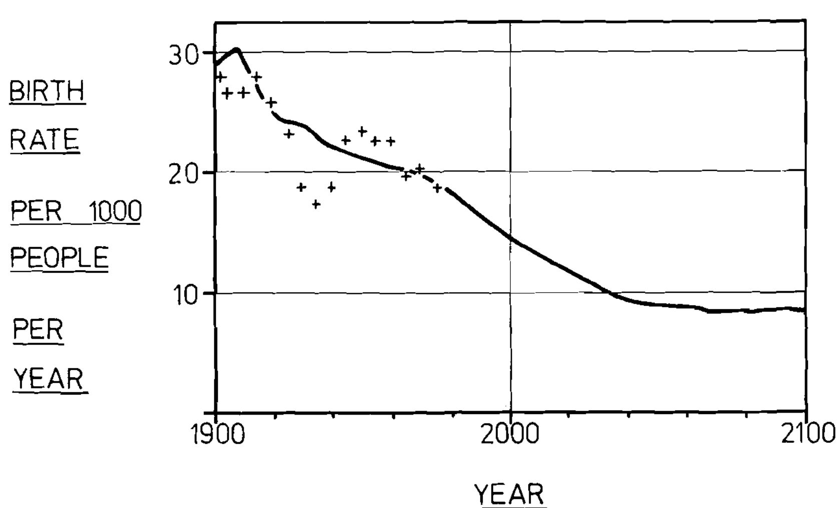
MIGRATION



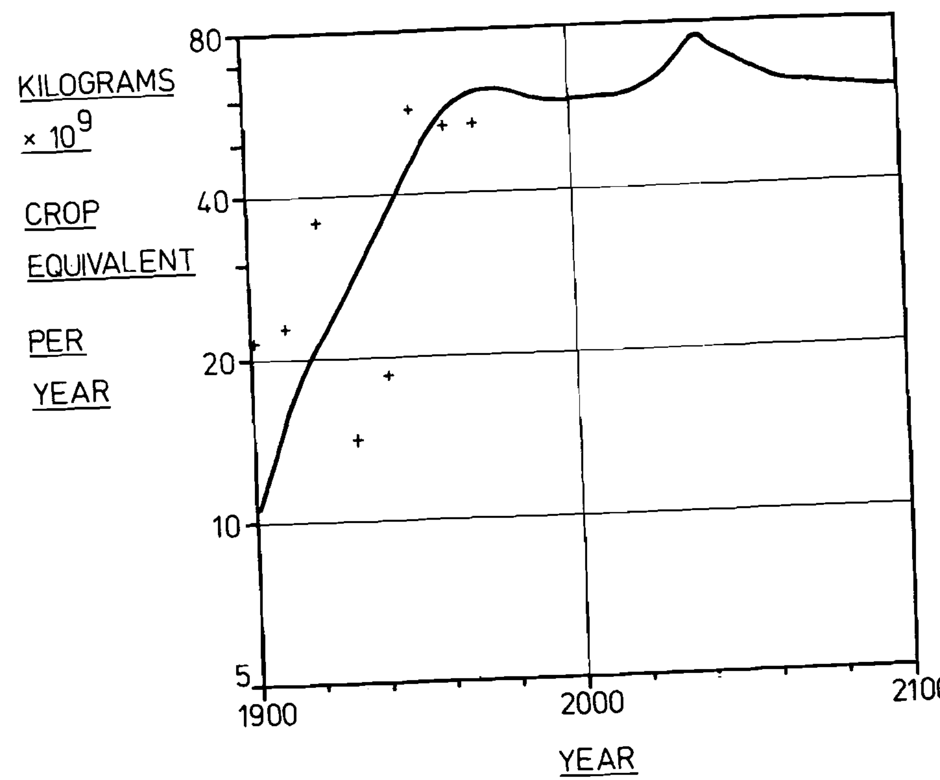
A 3
DEATH RATES



A 4
BIRTH RATES

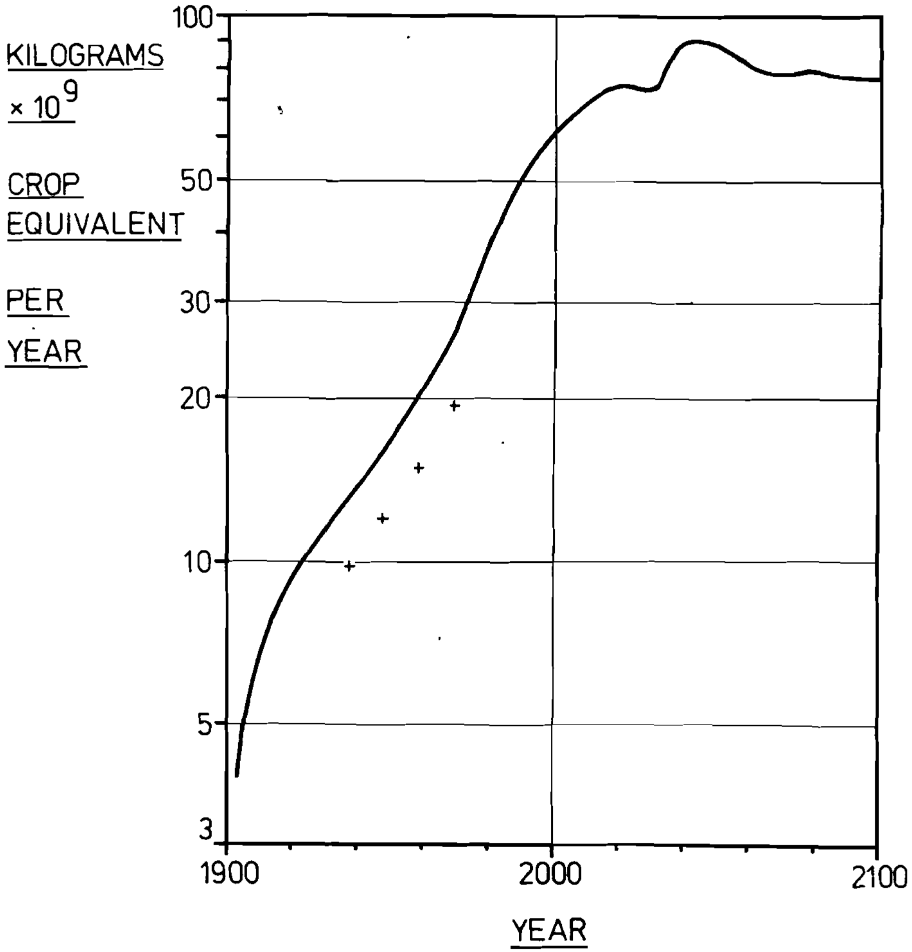


A 5
AGRICULTURAL PRODUCTION



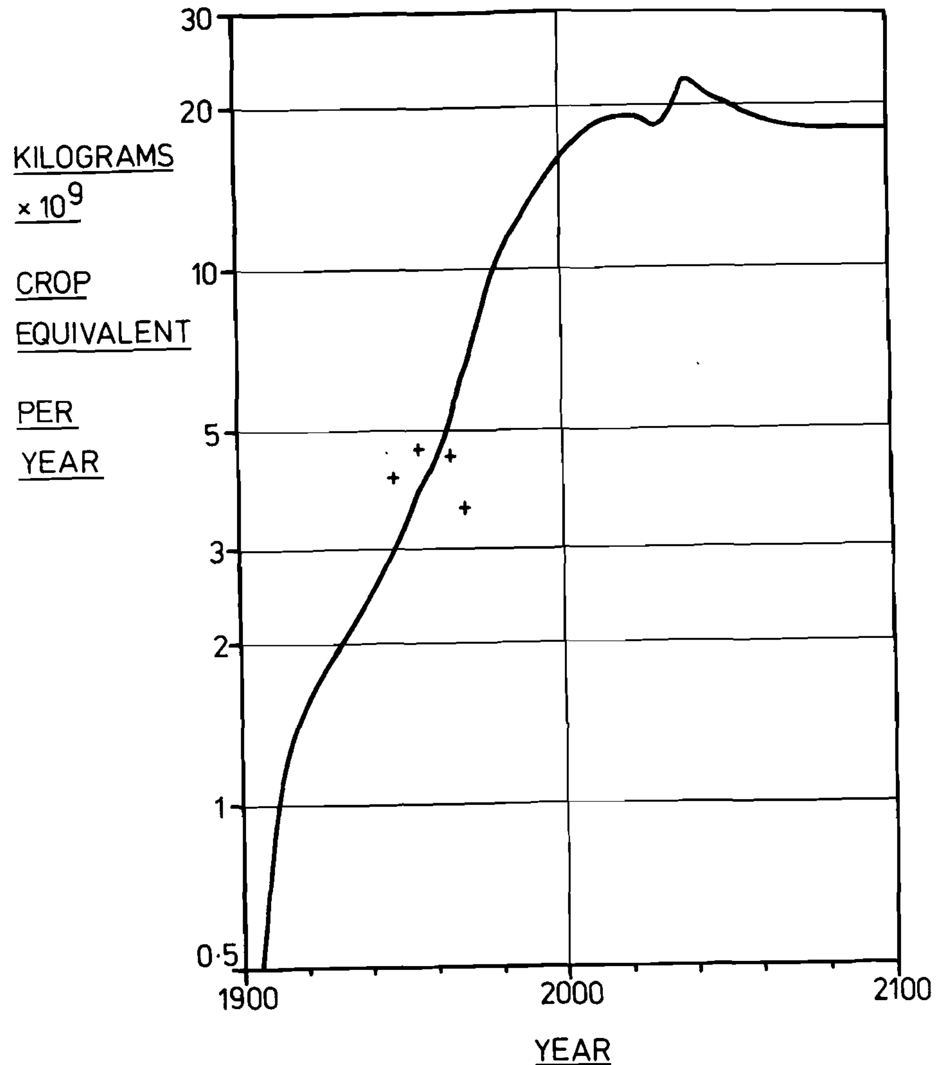
A 6

FOOD CONSUMPTION



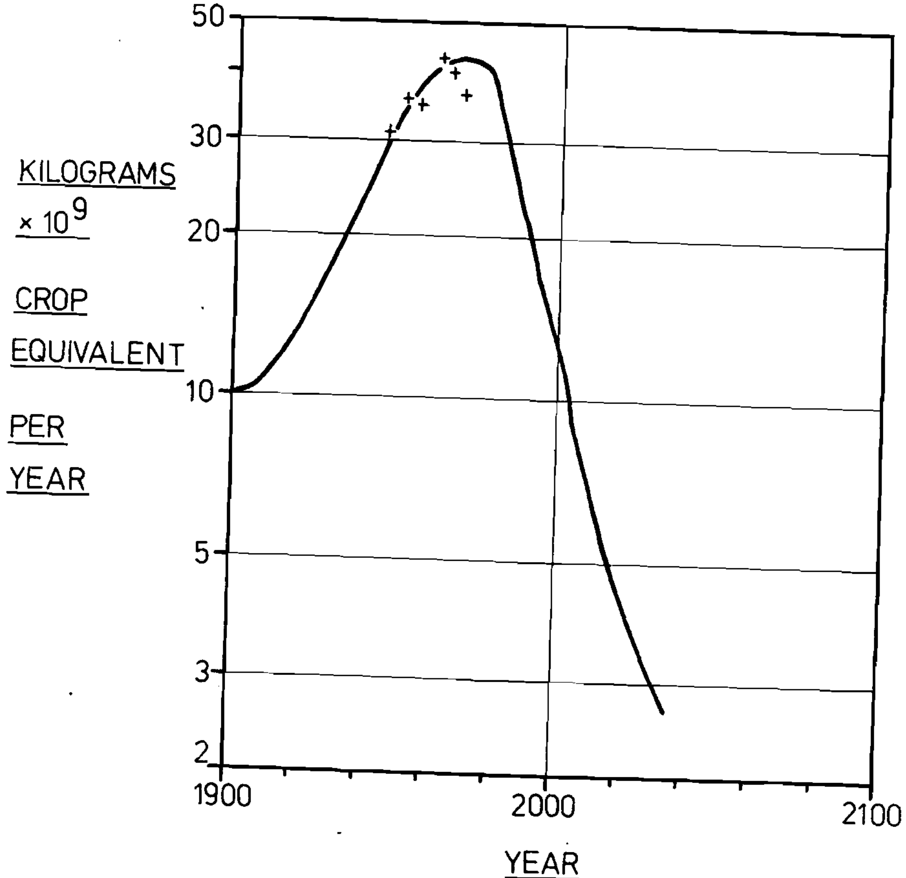
A 7

FOOD IMPORTS



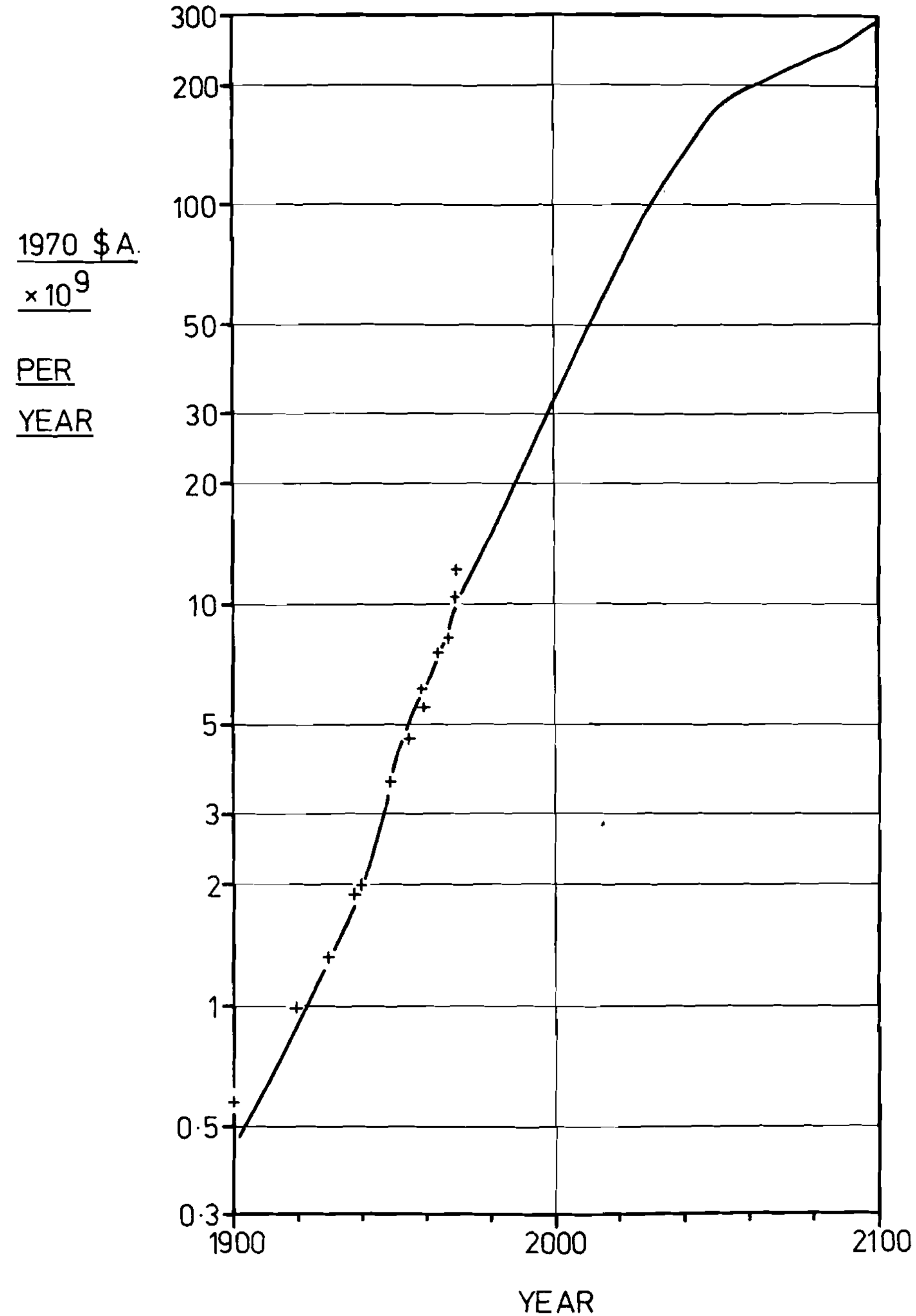
A 8

FOOD EXPORTS

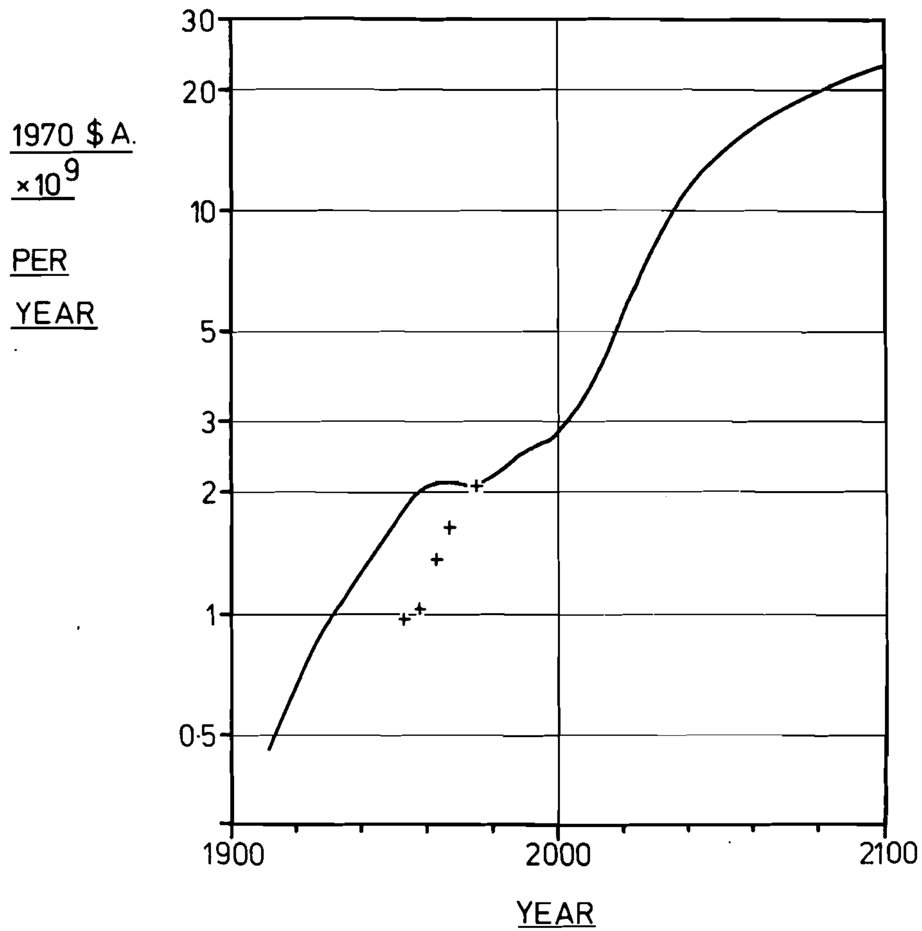


A 9

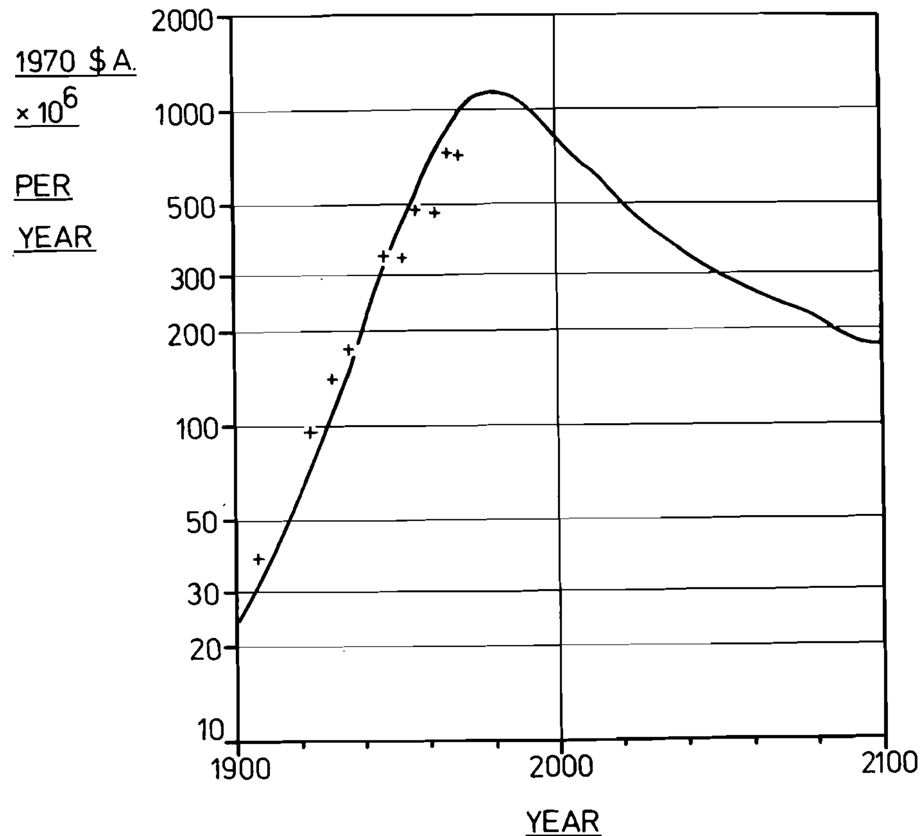
INDUSTRIAL PRODUCTION



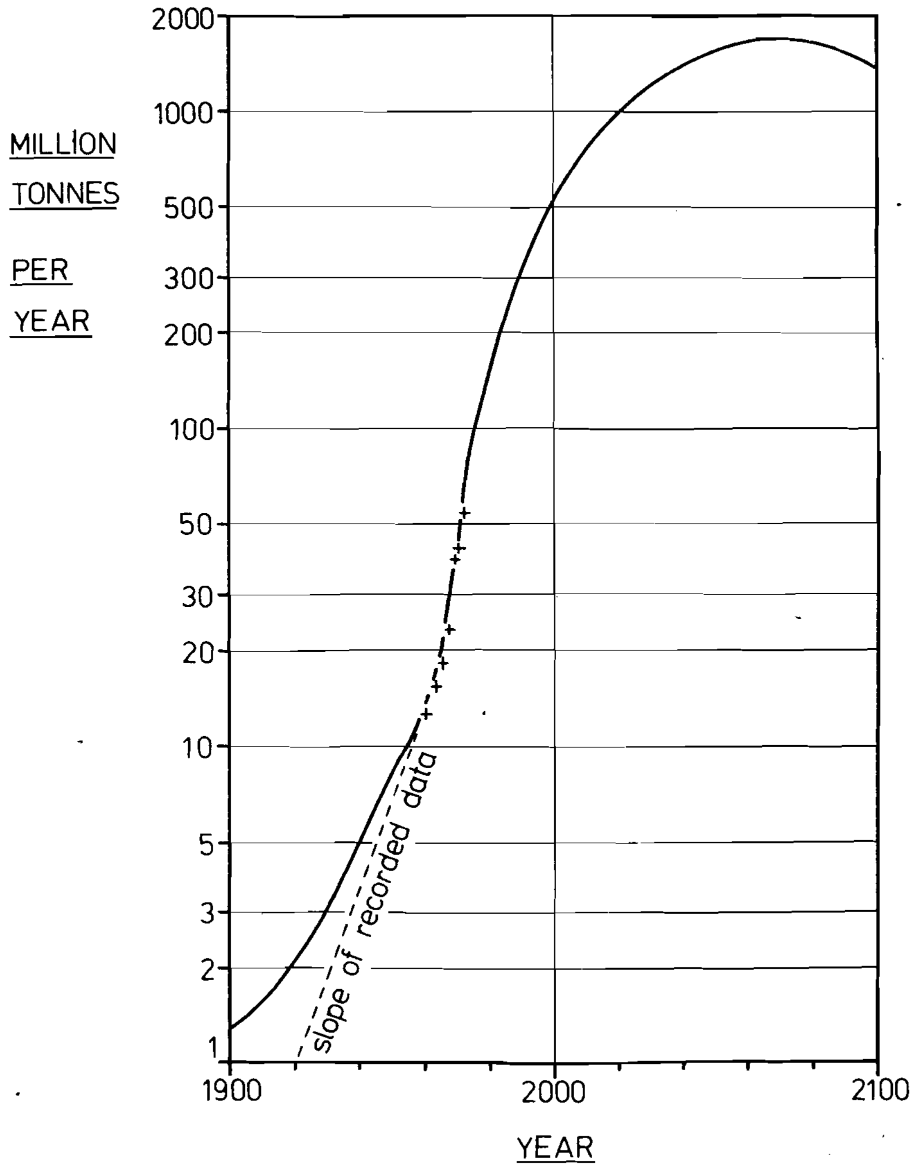
A 10
INDUSTRIAL IMPORTS



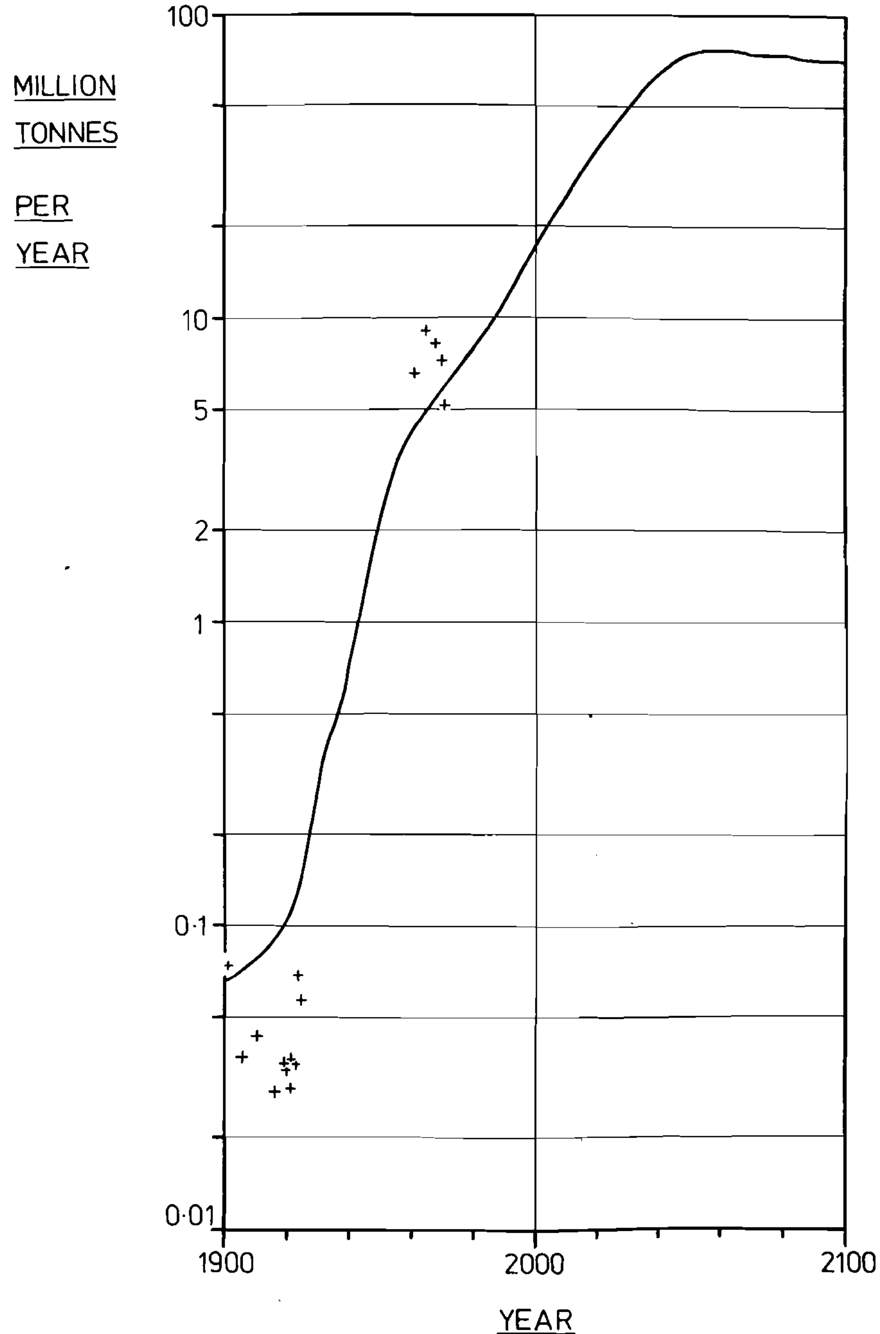
A 11
INDUSTRIAL EXPORTS



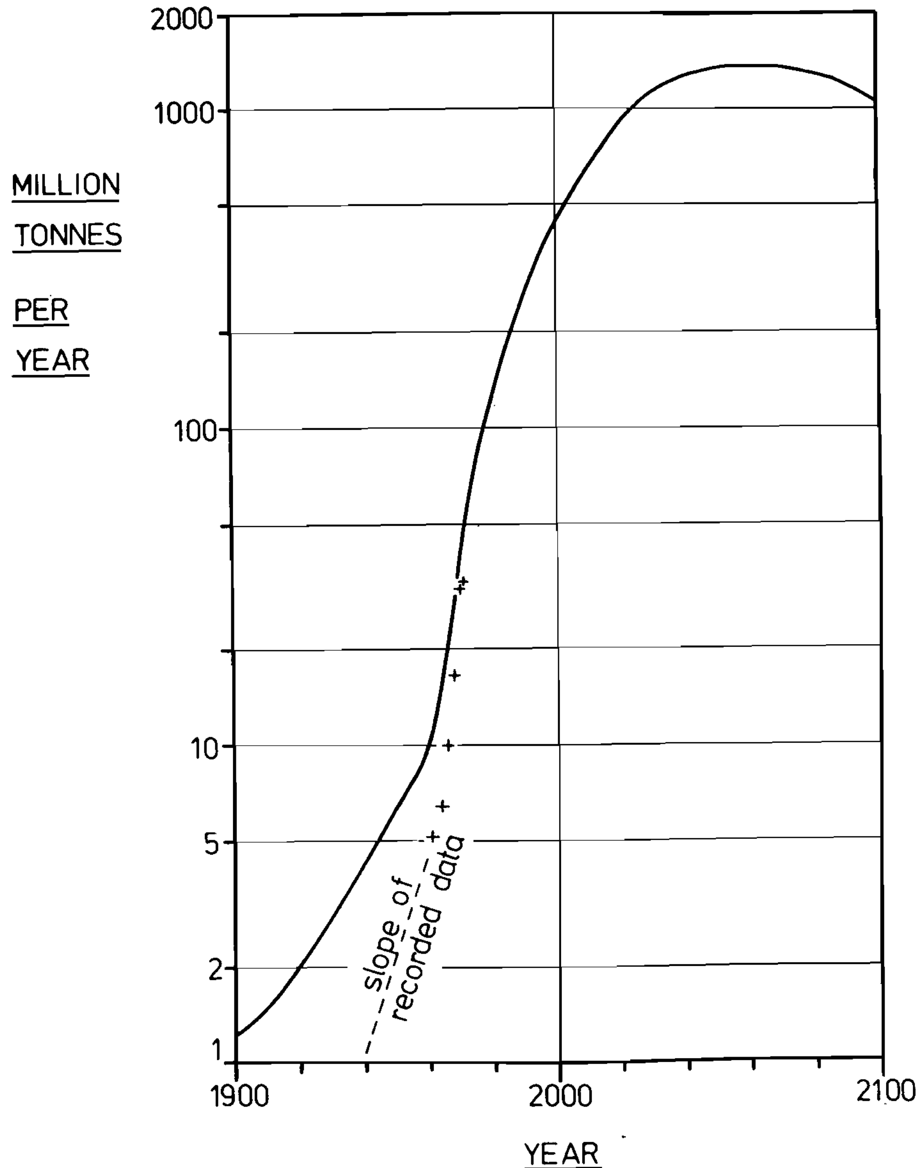
A 12
MINERAL PRODUCTION



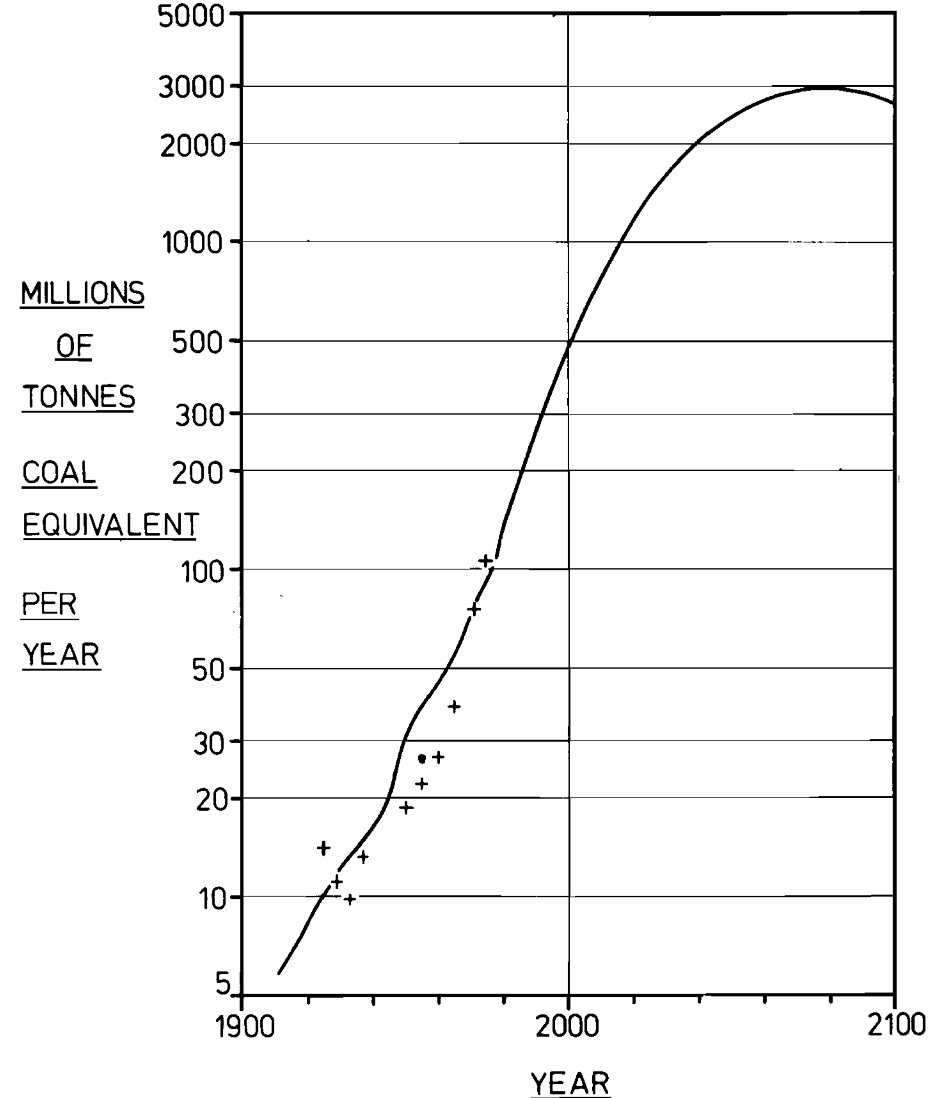
A 13
MINERAL IMPORTS



A 14
MINERAL EXPORTS

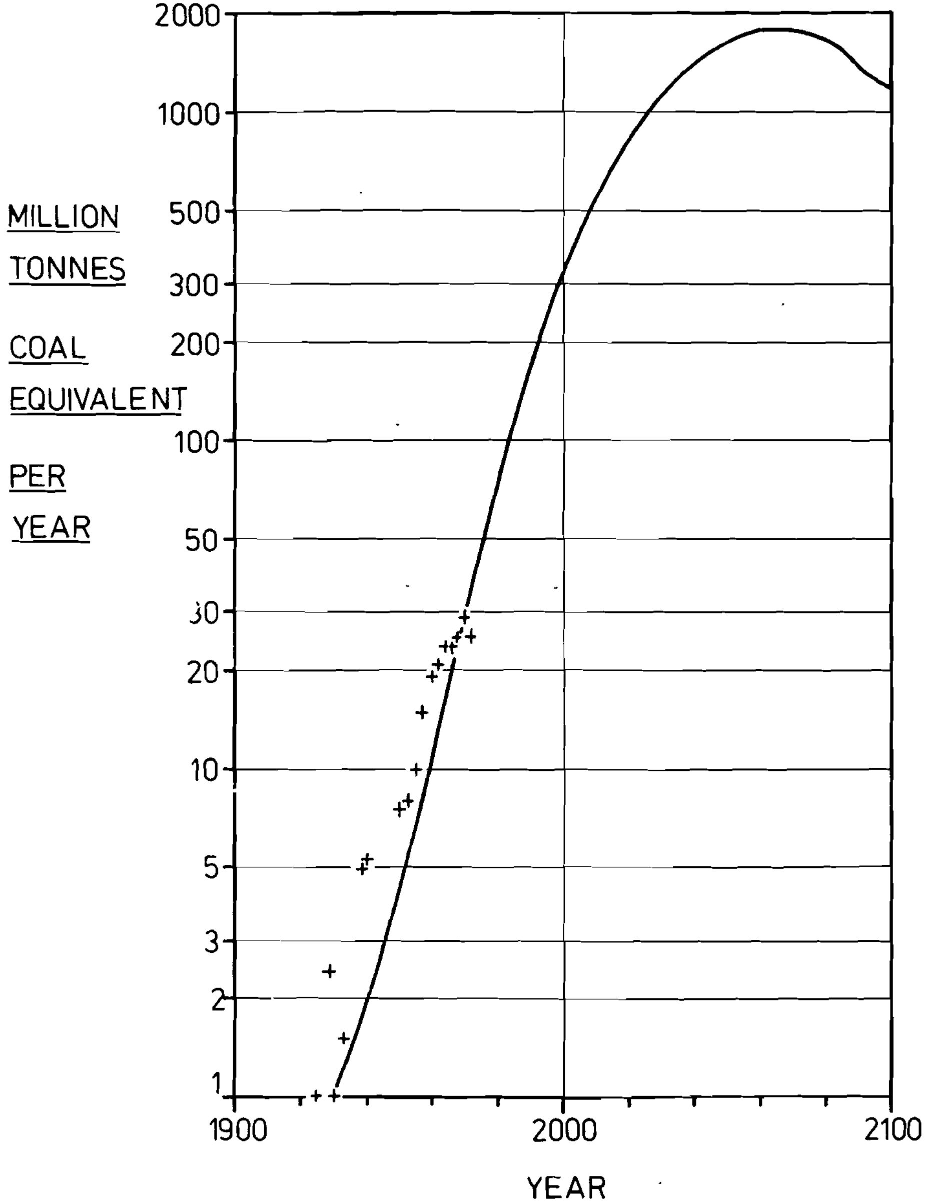


A 15
PRIMARY ENERGY PRODUCTION



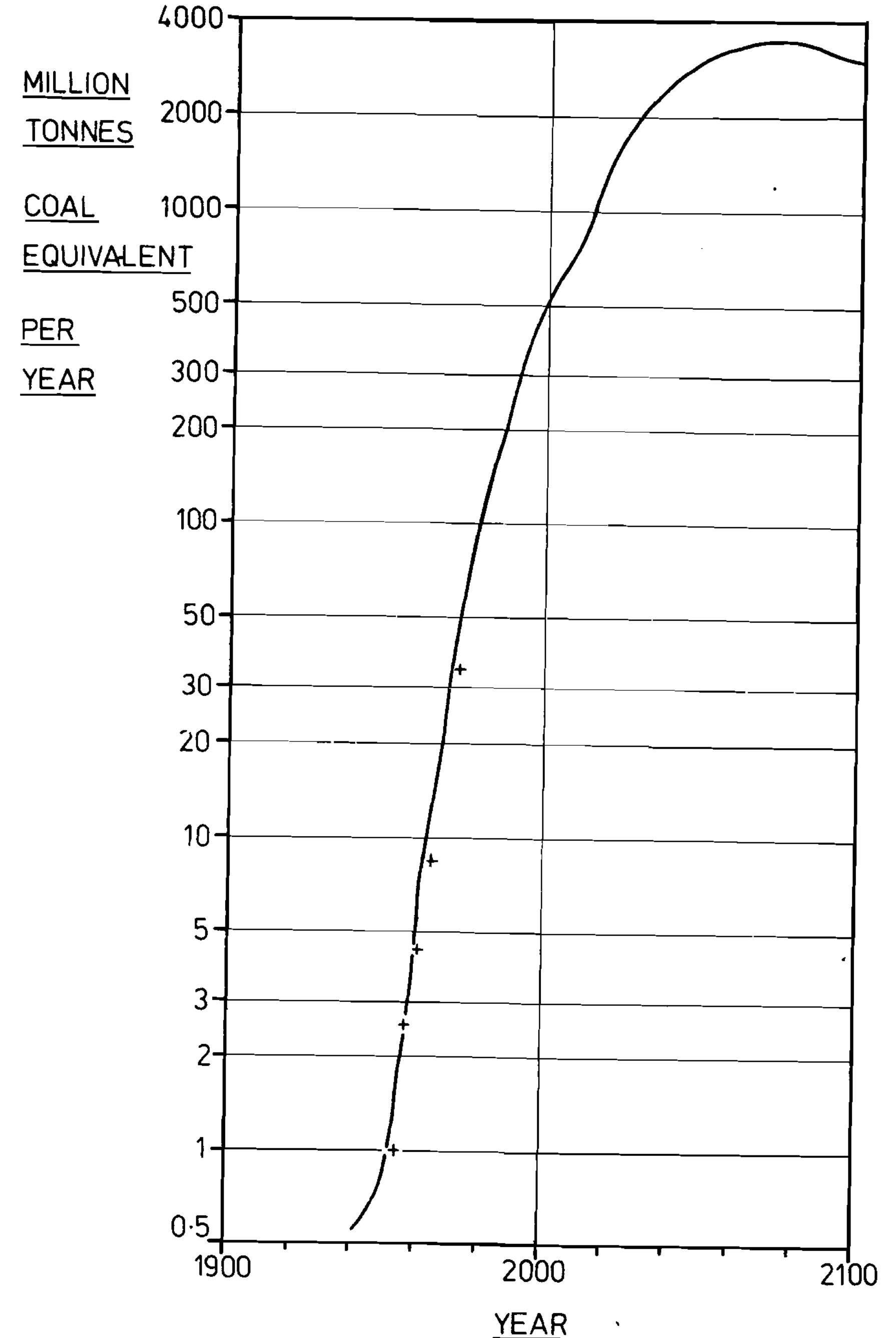
A 16

ENERGY IMPORTS



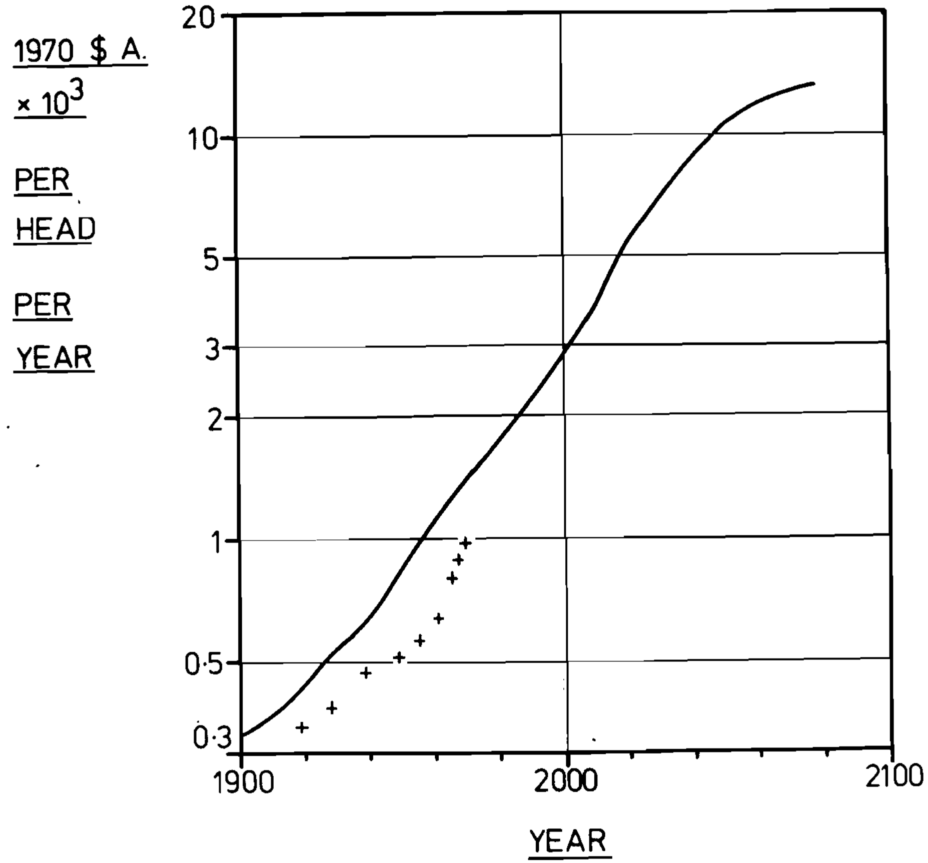
A 17

ENERGY EXPORTS



A 18

SERVICE OUTPUT PER CAPITA



APPENDIX B: TECHNICAL NOTE ON MODIFICATIONS MADE TO "The Limits to Growth" (world 3) MODEL

CRITICISM WIDE AND VARIED

To determine the suitability of *The Limits to Growth* model[1] as a basis for further research, criticisms of a wide and varied nature were investigated. The criticisms ranged from Boyle[2] finding an error in the listing of the model to the more detailed analysis of the methodology of the technique used i.e. system dynamics, by Sharp[3].

Clearly the authors of *World 3* intended that criticism should be levelled at their work —

> *". . . every assumption we make is written in a precise form so that it is open to inspection and criticism by all"*

and indeed it has been and continues to be so. A lot of the early criticism stemmed from the fact that the Technical Report[4] to back up the book had not been released to scientific circles at the same time or shortly after *The Limits to Growth.* A fortunate few, including Mula, had been able to obtain a copy of the preliminary draft.

In this note, several criticisms are cited. Evidence is shown of the importance that even the critics still place on work of this nature. It was decided to use *World 3* in a revised form in order to respond to some of the criticisms, and to develop a *World-Australia Solar Model.*

CATEGORIES OF CRITICISMS OF PREVIOUS MODELS

Three broad headings have been chosen to discuss the criticisms. Under the first heading of "Structure" items such as the amount of detail, the degree of aggregation and interaction between the main parameters are considered. The reader is referred to Mula's thesis[5] for a more detailed discussion of structure.

The second heading of "Data" includes a general discussion on the data base and its extrapolation and more specific discussion on the data criticisms of the individual sectors of the model. The thesis also includes all data used in *World 3.*

The final heading reviews the criticisms of the methodology both as used in *World 3* and *System Dynamics.* In this section the reader is referred to some excellent work by other authors for more rigorous discussion.

Structure

A great deal of criticism has been levelled at the model's structure. Although most critics would agree that *World 3* is a more improved model over *Forrester's World 2*[6] some have claimed that the complexity was not necessary[7]. Many of the structural problems stem from a lack of data, and the questionability of variables (included or not included), which determine the behaviour of the system. Others feel that it is not the exclusion or inclusion of special aspects but rather the way they are represented[8].

Underlying any structure there is a set of assumptions and these too have come in for their share of criticism.

> *"The nature of their assumptions is not a purely technical problem. It is essential to look at the political bias and the values implicitly or explicitly presented in any study of social systems"*[7].

Such assumptions have been chosen among alternatives thus making the examination of those assumptions the most important part of any critique.

> *"We would, nevertheless, certainly accept that the views advanced in these essays reflect our own political bias and subjective limitations. Our value judgements and intellectual assumptions are as much a part of the debate as those of M.I.T."*[7]

Some critics believe that, consciously or unconsciously the assumptions underlying *World 3* are gloom-laden. These critics attack the assumption that the rest of the world will follow the same industrial and social path of the United States[9]. Detailed limiting assumptions are also attacked, and these are discussed under the *Data* heading.

Aggregation on a global scale is the basis of looking at the world as a homogeneous entity. This has its advantages but is also the subject of severe criticism and debate. Most feel that the world is made up of quite different but interacting regions[10], but if this is so the question arises as to how does one disaggregate the world[8]. Some have attempted to disaggregate the world using *World 3* as a base[11], whereas others have plunged into a more sophisticated exercise[12]. Sharp[3] has even gone as far as setting out *rules of thumb* for model structure.

Another great bone of contention with the critics is the lack of social and technological feedback[7]. Over-emphasis has been placed on the physical aspects and limitations of the world to the detriment of the rest[10]. Thus very little human intervention is allowed for example in curbing pollution when it starts to rise dramatically[13]. Critics have shown that by the introduction specifically of technology, any catastrophe can be averted[2, 14].

Data

As mentioned above, it is difficult to separate *data* from assumptions because assumptions in verbal form are represented empirically by data (*the vicious circle*). Reliance on good supportive data collected for the purpose required, will eliminate bias from assumptions[7]. The lack of empiricism has been attacked by many of the critics cited above. Some in particular have attacked individual sectors of the model.

The non-renewable resource sector has been the one most criticised for its limiting assumption on the life-index of total exploitable stocks, taken to be 250 times the amount consumed globally in 1970[15]. Such a limitation is the seed of the "collapse" that occurs in *World 3*. Some feel that such an assumption does not make economic sense[16] while others would say that in terms of certain minerals, such as copper and lead, the assumption is generous[17]. To that end, work has been carried out to show that non-renewable resources are enormous if we are prepared to pay the price of extraction[18, 19, 20]. Others have either introduced the addition of new-found resources at possibly lower grades[13] or introduced recycling and efficiency of use of resources[7]. Still again others indicate that the limitation will be energy and it should not have been treated together with minerals under the guise of non-renewable resources.

The next most criticised sector is pollution. The basic underlying criticism is the unified treatment of all types of pollutants[21, 22]. Some attack the data on the basis that so little is known about pollutants and their rise and fall, in conjunction with the fact that very little historical data exists[7].

The remaining sectors of population, agriculture and capital-output are also criticised in the same manner cited above and in particular the sensitivity of very important constants' values which have been globally aggregated[7]. The same critic attacks the extrapolation of the data past known historical fact as being a very risky business, since any error will lead to magnification by the use of multipliers. This leads into the methodology.

Methodology

As has been shown critics abound, but when work of this nature is introduced as a scientific exercise it must stand up to the rigours of scientific analysis. *World 3* is based on a methodology that has been criticised for quite some time before this model was ever considered. With the publication of *The Limits to Growth* renewed interest has been shown by this form of critique.

A great controversy was started over "backcasting" dynamical systems[24]. This was hotly pursued by Meadows[25] and others[26]. Some theoretical work has been carried out on this subject by Sharp[3].

The same critics have also attacked the approximation methods used in the linear interpolation of the table functions and the Euler approximation method for carrying out the calculation of the equations[7]. Others have tried different calculation methods and found only slight differences[3]. Validation and sensitivity testing have also come under scrutiny and some suggestions have been made by various authors as to how the methodology could be improved[3, 27, 28].

Isolation of sensitive areas of the model have been investigated by other authors to discover the hierarchical structure of these types of models so that their behaviour may be better understood[29].

Despite all these criticisms many of the above authors have nothing but praise for the work in its capacity as a stepping stone and point of debate around which current world problems can be discussed. To cite the largest critique writer[7] in this field —

> *"Nevertheless, whether or not their results deserve such publicity, recognition is certainly due to them for their pioneering work in the field of global modelling."*

THE DECISION TO USE *World 3*

After considering these criticisms and weighing up the conclusions, it was decided to use *World 3* as was described in the first draft of the Technical Report (the final Technical Report was not available at the time). However, not all the criticisms could be ignored as it was felt that some of the underlying assumptions to the structure of *World 3* should be changed.

Firstly the non-renewable resource sector was very primitive and since, as pointed out by every critic, it harboured the seeds of destruction, it was decided to change this sector.

The change took the form of a need to break the sector into minerals and energy because of the axiom that the two types of resources are distinctively different, both in their availability and their use. The simple truth is that if anything is limiting it is energy and not minerals. Thus the application of capital to extract lower and lower grades of minerals is of no avail if there is no energy to power the equipment which becomes even more energy demanding as lower grades are extracted.

Secondly this sector had a physically limiting assumption of an absolute limit to resources. It was felt in the light of detailed studies that such a limit should be removed although remaining within sensible boundaries. The Japanese team[18] has shown that the absolute limit of minerals is 5.6×10^6 times greater than proven reserves but that the price of these minerals increases as the qualities of ores decrease. An increase in proven reserves of this magnitude raises the absolute limit of iron, for example to 1×10^{18} tonnes from a proven reserve figure of 2.5×10^{11} tonnes.

To remove any absolute limit on minerals or energy, instead of drawing from a pool of resources, the usage rates add to the cumulative consumption of those resources. The level of this cumulative consumption is then used to determine the amount of capital necessary to obtain more resources. This structure is used for both non-renewable minerals and non-renewable energy.

By these changes two important points were rectified — firstly the necessary division between minerals and energy and secondly the removal of a "limiting assumption" on absolute amounts of non-renewable resources available. However it would be foolish not to recognise that there are limits to the use of resources, and in particular to the amount of non-renewable energy resources. With this point in mind, other forms of energy have to be found to either replace or supplement the fossil fuels being used at present in ever-increasing quantities.

Thirdly, a note was made of the fact that some authors felt that energy would be the limiting resource factor. In the face of the enormous potential

of solar energy, it was felt that such a limitation could be overcome given time for development. This conclusion has since been reached in a report by Mesarovic[12]. Thus a renewable energy sub-sector was introduced.

This study on "Solar Energy" is an extension of the original thesis based around the time factor of the delays.

Finally, pollution came into its share of criticism. The lack of human response in the way of social and technological feedback to an ever increasing pollution problem which when combined with resource depletion, contributed to the collapse in *World 3*. Social response or feedback plays an important role in the control of pollution. Combined with the technological feedback from the balance between the use of non-renewable and renewable resources, social feedback is introduced into the pollution sector.

The method used to model this effect is that, by the application of capital, pollution can be abated and controlled. Evidence of this fact has been reported in a number of countries. However this application of capital is forthcoming only when the problem appears and consequently more capital is required not only to reduce its effects in the future but also to clean up the mistakes of the past. This total pollution control cost is expensive and it has been suggested that 10% of industries' capital investment be spent, per annum, to combat the problem[30]. Capital for this purpose must also compete with other demands on the economy, including resource demands.

All the modifications stated above have been incorporated in the model to form what is now called *Solar World*.

Disaggregation of the world was not a necessary change as interest lay in one part of that world, namely Australia. The world formed a boundary around the Australian system and thus to obtain the required boundary states, it was not necessary to disaggregate.

WORLD-AUSTRALIA SOLAR MODEL

These modifications were carried out for two purposes. Firstly, a model was required that would enable Australian policies to be explored in the face of a changing world. Thus a world model was necessary to form the boundary of the total model. Secondly, the world model chosen had to be able to be used as a structure for Australia. Thus the model had to be acceptable and any changes made to the existing Meadows' model had to be in the light of current thinking and research. To this aim *World 3* was modified and *Solar World* was the outcome.

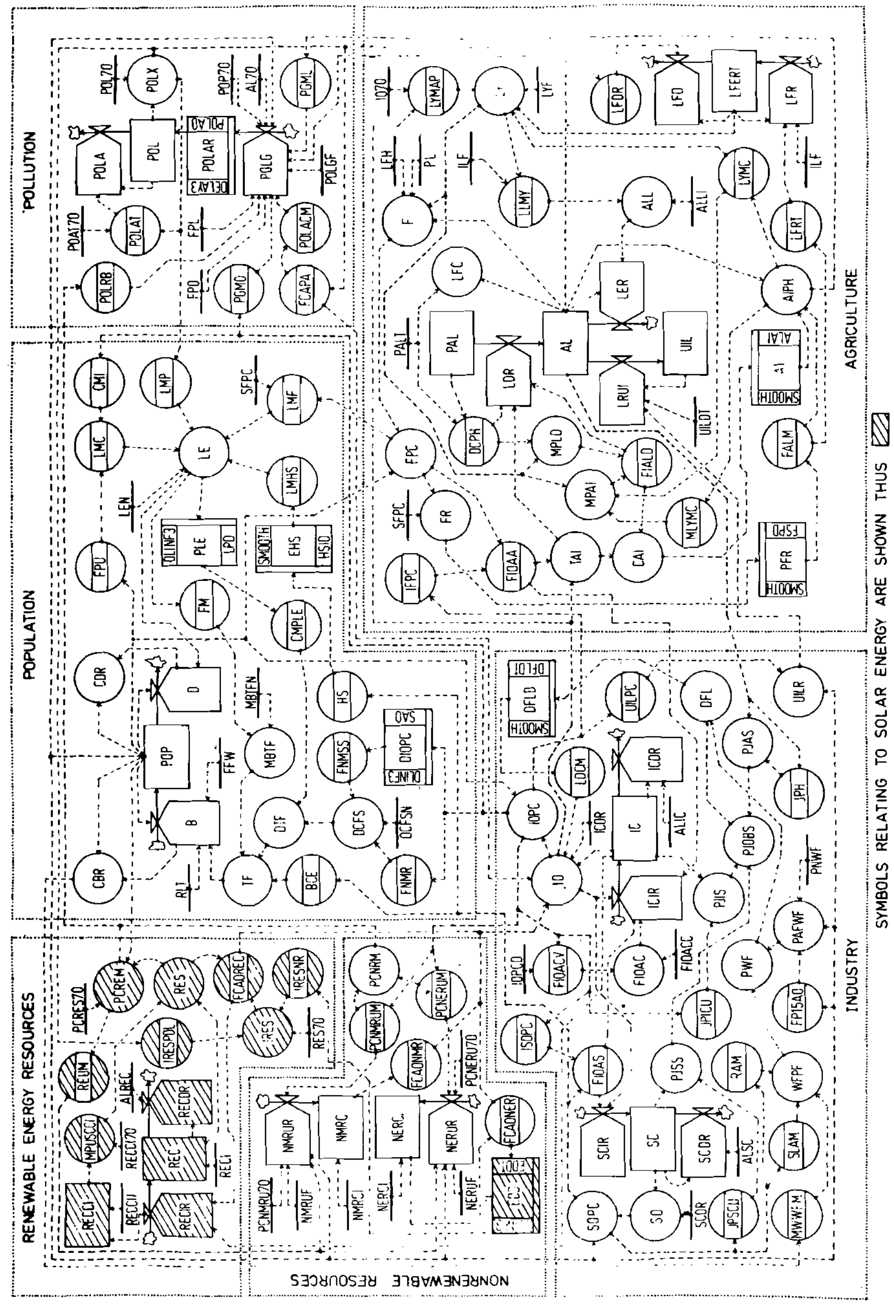
The present *World-Australia Solar* model is basically two solar worlds side by side (except for one small sub-sector) and of course the different data required for each sub-model. No attempt has been made to remove from the world part of the model that which can be attributed to Australia. Thus the world sub-model represents the whole world.

In a physical way Australia trades with the world and accepts people from the world. Interactions of this nature had to be incorporated into the model to make it complete. These interactions are included in the Interface sector.

With the abovementioned modifications to *World 3* made to both the world and Australia, and the incorporation of the Interface, the *World-Australia Solar* model is complete. However, as is well known by researchers in this field, models of this nature are continually under review. Since the original thesis was completed, further work has been carried out on the model under the direction of R. A. Ward at the Thames Polytechnic, London, and some changes have been made, particularly to the trade sector. This revised model has been used for this study.

The *Solar Australia* flow diagram for this study indicating the main subsectors and some of the relationships affected by the changes in the renewable energy subsector is given in figure 32.

FIGURE 32 SOLAR AUSTRALIA FLOW DIAGRAM



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APPENDIX C

Focus *A forum where independent contributors put their own views on economic topics*

*The Fallacy of Finite Resources

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THE last few years have seen the emergence of a widespread anti-growth movement. Its philosophy has been based on a variety of arguments: that economic growth is soul-destroying, polluting, or leading to the sudden exhaustion of supplies of key raw materials and minerals. The last fear, namely that if economic growth continues then the world will suddenly come up against the limits imposed by finite resources, is one which, on the face of it, seems to have the greatest plausibility and is also the one that, again on the face of it, does seem to have obtained some support from events of the past two years, notably the "oil crisis" and the widespread famine in many parts of the world. Many people have discovered, as soon as they made any serious attempt to acquaint themselves with the facts, that it is relatively simple and cheap to reduce the most common forms of pollution to insignificant levels. They cannot, however, see any possible answer to the problem of how to reconcile continued rapid economic growth with finite resources. For this enigma appears to be logically insoluble, and hence not a matter of technological progress or of tinkering with the price mechanism or introducing some new tax, such as a tax on pollution.

The finite resources problem, however, is the least of the problems that the human race needs to face in the foreseeable future—and even beyond that. Of course, very many serious problems face us, some of them associated with economic growth and some of them not. Almost all of them—such as the problems of tolerance, peace, stability, crime, income distribution, and so on—are problems that arise on account of man's conflict with man, not man's conflict with the environment. And, of the problems that arise out of man's conflict with the environment, only pollution calls for government intervention to correct the inadequacy of the market mechanism. By contrast, the resources problem is a relatively minor problem for society as a whole and does not, in general, require government intervention for its solution.

First, resources are not really "finite" in any meaningful sense or in any sense that has any implications for human decisions over the sort of time span that mankind can take into account. In a trivial sense it may well be true to say that the resources of the universe are "finite"—i.e. in the sense that it is beyond human capacity to add to the contents of the universe from outside it, or to

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add to the supplies of any particular resources in the universe except by converting some other resource. But this maxim is about as relevant to any decisions that the human race is ever likely to need to make as the knowledge that, one day, the sun will not supply us with its present heat and light. For even this eventuality will only happen in a few billions of years time and we do not really have to take decisions in the next few million years in order to protect ourselves against such an event. In other words, although the universe does not possess infinite resources, infinity is a long way off—more than just a few million years.

Unfounded Predictions of Mineral Scarcities

The only interesting question, therefore, is whether, before we reach infinity, the rising demand for raw materials and resources is likely to exhaust the supplies that are likely to be available to meet these demands. And the answer to this question is "No". The reasons for this equanimity emerge clearly when one considers why some earlier predictions that the world would soon run out of supplies of some key resources turned out to be wildly wrong. Such false predictions have been numerous in the past.

For example, just over one hundred years ago, a distinguished occupant of my chair in Political Economy at University College, London, the great economist Stanley Jevons, predicted an inevitable shortage of coal within a short space of time. But, although coal demand has since increased far more than Jevons anticipated, known world coal reserves are now estimated at about 600 years' supply.

A recent World Bank report quotes a 1929 study that concluded: "assuming a continuity of present techniques and a London price of 3 cents per pound it is clear that the world's resources of lead cannot meet present demands", and added that now, 43 years later, nobody is worried about a lead shortage. In fact, people are more worried about there being too much of it around. The same 1929 report concluded that "the known resources of tin . . . do not seem to satisfy the ever-increasing demands of the industrial nations for more than 10 years".[1] But, over 40 years later, the report on *The Limits to Growth* that was produced under the auspices of the Club of Rome expressed anxiety because existing "known" reserves of tin were only enough for another 15 years. Still, that estimate is better than in 1929 when reserves were only enough to last us for 10 years. At this rate, by the year 2100 I suppose we shall only have enough tin reserves to last us for another 30 years. It looks as if we shall have to wait millions of years before we have identified enough tin reserves to last us for ever. Meanwhile, we shall just have to go on using up those 10-years' supply which was all we had back in 1929.

Thus, as a matter of straight historical fact, however fast demand has expanded in the past, and for however long, new mineral reserves have been found, or some other painless adjustment process has taken place. This well-known fact is frequently met by the reply: "ah, yes, but growth is much faster than in the past and the whole scale of consumption of raw materials is incomparably greater than in the past". In the first place, however, such propositions are not very helpful since they are of a purely vague qualitative character. Secondly, they tell us only about the relationship between current rates of growth or levels of consumption and past rates or levels—not about the relationship between changes in demand *and changes in supplies*. And it is this relationship between changes in supply and demand that matters. For the fact that demand may be rising faster today than in the past would only imply that the prospects are more serious today than in the past if one assumed that the faster pace of demand increase has not been matched by a faster pace of supply increase. In other words, propositions about the demand side of the story no more imply an inevitable shortage than would equally valid propositions such as that "supply is rising much faster than in the past" imply an inevitable surplus.

This somewhat abstract argument can be illustrated by the record of what has happened to supplies of certain materials in the past in spite of acceleration in the rate of growth of demand. In the 19th century copper consumption rose about forty-fold, and demand for copper was accelerating around the turn of the century from an annual average growth rate of about 3.3% p.a., taking the average of the 19th century as a whole, to about 6.4% p.a. during the period 1890 to 1910. Annual consumption had been about 16,000 tons in the first decade of the 19th century, and was over 700,000 tons in the first decade of the 20th century. Given the rapid growth of consumption, the "known" reserves of copper at almost any time in the 19th century would have been exhausted many times over by subsequent consumption if there had been no new discoveries. But at[2] the end of the 19th century known reserves were bigger than at the beginning.

And this is far from being the end of the story. Even in the post-war world, when we are apparently in a new ball-game on account of what are believed to be unprecedented rates of economic growth, the story is the same. Resources have still increased to match demand. For example, in 1945 estimated known copper reserves were 100m. metric tons. During the following 25 years 93m. metric tons were mined; so if one were to accept the eco-doomsters' sort of analysis, there should be almost no copper left by now, and the last few precious scraps are presumably being extracted at astronomic cost as I write these lines. But no. Present known reserves are over 300m. tons., i.e. three times what they were 25 years ago. In fact, copper consumption has trebled during the last 20 years and we still have more copper left in the known reserves than we had at the outset.

No Point in Prospecting for Eternity

Why have the past predictions of scarcities proved unfounded and why has supply always risen more or less to match increased demand over the past? These two questions are inter-related. Comparisons of existing reserves with projected demand overlook the fact more reserves would be sought and found *provided there is sufficient incentive to go and look for them and to exploit them.* In other words, estimates of reserves at any moment of time do not represent true reserves in the sense of being all that can ever be found, irrespective of the demand and the price and technical progress. As I have pointed out already elsewhere, is it seriously imagined that, if there were already 20,000 years of known reserves of copper, any geologists would be employed in looking for new copper supplies?

At no point of time is it worth while prospecting for enough to last to the end of eternity, or even some compromise period, such as 100m. years, or even 1,000 years. Generally, new reserves are found as they are needed, and do not always rise exponentially at past rates.

The incentive to explore for new reserves if, for a time, demand increases faster than supplies at the old price, is merely one of the economic feed-backs that tends to keep changes in demand and supply for raw materials in equilibrium over the longer run, though not always at the same price. Innumerable other such feed-backs include technical progress in exploiting or treating materials or in developing substitutes. For example, radical changes in techniques of extracting or refining materials from ores have enabled lower and lower grades of ores to be handled economically, such as the reduction in

the lowest grade of copper that could be handled economically from about 3% in 1880 to almost 0.4% now.

Another kind of technological progress is the development of synthetic products, of which rubber and plastics are the most obvious examples. In any inventory of the world's resources taken a century ago no mention would have been made of synthetic rubber or plastics. Similarly, the usefulness of a mineral such as bauxite has been transformed following the development of methods of converting it into aluminium.

In other words, the notion of resources must not be interpreted in a static sense to refer to the known reserves of resources that have been worth while discovering given current (and past) prices, demands, and technological conditions.

Resources Depend on Usefulness

Resources cannot be usefully measured just in terms of physical amounts of certain minerals that may exist at any moment of time. This way of looking at them is fundamentally misleading. Many physical elements in the world are of absolutely no use at all given present costs of exploration and utilization, present techniques for using them, and the present demand for the products in which they might conceivably be used. But tomorrow all these things may change. What is a resource depends on the economic conditions determining the usefulness of the materials in question. If economically worth while, unused land can be turned into a usable resource by irrigation, drainage of swamps, clearing of forests, and so on. Sea water contains unlimited supplies of uranium for use in nuclear power production, and already it is thought to be possible to extract the uranium from sea water at a not astronomic cost. It has been estimated that sea water contains about a billion years' supply of sodium chloride and magnesium, 100m. years' supply of sulphur, borax, and potassium chloride, more than 1m. years' supply of molybdenum, uranium, tin, and cobalt, and so on.[2] Yet 30 or more years ago who would have thought of including sea water in the list of resources available to us?

Of course it is possible that if their relative prices were to be kept fixed we might eventually run out of supplies of one or two minerals. But in the first place, it is inconceivable that the relative price of the mineral in question would remain fixed under such conditions. As supplies of it failed to increase in line with demand at the old price, the inevitable shortages would sooner or later drive up the price and its use would become increasingly restricted to those purposes for which it was still worth while paying the increasingly high relative price.

"Oil Crisis" Not Failure of Supply

It is true that if the mineral in question happened to be one, such as oil, that has become a key input into our productive processes, a sudden shortage or dramatic rise in price could be a nuisance. But there is no reason why the growth of demand alone should lead to such a situation. Those people who cite the "oil crisis" as evidence that they have been right all along about the impending mineral exhaustion of the planet are making a big mistake. For the quadrupling of the oil price had nothing at all to do with any sudden failure of supply to keep pace with the rise in demand. Oil is not now being sold at US$10 per barrel instead of its earlier price of about US$2.50 because the Middle East oil producers have suddenly run out of cheap oil and are now scraping up the last few drops at a cost that is four times as high as the cost of the earlier and more abundant supplies. Oil in the Middle East still only costs about 10c a barrel to produce. Yet it sells at one hundred times this price on account of change in the marketing power of producers that have nothing to do with changes in their real costs.

In fact, the rise in the oil price, far from proving that the finite-resources school of thought were right all along, happens to be a change in the situation that will help prove them wrong. For it was probably true that the price of oil had been artificially low during the previous 20 years, so that demand had been rising faster than was optimal given the longer-run price prospects. It was already known that the equilibrium price of oil would have to rise over the long run. The recent quadrupling of its price is an over-correction and will do more than anything to slow down the rise in demand and to stimulate the development of substitute sources of oil or of other forms of energy. Hence, we are likely to run out of oil far less quickly than would have been the case in the absence of the so-called energy crisis.

Furthermore, a sudden overnight quadrupling of the oil price was an even more abrupt change than had been envisaged in the gloomiest views of the anti-growth and finite-resources school of thought. Yet in the end, and leaving aside its impact on international monetary payments arising out of the fact that the owners of this particular resource happen to be unable to spend their revenues very easily, it is remarkable how little real economic damage it has done. The recent economic crisis in the Western world—including the inflation accompanied by rising unemployment—has been the delayed effect of previous economic mismanagement, and the "oil crisis" has merely exacerbated the situation, not caused it. Indeed, in the longer run, the impact of the "oil crisis" on the growth rates of the industrialized world is likely to be negligible by comparison with possible damage which can be done by panic government measures in some countries, or failure to solve the problems of international monetary co-operation.

In other words, whichever way one looks at the "oil crisis", far from demonstrating that there is a genuine problem of "finite resources", it proves just the reverse:—

(a) The crisis did not arise as a result of economic growth but as a result of the Yom Kippur war—i.e. as a result of a failure to solve one of the problems of the relationship between man and man; (b) it will lead to oil reserves running out later rather than sooner; and (c) in spite of it representing a far more sudden rise in price overnight than had been dreamt of in the wildest fantasies of the eco-doomsters, and to a product that could hardly be more basic to modern industry, the degree of inevitable economic dislocation has been remarkably small.

Food Production Rising Faster than Population

It is equally wrong to believe that the famine of the last couple of years demonstrates the validity of the finite resources argument. For over the longer run in the past—i.e. the last 20 to 30 years (and even over the last 50 years)—world food production has been rising faster than world population. Moreover, as Professor Arndt of the Australian National University has pointed out, even predictions that the world population will not reach stability until well into the first half of the next century at about 13 to 15 billion only imply growth rates of population of about 1.3% p.a. These increases are only just over half the longer-run growth rates of world food output. The famines of the last two years have been largely the result of unprecedented bad harvests which, in the main, stemmed from adverse climatic conditions occurring simultaneously in several regions of the world, and did not result from adverse longer-run trends in the relative growth rates of food and population.

Of course, the regional pattern of food and population growth has been changing and the developing countries are likely to become increasingly dependent on the countries that are far more efficient agricultural producers. This situation, however, has nothing to do with finite resources. But, like oil, it has a lot to do with what I have said is the major problem facing the human race, namely the relationships between different groups of people. For it raises the whole question of, for example, the economic dependence of much of the Third World on the U.S.A. or other large-scale potential food surplus areas, and the extent to which the U.S.A. will take advantage of this dependence to retain world-wide economic ascendency in face of the changed oil situation.

Government Responsibility to Solve Food Problem

Thus the oil and food issues are linked in ways that the naive systems analysts of the Club of Rome have not been able to feed into their computers. These are the real problems of resources, and they are the problems that governments need to be concerned with. Governments do not, however, need to be concerned with the rate at which the private sector extracts certain minerals. Even if the supply of some minerals is finite, there is still some optimum rate at which it should be then used up in the interests of maximum human welfare, and the criteria determining this optimum are well known in the literature of economic theory. In general, nothing in these criteria implies that the free market will not use supplies up at the optimum rate, apart from the usual situation where the market is not really free and is under monopolistic influence. But food is very different, for a shortage of food means that some people will starve; the equilibrating mechanism of a rise in its price will not avoid this tragedy when many people are unable to pay the price. Hence, governments have some responsibility for helping to solve the food problem.

Human Knowledge Limitless

In this article I have not touched at all on the many purely logical, philosophical, and moral muddles implicit in the argument that we should slow down economic growth on account of finite resources.[3] But I would like to mention just one of them as a parting word. Either resources are finite or they are not. If they are not, then this particular anti-growth argument collapses. But if they are really finite then *even stopping economic growth will not save us in the longer term.* It would merely mean that we would run out of resources in, say, 1,000 years rather than 500 years. And what is so good about that?

But in case anybody is really worried about this prospect, let me reassure them. One of the features of the illustrations given above concerning the way economies adapt to changes in the supply/demand balance for any product was the application of human ingenuity and technical knowledge. And these skills largely result from increasing education and an apparently insatiable human appetite for knowledge. Indeed, there is no reason why this process should ever come to an end; the world's chief resource is its population and the human capital thus represented. As long as there is no limit to human knowledge, there is no effective limit to any of the other resources that make up this universe.

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APPENDIX D: RELATED READING

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