SP-74-4

TERNATIONAL INSTITUTE FOR IIASA APPLIED SYSTEMS ANALYSIS

SYMPOSIUM PROCEEDINGS

MULTILEVEL COMPUTER MODEL OF WORLD DEVELOPMENT SYSTEM

EXTRACT
from the
PROCEEDINGS OF THE SYMPOSIUM
HELD AT IIASA, LAXENBURG
April 29 – May 3, 1974

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VOLUME IV

SCHLOSS LAXENBURG
A-2361 AUSTRIA

TABLE OF CONTENTS

PART A CONSTRUCTION OF WORLD SYSTEM MODEL

A-1 MOTIVATION, OBJECTIVES, AND CONCEPTUAL FOUNDATION VOLUME I
A-2 METHODOLOGY FOR CONSTRUCTION AND STRUCTURE OF THE MULTILEVEL WORLD SYSTEM MODEL VOLUME I

PART B SPECIFICATION OF SUBMODELS AND LINKAGES

B-1 ECONOMICS VOLUME II
B-2 POPULATION VOLUME III
B-3 FOOD VOLUME III
B-4 ENERGY VOLUME IV
B-5 ENVIRONMENT VOLUME V

PART C COMPUTER IMPLEMENTATION AND SIMULATION OF NORMS AND DECISION PROCESSES

C-1 AN APPROACH TO MODELING OF HIGHER STRATA VOLUME VI
C-2 INTERACTIVE MODE AND COMPUTER IMPLEMENTATION VOLUME VI

PART D THEORETICAL SUPPORT

D-1 MATHEMATICAL FORMULATION VOLUME VI
D-2 STATISTICAL ANALYSIS VOLUME VI

VOLUME IV

PART B SPECIFICATION OF SUBMODELS AND LINKAGES

B-4 ENERGY

Page

IV.1. PREFACE B 687
M. Mesarovic, E. Pestel

IV.2. ENERGY RESERVES AND RESOURCES SUBMODEL B 691
R. Bauerschmidt, R. Denton, H.H. Maier

IV.3. ENERGY DEMAND SUBMODEL B 773
N. Chu, B. Hughes

IV.4. ENERGY SUPPLY SUBMODEL B 833
H. Bossel

IV.5. WORLD OIL SYSTEM SUBMODEL B 971
B. Hughes

IV.1. PREFACE

M. Mesarovic, E. Pestel

April 1974

IV. 1. Preface

Energy submodels are constructed on the technology and environment strata with intimate linkages to population, economic, emission and other submodels. In this chapter we shall present the following submodels together with their linkages with other parts which intergrate them into the total world system model:

(a) Energy Resources Model

It is designed to specify the availability of various energy resources as a function of potential discoveries and changes in ultimate reserves. It is integrated with the demand and supply submodels into the complete energy submodel of the total world system model.

(b) Energy Demand Submodel

It is designed to specify the total energy needs to achieve certain development objectives as well as to indicate various forms - liquid, solid, etc. - in which the energy could be used. In addition to the specification of the model and its construction as a demonstration of the use of the model the assessment of oil needs in various regions in the model until year 2000 and beyond is given.

(c) Energy Supply Model

It is designed to specify how the energy needs might be met in each of the regions depending on the technological changes, investment and development policies, export and import conditions, etc. There is a large number of alternative policies which can be implemented in this respect depending on the options selected as to the future energy supplies system development;as an illustration of the use of this submodel the consequences of selecting some of the most considered options for solving the energy crises in North America and Western Europe are presented.

(d) World Oil Market Submodel

The objective in designing this submodel was to assess the consequences of alternative policies by oil exporting and importing regions. In addition to the world oil commodity market the submodel after being interlinked with the total world system model provides for the decrease in economic and industrial development in any of the regions, resulting from the oil shortage as well as for the reduction in oil needs due to the development of alternative sources. As an illustration of the use of the model, the manners of conflict resolution between oil exporting and importing regions as a function of price fluctuations is presented.

Mihajlo Mesarovic Eduard Pestel

IV.2. ENERGY RESERVES AND RESOURCES SUBMODEL

R. Bauerschmidt, R. Denton, H.H. Maier

April 1974

Table of Contents

		Page
2.	Energy Reserves and Resources Submodel	B 693
2.1.	Energy Reserves and Resources Data	B 693
2.1.1.	Fossil fuels	B 693
2.1.2.	Nuclear fuels	B 727
2.2.	Energy Resource Model	B 735
2.2.1.	Introduction	B 735
2.2.2.	Subdivisions of the resource model	B 737
2.2.3.	Coordination of demands, produciton, imports and exports	B 738
2.2.4.	Some comments concerning application of the model to U.S. oil	B 741
2.2.5.	Some of the Main features of the resource model for U.S. oil	B 742
2.2.6.	Definition of the variables	B 744
2.2.7.	Equations	B 746
2.2.8.	Description of the Model	B 748
2.2.9.	SYSTRU-diagram	B 761
2.2.1o.	Computer Outputs	B 762
2.2.11.	Results	B 769

2. ENERGY RESERVES AND RESOURCES

2.1. Energy Reserves and Resources Data

2.1.1 Fossil fuels

General

The energy supplies in the last century were initially based on wood fuels alone, but in about the middle of the 19th century coal began to replace wood as the most important energy carrier. In our century another replacement has occured with the development of two new energy sources: oil and gas. The rapid expansion in the use of these new energy carriers has caused coal to be left far behind in the competition.

Despite the constantly increasing energy requirements the new exploration methods, improvements in resource development techniques and rapid advances in geological knowledge have allowed the growing demands to be met with relative ease up to this time. Furthermore, the reserve levels have constantly increased. As late as 1968 the general report in the section National Surveys of Energy Resources of the World Power Converence contained the following statement: "World energy resources are practically inexhaustible".

Since the use of energy has increased very sharply in the last few years but yet the discovery of new reserves is increasingly more difficult, for the first time in the developments relating to energy reserves a change in the trend can be established - even though it is not large at present. This fact and the slowdown of oil deliveries ordered by the OPEC countries in fall 1973 (motivated mainly for political reasons) has brought to the public consciousness for the first time the fact that our fossil fuels, upon which the lion's share of our energy supplies of today depend, are only finite. Since the fossil fuels are at the most very slowly renewable[1], mankind is essentially using finite resources, the size of which are often indicated only by relatively uncertain estimates.

How does the future look concerning the fossil fuel energy supply? There has been much interest lately in the answer to this question. The purpose of the present chapter is to collect a number of more recent statistics on proven reserves and further possible discoveries. Although no essentially new answer to the question itself will be given, it is necessary to present a brief summary of the energy outlook under various assumptions in order to provide a basis for the construction of the models found in the other chapters.

In the interpretation of the various statistics compiled on reserves, particular attention must be paid to the definitions and a number of basic assumptions. The assumptions underlying the statistics found in the literature vary tremendously, and failure to note them can lead to incorrect conclusions. Some of the assumptions and concept definitions will be discussed below - at least to the extent that it is felt appropriate now- and more

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[1] For example the oil resources are renewed very slowly, since ever, at the present time oil is formed in appropriate geological strata. However, the necessary time is millions of years, and in fact this renewal rate is negligibly small with respect to the extraction rate of today.

detailed descriptions will be given in the later discussions of the energy carriers. It appears reasonable to follow the terminology of Mc Kelvey[1] as far as possible.

Resources are distinguished according to a) degree of certainty and b) feasibility of recovery. The representation according to these terminologies is given in Fig. (2.1.1), which was taken from Mc Kelvey. The degree of certainty is indicated by the terms proven, probable, and possible; these three classifications together make up the category "identified". A further category is for "undiscovered" resources. In the case of coal the terms proved, probable, possible, and undiscovered are usually replaced with measured, indicated, inferred, and speculative, respectively. The feasibility of economic recovery is described by the terms recoverable, paramarginal, and submarginal. Mc Kelvey defined paramarginal resources as those which are recoverable at prices as much as 1.5 times prevailing prices. As an example of this terminology proven reserves would be equivalently classified as proven paramarginal or proven submarginal, etc.

As can be seen in the figure "reserves" must be either proven, probable, or possible as opposed to not yet discovered; in addition they must be recoverable from an economic standpoint. The undiscovered as well as the paramarginal and submarginal categories will be referred to as resources. In turn we will use the expression "ultimate 'y' in place", where 'y' can be oil, coal, gas etc., to refer to the sum of all reserves and resources af a given raw material.

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[1] V. E. Mc Kelvey, "Mineral Resource Estimates and Public Policy", American Scientist 60m No. 1., Jan.- Feb. 1972.

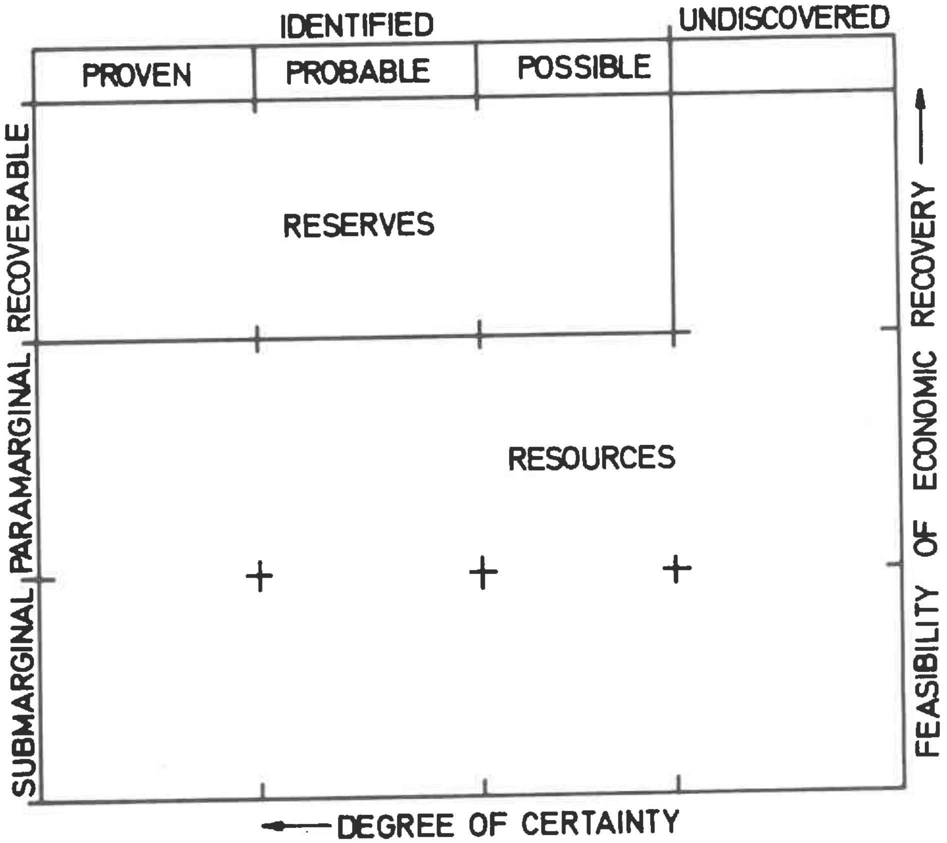

Fig. 2.1.1 Classification System Recommended by V.E.Mc Kelvey

Coal, Brown Coal and Lignite

For the data on reserves and resources in coal deposits one has generally gone over to certain physical parameters which influence the numbers given. The following parameters are typically applied:

a) seam; for inclusion in the statistics the seams or coal layers must have given minimum thickness.

b) deposit depth: the economy of extraction depends on this number.

c) recoverability; this parameter also depends on the deposit depth, but in addition encompasses the geological structure of the strata lying above the coal.

These parameters are included in the statistical reports from the various mining companies, so that one is enabled to make uniform comparisons between individual countries or regions. In the case of estimates the data depends to a large extend on which conclusions were drawn from already present geological data and previous exploration activities. Thus for the estimates there is naturally an influence from more subjective considerations.

For the terminologies used for the individual types of reserves one can infer the degree of certainty for the data, as has already been mentioned. P. Averitt[1], for example, subdivides his "coal resource estimates" into "hypothetical" and "identified resources". The "hypothetical resources" were defined as containing undiscovered mineral deposits, whether of recoverable or subeconomic grade, that are geologically predictable as existing in a known district. In our

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[1] United States, mineral resources, Geological Survey Professional Paper 820, 1973.

terminology these would be undiscovered resources, whereas his "identified resources" would not necessarily be recoverable; in our terminology this would include both reserves and resources included in the category "identified" (see Fig. (2.1.1)) which we write as identified reserves-resources[1].

Since for the coal data a number of statistics from the World Power Conference (WPC) were taken, the above definitions have been applied in a manner consistent with their data. The definitions are applied according to the following scale[2]:

1. Measured reserves-resources refer to those whose observation and measurement are so closely spaced and the thickness of the coal so well defined that the computed tonnage is judged to be accurate within 20 %.
2. Indicated reserves-resources are estimated partly from projections of visible data for a reasonable distance on the basis of geological evidence.
3. Inferred reserves-resources, while still applying to coal occuring within overall mapped and explored areas, are those for which "quantitative estimates are based largely on broad knowledge of the geologic character of the bed or region and for which measurement of bed thickness are available".

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[1] Breaking this down further, the identified reserves-resources in the U.S. consist of 8 % measured, 27 % indicated, and 65 % inferred.

[2] P. Averitt (Coal Resources of the United States, 1967, Geological Survey Bulletin 1275) provides these definitions of the three categories of estimates.

In addition, the tables on coal which will appear later in the text implicitly contain the following parameter limits:

a) for coal: the seams are at least 30 centimeters and the deposit depths are 1200 meters or less.

b) for brown coal and lignite: the seams are at least 30 centimeters and the deposit depths are 500 meters or less.

Exceptions to these conventions will be listed in footnotes to the corresponding tables, at least to the extent that they are known.

The data in the tables, with the exception of the data on China[1], is taken from:

World Power Conference, Survey of Energy Resources 1968. Data found in this survey was obtained from reports written by the individual coal producing countries. The composition and heating value of the coals in the various reports varied greatly , and since the terminology used by the individual countries was not always the same the WPC did not break down the coals into uniform individual groupings.

The heating values corresponding to both the coal and brown coal groups actually vary, but since a number of countries are collected together into each region, one can assign an average

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[1] The data for the region China was taken from the book " Die Energiewirtschaft der Volksrepublik China" (Verlag Glueckauf) which was printed in 1973; this data could thus be more reliable than the WPC data of 1968.

heating value to each group.

The quantities of coal given in Table 2.1 as World Coal and Table 2.2 as World Brown Coal and Lignite correspond to the identified reserves-resources deposited in the earth.[1]

The identified reserves-resources of brown coal in China was taken to be 10 % of the total in this category.[2] The results in the column four of Table 2 do not agree line for line with the sums of columns two and three,since for some of the countries in the regions considered there was no breakdown into measured, indicated and inferred reserves-resources although the overall identified reserves-resources were given.

In Table 2.3 various statistics on the sum of coal plus brown coal along with their "life-indices" are tabulated in tce energy units.[3] Altough the table is primarily devoted to the reserves in the individual regions of the world; the identified reserves-resources and ultimate coal in place are also included for comparison. To avoid confusion we mention again that ultimate coal in place denotes all reserves and resources, whether discovered or not; the undiscovered partof the ultimate coal in place can of course only be estimated.

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[1] Consistent with our terminology these quantities are not necessarily all recoverable.

[2] This percentage is a realistic estimate: see footnote 1 , page 2.6. U.S. example.

[3] tce:1 ton (1000 kg) of so-called tons coal equivalent, which contains a heating value of 7000 Kcal/kg. The average heating value of brown coal is assumed to be 3500 Kcal/kg, so 2000 kg is equivalent to 1 tce.

Table 2.1 - WORLD COAL RESERVES-RESOURCES [1]

Name of Region	Coal (in millions of metric tons)			
	Measured reserves-resources	Indicated and inferred reserves-resources	Identified reserves-resources (columns 2 + 3)	
1	2	3	4	
NORTH AMERICA (1)	114 600.0	1 046 400.0	1 161 000.0	2)
WESTERN EUROPE (2)	88 275.9	6 233.8	94 509.7	5)
JAPAN (3)	5 723.0	13 525.0	19 248.0	
REST OF DEVELOPED (4)	40 175.0	49 135.0	89 310.0	
EASTERN EUROPE (5)	184 235.0	3 995 829.0	4 180 064.0	3)
LATIN AMERICA (6)	4 077.4	13 117.9	17 195.3	
MIDDLE EAST (7)	23.8	92.0	115.8	
MAIN AFRICA (8)	4 761.0	8 362.0	13 123.0	4)
SOUTH EAST ASIA (9)	14 467.0	96 765.0	111 232.0	
CHINA (10)	70 000.0	1 497 000.0	1 567 000.0	
W O R L D	556 338.1	6 726 459.7	7 252 797.8	

1) Survey of Energy Resources 1968, World Power Conference.

2) USA: Measured reserves-resources include coal in the ground in beds of 71 cm or more thick and less than 305 meters below the surface. Indicated and inferred reserves-resources include coal in the ground in beds of 35 cm or more thick and less than 914 metres below the surface.

3) U.S.S.R: Numbers have been estimated regarding to seams containing coal of not less than 50 cm in thickness and situated not more than 1200 metres below the surface, with the exception of Donbass where seams have been measured up to 1500 metres below the surface.

4) Swaziland: Coals up to a depth of 500 metres only included.

5) In the Region W.E. 160 000 · 10^6 tons of coal in Western Germany were not included, since they lay deeper than the parameter limit of 1200 meters.

Table 2.2 - WORLD BROWN COAL AND LIGNITE RESERVES-RESOURCES [1]

Name of Region	Brown coal and lignite (in millions of metric tons)			
	Measured reserves-resources	Indicated and inferred reserves-resources	Identified reserves-resources [2] (columns 2+ 3)	
1	2	3	4	
NORTH AMERICA (1)	21 650	408 450	430 100	3)
WESTERN EUROPE (2)	75 799	17 780	93 673	
JAPAN (3)	238	1 495	1 733	
REST OF DEVELOPED (4)	48 417	47 569	95 986	
EASTERN EUROPE (5)	120 154	1 312 062	1 469 262	4)
LATIN AMERICA (6)	355	9 640	9 999	
MIDDLE EAST (7)	–	–	–	
MAIN AFRICA (8)	18	88	106	
SOUTH EAST ASIA (9)	2 351	277	4 956	5)
CHINA (10)	1 121	u	11 210	
WORLD			2 117 025	

Definition of Symbols: u - unknown; – - no reserves-resources exists;

1) Survey of Energy Resources 1968, World Power Conference.

2) Results in column 4 do not agree line for line with the sums of column 2 and 3, since some countries do not report measured and indicated and inferred reserves-resources separately.

3) USA: Measured reserves-resources include lignite in beds of 1.52 metres or more in thickness and less than 305 metres below the surface. Indicated and inferred reserves-resources include lignite in beds 76 centimetres or more in thickness and less than 814 metres below the surface.

4) Poland: Additional reserves-resources expected from future assessment amounted to 35.000 million tons, but was not included in the reported data.

5) Indonesia: The estimate refers to reserves-resources in seams of not less than 1 metre in thickness and situated not more than 600 metres below the surface.

Table 2.3 - TOTAL COAL [1]
(in millions of metric ton of coal equivalent)

Region	Measured reserves	Identified reserves	Production [2]	Life-Indices[3] static (measured reserves)	static (reserves)	dynamic (measured reserves) 2%	3%	5%[4]	dynamic (reserves) 2%	3%	5%[4]
1	2	3	4	5	6	7			8		
NORTH AMERICA (1)	62 713	688 025	556.106	113	1 237	60		39	164		85
WESTERN EUROPE (2)	63 088	70 673	384.826	164	184	73		45	78		48
JAPAN (3)	2 921	10 057	39.759	73	253	46		32	91		54
REST OF DEVELOPED(4)	32 192	68 652	109.794	293	652	97		56	131		71
EASTERN EUROPE (5)	122 156	2 457 348	821.060	149	2 993	70		44	207		103
LATIN AMERICA (6)	2 127	11 097	9.141	233	1 214	87		52	163		84
MIDDLE EAST (7)	12	58	0.771	16	75	14		12	46		32
MAIN AFRICA (8)	2 385	6 588	4.237	563	1 555	127		69	175		89
SOUTH EAST ASIA (9)	7 821	56 855	88.065	89	646	52		35	133		72
CHINA (10)	35 280	786 303	395.589	89	1 988	52		35	187		94
WORLD	330 695	4 155 656	2 409.348	137	1 725	67	55	42	180	134	118
P. Averitt estimates	Identified reserves-resources	Ultimate coal in place		static (column 2)	static (column 3)	dynamic (column 2) 2%	3%	5%	dynamic (column 3) 2%	3%	5%
	8 618 400	15 300 176		3 577	6 350	216	158	106	245	178	118
	Identified reserves	recoverable res.-resources									
	4 309 200	7 650 088		1 789	3 175	182	135	92	210	155	104

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1) Coal means in this table coal and brown coal together. Detailed description of calculating this numbers is given in the text.
2) Coal production data (1970) are taken from: World Energy Supplies 1961-1970, UN Series J.No. 15.
3) Numbers given for life indices are rounded to integers.
4) x% growth rate.

Of the identified reserves-resources in each country the fraction which can actually be extracted economically varies considerably.[1] Information on these recoverability fractions are included in the WPC-statistics, and from these one can conclude that the world-wide average for the fraction of coal which is recoverable is about 50 %.[2]

The data on identified reserves-resources and the ultimate coal in place along with the corresponding recoverability fractions were taken from P. Averitt. His estimates were based on the same physical parameters as the WPC. Consistent with this one can note that the identified reserves-resources multiplied with a 50 % recoverability fraction agrees well with the total of the reserves. The "life indices" were calculated for the reserves and also for the estimates of ultimate coal in place, where in the latter case both a 100 % and a 50 % recoverability fraction was used. The static live index indicates how long the reserves or resources would last if the production remains at a given level; in the case of measured reserves this is usually called the static reserve index. This definition explicitly excludes future changes in the production.

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[1] Example:East Pakistan (Bangla-Desh) has huge quantities of identified coal reserves-resources, of which only 20 % can be extracted profitably. West Pakistan has less coal, but can nevertheless extract up to 80 % profitably.

[2] These conclusions were reached by P. Averitt, United States Mineral Resources,U.S.Govt. Printing Office, 1973, and by. I Darmstadter, et al, Energy in the World Economy, The John Hopkins Press, 1971.

For this reason we have also carried out the calculations for the regions with a 2 % and 5 % growth rate, and again for the world-wide production with a growth rate of 2 %, 3 %, and 5 %. One might choose to refer to these results as "dynamic life indices" to distinguish them from the "static" case.

At least if one considers the earth as a whole (the growth in individual well-developed countries such as the U.S. could eventually saturate), the dynamic life indices should give a more realistic idea of the lifetimes than the usual static life indices. The actual differences involve a factor of 10. This difference is particularly striking in the case of ultimate coal in place. The static life index is about 3175 years, whereas with a 2 % growth rate the production could only last 210 years and with 5 % growth only 107 years.

These estimates contain the assumption that as long as the supply lasts it can be distributed smoothly to regions where there is a demand, which cannot be expected to remain true as the future exhaustion becomes apparent. At that point one would expect that especially the supplying countries would take measures to project their own interests, which could include abrupt decreases in supply exports.

Even a doubling of the ultimate coal in place would only extend the lifetime from 210 years to about 250 years in the case of 2 % growth. In the last few years the exploration activity has decreased due to the declining use of coal, and the estimates given from 1968 might no longer be correct. However,even if the estimates were to be increased due to the sudden new start-up in exploration and corresponding discovery of new deposits, this example shows that the increase in the lifetime is relatively small under the assumption of continuing growth - even at the low level of 2 %.

It is interesting to consider how long a train, each freight car of which being capable of carrying 20 tons of coal, would have to be in order to transport the daily coal production of say, the year 2150. Assuming a 1970 production of 2400 million tons, and 2 % growth, one obtains a yearly production in 2150 of 88 x 10^9 metric tons. To transport the daily production 12.1 million freight cars would be needed, which in a single train would stretch out a distance .15 million kilometers - 4 times around the earth!Although the example is a little far-fetched, it does indicate that quite apart from eventual energy supply shortages there would be other problems as well.

Oil and Natural Gas

The definitions of reserves and resources given previously can also be applied to oil and natural gas. The basic categories remain, but the scales used to indicate, for example, the degree of reliability are different than those used for coal. Similarly the relative importance attached to each category is different. Also, just as with discussions of coal the same word may be used to indicate different concepts in the literature; one must therefore check the context carefully. We indicate below our usage of the main terms.

Proven reserves represent a "minimal estimation" of the reserves found in a region, i.e. there is a fairly high certainty associated with the estimate. This category coincides with the proven reserves in Fig. (2.1.1), and is the quantity of oil or gas, estimated for fundamental geological and technological information, which one can with high certainty obtain at currently competitive prices, from known deposits. The data on proven reserves are based on both measurements and estimations using various calculation procedures.

Recently, some doubt has been cast on some of the data arising from calculations.[1] As an example of the uncertainty associated even with proven reserves, A. D. Zapp mentions the East Texas oil field which was discovered in 1930. Up to 1935

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[1] A. D. Zapp, "Future Petroleum Producing Capacity of the United States", 1962, Geological Survey.

there had been 19 520 drillings which provided extensive geological information an the structure of the field. At that time the statistical numbers reported that the maximum quantity of recoverable crude oil was 2 1/8 x 10^9 barrels. However up to the end of 1957 3 x 10^9 (billion) barrels had already been extracted, and in the meantime the estimate of the maximum recoverable quantity had been moved upwards to 5 x 10^9 (billion) barrels. He traced this descrepancy back to insufficient the calculation procedures which were used.

On the other hand H. Warman[1] indicates that once an oil field has been discovered and a number of drillings have been made, then one can determine the size of a deposit to a good approximation[2] through measurements of the sample porosity along with the oil and water content. This was said to be particularly true for in the last couple of decades, the experience in extraction from oil and gas fields has been extensive; the quantity of oil which one can extract[3] in the course of just 10 to 20 years, with today's knowledge, can now be determined to a high degree. Moreover, he maintains that from a global standpoint there have been both too low and too high estimates which average out, although

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[1] H. R. Warman, The Future Availability of Oil 1973, World Energy Supplies, Conference organized by the Financial Times.

[2] Calculation methods include 1) Decline-curve method, 2) Volumetric computations, 3) Material balance calculations, 4) Seismographic-reflection methods.

[3] H. Warman employs the term "recoverable resources" to include all estimated oil which can be extracted by known extraction technologies, whether of primary, secondary, or tertiary nature. They need only have a significant influence on the recovery factor during the 20 - 30 year lifetime of an oil deposit.

the trend in the U.S. has been towards higher estimates. Thus it would be false to claim that all inital estimates would habe to be increased a factor 5 or so in the course of time.

The comments of A. D. Zapp and H. Warman refer to a large extent to the experience in North America. There the proven reserves data is based on established rules, according to which reserves only indicate what can be extracted with existing technology and consistent with today's prices. One should keep in mind also the fact that the oil companies tend to publish extremely conservative estimates, since this is a saver basis from their own economic standpoint.

The size of the proven reserves can change for several reasons. A change in price levels can mean that the boundary between "recoverable" and "paramarginal" is lowered, thus increasing the proven reserves. Also, as new extraction technologies come into being, and to some extent with new drilling in a known oil field, the proven reserves increase.

Although proven reserves will have a central role in what follows, it is somewhat restrictive. Therefore the further terms "probable" and "possible", introduced previously, will find some application. Data indicated by probable or possible are based on geologica-theoretical analysis, but can have a relatively large uncertainty. The two expressions "probable reserves" and "possible reserves" are often classified together as "unproven reserves".[1]

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[1] Darmstadter, Energy in the World Economy, The John Hopkins Press, 1971, page 45.

Because of the uncertainties involven in oil and gas it is difficult to establish clearly the border between"possible reserves" and undiscovered resources (see Fig. (2.1.1)).

Consistent with the previous definitions ultimate oil in place refers to the sum of all reserves and resources;here as before in the case with coal there are relatively high uncertainties associated with this quantity. It depends not only on scientific judgements but to some extent also an subjective considerations of the person who makes the estimate. For this reason there are often large differences in the estimates found in the literature, as the following table shows:

Table -2.4- Estimates of World Ultimate Recoverable Reserves and Resources of Crude Oil

From Conventional Sources

Year of Estimate		$x\ 10^9$ bl
1942	Pratt, Weeks and Stebinger	600
1946	Duce	400
1946	Pogue	555
1948	Weeks	610
1949	Levorson	1.500
"	Weeks	1.010
1953	Mac Naughton	1.000
1956	Hubbert	1.250
1958	Weeks	1.500
1959	"	2.000
1965	Hendricks (U.S.G.S.)	2.480
1967	Ryman (ESSO)	2.090
1968	Shell	1.800
1968	Weeks	2.200
1969	Hubbert	1.350 - 2.100
1970	Moady	1.800
1971	Warman (BP)	1.200 - 2.000
1971	Weeks	2.290
1972	Warman	1.900
1972	Bauquis, Brasseurand Masseron	1.950

One immediately sees two things in this table:

1. The estimates have increased in the course of time
2. The data appears to "settle down" to a value between 1.600 and 2.000 x 10^9(billion) barrels.

In all fairness it should be mentioned that the estimates are based on varying assumptions - even in the case when one person has made several estimates. For example it is contended that the first estimate made by Weeks took only the land areas into account, but the later ones also includes offshore oil deposites.

There are not as many estimates of ultimate gas in place, since gas has only become significant in more recent years, as gas technology has been more fully developed.[1]

The tables below contain various statistics on the proven reserves and the ultimate amounts in place for both gas and oil, broken down into regions.

Oil

If based on proven reserves and the 1972 production of crude oil the static reserves index is only 37 years. In the past this value has been only slightly larger. Thus in the past the oil exploration and development has only been carried out to the extent necessary to maintain a "balanced" relationship between oil production and crude oil reserves.

For the future, however, one can expect more and more exploration activity. Since the static reserve index does not take into account the

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[1] Construction of pipelines, building of ships for transporting natural gas liquids, etc.

growth in energy demand, it is more reasonable to consider when the reserves would be exhausted with, say, a 5 % growth rate being considered.[1] In that case the depletion of the proven reserves would occur 16 years sooner (see Table (2.5)).

Now let us go a step further and assume predictions based on proven reserves alone are too restrictive. We want to consider an approximate answer to the question:"How long could the crude oil of the earth last?" As in the case with coal, it is perhaps more realistic to use the ultimate oil in place as a basis in which a future "possible" recovery factor is to be used. We have to keep in mind that there can be a large uncertainty in an estimate of this nature, but on the other hand the intent is to obtain a result which if anything gives too large a value (a possible upper limit) for the lifetime.

For this reason we have used the estimate of ultimate oil in place from T. Hendricks, which up to the present has been the highest value given (see Table (2.6)).[2] At the present time the world average for the recovery factor is about 30 %, and for the future it is believed that the upper limit for the recovery factor should be about 60 %. Now under the assumption that production remains constant at today's levels,

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[1] The growth rate in the world's total energy demand is estimated to be at 5.4 % annually until 1985. (Study of ESSO, AG: Gegenwaertige und kuenftige Probleme der Energieversorgung). The oil growth rate is even faster, so this is a conservative estimate.

[2] T. A. Hendricks:Resources of Oil, Gas, and Natural Gas-Liquids in the United States and the World. U.S. Geological-Survey Circular 522 (1965 (67)). The various regional divisions of the earth are different than those in the M.P.-World Project

Table 2.5 - OIL RESERVES [1]

	Oil reserves (in thousand of barrels)				
Region	Proven reserves [2]	Percentage of World's total %	Life index static	Growth rate 5%	Prod. (1972)
NORTH AMERICA (1)	47 023 271	7.1	12	9	4 011 350
WESTERN EUROPE (2)	12 632 000	1.9	80	33	157 680
JAPAN (3)	23 000	0.003	4	4	5 475
REST OF DEVELOPED (4)	2 354 460	0.3	15	11	157 206
EASTERN EUROPE (5)	78 500 000	11.8	26	17	3 066 000
LATIN AMERICA (6)	32 601 750	4.9	19	14	1 739 079
MIDDLE EAST (7)	438 894 000	65.8	58	28	7 519 110
MAIN AFRICA (8)	22 801 000	3.4	30	19	754 638
SOUTH EAST ASIA (9)	12 553 800	1.9	23	16	543 084
CHINA (10)	19 500 000	2.9	105	38	186 150
WORLD	666 883 281	100	37	21	18 140 122

1) Numbers given for life indices are rounded to integers.
2) The data on proven reserves was reported by the "Oil and Gas Journal" (25.12.72), the annual oil production was taken from the same source.

Table 2.6 - CRUDE OIL

Oil, estimated ultimate in place and ultimate discoveries 1) (10^9 (billion) barrels)

Region 1)	I 3)	II 4)	Recoverable reserves-5) resources 0.3	0.6	Production 6) (10^3 barrels)	Life indices 0.3 stat.	0.6 stat.	0.3 5% 7)	0.6 5% 7)
1	2	3	4	5	6	7	8	9	10
CANADA, MEXICO, CENTRAL AMERICA AND CARIBBEAN	500	300	90	180	705 728	128	256	41	54
SOUTH AMERICA	800	500	150	300	1 577 202	95	190	36	48
EUROPE	500	300	90	180	133 955	672	1 344	73	87
AFRICA	1 800	1 100	330	660	2 068 017	160	320	45	58
MIDDLE EAST	1 400	900	270	540	6 273 255	43	86	24	34
SOUTH ASIA	200	100	30	60	173 704	173	346	46	60
USSR, CHINA, AND MONGOLIA	2 900	1 800	540	1 080	3 252 150	166	332	46	59
AUSTRALIA, EAST INDIES, AND PACIFIC ISLANDS	300	200	60	120	488 261	123	246	40	53
UNITED STATES	1 600	1 000	300	600	3 467 500	87	174	34	46
WORLD	10 000	6 200	1 860	3 720	18 140 000	103	206	37	50

1) Data was taken from T. A. Hendricks, "Resources of Oil and Gas", US Geological Survey Circular 522, 1965
2) Regions are not comparable to those of M.-P.-World Model. They are taken from the original statistic.
3) Column I refers to "ultimate oil in place".
4) Column II refers to "possible ultimate discoveries".
5) Columns 4 and 5 refer to recoverable reserves-resources assuming recoverability of 0.3 and 0.6.
6) Production data are taken from "Oil and Gas Journal" (25.12.72).
7) Columns 9 + 10 refer to dynamic life-indices, assuming a recovery factor of 0.3 respectivly 0.6 and a 5% annual production growth rate.

then with the 30 % recovery factor the lifetime would be 103 years, and with 60 % recovery it would be 206 years. But with a 5 % growth rate the lifetimes would be 37 years for 30 % recovery but only 50 years with 60 % recovery.

These lifetimes, we emphasize, are based on optimistic data. If one considers that the crude oil production growth rate since 1967 has always been more than 7 %, and at times has even reached 10 %,[1] then if production were to follow demand alone all exploitable oil could well be gone before 50 years has gone by.

Natural Gas

For this energy carrier the table has the same form as in the oil table. The proven reserves would last for 41 years if the production were to remain constant on 1972 levels, but only 23 years for a 5 % annual growth starting from 1972 production levels. Use of natural gas has only become significant in more recent years, and its growth rate has been larger than that of oil.Since 1969 the annual growth has been at about 9 %. The static reserve index, similar to the case of oil, has remainded about constant since 1966.

Also for naturalgas an estimate can be made of the largest "probable" lifetime based on ultimate gas in place; we use again the data from T. A. Hendricks. Assuming a recovery factor of 0.8 the recoverable reserves-resources are about a factor of 8 larger than the proven reserves. The static life index turns out to be 333 years, based on current (1972) production,while a 5 % growth rate the lifetime is shortened to 59 years, and 10 % growth leads to a 37 years lifetime.

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[1] Future growth rates are now somewhat uncertain due to question about longer-term Arab intentions, which arose after the fall of 1973.

Table 2.7 - GAS RESERVES 1)

Region	Gas reserves (10^9 m^3)				Production (1972) 2)
	Proven reserves	Percent of World's total %	Life index static	dynamic (5 %)	
1	2	3	4	5	6
NORTH AMERICA (1)	9 244	17.3	13	10	713.471
WESTERN EUROPE (2)	5 056	9.5	41	22	123.67
JAPAN (3)	11	0.02	4	4	2.577
REST OF DEVELOPED (4)	1 509	2.8	438	64	3.442
EASTERN EUROPE (5)	18 219	34.2	69	31	263.935
LATIN AMERICA (6)	2 243	4.2	24	16	92.655
MIDDLE EAST (7)	13 733	25.8	248	53	55.316
MAIN AFRICA (8)	1 359	2.5	648	72	2.097
SOUTH EAST ASIA (9)	1 348	2.5	101	37	13.292
CHINA (10)	595	1.1	150	44	3.968
WORLD	53 317 3)	100 6)	41	23	1 298.628 4)

1) Data on proven reserves was reported by the "Oil and Gas Journal" (25.12.72)
2) Production numbers are taken from Felix,Fremont, "The Future of Energy Supply: The Long Haul", 1973
3) Estimates reported by Felix,Fremont "The Future of Energy Supply: The Long Haul" totals to 53 719 x 10^9 m^3
4) When added, total of column 6 may not equal the world total as some individual figures are not available.
5) Conversion factor used: 1 m^3 = 35.3149 cuft.
6) When added, total of column 3 may not equal 100 % in account of round of-errors in individual numbers.

Table 2.8 - NATURAL GAS

Region	Natural gas, estimated ultimate in place and ultimate discoveries 1) (10^{12} m^3)							Prod. (1972) (10^9 m^3)
			Recoverable 80 % 10^{12} m^3	Life index				
				static	dynamic			
	I	II			5 % 3)	7.5 % 2)	10 %	
1	2	3	4	5	6			7
CANADA, MEXICO, CENTRAL AMERICA, CARIBBEAN	99	62	49.6	491	66	50	41	100.916
SOUTH AMERICA	71	45	36	517	67	51	42	69.666
EUROPE	37	23	18.4	110	38	31	26	166.695
AFRICA	153	96	76.8	8 691	125	90	71	8.837
MIDDLE EAST	102	62	49.6	1 065	82	61	49	46.57
SOUTH ASIA	17	11	8.8	735	74	56	45	11.978
USSR, CHINA AND MONGOLIA	241	150	120	534	68	51	42	224.878
AUSTRALIA, EAST INDIES, PACIFIC ISLANDS	31	20	16	2 219	97	71	57	7.211
UNITED STATES	113	71	56.8	89	35	28	24	635.544
WORLD	864	540	432	333	59	45	37	1298.628

1) Data was taken from Hendricks,"Resources of Oil and Gas".
2) The average growth rate of production amounts to 7.5 % in the past decade.
3) A 5 % growth rate was estimated to be true for world total primary energy demand in the future. (ESSO STUDIE 1973, Gegenwaertige und kuenftige Probleme der Energieversorgung.)

Summary: Coal, Oil and Natural Gas

Lifetimes based on constant growth rates and not constant production - indicate the realistic time limits for the availability of coal, oil, and gas. The resulting dynamic life indices, or lifetimes, are not large and show that the production cannot continue to increase very long into the future. Therefore fossil fuels might be able to supply the demand much longer than the so called "dynamic life indices" show. No definitive criterion, however, is known for where the eventual per capita limits to growth might be. In the U.S.A. the per capita annual energy consumption lies at about 90.000 kwh and the growth rate to 1985 is expected to be about 4.4 %.[1] The per capita consumption in Europe lies at about half the U.S. value, and due to possible demand could have a large growth rate.

A carrying of these energy consumption relationships over to the entire world population raises more serious doubts concerning adaequacy of the reserves and resources. Although one cannot expect the consumption of the developing countries to reach the level of Europe or the U.S.A. in the next decades, the U.S. and European living standards are held out as an example; from a long-term standpoint a large annual growth rate for the developing countries should therefore be considered as a very real possibility.

These considerations of per capity consumption bring other aspects of the raw materials problem to the foreground, if one keeps in mind the size of the constantly increasing world population. With a 5 %

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[1] ESSO Studie 1973, Gegenwaertige und kuenftige Probleme der Energieversorgung

growth of energy consumption over several more decades a number of technological problems become particularly grave. To mention a few:

- World-wide ecological burdens due to air pollution, warming up rivers, climatic changes, etc.
- Limitations of mining and transport capabilities (with reference with the example given in discussing coal, a 5 % growth until exhaustion of coal resources would require a daily mining production which is equal to the present yearly production).

A calculation or model which does not include effects due to such factors can only admit limited conclusions.

Oil Shale and Tar Sands

Up to this time in the discussion the possibilities for obtaining oil from shale and tar sands have not been mentioned. The total hypothetical quantity of oil in these non-conventional sources is very large, but the reserves which can be used in the next ten to twenty years are very difficult to quantify, and they are perhaps generally overestimated. To give the actual proven reserves, which by definition indicates the quantity of oil which is recoverable and proved out to a relativ high degree of certainty(i.e. economically feasible to extract) is even more difficult because of large uncertainties concerning the costs, involved, the large-scale technologies still to be developed, and the availability of investment funds. The possible ecological burden is a further problem which increases the uncertainties relating to proven reserves. Nevertheless, if one adds these unconventional oil sources (liquefaction of coal will be neglected for the present) to the conventional ones, then on the basis of the total theoretically recoverable quantities one has the impression of a more than sufficient oil supply.

One should not come to the false conclusion, however, that there is any simple solution to the problem of oil supplies for the next ten to twenty years. The deposits of tar sands are probably easiest to develop, but there are still large difficulties involved in the extracting of oil. The largest known deposits are in North America, among which the largest are the Athabasca Tar Sands in Canada; it is assumed that these contain about 300 x 10^9(billion) barrels. This corresponds to the size of the reserves in the Middle East. However to extract the same amount of oil as is produced in the Middle East one would face immense financial problems. H. R. Warman indicates that for the most favorably situated deposits the initial capital investment would be $ 5.ooo per barrel produced. To produce an appreciable fraction of the world crude oil, say 5 million barrels per day, one would need to use the deeper and less favorable sands.This would require double the investment or $ 10.000 per barrel. Thus for the production of 5 million barrels per day an investment of $ 50 x 10^9 (billion) would be necessary. The production costs, also estimated by Warman , would be $ 1 to $ 2 per barrel. To cover the total costs would require a price of about $ 10 per barrel, if the royalties and taxes are not taken into account. Nevertheless, from the price development which has taken place since the end of 1973, one can expect this price to eventually be reached.

Another barrier to this method of obtaining oil is represented by limited construction capacity. The Canadian economy cannot support construction of more than about one plant per year with a plant capacity of 100.000 barrels per day.

The problems associated with the extraction of oil from shale are significant greater. This is primarily due to its much less favorable oil per volume ratio: Roughly a ton and a half of shale is required for a barrel of oil. Also, the process involved is much more difficult. In spite of this it is estimated that one could produce oil from shale at about $ 6.00 per barrel.[2]

The National Petroleum Council of the U.S.A. has made the following estimation of non-conventional oil production in North America:[1]

Oil Sands	500.000 - 1.250.000 barrels/day by 1985
Oil Shale	100.000 - 400.000 barrels/day by 1985

These quantities are not very impressive, when one consideres that the U.S. demand alone in 1985 will be about 29 million barrels/day.

The North American example has special significance, when one notes that this is the location of the largest deposits of tar sands and more suitable oil shale, and furthermore that their oil technologies are the most advanced in every area.

Apart from technological or economic considerations one should also note that the volume of rock produced after oil extraction is about 12 % larger, and this presents major disposal problems.

The shale oil reserves of the world are given in the following table (units are billions of barrels).

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[1] NPC: Report on United States Energy Outlook 1972

[2] Price estimates vary. In the report "Energy and the Future" (AAAS, Washington D.C. 1973) an estimate by A.L. Hammond, W.D. Metz and T.H. Maugh given to $ 4.5 per barrek,

Table 2.9 - Shale Oil Reserves and Resources [4]

Regions	Identified[1]		Hypothetical[2]		Speculative[3]	
	25-100	10-25 gal.p.t.	25-100	10-25 gal.p.t	25-100	10-25
Africa	100	small	Ne	Ne	4000	80000
Asien	90	14	2	3700	5400	110000
Australia + New	small	1	Ne	Ne	1000	20000
Europe	70	6	100	200	1200	26000
North America (excl.USA)	small	small	50	100	1000	23000
South America	small	800	Ne	3200	2000	36000
USA	418	1600	300	1600	600	23000
Total	678	2421	452	8800	15200	318000

1. Identified reserves-resources: Specific, identified mineral deposits that may or may not be evaluated as to extent and grade, and whose contained minerals may or may not be profitably recoverable with existing technology and economic conditions.

2. Hypothetical resources: Undiscovered mineral deposits, whether of recoverable or subeconomic grade, that are geologically predictable as existing in known districts.

3. Speculative resources: Undiscovered mineral deposits, whether of recoverable of subeconomic grade, that may exist in unknown districts or in unrecognized or unconventionell form

Ne - not estimated

4. Table from Duncan and Swanson 1965, Organic Rich Shale of the United States and World Land Areas.

This table gives the ultimate oil in place (from shale) and was taken from the U.S. Geological Survey, circular 523, (the definition of the regions is different than in the M. P. World Model).

According to Bischoff (Energiehandbuch) tar sands amount to about 350 x 10^9 (billion) tons of oil, and oil from shale about 200 - 500 x 10^9(billion)tons of oil. Weeks estimate of tarsands amount, however, to 900 x 10^9 tons of oil In Figure 2.1.2. conventinal is compared to unconventional crude oil.

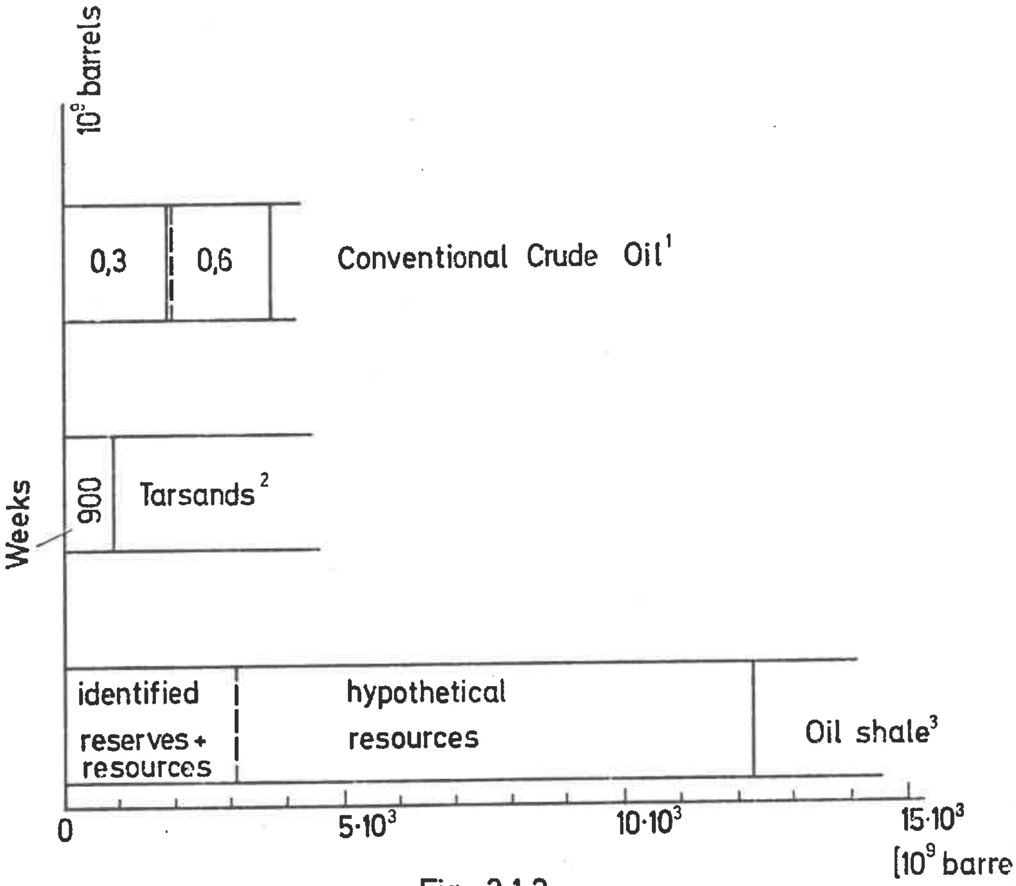

Fig. 2.1.2

Comparison of conventional and nonconventional oil

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[1] The column as a whole refers to the recoverable reserve-resources, assuming a recovery factor of 0.6. Up to the broken line the column shows the crude oil recoverable with present days technology (recovery factor 0.3).
The estimate of ultimate oil in place was taken from T. A. Hendricks "Resources of Oil and Gas".

[2] Estimated by Weeks "Finding Oil in The Sea" 1970. The estimate refers to recoverable and paramarginal reserves-resources.

[3] More detailed information is given in Table 2.9.

2.1.2 Nuclear fuels

Uranium

In addition to the fossil fuels the fuels for nuclear reactors have become more important in recent years, as increasingly more electricity production is accomplished through nuclear power. A comparison of the energy content of nuclear and fossil fuels gives an impressive result: The available energy in one gram of uranium 235 is 8.1×10^{10} joules, which corresponds to 2.7 metric tons of coal or 13.7 barrels of crude oil.[1] With such a high energy content in U^{235} it can be economically feasible to mine even low-grade uranium reserves.

As with the previous energy carriers, uranium can be broken down into categories indicating economic feasibility and degree of certainty of the deposits. The cost classification is typically as follows:

	Grade	Prices
Category I:	2 lb U_3O_8/short ton uranium ore	\$ 10/lb U_3O_8
Category II:	.6-2.0 lb U_3O_8/ ...	\$ 10-15/lb U_3O_8
Category III:	.6 lb U_3O_8/...	\$ 15/lb U_3O_8

Categories I and II can be included in the "recoverable" classification; whereas Category III is presently paramarginal and lower.

The largest interest is naturally in the actual "reserves", and the following table gives an overall view of these:

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[1] Energy and Power, A Scientific American Book, W. H. Freeman and Company, San Francisco.

Table 2.10 - **Uranium Reserves** 1)
(10^3 metric tons of U_3O_8)

Price category	I		II	
REGION	Proven reserves	Probable and possible reserves	Proven reserves	Probable and possible reserves
USA	355	590	172	327
CANADA	210	209	118	153
SSOUTH AFRICA	272	—	—	—
SWEDEN	—	—	318	—
AUSTRALIA	100	5	7	5
FRANCE	35	19	7	12
NIGERIA	20	29	10	10
OTHERS	49	73	296	146
WORLD 2)	1 041	925	928	653

1) Uranium 71 J.T. Sherman in Jahrbuch der Atomwirtschaft 73.
2) World total include only western world.

The table only includes data from the western world, since the available sources do not have data on the communist countries.

A typical light water reactor requires .45 to .6 tons of U_3O_8 per Mwe for the initial installation, and about .17 to .19 tons of U_3O_8 per Mwe per year for continuing operation. If one considers the increase in nuclear power application as represented in Fig. (2.3), then the estimated uranium requirements are as shown in Fig. (2.4).

From this one finds that the uranium demands will increase by about 13 % annually. If the light water reactor were to be used in the future, then with this 13 % growth rate the reserves of $3547 \cdot 10^3$ tons U_3O_8 would be exhausted in about 28 years. If one includes in addition the paramarginal Category III in the calculation, which amounts to $1790 \cdot 10^3$ tones more [1], then the lifetime would be increased to 31 years.

Since a 13 % growth rate past 1980 is perhaps unrealistic for the sake of argument, as life index for a declining growth rate will also be calculated as follows. We assume a 13 % growth up to 1980, 10% thereafter until 1990, and after 1990 a growth rate of 8 % (this latter growth rate in light water reactors is somewhat larger than the present overall power plant growth rate). It then turns out that the lifetime for the first two categories of uranium together is 33 years. Use of the third category then lengthens the total lifetime to 38 years.

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[1] Source:Energy and Power, A Scientific American Book , W.H. Freeman and Company, San Francisco

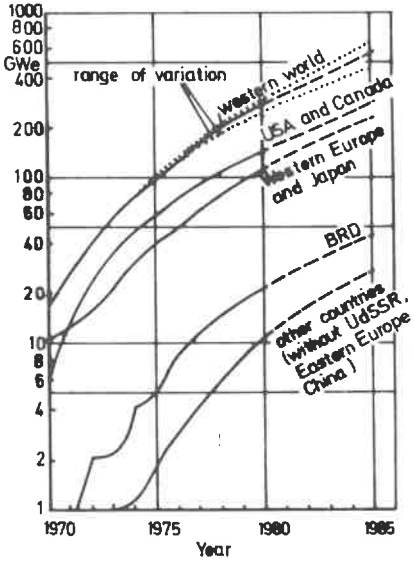

Fig. 2.1.3
Estimated inerease of installed nuclear capacity

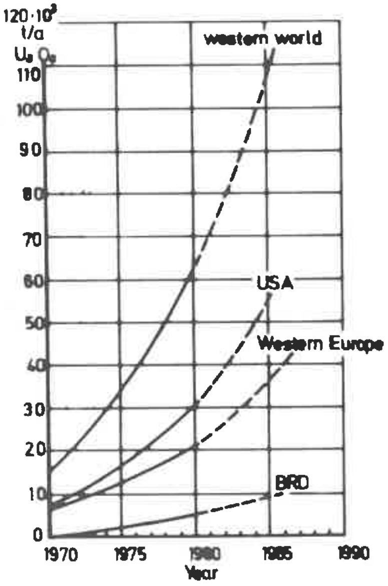

Fig. 2.1.4
Estimated annual uranium demand

When one alters the reactor concept and proceeds with the development and production of breeder reactors, then the fuel situation is altered drastically. In the light water reactor U-235 is the main fissionable material, which is enriched to varying degrees; the actual degree depends largely on the actual reactor type.

Now the conventional reactors have in addition to U-235 an amount of U-238 which by absorption of a neutron is convertible to plutonium 239. This is also fissionable. The ratio of this production of fissionable plutonium to the U-235 which is used up, however, is less than 1. In the breeder reactors this ratio is larger than 1, so that more fissionable material is produced than is used up. Thus although the U-235, which anly accounts for 0.7 % by weight of all uranium, is eventually used up, the conversion of the U-238 isotope to P-239 extends the overall lifetime of the reserves by several orders of magnitude.

M. K. Hubbert estimates that the lifetime of the reserves if used for breeder reactors would be several powers of ten larger than all fossil fuels together - enough to last for thousands of years. (His estimate also takes account of the thorium reserves, which can produce fissionable material by a similar absorption reaction.)

The possible solution to meeting energy requirements using breeder reactors unfortunately has several major disadvantages. The waste products obtained from the fuel elements contain plutonium, 90 % of which is P-239. From the fuel inventory or from these waste products one could obtain large quantities of P-239 without too much effort; weapons would not be difficult to produce using this P-239, which in addition is highly poisonous.

Since the plutonium decay time is very long (about 24400 year halflife), the wastes must be stored in a safe way for hundreds of centuries. It is difficult to estimate today either the exact reliability in the operation of breeders or the dangers associated with the transport of large quantities of waste material; up to the present time the operation of breeders and transportation of materials has been on a practically insignificant scale.

Thorium

In the past there has been no great significance attached to thorium reserves, since the demand has been small. With the development of breeder reactors one can expect this demand to increase. The identified reserves are shown in the following table.

Table 2.11 - Identified Thorium Reserves (10^3 metric tons)

Country	Recoverable primarily as by product or coproduct.	Recoverable primarily for ThO_2 of grade.	
		0.1 %	0.1 %
USA	42	97	129
Australien	45	—	
Brazil	136	13	
Canada	526		
Groenland	—		680
India	408		
Kenya	19		
Korea	5		
Malagasy	9		
Malaysia	18		
Malawi	—		98
South Africa	68		
Uganda	2		
Egypt	9		
Nigeria	14		
Sierra Leone			
Total	1301	110	818

B 734

Other Energy Forms

Tidal Power: Tidal power is obtained from the kinetic energy of the world's oceans. This potential source of energy can be converted to useful energy by filling and emptying a bay or an estuary which can be closed by a dam. The enclosed basin is allowed to fill and to empty only during brief periods at high and low tides in order to develop as much power as possible. There are some promising sites, with potential capacities ranging from two megawatts to 20.000 megawatts each. The total potentially usable tidal power amounts to about 64.000 megawatts, which is only 2 percent of the world's total potential water power. Only one full scale tidal-electric plant has been built; it is on the Rance estuary on the Channel Island coast of France. Its capacity at start-up in 1966 was 240 megawatts; an ultimate capacity of 320 Mw is planned.

Solar Sea Power: The power, which can be delivered from heat engines operating in the tropical oceans by using temperature difference between the warm upper layer and the cold deeper water, may appropriately be called "solar sea power". To extract this energy specially designed ships would be anchored in a favorable location such as the Gulf stream, for example. The warm surface waters are passed through heat exchangers which boil a fluid such as propane or a freon to drive huge turbines coupled to generators. Since the overall temperature differences are small the Carnot efficiency would only be about 3 %. Practically, because of many energy requirements in related machinery and because of many losses, the efficiency obtainable could not be more than about 2 - 2,5 %.

Wind Power: Solar energy sustains the winds. The power potential in the winds over the continental U.S. and the Eastern Seaboard alone exceeds about 100 billion kw electric. The momentum in moving air can be extracted by wind turbines located in suitable locations such as plains, valleys and along the continental coastal shelves. A desireable windpowersystem would include its own electricity storage. Thus it would be able to supply the users even at times when the wind has temporarily diminished. Substantial advances in the design of very light-weight aeroturbines indicate that small as well as large scale wind power generation may be feasible.

2.2 Energy Resource Model

2.2.1 Introduction

The total energy model can be broken down into various submodels: The demand model attempts to clarify the main interactions in that sector, the supply model treats the factors determining which needs are going to be met and in what manner, and the resource model is occupied with the main factors influencing the supply of raw materials. It is the construction of the resources model which will be the subject of the present section. This model is still in its preliminary stages; eventually it is to be integrated into the total energy model.

It was shown in the discussion of fossil fuels in section 2.1. that a small but constant growth rate would lead to their depletion in a few generations. The assumption that a growth rate could be maintained until final exhaustion of the reserves is, of course, completely hypothetical, and it was made in that section merely to give a rough scale of the reserve and resource lifetimes. Whether one assumes a constant growth rate or in some other way tries to extend historic trends into the future, the uncertainties presented by such "static" methods remain. What is needed is a dynamic resources model: a model which attempts to describe the main factors involved in the production of raw materials and which incorporates the interactions among these factors in such a manner so that the model remains a good representation of the resources sector as a function of time. By taking account of the various interlocking effects in the resources sector, one might hope to clarify such details as the following:

1) How technological advandes in extraction methods affect the reserves and resources.
2) Which efforts should be taken in order to maintain the production at a given level, or the static reserve index at a given level.
3) The effect demand, improvements in technology, and the availability of imports on the static reserve index.

A model of this nature might, for example, be able to clarify the reason for a particular production maximum, but necessarily giving also other important details such as which individual oil reserves and resources are exhausted. With the help of such a model, particular behavioral patterns of both the producing industries and of consumers could be simulated in order to determine what the effects would be.

The model is currently being applied to the U.S. oil reserves and resources; it is necessary to clarify that the model also applies to other oil producing regions and to other primary energies. At this point, though,we can check to see that the principal relationships have been accounted for properly, and that the behavior of the model corresponds roughly to reality. The next step is then to couple the demand and supply models to the resources model, in order to procuce the total energy model.

2.2.2 Subdivisions of the resource model

As shown in figure 2.2.1 the resources model is broken down into the submodels of the individual primary energies and these submodels are further broken down regionally; the regions in turn are connected with one another through imports and exports. The primary energy submodels themselves have no direct links with one another. It is assumed that a shortage in a particular primary energy in one region initially increases the demand for that energy in the other regions. The demand in a given region consists of both the demand arising from within the region as well as the demand which comes from other regions. But this can eventually result in an increasing demand for the other primary energies in the first region; thus there can be (and generally are) indirect interactions among the primary energy submodels.

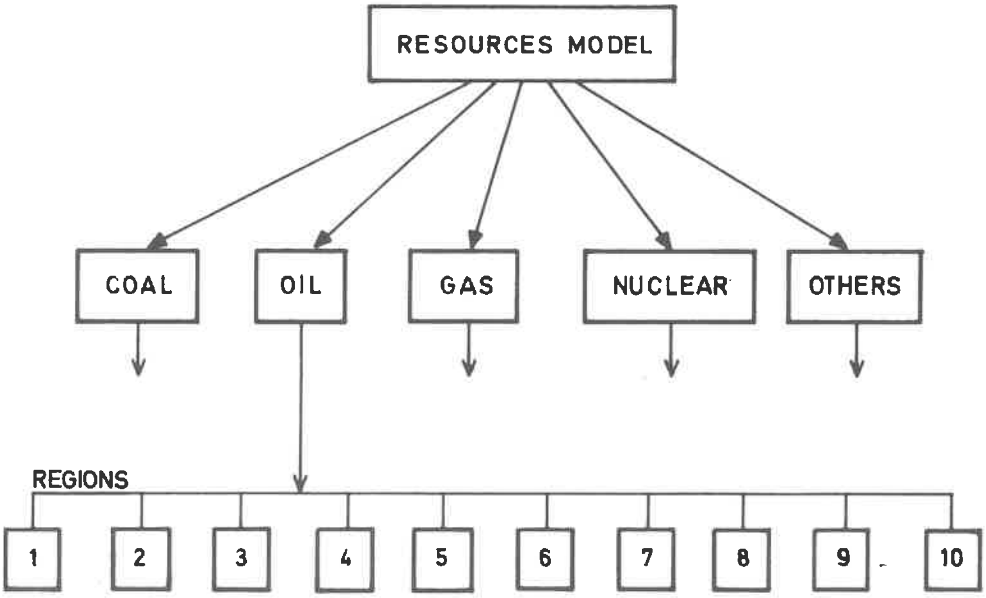

Fig. 2.2.1

2.2.3 Coordination of demands, production, imports and exports

The coordination which takes place with respect to a given primary energy is scheduled in such a manner that production, imports and exports are initially only influenced by the demand. Domestic demand directly influences imports and production of that region, whereas demands from other regions influence that production through their imports obtained from the given region. The direction of these influences is shown in figure 2.2.2.

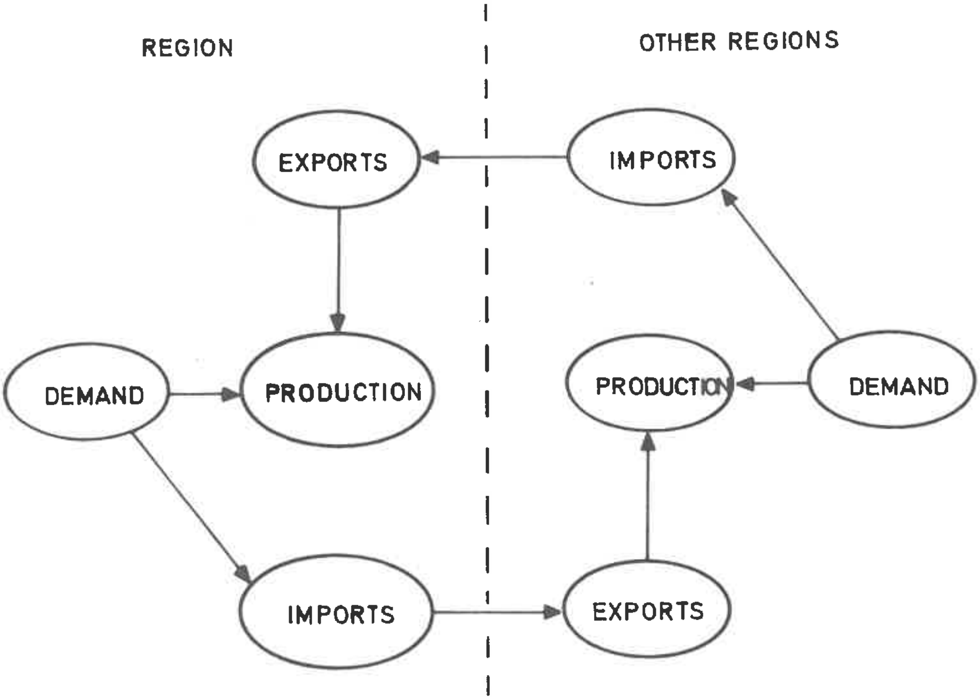

Fig. 2.2.2

Direction of influences from demand

For verification of the model this coordination must take place under the constraint that it remain true to the historical development and that the historical trade balance remains correct. Accordingly a region which is a major producer or consumer of some primary energy can have exports or imports, respectively, accounting for almost 100 % of the total production - this is particularly true for products such as oil.

As long as reserves are available in sufficient quantities in all regions, no limitations are to be expected from the resource model. It is assumed that no changes occur unless the static reserve index falls below a value which is considered "critical". Whether this occurs because of too little exploration or too rapid increase in the production with respect to reserves is unimportant. At this point the controlling effects in the resources model begin to be felt. The production rate is then lowered and, if the region is already an importer of that product, to achieve the desiered supplies the lowered production is compensated through additional imports. If the region is an exporter, however, the lowered production decreases the exports.

Based on the assumption of steady state growth, the direction of the additional influences due to shortages of reserves in one region, are shown in Fig. 2.2.3.

The imports, however, cannot simply be increased arbitrarily since this would cause significant financial burdens for the region and also since there would be limits to the exporting capabilities of the other regions, which are determined in the resource models for the other regions. Now, in the case that sufficient imports are no langer available, the possibilities for a decrease in the demand must be examined, whether it be by through substitution of other energy carriers or by conservation in total energy consumption.

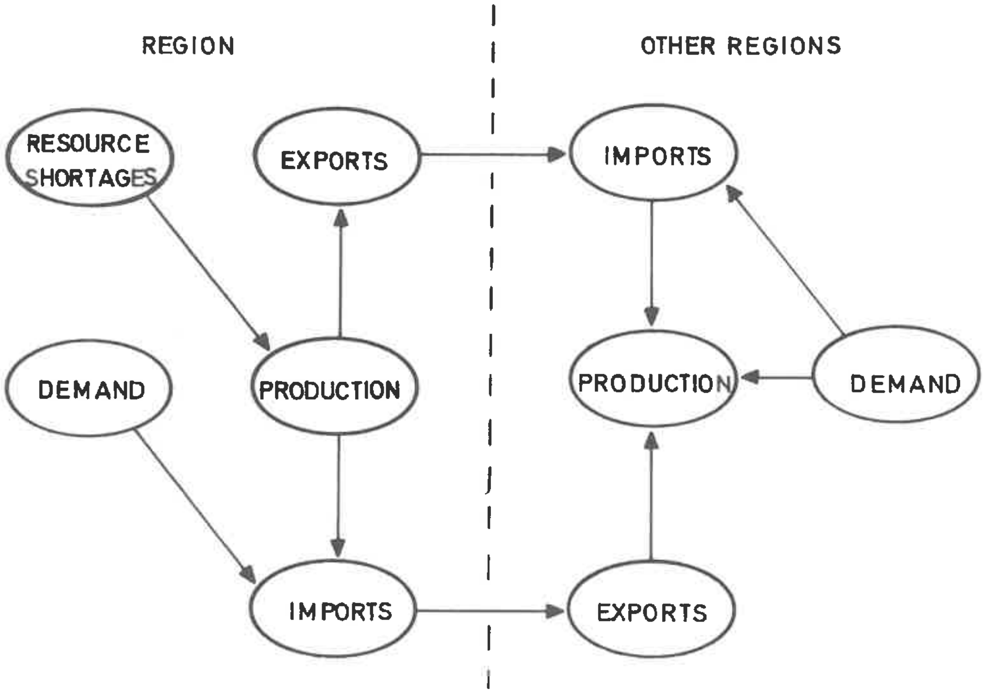

Fig. 2.2.3

Additional influences from recource shortages

2.2.4 Some comments concerning application of the model to U.S. oil

There are several reasons to take the U.S. oil resources as an example for the demonstration of the resource model:

(1) The United States are still the largest producer of oil in the world, so that they are relatively independent from other regions and influences from other regions are felt not too strongly. This is important, because up to now we have not developed models for other regions and cannot simulate those influences from other regions.

(2) The amount of U.S. oil consumption is absolutely as well as per capita much higher than the amount in any other country or region, so that the effects due to resources depletion, which are decreasing domestic production and increasing imports, will be more strongly felt than in other regions.

(3) U.S. oil resources are depleted to a further extent than those of any of the other large producer regions so that shortages due to resources depletion will probably come earlier than in other regions and shortages due to proven reserves are already felt now.

(4) U.S. oil resources are well examined. Drilling efforts as well as many additional geological examinations have been made in previous years, so that fairly good estimates of the resource base are available.

(5) Excellent statistics are available.

2.2.5 Some of the main features of the resource model for U.S. oil

The resource model as applied to U.S. oil is concerned primarily with the production, the proven reserves, and the effects due to technological innovation in extraction methods as measured by the recovery factor.These interactions are sketched in Fig. (2.2.4). The system is actually "controlled" by changes in the various growth rates. Before describing the variables in detail we will give a brief summary of the main features of the model operation below.

If the static reserve index indicates that for a given region there are no longer sufficient proven reserves then it is not assumed that the production itself immediately decreases; initially only the growth rate is lowered. Further on it is assumed that greater engineering efforts are expected to improve the extraction from known reserves, which results in a higher recovery factor. Also, depending on the size of the estimated undiscovered oil resources, one increases the explorations in order to increase the discovery rate.

The effects which are thereby introduced could in principle have two different consequences: Either the reserves are again built up to the point that the reserve index reaches a satisfactory level, or a second problem arises; namely the strongly increasing exhaustion of further resources. In the first case there are no longer restrictions due to shortages in reserves so that the production can once again follow the total demand. In the second case there are several possibilities: (1) One can drastically reduce the production rate in order to maintain a relatively low production rate as long as possible to take advantage of improved extraction methods which develop in the course of time. (2) One continues the production at a high level during which time substitution energies are intensively developed and introduced by the time the oil is exhausted.

Scenarios illustrating these possibilities have been studied in the simulation runs.

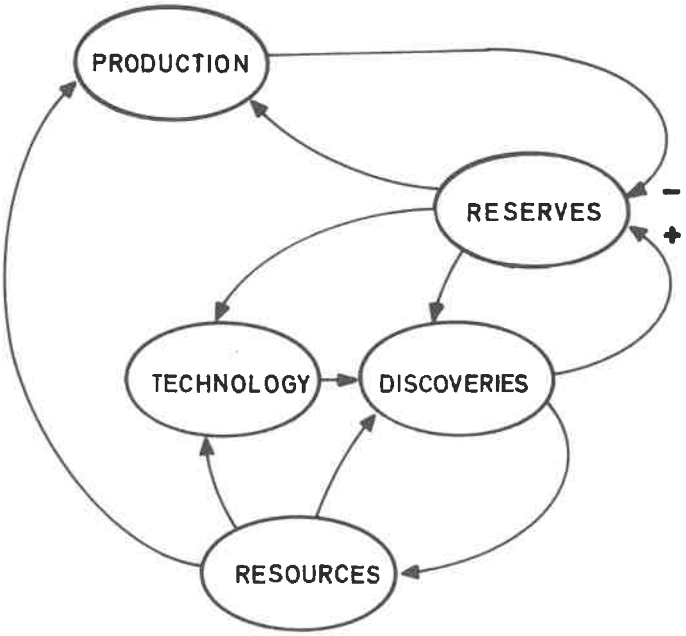

Fig. 2.2.4

Main features of the resource model

2.2.6 Definition of the variables

The labels for the variables were chosen from mnenonic standpoint, so that the equations and the structural SYSTRU-diagram of the model of the U.S. oil resources are more easily understandable. Some letters in the labels, especially the initial letters, often indicate particular meanings, such as

S —— sum, R —— rate, G —— goal, L —— life-index, D —— difference,
Q —— quotient.

The variables are divided into two groups, general variables and control variables. The general variables are general and not specific. to this model and describe the exact physically variables of the mode The control variables are chosen by us to compute the growth rates of production and discoveries and the changing of the recovery factor depending on the availability of reserves and resources. It is emphasized that the chosen control variables are not unique; they represent merely a particular choice.

1. General variables

OIP - original oil-in-place
RPOIP - recoverable part of oil:in-place
POT - remaining part of recoverable part of oil-in place
POTD - potential discoverable part of the recoverable part of oil-in-place
PRO - annual production
SPRO - cumulative production
RPRO - growth rate of production
DIS - part of annual discoveries which is recoverable with actual recovery methods.

SDIS - cumulative value of discoveries
RDIS - growth rage of discoveries
RES - proven reserves (part of POT) corresponding to definition given in chapter 2.1.
REC - recovery factor;indicates the percentage of oil-in-place which is extracted by actual recovery methods
RREC - growth rate of recovery factor

2. Control variables

RL - static life-index of reserves, ratio of reserves to production
GRL - goal for static life-index of reserves
DRL - difference between GRL and RL
QRL - quotient of RL and GRL
DL - life-time of possible discoveries ratio of potiential discoveries to actual yearly discoveries
GDL - goal for DL
DDL - difference of GDL and DL
QDL - quotient of DL and GDL

3. Time indices

0 - initial point of the simulation
t - index for a given year
$t-1$ - previous year
$t+1$ - following year

Symbols which have no superscripts are constants.

2.2.7 Equations

Initial conditions

OIP ——— derived from several estimates of U. S. geologists

$$\left.\begin{array}{l} PRO^{o} \\ SPRO^{o} \\ DIS^{o} \\ SDIS^{o} \\ RPRO^{o} \\ RDIS^{o} \\ REC^{o} \end{array}\right\} \text{smoothed from historical data}$$

(1) $RPOIP^{o} = OIP * REC^{o}$

(2) $POT^{o} = RPOIP^{o} - SPRO^{o}$

(3) $POTD^{o} = RPOIP^{o} - SDIS^{o}$

(4) $RES^{o} = SDIS^{o} - SPRO^{o}$

Model variables

(5) $RPOIP^{t} = OIP * REC^{t}$

(6) $PRO^{t} = PRO^{t-1} * (1 + RPRO^{t})$

(7) $SPRO^{t} = SPRO^{t-1} + PRO^{t}$

(8) $DIS^{t} = DIS^{t-1} * (1 + RDIS^{t}) * (1 + RREC^{t})$

(9) $SDIS^{t} = SDIS^{t-1} + DIS^{t}$

(1o) $POTD^{t} = POTD^{t-1} * (1 + RREC^{t}) - DIS^{t}$

(11) $RES^{t} = RES^{t-1} * (1+RREC^{t})+DIS^{t} - PRO^{t}+TT * SPRO^{t} * RREC^{t}$

(12) $POT^{t} = POTD^{t} + RES^{t}$

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Control variables

(13) $RL^{t} = RES^{t}/PRO^{t}$

(14) $DRL^{t} = GRL - RL^{t}$

(15) $QRL^{t} = RL^{t}/GRL$

(16) $DL^{t} = POTD^{t}/DIS^{t}$

(17) $DDL^{t} = GDL - DL^{t}$

(18) $QDL^{t} = DL^{t}/GDL$

(19) $RPRO^{t+1} = RPRO^{t} - DRL^{t} * QDL^{t} * \text{constant}$

(20) $RDIS^{t+1} = RDIS^{t} - DDL^{t} * QRL^{t} * \text{constant}$

(21) $REC^{t+1} = REC^{t} + DRL^{t} * QDL * \text{constant}$

(22) $RREC^{t+1} - REC^{t+1}/REC^{t-1}$

2.2.8 Description of the Model

Initial values

For the simulation process we need a starting point. One could use the point when oil production first began in 1860, but for the initial period only rough estimates are available. Effects of shortages in reserves and additional resources cannot be studied for this period.

For this reason we choose a point in time when still only primary extraction methods were used and therefore the recovery factor has changed little and can therefore be regarded as constant throughout the previous period. This is clearly not the case in reality, but this assumption introduces only a small error in the whole simulation.

With help of figures 2.2.5 and 2.2.6 we shall explain now how the variables used in the model were computed at the starting point of the simulation and why this was done. As already said before, an estimate of the original oil in place is the basis for further computations. But in case of oil it is clear that only a part of the original oil in place can be recovered and only this part is important for future production.

We call this the "recoverable part of oil in place" and compute it as the oil-in-place multiplied by the recovery factor.
It is evident that this part increase with a higher recovery factor; these dynamic effects are explained in the next chapter.

$$RPOIP = OIP * REC \qquad (1)$$

We get the remaining part of the recoverable part of oil-in-place when subtract the cumulative production, which is that part which has already been produced in the past.

We call this still remaining and recoverable part POT as it designates the amount of estimated resources which can be potentially recovered in the future out of the estimated oil in place using current recovery methods.

$$POT^{o} = RPOIP^{o} - SPRO^{o} \qquad (2)$$

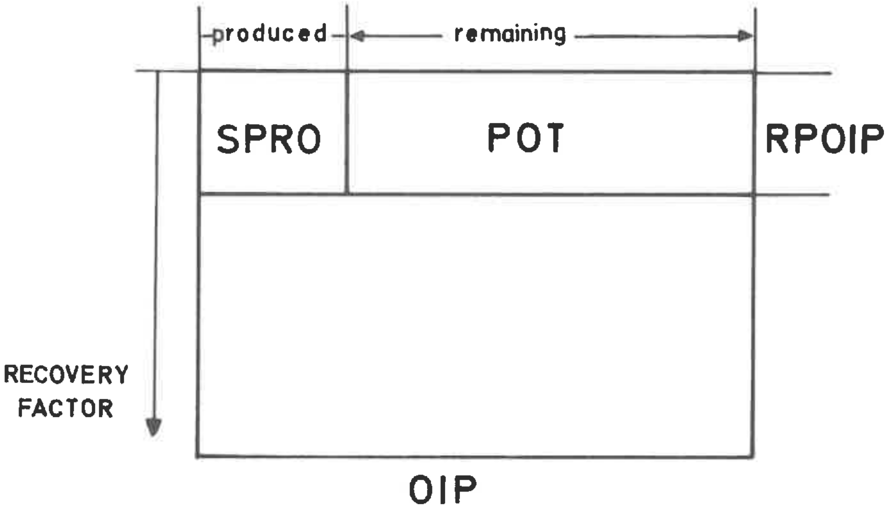


Fig. 2.2.6

Some of the potentially recoverable resources are already discovered and make up the proven reserves (RES). In terms of discoveries and production they are the difference between cumulative discoveries and cumulative production as long as the recovery factor remains constant.

$$RES^{o} = SDIS^{o} - SPRO^{o} \qquad (3)$$

As the proven part of the potentially recoverable resources is already disconvered, we call the part still to be discovered potential discoveries, and compute it as difference between the potential recoverable reserves-resources and the proven reserves.

$$POTD^{o} = POT^{o} - RES^{o} \qquad (4)$$

We need such variables as POT and POTD for the simulation program, because these variables indicate wether there are further production and discoveries possible, respectively. If these values approach zere, production or discoveries must approach zero as well.

The initial values of all variables of which exact historical data are available are listed in the last chapter. They have been smoothed from the available date. Smoothing seems to be meaningful since the historical development of these values has not been continous, so that the samples are a bit random, especially in the case of yearly discoveries and growth rates. Without smoothing the simulation results would have been too strongly dependent upon the choice of the starting year for the simulation. It is clear, however, that the cumulative values do not vary as much as yearly values or growth rates, so that they may be taken from historical data.

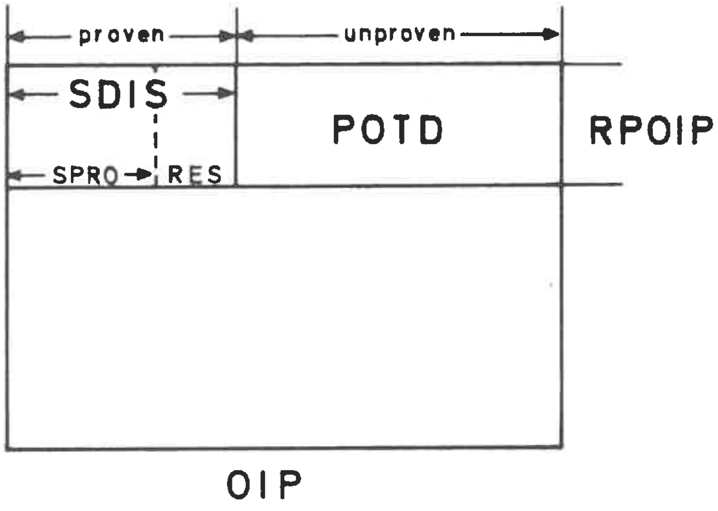


Fig. 2.2.7 Relation of variables at starting point

General Variables

Up to now we discussed only the static state at the beginning of the simulation. We now want to show with the helf of Fig. 2.2.7 how the model responds under the "normal" circumstances of continuing production, and increase in the recovery factor, and some new discoveries. The scales of the figure are somewhat distorted to better show these effects. All variables now carry time indices. We will show how the variables of a year t are derived from those of the previous year t-1 and actual changes during the year t. All actual growth rates and the actual recovery factor of the year t are computed first as functions of the amount of production and remaining recoverable resources, of discoveries, and of potential discoveries from the previous yer t-1. But as these functions are better understood after the explanation of the effects within the model, they shall be described in the following chapter.

When the recovery factor increases, the recoverable part of the oil-in-place increases also to the same extent:

$$RPOIP^{t} = OIP * REC^{t} \qquad (5)$$

The production of a given year is computed in Eq. (6) from that of the previous year t-1 and the actual growth rate of the production. The cumulative production up to an including year t is obtained as shown in Eq. (7) by adding the current year's production to the cumulative production up to year t-1.

$$PRO^{t} = PRO^{t-1} * (1+ RPRO^{t}) \qquad (6)$$

$$SPRO^{t} = SPRO^{t-1} + PRO^{t} \qquad (7)$$

The annual new discoveries in the model are calculated by taking the current recovery level into account. These means that the discoveries are dependent upon two factors: the actual discovery rate and the development of the recovery factor, as expressed in Eq. (8). The decrease in the discovery rate can thus be compensated for by a corresponding increase in the recovery level. At this point changes in the amounts of the finds which are also important have not been considered. In the course of time it generally becomes more and more difficult to discover new resource areas, or expressed in another way, for a given level of reserves addes more and more exploration would be necessary and along with this the necessary costs would also rise more rapidly. The actual cumulative discoveries, as shown in Eq. (9), are summed up from those of the previous year and the actual discoveries.

$$DIS^{t} = DIS^{t-1} * (1 + RDIS^{t}) * (1 + RREC^{t}) \quad (8)$$

$$SDIS^{t} = SDIS^{t-1} + DIS^{t} \quad (9)$$

As already mentioned, the annual new discoveries always take account of the current recovery factor, and the potentially discoverable resources must also be consistent with this factor. To achieve the potentially discoverable resources of year t the part to those of the previous year t-1 has to be added, which comes from the higher recovery factor. Furthermore, the annual discoveries must be subtracted from this value. These considerations are represented in Eq. (10).

$$POTD^{t} = POTD^{t-1} * (1 + RREC^{t}) - DIS^{t} \quad (10)$$

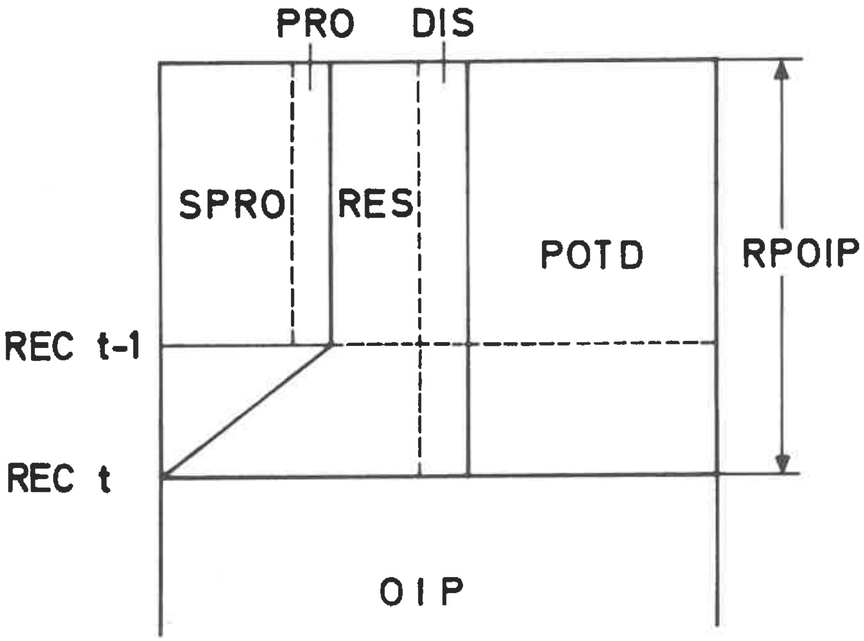


Fig. 2.2.8

Diagram to show the effectes of the dynamic recovery factor

The quantity of oil which one can extract from the already proven reserves naturally also increases when the extraction techniques are improved. This value must also include the difference between the annual discoveries and the production of that year. If one wishes to obtain a realistic value for the actually existing reserves, however, one must include a further effect.

In the extraction process a large part of the originally existing oil is actually left in the ground. However, since the extraction takes place over a long period of time (it can be 20 to 40 years, and sometimes even longer) a fraction of this oil which has been left in the ground is certainly not lost forever; it can eventually be extracted through secondary and tertiary methods. With very large oil fields and with increasing depletion of other sources it is also possible to redevelop areas which are no longer producing and apply new extraction methods. This means that depending upon the state of the art concerning new extraction methods a fraction associated with previous production must be added back to the actual reserves. No one can exactly say how large this fraction should be. But it could lie somewhere between o.5 and 1.

In Fig. 2.2.7 we show the case where half of the fraction will be further recoverable. This gives the triangle shown. Assuming that all of the fraction is still producible, the whole rectangle below the cumulative production will be counted as additional reserves. In Eq. (11) the factor representing the fraction is called TT. In the computer runs, this factor is varied from .5 to 1. to show how this influences amount and duration of the future production.

Eq.(11) $RES^{t} = RES^{t-1} * (1 + RREC^{t}) + DIS^{t} - PRO^{t} + TT * SPRO^{t} * RREC^{t}$

Control Mechanism

Since the total energy model is not yet so developed that the various sub-models could be coupled together with one another the task of designing an adequate resources model is somewhat more difficult; at this point one does not have the advantage of being able to fall back on experiences which actually apply to the operation of the overall model.

Scarcities in the supply, as have occured in the last few years, have clearly not been simply due to actual resource shortages; instead, they have often been due to economic or political reasons. For example, the difficulties relating to gas supplies in the United States can be traced back to artificially low price-levels which prompted no new exploration and therefore led to supply scardities. As another example the so-called oil crisis after the fourth Arab-Israeli War can be traced back to political reasons. This was made clear from the beginning by the Arab initiators of the oil boycott, and was substantiated in the weeks following.

Now, although actual limitations as a consequence of long term resource scarcities have not occured up to now, one is nevertheless interested in knowing what the effects could be. That at some time in the future these scarcities will actually occur there should be no doubt. In order to consider these effects one must take account of the averall economic consequences in addition to considering the availability of reserves and resources. As a result one cannot take technological measures which are arbitrarily large in scope or which increase arbitrarily rapidly; similarly, in the case of production and exploration increases there are certainly economic and above all financial limitations. One would need to be blindly optimistic to overlook these factors. However, there are not only limitations in the case of growth;neither can negative growth (declines) occur arbitrarily rapidly. Here severe economic dislocations are to be avoided. Besides the economic limitations there are naturally others which are based principally on ecological grounds, but which include questions such as the availability of water and other raw materials. These limitations are already described in other publications.

Since we have not yet been able to use directly the economic effects which arise out of the economic model, we have attempted to include the economic limitations described above implicitly for the operation of the resources model. Thus, neither the quantities such as the annual production or discoveries nor their rates are driven directly; rather, changes in the rates are taken into account. This has the advantage that changes in the quantities or the rates only begin to take place very slowly and thereby a relatively continuous behaviour is obtained. However, it does have the disadvantage that the model at least in the present mode of operation reacts too slowly to critical situations.

The question still remains,"What causes the changes to take place?" There is not an absolutely clear answer to this question.

But the experiences in the United States do indicate that the static reserve index plays a significant role. Therefore, we have taken the static reserve index to be the decisive control variable of the model which nevertheless is not completely sufficient by itself. For example, when the reserves decrease too sharply one can initially counteract this by either an increase in the exploration or an increase in the recovery factor. However, if there are no longer resources to discover then a further increase in the discoveries has no meaning. Therefore, we have defined a discovery life index which is derived from estimates concerning inferred resources and numbers on already discovered reserves. This quantity is taken to be the second control variable.

Moreover, threshold values were assigned to the control variables which indicate those points beyond which the control variables are taken to be critical. Four cases are to be distinguished depending upon whether there are adequate proven reserves or not and whether there are adequate existing resources or not.

In the actual simulation the various variables must be initially set at values believed to be appropriate; these values can be taken from the historic data. The simulation then runs freely until the static reserve index chances to go below the previously set threshold value. The goal is thereafter to alter the production discovery and recovering factor consistently in such a manner that the static reserve index once again increases past its threshold and remains above this value as long as possible; for our purposes this is considered to be satisfactory behavior. Here we are not interested in actually developing an optimal strategy since it is sufficient if a previously given level of reserves are available. Abrupt variations have not been admitted to the simulation since this is generally inconsistent with smooth operation of the economy.

In principle the control of the system is similar for each of the four cases mentioned above although the directions and corresponding strength vary. Let us begin with the case where the reserve index has fallen below its threshold but there are still adequate resources. Here the production rate is lowered but the discovery rate and recovery factor can be increased. The size of the changes in the production rate and recovery factor depends upon the difference between the reserve index and the previously given threshold value. The actual threshold value to be used depends upon the scenario and must reflect two factors: the size of the resources, which can only be guessed at, and the influence of demand. If the difference is large (reserve index lies far below the threshold) then the control mechanism has a large influence. However, if there are sufficient resources then the exploration is simply increased and the control mechanism does not cause the production rate to be reduced sharply. A large demand similarly reduces the production rate change. Increases in the recovery factor do not occur as readily if there are large possible resources as opposed to smaller amounts which could be available. We have neglected the dependence of the recovery factor on demand, since this is normally a very small influence. The increase in the discovery rate was analogously established by means of the difference between the discovery life index and its threshold value; this difference was also weighted by the ratio between the reserve index and its threshold value. The end effect is that the discovery rate increase can be fairly large when the resources are large and particularly so when the reserve index is much smaller than its threshold or minimum desirable value.

There is an additional constraint relating to increases in the recovery factor since these cannot continue to increase arbitrarily; an upper limit must exist which naturally must lie under 1oo %. Experts estimate that today the upper limit for this recovery factor lies at about 6o %. Thus, in our simulations we have taken this to be the maximum value and an increase in the recovery factor was made more and more difficult as the maximum value was approached. This, of course, simply recognizes the fact that the initial increases (starting at zero) are much easier to accomplish than when the recovery factor is already large and it is difficult to improve the relevant technologies further.

The second case occurs when the reserves have not yet increased back to the previously given threshold value, and when in addition the resources have declined to such a point that the discovery life index also falls below its threshold value. From this point on the discovery rate decreases, the production is more sharply curtailed, but the recovery factor increases further. All of the changes are controlled as previously in the first case, but more strongly so.

If, however, the reserve index does increase back to its threshold value but nevertheless the resources are so low that the discovery life index falls below its threshold value this means that the discovery rate is sharply reduced but the recovery factor tends to increase. The production rate will also increase somewhat because it is assumed that the production depends primarily upon the proven reserves which for this third case are large enough for an increase in the production rate. This increase, however, is not very large.

The fourth case - where there are both sufficient reserves and sufficient resources - should actually be handled in such a way that the production is only dependent upon the demand and the available imports. However, since up to now the resources model has only been tried out for a single region this sort of coordination has not been possible up to the present time. Instead the parameters were set so that the historical development from about 195o until 1972 was roughly reproduced. Under these conditions it turns out that the changes in the production and discovery rates are very small (the initial 195o production rate was already at a fairly high level of about 3 % annually whereas discoveries were more or less stagnated over this 22-year-period of time).

2.2.9 SYSTRU-diagram

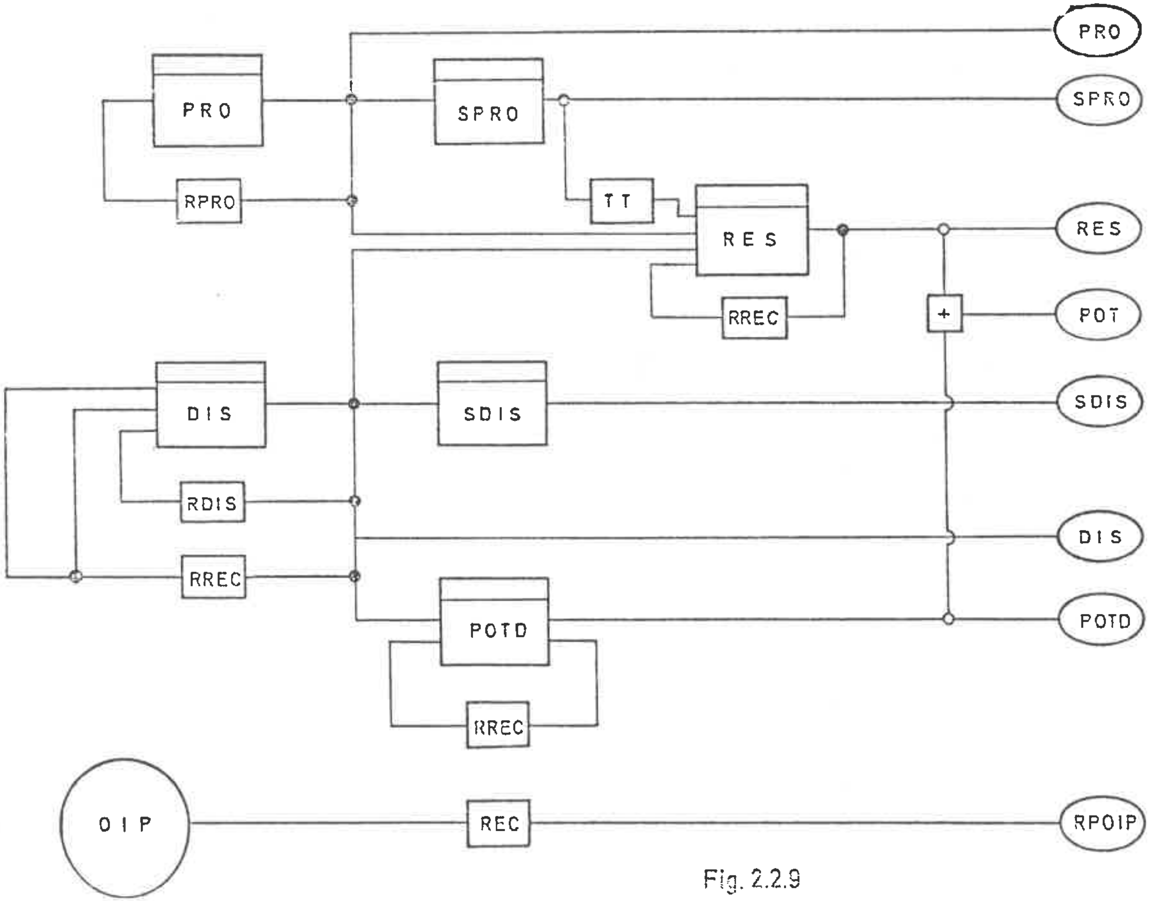


Fig. 2.2.9

2.2.1o Computer Outputs

Commentary on the computer output

The computer output included both graphs and detailed tables of all important values. The graphs give an overall impression of the time varying behavior of the frequently occurring quantities while the tables supplement these by giving the exact values.

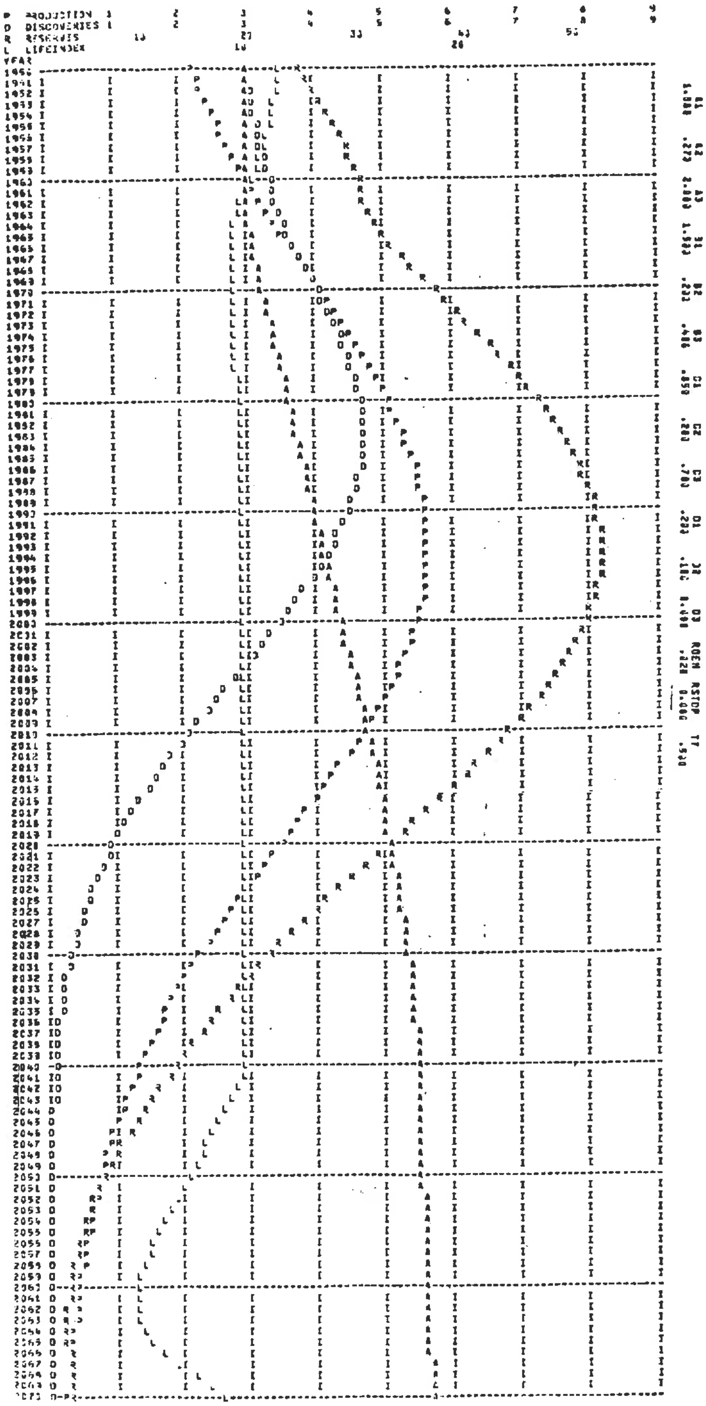
All quantities are given in billions ($1o^9$) of barrels; units for the life-indices are years, and rates are naturally dimensionless.

The important quantities are plotted against time on each graph and it should be emphasized that for each quantity different scales have been used. Regardless of the scales, however, the basic unit corresponds to ten spaces as can be seen. The basic unit for each variable is as follows:

production and discoveries, one billion barrels;
reserves, 2o/3 billion barrels;
recovery rate, 10 %;
discovery life index, 3.33 years, i. e. three basic units = 1o years.

To avoid possible confusion we emphasize that the reserves have been plotted on a scale which is much smaller than the scale for production and discoveries.

Fig. 2.2.10 : STANDARD RUN



YEAR	PRO	DIS	RES	SPRO	SDIS	POT	POTD	RL	DL	REC
1951	2.2	3.0	25.3	40.9	66.2	229.1	203.9	11.5	67.9	.300
1952	2.3	3.0	26.0	43.2	69.2	226.8	200.9	11.6	66.2	.300
1953	2.3	3.1	26.8	45.5	72.3	224.5	197.7	11.5	64.5	.300
1954	2.4	3.1	27.3	47.9	75.4	222.1	194.5	11.4	62.8	.300
1955	2.5	3.1	28.1	50.4	78.5	219.5	191.5	11.4	61.1	.300
1956	2.6	3.2	28.7	52.9	81.7	217.1	188.3	11.2	59.4	.300
1957	2.6	3.2	29.3	55.6	84.9	214.6	185.1	11.1	57.7	.300
1958	2.7	3.2	29.9	58.3	88.1	211.7	181.9	10.9	56.1	.300
1959	2.8	3.3	30.3	61.1	91.4	208.9	178.5	10.7	54.4	.300
1960	2.9	3.3	30.7	64.0	94.7	206.0	175.3	10.5	52.7	.300
1961	3.0	3.4	31.1	67.1	98.1	202.9	171.9	10.3	51.1	.300
1962	3.1	3.4	31.3	70.2	101.5	199.8	168.5	10.1	49.5	.300
1963	3.2	3.4	31.5	73.4	105.0	196.6	165.0	9.8	47.9	.300
1964	3.3	3.5	32.0	76.7	108.5	194.1	162.1	9.6	46.3	.301
1965	3.4	3.6	32.6	80.1	112.1	192.2	159.6	9.5	44.7	.303
1966	3.5	3.6	33.4	83.7	115.7	190.9	157.5	9.4	43.2	.306
1967	3.7	3.7	34.3	87.4	119.4	189.9	155.5	9.4	41.8	.309
1968	3.8	3.8	35.3	91.1	123.2	188.8	153.5	9.4	40.3	.313
1969	3.9	3.9	36.3	95.0	127.1	187.8	151.5	9.4	38.9	.317
1970	4.0	4.0	37.4	99.0	131.1	186.7	149.4	9.4	37.6	.321
1971	4.1	4.1	38.4	103.1	135.1	185.6	147.2	9.4	36.2	.325
1972	4.2	4.1	39.5	107.3	139.3	184.4	144.9	9.4	35.0	.329
1973	4.3	4.2	40.6	111.6	143.5	183.0	142.4	9.4	33.7	.333
1974	4.4	4.3	41.6	116.0	147.8	181.5	139.8	9.4	32.5	.337
1975	4.5	4.4	42.7	120.6	152.2	179.8	137.1	9.4	31.4	.341
1976	4.6	4.4	43.7	125.2	156.6	178.0	134.3	9.5	30.3	.345
1977	4.7	4.5	44.7	129.9	161.1	176.0	131.3	9.5	29.2	.348
1978	4.8	4.5	45.7	134.7	165.6	173.9	128.2	9.5	28.2	.352
1979	4.9	4.6	46.6	139.6	170.2	171.5	125.0	9.5	27.2	.355
1980	5.0	4.6	47.5	144.6	174.8	169.2	121.7	9.5	26.3	.359
1981	5.1	4.7	48.4	149.6	179.5	166.6	118.3	9.5	25.4	.364
1982	5.1	4.7	49.2	154.8	184.2	163.9	114.9	9.6	24.5	.367
1983	5.2	4.7	49.9	160.0	188.9	161.1	111.2	9.6	23.7	.371
1984	5.3	4.7	50.6	165.3	193.6	158.2	107.6	9.6	22.9	.374
1985	5.3	4.7	51.3	170.6	198.3	155.2	103.9	9.6	22.1	.378
1986	5.4	4.7	51.9	176.0	203.0	152.1	100.2	9.6	21.4	.382
1987	5.5	4.7	52.4	181.5	207.6	149.0	96.5	9.6	20.7	.385
1988	5.5	4.6	52.9	187.0	212.2	145.7	92.8	9.6	20.0	.389
1989	5.5	4.5	53.4	192.5	216.8	142.4	89.0	9.6	19.4	.392
1990	5.6	4.5	53.7	198.1	221.4	139.0	85.3	9.6	18.8	.396
1991	5.6	4.5	54.0	203.7	225.9	135.6	81.6	9.6	18.2	.400
1992	5.6	4.4	54.3	209.3	230.3	132.2	77.9	9.7	17.7	.403
1993	5.6	4.3	54.4	214.9	234.6	128.7	74.3	9.7	17.1	.407
1994	5.6	4.3	54.5	220.6	238.9	125.2	70.7	9.7	16.6	.410
1995	5.6	4.2	54.5	226.2	243.0	121.7	67.2	9.7	16.1	.414
1996	5.6	4.1	54.5	231.9	247.1	118.2	63.7	9.7	15.7	.418
1997	5.6	4.0	54.4	237.5	251.0	114.7	60.3	9.7	15.3	.422
1998	5.6	3.9	54.2	243.1	254.9	111.2	57.0	9.7	14.8	.425
1999	5.6	3.7	53.9	248.6	258.6	107.7	53.8	9.7	14.4	.429
2000	5.5	3.6	53.6	254.2	262.2	104.3	50.7	9.7	14.1	.433
2001	5.5	3.5	53.2	259.6	265.7	100.9	47.7	9.7	13.7	.437
2002	5.4	3.3	52.7	265.1	269.0	97.5	44.7	9.7	13.4	.440
2003	5.4	3.2	52.2	270.5	272.2	94.1	41.9	9.7	13.1	.444
2004	5.3	3.1	51.6	275.8	275.3	90.8	39.2	9.7	12.8	.448
2005	5.2	2.9	50.9	281.0	278.2	87.5	36.5	9.7	12.5	.452
2006	5.2	2.8	50.1	286.2	281.0	84.3	34.1	9.7	12.3	.455
2007	5.1	2.6	49.3	291.2	283.7	81.1	31.8	9.7	12.0	.459
2008	5.0	2.5	48.5	296.2	286.2	78.0	29.5	9.7	11.8	.463
2009	4.9	2.4	47.6	301.1	288.5	75.0	27.4	9.7	11.6	.467
2010	4.8	2.2	46.6	305.9	290.7	72.0	25.4	9.7	11.4	.471
2011	4.7	2.1	45.6	310.6	292.8	69.1	23.5	9.7	11.3	.474
2012	4.6	2.0	44.5	315.1	294.9	66.3	21.7	9.7	11.1	.478
2013	4.5	1.9	43.4	319.6	296.6	63.5	20.1	9.8	11.0	.482
2014	4.3	1.7	42.3	323.9	298.3	60.9	18.5	9.9	10.9	.485
2015	4.2	1.6	41.1	328.1	299.9	58.2	17.1	9.9	10.9	.489
2016	4.1	1.4	39.9	332.2	301.3	55.7	15.8	9.9	10.8	.492
2017	4.0	1.3	38.7	336.2	302.7	53.2	14.5	9.9	10.8	.495
2018	3.8	1.2	37.5	340.2	303.9	50.9	13.4	9.9	10.8	.499
2019	3.7	1.1	36.3	343.8	305.0	48.6	12.3	9.9	10.9	.502
2020	3.6	1.0	35.0	347.3	306.1	46.4	11.4	9.9	11.0	.505
2021	3.5	.9	33.7	350.8	307.0	44.3	10.5	9.9	11.2	.508
2022	3.3	.9	32.5	354.1	307.9	42.2	9.7	9.9	11.3	.511
2023	3.2	.8	31.3	357.3	308.7	40.3	9.0	9.9	11.6	.514
2024	3.1	.7	30.0	360.4	309.4	38.4	8.3	9.9	11.9	.517
2025	2.9	.6	28.8	363.3	310.0	36.5	7.8	9.8	12.3	.519
2026	2.8	.6	27.6	366.1	310.5	34.9	7.2	9.9	12.8	.522
2027	2.7	.5	26.4	368.8	311.1	33.2	6.7	9.8	13.4	.524
2028	2.6	.4	25.2	371.4	311.5	31.6	6.3	9.8	14.1	.527
2029	2.5	.4	24.1	373.9	311.9	30.1	6.0	9.8	14.9	.529
2030	2.4	.4	23.0	376.2	312.3	28.6	5.6	9.8	15.8	.531
2031	2.2	.3	21.9	378.5	312.6	27.2	5.3	9.8	16.9	.533
2032	2.1	.3	20.9	380.6	312.9	25.9	5.1	9.8	18.3	.535
2033	2.0	.2	19.9	382.7	313.1	24.6	4.9	9.7	19.9	.537
2034	1.9	.2	18.9	384.6	313.3	23.4	4.7	9.7	21.7	.539
2035	1.8	.2	17.8	386.4	313.5	22.3	4.5	9.7	23.8	.541
2036	1.7	.2	16.9	388.2	313.7	21.2	4.3	9.7	26.4	.542
2037	1.7	.1	16.0	389.9	313.8	20.2	4.2	9.7	29.3	.544
2038	1.6	.1	15.1	391.4	313.9	19.2	4.1	9.7	32.7	.545
2039	1.5	.1	14.3	392.9	314.0	18.3	4.0	9.6	36.7	.547
2040	1.4	.1	13.5	394.3	314.1	17.4	3.9	9.6	41.4	.548
2041	1.3	.1	12.7	395.5	314.2	16.5	3.8	9.6	46.8	.549
2042	1.3	.1	12.0	396.9	314.3	15.6	3.8	9.6	53.1	.550
2043	1.2	.1	11.0	398.0	314.4	14.7	3.7	9.2	60.3	.551
2044	1.1	.1	10.0	399.2	314.4	13.7	3.7	8.9	68.5	.551
2045	1.1	.0	9.2	400.2	314.5	12.8	3.6	8.7	78.1	.551
2046	1.0	.0	8.4	401.2	314.5	12.0	3.6	8.4	88.9	.552
2047	.9	.0	7.7	402.2	314.5	11.2	3.5	8.1	101.0	.552
2048	.9	.0	7.0	403.1	314.6	10.5	3.5	7.8	114.5	.553
2049	.8	.0	6.4	403.9	314.6	9.9	3.5	7.5	129.3	.553
2050	.8	.0	5.9	404.7	314.6	9.3	3.5	7.3	145.3	.554
2051	.8	.0	5.3	405.5	314.6	8.7	3.5	7.0	162.1	.554
2052	.7	.0	4.8	406.2	314.6	8.2	3.4	6.7	179.5	.555
2053	.7	.0	4.3	406.9	314.7	7.7	3.4	6.4	196.5	.555
2054	.6	.0	3.9	407.5	314.7	7.3	3.4	6.1	212.9	.555
2055	.6	.0	3.5	408.1	314.7	6.9	3.4	5.8	227.0	.556
2056	.6	.0	3.1	408.6	314.7	6.5	3.4	5.5	238.4	.557
2057	.5	.0	2.8	409.2	314.7	6.1	3.4	5.2	245.9	.557
2058	.5	.0	2.5	409.7	314.7	5.8	3.4	4.9	248.6	.558
2059	.5	.0	2.2	410.2	314.8	5.6	3.4	4.6	245.4	.559
2060	.4	.0	2.0	410.6	314.8	5.3	3.3	4.4	239.1	.559
2061	.4	.0	1.8	411.0	314.8	5.1	3.3	4.3	227.3	.560
2062	.4	.0	1.7	411.4	314.8	5.0	3.3	4.2	211.7	.560
2063	.4	.0	1.6	411.8	314.8	4.9	3.3	4.2	193.7	.561
2064	.4	.0	1.5	412.2	314.8	4.9	3.3	4.3	174.3	.562
2065	.3	.0	1.4	412.5	314.9	4.8	3.3	4.6	154.9	.563
2066	.3	.0	1.5	412.8	314.9	4.9	3.3	5.0	135.9	.564
2067	.1	.0	1.7	413.1	314.9	4.9	3.2	5.6	115.7	.565
2068	.2	.0	1.8	413.4	314.9	5.0	3.2	6.4	[illegible]	.566
2069	.2	.0	1.9	413.7	315.0	5.1	3.2	[illegible]	88.1	.567
2070	.3	.0	2.0	[illegible]	315.0	5.2	3.1	8.7	[illegible]	.567

Fig. 2.2.11 : HIGH RUN

B 765

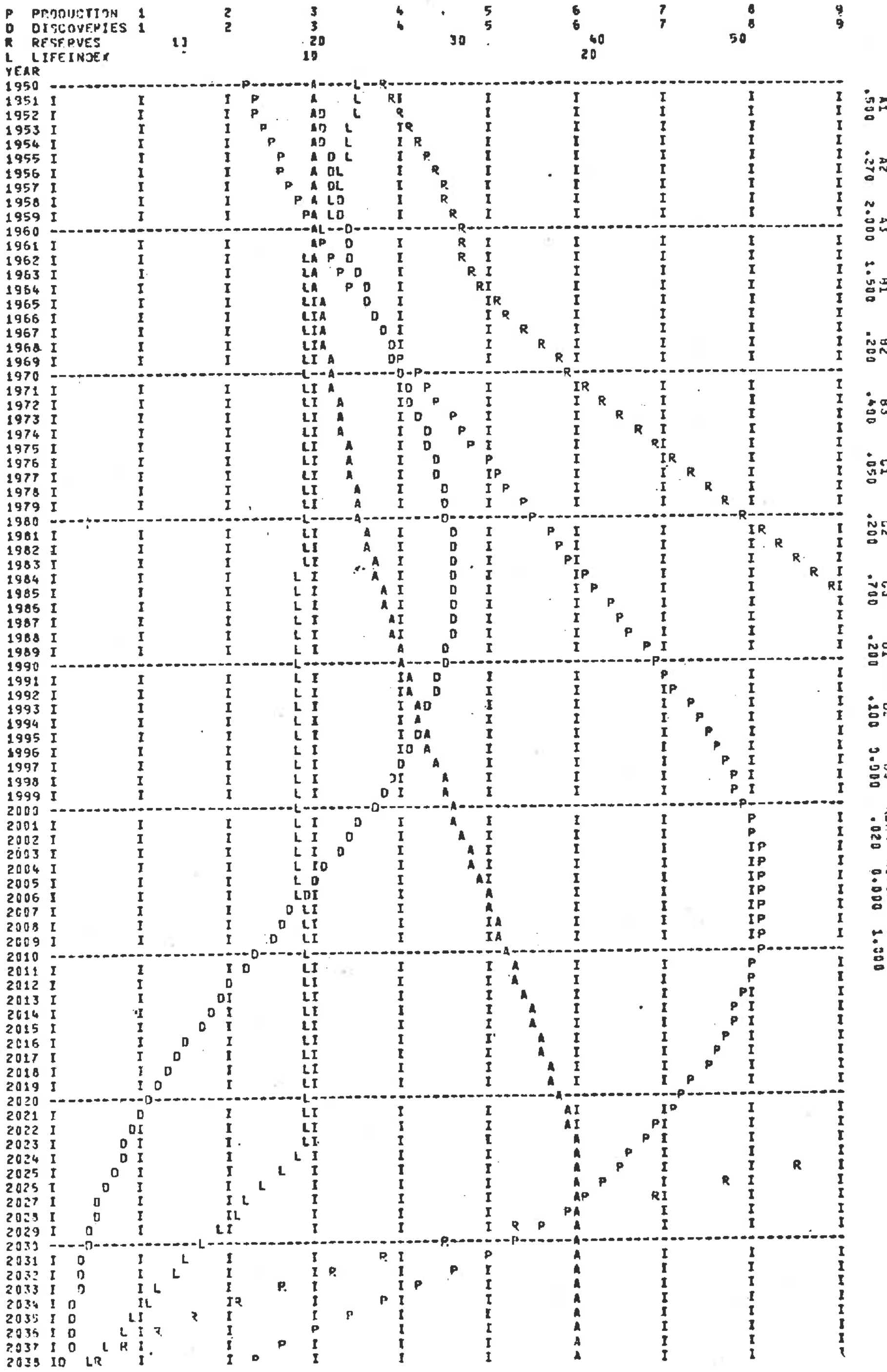
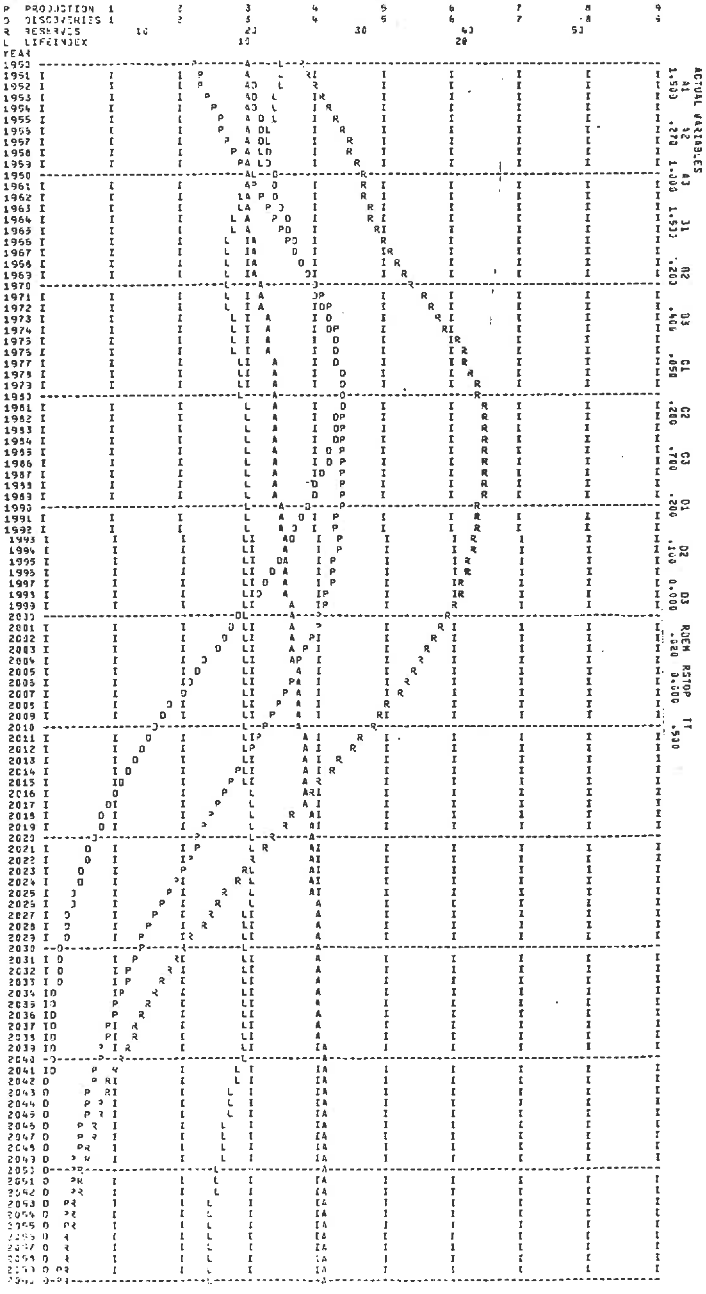


Table 2.2.11 : HIGH RUN

B 766

YEAR	PRO	DIS	RES	SPRO	SDIS	POT	POTO	RL	DL	REC
1951	2.2	3.0	25.3	40.9	66.2	229.1	203.8	11.5	67.9	.300
1952	2.3	3.0	26.0	43.2	69.2	226.9	200.8	11.5	66.2	.300
1953	2.3	3.1	26.8	45.5	72.3	224.5	197.7	11.5	64.5	.300
1954	2.4	3.1	27.5	47.9	75.4	222.1	194.6	11.4	62.8	.300
1955	2.5	3.1	28.1	50.4	78.5	219.6	191.5	11.4	61.1	.300
1956	2.6	3.2	28.7	52.9	81.7	217.1	188.3	11.2	59.4	.300
1957	2.6	3.2	29.3	55.6	84.9	214.4	185.1	11.1	57.7	.300
1958	2.7	3.2	29.8	58.3	88.1	211.7	181.9	10.9	56.1	.300
1959	2.8	3.3	30.3	61.1	91.4	208.9	178.6	10.7	54.4	.300
1960	2.9	3.3	30.7	64.0	94.7	206.0	175.3	10.5	52.7	.300
1961	3.0	3.4	31.1	67.1	98.1	202.9	171.9	10.3	51.1	.300
1962	3.1	3.4	31.3	70.2	101.5	199.8	168.5	10.1	49.5	.300
1963	3.2	3.4	31.6	73.4	105.0	196.6	165.0	9.8	47.9	.300
1964	3.3	3.5	32.1	76.7	108.5	194.2	162.1	9.7	46.3	.301
1965	3.4	3.6	32.9	80.1	112.0	192.5	159.5	9.6	44.7	.303
1966	3.6	3.6	33.9	83.7	115.7	191.0	157.1	9.5	43.2	.305
1967	3.7	3.7	35.0	87.4	119.4	189.7	154.7	9.5	41.8	.308
1968	3.8	3.8	36.1	91.2	123.1	188.4	152.3	9.5	40.3	.310
1969	3.9	3.9	37.2	95.1	127.0	187.1	149.9	9.5	38.9	.313
1970	4.0	3.9	38.4	99.1	130.9	185.7	147.4	9.5	37.6	.316
1971	4.2	4.0	39.6	103.3	134.9	184.4	144.8	9.5	36.3	.319
1972	4.3	4.1	40.8	107.5	139.0	182.9	142.1	9.5	35.0	.322
1973	4.4	4.1	42.0	112.0	143.1	181.5	139.4	9.5	33.8	.326
1974	4.6	4.2	43.3	116.5	147.3	179.9	136.6	9.5	32.6	.329
1975	4.7	4.3	44.6	121.2	151.6	178.4	133.8	9.5	31.4	.332
1976	4.8	4.3	45.9	126.0	155.9	176.7	130.9	9.5	30.3	.336
1977	5.0	4.4	47.2	131.0	160.2	175.1	127.9	9.5	29.3	.339
1978	5.1	4.4	48.5	136.1	164.7	173.4	124.9	9.5	28.2	.343
1979	5.2	4.5	49.8	141.3	169.1	171.6	121.8	9.5	27.3	.347
1980	5.4	4.5	51.1	146.7	173.6	169.8	118.7	9.5	26.3	.351
1981	5.5	4.5	52.5	152.2	178.2	167.9	115.5	9.5	25.4	.355
1982	5.7	4.6	53.8	157.9	182.8	166.0	112.2	9.5	24.6	.359
1983	5.8	4.6	55.2	163.7	187.3	164.1	109.0	9.5	23.7	.363
1984	5.9	4.5	56.5	169.6	191.9	162.1	105.6	9.5	22.9	.367
1985	6.1	4.6	57.8	175.7	196.6	160.1	102.3	9.5	22.2	.372
1986	6.2	4.6	59.1	181.9	201.2	158.1	98.9	9.5	21.4	.376
1987	6.4	4.6	60.4	188.3	205.8	156.0	95.6	9.5	20.8	.381
1988	6.5	4.6	61.7	194.9	210.4	153.9	92.2	9.5	20.1	.386
1989	6.6	4.6	63.0	201.4	214.9	151.8	88.8	9.5	19.4	.391
1990	6.8	4.5	64.2	208.2	219.5	149.6	85.4	9.5	18.8	.396
1991	6.9	4.5	65.5	215.1	224.0	147.5	82.0	9.5	18.3	.401
1992	7.0	4.4	66.6	222.1	228.4	145.3	78.6	9.5	17.7	.406
1993	7.1	4.4	67.8	229.3	232.8	143.1	75.3	9.5	17.2	.412
1994	7.3	4.3	68.9	236.5	237.1	140.9	72.0	9.5	16.7	.417
1995	7.4	4.2	69.9	243.9	241.3	138.6	68.7	9.5	16.2	.423
1996	7.5	4.2	70.9	251.4	245.5	136.4	65.5	9.5	15.7	.428
1997	7.6	4.1	71.9	259.0	249.6	134.1	62.3	9.5	15.3	.434
1998	7.7	4.0	72.8	266.7	253.6	131.9	59.1	9.5	14.9	.440
1999	7.8	3.9	73.6	274.4	257.4	129.6	56.1	9.5	14.5	.446
2000	7.8	3.8	74.3	282.3	261.2	127.4	53.0	9.5	14.1	.452
2001	7.9	3.7	75.0	290.2	264.9	125.1	50.1	9.5	13.7	.458
2002	8.0	3.5	75.6	298.1	268.4	122.9	47.3	9.5	13.4	.464
2003	8.0	3.4	76.1	306.2	271.9	120.6	44.5	9.5	13.1	.470
2004	8.1	3.3	76.5	314.2	275.1	118.3	41.8	9.5	12.8	.477
2005	8.1	3.1	76.9	322.3	278.2	116.1	39.2	9.5	12.5	.483
2006	8.1	3.0	77.1	330.5	281.2	113.8	36.7	9.5	12.2	.489
2007	8.1	2.9	77.3	338.6	284.1	111.6	34.3	9.5	11.9	.496
2008	8.1	2.7	77.3	346.7	286.8	109.3	32.0	9.5	11.7	.502
2009	8.1	2.6	77.3	354.9	289.4	107.1	29.8	9.5	11.5	.509
2010	8.1	2.5	77.1	363.0	291.9	104.9	27.7	9.5	11.3	.515
2011	8.1	2.3	76.8	371.0	294.2	102.6	25.8	9.5	11.1	.521
2012	8.0	2.2	76.5	379.1	296.4	100.4	23.9	9.5	10.9	.527
2013	8.0	2.0	76.0	387.1	298.4	98.2	22.1	9.5	10.8	.534
2014	7.9	1.9	75.5	395.0	300.4	95.9	20.5	9.5	10.7	.540
2015	7.8	1.8	74.8	402.9	302.2	93.7	18.9	9.5	10.6	.546
2016	7.8	1.7	74.1	410.6	303.8	91.5	17.4	9.5	10.5	.552
2017	7.7	1.5	73.2	418.2	305.4	89.3	16.1	9.5	10.4	.558
2018	7.6	1.4	72.3	425.8	306.8	87.1	14.8	9.6	10.4	.564
2019	7.5	1.3	71.2	433.3	308.1	84.9	13.7	9.6	10.4	.569
2020	7.3	1.2	70.1	440.6	309.3	82.7	12.6	9.6	10.4	.575
2021	7.2	1.1	68.9	447.8	310.4	80.6	11.6	9.6	10.5	.580
2022	7.1	1.0	67.7	454.9	311.4	78.4	10.7	9.6	10.6	.585
2023	6.9	.9	66.3	461.8	312.3	76.2	9.9	9.6	10.8	.591
2024	6.8	.8	64.9	468.6	313.2	74.1	9.1	9.6	11.0	.596
2025	6.6	.8	62.7	475.2	313.9	71.2	8.5	9.5	11.2	.600
2026	6.5	.7	56.9	481.7	314.6	64.7	7.8	8.8	11.6	.600
2027	6.3	.6	51.2	488.0	315.2	58.4	7.2	8.1	12.0	.600
2028	6.1	.5	45.7	494.1	315.7	52.3	6.6	7.5	12.4	.600
2029	5.9	.5	40.3	500.9	316.2	46.5	6.2	6.9	13.0	.600
2030	5.4	.4	35.1	505.5	316.6	40.9	5.8	6.3	13.7	.600
2031	5.3	.4	30.2	510.8	317.0	35.6	5.4	5.7	14.5	.600
2032	5.0	.3	25.6	515.8	317.3	30.6	5.1	5.2	15.4	.600
2033	4.6	.3	21.3	520.4	317.6	26.0	4.8	4.6	16.4	.600
2034	4.2	.3	17.3	524.6	317.9	21.5	4.5	4.1	17.6	.600
2035	3.8	.2	13.7	528.4	318.1	18.0	4.3	3.6	19.0	.600
2036	3.4	.2	10.5	531.8	318.3	14.6	4.1	3.1	20.6	.600
2037	3.0	.2	7.7	534.8	318.5	11.6	3.9	2.5	22.5	.600
2038	2.6	.2	5.2	537.5	318.6	8.7	3.8	2.0	24.6	.600
2039	2.3	.1	3.0	539.8	318.8	5.7	3.6	1.2	27.0	.600

Fig. 2.2.12 : LOW RUN



YEAR	PRO	DIS	RES	SPPO	SOIS	POT	POTD	RL	OL	REC
1951	2.2	3.0	25.3	40.9	66.2	229.1	203.8	11.5	67.9	.300
1952	2.3	3.0	26.0	43.2	69.2	226.8	200.8	11.5	66.2	.300
1953	2.3	3.1	26.8	45.5	72.3	224.5	197.7	11.5	64.5	.300
1954	2.4	3.1	27.5	47.9	75.4	222.1	194.6	11.4	62.8	.300
1955	2.5	3.1	28.1	50.4	78.5	219.6	191.5	11.4	61.1	.300
1956	2.6	3.2	28.7	52.9	81.7	217.1	188.3	11.2	59.4	.300
1957	2.6	3.2	29.3	55.6	84.9	214.4	185.1	11.1	57.7	.300
1958	2.7	3.2	29.8	58.3	88.1	211.7	181.9	10.9	56.1	.300
1959	2.8	3.3	30.3	61.1	91.4	208.9	178.6	10.7	54.4	.300
1960	2.9	3.3	30.7	64.0	94.7	206.0	175.3	10.5	52.7	.300
1961	3.0	3.4	31.1	67.1	98.1	202.9	171.9	10.3	51.1	.300
1962	3.1	3.4	31.3	70.2	101.5	199.8	168.5	10.1	49.5	.300
1963	3.2	3.4	31.6	73.4	105.0	196.6	165.0	9.8	47.9	.300
1964	3.3	3.5	31.9	76.7	108.5	193.7	161.8	9.6	46.3	.300
1965	3.4	3.5	32.2	80.1	112.0	191.1	158.9	9.4	44.7	.302
1966	3.5	3.6	32.7	83.7	115.5	188.9	155.2	9.2	43.2	.303
1967	3.6	3.7	33.3	87.3	119.3	186.9	153.6	9.1	41.8	.305
1968	3.7	3.7	34.0	91.1	123.0	185.1	151.1	9.1	40.3	.308
1969	3.8	3.8	34.7	94.9	126.9	183.4	148.7	9.0	38.9	.311
1970	3.9	3.9	35.5	98.9	130.8	181.7	146.2	9.0	37.6	.314
1971	4.0	4.0	36.3	102.9	134.7	180.0	143.7	9.0	36.2	.317
1972	4.1	4.0	37.1	107.0	138.8	178.2	141.1	9.1	35.0	.320
1973	4.2	4.1	38.0	111.1	142.9	176.3	138.4	9.1	33.7	.323
1974	4.2	4.2	38.8	115.3	147.0	174.2	135.5	9.2	32.5	.326
1975	4.3	4.2	39.6	119.6	151.2	172.0	132.4	9.3	31.4	.329
1976	4.3	4.3	40.3	123.9	155.5	169.5	129.1	9.4	30.3	.331
1977	4.3	4.3	41.0	128.2	159.8	166.7	125.7	9.5	29.2	.334
1978	4.3	4.3	41.7	132.5	164.2	163.8	122.1	9.6	28.2	.336
1979	4.4	4.4	42.2	136.9	168.5	160.5	118.4	9.7	27.2	.337
1980	4.4	4.4	42.6	141.3	172.9	157.1	114.5	9.7	26.2	.339
1981	4.4	4.4	43.0	145.7	177.2	153.5	110.5	9.8	25.3	.340
1982	4.4	4.4	43.3	150.1	181.5	149.7	106.4	9.8	24.4	.341
1983	4.4	4.3	43.4	154.5	185.9	145.7	102.3	9.9	23.6	.341
1984	4.4	4.3	43.5	158.9	190.2	141.7	98.2	9.9	22.8	.342
1985	4.4	4.3	43.6	163.2	194.5	137.6	94.0	9.9	22.1	.342
1986	4.4	4.2	43.6	167.6	198.7	133.5	89.9	9.9	21.3	.343
1987	4.4	4.2	43.5	172.0	202.9	129.4	85.9	9.9	20.6	.343
1988	4.4	4.1	43.4	176.4	207.0	125.3	81.9	9.9	20.0	.344
1989	4.4	4.0	43.3	180.8	211.0	121.3	78.0	9.9	19.3	.344
1990	4.4	4.0	43.1	185.2	215.0	117.3	74.2	9.9	18.7	.345
1991	4.4	3.9	42.9	189.5	218.8	113.4	70.5	9.9	18.2	.346
1992	4.3	3.8	42.7	193.9	222.6	109.6	66.9	9.9	17.6	.347
1993	4.3	3.7	42.5	198.2	226.3	105.8	63.3	9.8	17.1	.347
1994	4.3	3.6	42.2	202.5	229.9	102.1	59.9	9.8	16.6	.349
1995	4.3	3.5	41.9	206.7	233.4	98.5	56.6	9.8	16.1	.350
1996	4.2	3.4	41.5	211.0	236.9	95.0	53.4	9.8	15.7	.351
1997	4.2	3.3	41.2	215.2	240.1	91.5	50.3	9.8	15.3	.352
1998	4.2	3.2	40.8	219.3	243.3	88.1	47.3	9.8	14.9	.353
1999	4.1	3.1	40.3	223.5	246.4	84.8	44.4	9.8	14.5	.355
2000	4.1	2.9	39.8	227.5	249.3	81.5	41.6	9.8	14.1	.356
2001	4.0	2.8	39.3	231.5	252.2	78.3	39.0	9.8	13.8	.358
2002	4.0	2.7	38.7	235.5	254.9	75.2	36.5	9.8	13.5	.359
2003	3.9	2.6	38.1	239.4	257.4	72.1	34.0	9.8	13.2	.361
2004	3.8	2.5	37.4	243.2	259.9	69.2	31.7	9.8	12.9	.362
2005	3.7	2.3	36.7	246.9	262.2	66.3	29.5	9.8	12.7	.364
2006	3.7	2.2	36.0	250.6	264.4	63.4	27.4	9.8	12.4	.365
2007	3.6	2.1	35.2	254.2	266.5	60.7	25.5	9.8	12.2	.367
2008	3.5	2.0	34.4	257.7	268.5	58.0	23.6	9.8	12.0	.369
2009	3.4	1.8	33.5	261.1	270.3	55.4	21.9	9.8	11.8	.370
2010	3.3	1.7	32.7	264.4	272.1	52.9	20.2	9.8	11.7	.372
2011	3.2	1.5	31.8	267.7	273.7	50.5	18.7	9.8	11.6	.373
2012	3.1	1.3	30.9	270.8	275.2	48.1	17.3	9.8	11.5	.375
2013	3.0	1.4	29.9	273.9	276.6	45.9	16.0	9.8	11.4	.377
2014	2.9	1.3	28.9	276.9	277.9	43.7	14.7	9.8	11.3	.378
2015	2.8	1.2	28.0	279.6	279.1	41.5	13.6	9.8	11.3	.380
2016	2.7	1.1	27.0	282.4	280.2	39.5	12.5	9.8	11.3	.381
2017	2.6	1.0	26.0	285.0	281.2	37.6	11.6	9.8	11.4	.383
2018	2.5	.9	25.0	287.6	282.2	35.7	10.7	9.8	11.5	.384
2019	2.4	.9	24.1	290.0	283.0	33.9	9.9	9.8	11.6	.385
2020	2.3	.8	23.1	292.4	283.8	32.2	9.1	9.8	11.8	.387
2021	2.2	.7	22.1	294.6	284.5	30.5	8.5	9.8	12.0	.388
2022	2.2	.6	21.2	296.9	285.1	29.0	7.8	9.8	12.3	.389
2023	2.1	.6	20.2	298.8	285.7	27.5	7.3	9.8	12.7	.391
2024	2.0	.5	19.3	300.9	286.2	26.1	6.8	9.8	13.2	.392
2025	1.9	.5	18.4	302.7	286.7	24.8	6.4	9.8	13.7	.393
2026	1.8	.4	17.5	304.4	287.1	23.5	6.0	9.8	14.4	.394
2027	1.7	.4	16.7	306.1	287.5	22.3	5.6	9.8	15.1	.395
2028	1.6	.3	15.9	307.7	287.8	21.1	5.3	9.8	16.0	.396
2029	1.5	.3	15.0	309.3	288.1	20.0	5.0	9.8	17.1	.397
2030	1.4	.3	14.2	310.7	288.3	19.0	4.8	9.8	18.4	.398
2031	1.4	.2	13.5	312.1	288.6	18.0	4.5	9.8	19.9	.399
2032	1.3	.2	12.8	313.4	288.8	17.1	4.4	9.8	21.6	.400
2033	1.2	.2	12.1	314.6	288.9	16.2	4.2	9.8	23.6	.401
2034	1.2	.2	11.4	315.8	289.1	15.4	4.0	9.8	25.9	.402
2035	1.1	.1	10.7	316.9	289.2	14.5	3.9	9.8	28.7	.402
2036	1.0	.1	10.1	317.9	289.4	13.9	3.8	9.8	31.9	.403
2037	1.0	.1	9.5	318.9	289.5	13.2	3.7	9.8	35.6	.404
2038	.9	.1	9.0	319.8	289.6	12.6	3.6	9.7	39.8	.404
2039	.9	.1	8.4	320.7	289.6	12.0	3.5	9.7	44.8	.405
2040	.8	.1	7.9	321.5	289.7	11.4	3.5	9.7	50.5	.405
2041	.8	.1	7.3	322.3	289.8	10.7	3.4	9.5	57.1	.406
2042	.7	.1	6.8	323.0	289.8	10.1	3.4	9.4	64.6	.406
2043	.7	.0	6.3	323.7	289.9	9.6	3.3	9.2	73.2	.406
2044	.6	.0	5.8	324.3	289.9	9.1	3.3	9.1	83.0	.407
2045	.6	.0	5.4	324.9	289.9	8.7	3.3	9.0	94.0	.407
2046	.6	.0	5.0	325.5	290.0	8.3	3.2	8.9	106.3	.407
2047	.5	.0	4.7	326.0	290.0	7.9	3.2	8.8	119.8	.408
2048	.5	.0	4.4	326.5	290.0	7.6	3.2	8.7	134.7	.408
2049	.5	.0	4.1	327.0	290.0	7.2	3.2	8.5	150.6	.409
2050	.4	.0	3.8	327.4	290.1	6.9	3.2	8.5	167.5	.409
2051	.4	.0	3.5	327.8	290.1	6.6	3.1	8.4	184.9	.409
2052	.4	.0	3.3	328.2	290.1	6.4	3.1	8.3	202.4	.410
2053	.4	.0	3.0	328.6	290.1	6.1	3.1	8.2	219.5	.410
2054	.3	.0	2.8	328.9	290.1	5.9	3.1	8.1	235.4	.410
2055	.3	.0	2.5	329.3	290.1	5.7	3.1	8.0	249.5	.410
2056	.3	.0	2.4	329.6	290.1	5.5	3.1	8.0	261.1	.411
2057	.3	.0	2.3	329.9	290.2	5.4	3.1	7.9	269.4	.411
2058	.3	.0	2.1	330.1	290.2	5.2	3.1	7.9	274.1	.411
2059	.3	.0	2.0	330.4	290.2	5.1	3.1	7.9	274.9	.412
2060	.2	.0	1.9	330.6	290.2	4.9	3.0	7.9	271.8	.412

2.2.11 Results

In the present model one can change the strength of the functional dependence of production, discoveries, and recovery factors on reserves by varying constant factors in the computation of the respective growth rates. Thus the difference between the actual life-index of the reserves and the corresponding goal results in different changes of the growth rates of production and of the recovery factor. We have used this feature in several computer runs to show possible future developments of U. S. oil production under several conditions. Only some typical runs illustrating the scenarios discussed earlier will be shown here. We use one of the runs giving intermediate results as a "standard" reference, discussing other runs in relationship to this "standard run". This notation is not meant to imply that we consider the standard run any more probable than other runs.

All runs show that discoveries will only grow for a few more decades and will then slowly decrease to zero. This period will last some 5o years. The present amount of production approximately equals the rate of discoveries, and it will surely be higher in the future. This results in efforts increasing the possibilities of additional oil extraction from already known and proven oil fields. All runs show this effect of a dynamic recovery factor very well. However, it should be emphasized again that increases in the recovery factor mean huge investments for research and development in advanced recovery methods. The value of such investments can hardly be debated when one considers the particular advantages of oil (and natural gas) with respect to extraction, transport, storage, handling, and use, and compares them to the respective properties of competing fuels, such as coal, oil shale, or tar sands. Besides, petroleum and natural gas will certainly for some time to come continue to form the basis of chemical industries.

Failing an improvement in the recovery factor, the production curve would have to follow that for the discoveries. The huge difference in the cumulative amounts, as a function of different recovery factors, is obvious from the print plots (Figs. 2.21o to 2.212). In these figures, the area between the two curves represents that difference. It may amount to 1oo to 2oo billion barrels, depending on the recovery factor and on the extent and location of application of improved recovery methods. The potential additional amount form improved recovery methods approximately equals total cumulative U. S. oil production to the present.

Standard run

In the "standard" run (Fig. 2.2.1o) the recovery factor gradually increases to its maximum value. For the next 5o years a nearly constant growth rate of the recovery factor obtains; later this rate decreases as the assumed limit of the recovery factor is approached.

Production still increases until 199o, then remains constant for a short while, and then slowly decreases to zero towards the second half of the next century. The lifetime of reserves increases somewhat due to better recovery methods and then decreases somewhat below its goal value until the recovery factor approaches its limit. As production goes to zero, the life-index increases again. This effect is to be expected and is inconsequential for the simulation. As the life-index of reserves remains nearly constant most of the time, the curve for reserves resembles that for production. However, the amounts of reserves are approximately ten times greater than those of annual production. (Note that these relations are distorted in the print plots due to different scales).

High runs

In the "high" runs (Fig. 2.2.11), the factor controlling the decrease of the production rate when the reserves are below a desired value is very small. As a result, the production still increases when the life-index of the reserves is already less than its goal. In order to reach this goal again, the factor which increases the recovery factor is made quite large in this case, leading to a fast increase of the recovering factor. In addition the factor TT, which secifies that fraction of previously exploited reserves which will be reactivated using improved recovery methods, is set equal to unity, i. e. its maximum value. These changes result in very high production until the end of the century, followed by a drop to zero in less than thirty years. This despite the fact that the most optimistic assumptions with respect to growth of the recovery factor and utilization of previously exploited oilfields have been made. If one compares this course of production with the likely demand, the dire consequences of a constantly growing demand on the oil resources of the United States become very obvious.

Low runs

The results of the "low" runs (Fig. 2.2.12.) show the consequences if the recovery factor is allowed to rise to only 4o %. The total possible production is then only a little higher than with primary methods. The peak of production will thus be less than 4.5 billion barrels, a value which is more than 2 billion barrels lower than in the standard run, and only reaches approximately fifty percent of the high runs. Nevertheless, oil production will again cease at approximately the same time as in the standard run.

B 772

IV.3. ENERGY DEMAND SUBMODEL

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April 1974

Table of Contents

Page

3. Energy Demand Submodel B 775

3.1. Introduction B 775

3.2. Data Base B 777

3.3. Structure of the Aggregate Energy Demand Model B 781

3.4. Estimation of Parameters and Comparative Analysis of Region-Specific Models B 785

3.5. Generic Demand Prediction Approaches B 815

3.6. Scenario Analysis and Assessment of Future Demands B 827

3. A REGIONALIZED MODEL FOR ENERGY DEMAND

3.1 Introduction

Traditionally, future energy demand is determined by a projection of historical trends in a procedure which can be termed 'curve projection' or extrapolation. While this might be reasonable for short term predictions, use of such procedures in long term assessments is highly questionable. Indeed, in the context of a larger model such as the world model such straight projections would likely lead to absurd conclusions which would in turn certainly affect the total model not simply sectoral demands. In sum, curve extrapolation is simply not satisfactory for the scenario assessment approach used in the overall project. A preferable approach is to determine energy demand, both in the aggregate and in reference to specific energy forms, as a function of other development variables and subsystems of the total world system. Only in such a way can alternative patterns of energy demand be assessed as functions of and as determinants of overall development. Essentially this requires construction of an energy demand model which is embedded within the total world model; i.e., it is dependent on the response of some submodels and determines the behavior of others. Development of such a model is the overall objective of this effort. Specifically, at the present time we have developed an energy demand model as a function of the overall economic model and of population. There were intuitive reasons supporting such an approach and, indeed, the analysis as reported here bears out the expectations. "Closing of the loop" by specifying the submodels which depend on the energy demand model will not be done here. However, the model is designed so as to enable its incorporation within a total energy model which will include both production and supply efficiency and users technology, resources development and reserves discoveries, etc.

In this paper we shall only report on the energy demand model on growth and macro level. On the growth level the energy demand will be represented as a function of total net regional output, i.e., the gross regional product (GRP) and the total population level. Specifically, energy consumption will be related to the gross regional product per capita. In future work on the micro level, energy consumption will be specified in terms of primary resources used, i.e., liquid fuel, gas, coal, hydro, nuclear and others.

3.2 Data Base

The data sources for the economic and population variables and indicators are described in appropriate reports elsewhere. As the base for energy data we have used the excellent report by J. Darmstadter, Energy in the World Economy, Resources for the Future, 1971. On occasion an independent check of some data points was also made.

The data were aggregated according to the regionalization in our project. The energy data, both in Darmstadter as well as in other sources such as the U.N. reports, are given in terms of consumption of primary energy. That is, they consist of total energy consumption and not of energy actually delivered to users, i.e. secondary energy. A close relationship between secondary energy and economic variables is more logical than one between primary energy and the economy since much energy is lost in conversion and transmission processes. For instance, the waste heat of nuclear plants currently satisfies no industrial or residential consumption needs, and with a given users technology one cannot expect a reduction of actual energy consumption simply because there is more energy lost in conversion processes (unless, of course, this leads to shortages or higher prices). This effect will be considered in conjunction with the production and energy use model. The data were converted to a common energy equivalent unit. Because of the frequent need in both energy supply and demand statistics for conversion between units, Table I summarizes conversion coefficients used in the project.

TABLE I

Energy Conversion Factors

Fuel Type	BTU Value
1. Crude Oil	
A. Barrel	5.8×10^6
B. Metric Ton	42.3×10^6
2. Natural Gas Liquids -- barrel	4.35×10^6*
3. Natural Gas -- cubic foot	1,032
4. Electricity	
A. Kilowatt-hour	3412.8
B. Megawatt-year	2.992×10^{10}
5. Coal -- undifferentiated short ton	26×10^6
A. Anthracite -- short ton	25.4×10^6
-- metric ton	27.9×10^6
B. Bituminous -- short ton	26.2×10^6
-- metric ton	28.8×10^6
C. Sub-bituminous -- short ton	19.0×10^6
-- metric ton	20.9×10^6
D. Lignite -- short ton	13.4×10^6
-- metric ton	14.7×10^6
6. Nuclear	
A. Uranium -- short ton of U_3O_8 at 1% theoretical	$.56 \times 10^{12}$
-- short ton of U_3O_8 at 80% theoretical	56×10^{12}
B. Fissionable Material -- gram of U-235; 192 MeV fission	74×10^6
C. Thorium -- short ton converted to U-233 at 88% theoretical	58×10^{12}

*Average of two sources with little difference.

Sources: U.S. Department of Interior, *U.S. Energy: A Summary Review*, p. 14; Associated Universities, Inc., *Reference Energy Systems and Resource Data for Use in the Assessment of Energy Technologies*, pp. C-1, C-2; OECD, *1971 Oil Statistics*. p. 7.

The data essentially cover the 1950-65 period, albeit with some gaps which were closed by interpolation. The aggregate energy consumption data for all the regions are given in Table II. For some items, like liquid fuel consumption and production the data goes back to 1925 although only spottily and with many gaps.

TABLE II

Aggregate Energy Consumption Data for All Regions, 1950-1965

Year	North America	Western Europe	Japan	Rest of Developed	Eastern Europe	Latin America	Middle East	Africa	S.E. Asia	China
1950	1276	588	46	57	464	66	18	6.4	47	43
1951	1310	616	53	59	502	71	18	7.2	50	51
1952	1344	645	61	61	539	77	19	8.0	53	59
1953	1378	673	68	63	577	82	19	8.7	57	67
1954	1420	714	67	69	634	94	23	9.9	63	82
1955	1461	754	66	75	691	105	26	11.1	69	98
1956	1509	787	78	78	745	117	29	12.1	75	115
1957	1557	820	90	80	800	129	33	13.1	81	132
1958	1591	832	97	84	845	138	37	13.1	87	166
1959	1625	844	104	87	890	145	40	13.2	92	201
1960	1659	856	111	91	935	153	44	13.3	98	235
1961	1694	885	132	95	979	163	46	14.1	107	265
1962	1772	949	141	98	1042	173	48	14.5	117	267
1963	1860	1014	157	103	1123	177	49	15.4	126	287
1964	1951	1084	174	111	1188	190	52	17.3	128	308
1965	2040	1129	189	122	1256	200	58	18.9	139	323

B 780

Units: Millions of metric tons of coal equivalent.
Source: Joel Darmstadter, *Energy in the World Economy* (Baltimore: Johns Hopkins Press, 1971).

3.3 Structure of the Aggregate Energy Demand Model

In the absence of a documented theory on the dependence of energy consumption on gross economic variables one has to postulate some plausible relationships and test their validity in reference to the available data. The data, however, should not be allowed to determine fully the model construction. Rather, the structure of the model should be based on certain hypotheses where validity is tested by means of data. We shall assume therefore a set of alternative relationships, estimate the parameters, and perform a comparative analysis with respect to historical development as reflected in data.

Two approaches have been investigated:

(1) Region specific models are developed for each of the regions separately giving energy consumption as a function of gross regional product. Each model reflects the specific condition and stage of development in the respective region.

(2) 'Generic' models, which have the stage of economic development as a parameter (explicit or implicit), have been developed so that one and the same relationship between energy consumption and gross regional product can be used for any region and at any stage of development. Obviously, this type of model captures more of the structural relationships and technological change in the actual system and provides a much more reliable basis for future assessments. Actually the two approaches can be considered two subsequent steps in the development of a more sophisticated model.

In the analysis of the first (regionally specific) approach, the seven types of relationships given in Table III have been analyzed. In the first two approaches the coefficient α is a constant while in approaches 3 and 4 α is a function of time, namely a linear function of time and a growth type relationship. The relationships 5-7 are of an elasticity-type relating growth in energy consumption to growth of economic activity, i.e., percentage change in energy consumption to the percentage change in GRP. Thus an elasticity of 2.0 means that every 1% increase in GRP is accompanied by a 2% increase in energy demand. In general, more industrialized regions have lower elasticities than less industrialized regions, because of the large energy requirements of industrialization and the lesser requirements of regions who have acquired basic economic infrastructure and capital stock, and in which services increasingly dominate the GNP. In relationship 5 the elasticity ε is constant while in 6 and 7 it is a function of time. The elasticity in 7 is determined as a "moving average" over a certain number of years.

In the second stage (the development of a generic approach) the same basic relationships given in Table III are used but the respective coefficients were not considered as constants or functions of time. Rather they are treated as functions of changes in the levels of economic development. In other words, the variable coefficients are endogenized within the submodel itself. For example, for Model 1 we have

$$EC = \alpha\ (GRPPC) * GRP$$

TABLE III

Seven Models for the Projection of Energy Demand

Model 1: $EC_t = \alpha \, GRP_t$

Model 2: $EC_t = \alpha \, GRP_t + C$

Model 3: $EC_t = \alpha_t \, GRP_t$ with $\alpha_t = a + bt$

Model 4: $EC_t = \alpha_{t-1}(1 + \rho_t) \, GRP_t$ with $\rho_t = a + bt$

Model 5: $\Delta EC_{t,t+1} = \varepsilon \dfrac{\Delta GRP_{t,t+1}}{GRP_t} EC_t$

Model 6: $\Delta EC_{t,t+1} = \varepsilon_t \dfrac{\Delta GRP_{t,t+1}}{GRP_t} EC_t$ with $\varepsilon_t = a + bt$

Model 7: $\Delta EC_{t,t+1} = \varepsilon_t \dfrac{\Delta GRP_{t,t+1}}{GRP_t} EC_t$

with ε_t = moving average over 5 years.

while for an elasticity type model, say 5,

$$\Delta EC = \varepsilon\ (GRPPC) * \frac{\Delta GRP}{GRP}$$

These two equations are then used for all of the regions both in past validation and for future assessment.

The difficulty in deriving a "universal" or "generic" type of relationship stems from the fact that it depends not only on economic processes but on political decisions as well. In particular, it depends on the approach taken in the implementation of development policies and the adoption of technologies. For example, it is known that in the centrally planned economics there is a planned, staged process in which the emphasis in the early stages is on energy intensive heavy industry with the attention turned to consumption only during the later stages. On the other hand, the balance between consumption and heavy industry in the market economies is more even through the entire path of development. This conclusion is fully supported by the data as will be shown in Sec. 5. To account for these differences the energy model for regions 5 and 10 will contain an explicit policy component. The way in which this component is represented and the specific types of relationships used for α(GRPPC) and ε(GRPPC) will be discussed in more details in Sec. 5.

3.4 Estimation of Parameters and Comparative Analysis of Region-Specific Models

The parameters for the seven models given in Table III have been estimated from the data using a standard least squares estimation procedure; e.g. for Model 1 the coefficient α is selected to minimize the expression

$$\min_{\alpha} \sum_{t} (EC_t - \alpha * GRP_t)^2$$

There are, of course, many other ways to estimate the parameters. In particular, for the elasticity-based Model 5 three methods were tried; these are given in Table IV. The first of the three computes annual elasticities, then averages them to find the final elasticity. The second computes an elasticity factor on the basis of total change in energy consumption and GRP over the entire 15 year period. The third determines the total of annual percentage changes of energy consumption and divides this by the total of annual percentage changes in GRP. The advantage of this computational approach is that it guarantees that the sum of all annual percentage changes in energy consumption is equal to the elasticity times the sum of all annual percentage changes in GRP. There are therefore three variations of the Model 5.

The results of estimation aregiven in Table V where the values for all coefficients are given. Comparison between the models is presented in Table VI where the sum of the squares of deviations of predicted energy consumption values from actual energy consumption values over the entire estimation period are given. The table includes the sum of squares for

TABLE IV

Three Elasticity Computation Approaches

Approach A: $$\varepsilon = \left(\Sigma \frac{\Delta EC_{t,t+1}/EC_t}{\Delta GRP_{t,t+1}/GRP_t} \right)/N$$

Approach B: $$\varepsilon = \frac{\Delta EC_{1,N}/EC_1}{\Delta GRP_{1,N}/GRP_1}$$

Approach C: $$\varepsilon = \left(\Sigma \frac{\Delta EC_{t,t+1}}{EC_t} \right) / \left(\Sigma \frac{\Delta GRP_{t,t+1}}{GRP_t} \right)$$

each of the five models and the various approaches to computing the elasticity, as applied to each of the 10 regions. Note that the models are comparable within each region but not across regions, since scale factors vary among regions. Below the sum of squares is the ranking of each method for each region -- the higher the rank, the better the fit between data and model. At the bottom of each column is the average rank of that model across all 10 regions.

Table VI indicates that Model 2 on average best fits the data. It provides the best fit for all 5 developed regions and relatively good fits for all others. The difficulty with Model 2 is the variability of C for which there is no theoretical or logical interpretation. It varies greatly in magnitude and also changes sign. In three cases (Region 1, 2 and 5) the sign was positive. In the others, it was negative. Model 3

TABLE V

Values of All Model Coefficients

	Model 1	Model 2		Model 3		Model 4		Model 5a	Model 6	
Region	α	α	c	a	b	a	b	ε	a	b
North America	2.96	2.52	229.41	-.0123	27.08	.0100	-197.13	.58	.0825	-160.00
Western Europe	3.40	2.01	128.06	-.0183	38.18	.0109	-21.85	.97	.0051	-8.99
Japan	2.26	2.34	-3.07	.0124	-22.05	-.4186	820.75	1.40	-.0807	159.38
Rest of Developed	2.82	3.01	-5.21	.0113	-19.25	-.0410	80.92	1.26	-.0209	42.13
Communist Europe	4.06	3.36	128.32	-.0525	106.86	.0896	-176.52	.92	.0189	-36.12
Latin America	2.00	2.78	-46.82	.0452	-86.42	-.3992	783.32	1.50	-.0824	1.63
Middle East	1.83	2.20	-6.25	.0313	-59.35	-.1004	197.31	1.15	-.0153	31.02
Africa	.66	1.00	-5.98	.0143	-27.35	-.3043	598.71	1.91	-.0373	74.97
S.E. Asia	1.17	2.15	-66.28	.0401	-77.31	-.2159	425.48	2.21	-.0831	164.84
China	2.70	7.05	-248.59	.2722	-530.11	-.3514	696.99	.79	-.4172	817.20

TABLE VI

The Results of Seven Models

Region	1	2	3	4	5a
North America	36,618 6	12,849 1	18,058 2	28,701 5	171,120 9
Western Europe	23,064 8	8,172 1	8,602 2	11,186 6	24,169 9
Japan	321.5 3	275.3 1	305.1 2	869.8 5	5,893 9
Rest of Developed World	101.8 4	79.4 1	82.5 2	119.5 5	357.1 9
Eastern Europe	50,939 10	5,552 1	8,892 5	7,478 3	41,125 9
Latin America	2,838 9	408.5 4	703.9 5	119.3 2	1,156 7
Middle East	172.6 9	85.6 2	108.0 4	87.5 3	120.4 6
Africa	30.2 9	8.6 1	9.8 2	16.1 4	27.9 8
South East Asia	2,362 9	119.4 3	82.2 1	102.3 2	1,322 8
China	95,712 4	59,832 3	10,385 1	12,865 2	273,998 10
	7.1	1.8	2.4	3.7	8.4

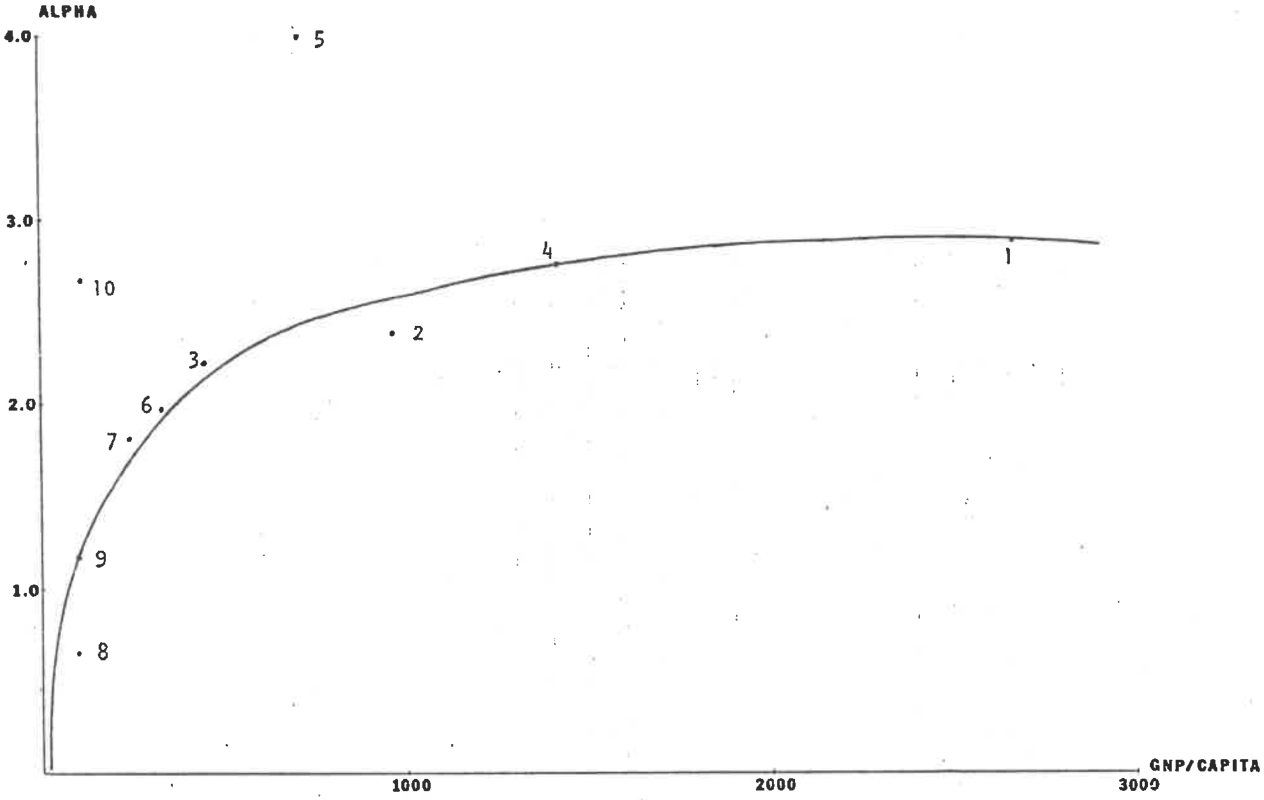
B 789

5b	5c	6	7
20,292	22,659	608,379	85,843
3	4	10	7
9,367	11,272	26,945	9,505
3	7	10	4
3,238	1,043	8,617	780.6
8	6	10	4
261.0	145.1	417.1	128.3
8	7	10	6
18,970	7,744	32,653	9,405
7	4	8	6
3,229	1,192	400.5	1,114
10	8	3	6
116.6	128.1	83.7	162.4
5	7	1	8
111.9	19.6	26.8	16.4
10	6	7	5
128.9	305.9	3,450	296.4
4	6	10	5
253,259	107,673	110,741	242,171
6.7	6.0	7.5	5.9

provides the second best fit. But as in the case of Model 2, it encompasses variations in the coefficients a and b (as shown in Table V) for which no good theoretical explanation exists at present.

Of the models which focus on the relationship between gross national product and energy consumption (rather than on the changes in each) i.e., 1-4, the one which has best balance between data fit, explanation and use in scenario analysis is Model 1. Graph 1 shows the relationship between the alphas from that model and the GRP/POP for each region. With two rather major exceptions, the points are monitonically increasing and the curve is quite smooth. The alphas appear to level off just below 3.0 in the most developed economies. Even the exceptions, however, are interesting. Both communist regions have alphas significantly higher than the non-communist regions of comparable economic development. As mentioned, their economies, with emphasis on development of heavy industry and economic infrastructure at the expense of lighter consumer industry and services appear much more energy intensive than the Western economies. A small proportion of the differences between communist and non-communist regions can be attributed to data differences. The net material product reported by communist countries and used here as GRP data actually exclude some service sectors which add to the gross national products of Western regions. The differences between communist and other regions are, however, far greater than can be explained by data differences.

It should be pointed out that the fit of the predicted energy consumption values using this model to the actual ones of the 1950-65 period is clearly not as close as for Models 2 and 3. Fit is not the sole criterion for selection, however, or even the most important. Naturally Models 2 and 3, with the advantage



Graph 1. Empirical Alphas from Model 1 versus GNP/Capita in 1958

1. North America
2. Western Europe
3. Japan
4. Rest of Developed
5. Eastern Europe
6. Latin America
7. Middle East
8. Africa
9. Southeast Asia
10. China

of additional parameters will fit the data better than Model 1 -- but if that additional parameter has no interpretation, it is highly dependent on the specific data set used in the regression, and can be very misleading in future assessment.

Graph 2 illustrates the fit of Model 1 to data. In most cases, for example North America and Japan, the fit is clearly quite good. In other cases, such as China, the fit is rather poor. None of the models fit the Chinese data at all well. The reason is that the 15-20% decrease in Chinese GNP between 1959 and 1961 (the Great Leap Forward) scarcely slowed energy consumption growth. Interestingly, energy consumption grew relatively little between 1962 and 1965, and economic growth began again. This implies either a time lag before the effect on energy consumption is felt, or poor data reporting.

Turning to the models which focus on changes in GNP and changes in energy consumption, the same distinction appears between those with the additional parameters from regression overtime, and those with single parameters. There is invariably somewhat better fit in the former case, although unlike the above class of models, the differences are small.

Of the three methods for calculating time invariant elasticity coefficients, the best is Approach C (see Table IV). This is understandable because it guarantees that the predicted values of energy consumption in 1965 using Model 5 will be identical to the data value in that year -- that is, the procedure better calculates the real elasticity value of the period for which we have data.

B 793

Region 1

Graph 2.1

```
REGRESSION WITH ALPHA=A CONSTANT **********

NO. OF COEFFICIENTS AND OBSERVATIONS    1  16
                         COMPUTED COEFFICIENTS      2.96112E 00
 DEPENDENT        CALCULATED      DEVIATION       INDEPENDENT
3.17944E 00      2.96112E 00     2.18319E-01      1.00000E 00
2.98024E 00      2.96112E 00     1.91248E-02      1.00000E 00
2.97140E 00      2.96112E 00     1.02762E-02      1.00000E 00
2.92299E 00      2.96112E 00    -3.81286E-02      1.00000E 00
3.05228E 00      2.96112E 00     9.11577E-02      1.00000E 00
2.90293E 00      2.96112E 00    -5.81936E-02      1.00000E 00
2.96067E 00      2.96112E 00    -4.45700E-04      1.00000E 00
2.98020E 00      2.96112E 00     1.90556E-02      1.00000E 00
3.08307E 00      2.96112E 00     1.21947E-01      1.00000E 00
2.96605E 00      2.96112E 00     4.92577E-03      1.00000E 00
2.95945E 00      2.96112E 00    -1.66763E-03      1.00000E 00
2.95540E 00      2.96112E 00    -5.72248E-03      1.00000E 00
2.89682E 00      2.96112E 00    -6.42960E-02      1.00000E 00
2.91702E 00      2.96112E 00    -4.41040E-02      1.00000E 00
2.79117E 00      2.96112E 00    -1.69947E-01      1.00000E 00
2.85879E 00      2.96112E 00    -1.02330E-01      1.00000E 00
     SST =           SSR =           SSH          CHECK SST       MEAN DEP
1.22012E-01      1.22012E-01     0.00000E 00      1.22012E-01    2.96112E 00
COEFFICIENT OF DETERMINATION IS R**2 =  0.0000        THE STANDARD DEVIATION IS    9.0189494E-02
******************************


   ACTUAL           CALCULATED          DIFFERENCE

 1.27634E 03       1.18870E 03        8.76411E 01
 1.31032E 03       1.30191E 03        8.40859E 00
 1.34430E 03       1.33965E 03        4.64907E 00
 1.37827E 03       1.39625E 03       -1.79787E 01
 1.41978E 03       1.37733E 03        4.24026E 01
 1.46130E 03       1.49059E 03       -2.92937E 01
 1.50923E 03       1.50946E 03       -2.27200E-01
 1.55717E 03       1.54720E 03        9.97229E 00
 1.59127E 03       1.52833E 03        6.29405E 01
 1.62537E 03       1.62267E 03        2.69924E 00
 1.65947E 03       1.66041E 03       -9.36220E-01
 1.69486E 03       1.69814E 03       -3.28173E 00
 1.77204E 03       1.81137E 03       -3.93310E 01
 1.86047E 03       1.88860E 03       -2.81289E 01
 1.95120E 03       2.07000E 03       -1.18803E 02
 2.04016E 03       2.11319E 03       -7.30271E 01

 SUM OF SQUARES OF DEVIATIONS = 3.66179E 04
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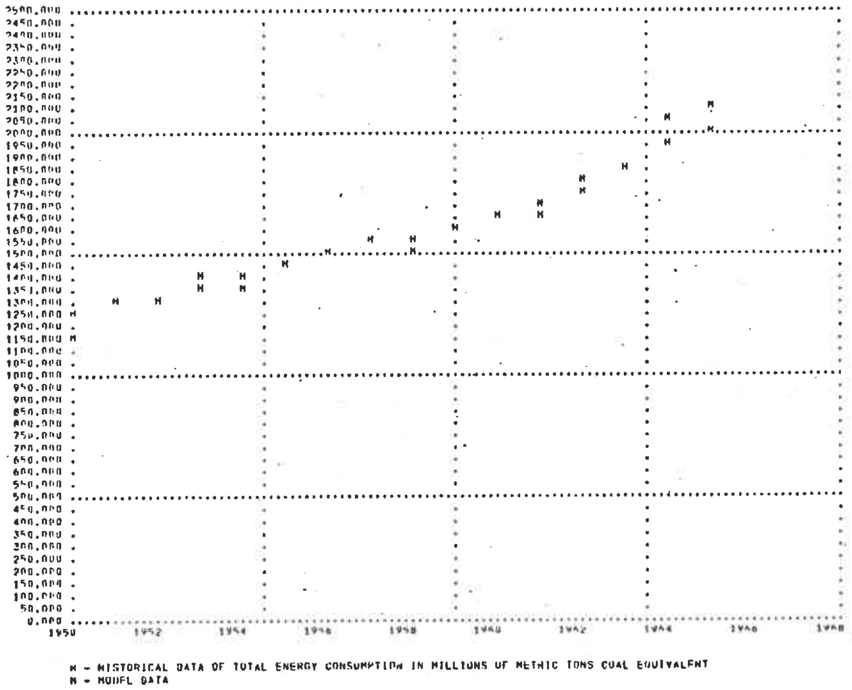


H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

************** NORTH AMERICA   1 **************

B 794 Region 2

Graph 2.2

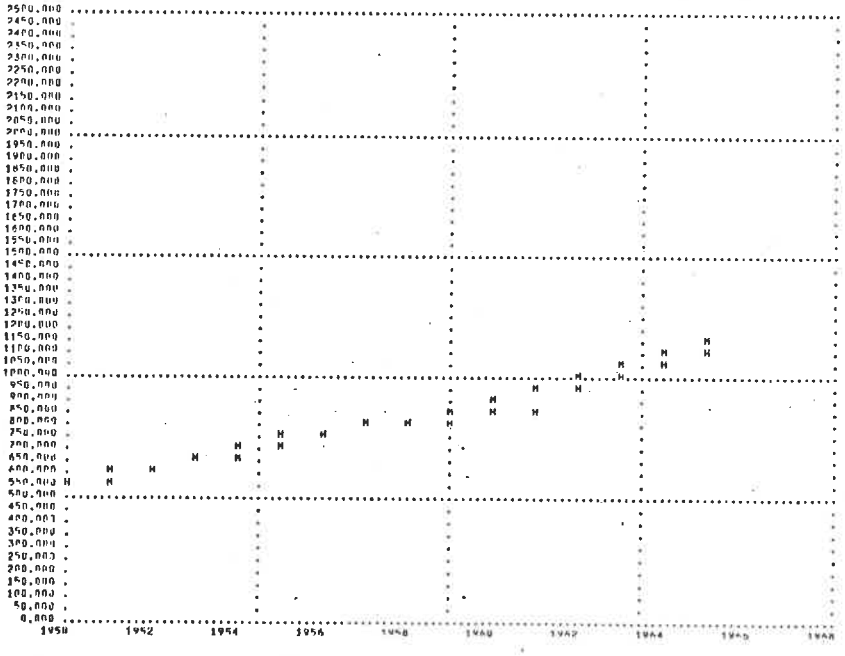
```
REGRESSION WITH ALPHA=A CONSTANT **********

NO. OF COEFFICIENTS AND OBSERVATIONS   1  16
                        COMPUTED COEFFICIENTS    2.40322E 00
 DEPENDENT        CALCULATED      DEVIATION      INDEPENDENT
 2.48762E 00      2.40322E 00     8.43946E-02    1.00000E 00
 2.51500E 00      2.40322E 00     1.11773E-01    1.00000E 00
 2.49759E 00      2.40322E 00     9.43659E-02    1.00000E 00
 2.48174E 00      2.40322E 00     7.85541E-02    1.00000E 00
 2.50903E 00      2.40322E 00     1.05809E-01    1.00000E 00
 2.49723E 00      2.40322E 00     9.40013E-02    1.00000E 00
 2.46354E 00      2.40322E 00     6.03214E-02    1.00000E 00
 2.46546E 00      2.40322E 00     6.22358E-02    1.00000E 00
 2.46941E 00      2.40322E 00     6.61043E-02    1.00000E 00
 2.38157E 00      2.40322E 00    -2.16597E-02    1.00000E 00
 2.24915E 00      2.40322E 00    -1.54070E-01    1.00000E 00
 2.19888E 00      2.40322E 00    -2.04348E-01    1.00000E 00
 2.25799E 00      2.40322E 00    -1.45235E-01    1.00000E 00
 2.31643E 00      2.40322E 00    -8.67902E-02    1.00000E 00
 2.33670E 00      2.40322E 00    -6.65235E-02    1.00000E 00
 2.32419E 00      2.40322E 00    -7.90379E-02    1.00000E 00
     SST =           SSR +            SSM          CHECK SST       MEAN.DEP
 1.71884E-01      1.71884E-01     0.00000E 00    1.71884E-01     2.40322E 00
COEFFICIENT OF DETERMINATION IS R**2 =  0.0000       THE STANDARD DEVIATION IS    1.07046316E-01
****************************


   ACTUAL          CALCULATED        DIFFERENCE

 5.87827E 02      5.67884E 02      1.99425E 01
 6.16328E 02      5.88937E 02      2.73913E 01
 6.44828E 02      6.20465E 02      2.43634E 01
 6.73329E 02      6.52017E 02      2.13124E 01
 7.13672E 02      6.83576E 02      3.00963E 01
 7.54015E 02      7.25632E 02      2.83828E 01
 7.86987E 02      7.67708E 02      1.92792E 01
 8.19959E 02      7.99260E 02      2.06992E 01
 8.32065E 02      8.09764E 02      2.23008E 01
 8.44172E 02      8.51850E 02     -7.67753E 00
 8.56278E 02      9.14934E 02     -5.86562E 01
 8.85246E 02      9.67514E 02     -8.22683E 01
 9.48586E 02      1.00960E 03     -6.10136E 01
 1.01367E 03      1.05166E 03     -3.79831E 01
 1.08390E 03      1.11476E 03     -3.08575E 01
 1.12895E 03      1.16734E 03     -3.83917E 01

 SUM OF SQUARES OF DEVIATIONS = 2.30637E 04
```



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H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

              ************** WESTERN EUROPE      2 *************
```

B 795

Region 3

Graph 2.3

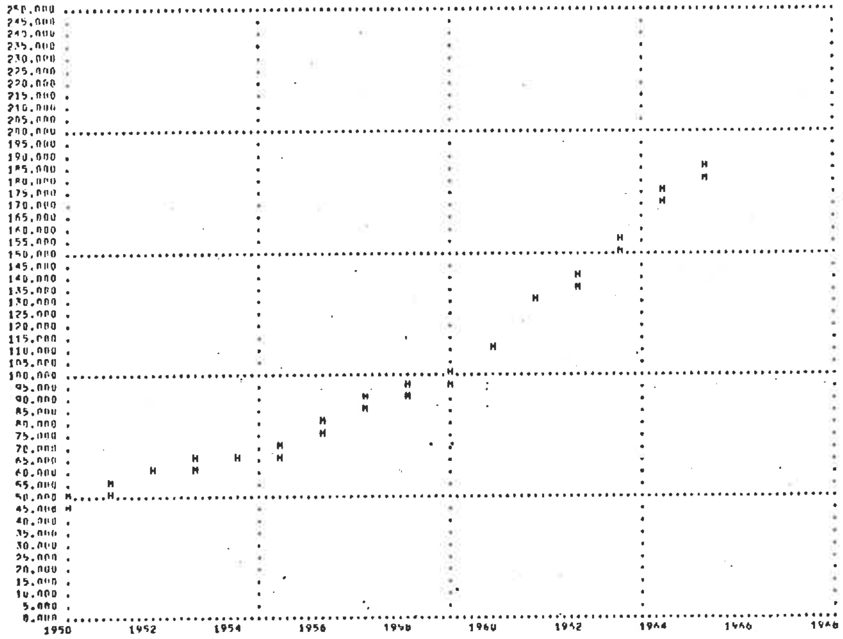
```
REGRESSION WITH ALPHA=A CONSTANT **********

NO. OF COEFFICIENTS AND OBSERVATIONS   1  16
                          COMPUTED COEFFICIENTS    2.25612E 00
  DEPENDENT       CALCULATED      DEVIATION      INDEPENDENT
 1.90507E 00     2.25612E 00    -3.51048E-01     1.00000E 00
 2.11052E 00     2.25612E 00    -1.45596E-01     1.00000E 00
 2.29168E 00     2.25612E 00     3.55618E-02     1.00000E 00
 2.44907E 00     2.25612E 00     1.92949E-01     1.00000E 00
 2.24957E 00     2.25612E 00    -6.55420E-03     1.00000E 00
 2.03170E 00     2.25612E 00    -2.24418E-01     1.00000E 00
 2.21377E 00     2.25612E 00    -4.23469E-02     1.00000E 00
 2.36926E 00     2.25612E 00     1.13140E-01     1.00000E 00
 2.41976E 00     2.25612E 00     1.63646E-01     1.00000E 00
 2.38794E 00     2.25612E 00     1.31818E-01     1.00000E 00
 2.23164E 00     2.25612E 00    -2.44760E-02     1.00000E 00
 2.27305E 00     2.25612E 00     1.69285E-02     1.00000E 00
 2.30716E 00     2.25612E 00     5.10374E-02     1.00000E 00
 2.29748E 00     2.25612E 00     4.13552E-02     1.00000E 00
 2.23390E 00     2.25612E 00    -2.22251E-02     1.00000E 00
 2.32634E 00     2.25612E 00     7.02205E-02     1.00000E 00
      SST =           SSR +            SSH         CHECK SST        MEAN DEP
 3.02712E-01     3.02712E-01     0.00000E 00     3.02712E-01     2.25612E 00
COEFFICIENT OF DETERMINATION IS R**2 =  0.0000       THE STANDARD DEVIATION IS     1.4205923E-01
******************************


    ACTUAL          CALCULATED        DIFFERENCE

  4.58170E 01      5.42597E 01      -8.44270E 00
  5.33540E 01      5.70347E 01      -3.68073E 00
  6.08900E 01      5.99451E 01       9.44876E-01
  6.84270E 01      6.30360E 01       5.39099E 00
  6.74420E 01      6.76385E 01      -1.96495E-01
  6.64570E 01      7.37977E 01      -7.34070E 00
  7.84340E 01      7.99344E 01      -1.50035E 00
  9.04110E 01      8.60936E 01       4.31744E 00
  9.72750E 01      9.06960E 01       6.57895E 00
  1.04138E 02      9.83894E 01       5.74858E 00
  1.11002E 02      1.12219E 02      -1.21744E 00
  1.31655E 02      1.30675E 02       9.80496E-01
  1.41498E 02      1.38368E 02       3.13013E 00
  1.56550E 02      1.53732E 02       2.81794E 00
  1.73529E 02      1.75255E 02      -1.72645E 00
  1.88643E 02      1.82949E 02       5.69418E 00

 SUM OF SQUARES OF DEVIATIONS = 3.21514E 02
```



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H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

              ************** JAPAN  .           3 **************
```

B 796

Region 4

Graph 2.4

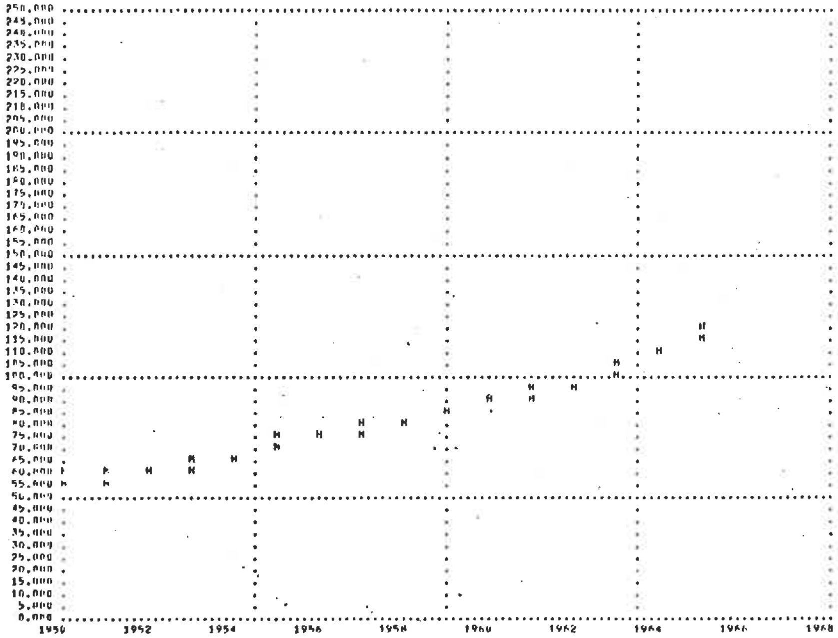
```
REGRESSION WITH ALPHA=A CONSTANT **********

NO. OF COEFFICIENTS AND OBSERVATIONS    1  16
                        COMPUTED COEFFICIENTS     2.82363E 00
 DEPENDENT        CALCULATED      DEVIATION       INDEPENDENT
 2.65643E 00      2.82363E 00    -1.67195E-01     1.00000E 00
 2.70322E 00      2.82363E 00    -1.20408E-01     1.00000E 00
 2.67696E 00      2.82363E 00    -1.46663E-01     1.00000E 00
 2.72152E 00      2.82363E 00    -1.02103E-01     1.00000E 00
 2.80897E 00      2.82363E 00    -1.46574E-02     1.00000E 00
 2.91605E 00      2.82363E 00     9.24262E-02     1.00000E 00
 2.92017E 00      2.82363E 00     9.65466E-02     1.00000E 00
 2.93590E 00      2.82363E 00     1.12277E-01     1.00000E 00
 2.88694E 00      2.82363E 00     6.33310E-02     1.00000E 00
 2.86121E 00      2.82363E 00     3.75812E-02     1.00000E 00
 2.85757E 00      2.82363E 00     3.39435E-02     1.00000E 00
 2.89071E 00      2.82363E 00     6.70853E-02     1.00000E 00
 2.81601E 00      2.82363E 00    -7.61396E-03     1.00000E 00
 2.77532E 00      2.82363E 00    -4.83099E-02     1.00000E 00
 2.79796E 00      2.82363E 00    -2.56640E-02     1.00000E 00
 2.95303E 00      2.82363E 00     1.29404E-01     1.00000E 00
     SST =          SSE +           SSR           CHECK SST        MEAN DEP
 1.35946E-01      1.35946E-01     0.00000E 00     1.35946E-01     2.82364E 00
COEFFICIENT OF DETERMINATION IS R**2 =  0.0000        THE STANDARD DEVIATION IS     9.5200165E-02
*******************************


    ACTUAL          CALCULATED         DIFFERENCE

  5.65820E 01      6.01432E 01      -3.56125E 00
  5.87950E 01      6.14139E 01      -2.61888E 00
  6.10080E 01      6.43504E 01      -3.34245E 00
  6.32210E 01      6.55928E 01      -2.37184E 00
  6.92130E 01      6.95742E 01      -3.61156E-01
  7.52050E 01      7.28213E 01       2.38367E 00
  7.75890E 01      7.50238E 01       2.56524E 00
  7.99740E 01      7.69156E 01       3.05841E 00
  8.35780E 01      8.17440E 01       1.83401E 00
  8.71810E 01      8.60359E 01       1.14510E 00
  9.07850E 01      8.92066E 01       1.57838E 00
  9.46130E 01      9.24173E 01       2.19570E 00
  9.74030E 01      9.76669E 01      -2.63896E-01
  1.02992E 02      1.04785E 02      -1.79278E 00
  1.11191E 02      1.12211E 02      -1.01992E 00
  1.22285E 02      1.16926E 02       5.35862E 00

SUM OF SQUARES OF DEVIATIONS = 1.01783E 02
```



H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

************** REST OF DEV WORLD 4 **************

B 797

Region 5

Graph 2.5

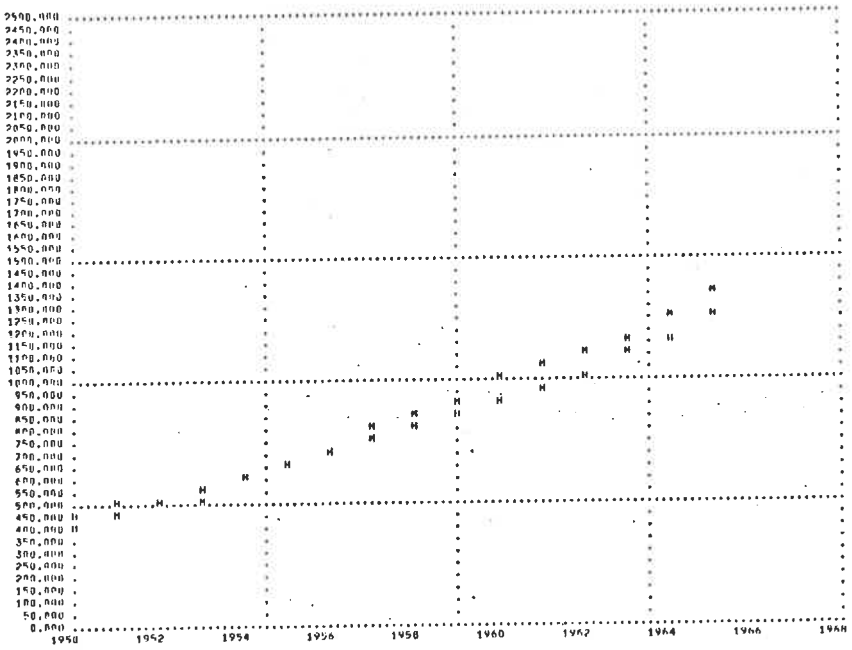
```
REGRESSION WITH ALPHA=A CONSTANT **********

NO. OF COEFFICIENTS AND OBSERVATIONS    1  16
                        COMPUTED COEFFICIENTS     4.05791E 00
  DEPENDENT       CALCULATED       DEVIATION     INDEPENDENT
 4.46866E 00     4.05791E 00     4.10748E-01     1.00000E 00
 4.34705E 00     4.05791E 00     2.89142E-01     1.00000E 00
 4.34617E 00     4.05791E 00     2.88260E-01     1.00000E 00
 4.34569E 00     4.05791E 00     2.87780E-01     1.00000E 00
 4.30849E 00     4.05791E 00     2.50575E-01     1.00000E 00
 4.20307E 00     4.05791E 00     1.45155E-01     1.00000E 00
 4.23538E 00     4.05791E 00     1.77471E-01     1.00000E 00
 4.13645E 00     4.05791E 00     7.85369E-02     1.00000E 00
 4.01008E 00     4.05791E 00    -4.78359E-02     1.00000E 00
 3.85413E 00     4.05791E 00    -2.03776E-01     1.00000E 00
 3.76655E 00     4.05791E 00    -2.91365E-01     1.00000E 00
 3.68971E 00     4.05791E 00    -3.68198E-01     1.00000E 00
 3.76250E 00     4.05791E 00    -2.95414E-01     1.00000E 00
 3.89131E 00     4.05791E 00    -1.66605E-01     1.00000E 00
 3.77645E 00     4.05791E 00    -2.81460E-01     1.00000E 00
 3.78491E 00     4.05791E 00    -2.73005E-01     1.00000E 00
      SST =            SSR +           SSR          CHECK SST       MEAN DEP
 1.07281E 00     1.07281E 00     0.00000E 00     1.07281E 00   . 4.05791E 00
COEFFICIENT OF DETERMINATION IS R**2 =  0.0000       THE STANDARD DEVIATION IS    2.674333HE-01
******************************


     ACTUAL           CALCULATED         DIFFERENCE

   4.64115E 02       4.21455E 02        4.26603E 01
   5.01650E 02       4.68283E 02        3.33670E 01
   5.39186E 02       5.03424E 02        3.57615E 01
   5.76721E 02       5.38529E 02        3.81915E 01
   6.33955E 02       5.97085E 02        3.68699E 01
   6.91190E 02       6.67319E 02        2.38705E 01
   7.45385E 02       7.14152E 02        3.12332E 01
   7.99580E 02       7.84398E 02        1.51817E 01
   8.44558E 02       8.54633E 02       -1.00747E 01
   8.89536E 02       9.36570E 02       -4.70340E 01
   9.34514E 02       1.00680E 03       -7.22904E 01
   9.79331E 02       1.07706E 03       -9.77280E 01
   1.04206E 03       1.12388E 03       -8.18182E 01
   1.12264E 03       1.17071E 03       -4.80655E 01
   1.18758E 03       1.27609E 03       -8.85104E 01
   1.25576E 03       1.34634E 03       -9.05779E 01

   SUM OF SQUARES OF DEVIATIONS = 5.09392E 04
```



```
H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

              ************** EASTERN EUROPE     5 **************
```

B 798   Region 6

Graph 2.6

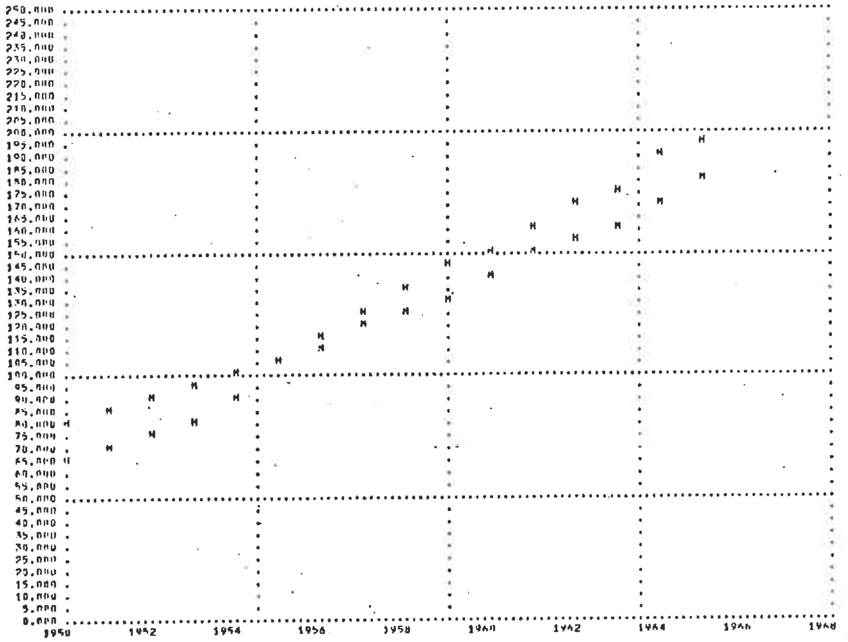
```
REGRESSION WITH ALPHA=A CONSTANT **********

NO. OF COEFFICIENTS AND OBSERVATIONS    1  16
                          COMPUTED COEFFICIENTS     1.99540E 00
  DEPENDENT        CALCULATED      DEVIATION      INDEPENDENT
 1.57846E 00     1.99540E 00    -4.16945E-01     1.00000E 00
 1.61009E 00     1.99540E 00    -3.85306E-01     1.00000E 00
 1.66693E 00     1.99540E 00    -3.28466E-01     1.00000E 00
 1.72029E 00     1.99540E 00    -2.75111E-01     1.00000E 00
 1.81295E 00     1.99540E 00    -1.82448E-01     1.00000E 00
 1.92012E 00     1.99540E 00    -7.52838E-02     1.00000E 00
 2.04846E 00     1.99540E 00     5.30535E-02     1.00000E 00
 2.13777E 00     1.99540E 00     1.42372E-01     1.00000E 00
 2.12841E 00     1.99540E 00     1.33007E-01     1.00000E 00
 2.19799E 00     1.99540E 00     2.02590E-01     1.00000E 00
 2.14591E 00     1.99540E 00     1.99513E-01     1.00000E 00
 2.16570E 00     1.99540E 00     1.79302E-01     1.00000E 00
 2.21154E 00     1.99540E 00     2.16135E-01     1.00000E 00
 2.19000E 00     1.99540E 00     1.94600E-01     1.00000E 00
 2.18315E 00     1.99540E 00     1.87745E-01     1.00000E 00
 2.16863E 00     1.99540E 00     1.73230E-01     1.00000E 00
      SST =           SSR +            SSR         CHECK SST        MEAN DEP
 8.41792E-01     8.41792E-01     0.00000E 00     8.41792E-01     1.99540E 00
COEFFICIENT OF DETERMINATION IS R**2 =  0.0000        THE STANDARD DEVIATION IS     2.3689541E-01
******************************


   ACTUAL            CALCULATED          DIFFERENCE

  6,62370E 01        [illegible] 01      -1,24[illegible] 01
  7,10560E 01        [illegible] 01      -1,20[illegible] 01
  7,66770E 01        9,17864E 01         -1,51094E 01
  8,19030E 01        9,50010E 01         -1,30980E 01
  9,36390E 01        1,03062E 02         -9,42345E 00
  1,05376E 02        1,09508E 02         -4,13158E 00
  1,17377E 02        1,14336E 02          3,04055E 00
  1,29378E 02        1,20762E 02          8,61637E 00
  1,37410E 02        1,28823E 02          8,58695E 00
  1,45441E 02        1,32036E 02          1,34054E 01
  1,53473E 02        1,40097E 02          1,33759E 01
  1,62536E 02        1,49755E 02          1,27812E 01
  1,73119E 02        1,56200E 02          1,69191E 01
  1,76733E 02        1,61029E 02          1,57042E 01
  1,90283E 02        1,73919E 02          1,63639E 01
  1,99514E 02        1,83577E 02          1,59372E 01


SUM OF SQUARES OF DEVIATIONS = 2.83805E 03
```



```
H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

              ************** LATIN AMERICA      6 **************
```

B 799

Region 7

Graph 2.7

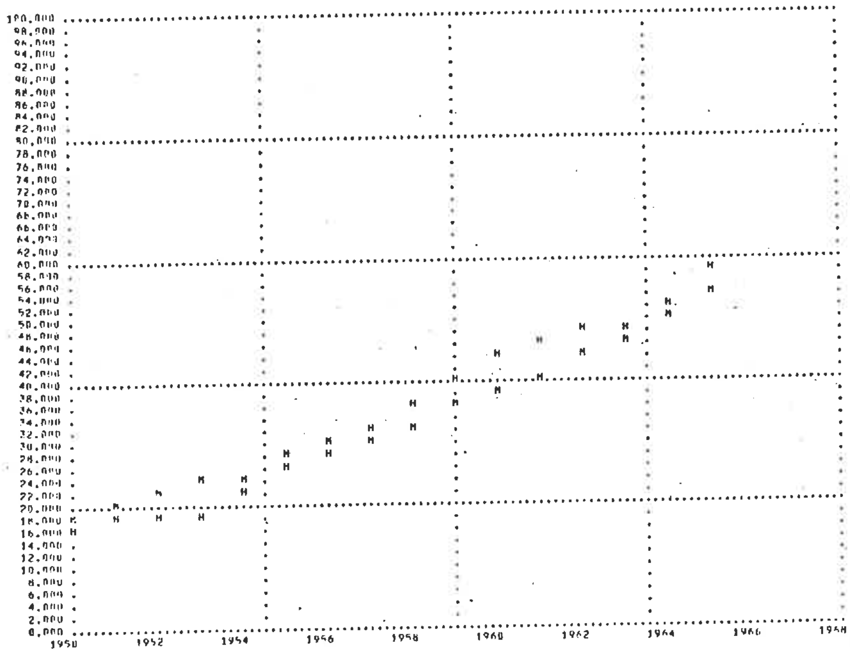
```
REGRESSION WITH ALPHA=A CONSTANT **********

NO. OF COEFFICIENTS AND OBSERVATIONS   1  16
                              COMPUTED COEFFICIENTS    1.82696E 00
  DEPENDENT        CALCULATED       DEVIATION       INDEPENDENT
 1.68210E 00      1.82696E 00    -1.44860E-01     1.00000E 00
 1.62094E 00      1.82696E 00    -2.06015E-01     1.00000E 00
 1.53581E 00      1.82696E 00    -2.91154E-01     1.00000E 00
 1.49166E 00      1.82696E 00    -3.35302E-01     1.00000E 00
 1.62314E 00      1.82696E 00    -2.03819E-01     1.00000E 00
 1.70846E 00      1.82696E 00    -1.18498E-01     1.00000E 00
 1.79976E 00      1.82696E 00    -2.71996E-02     1.00000E 00
 1.88041E 00      1.82696E 00     5.34510E-02     1.00000E 00
 1.97948E 00      1.82696E 00     1.52516E-01     1.00000E 00
 2.04179E 00      1.82696E 00     2.14830E-01     1.00000E 00
 2.09662E 00      1.82696E 00     2.69664E-01     1.00000E 00
 2.08815E 00      1.82696E 00     2.61192E-01     1.00000E 00
 2.00864E 00      1.82696E 00     1.81676E-01     1.00000E 00
 1.89645E 00      1.82696E 00     6.94912E-02     1.00000E 00
 1.87728E 00      1.82696E 00     5.03246E-02     1.00000E 00
 1.90056E 00      1.82696E 00     7.36022E-02     1.00000E 00
      SST =           SSR =           SSP         CHECK SST        MEAN DEP
 5.75976E-01      5.75976E-01     0.00000E 00    5.75976E-01     1.82696E 00
COEFFICIENT OF DETERMINATION IS R**2 =  0.0000       THE STANDARD DEVIATION IS    1.9595543E-01
******************************


    ACTUAL          CALCULATED        DIFFERENCE

  1.76620E 01     1.91830E 01     -1.52103E 00
  1.82680E 01     2.05398E 01     -2.27179E 00
  1.88750E 01     2.24533E 01     -3.57829E 00
  1.94510E 01     2.38300E 01     -4.37904E 00
  2.28700E 01     2.57418E 01     -2.87180E 00
  2.62590E 01     2.80803E 01     -1.82131E 00
  2.94960E 01     2.99414E 01     -4.45401E-01
  3.27380E 01     3.18073E 01      9.30704E-01
  3.65020E 01     3.36891E 01      2.81294E 00
  4.02650E 01     3.60276E 01      4.23744E 00
  4.40290E 01     3.83661E 01      5.66293E 00
  4.59810E 01     4.02296E 01      5.75144E 00
  4.83430E 01     4.37743E 01      4.57313E 00
  4.85660E 01     4.67863E 01      1.77967E 00
  5.23950E 01     5.07903E 01      1.60467E 00
  5.79290E 01     5.56856E 01      2.24340E 00

 SUM OF SQUARES OF DEVIATIONS = 1.72628E 02
```



```
H - HISTORICAL DATA OF TOTAL ENERGY CONSUPPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

              ************** MIDDLE EAST          7 **************
```

```
REGRESSION WITH ALPHA*A CONSTANT **********
```

B 800   Region 8

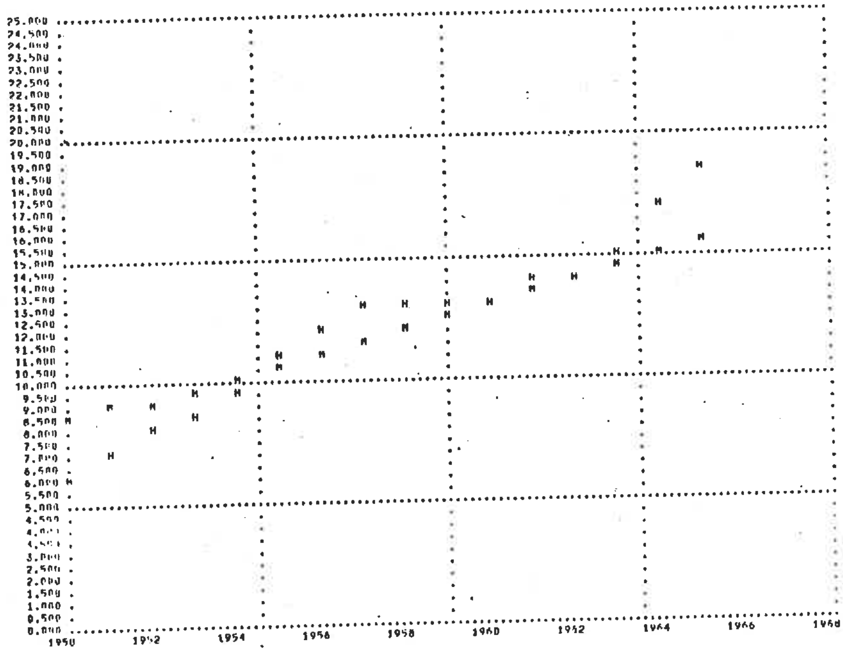
Graph 2.8

```
NO. OF COEFFICIENTS AND OBSERVATIONS    1  16
                                   COMPUTED COEFFICIENTS      6.58711E-01
   DEPENDENT         CALCULATED        DEVIATION          INDEPENDENT
  4.90770E-01       6.58711E-01     -1.67940E-01        1.00000E 00
  5.25712E-01       6.58711E-01     -1.32998E-01        1.00000E .00
  5.56324E-01       6.58711E-01     -1.02386E-01        1.00000E 00
  5.83155E-01       6.58711E-01     -7.55559E-02        1.00000E 00
  6.35573E-01       6.58711E-01     -2.31379E-02        1.00000E 00
  6.82843E-01       6.58711E-01      2.41326E-02        1.00000E 00
  7.09560E-01       6.58711E-01      5.08496E-02        1.00000E 00
  7.32025E-01       6.58711E-01      7.33141E-02        1.00000E 00
  7.05582E-01       6.58711E-01      4.68719E-02        1.00000E 00
  6.79569E-01       6.58711E-01      2.08583E-02        1.00000E 00
  6.55086E-01       6.58711E-01     -3.62494E-03        1.00000E 00
  6.79768E-01       6.58711E-01      2.10577E-02        1.00000E 00
  6.73312E-01       6.58711E-01      1.46011E-02        1.00000E 00
  6.90758E-01       6.58711E-01      3.20477E-02        1.00000E 00
  7.54617E-01       6.58711E-01      9.59062E-02        1.00000E 00
  7.84714E-01       6.58711E-01      1.26004E-01        1.00000E 00
        SST =            SSR +             SSR          CHECK SST        MEAN DEP
  1.00566E-01       1.00566E-01      0.00000E 00      1.00566E-01      6.58711E-01
COEFFICIENT OF DETERMINATION IS R**2 =  0.0000        THE STANDARD DEVIATION IS     8.1880470E-02
******************************
```

```
      ACTUAL             CALCULATED          DIFFERENCE

    6.43400E 00         8.63570E 00        -2.20170E 00
    7.19700E 00         9.01775E 00        -1.82075E 00
    7.96100E 00         9.42615E 00        -1.46515E 00
    8.72400E 00         9.85431E 00        -1.13031E 00
    9.93400E 00         1.02956E 01        -3.61646E-01
    1.11440E 01         1.07502E 01         3.93844E-01
    1.20980E 01         1.12310E 01         8.66985E-01
    1.30520E 01         1.17448E 01         1.30719E 00
    1.31450E 01         1.22718E 01         8.73223E-01
    1.32380E 01         1.28317E 01         4.06319E-01
    1.33310E 01         1.34048E 01        -7.37594E-02
    1.40780E 01         1.36419E 01         4.36105E-01
    1.44560E 01         1.41425E 01         3.13485E-01
    1.53970E 01         1.46827E 01         7.14342E-01
    1.73260E 01         1.51240E 01         2.20201E 00
    1.89430E 01         1.59013E 01         3.04173E 00

 SUM OF SQUARES OF DEVIATIONS = 3.01659E 01
```



```
H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

              ************** MAIN AFRICA        8 **************
```

B 801 Region 9.

Graph 2.9

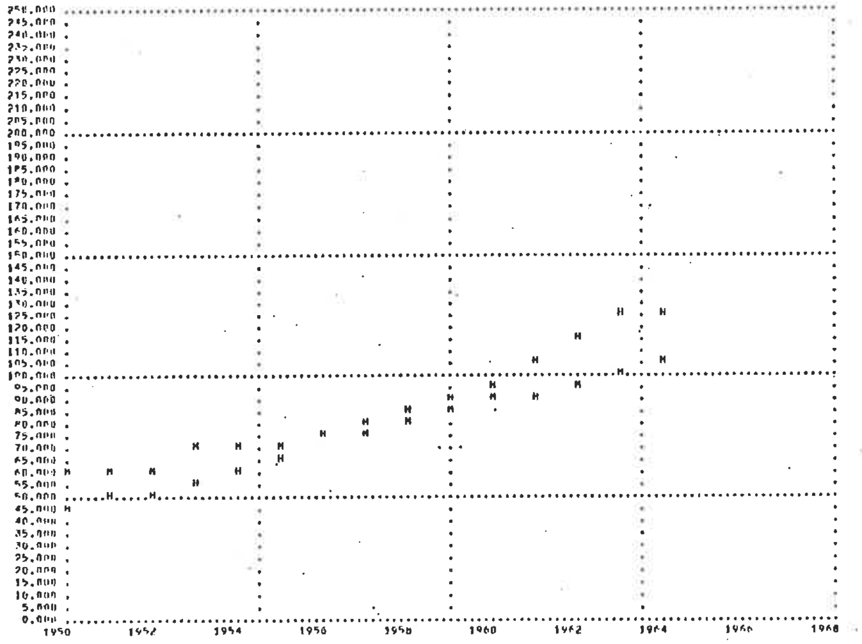
```
REGRESSION WITH ALPHA=A CONSTANT **********

NO. OF COEFFICIENTS AND OBSERVATIONS    1  15
                         COMPUTED COEFFICIENTS      1.16957E 00
  DEPENDENT        CALCULATED       DEVIATION      INDEPENDENT
 9.05772E-01      1.16957E 00    -2.63794E-01      1.00000E 00
 9.37016E-01      1.16957E 00    -2.32548E-01      1.00000E 00
 9.66280E-01      1.16957E 00    -2.03296E-01      1.00000E 00
 9.49753E-01      1.16957E 00    -2.19583E-01      1.00000E 00
 1.02434E 00      1.16957E 00    -1.45223E-01      1.00000E 00
 1.09456E 00      1.16957E 00    -7.50102E-02      1.00000E 00
 1.12940E 00      1.16957E 00    -4.01672E-02      1.00000E 00
 1.20587E 00      1.16957E 00     3.63262E-02      1.00000E 00
 1.24001E 00      1.16957E 00     7.04496E-02      1.00000E 00
 1.27149E 00      1.16957E 00     1.01920E-01      1.00000E 00
 1.27118E 00      1.16957E 00     1.01611E-01      1.00000E 00
 1.32468E 00      1.16957E 00     1.55118E-01      1.00000E 00
 1.40195E 00      1.16957E 00     2.32383E-01      1.00000E 00
 1.43734E 00      1.16957E 00     2.67617E-01      1.00000E 00
 1.38335E 00      1.16957E 00     2.13777E-01      1.00000E 00
       SSI =           SSR +            SSD         CHECK SSI           MEAN DEP
 4.64067E-01      4.64067E-01    -3.00000E 00      4.64067E-01      1.16957E 00
COEFFICIENT OF DETERMINATION IS R**2 =  0.0000        THE STANDARD DEVIATION IS      1.8206499E-01 .
********************************

     ACTUAL            CALCULATED          DIFFERENCE

  4.67650E 01         6.03847E 01        -1.36197E 01
  5.00180E 01         6.24314E 01        -1.24134E 01
  5.32710E 01         6.44782E 01        -1.12072E 01
  5.65240E 01         6.95492E 01        -1.30252E 01
  6.27410E 01         7.16359E 01        -8.89490E 00
  6.89570E 01         7.36826E 01        -4.72564E 00
  7.51050E 01         7.77761E 01        -2.67112E 00
  8.12530E 01         7.88053E 01         2.44766E 00
  8.68010E 01         8.18696E 01         4.93140E 00
  9.23480E 01         8.49456E 01         7.40244E 00
  9.78960E 01         9.00566E 01         7.83944E 00
  1.06637E 02         9.41500E 01         1.24870E 01
  1.16544E 02         9.72260E 01         1.93180E 01
  1.25771E 02         1.02337E 02         2.34340E 01
  1.28305E 02         1.08477E 02         1.98280E 01

 SUM OF SQUARES OF DEVIATIONS = 2.36248E 03
```



```
H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

              ************** S. E. ASIA         9 **************
```

B 802 Region 10

Graph 2.10

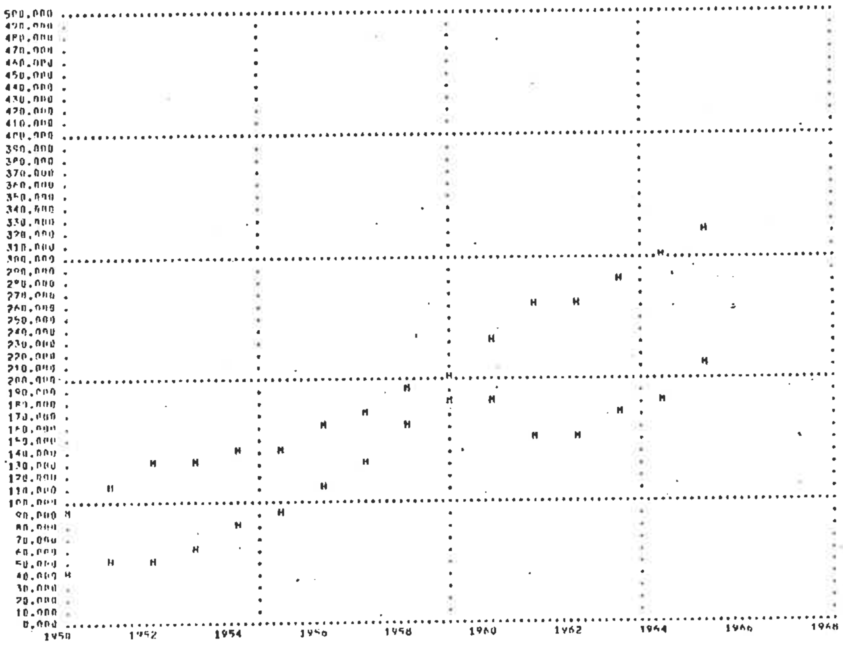
```
REGRESSION WITH ALPHA=A CONSTANT **********

NO. OF COEFFICIENTS AND OBSERVATIONS    1  16
                         COMPUTED COEFFICIENTS     2.69523E 00
 DEPENDENT       CALCULATED      DEVIATION      INDEPENDENT
 1.18294E 00     2.69523E 00    -1.51229E 00     1.00000E 00
 1.20639E 00     2.69523E 00    -1.48884E 00     1.00000E 00
 1.18190E 00     2.69523E 00    -1.51333E 00     1.00000E 00
 1.32087E 00     2.69523E 00    -1.37436E 00     1.00000E 00
 1.56341E 00     2.69523E 00    -1.13181E 00     1.00000E 00
 1.77965E 00     2.69523E 00    -9.15577E-01     1.00000E 00
 1.86962E 00     2.69523E 00    -8.25607E-01     1.00000E 00
 2.07346E 00     2.69523E 00    -6.21764E-01     1.00000E 00
 2.35672E 00     2.69523E 00    -3.38512E-01     1.00000E 00
 2.90325E 00     2.69523E 00     2.08027E-01     1.00000E 00
 3.47236E 00     2.69523E 00     7.77136E-01     1.00000E 00
 4.56712E 00     2.69523E 00     1.87189E 00     1.00000E 00
 4.54206E 00     2.69523E 00     1.84683E 00     1.00000E 00
 4.50927E 00     2.69523E 00     1.81405E 00     1.00000E 00
 4.43348E 00     2.69523E 00     1.73825E 00     1.00000E 00
 4.16092E 00     2.69523E 00     1.46569E 00     1.00000E 00
      SST =           SSR +           SSE          CHECK SST       MEAN DEP
 2.80070E 01     2.80070E 01     0.00000E 00     2.80070E 01     2.69523E 00
COEFFICIENT OF DETERMINATION IS R**2 =  0.0000       THE STANDARD DEVIATION IS     1.3664297E 00
******************************


    ACTUAL          CALCULATED        DIFFERENCE

  4.31300E 01      9.82679E 01     -5.51379E 01
  5.09700E 01      1.13873E 02     -6.29033E 01
  5.88110E 01      1.34114E 02     -7.53035E 01
  6.66510E 01      1.36001E 02     -6.93501E 01
  8.24700E 01      1.42173E 02     -5.97032E 01
  9.82900E 01      1.48857E 02     -5.05673E 01
  1.15050E 02      1.65837E 02     -5.07873E 01
  1.31810E 02      1.71336E 02     -3.95265E 01
  1.66314E 02      1.90202E 02     -2.38881E 01
  2.00819E 02      1.86429E 02      1.43902E 01
  2.35322E 02      1.82655E 02      5.26665E 01
  2.65030E 02      1.56404E 02      1.08626E 02
  2.66755E 02      1.58291E 02      1.08464E 02
  2.86925E 02      1.71497E 02      1.15428E 02
  3.08039E 02      1.87264E 02      1.20774E 02
  3.23012E 02      2.09310E 02      1.13702E 02

 SUM OF SQUARES OF DEVIATIONS = 9.57119E 04
```

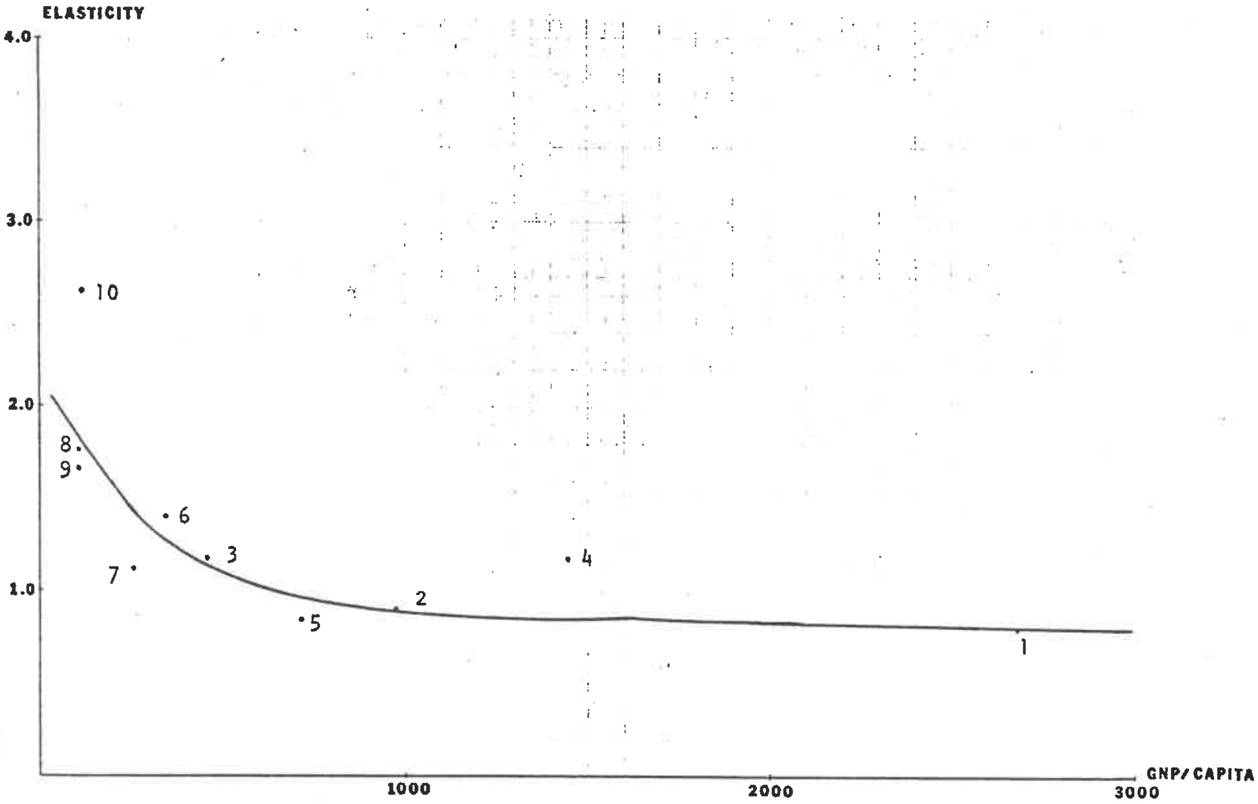


```
H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

              ************** CHINA            10 **************
```

Graph 3 presents the elasticities using Approach C for each region throughout the 1950-65 period against the GNP/capita of each region in 1958 (the midpoint of the period). There is again a clear relationship, with the elasticities for the least developed regions approaching 2 (i.e., 2% energy growth for each 1% GNP growth) and those in the most developed regions around 1. The major exception to the pattern is China with an elasticity of 2.66. It is interesting that the Soviet Union and Communist Europe (Region 5) fit into the curve quite well, in contrast to Graph 1. The logical explanation is that both Communist regions are more energy intensive (as Graph 1 shows), but that the pattern is still in the process of developing in China, while the energy intensiveness of Eastern Europe is decreasing. The completion of much of the economic infrastructure and heavy industry in Region 5, along with the turn towards greater (albeit limited) consumer production and services, is changing the energy/GNP relationship. Using this elasticity computation, Graph 4 shows the fit of Model 5, Approach C, predictions to the data. China remains the least certain.

This analysis clearly indicates the importance of major energy consumption increases in the development process. Part of this is data error, as unmeasured forms of energy, like animal labor and biological fuels, are replaced by fossil energy. Much of the increased use is, however, economically required. This bodes ill for Africa and Southeast Asia, particularly the latter, where development of modern economies is in early stages and energy supplies are short.



Graph 3. Empirical Elasticity from Model 5 Approach C versus GNP/Capita in 1958

1. North America
2. Western Europe
3. Japan
4. Rest of Developed World
5. Eastern Europe
6. Latin America
7. Middle East
8. Africa
9. Southeast Asia
10. China

B 805

```
                                         ************** NORTH AMERICA        1 **************
```

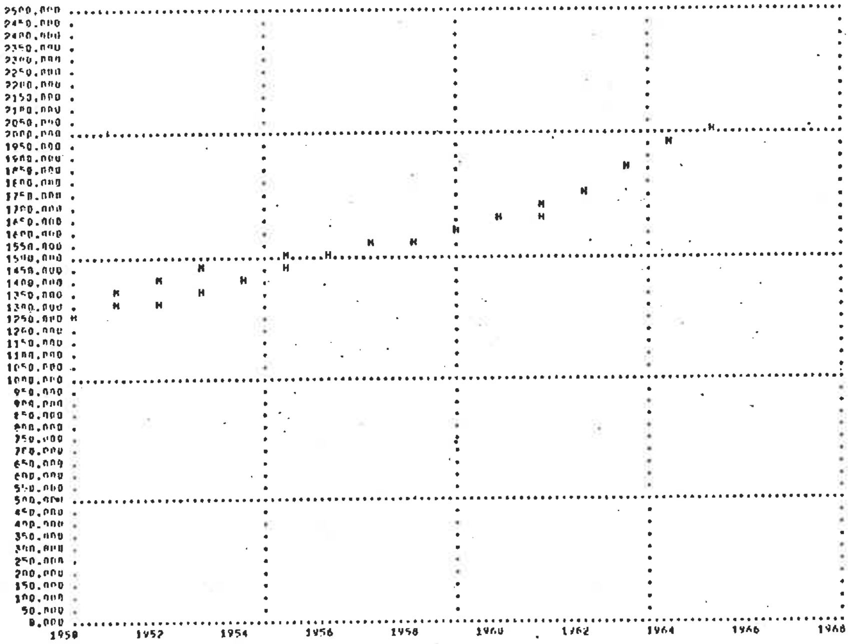
Graph 4.1

```
ELASTICITY=   0.80259

   ACTUAL           CALCULATED          DIFFERENCE

 1.27634E 03       1.27634E 03        0.00000E 00
 1.31032E 03       1.37390E 03       -6.35826E 01
 1.34430E 03       1.40438E 03       -6.00881E 01
 1.37827E 03       1.44997E 03       -7.16991E 01
 1.41978E 03       1.43502E 03       -1.52375E 01
 1.46130E 03       1.52868E 03       -6.73824E 01
 1.50923E 03       1.54353E 03       -3.42932E 01
 1.55717E 03       1.57381E 03       -1.66395E 01
 1.59127E 03       1.55857E 03        3.27015E 01
 1.62537E 03       1.63740E 03       -1.20339E 01
 1.65947E 03       1.66774E 03       -8.27017E 00
 1.69486E 03       1.69801E 03       -3.14897E 00
 1.77204E 03       1.78871E 03       -1.66702E 01
 1.86047E 03       1.84935E 03        1.11243E 01
 1.95120E 03       1.99277E 03       -4.15714E 01
 2.04016E 03       2.02544E 03        1.47191E 01

SUM OF SQUARES OF DEVIATIONS = 2.26586E 04
```



```
H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

                  ************** NORTH AMERICA       1 **************
```

B 806

```
************** WESTERN EUROPE      2 **************
```

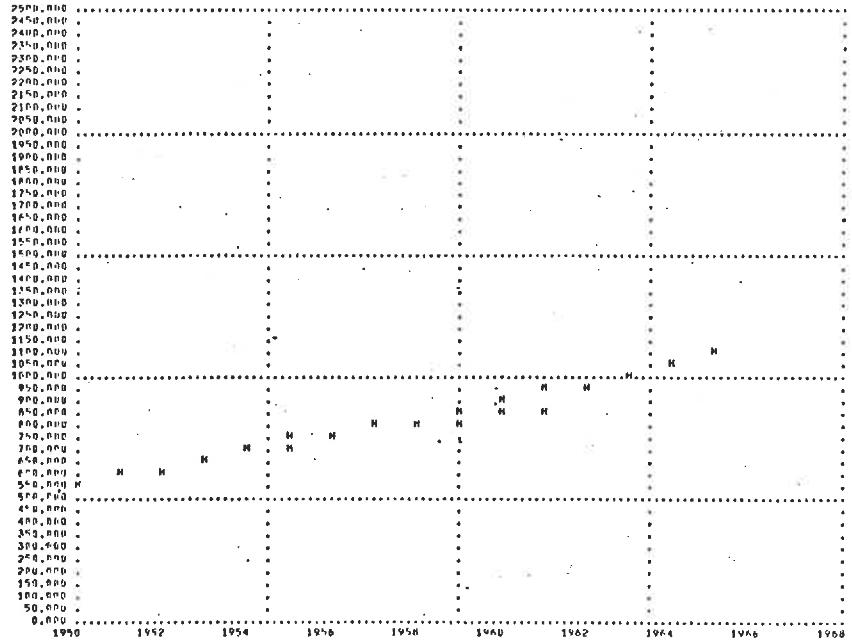
Graph 4.2

```
ELASTICITY=    0.90541

    ACTUAL           CALCULATED          DIFFERENCE

  5.87827E 02       5.87827E 02        0.00000E 00
  6.16328E 02       6.07557E 02        8.77080E 00
  6.44828E 02       6.37430E 02        7.39759E 00
  6.73329E 02       6.67119E 02        6.20954E 00
  7.13672E 02       6.96627E 02        1.70447E 01
  7.54015E 02       7.36382E 02        1.76331E 01
  7.86987E 02       7.75968E 02        1.10194E 01
  8.19959E 02       8.05252E 02        1.47067E 01
  8.32065E 02       8.15009E 02        1.70555E 01
  8.44172E 02       8.54163E 02       -9.99112E 00
  8.56278E 02       9.10766E 02       -5.44876E 01
  8.85246E 02       9.55320E 02       -7.00739E 01
  9.48586E 02       9.90184E 02       -4.15982E 01
  1.01367E 03       1.02596E 03       -1.22881E 01
  1.08390E 03       1.08103E 03        2.86988E 00
  1.12895E 03       1.12732E 03        1.62728E 00

SUM OF SQUARES OF DEVIATIONS = 1.12716E 04
```



H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

```
************** WESTERN EUROPE      2 **************
```

B 807

```
************** JAPAN                    3 **************
```

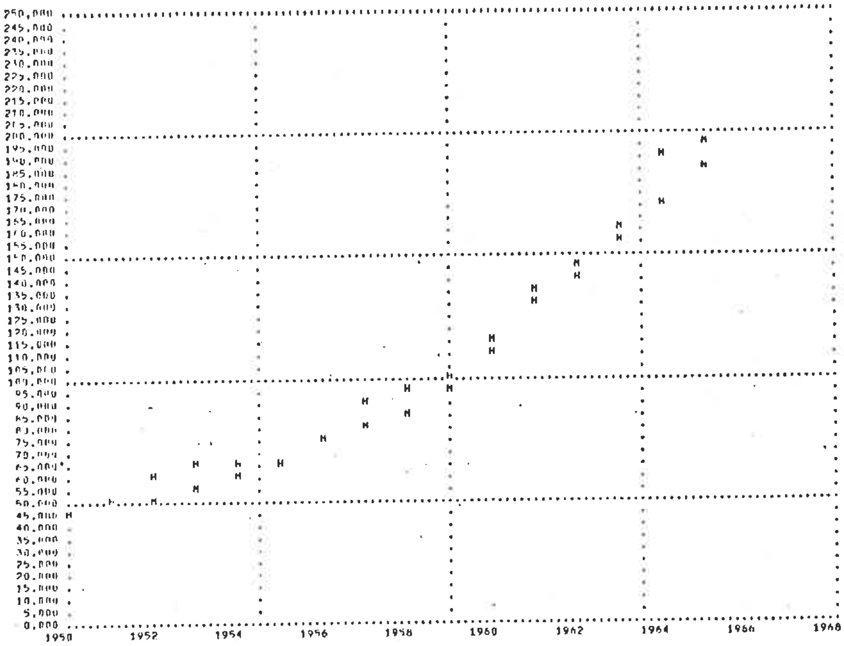
Graph 4.3

```
ELASTICITY=    1.18308

     ACTUAL             CALCULATED          DIFFERENCE

  4.58170E 01        4.58170E 01         0.00000E 00
  5.33540E 01        4.85892E 01         4.76476E 00
  6.08900E 01        5.18103E 01         9.07973E 00
  6.84270E 01        5.55247E 01         1.29023E 01
  6.74420E 01        6.14355E 01         6.00653E 00
  6.64570E 01        6.87011E 01        -2.24414E 00
  7.84340E 01        7.52391E 01         3.19488E 00
  9.04110E 01        8.23892E 01         8.02181E 00
  9.72750E 01        8.81074E 01         9.16763E 00
  1.04138E 02        9.78695E 01         6.26851E 00
  1.11002E 02        1.15188E 02        -4.18550E 00
  1.31655E 02        1.36784E 02        -5.12947E 00
  1.41498E 02        1.45955E 02        -4.45665E 00
  1.56550E 02        1.64543E 02        -7.99292E 00
  1.73529E 02        1.90474E 02        -1.69446E 01
  1.88643E 02        1.99486E 02        -1.08428E 01

 SUM OF SQUARES OF DEVIATIONS = 1.04289E 03
```



```
H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

            ************** JAPAN              3 **************
```

```
************** REST OF DEV WORLD  4 **************

ELASTICITY=   1.16560

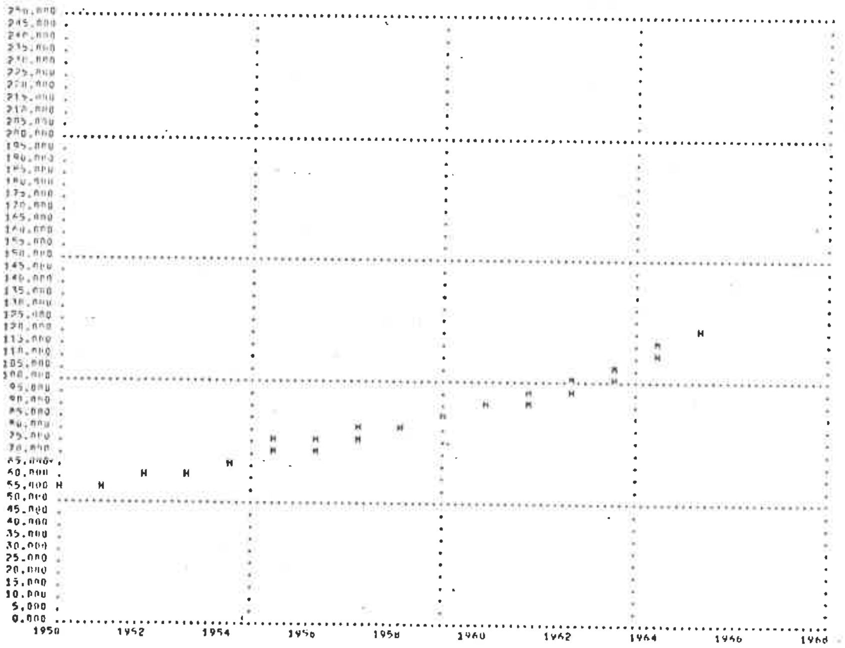
     ACTUAL            CALCULATED          DIFFERENCE

  5.65820E 01        5.65820E 01         0.00000E 00
  5.87950E 01        5.79754E 01         8.19642E-01
  6.10080E 01        6.12523E 01        -2.44254E-01
  6.32210E 01        6.26252E 01         5.95824E-01
  6.92130E 01        6.70966E 01         2.11562E 00
  7.52050E 01        7.08632E 01         4.34177E 00
  7.75890E 01        7.35144E 01         4.07459E 00
  7.99740E 01        7.57949E 01         4.17907E 00
  8.35780E 01        8.16467E 01         1.93131E 00
  8.71810E 01        8.67616E 01         4.19417E-01
  9.07850E 01        9.10971E 01        -3.12111E-01
  9.46130E 01        9.42947E 01         3.18339E-01
  9.76030E 01        1.00798E 02        -3.19462E 00
  1.02992E 02        1.08839E 02        -5.84736E 00
  1.11191E 02        1.17347E 02        -6.15617E 00
  1.22285E 02        1.22794E 02        -5.08541E-01

SUM OF SQUARES OF DEVIATIONS = 1.45137E 02
```

B 808

Graph 4.4



```
H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

************** REST OF DEV WORLD  4 **************
```

B 809

```
************** EASTERN EUROPE     5 **************

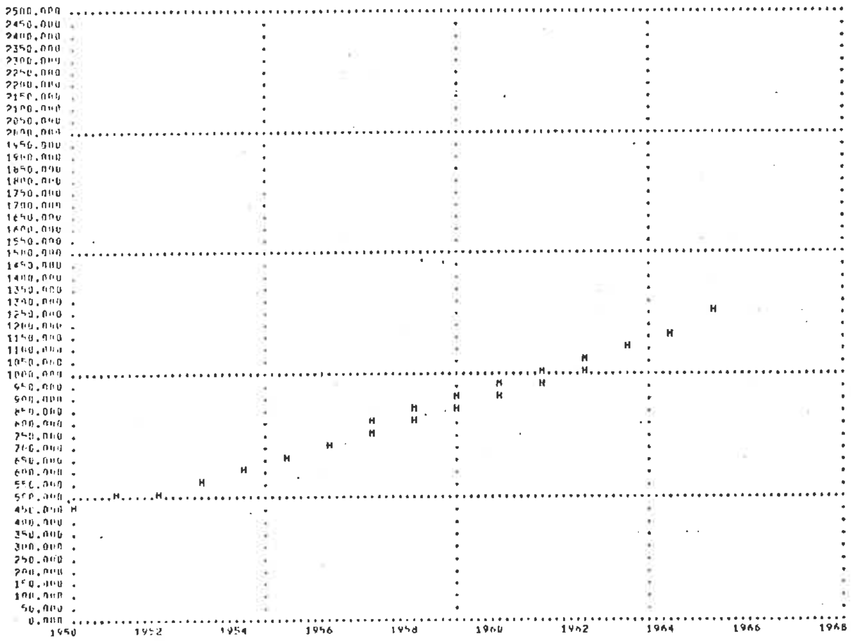

ELASTICITY=   0.85092

    ACTUAL          CALCULATED        DIFFERENCE

  4.64115E 02      4.64115E 02      0.00000E 00
  5.01650E 02      5.07996E 02     -6.34565E 00
  5.39186E 02      5.40029E 02     -8.43029E-01
  5.76721E 02      5.72023E 02      4.69837E 00
  6.33955E 02      6.25363E 02      8.57246E 00
  6.91190E 02      6.88837E 02      2.35319E 00
  7.45335E 02      7.30113E 02      1.52719E 01
  7.99580E 02      7.92502E 02      7.07839E 00
  8.44558E 02      8.53422E 02     -8.86423E 00
  8.89536E 02      9.22323E 02     -3.27867E 01
  9.34514E 02      9.79085E 02     -4.45713E 01
  9.79331E 02      1.03457E 03     -5.52432E 01
  1.04206E 03      1.07080E 03     -2.87377E 01
  1.12264E 03      1.10775E 03      1.48961E 01
  1.18758E 03      1.19373E 03     -6.15742E 00
  1.25576E 03      1.24937E 03      6.39404E 00

SUM OF SQUARES OF DEVIATIONS = 7.74391E 03
```

Graph 4.5



H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

************** EASTERN EUROPE   5 **************

B 810

```
************** LATIN AMERICA       6 **************

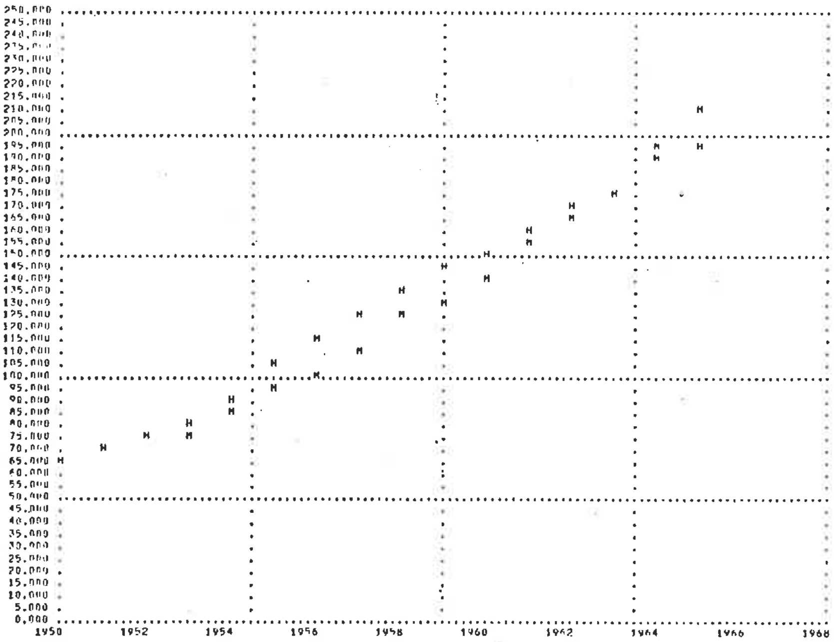
ELASTICITY=    1.42417

    ACTUAL            CALCULATED          DIFFERENCE

  6.62320E 01        6.62320E 01        0.00000E 00
  7.14560E 01        7.16721E 01       -2.16117E-01
  7.66790E 01        7.53868E 01        1.29216E 00
  8.19030E 01        7.92090E 01        2.69403E 00
  9.36390E 01        8.91069E 01        4.53212E 00
  1.05376E 02        9.74466E 01        7.92944E 00
  1.17377E 02        1.04064E 02        1.33128E 01
  1.29378E 02        1.13458E 02        1.59199E 01
  1.37410E 02        1.25758E 02        1.16520E 01
  1.45441E 02        1.30638E 02        1.48027E 01
  1.53473E 02        1.43285E 02        1.01883E 01
  1.62536E 02        1.58352E 02        4.18390E 00
  1.73119E 02        1.68314E 02        4.80455E 00
  1.76733E 02        1.75936E 02        7.96534E-01
  1.90283E 02        1.96085E 02       -5.80170E 00
  1.99514E 02        2.11133E 02       -1.16190E 01

SUM OF SQUARES OF DEVIATIONS = 1.19164E 03
```

Graph 4.6



```
H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

************** LATIN AMERICA       6 **************
```

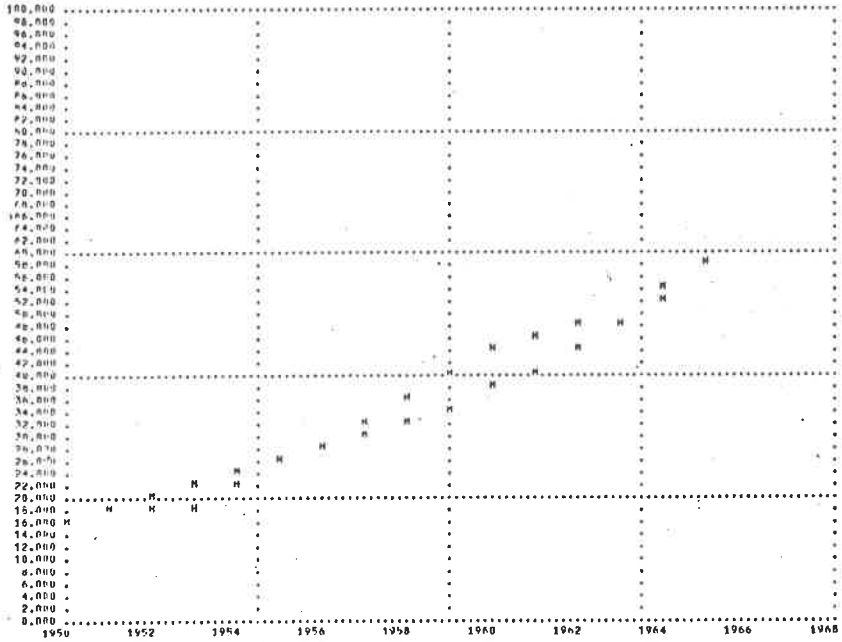
Graph 4.7

```
ELASTICITY=   1.13156

   ACTUAL           CALCULATED         DIFFERENCE

 1.76620E 01       1.76620E 01       0.00000E 00
 1.82680E 01       1.91276E 01      -8.59612E-01
 1.88750E 01       2.09985E 01      -2.12349E 00
 1.94810E 01       2.23366E 01      -2.85563E 00
 2.28700E 01       2.40752E 01      -1.20517E 00
 2.62590E 01       2.64261E 01      -1.67113E-01
 2.94980E 01       2.83980E 01       1.10000E 00
 3.27380E 01       3.04753E 01       2.26274E 00
 3.65020E 01       3.26669E 01       3.83510E 00
 4.02650E 01       3.55340E 01       4.73100E 00
 4.40290E 01       3.84914E 01       5.53761E 00
 4.59810E 01       4.09113E 01       5.06971E 00
 4.83480E 01       4.57552E 01       2.59284E 00
 4.85680E 01       4.92554E 01      -6.87424E-01
 5.23950E 01       5.41911E 01      -1.79609E 00
 5.79290E 01       5.96504E 01      -1.72144E 00

SUM OF SQUARES OF DEVIATIONS = 1.28055E 02
```



```
H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA
```

```
************** MAIN AFRICA          8 **************
```

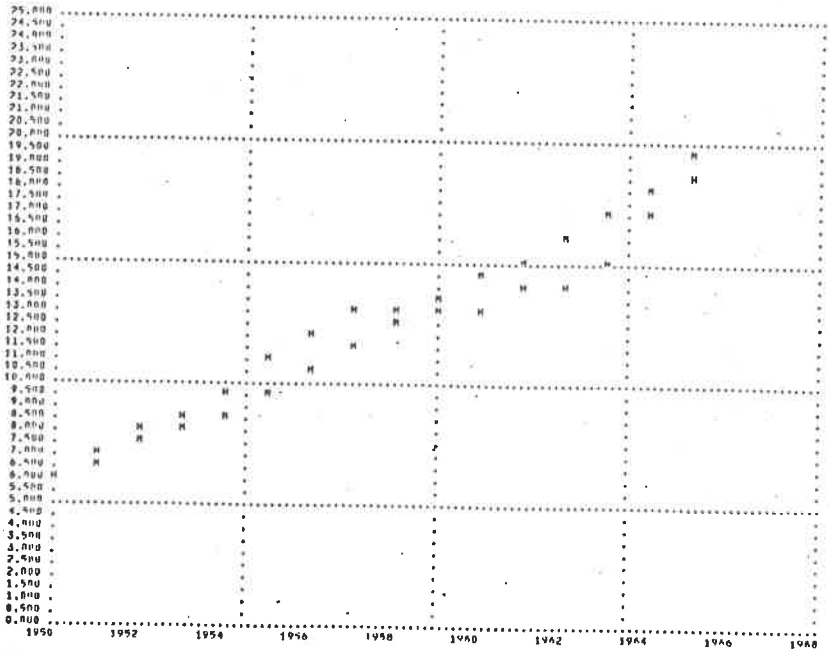
Graph 4.8

```
ELASTICITY=    1.81761

     ACTUAL            CALCULATED          DIFFERENCE

   6.43400E 00        6.43400E 00        0.00000E 00
   7.19700E 00        6.95138E 00        2.45624E-01
   7.96100E 00        7.54381E 00        4.17191E-01
   8.72400E 00        8.20107E 00        5.22925E-01
   9.93400E 00        8.91124E 00        1.02276E 00
   1.11440E 01        9.70834E 00        1.43566E 00
   1.20960E 01        1.06144E 01        1.48156E 00
   1.30520E 01        1.16203E 01        1.43166E 00
   1.31450E 01        1.26648E 01        4.80236E-01
   1.32390E 01        1.37749E 01       -5.35864E-01
   1.33310E 01        1.48495E 01       -1.51844E 00
   1.40780E 01        1.52781E 01       -1.20013E 00
   1.44560E 01        1.62171E 01       -1.76114E 00
   1.53970E 01        1.72207E 01       -1.82367E 00
   1.73260E 01        1.80619E 01       -7.35875E-01
   1.89430E 01        1.96804E 01       -7.37357E-01

SUM OF SQUARES OF DEVIATIONS = 1.96245E 01
```



```
H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

************** MAIN AFRICA          8 **************
```

B 813

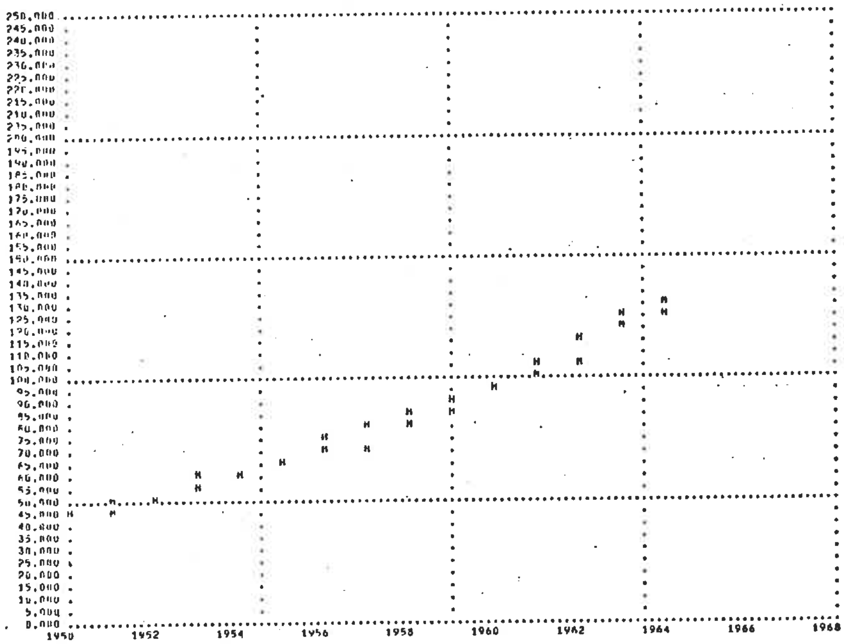
Graph 4.9

```
ELASTICITY=   1.74910

   ACTUAL            CALCULATED          DIFFERENCE

 4.67650E 01        4.67650E 01        0.00000E 00
 5.00180E 01        4.95375E 01        4.80494E-01
 5.32710E 01        5.24057E 01        8.65347E-01
 5.65240E 01        5.97915E 01       -3.26749E 00
 6.27410E 01        6.26993E 01        4.16738E-02
 6.89570E 01        6.58346E 01        3.12223E 00
 7.51050E 01        7.25355E 01        2.56951E 00
 8.12530E 01        7.42739E 01        6.97913E 00
 8.68010E 01        7.98001E 01        7.00094E 00
 9.23480E 01        8.55043E 01        6.84370E 00
 9.78960E 01        9.52230E 01        2.67299E 00
 1.06637E 02        1.03006E 02        3.63080E 00
 1.16544E 02        1.09100E 02        7.44407E 00
 1.25771E 02        1.19816E 02        5.95516E 00
 1.28306E 02        1.33015E 02       -4.70904E 00

SUM OF SQUARES OF DEVIATIONS = 3.05947E 02
```



H - HISTORICAL DATA OF TOTAL ENERGY CONSUMPTION IN MILLIONS OF METRIC TONS COAL EQUIVALENT
M - MODEL DATA

B 814

Graph 4.10

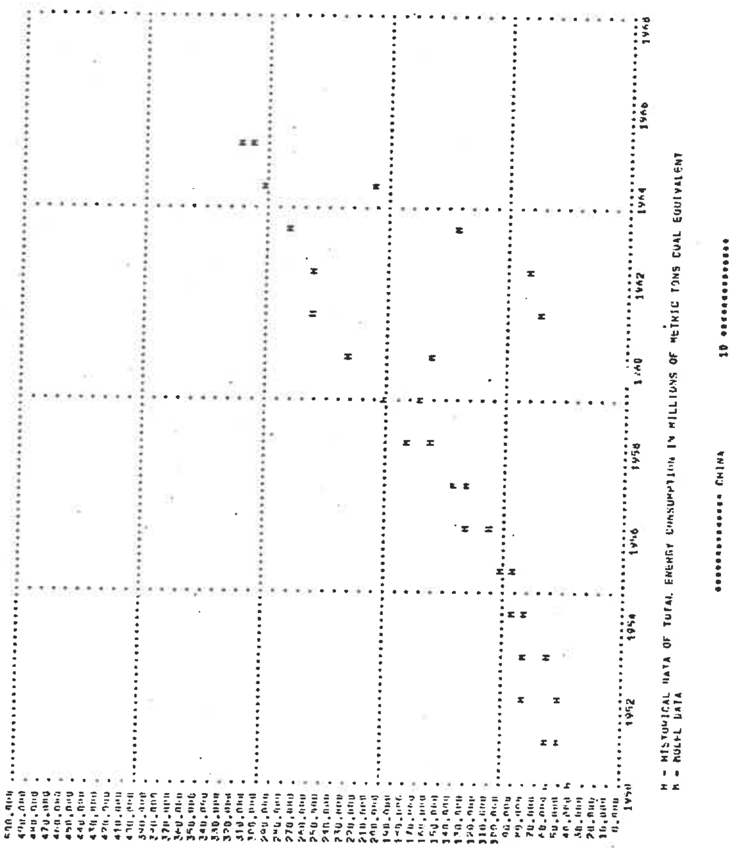
```
                              ************** CHINA                10 **************

ELASTICITY=    2.66153

   ACTUAL              CALCULATED          DIFFERENCE

4.31300E 01         4.31300E 01         0.00000E 00
5.09700E 01         6.13594E 01        -1.03894E 01
5.88110E 01         8.54729E 01        -2.66619E 01
6.66510E 01         8.76748E 01        -2.10238E 01
8.24700E 01         9.57254E 01        -1.32554E 01
9.82900E 01         1.06045E 02        -7.75482E 00
1.15050E 02         1.35885E 02        -2.08353E 01
1.31810E 02         1.46038E 02        -1.42276E 01
1.66314E 02         1.84668E 02        -1.83536E 01
2.00818E 02         1.75886E 02         2.49319E 01
2.35322E 02         1.65068E 02         7.02538E 01
2.65030E 02         7.50531E 01         1.89977E 02
2.66755E 02         8.35620E 01         1.83193E 02
2.86925E 02         1.42797E 02         1.44129E 02
3.08038E 02         2.13006E 02         9.50317E 01
3.23012E 02         3.09175E 02         1.38370E 01

SUM OF SQUARES OF DEVIATIONS = 1.07673E 05
```



3.5 Generic Demand Prediction Approaches

Although the models considered in the preceding section are of the same form for all the regions they are also region specific in the sense that the values of the parameters are estimated separately for each of the regions. Whether the parameters are constant or are functions of time, they are not related to parameters in any other region. That essentially means that the differences between the regions, with respect to the pattern of energy consumption, will persist in the future regardless of level of economic development. However, it might very well be hypothesized that the pattern of energy consumption is determined to a significant degree by the level of economic activity and the kind of technology associated with that activity. If the progress in development of the less developed regions is based on the transfer of technology from the developed world, there is no reason to assume that the pattern of energy consumption will be that different - allowing, of course, for local conditions and minor modifications as a result of greater awareness of energy conservation importance. To test the hypothesis that there exist such universal relationships which are by and large region independent the parameters in the demand models have to be endogenized, i.e., made dependent on other systems variables so that the relationship changes with the progress in development rather than purely with time. Specifically, we shall attempt to identify α and ε as functions of average economic output, i.e., GRP/capita.

We have directed our attention to Models 1 and 5 from Sec. 4 for the reasons indicated in that section. The problem of developing generic energy demand relation boils down to identifying the relationships $\alpha = \alpha(\mathrm{GRP/POP})$

and $\varepsilon = \varepsilon$(GRP/POP). The difficulty is that they are surely non-linear.

First we have used the average coefficients for α and ε as computed earlier. The values of the parameter α are plotted in Graph 5 against GRP/POP. The problem of finding the generic $\alpha = \alpha$(GRP/POP) relationships has three parts:

(i) Finding a curve for α which approximates reasonably well the trend apparent in Graph 5.

(ii) Explaining the differences between α from the data and α as computed by the generic relationships.

(iii) Accounting for apparent differences between the centrally planned regions, i.e., 5 and 10, and others.

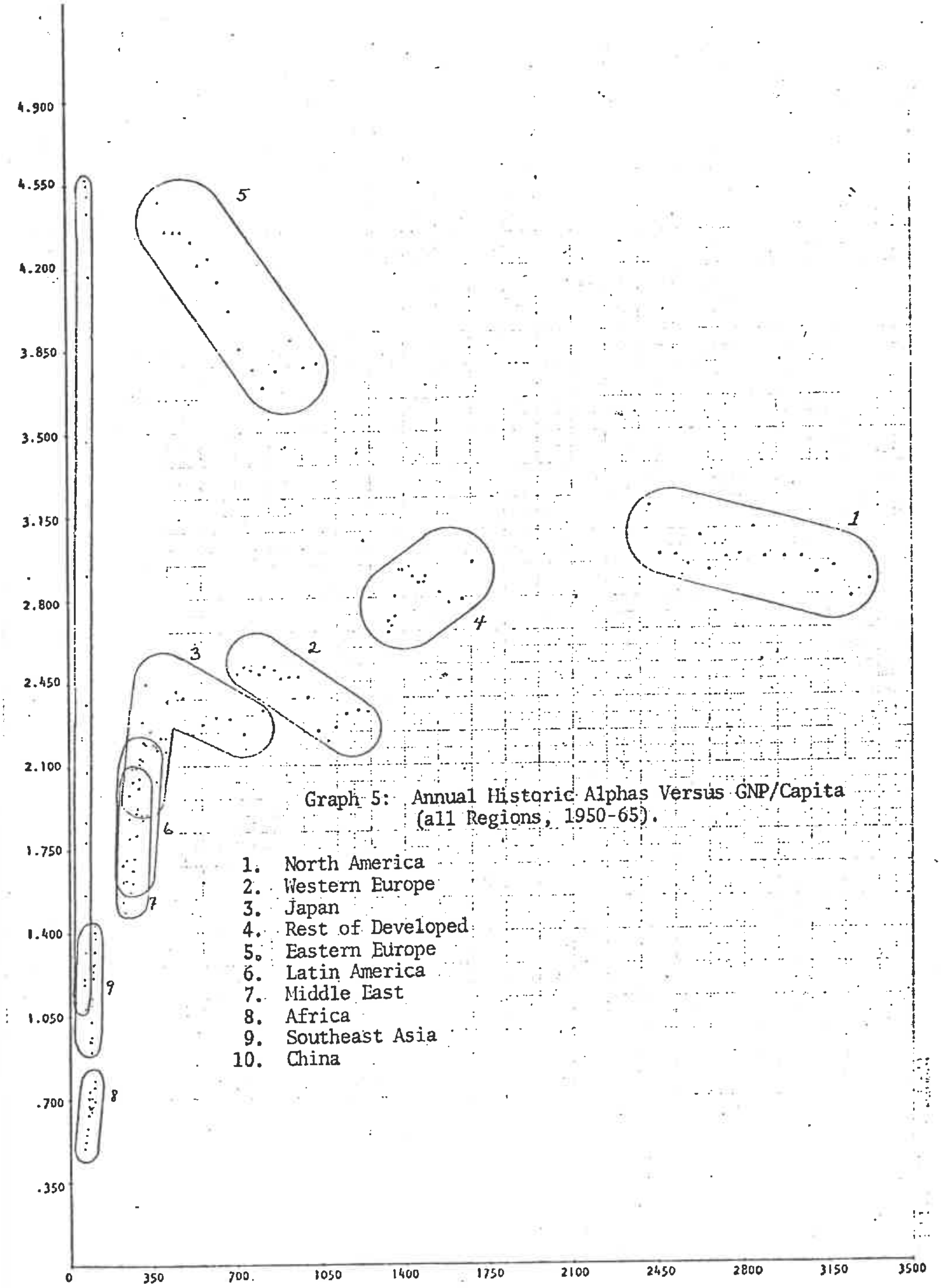
In reference to items (ii) and (iii) the parameter α is assumed to have two components: α_E dependent on economic relationships and α_P dependent on political decision.

$$\alpha = \alpha_E + \alpha_P$$

Both α_E and α_P are considered functions of GRP/POP.

The economic component, α_E, has been estimated from the data for all regions except 5 and 10. Two types of functions were used; exponential and hyperbolic. The best fitting exponential function proved to be:

$$\alpha = 3 * (1 - e^{-2.66\ \mathrm{GRP/POP}})$$



Graph 5: Annual Historic Alphas Versus GNP/Capita (all Regions, 1950-65).

No exponential function worked very satisfactorily, and a hyperbolic equation proved a better fit.

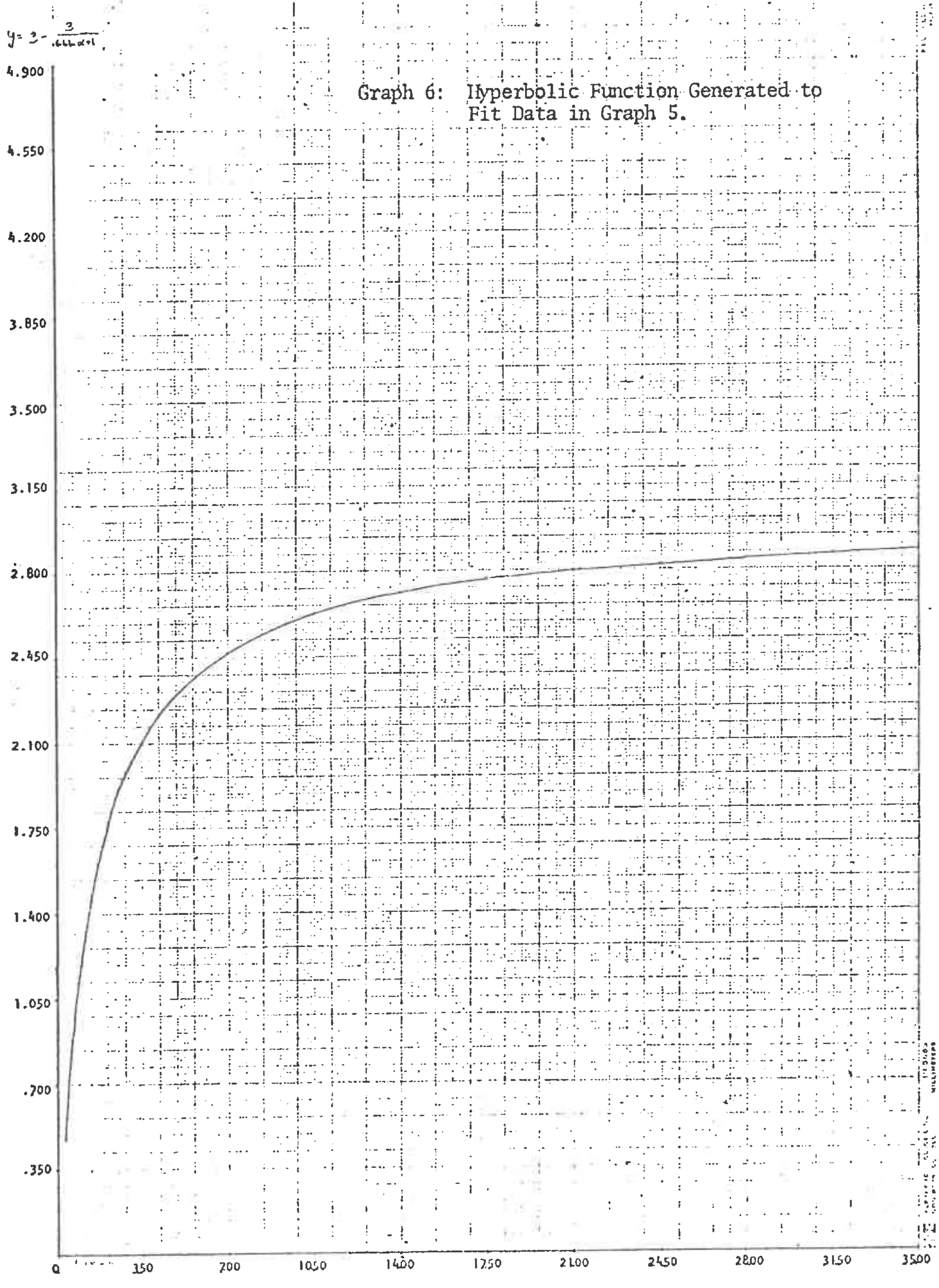
$$\alpha = 3 - \frac{3}{\frac{2}{3}X + 1} \quad \text{where } X = \text{GNPPC} * 10^{-2}$$

That function can be seen in Graph 6.

The fit of this hyperbolic function based model to all 10 regions is in Appendix A. We did not create such an analytic model for elasticity, for reasons to be given below.

The hyperbolic function fits reasonably well, but not completely satisfactorily. In particular, its initial slope is too low to capture the extremely rapid increase in alpha of Africa and Southeast Asia as their GNPs/capita increase. The data cannot easily be fitted with any analytical function. Thus another approach to the specification of α_E was to use a table function derived from Graph 1. Because there is a clear relationship in the graph between α_E and GNP/capita, there is no difficulty in capturing it in a table function. Appendix B includes graphs showing the fit of that function to the historic data for all regions.

These curve fitting approaches leave the problem of explaining the differences between α as computed by the generic relationship and the initial empirical values of alpha. Either we can treat the differences as noice or error, or we can treat them as regional functions which cause slight shifts in the total function for each region. The latter approach appears undesirable because in regions with high GNPs/capita the parameters approach "steady state" values which are region independent. For example, alphas from Model 1 appear to be asymptotically approaching the value of 3.0 as GRP/capita approaches $3000. Similarly, the elasticity factor averages



Graph 6: Hyperbolic Function Generated to Fit Data in Graph 5.

.93 for all four regions with GNPs/capita above $600, and all four regions are very close to that average.

Although the "steady state" values of α and ε might be regionally independent it is still possible that initial values reflect regional characteristics.

We thus also experimented with another type of generic relationship, in which initial differences were treated as regional characteristics rather than as data noise. These functions allow the alpha and the initial empirical elasticity coefficients to change linearly as functions of GNP/capita towards values of $\alpha = 3.0$ at GNP/capita = $3000 and $\varepsilon = .93$ at GNP/capita = $700. The functions are shown in Table VII.

TABLE VII

An Alternative Generic Approach

Model 1: $EC_t = \alpha_t GRP_t$

$$\text{where } \alpha_t = \alpha_I + (3 - \alpha_I) \times \frac{(GRP_t/POP_t - GRP_I/POP_I)}{(3000 - GRP_I/POP_I)}$$

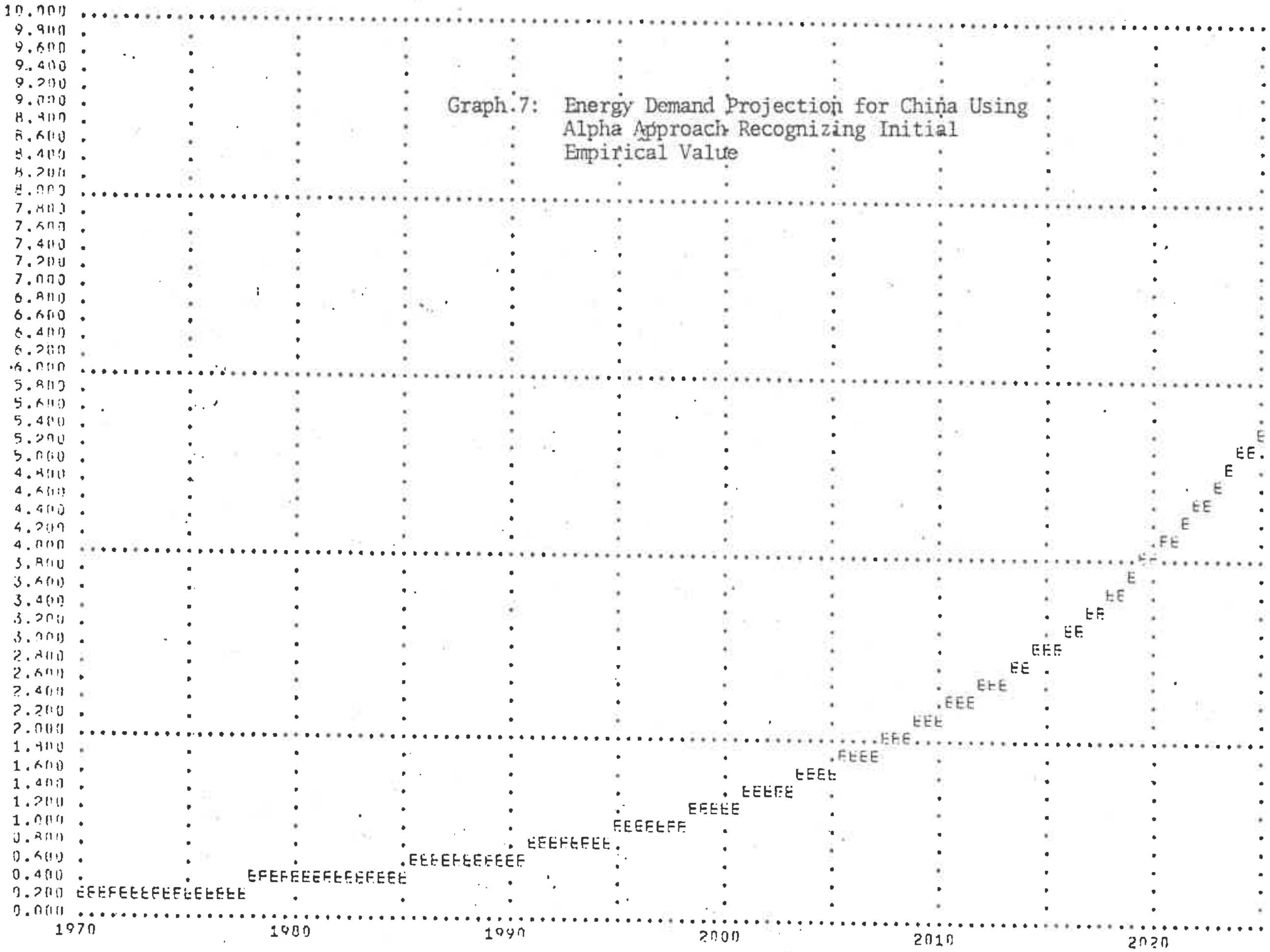
if $GRP_t/POP_t \geq \$3000_j \quad \alpha_t = 3.0$

Model 5: $\Delta EC_{t,t+1} = \varepsilon_t \, \Delta \, GRP_{t,t+1}$

$$\text{where } \varepsilon_t = \varepsilon_I - (\varepsilon_I - .93) \; \frac{(GRP_t/POP_t - GRP_I/POP_I)}{(700 - GRP_I/POP_I)}$$

if $GRP_t/POP_t \geq \$700, \quad \varepsilon_t = .93$

When these generic equations were used to predict energy demand, they generally predicted quite similar demand levels. Yet there were always differences, and these were extraordinarily great for China. Graphs 7 and 8 show energy demand predictions for China using both alpha and elasticity approaches. The reason for the major differences lies in the nature of the elasticity model. It relates percentage changes in GNP to percentage changes in energy consumption. This gives it the nature of an integrator because it always builds on present values of energy consumption to predict future ones -- the alpha model uses only the present values of GRP. If the energy consumption/

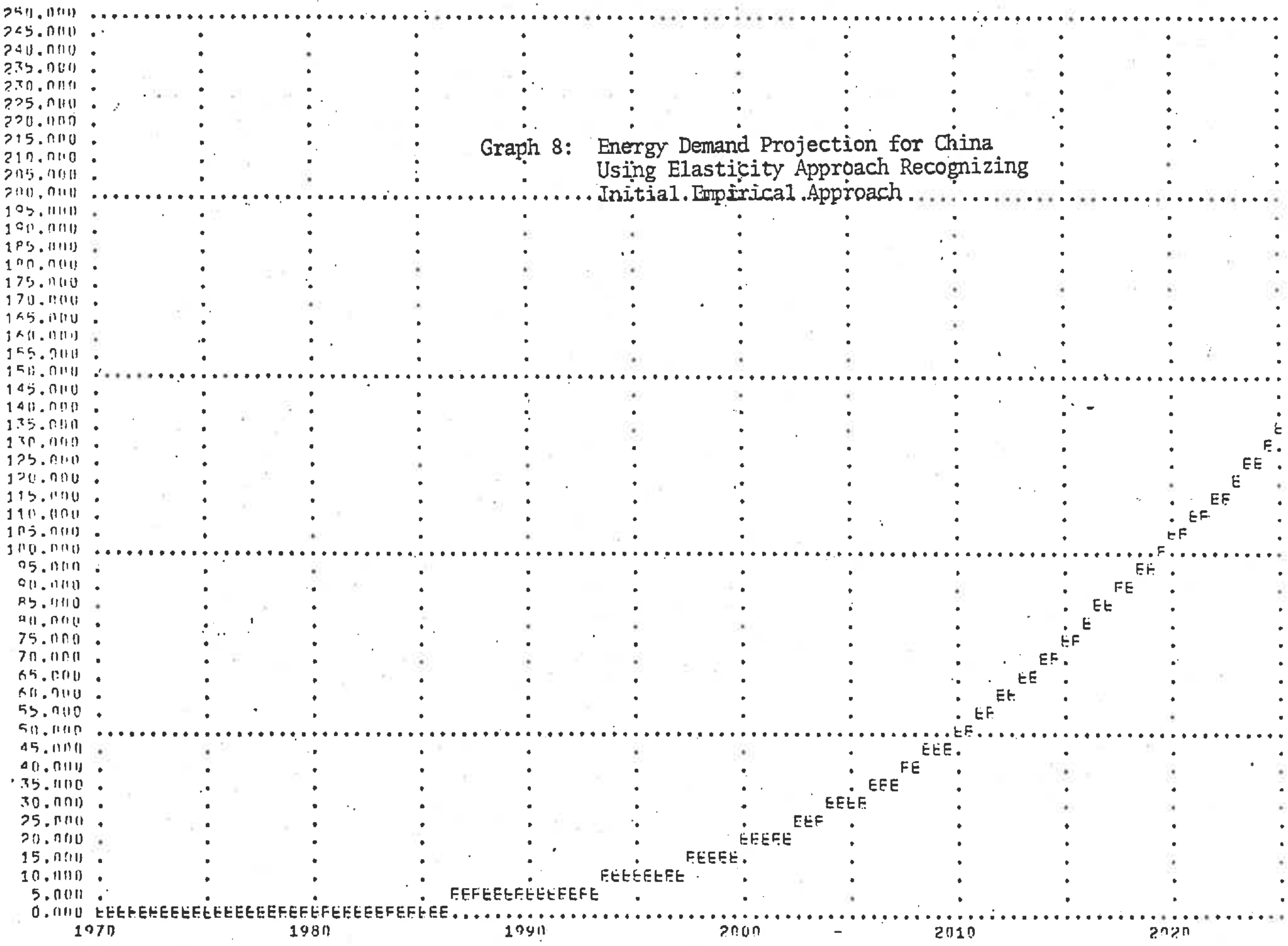


Graph 7: Energy Demand Projection for China Using Alpha Approach Recognizing Initial Empirical Value

E - ENERGY CONSUMPTION PROJECTION FOR 1970-2025 IN BILLIONS OF METRIC TONS COAL EQUIVALENT

************** CHINA 10 **************

Graph 8: Energy Demand Projection for China Using Elasticity Approach Recognizing Initial Empirical Approach



E - ENERGY CONSUMPTION PROJECTION FOR 1970-2025 IN BILLIONS OF METRIC TONS COAL EQUIVALENT

************** CHINA 10 **************

GRP ratio is initially large (as it is for both Eastern Europe and China) and elasticity is greater than 1.0 (for China it was 2.66), energy consumption grows very rapidly. Even a drop in elasticity towards .93 with increasing GNP/capita does not bring the energy consumption/GNP ratio down to reasonable levels. A procedure for correcting this fault of the elasticity approach is implicit in the USSR data -- elasticity must drop considerably faster and perhaps even further for the communist regions once industrialization and the high energy consumption/GRP ratio are reached. In other words, some political factor would need to be added to this elasticity demand prediction model.

Although it is possible to add such a factor, as was done above for the alpha model, the elasticity approach and the integrating computational procedure makes correction more difficult. The alpha model avoids the difficulty and recommends itself for our use. The following section will use the alpha models laid out above for prediction of energy consumption through 2025.

The predictions of the next section will rely upon both the parabolic function and the table function approaches to the relationship between GNP/capita and alpha. Although the table function approach best fits the data, it will be interesting to compare results of the two approaches. Neither of them is, of course, completely satisfactory, because there are some regionally specific factors involved in energy demand. This is suggested by Graph 5. That graph suggests, in fact, that the final value of alpha may not be 3, and there is no logical reason that there should be any final, stable value. Instead, it appears that each region may have very rapidly increasing alphas as it industrializes, and then very gradually decreasing alphas in the post industrial era. Note that alphas were generally decreasing in the post W.W.II period in North America, Western Europe, and Japan, as well as in Eastern Europe. This was also implicit in the elasticities of less than 1 for those regions. Each region appears to trace a somewhat different pattern that may be primarily dependent on the rate of industrialization and the regional energy resource base. The faster the rate of industrialization, the greater the increase in and peak of alpha, as both China and Eastern Europe show. Those regions which reach a higher peak can also be expected to fall from the peak faster, however, and post-war Eastern Europe bears this out. The maximum value or peak of alpha and the point at which it is reached may also be dependent on the regional energy base. Note that Western Europe and Japan have slightly decreasing alphas at lower GNPs/capita than the U.S. -- they have had to import energy while North America and the Rest of the Developed World regions were largely independent. The lesser population densities in the last two regions may be still another factor in the different patterns, as may be energy saving technology now available to all industrialized regions regardless of GNPs/capita, but not earlier available.

Because of the good fit of the two generic models discussed above, especially that of the table function, there is little reason to try to react to most of the divergencies between data and model. The one exception, to which future thought and research ought to be directed is the apparent decrease in alpha of most industrialized regions. The emergence of post industrial societies with large service sectors demanding somewhat less energy than industry may be the principal reason. If so, the decreases should not continue for long, because the size of the service sector should peak. If there is to be a post-service economy, perhaps a leisure society, it could be either more or less energy intensive. Energy demand predictions for the less developed regions are little affected by these considerations, but energy demand for the more developed regions will be, and further attention to these issues is desireable.

3.6 Scenario Analysis and Assessment of Future Demands

Future energy demand cannot simply be "predicted." Assumptions about economic growth, population growth, energy conservation technology and so on affect that demand. Instead of prediction, we can make "if-then" statements about the future. The "if" is a scenario which specifies values of major economic and other parameters, while the "then" is likely energy demand.

As an aid to scenario development in the context of the Mesarovic-Pestel world model, Table VIII lists the parameters which a model user should specify. The first four, GI, GC, GX, and GM, determine investment, consumption, export, and import needs in the economy of each region. POPR is the rate of population growth in the simplest population model -- for the purpose of demand projection, the more sophisticated population models which specify size of various age groups need not be used.

The last three values in that table set major parameters in the energy prediction model itself. The first, δ_1, determines the steady state value of the energy consumption - GRP/capita relationship, i.e., the value of alpha. This value approached 3.0 for the most developed regions but there is no reason that it could not climb higher or decrease. The second parameter, δ_2, specifies the efficiency of the energy conversion and transmission system. The efficiency of U.S. energy system 1965 and in 1970 was about 50%. One fairly standard projection is for this to decrease to 40% in 1985 because of increasing nuclear electric production. The energy demand model is theoretically sound only for user energy levels plus a constant proportion of energy wasted in conversion and transmission. If the system efficiency

TABLE VIII

Major Scenario Variables

Region	GI	GC	GX	GM	POPR	δ_1	δ_2	δ_3

value increases, primary energy demand should be reduced accordingly, if the value decreases, primary energy demand predictions should be raised.

The final variable in Table VIII sets a limit on the per capita use of energy.

It has sometimes been argued that there are upper limits upon the amount of energy which any person can actually use -- at least in a society with a specified technology. For instance, a Rand Corporation study argued that the 10 kilowatt continuous power which constitutes the present average energy consumption of Americans could be increased only up to 15 kilowatt even with saturation of the American public with all energy using devices. Even allowing for hypothetical introduction of additional energy consuming technology, a 20 kilowatt continous power consumption level seems an upper limit in the foreseeable future. Presumably, world regions with higher population densities have even lower limits in the foreseeable future. Although there will be no demand limit/capita in many energy demand scenarios, a model user might like to see the impact of such limits.

Several scenarios have been examined with the energy demand model. These have not used the entire macro economic model of the M-P project, but only a growth economic model. Thus rather than specifying GI, GC, GX, and GM, only an economic growth rate, YR, was set. A second simplfication was to assume that no change in energy system efficiency occurs.

The first two scenarios look at the impact on energy demand at two different sets of economic growth rates. The first set, YR1, corresponds fairly closely to actual growth rates in 1970, although slightly on the high side. The second set, YR2, posit more moderate growth for all regions. The values for all scenario variables can be seen in Table IX. The results of the projection through 2025 are in Appendix C. That appendix contains all of the graphs for each region using both hyperbolic function and table function energy demand predictions and with both high and moderate economic growth rates. It also contains the population and economic projections which underly the demand model. The hyperbolic function and table function approaches lead to highly similar results for all regions except China; in fact, the results of the two approaches in Appendix C are indistinguishable except for China. Hyperbolic projections for China have no meaning because they do not include the impact of α_p -- the table function projections should be used for that country. Data are presented as well as graphs throughout this report and in the appendixes. The columns of data counting from left to right, always correspond to the symbols on the graphs.

Two additional scenarios posited 10 and 20 kilowatt continuous consumption/capita upper limits, with the lower economic growth rates. The scenario values are shown in Table X. The table function generic demand prediction approach was used in the computation of the projections in Appendix D.

A final scenario posits an increase in energy system efficiency over time up to a maximum of 25% in 2025. This efficiency increase could be of two types. First, it could represent better energy conversion and transmission processes, i.e., less loss between primary energy and energy delivered to users. Second, it could represent increasing efficiency of final use. For instance, better home insulation and smaller cars could reduce final demand. This latter case is quite possible as energy prices increase. Projections of energy demand with increased efficiency are also portrayed in Appendix D, along with those of the two limited demand scenarios.

TABLE IX

Two Economic Growth Based Scenarios

Region	YR1	YR2	POPR	δ_1	δ_2	δ_3
North America	4.5%	3.5%	1.1%	3.0	none	C
Western Europe	4.5	3.5	1.0	3.0	none	C
Japan	6.5	5.5	.9	3.0	none	C
Rest of Developed	4.5	3.5	1.9	3.0	none	C
Eastern Europe	5.0	4.0	.8	3.0	none	C
South America	6.0	5.0	2.4	3.0	none	C
Middle East	9.0	8.0	3.1	3.0	none	C
Africa	6.0	5.0	2.7	3.0	none	C
Southeast Asia	6.0	5.0	2.3	3.0	none	C
China	6.0	5.0	2.1	3.0	none	C

TABLE X

Two Energy Demand Limit Scenarios

Region	YR	POPR	δ_1	δ_2	δ_3
North America	3.5%	1.1%	3.0	10,20	C
WEstern Europe	3.5	1.0	3.0	10,20	C
Japan	5.5	.9	3.0	10,20	C
Rest of Developed	3.5	1.9	3.0	10,20	C
Eastern Europe	4.0	.8	3.0	10,20	C
South America	5.0	2.4	3.0	10,20	C
Middle East	8.0	3.1	3.0	10,20	C
Africa	5.0	2.7	3.0	10,20	C
Southeast Asia	5.0	2.3	3.0	10,20	C
China	5.0	2.1	3.0	10,20	C

IV.4. ENERGY SUPPLY SUBMODEL

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April 1974

Table of Contents

		Page
4.	Energy Supply Submodel	B 835
4.1.	A Simulation Model of the Energy Conversion and Distribution System	B 836
4.2.	Energy System Simulations	B 859
4.3.	Evaluation of Scenarios	B 930
4.4.	Decision Criteria with Respect to the Energy System of Developed Regions	B 938
4.5.	Decision Criteria with Respect to the Energy System of Oil-Exporting Regions	B 938

4. ENERGY SUPPLY

Survey

Section 4.1 presents the description of a simulation model for detailed planning of a regional energy system from the primary energy inputs to secondary energy distribution to the final user. The model structure consists of a network of elementary allocation, collection, and conversion processes. 13 different primary and 7 secondary energy forms are considered. The model incorporates some 25 conversion processes. All presently conceivable energy forms and conversion processes are included. Exports, imports, as well as concentrated and distributed waste energies are accounted for. Primary and secondary energy costs, capital investment in conversion plants, and the number of plants, are computed. The flexibility of the model allows the simulation of a wide variety of possible energy supply systems. Results are presented in the form of tables and plots.

The simulation model has been applied to compute nuclear and non-nuclear energy scenarios for the United States and Western Europe, as well as oil and hydrogen production scenarios for the Middle East from 1970 to 2025. These results are reported in Sec. 4.2.

Sec. 4.3 presents a discussion of scenario evaluation, with an application to the results of Sec. 4.2.

A simplified, highly aggregated model of the energy supply system derived from the full simulation model, is given in Sec. 4.4. This model can be used for exploratory study and interactive applications.

4.1 A Simulation Model of the Energy Conversion and Distribution System

Introduction

From extraction or collection of primary energy, through different conversion processes, and finally to distribution to end users, the energy system of all but the most primitive societies represents a complex interwoven net of allocation, collection, and conversion processes. The net contains allocations and reallocations of energies in different forms to different receivers, conversions of one form of energy to other forms, efficiencies of conversion, and energy losses to unrecoverable heat.

The energy system of a given society has grown to what it is today by (1) the nature and availability of natural supplies; (2) the technologies of conversion which have evolved in the course of time; (3) user demand. This process has been iterative and adaptive, and has until recently worked reasonably well to keep up with the demand of energy in its various forms. Given unlimited primary energy supplies and/or an omnipotent technology, and unlimited investment capital, the system could, in theory, adjust to any demand rapidly.

In the past, both the actual demand and its rate of growth have been relatively small, supplies have been plentiful, technology has been very innovative at moderate cost, investments in the energy system have been a small fraction af the gross national product. As a result, the system has been able to adjust satisfactorily to changes in demand. The situation has changed in the past few years.

Today, we are faced both with a demand and a rate of demand growth which have become substantial. At the same time supplies of primary energy dwindle, energy technology has become stagnant and costly, and requires long lead times,and necessary investments in the energy system constitute a significant fraction of the gross national product. A merely adaptive, response-to-the-market control of the energy sector is no longer possible and may lead to crisis. Anticipative adaptive control with a feed-forward time constant measured in decades, not months, becomes necessary. The structural complexities of the energy system and its inherent dynamics almost preclude the possibility of reaching good or even satisfactory policy decisions in the traditional way - by exercising crude mental models behind desks or in smoke-filled committee meetings.

Computer simulation offers a fast and inexpensive way to try out policies, to learn from mistakes at the mere cost of computer time and wasted paper, to develop satisfactory policy mixes which have some assurance of achieving the desired effect, and to keep ahead of developments by updating the simulation continuously, projecting likely resulting developments and making the required policy changes. Obviously, this requires a good model to begin with [1].

In the present paper we describe a tool for the long-range planning of the energy supply system of a community, state, country, or multicountry region by using simulation on the computer. The model

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[1] A collection of energy models is found in: Milton Searle, Energy Modeling, Resources for the Future, Washington, Dec. 1973. The modeling approach of the present section is very similar to that in: Reference Energy Systems and Resource Data for Use in the Assessments of Energy Technologies, Associated Universities, Inc., Upton, New York 1973, and in:W.E.Winsche, K.C.Hoffman, F.J.Salzano, "Hydrogen:Its Future Role in the Nation's Energy Economy", Science, 29 June 1973, Vol. 180, No. 4093, p. 1325 - 1332.

includes all conceivable sources of primary energy (from biomatter to an unspecified hypothetical future source). It ties these sources to respective specific conversion processes by a detailed allocation scheme.After a first conversion, some of the converted energy undergoes a second conversion by another set of specific conversion processes. Energy is then collected as secondary emergy in various forms and allocated to various users. All wastes are accounted for and recorded.

The model consists of a complex structure made up of very few elementary processes:

(1) elementary allocation processes

(2) elementary collection (addition) processes

(3) elementary conversion processes.

The program provides merely a framework. The energy flow through the system is exlusively controlled by the parameters provided by the user. In particular, the user must supply (1) all allocation fractions (0.0 to 1.0) in the different branches of the program, and (2) all efficiencies of conversion processes. This allows a complete tayloring af the simulation to any specific setting, whether rural village or multinational developed region, and the introduction of specific technologies and uses. It is thus the user who sets all the valves of the energy supply planning model himself; nothing, except all physically possible structural connections of the flow net, has been preprogrammed.

Overall Structure

The model traces interconnected flows of energy from primary energy inputs through conversion processes (with their inherent losses of useful energy) to distribution and allocation to the ultimate user. The elementary steps in this energy flow net are:

(1) Distribution of energy flows from a particular energy source to different energy receivers ("allocation").

(2) Summation of energy flows from different sources ("collection").

(3) Conversion of energy from one form to several others (useful energy plus rejected heat;some heat may be recovered).

The model breaks down into several submodels which are traversed in sequence in the course of the calculations for a given simulated year (Fig. 4.1).

(1) Distribution of primary energy inputs.

(2) Allocation of primary energy inputs to primary conversion processes or direct use.

(3) A sequence of one or several conversion processes to convert primary energy to the secondary energy forms used in the user sector.

(4) Distribution and transmission (here incorporated into the conversion sector).

(5) Allocation of secondary or primary energy inputs to the different users in the user sector.

These submodels are shown in Figs. 4.2 - 4.7 (to aid in understanding these diagramms, a list of symbols is found in Appendix 4 A).

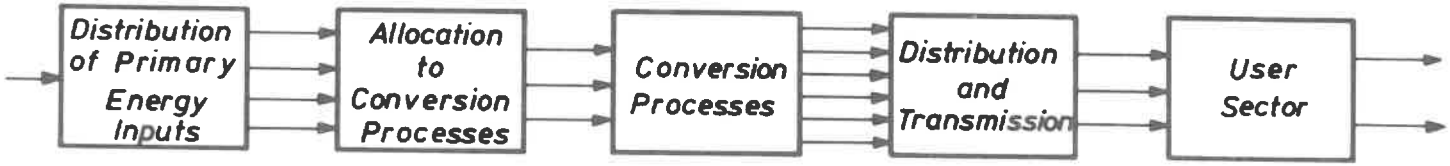

Fig. 4.1 - Overall Structure of Energy Supply Model

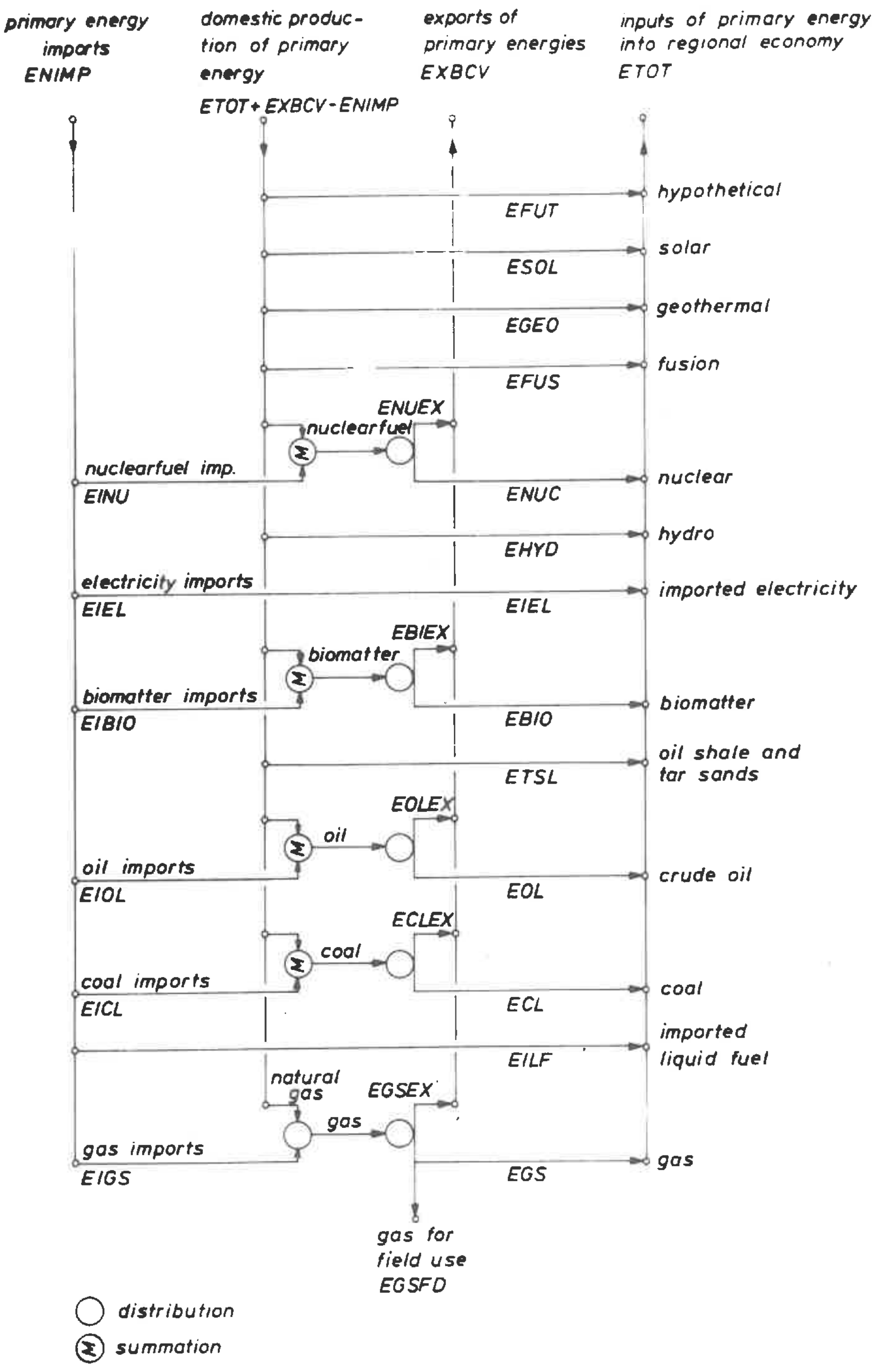

Fig. 4.2 Primary Energy Inputs; Imports and Exports

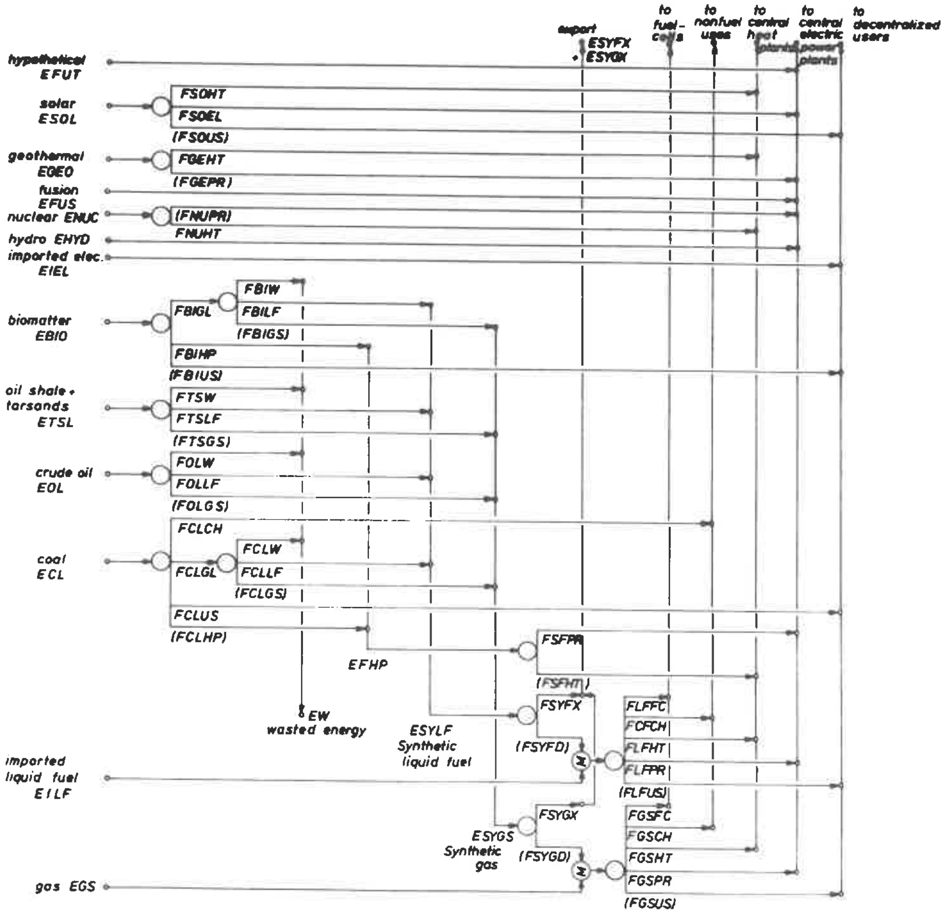

Fig. 4.3 Allocation of Primary Energy Inputs to Conversion Processes and Users

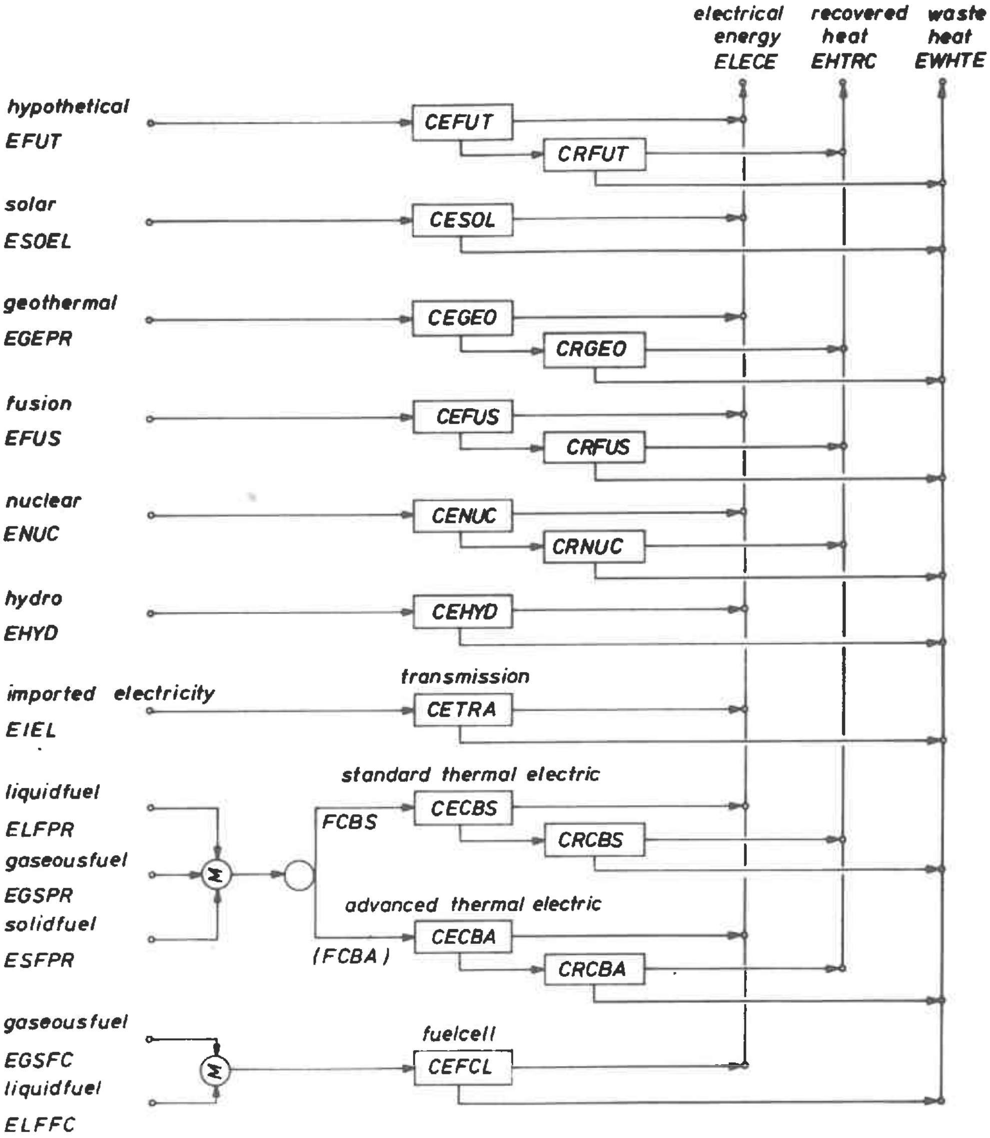

Fig.4.4 Conversion to Electrical Energy

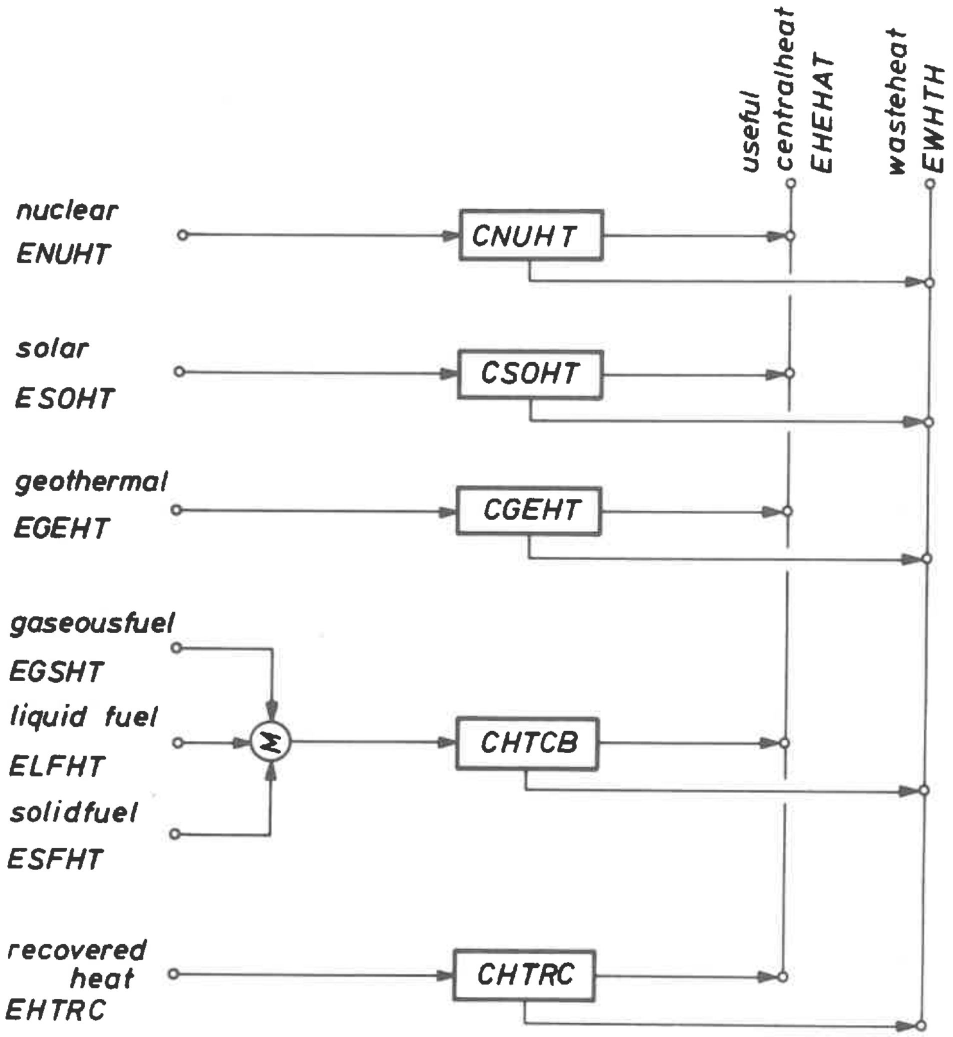

Fig. 4.5 Conversion to Central Heat

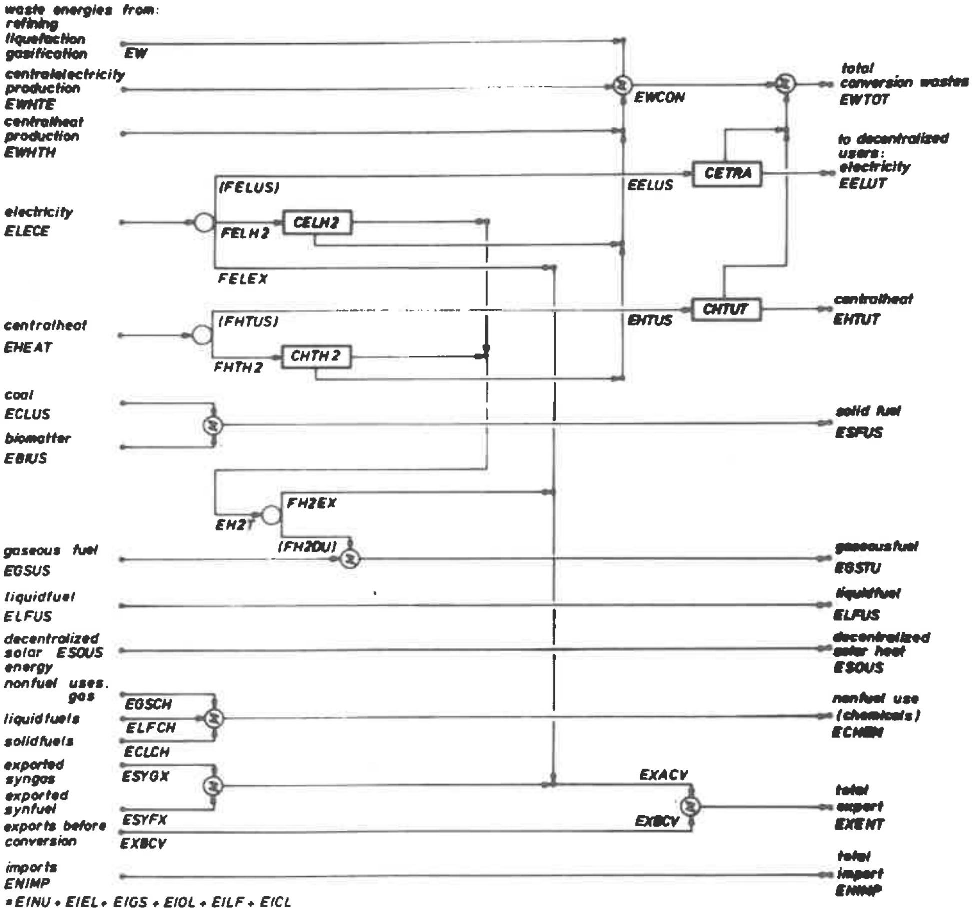

Fig. 4.6 Final Stages of Conversion and Inputs to Decentralized Users

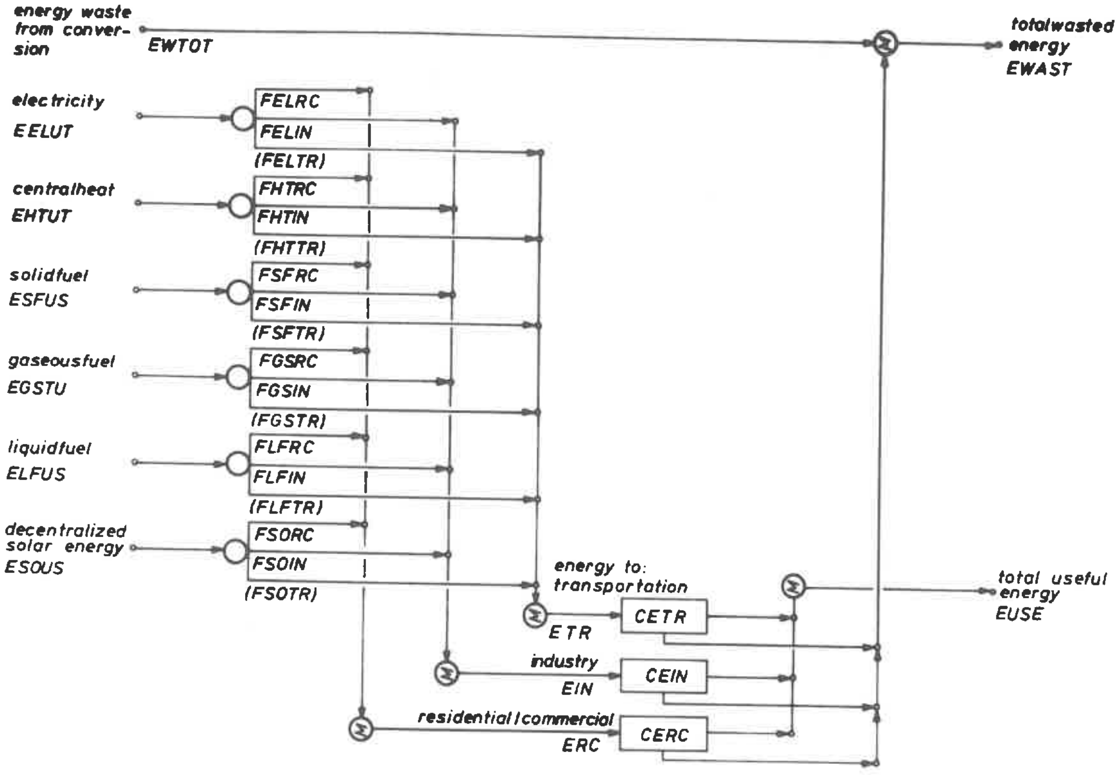

Fig. 4.7 Energy Allocation in User Sector

Approach

The model has been designed from the outset as a planning tool for the policy maker. In its present noninteractive version, it requires simple input in the form of data cards.

The program operates sequentially. For a given year it computes from the primary energy inputs and the allocation fractions the inputs to the various conversion processes. Using the prescribed efficiencies, the waste energy and the useful energy are computed for each conversion process. Identical energy forms from different conversion and transmission processes are then combined and allocated to the different users. New allocation fractions and efficiencies for a next point in time are supplied externally by time-series representing scenarios.

Key Features of the Model

The usefulness of any model and its range of applicability are determined by the variables and parameters included. In order to insure applicability to as wide a range of conceivable energy supply systens as possible, especially those of developing countries on one hand, or those of future decades on the other, we have included a wide range of possible primary and secondary energy forms and conversion processes.

The primary energy forms presently included are:

- an unspecified hypothetical future energy source EFUT
- solar energy ESOL

- geothermal energy EGEO
- fusion energy EFUS
- nuclear energy ENUC
- hydrodynamic energy EHYD
- imported electrical energy EIEL
- energy in wood, wastes, and biomatter of different origin EBIO
- energy in oil shale and tar sands ETSL
- natural gas (domestic and imported) EGS
- imported liquid fuel EILF
- petroleum (domestic and imported) EOL
- coal (domestic and imported) ECL

A part of these primary energies (such as certain percentages of coal, liquid fuel, and gas) are distributed to domestic or foreign users without further conversion (exports before conversion:EXBCV). The remainder undergoes conversion processes. We have included the following processes:

- conversion of the hypothetical energy EFUT to electrical energy (conversion efficiency CFUT).
- conversion of solar energy to heat in central plants (for smelting, district heating, district air conditioning, refrigeration, etc.) (CSOHT)
- conversion of solar energy to electricity in central solar 'farms' (CESOL)
- decentralized conversion of solar energy by residential and commercial users for water and space heating, refrigeration,

air conditioning, electric power generation, etc.

- conversion of geothermal energy to heat in central plants (for the same purpose as above) (CGEHT)
- conversion of geothermal energy to electricity in central plants (CGEO)
- conversion of fusion energy to electricity (CEFUS)
- conversion of fission energy to electricity (CENUC)
- conversion of fission energy to process heat (CNUHT)
- conversion of hydrodynamic energy to electricity (CEHYD)
- conversion of energy in wood, wastes, biomatter (EBIO) to heat in central plants (CHTCB)
- conversion of EBIO to electricity in large plants (CECBS or CECBA)
- conversion of EBIO to liquid or gaseous fuels (by pyrolysis, destructive distillation, ets.) (waste fraction: FBIW)
- conversion of energy in oil shale and tar sands ETSL to liquid and gaseous fuels (waste fraction:FTSW)
- refining of oil to liquid and gaseous fuels (waste fraction: FOLW)
- conversion of gaseous, liquid, and solid fuels to non-fuel use (fractions FCLCH, FGSCH, FLFCH)
- conversion of energy in gaseous, liquid fuels to electrical energy in fuel cells (CEFCL)
- conversion of energy in gaseous, liquid, or solid fuels to heat of combustion for electric power generation (in CECBS, CECBA)

- conversion of energy in gaseous, liquid, or solid fuels to heat of combustion for central heat purpose (CHTCB)
- conversion of heat of combustion to electricity by standard processes (steam power plant with an efficiency of approx. 35 percent) (CECBS)
- conversion of heat of combustion to electricity by advanced processes (such as magnetohydrodynamic (MHD) power generation; topping cycles, etc.) (CECBA)
- conversion of (collection of) rejected heat from electricity generating processes to useful heat for central heat plants (CHTRC)
- conversion of coal to liquid and gaseous fuels (waste fraction: FCLW)
- generation of hydrogen by using electrical energy (CELH2)
- generation of hydrogen by heat processes (CHTH2)

Some of these processes (gasification, liquefaction, refining) require an external source of energy to run the process, while the energy content of the energy flow passing through the conversion process may not be significantly affected. Such process energies are here accounted for in the industrial sector. Similarly, the transmission losses of pipelines, or of fuel transportation by ships and vehicles, are accounted for in the transportation sector, as the energy content reaching the consumer in not changed. Transmission losses for electricity and heat are explicitly accounted for, as only part of the energy entering the transmission line reaches the consumer. Storage losses, such as incurred in the temporary storage of heat in underground aquifers, should be included in the transmission losses.

The model allows for possible export of processed gaseous and liquid fuels and of electricity following the conversion sector.

Energy leaves the conversion and transmission sector (resp. is transmitted directly from the primary source) in one of the following forms:

- waste heat (except for transmission losses, this waste heat occurs at point sources and may pose environmental problems) EWTOT
- electricity EELUT
- central heat EHTUT
- solid fuel ESFUS
- gaseous fuel EGSTU
- liquid fuel ELFUS
- decentralized solar heat ESOUS
- nonfuel (for production of petrochemicals, fertilizer, plastics etc.) ECHUS
- exports of energy after conversion EXACV

In the user sector, the incoming energies in their various forms (excluding waste heat, nonfuels, and exports) are allocated to either the residential/commercial sector, to the industrial sector, or to the transportation sector. In this approach, we have followed the standard pattern of energy statistics. Eventually it might be advisable to develop a somewhat more detailed model which distinguished between residential and commercial uses, between different kind of industry, and between individual and mass and freight transportation.

The aggregation used requires the assignment of an overall efficiency to each of the three sectors to determine useful energy and wastes. We have used the estimates of two sources[2] although these efficiencies can only be meaningfully determined in the transportation sector and are meaningless where heating processes are involved (as in the residential/commercial and industrial sectors). However, these efficiencies obviously play no role as far as the energy supply problem (treated here) is concerned. The question of how much energy demand can be reduced by improving user efficiencies would have to be answered by including efficiencies and saturation estimates for individual energy-consuming devices.

Computer Program

The essential part of the simulation program ESP (Energy Supply Planning) is listed in Appendix 4 B. It follows the diagrams of Fig. 4.1 and Figs. 4.2 to 4.7 from left to right. Quantities beginning with the letter F are allocation parameters. All quantities beginning with a C are conversion efficiencies. (A full listing with explanations of all parameters is given in Appendix 4 A.) The parameters F in parentheses are computed by the program by $F_n = 1 - \sum_{i=1}^{n-1} F_i$.

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[2] Joint Committee on Atomic Energy, "Certain Background Information for Consideration When Evaluating the 'National Energy Dilemma'", (Washington: U.S. Government Printing Office, 1973), Stock No. 5270-01801; Scientific American, Energy and Power (San Francisco: W. H. Freeman and Co., 1971).

All energy flows start with the letter E. Generally the energy flows leaving a branch carry the same name as the respective allocation parameters except for a change of the initial letter from F to E. Energy flows are computed by multiplying the input energy flow by the applicable allocation parameters. Thus, as an example, the energy in liquid fuel produced by coal liquefaction (Fig. 4.3) is

$$\mathrm{ECLLF = ECL * FCLGL * FCLLF}$$

Energy flows from a conversion process are computed by multiplying incoming energy flow by the efficiency of the process; for example the electrical energy generated from fuel combustion, steam generation, and subsequent expansion in steam turbines driving electric generators is given by

$$\mathrm{ELCBS = ECBS * CECBS}$$

This process generates an energy flow in rejected heat corresponding to ECBS * (1. - CECBS). Some of this heat may in fact be recovered for useful purposes:

$$\mathrm{HTCBS = ECBS * (1.-CBCS) * CRCBS}$$

The remainder goes to waste:

$$\mathrm{WCBS = ECBS * (1.-CECBS) * (1.-CRCBS)}$$

The program can use any desired unit of energy flow (i.e. tons of coal equivalent per year (tce/yr), barrels per day of oil equivalent (BDOE), British thermal units per year (Btu/yr), megawatts (MW), kilocalories per hour (kcal/h) etc.). Once the original input has been made in a given unit, all energy flows are subsequently computed and printed for the same unit.

The parameter and variable names are mnemonic and should be understandable with the help of Figs. 4.2 - 4.7 and the listings of the parameters in Appendix 4 A. Some of the abbreviations used are: FUT (future hypothetical source), SO or SOL (solar), GEO or GE (geothermal), FUS (fusion), NUC or NU (nuclear), HYD (hydropower), BIO or BI (wood, wastes, biomatter), I or IM (imports), E or EX (exports), TSL (tar sands or oil shale), GS (gas), OL (oil), LF (liquid fuel), CL (coal), SF (solid fuel), U or US (going to decentralized users), CH (nonfuel use, chemicals), W (waste), H or HT (heat), P or PR (electric power stations), SY (synthetic or refined), FC or FCL (fuel cell), H2 (hydrogen), TRA (transmission), E or EL (electricity), CB (combusion), RC (residential and commercial), IN (industrial), TR (transportation).

Estimates of capital investment are obtained by applying a cost of x dollars per kWe (or equivalent energy flow unit) of installed capacity to any conversion process (including gasification , liquefaction, thermal powerplants, dams, etc.). A rough estimate for the number of required plants follows by assuming an average size of 1000 MWe and an average utilization of 75 percent.

Use of the ESP simulation model

The ESP simulation model traces physically possible energy flows in a complex network. The program does not contain any fixed parameters. The individual flows in each of the branches of the network representing the energy system of a given economy must be controlled externally by proper setting of respective parameters. Moreover, many of these parameters will change with time, and must therefore be supplied as time-series. The running of a simulation therefore requires the careful preparation of "scenarios" prescribing each of the parameters over the time period in question (here 1970 to 2025).The preparation of the scenarios is somewhat simplified by the fact that many parameters are (approximate) constants and do not change from simulation to simulation (i.e. conversion efficiencies), and that other parameter time-series can be used unaltered for several simulations (e.g. a given nuclear energy scenario).

The input data deck consists of 109 cards specifiying time-series for 99 parameters, some 23 parameters which remain constant during the computations, and five labels for the printout of results. The time-series are limited to 12 datapoints per parameter, corresponding to 5 (10) year time increments for a computation period of 55 (110) years. Each time-series fits on one data card per format 12F6.2. Data cards are numbered to facilitate exchange of individual time series. The preparation of scenario input is simplified by a special set of keypunch forms.

The input data are grouped in the following order:

- region label
- scenario label
- units of energy and cost (generally 10^9 metric tons of coal equivalent per year and US dollars)
- number of data years (present scenarios: 12)
- data years (presently:1970, 1975, 1980, ..., 2025)
- net primary energy inputs (13 time-series)
- energy import and export before conversion (11 time-series)
- energy allocation fractions before conversion (33 time-series)
- energy distribution fractions to users (12 time-series)
- conversion efficiencies (24 time-series)
- user sector efficiencies (5 time-series)
- primary energy prices
- capital investment cost
- secondary energy prices to users
- region label (for plots)
- scenario label (for plots)

Corresponding to these inputs, the scenarios which can be investigated have the following aspects:

- primary energy inputs
- import/export
- technological
- distribution
- prices and costs.

Generally several of these aspects will have to be considered at the same time.

Input scenarios are prepared in a sequence of steps:

(1) General agreement on the aspects to be investigated.

(2) Qualitative outline of the affected time-series.

(3) Generation of the necessary numerical time-series, using statistical data, general considerations, consistency and feasibility checks.

(4) Coordination of related time-series (e.g. secondary energy generation and use, imports and need, etc.).

(5) Preparation of key-punch forms.

Once a scenario has been run, the results from the simulation will usually suggest changes in the input data. Changes are made in the input data until the simulation results have produced the required information.

Output

The program provides 17 pages of output in the form of tables and plots. On the first four pages the input scenario is reproduced; the remaining 13 pages present the results of the simulation in time-steps of one year for the full period of the simulation.

p. 1:
Region and scenario labels; units
Net primary inputs into region
Imports, exports and field use contributing to net inputs

p. 2:
Energy allocation fractions before conversion

p. 3:
Energy distribution to users
Conversion efficiencies

p. 4:
User efficiencies
Primary energy prices
Capital investment cost
Secondary energy cost to user

p. 5:
Net primary input energies (individual energies and total)

p. 6:
Primary energy inputs(amounts and costs) by groups (coal and lignite; gas and liquid energies; "ecological energies" (imported electricity, biomatter, hydro, geothermal, solar); fission and fusion; total)

p. 7:
Plot of energy input amounts (same groups as p. 6)

p. 8:
Plot of energy input costs (same groups as p. 6)

p. 9:
Imports and exports of primary and secondary energies (individual energy amounts)

p. 10:
Import and export total amounts and total costs

p. 11:
Plot of import and export total amounts and total costs

p. 12:
Number of 1000 MWe energy conversion plants and corresponding capital investment (annual increment and cumulative)

p. 13:
Plot of number of 1000 MWe energy conversion plants and corresponding cumulative capital investment

p. 14:
Secondary energies to user sector: total amount and total cost, and breakdown by energy kind and user sector

p. 15:
Plot of secondary energies to user sector by energy kind (electrical, heat, solid fuel, gaseous fuels, liquid fuels)

p. 16:
Plot of secondary energies to user sector by user sector (residential/commercial, industrial, transportation, total amount and total cost)

p. 17:
Overall efficiency of energy conversion and distribution and concentrated waste heat

4.2 Energy System Simulations

Objectives of the simulations

We report here on simulations undertaken for the energy systems of the United States, Western Europe, and the Middle East. These results are of an exploratory nature; they should not be construed as definitive and authoritative studies. In some of them, we have purposely focussed on extreme scenarios in order to demonstrate the latitude of the model, or to show the (positive or negative) consequences of some proposed solutions. In particular, we wish to make clear that we are not advocating any of the scenarios we have investigated. All of them have serious drawbacks. Better solutions would have to be found through the study of many more scenarios. The few results presented here should be taken as "food for thought" - steps in a lengthy iterative process at finding satisfactory long-range solutions for the energy system of a given region by using a reasonably comprehensive model to aid in the decision-making process.

The model was validated using 1970 data for the energy system of the United States[1]. The results of the simulation agreed within a few percent with those of the energy breakdown given in Ref. 1. Several different runs, some of them using quite unrealistic assumptions, were made for the United States energy system, and to study the general plausibility of the results.

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[1] Joint Committee on Atomic Energy, 93rd Congress, 1st Session: Certain Background Information for Consideration when Evaluating the "National Energy Dilemma". U.S. Government Printing Office, Washington, D.C., 1973. Stock No. 5270 - 01801.

Only some of the scenarios studied will be presented and discussed here, in particular:

United States:

(1) A standard energy scenario (JCAE7) of the Joint Committee on Atomic Energy. The JCAE scenario is specified to the year 2000, taking into account the depletion of oil and gas reserves (details below). The scenario assumes a substantial role of nuclear energy and an increasing role for coal.

(2) A non-nuclear energy alternative scenario supplying approximately the same amount of secondary energies to users as the JCAE-scenario, and making extensive use of advanced energy technologies.

Western Europe:

(1) A standard energy scenario for Western Europe.[2] This scenario assumes an increasing role for nuclear energy, and initial continued availability of oil and gas, modified later by supply limitations.

(2) A non-nuclear alternative scenario which assumes gradual conversions of the Western European economy to synthetic liquid and gaseous fuels from coal. Fuel imports are discontinued by 2000. No new nuclear facilities are put into operation, existing ones produce until 1985.

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[2] See, for example, H. Mandel, "Strukturen der nuklearen Stromerzeugung in den 70er und 80er Jahren". Atomwirtschaft, January 1973, p. 18-24.

Rejected heat from power stations is partially used. The liquid fuel produced supplies mainly the transportation sector after 2000. The primary energy input is held at the 5 kw/cap level. Service equivalent to the present 10 kw/cap level would result if 50 % overall savings in user efficiency could be introduced.

Middle East:

(1) The scenario assumes a gradual build-up of hydrogen production using solar energy. Hydrogen exports from the region replace and surpass oil and gas exports after the year 2000.

A note of caution

The scenarios described on the following pages are not predictions. Correspondingly, neither do the simulations have any predictive character. The scenario inputs are merely assumptions, although we have tried to use consistent and plausible sets of input data. The purpose of considering a wide spectrum of scenarios, some of them extreme, has been to explore a number of possible developments of the energy system and their consequences. It would take considerable and coordinated control efforts to realize most of the scenarios we have investigated.

Fixed scenario inputs

In reality all parameter inputs to the energy system change with time: prices and investment costs change, new technological processes appear, efficiencies improve (or, in the case of consumer products, decrease), consumption patterns change. These inputs should therefore be represented by time-series describing likely developments.

The ESP simulation model requires the specification of some 122 parameters, of which 99 are to be represented by time-series. While this provides great flexibility for scenario studies, some simplifying assumptions had to be introduced for the exploratory simulations which are the subject of this report. In particular, we have assumed (with a few exceptions)

- fixed conversion efficiencies
- fixed efficiencies of energy end use
- fixed primary energy cost
- fixed secondary energy cost
- fixed capital investment costs.

These assumptions require some justification.

Efficiencies: Engineering science has traditionally placed great emphasis on the efficiencies of energy conversion and transportation processes. As a result, the efficiencies of tried and proven processes have gradually approached plateaus which are only somewhat lower than theoretically possible efficiencies (e.g. Carnot cycle efficiency, efficiency of conversion of electrical or hydrodynamic energy into mechanical, etc.). Improvements have been minor in recent decades. Exceptions are those cases where different processes are introduced (MHD, topping cycles, supraconductors, fuel cells, etc.). Under these circumstances we feel justified in assuming fixed conversion and transportation efficiencies for the scenarios. For processes currently in widespread use we have used current average efficiencies (see the briefs on the different processes for details).

For new processes not yet introduced on a larger scale, we have generally kept to the conservative side of efficiency estimates found in the literature (see again the corresponding briefs).

The efficiency of energy use in the end user sector is an entirely different matter. Very significant improvements in the efficiency of energy use can here still be had on two levels: by increasing the efficiencies of the energy using processes or devices directly, and by "cascading" energy using processes in such a manner that the rejected energy from one process becomes the input energy for the next.[3] The latter aspect requires a departure from the optimization of individual units or processes (which usually represents suboptimization for the total system) to an optimization of integrated and usually complex energy systems (residential energy systems, integrated industrial processes). We are only beginning to think about such aspects of user energy systems.

The former aspect is more straightforward. Improvements in the efficiencies of many important devices or processes are easily possible technologically, and corresponding energy savings can be very significant. Thus energy use for space heating could be reduced by a factor of four through better insulation and the use of heat pumps; energy use in individual transportation could be reduced by at least a factor of two for the same transportation performance by going to smaller cars with more efficient engines (especially in the United States); energy use in

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[3] see, for example: Eugene G. Kovach (ed), Technology of Efficient Energy Utilization. Scientific Affairs Division, North Atlantic Treaty Organization, Brussels, 1973.

industry could be reduced significantly by switching to less energy-intensive processes and materials (examples: energy need of lumber production is 4 megajoules/kg, of aluminum production 60 - 270 megajoules/kg[4]) and by restricting the production of throw-away products.

In the present ESP simulation model the efficiencies of energy use in the different user sectors are only of indirect interest. They have no effect on the results of the computations. No weight should therefore be attached to the user efficiencies listed below; they have been taken from the literature[5] but appear far too optimistic. The energy reaching the user sector is supposed to correspond to consumption need;it is here a function of the assumed primary energy supply scenario. In a future version of the model, one could introduce service needs as the driving force, and compute primary energy requirements from

$$\text{secondary energy need} = \frac{\text{service need}}{\text{energy use efficiency}}$$

$$\text{primary energy need} = \frac{\text{secondary energy need}}{\text{energy conversion efficiency}}$$

Assumed efficiencies of conversion processes

The efficiencies used in the simulations are assumed to represent average values for large- scale applications. More complete information on the different processes and their efficiencies is found in the respective briefs. Listed below are only the efficiencies of processes actually activated in the simulations. In the alternative 'A' scenarios

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[4] Kovach, op.cit., p. 56

[5] JCAE report, op.cit., and Scientific American, Energy and Power, W. H. Freeman, San Francisco, 1971.

time-series were assumed for an increasing use of rejected heat from electricity generating processes. Only a qualitative description of these time-series is given below; the full numerical sequences are listed in the scenario printouts appended to this report.

- solar energy to electricity; 15 % efficiency (CESOL) Middle East scenario:20 %
- geothermal energy to electricity: 35 % (CEGEO)
- percentage of rejected heat from this process recovered for use in a cascaded process: 0 %; resp. for 'A' scenarios: 0 % until 1985, 5 % in 1985, increasing linearly to 45 % in 2025 (CRGEO)
- nuclear energy (thermal) to electrical: 30 % (CENUC)
- percentage of rejected heat from this process recovered for use in a cascaded process: 0 % resp. for 'A' scenarios: 0 % until 1985, 5 % in 1985, increasing to 60 % in 2025. (CRNUC)
- Hydrodynamic energy to electrical: 90 % (CEHYD)
- transmission of electricity over large distances: 90 % (CETRA)
- combustion heat to electricity in large powerplants by present standard processes: 35 % (CECBS)
- percentage of rejected heat from this process recovered for use in a cascaded process: 0 %; resp. for 'A' scenarios: 0 % until 1990, 5 % in 1990, increasing to 25 % in 2025 (CRCBS).
- combustion heat to electricity in large powerplants by advanced processes (topping cycles, MHD): 55 % (CECBA)
- percentage of rejected heat from this process recovered for use in a cascaded process: 0 %; resp. for 'A' scenarios: 0 % until 1990, 10 % in 1990, increasing to 35 % in 2025 (CRCBA).
- fuel energy to electricity in fuel cells: 65 % (CEFCL)
- solar energy to central process heat: 20 % (CSOHT)
- fuel energy to heat of combustion in large plants: 90 % (CHTCB)
- heat recovery from rejected heat (from electricity generation processes): 90 % (CHTRC)
- electrical energy to chemical energy (hydrogen) by electrolysis: 70 % (CELH2)
- heat energy to chemical energy (hydrogen) by heat process:60 % (CHTH2)
- heat transmission over intermediate distances: 80 % (CHTUT)
- nuclear (thermal) energy to process heat: 90 % (CNUHT)

Costs

In contrast to the relatively stable and predictable values for efficiencies, energy prices (and to a lesser degree, capital investment requirements for conversion plants) may fluctuate wildly as a result of economic or political developments. In view of recent experiences attempts at price predictions to 2025 seem absurd. We have therefore run all scenarios with identical and constant primary and secondary energy prices and capital investment costs. The results may be interpreted as representing constant 1974 uninflated U.S. dollars and fixed price ratios between competing energies. Variable price scenarios can be studied after a slight modification of the input format of the ESP simulation model. However, even the fixed-price scenarios reported here can be used to study the results of various price shifts by simply multiplying the computed costs by appropriate factors.

The prices and costs stated below were used in all simulation runs. The amounts represent average 1974 data. They are justified on separate briefs.

Primary energy prices: (tce - ton coal equivalent)

- solar energy: no cost (PESOL)
- geothermal energy:$ 3/tce (PEGEO)
- nuclear fuel (thermal equivalent): $ 8/tce (PENUC)
- hydrodynamic energy; no cost (PEHYD)
- imported electricity: $ 95/tce (PEIEL)
- wood, wastes, biomatter: $ 50/tce (PEBIO)
- oil shale and tar sands: $ 20/tce (PETSL)

- crude oil: $ 40/tce (PEOL)
- imported liquid fuel:$ 55/tce (PEILF)
- gas (natural or synthetic, incl. H_2): $ 60/tce (PEGS)

Secondary energy prices:

- electricity: $300/tce(PREL)
- central (process) heat: $60/tce (PRHT)
- coal and other solid fuel: $ 35/tce (PRSF)
- gas (natural or synthetic, incl. H_2): $ 100/tce (PRGS)
- liquid fuel: $ 80/tce (PRLF)
- solar energy: no cost (PRSO)

Capital investment per installed kilowatt (effective output) of conversion plant capacity:

- gasification and liquefaction plants,refineries, shale oil plants: $ 80/kWe (PIEGL)
- electric power plants, all kinds: $ 350/kWe (PIEET)
- central (process) heat plants: $ 70/kWe (PIEHT)
- hydrogen generation from electricity or heat: $ 80/kWe (PIEH2)

Energy Scenarios for the United States

Two different energy input scenarios will be discussed for the United States. The first ("standard" scenario) corresponds to the scenario of the Joint Commitee on Atomic Energy (JCAE "Option Exercise 7-A" 3-73) to the year 2000[6]. This scenario assumes a steeply increasing role for nuclear energy. It has been extended to the year 2025 in a manner consistent with the trends of the original scenario and the likely resource availability (Fig. 4.8).

In the second ("alternative" scenario) the primary energy input is restricted to the (present) 10 kW per capita level. (If a proper increase in the user efficiencies were eventually introduced, this could still correspond to a 20 kW/cap. energy service equivalent!). The primary energy input is provided by a strong and increasing share of coal, by oil (including that derived from oil shale and tar sands), by biomatter, and to a lesser degree by solar and geothermal energy.

The total primary energy demand curves for the two cases are given in Fig. 4.9. It is of some interest to note here that both supply comparable amounts of secondary energy to the user.

The input parameter time-series are listed in the scenario printout reproduced in the data appendix; the major assumptions will now be discussed briefly for each of the scenarios.

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[6] JCAE report, op. cit.

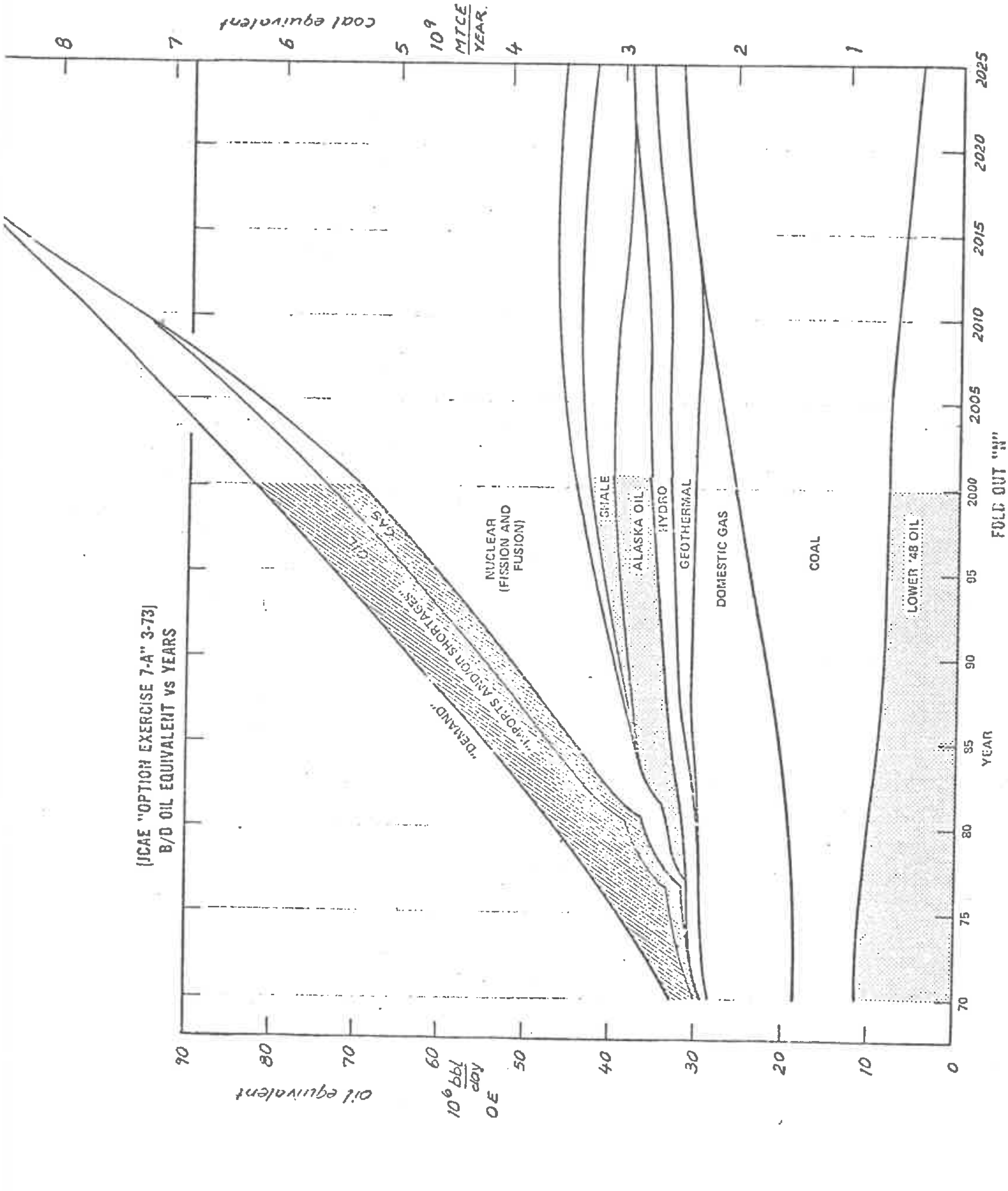

Fig. 4.8 - JCAE energy scenario extended to 2025

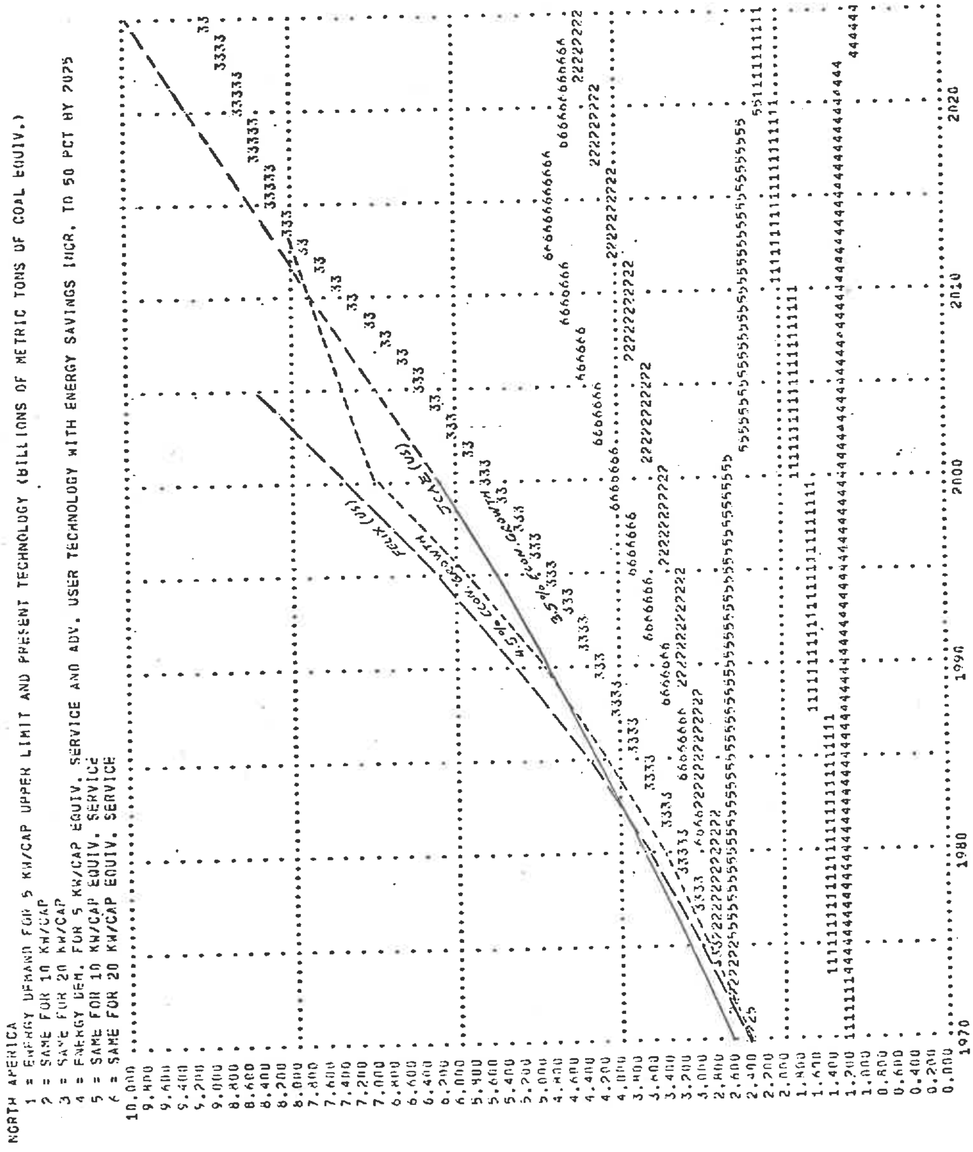

Fig. 4.9 - Regional energy demand for North America,
resp. United States

These time-dependent scenario inputs are

- the individual and total primary energy inputs
- primary energy imports and exports
- energy allocations to the different conversion processes
- energy distribution to users

As stated earlier, conversion efficiencies, user efficiencies, the prices of primary and secondary energies, and the capital investment costs of energy conversion plants are held constant.

JCAE ("standard") scenario

Primary energy inputs

The total primary energy input of the JCAE scenario is similar to the demand predicted by the EDP model (chapter 3) for an average 3.5 % growth of gross national product (Fig. 4.9). It is considerably below that predicted by Felix[7], especially in the last decades of this century and beyond. Total primary energy input increases from 2.46 billion tons of coal equivalent (Gtce) in 1970 to 6.09 Gtce in 2000 and 9.93 Gtce in 2025. In the later part of the scenario period, nuclear energy and coal account for the major portions of this energy. The breakdown of individual primary energies:

Solar energy begins to provide a substantial input around 1990 (.05 Gtce). This increases slowly to .12 Gtce in 2000 and .27 Gtce

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[7] Fremont Felix, "The Future of Energy Supply: The Long Haul". Paper prepared for Tokyo Conference of the Atlantic Institute of International Affairs, October 1973

in 2025. Geothermal energy remains on the same scale, but starts somewhat earlier (.07 in 1985, .2 in 2000, .28 in 2025). Fusion energy, if it becomes operational, is accounted for under nuclear energy. Nuclear energy enjoys spectacular growth; providing approximately two-thirds of the primary energy input by 2025 (.02 in 1975, 1.9 in 2000, 6.3 in 2025). Hydro energy is built up to the maximum feasible until the turn of the century (.04 in 1975, .17 in 2000, .18 in 2025). No imports of electrical energy or use of biomatter as an energy source is considered. The exploitation of oil shale and tar sands is begun around 1985. It increases to a point where the extent of (surface) mining operations reaches the same order of magnitude as coal mining operations (shale and tar oil: .08 in 1990, .2 in 2000, .4 in 2025).

The input of oil increases initially, but then declines with the exhaustion of supplies of recoverable lower '48 oil, Alaska oil, and imported oil (total oil input: 1.12 in 1970, 1.64 in 1985 (maximum), .4 in 2025). In contrast, the coal input climbs to roughly four times the 1970 level: .5 in 1970, 1.39 in 2000, 2.1 in 2025. The natural gas input increases somewhat initially, but then falls to zero with diminishing supplies (.8 in 1970, .95 in 1985 (maximum), .04 in 2015, zero thereafter).

Primary energy imports and exports

The scenario makes the assumption that initially a substantial portion of the oil and gas demand is covered by oil and gas imports. The total import peaks around 1995 and drops to zero by 2025 (.29 in 1970, .85 in 2000, .0 in 2025). Oil imports represent the major portion of imports (.25 in 1970, .65 in 1995 (maximum), .0 in 2025). The remainder are gas imports (.o4 in 1970, .25 in 1995 (maximum), .0 in 2025). Coal exports represent the only energy exports. They are held at approximately 12 % of total domestic coal production (coal exports: .06 in 1970, .16 in 2000, .24 in 2025). It is realized that there will probably be substantial exports of nuclear fuels to other countries. As these exports are irrelevant to the domestic energy picture, we have not entered them into the scenario. The field use of gas decreases from .08 in 1970 to .03 in 2000 and .0 in 2015 and thereafter.

Energy allocations to the different conversion processes

The energy allocation fractions capture the specific technological and economical character of the energy conversion and distribution system and deserve separate discussion. At each distribution point, the input energy is split into several fractions moving on into the energy system on separate paths.Thus, incoming coal and lignite is assigned to the production of chemicals, gasification and liquefaction, decentralized users (residential and commercial, industrial, transportation), and the production of electric power and central (process or district) heat. These fractions add up to unity. To avoid errors, the user supplies only (n-1) of these fractions in the input scenario; the program computes the n-th fraction. On the list of symbols, the corresponding fraction name is given in parentheses. These parameters do not appear on the scenario printouts.

The solar energy used by the system is initially all absorbed by decentralized units (mainly home and water heating). Beginning in 1995, an increasing amount of the captured solar energy is used for the central production of electricity on solar farms. This percentage increases from 5 % in 1995 to 30 % in 2025. A smaller percentage is used for the production of central process heat, mainly for smelting (2 % in 2000, 5 % in 2025).

Geothermal heat is all used for electric power generation. As geothermal heat sources are generally located in remote areas, use for district heating or process heat will not normally be feasible.

Of the recoverable energy in oil shale and tar sands, it is assumed that 15 % are lost in the crude oil (or gas) extraction process. This corresponds to the present recovery ratio of 80 to 90 %. Half of the recovered energy is assumed to appear in gaseous form; half in liquid form.

Energy losses in crude oil refining are assumed at 5 % of energy input. Gas production from the refining process is limited to 10 % of the energy input, leaving 85 % of the input energy for the production of liquids, mostly fuels.

Only 2 % of coal and lignite input go to nonenergy use (chemicals etc.). Gasification and liquefaction of coal begins on a commercial scale around 1980, and increases steadily to 20 % of the coal and lignite input by 2025 (2 % in 1980, 10 % in 2000, 20 % in 2025). The decentralized use of coal (mainly in industry) decreases over this period from 41 % in 1970 to 20 % in 2025. The remaining fraction(about 58 % during the period),of the coal and lignite input goes to central electric power generation. A loss of 5 % of incoming energy is assumed for the gasification and liquefaction of coal. Half of the remaining energy is assumed to be converted to gaseous, half to liquid fuels. All domestically produced synthetic gas or liquid fuel is used domestically; there are no syngas or synfuel exports.

The major portion of the (natural or synthetic) gas entering the economy goes to decentralized users (79 % in 1970, increasing to 92 % after 1995). Large scale central fuel cell installations are not anticipated. A constant 3 % of gas energy is needed for nonenergy products (chemicals, fertilizers, etc.). The fraction of gas used for electric power generation in central plants decreases from 18 % in 1970 to 5 % in 2000, remaining constant thereafter.

The greatest fraction of liquid fuels is consumed by decentralized users (residential and commercial, industrial, transportation). This fraction increases from 80 % in 1970 to 85 % in 2025. The use of liquid fuels in power plants decreases from 10 % of the liquid fuel input in 1970 to 5 % in 2025. Again, large scale use of liquid fuels in central fuel cell installations is not anticipated. Nonenergy use of liquid fuels (chemicals, plastics) remains at a constant 10 %. Use of liquid fuels in central heat plants is not anticipated.

The major portion of solid fuels to central heat and power plants (a constant 95 %) is assumed to be used in electric power plants, the remainder in central district heating plants.

It is assumed that initially standard combustion processes dominate in thermal electric powerplants, but that starting around 1985, an increasing percentage of thermal electric power plants uses advanced thermodynamic (topping cycles) or magnetohydrodynamic processes. This percentage increases from 5 % in 1985 to 25 % in 2025.

Almost all of the electricity generated goes directly to the user sector (100 % in 1970, 98 % in 2025). No electrical energy is exported; a small percentage is used in the central generation of hydrogen (1 % in 1995, 2 % in 2025). However, an increasing percentage of centrally generated heat is used for the production of hydrogen (beginning with 5 % in 1985, and increasing to 50 % in 2025). All hydrogen is used in the domestic economy; none is exported. Nuclear energy is used exclusively for central electric power generation.

Energy distribution to users

The residential/commercial sector remains the dominant user of electrical energy (58 % in 1970, 59 % in 2000, 62 % in 2025). The share of the industrial sector decreases from 42 % in 1970 to 37 % in 2000, and 30 % in 2025 . Corresponding to an increasing role of mass transportation, the share of the transportation sector increases from 1 % in 1980 to 4 % in 2000 and 8 % in 2025.

Centrally generated heat is initially used mainly for industrial purposes; this share decreases (95 % in 1970, 80 % in 2000, 50 % in 2025). Correspondingly, the share of the residential/commercial sector increases from 5 % in 1970 to 50 % in 2025. Use of heat in the transportation sector is not assumed, although the possibility exists.

The proportion of solid fuel consumed in the residential/ commercial sector decreases from 8 % in 1970 to 5 % in 2025. Correspondingly, the industrial sector increases its share from 92 % to 95 %. Solid fuel use in transportation is not assumed.

An increasing fraction of gas is consumed in the residential/ commercial sector. This fraction increases from 42 % in 1970 to 55 % in 2000. The share of the industrial sector drops from 55 % in 1970 to 35 % in 2025. The transportation sector takes an increasing fraction (3 % in 1970, 6 % in 2000, 10 % in 2025).

Due to increasing use of gas in the residential/commercial sector, the liquid fuel use in this sector drops from 22 % of liquid fuel input in 1970 to 15 % in 2025. The share of the industrial sector remains approximately constant (14 % in 1970 to 15 % in 2025). The major portion of liquid fuel is used in the transportation sector (64 % in 1970, 66 % in 2000, 60 % in 2025).

The use of solar energy is initially restricted to the residential/ commercial sector (space and water heating). Industry starts using some solar energy on a small scale in 1980 (1 % in 1980, 5 % in 2000, 10 % in 2025). The transportation sector makes no use of solar energy.

Results of the simulation

The full results of the simulation using this input scenario are given in the data appendix in the form of tables and plots. Figs. 4.10 and 4.11are excerpts.The results will be discussed together with those of the next input scenario, which represents a possible alternative to the JCAE-scenario.

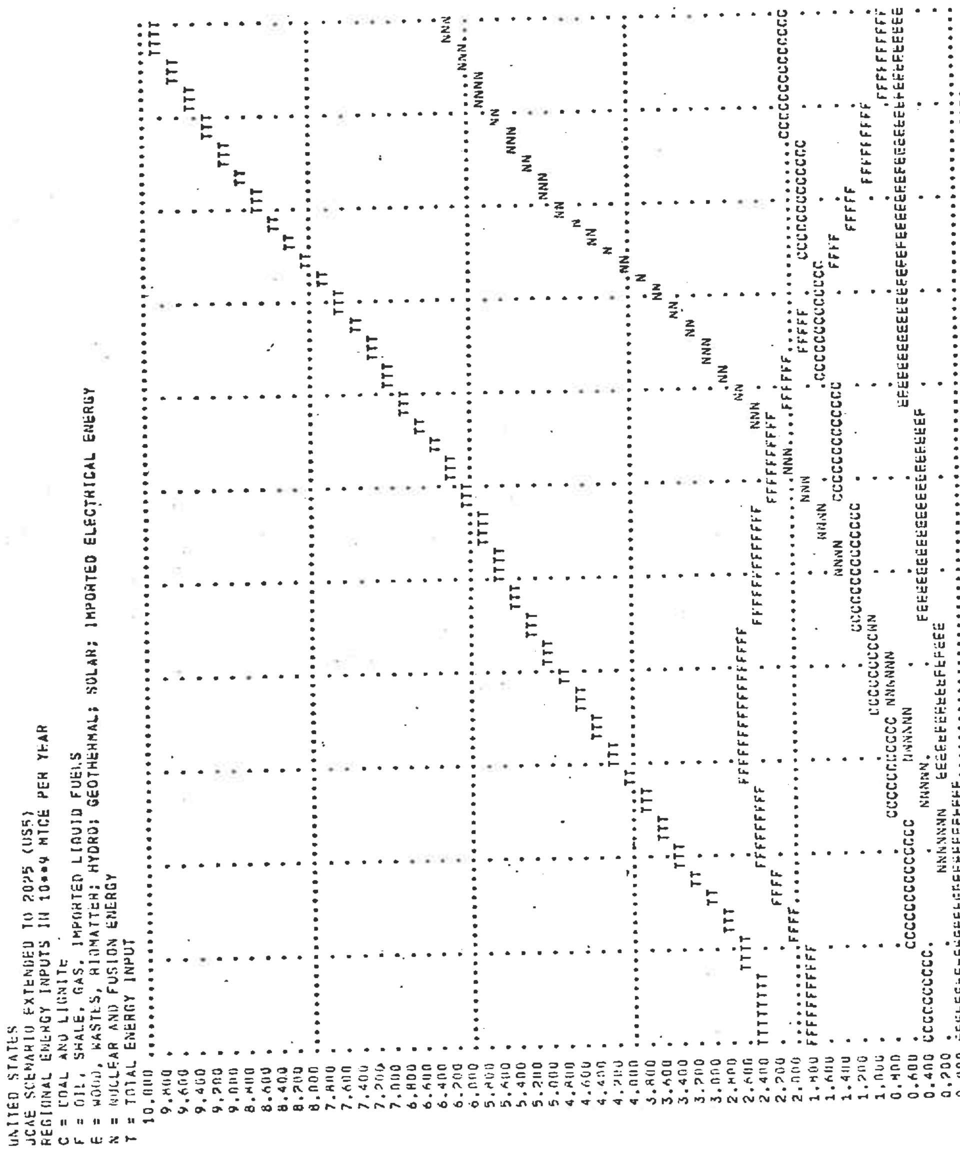

Fig. 4.10 - Primary energy inputs for the "standard" scenario for the United States

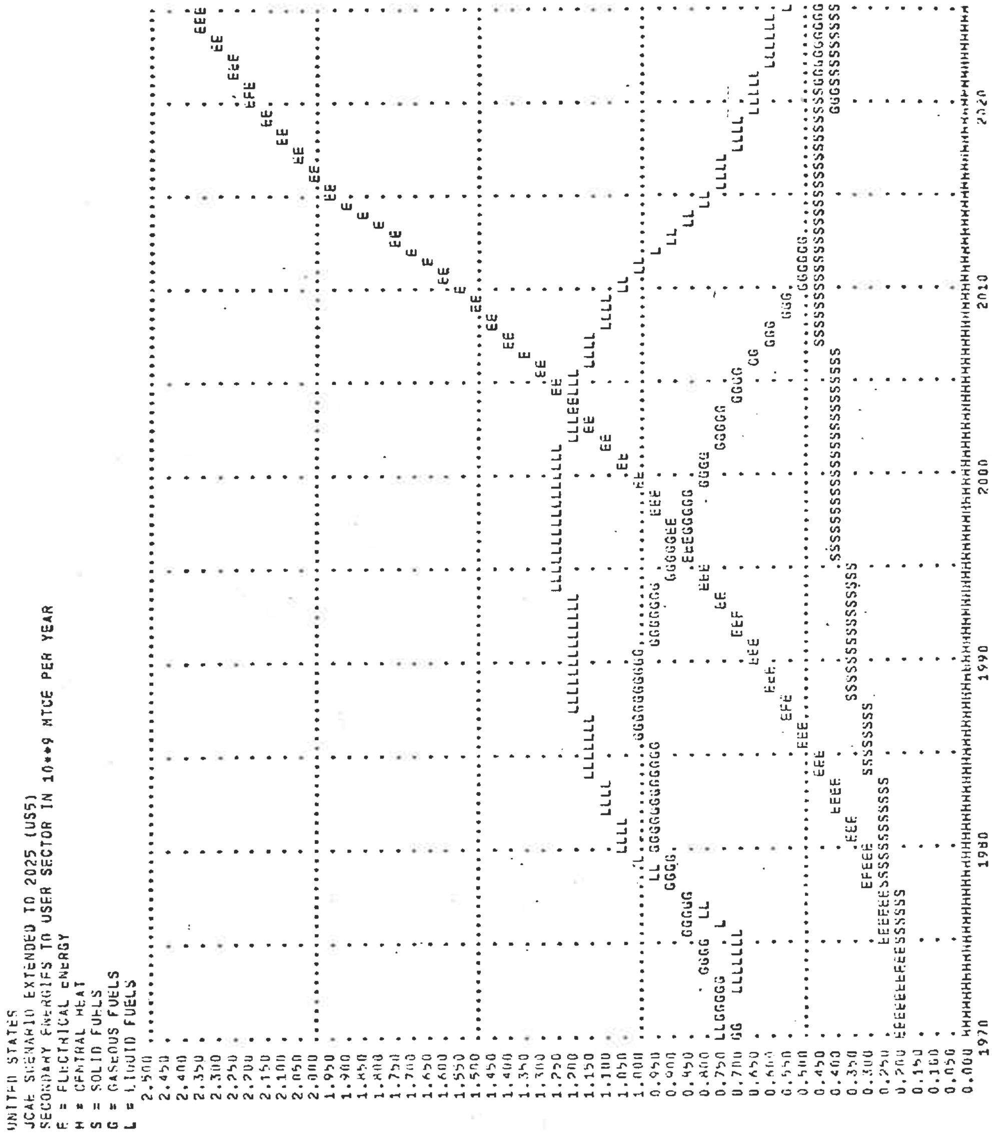

Fig. 4.11 - Secondary energy outputs for the "standard" scenario for the United States

An alternative scenario

The JCAE ("standard") scenario describes only one possible development of the US energy system. Many other possibilities exist and should be studied for their merits and demerits, before decisions are made which inevitably narrow future choices. To stimulate discussion, we include here a scenario which provides approximately the same amount of secondary energy to the user sector using a primary energy mix which differs considerably from that of the JCAE-scenario. In particular, we have not included nuclear energy in this scenario. Conversion efficiencies, user efficiencies, the prices of primary and secondary energies, and the capital investment costs of energy conversion plants are again the same as those listed earlier. We shall discuss here the time-dependent scenario inputs: primary energy inputs, primary energy imports and exports, energy allocations to different conversion processes, and energy distribution to users. The scenario input parameters and time-series are listed in the complete simulation printout in the Appendix.

Primary energy inputs

The total primary energy input is considerably lower than that for the JCAE-scenario. (However, due to much better overall conversion efficiency, the output of secondary energy is similar). The total primary energy input increases from a value of 2.41 billions of metric tons of coal equivalent (Gtce) in 1970 to 3.38 Gtce in 2000 and 4.72 Gtce in 2025. An increasing share of this total energy is taken over by coal and lignite, solar and geothermal energy, and energy in biomatter The breakdown:

Solar energy takes on an increasingly stronger role starting around 1985. It supplies .01 Gtce in 1985, .06 in 2000, and .4 in 2025 (more than JCAE). Geothermal energy is built up from .01 in 1980, to .08 in 2000, and .20 in 2025 (less than JCAE). There are no inputs from nuclear or fusion energy. Hydro energy is increased from the 1970 value of .04 to .10 in 2005, remaining constant thereafter (less than JCAE). There are no imports of electrical energy.

Wastes and biomatter provide substantial primary energy inputs to this scenario, starting around 1975 with .04 Gtce and increasing to .38 in 2000 and .6 in 2025. This input consists initially mainly of solid wastes, later also of field wastes, sewage, and livestock manure, and still later also of specially grown algae, grasses, plants or trees. Biomatter and wastes are used partly in combustion and partly in gasification and liquefaction processes.

The exploitation of oil shale and tar sands begins around 1980 and produces initially .03 Gtce, increasing to .15 in 2000, and .25 in 2025 (less than JCAE). The crude oil input is kept constant at 1.1 Gtce from 1970 to 2000, and then drops slowly to .9 in 2025 (total oil input in the period is about the same as in the JCAE-scenario, but a fast initial rise and correspondingly sharp drop later are avoided).

The *coal* input increases from .45 in 1970 to 1.12 in 2000 and 2.07 in 2025 (slightly lower than JCAE). The *gas* input decreases from .82 in 1970 to .40 in 2000 and .20 in 2025 (compared to the JCAE-scenario, the same supplies are stretched out over a longer period; see assumptions for oil).

Primary energy imports and exports

It is assumed in the scenario that the total *energy imports* decreases slowly from a 1970 level of .29 Gtce to .16 in 2000 and .14 in 2025. This reflects the assumption that both oil and gas imports are decreased to about 10 percent each of the total oil, resp. gas inputs to the economy. *Gas imports* climb somewhat from the initial value and then decrease again (.o4 in 1970, .07 in 1990 (peak), and .04 in 2025). *Oil imports* decrease more quickly from .25 in 1970 to .1 in 1985 and then remain constant at this value to 2025. There are no other energy imports. The only energy export is *coal export* corresponding to roughly 12 % of the domestic coal consumption (.06 in 1970, .15 in 2000, .26 in 2025). A decreasing amount of *gas* is required for *field use*: .09 in 1970, .04 in 2000, and .02 in 2025.

Energy allocation to the different conversion processes

The energy allocation fractions are identical with those of the JCAE-scenario with the exception of a greater amount of coal gasification and liquefaction, and an additional sector handling the wastes and biomatter.

Energy in wastes and biomatter is initially only used in combustion processes for the central generation of heat and electric power (100 % in 1975, 70 % in 2000, 50 % in 2025). Beginning 1990 there is significant gasification and liquefaction (pyrolysis, bacterial decomposition, etc.) of wastes, including perhaps field-wastes, plus later of specially grown algae, grasses, plants, or wood (2 % in 1980, 30 % in 2000, 50 % in 2025). The use of biomatter for decentralized use is negligible. A loss of 10 % of energy content is assumed in the gasification and liquefaction processes of wastes and biomatter. Half of the remaining energy is converted to gaseous fuels, the other half to liquid fuels.

A small fraction of 2 % of the total energy input in coal is assumed to be needed for the production of chemicals (nonenergy use). Significant use of coal in gasification and liquefaction starts around 1980 (with 2 %), increasing to 30 % in 2000, and 50 % in 2025. The decentralized use of coal decreases from 41 % in 1970 to 30 % in 2000 and 20 % in 2025. Correspondingly, the use of coal in central heat and electric power plants drops from 57 % in 1970 to 38 % in 2000, and 28 % in 2025. A loss of 5 % of input energy is assumed for gasification and liquefaction of coal. Half of the remaining energy is assumed to be converted to gaseous, half to liquid fuels.

Energy distribution to users

The distribution of the different secondary energies to the different users is identical to that in the JCAE-scenario.

Results of the simulation

The full results of the simulation for the "alternative" scenario are found in the data appendix. They will now be discussed together with the results form the "standard" JCAE-scenario. Figs. 4.12 and 4.13 are excerpts from the full simulation printout.

Simulation Results for the United States

The simulation results for the two scenarios ("standard" and "alternative") presented here represent two opposite ends of a spectrum. We do not advocate either one of them. The results are merely meant to demonstrate the relatively wide range of possibilities still open to us. A much more thorough investigation would be required before these or other simulation results can be made the basis for far-reaching policy decisions. In particular, we would like to remind the reader that the simulation results are completely dependent on the scenario inputs described on the previous pages. These inputs reflect present knowledge. Some of the inputs (e.g. efficiencies) can be predicted with considerable certainty, others (e.g. prices and costs) merely represent current conditions, as any other approach would be outright speculation. With this understanding, the scenario results should be taken with a grain of salt. More attention should be paid to the general tendencies and implications of the simulations than to the last two digits of the numbers.

The results are summarized in Table 4.1. We shall discuss the listed items point by point, referring to the printouts in the data appendix for more detailed information.

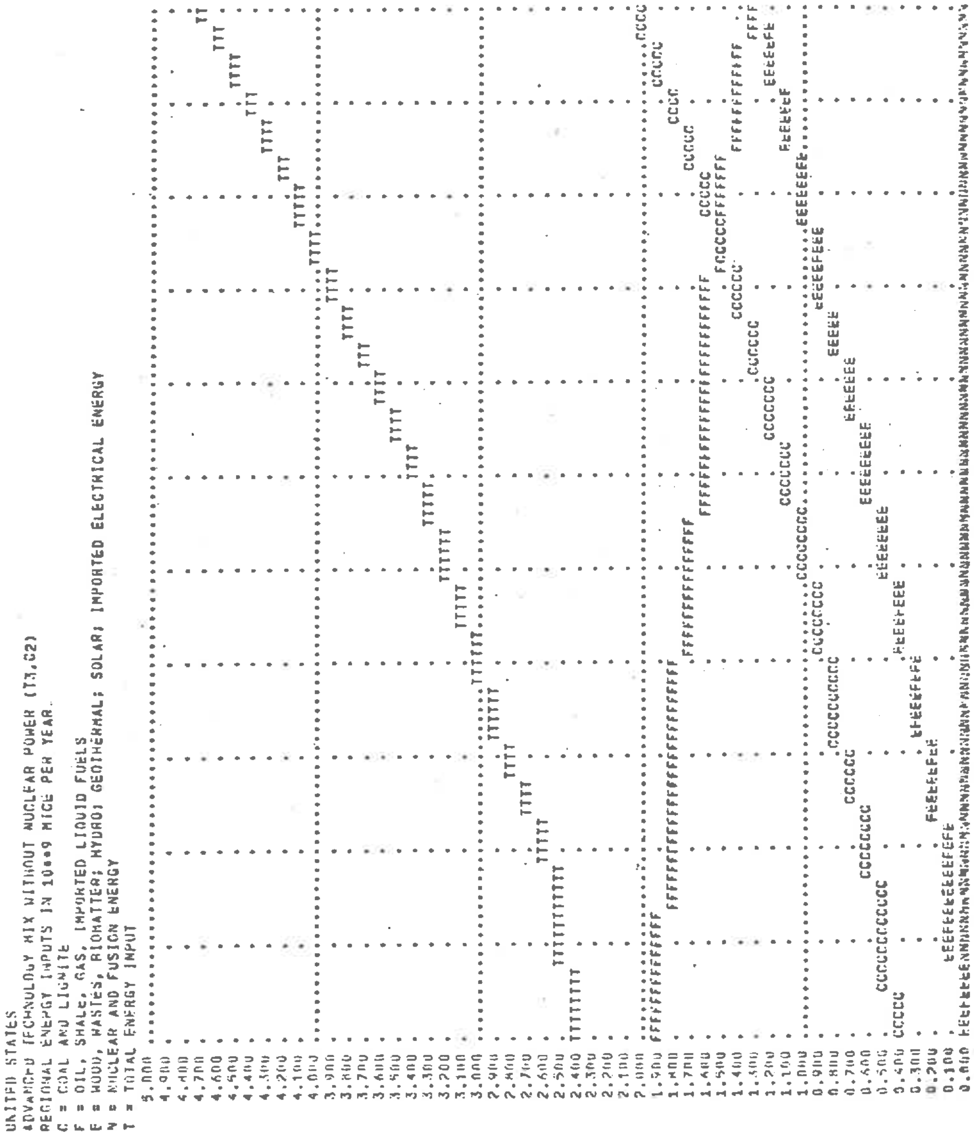

Fig. 4.12 - Primary energy inputs for the "alternative" scenario for the United States

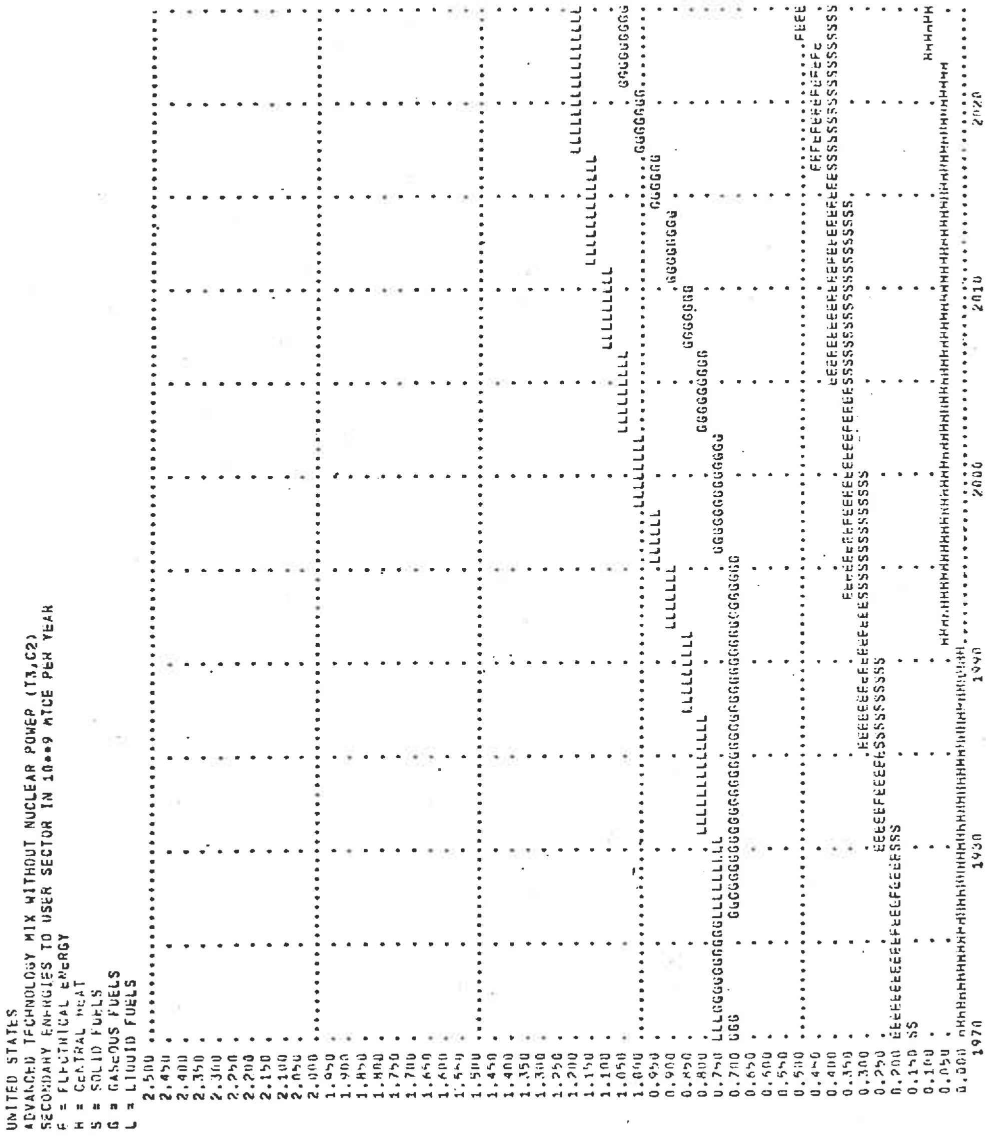

Fig. 4.13 - Secondary energy outputs for the "alternative" scenario for the United States

ESP - ISI/SRC January 1974
SUMMARY OF RESULTS
UNITED STATES ENERGY SYSTEM

		"standard" JCAE-scen. (US5)	"alternative" scen. (US3)	units
Primary Energy Input	1970	2.46	2.41	10^9 tce/yr
	2000	6.09	3.38	"
	2025	9.93	4.72	"
Annual Cost of Input Energy	1970	107.80	106.70	10^9 $/yr
	2000	156.90	123.80	"
	2025	138.10	145.70	"
Cost per Unit of Input Energy	1970	43.8	44.2	$/tce
	2000	25.8	36.6	"
	2025	13.9	30.9	"
Annual Cost of Energy Imports	1970	12.40	12.40	10^9 $/ye
	2000	39.00	7.60	"
	2025	0.00	6.40	"
No. of 1000 Mwe Plants	1970	1571	1535	
	2000	3597	2477	
	2025	4692	3636	
New Plants Per Year	1970	0	6	
	2000	70	55	
	2025	33	38	
Capital Investment Per year	1970	0	1.97	10^9 $/yr
	2000	21.83	(5.77)	"
	2025	16.61	7.33	"
Cumulative Capital Investment	1970	197.87	192.14	10^9 $
	2000	656.26	327.52	"
	2025	1239.34	474.14	"
Energy Mix to User (%) elec/coal/gas/liq.	1970	11/10/38/40*	10/ 9/39/40*	%
	2000	29/12/23/35	14/13/30/39	%
	2025	59/10/11/24	14/11/38/34	%
Total Energy to User	1970	1.90	1.87	10^9 tce/yr
	2000	3.63	2.58	"
	2025	4.04	3.57	"
Energy Cost to User per Year	1970	200.6	197.7	10^9 $/yr
	2000	502.6	279.9	"
	2025	822.8	377.3	"
Cost to User per Unit of Energy	1970	105.5	105.7	$/tce
	2000	138.3	108.4	"
	2025	203.5	105.7	"
Overall Efficiency to User	1970	.81	.82	
	2000	.62	.80	
	2025	.41	.80	
Concentrated Waste Heat	1970	.41	.39	10^9 tce/yr
	2000	2.16	.58	"
	2025	5.55	.86	"

* Where percentages do not total to 100, remainder is central heat or solar energy

Table 4.1 - Summary of Scenario Results for the United States

Primary energy input

The total primary energy input is a scenario assumption. The JCAE-input is somewhat higher than the primary energy demand predicted for 3.5 % annual growth of gross national product (GNP) (2.46 Gtce in 1970, 6.09 in 2000, 9.93 in 2025). The JCAE prediction reflects a continuation af historical trends in primary energy demand growth, without paying attention to possible changes in the energy system structure, e.g. the introduction of nuclear energy on a large scale. This change would reduce the overall efficiency of the energy system considerably, and would mean that the supply of energy on the user side would grow with less than the historic growth rate.

The alternative scenario supplies a constant 10 kw/cap throughout the simulation period (2.41 Gtce in 1970, 3.38 in 2000, 4.72 in 2025). This corresponds to the present level of primary energy use in the United States. This could come about by either a continuation of approximately the present conditions, or by raising the efficiency of energy use, and providing more service from the same amount of energy. Across-the-board energy savings of some 50 % appear technologically possible, while providing the same amount of energy service.

The results of the simulations will show that the vastly greater amounts of input energy in the JCAE-scenario do not result in a corresponding increase in energy supply to the user. The alternative scenario, although its primary energy input appears unreasonably low, is indeed competitive.

Annual cost of input energy

The annual cost of input energy is dictated by primary energy prices and amounts. Both scenarios use reduced amounts of relatively expensive primary energies (oil and gas) in the later part of the simulation period. As a result, the cost per unit of input energy drops in both cases. The large drop in the JCAE-scenario (from $ 43.8/tce to $ 13.9 /tce) is a result of the large increase in the use of relatively cheap nuclear energy. The drop in the average unit cost of input energy in the alternative scenario is much less pronounced (from $ 44.2/tce to $ 30.9/tce), as most primary energy forms used in this scenario are relatively expensive. In both cases the percentage of GNP required for the purchase of primary energy decreases with time. The total cost of primary energy is comparable in both cases (standard scenario:$107.8 billion in 1970, 156.9 in 2000, 138.1 in 2025; alternative scenario: 106.7, 123.8, 145.7, respectively).

Annual cost of energy imports

In the JCAE-scenario, imports initially increase strongly, reaching a peak of approximately three times their 1970 energy amount by 1995, and decreasing quickly thereafter, for lack of importable oil and gas. Correspondingly the annual cost of energy imports reaches some 25 % of the total energy input cost by the end of the century (standard scenario: $ 12.4 billion in 1970, 39.0 in 2000, zero by 2025).

In contrast, the energy imports of the alternative scenario are steadily decreased to a level of one half their 1970 level by 2025, when they represent only about 4 % of the total energy input cost ($ 12.4 billion in 1970, 7.6 in 2000, 6.4 in 2025). In the alternative scenario, energy dependence on foreign sources is never more than some 12 % and import cutoffs cannot seriously affect the economy.

Number of 1000 MWe conversion plants and capital investment

The increasing amounts of primary input energy must be handled by an increasing number of conversion plants. In the JCAE-scenario, the number of 1000 MWe conversion plants triples in the 55 years; it more than doubles in the alternative scenario (standard scenario: 1517 (1970), 3597 (2000), 4692 (2025); alternative scenario: 1535 (1970), 2477 (2000), 3636 (2025)). The number of new plants to be built each year is similar, although somewhat lower for the alternative scenario (standard: 70 (2000), 33 (2025);alternative: 55 (2000), 38 (2025)). However, a very significant difference appears when capital investment is considered.

In the JCAE-scenario the investment required is increasingly, and toward the end of the period almost exclusively, for nuclear electric power plants. These plants, like all electric power plants, have very high investment requirements per kilowatt of output energy. By contrast, in the alternative scenario investment is only partly for electric power plants; the number of new gasification and liquefaction plants built is larger. Since capital investment are lower for this type of plant, the total capital investment required for conversion plant construction is much lower in the alternative scenario. It follows that the cumulative capital investment in conversion plants will also be significantly lower (standard: $ 197.9 billion in 1970, 656.3 in 2000, 1239.3 in 2025; alternative: 192.1 (1970), 327.5 (2000), 474.1 (2025)). Throughout the period, the annual capital investment for the JCAE-scenario is some three to more than five times greater than for the alternative scenario (standard: $ 21.8 billion in 2000, 16.6 in 2025; alternative: 5.8 (2000), 7.3 (2025)). The simulation does not take into account the investment required for energy transportation system. These systems are much more expensive for electricity than for gas or liquid fuels (pipelines). Consideration of this factor would further favor a gas economy over an electric economy.

Total energy to user

As a result of conversion losses, only part of the primary energy input appears as secondary energy input to the user sector. Because of its emphasis on electrical energy, the conversion losses of the JCAE-scenario are particularly high. The total amount of energy reaching the user sector is therefore not much greater than that of the alternative scenario, even though the primary energy input in the JCAE-scenario grows to more than twice the input of the alternative scenario by 2025 (standard: 1.90 Gtce in 1970, 3.63 in 2000, 4.04 in 2025;

alternative: 1.87 (1970), 2.58 (2000), 3.57 (2025)). In both cases the amount of energy reaching the user roughly doubles by 2025 over the 1970 level.

Overall efficiency to user

The increasing role of electricity in the JCAE-scenario results in a very significant decrease of the overall efficiency of the energy system (energy output on the user side divided by primary energy input). The overall efficiency decreases from 81 % in 1970 to 62 % in 2000 and 41 % in 2025. By contrast, the efficiency remains at 80 % in the alternative scenario.

Annual energy cost to user

The cost of energy to the user roughly doubles in the alternative scenario; it more than quadruples in the JCAE-scenario (standard: $ 200.6 billion in 1970, 502.6 in 2000, 822.6 in 2025; alternative: 197.7 (1970), 279.9 (2000), 377.3 (2025)). The unit cost of energy is a more meaningful measure of energy cost increases: This cost remains practically constant in the alternative scenario ($ 105.7/tce in 1970, 108.4 in 2000, 105.7 in 2025), but doubles in the JCAE-scenario, due again to increasing share of costly electricity ($ 105.7/tce in 1970, 138.3 in 2000, 203.5 in 2025).

Energy mix to user

Changes in the relative shares of energies reaching the user mean changes in the number and kind of technological devices and processes using these energies. With other words: capital investments by the user.

Not all of this investment is investment which would otherwise not have taken place. Some of the change-over investments can be absorbed in the course of necessary replacements of worn-out or obsolete equipment. In other cases (new homes, new plants), the investment would have to be made anyway. The user is saddled with an unnecessary investment burden when some energy form becomes unavailable and he must replace equipment or processes before they have been depreciated. In addition, in any changeover he indirectly has to pay for the conversion of the energy system and connected production processes to the new energy form.

In the alternative scenario, change-over costs are minimal, if not nil. The energy mix (electricity/coal/gas/liquid fuel) hardly changes over the 55 years (1970: 10/9/39/40; 2000: 14/11/38/34). However, very fundamental changes in the energy mix appear in the JCAE-scenario (1970:11/10/38/40; 2000: 59/10/11/14). Electricity becomes the dominant energy form increasing its share in the user sector more than five-fold. The use of gas is reduced by almost a factor four, that of liquid fuels by approximately a factor of three. This has considerable consequences, especially for transportation technology. The necessary investments connected with this change-over in user technologies have not been computed, but they are presumably significant.

Concentrated waste heat

A most significant difference appears when the heat rejected from the large scale energy conversion processes is totalled up. This heat must be dissipated in the environment (rivers, lakes, atmosphere) by cooling processes. In the alternative scenario, the amount of concentrated waste heat more than doubles until 2025 (.39 Gtce in 1970, .58 in 2000, .86 in 2025); in the JCAE-scenario it increases by a factor of almost fourteen to a level which is more than twice the total primary energy input in 1970 (.41 in 1970, 2.16 in 2000, 5.55 in 2025)!

Conclusions

Some general conclusions from these simulations will be drawn in Sec. 4.3 following the discussion of the scenarios for Western Europe and the Middle East.

Energy Scenario for Western Europe

We discuss here two scenarios for the Western European region. One scenario ("standard" scenario) basically reflects present Western European energy policy. It assumes a rate of primary energy demand growth of 5 % until 1980, and 4 % thereafter (which, however, cannot be met after 1990). Initially this demand is covered mainly by increasing oil and gas consumption (mainly imported), later by a strong build-up of nuclear power capacity. Coal production is decreased somewhat and then remains constant. After 1990 difficulties develop in securing the required oil and gas supplies, and total energy input stagnates until around 2010. After 2010 the primary energy supply again increases sharply due to a strong nuclear power capacity.

The second ("alternative") scenario assumes that total primary energy demand is held at the (present) level of 5 kw/cap. Imports of oil and gas are gradually discontinued, while a synfuel and syngas industry is built up on a coal base. The liquid fuel produced supplies mainly the transportation sector after 2000. No new nuclear facilities are put into operation; existing ones produce until 1985.

The energy demand curves for the two cases are given in Fig. 4.14.

In the following, we shall discuss the time-dependent scenario inputs, i.e.: primary energy inputs, primary energy imports and exports, energy allocations to the different conversion processes, and energy distribution to users. (Most) conversion efficiencies, (most) user efficiencies, the prices of primary and secondary energies, and the capital investment costs of energy conversion plants are again

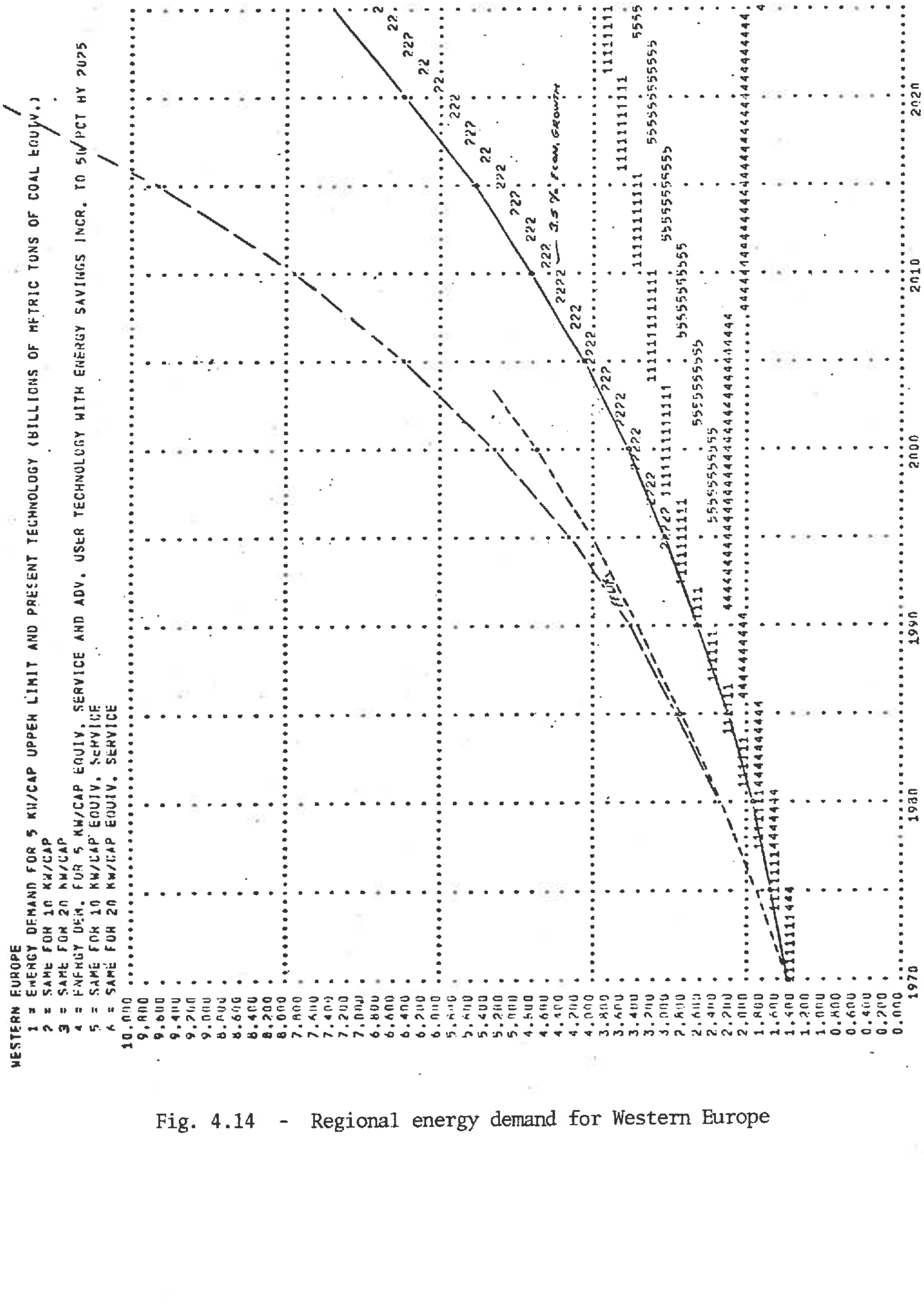

Fig. 4.14 - Regional energy demand for Western Europe

input also increase quickly to a peak around 1995 with about four times the 1970 value, and then falls of to approximately one half of the 1970 value by 2025 (.18 Gtce in 1970, .78 in 1995, .1 in 2025). The *coal* input is reduced by one third by 1990, and then remains at this level to the end of the period (.45 in 1970, .3 from 1990 to 2025).

Primary energy imports and exports

Before nuclear energy begins to have a major impact in this scenario, imported oil and gas provide the major share of primary input energy. The *total imports* reach a peak around 1995 (three times the 1970 value), and decrease to two thirds of their 1970 value by 2025 (.98 in 1970, 3.13 in 2000, .69 in 2025). *Oil imports* represent the major portion of total imports (.73 Gtce in 1970, 2.14 in 1995, .35 in 2025). *Gas imports* are assumed to similar climb and fall again (.18 Gtce in 1970, .77 Gtce in 1995, .1 in 2025). *Coal imports* remain at roughly 15 % of domestic coal consumption (.06 Gtce in 1970, .04 Gtce in 2025). Initially most of the *nuclear fuel* is imported, but the relative share decreases due to domestic production and the advent of the breeder reactor (.01 Gtce in 1970, .2 in 2000, and thereafter). There are no *energy exports*. The *field use* of gas is not considered.

held constant. Their respective values have been listed earlier. The full input scenarios are given in the data appendix.

The standard scenario

Primary energy inputs

The primary energy input grows at an annual rate of 5 % between 1970 and 1980, and continues at a rate of 4 % after 1980. However, this rate cannot be sustained due to a drop in available oil and gas supplies. As a result, the primary energy input remains approximately constant between 1995 and 2010. After this date it climbs again quickly as a result of rapid build-up of nuclear facilities. The input in terms of billions of tons of coal equivalent per year is 1.44 Gtce in 1970, 3.5 in 1990, 3.79 in 2010, and 9.01 in 2025. In the later part of the scenario period, nuclear power is the almost exclusive supplier of energy. The breakdown:

It is assumed that there are no significant inputs of solar energy, geothermal energy, energy from wastes and biomatter, oil shale and tar sands. Fusion energy, if any,is accounted for under nuclear energy.

Very high growth (around 1o % per year) is assumed for nuclear energy. It increases from .01 Gtce in 1970 to .73 in 2000 and 8.2 in 2025, supplying approximately half of the primary energy input by 2010, and 90 % by 2025. Hydro energy is built up another 50 % from .04 Gtce and then remains at .06 through the end of the period. The oil input increases to approximately three times the 1970 level by 1995. Oil availability then falls off to roughly one half of the 1970 value by 2025 (oil input is .76 in 1970, 2.35 in 1995, and .35 in 2025). The gas

Energy allocations to the different conversion processes

The energy allocation scenarios for the two Western European cases are somewhat simpler than the two scenarios for the United States, as fewer input energy forms are considered. Allocation fractions not mentioned are irrelevant to the computations.

Energy losses in crude oil refining are assumed at 11 % of crude oil input. This share includes gases, wastes, tars, heat, etc. 88 % of the input energy is converted to liquid fuels. (These figures differ slightly from those assumed for the US scenarios and reflect better information.)

It is assumed that 60 % of the energy in coal and lignite goes to decentralized (mostly industrial) use. Use of coal for chemical purposes is not considered, and there is no gasification or liquefaction of coal. This leaves 40 % of the coal energy input for use in central heat or electric power plants.

Of the total gas energy, a constant fraction of 9 % goes to nonenergy uses (chemicals, fertilizer, etc.). Another 16 % is used in central electric power generation using combustion. The remaining 75 % are piped to decentralized users.

10 % of the liquid fuel is used for the production of chemicals and plastics (nonenergy use). Another 12 % is for central electric power generation by combustion. The remaining 78 % finds decentralized applications, mostly in the transportation sector. There are no exports of domestically produced liquid fuels or gas.

Of the solid fuel going to central heat and power plants, 95 % is used for electric power generation by combustion. No advanced thermodynamic power cycles are introduced in the scenario period; thermal electric powerplants are assumed to operate with a constant efficiency of 35 %.

The scenario assumes no heat recovery from any of the conversion processes. The conversion efficiencies are otherwise the same as those given earlier.

Energy distribution to users

In contrast to the United States, the major user of electricity is the industrial, not the residential/commercial sector. The 1970 relationship is assumed to remain the same (industrial sector: 62 %, residential/commercial sector:35 %, transportation sector:3 %).

Centrally generated heat is all used in residential/ commercial applications (central space heating).

Of the solid fuel entering the user sector, 39 % is used in residential/commercial, 59 % in industrial,and 2 % in transportation applications.

Most of the gas (65 %) is used for industrial purposes. The remaining 35 % enters the residential/commercial sector; none is used in the transportation sector.

A constant 33 % of the liquid fuel enters the residential/ commercial sector, 39 % the industrial sector, and the remaining 38 % the transportation sector.

Results of the simulation

The full results from the simulation using this input scenario are given in the data appendix. The results will be discussed together with those of the following alternative scenario. Figs. 4.15 and 4.16 are excerpted from the full simulation printout.

An alternative scenario

Primary energy inputs

The alternative scenario assumes a lower primary energy input corresponding to a constant 5 kw per capita. In the later part of the scenario period, this input is almost exclusively supplied by coal. The total primary energy input climbs slowly from its value of 1.44 Gtce in 1970 to 2.96 in 2000 and 3.71 in 2025. The breakdown of primary energies:

It is assumed that there are no significant inputs from solar energy, geothermal energy, energy from wastes and biomatter, oil shale and tar sands, and fusion energy. The nuclear plants present in 1970 operate with a constant capacity of .01 Gtce until 1985 and are then phased out. No new nuclear facilities are built. Hydro energy increases by 50 % from its 1970 level of .04 Gtce to .06 in 1990, remaining constant thereafter.

The oil input into the economy increases slightly until 1980 and then decreases to zero by the year 2000 (.76 in 1970, .80 in 1980).

The gas input doubles initially, but then also falls to zero by 2000 (.18 in 1970, .37 by 1980).

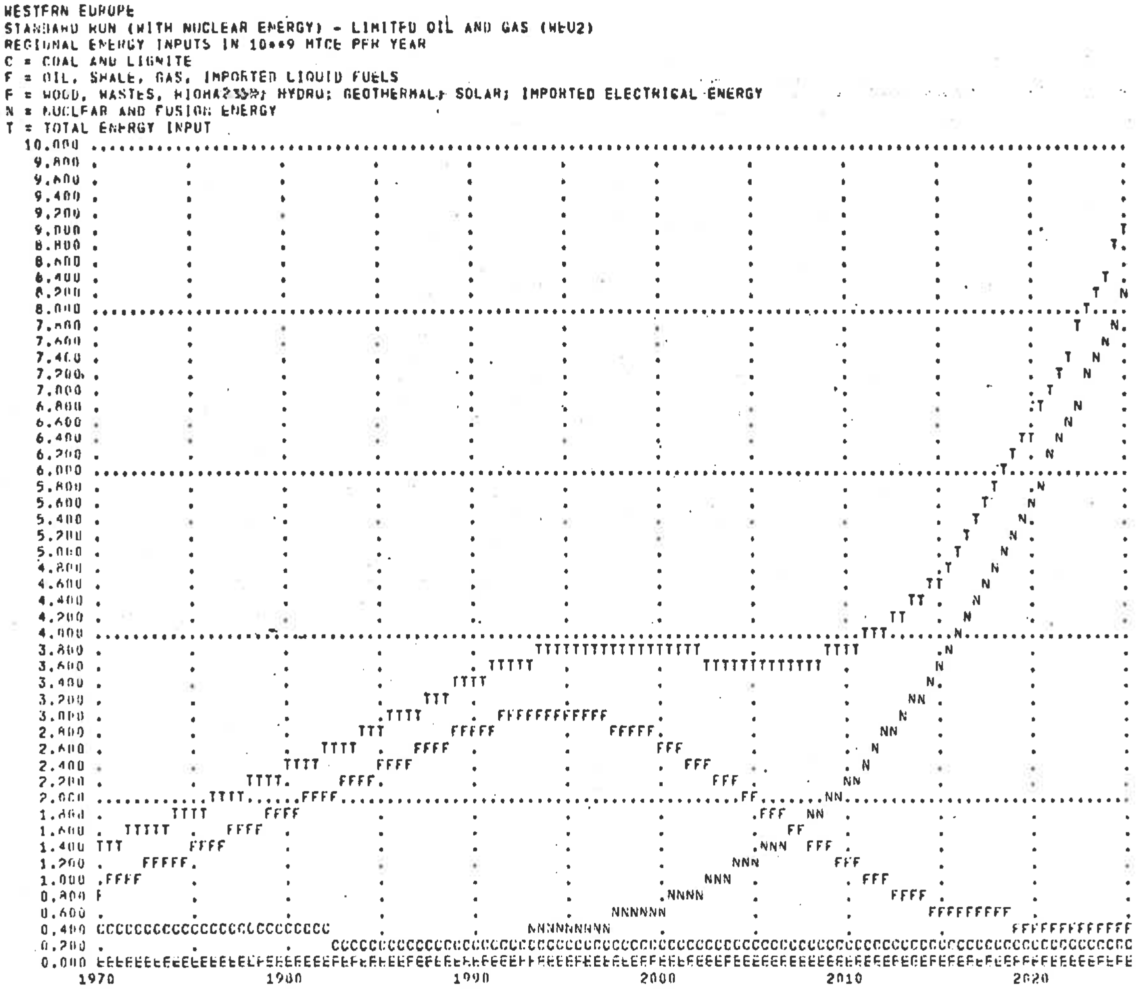

Fig. 4.15 - Primary energy inputs for the "standard" scenario for Western Europe

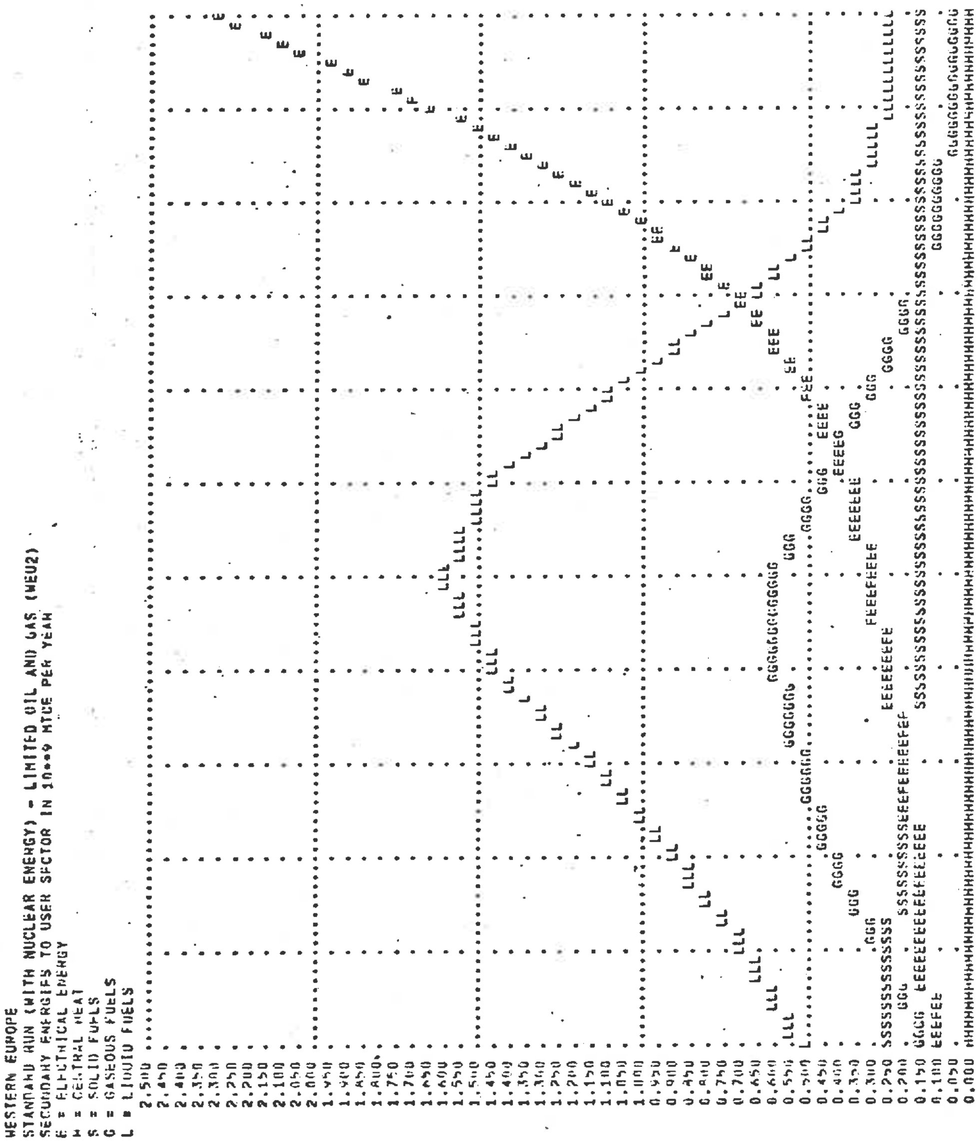

Fig. 4.16 - Secondary energy outputs for the "standard" scenario for Western Europe

a significant effect first appears in 1990.The percentage of standard cycle power plants using waste heat recovery is smaller, as the majority of these plants is older and the fitting of heat recovery processes provides more difficulties in these plants. Thus the percentage of heat recovery from standard cycles increases from 5 % in 1990 to 25 % in 2025, for advanced cycles from 10 % in 1990 to 35 % in 2025.

Energy distribution to users

The changes in the relative availabilities of different energy forms, especially of gas and liquid fuels, require certain changes in the energy distribution pattern to users.

The share of electrical energy in the residential and commercial sector is assumed to increase till the end of the century, while that of industry decreases (residential/commercial sector: 35 % in 1970, 45 % in 1995 and thereafter; industrial sector: 62 % in 1970, 50 % in 1995 and thereafter). The share of the transportation sector (mainly rail transportation) increases from 3 % in 1970 to 5 % in 1995 and later years.

Centrally generated heat initially goes almost exclusively to the residential/commercial sector, but this share decreases strongly in favor of the industrial sector (residential/commercial sector: 95 % in 1970, 50 % in 2025; industrial sector: 5 % in 1970 to 50 % in 2025).

Of the coal going decentralized use, industry takes an increasing share (residential/commercial sector: 39 % in 1970, 10 % in 2025; industrial sector: 59 % in 1970, 10 % in 2025). The very small percentage used in the transportation sector (2 % for railroads) disappears by 1990.

As liquid fuel for home and commercial space heating is partially replaced by gas, the share of gas used in the residential/commercial sector increases relative to the share of the industrial sector. Increasingly, gas is also used in the transportation sector (residential/commercial sector: 35 % in 1970, 55 % in 2025; industrial sector: 65 % in 1970, 35 % in 2025;transportation sector: 2 % in 1975, 10 % in 2025).

As a result of the smaller efficiency of liquefaction compared to gasification, the liquid fuel use in the residential/commercial and industrial sectors is sharply restricted in favor of the transportation sector by the end of the century (residential/commercial sector: 33 % in 1970, decreasing to 17 % by 2000 and thereafter; industrial sector: 39 % in 1970, decreasing to 17 % by 2000 and thereafter; transportation sector: 28 % in 1970, increasing to 66 % by 2000 and thereafter).

Results of the simulation

The full results of the simulation using this "alternative scenario" are given in the data appendix. They will now be discussed together with those of the "standard scenario". Excerpts are given in Figs. 4.17 and 4.18.

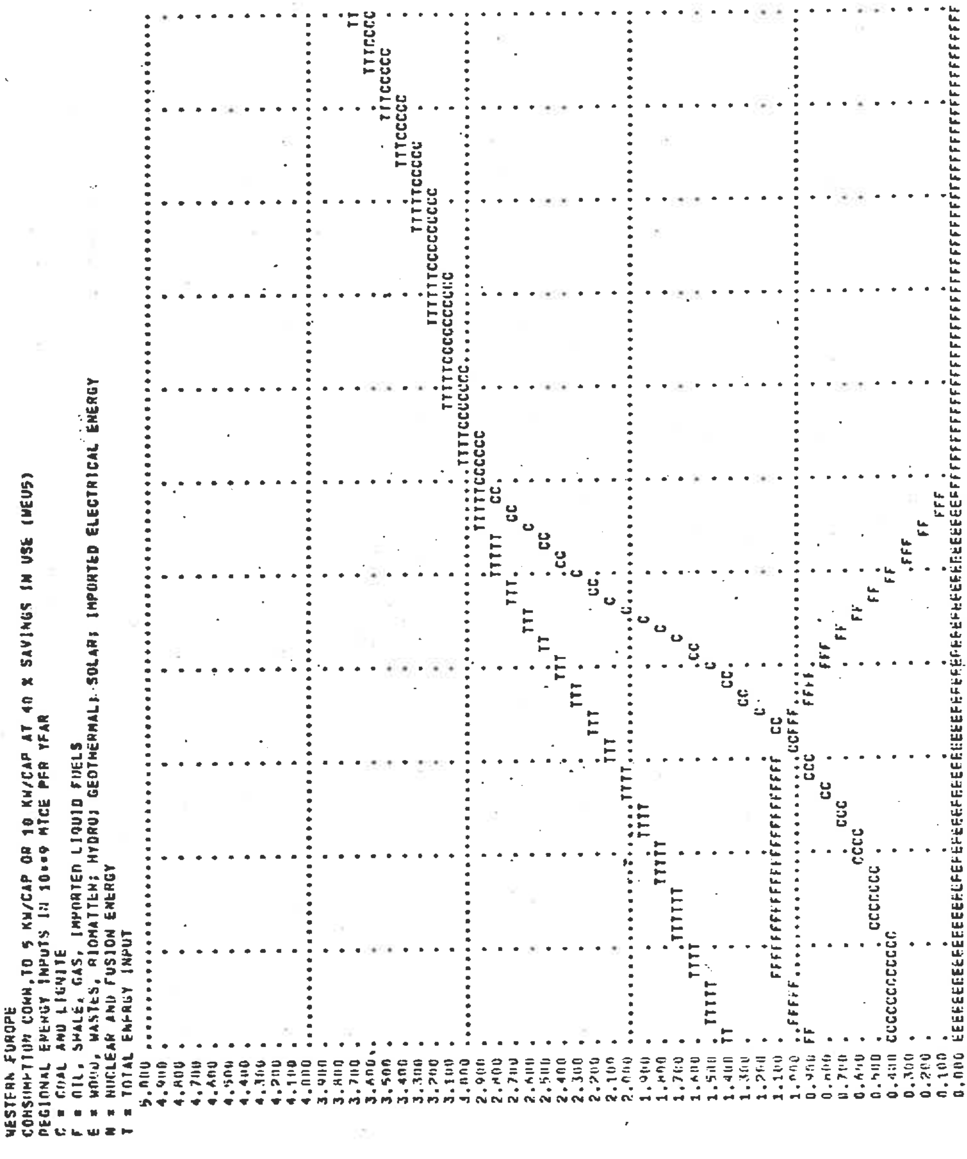

Fig. 4.17 - Primary energy inputs for the "alternative" scenario for Western Europe

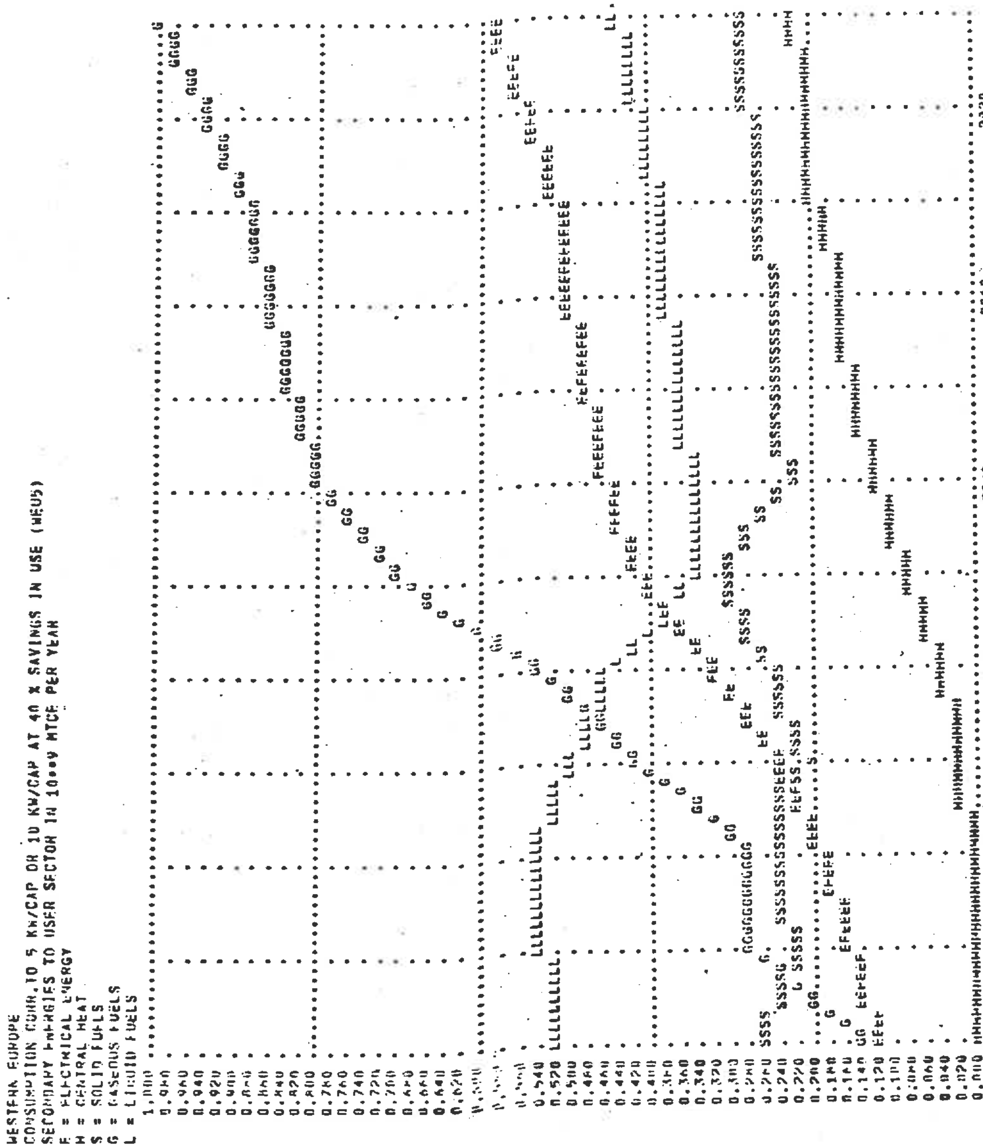

Fig. 4.18 - Secondary energy outputs for the "alternative" scenario for Western Europe

Simulation Results for Western Europe

As in the case of the two scenarios for the United States, the two scenarios for Western Europe represent only two of a very wide spectrum of possibilities. Both have their advantages and their drawbacks. It is the purpose of a simulation model such as the present one to provide a tool which permits a relatively thorough investigation of many energy system alternatives with a relatively small effort. Again, the two results should only be taken as a basis for further investigations.

The results for the "standard" and "alternative" scenarios are summarized in Table 4.2. They will be discussed point by point. More detailed results are found in the listings of scenario results in the data appendix.

Primary energy input

The total primary energy input for the "alternative" scenario corresponds to a primary energy input of 5 kw per capita, the present level in the advanced nations of Western Europe. As efficiency of energy use is increased (a 50 % increase appears technologically feasible), the energy service provided by the 5 kw could be substantially greater than today. With other words, the restriction to 5 kw/cap would by no means represent a stagnation at present conditions, especially for the lesser developed parts of Western Europe.

ESP - ISI/SRC January 1974
SUMMARY OF RESULTS
WESTERN EUROPE ENERGY SYSTEM

		"standard" scen. (WEU2)	"alternative" scen. (WEU5)	units
Primary Energy Input	1970	1.44	1.44	10^9 tce/yr
	2000	3.84	2.96	"
	2025	9.01	3.71	"
Annual Cost of Input Energy	1970	54.78	54.78	10^9 \$/yr
	2000	136.84	87.00	"
	2025	94.60	109.50	"
Cost per Unit of Input Energy	1970	38.0	38.0	\$/tce
	2000	35.6	29.4	"
	2025	10.5	29.5	"
Annual Cost of Energy Imports	1970	41.88	41.80	10^9 \$/yr
	2000	118.40	0.0	"
	2025	22.80	0.0	"
No. of 1000 Mwe Plants	1970	994	994	
	2000	2838	2486	
	2025	3496	3148	
New Plants Per Year	1970	61	13	
	2000	-25	(52)	
	2025	171	36	
Capital Investment Per Year	1970	6.81	3.37	10^9 \$/yr
	2000	2.94	6.42	"
	2025	62.75	5.59	"
Cumulative Capital Investment	1970	124.35	124.35	10^9 \$/yr
	2000	366.52	363.31	"
	2025	1119.91	464.02	"
Energy Mix to User elec/coal/gas/liq.	1970	11/25/13/49	11/26/13/49	%
	2000	15/ 7/19/59	23/12/41/18	%
	2025	82/ 6/ 3/ 9	23/12/40/17	%
Total Energy to User	1970	1.06	1.06	10^9 tce/yr
	2000	2.51	1.95	"
	2025	2.82	2.53	"
Energy, Cost to User, per Year	1970	102.75	102.72	10^9 \$/yr
	2000	286.56	258.81	"
	2025	782.11	334.23	"
Cost to User per Unit of Energy	1970	97.0	97.0	\$/tce
	2000	114.5	133.0	"
	2025	258.0	132.3	"
Overall Efficiency to User	1970	.78	.78	
	2000	.70	.69	
	2025	.31	.72	
Concentrated Waste Heat	1970	.28	.28	10^9 tce/yr
	2000	1.04	.79	"
	2025	5.89	.88	"

*Where percentages do not total to 100, remainder is central heat

Table 4.2 - Summary of the Scenario Results for Western Europe

The primary energy input in the "standard" scenario is substantially higher, beginning with a 5 % annual growth between 1970 and 1980, and continuing with a 4 % growth between 1980 and 1990. No structural changes are made in the energy system during this period, as the continued availability of oil and gas is assumed. Nuclear power is built up at a rapid pace to provide an increasing amount of electrical energy. This primary energy input provides the major energy component after the turn of the century. When oil and gas become less and less available to the region near the end of the century, electricity is assumed to substitute for them. However, the rapid build-up of nuclear power facilities cannot prevent stagnation of the primary energy supply around the turn of the century. The scenario captures some of the ingredients of current Western European energy policy: the assumption of continued, and increasing availability of oil and gas, when in fact the evidence is to the contrary;the almost exclusive reliance on nuclear energy as the 'energy of the future'; the assumption of sustitutability of fossil fuels by electricity; the neglect of long time constants in the development of new energy technologies.

The results of the simulations show again that the vastly greater amounts of primary energy input in the "standard" scenario only correspond to a marginal increase in the energy supply to the user. Indeed, the "alternative" scenario delivers more energy to the user than the "standard" scenario in the years between 2006 and 2022.

In the "standard" scenario, total primary energy input increases by more than a factor of six between 1970 and 2025 (from 1.44 Gtce/year in 1970 to 9.01 in 2025). The "alternative" scenario shows an increase of a little more than two and a half (from 1.44 in 1970 to 3.71 in 2025).

Annual cost of input energy

In the "standard" scenario, the annual cost of primary input energy first increases sharply, and then decreases again, as relatively cheap nuclear energy takes over the major share of primary energy input. In the "alternative" case, the input cost rises steadily. In both cases, the costs are comparable near the end of the simulation period, corresponding to approximately twice the 1970 total cost. The unit cost of primary energy declines in both cases: from \$ 38.0/tce in 1970 to \$ 10.5/tce in 2025 in the "standard" case (the reason is the increasing share of nuclear power), and to \$ 29.5/tce in 2025 in the "alternative" case (reason: exclusive use of coal and hydropower in 2025).

Annual cost of energy imports

In the standard scenario, an increasing amount of primary energy is imported until 1995, when this share reaches 80 % of the total input energy. The decreasing availability of oil and gas and the advent of nuclear power bring this share down to 10 % before 2025. The cost of energy imports correspondingly rises from \$ $41.88 * 10^9$

(billions) in 1970 to a peak of 134.44 in 1995, then decreasing again to 22.80 by 2025.

In the alternative scenario, import costs initially also rise (from $ 41.88 billion in 1970 to 51.20 in 1975) but then decline to zero by 2000. At this time the region becomes independent of external sources of primary energy.

Number of 1000 Mwe conversion plants and capital investment

In both cases the number of 1000 Mwe conversion plants more than triples in the time-period considered. However, the pattern of development is quite different.

In the standard scenario, the increasing dependence on oil and gas requires initially an increase in refinery capacity in addition to the construction of nuclear power plants. Plant construction reaches a peak in 1990 with 107 plants per year and a total annual investment of $ 12.42 billion. Thereafter, the construction rate declines again. A large part of the refinery capacity becomes superfluous after 1995, as oil and gas inputs decreases. At the end of the simulation period, construction of 1000 Mwe units has risen to 171 per year, at an annual investment cost of $ 62.75 billion. Practically all of these plants are nuclear power plants.

In the alternative scenario, plants construction rises to a peak of 93 units per year by 1995, then drops to a low of 17 units per year by 2015, rising again to 36 by 2025. The annual investment requirements are not quite proportinonal as the relative share of electric powerplants vs. gasification and liquefaction plants changes: the annual investment rises to a peak of $ 13.28 billion in 1995 (from 3.37 in 1970), then declines to 2.38 by 2015, rising again to 5.59 by 2025.

The difference between the two cases is very substantial especially near the end of the period: by 2025 the annual investments required in the standard case are more than eleven times those of the alternative case! A more complete analysis should also take into account the significant difference in investments required for the energy distribution systems of the two scenarios: the high relative cost of electricity transportation and transportation systems would further decrease the competitiveness of the standard scenario.

Total energy to user

In both cases the amount of energy reaching the user increases by a factor of approximately two and a half (from 1.06 Gtce in 1970 to 2.82 in the standard case, and 2.53 in the alternative case). The same factor is found in the primary energy input in the alternative case. However, to produce this increase in the standard case, the primary energy input had to increase by more than a factor of six, reflecting the poor overall efficiency of the mostly electrical economy.

After the year 2005 the secondary energy received by the user is comparable in the two cases (initally higher in the alternative case, later again higher in the standard case).

Overall efficiency to user

The increasing share of electricity in the standard scenario is reflected in a substantial decrease of overall efficiency of the energy system (from primary energy input to the user sector input) from 78 % in 1970 to 70 % in 2000 and finally 31 % in 2025. By contrast, the efficiency of the alternative system decreases only slightly to 69 % by 2000 and 72 % by 2025.

Annual energy cost to user

The annual cost of energy to the user sector increases by a factor of more than seven in the standard case, and more than three in the alternative case (from $ 102.75 billion per year in 1970 to 286.56 in 2000 and 728.11 in 2025 in the standard case, and to 258.81 in 2000 and 334.23 in 2025 in the alternative case). More meaningful in this connection are the changes in the unit cost of energy to the user: this cost increases by a factor of more than two and a half in the standard case, and by one third in the alternative case (from $ 97.0/tce in 1970 to 114.5 in 2000 and 258.0 in 2025 in the standard case, and to 133.0 in 2000 and 132.3 in 2025 in the alternative case).

Energy mix to user

In both scenarios there are significant changes in the relative shares of energies reaching the user. This would entail corresponding investments to take care of necessary changes in energy use technology.

The changes in the standard scenario are most extreme. Until the turn of the century, the changes are minor except for a strong decrease of coal delivered for decentralized use. Between 2000 and 2025 the user sector has to change to an almost complete (82 %) dependence on electricity.

In the alternative scenario, the relative shares of electricity, coal, gas, and liquid fuels change from (respectively) 11 %, 26 %, 13 % and 49 % in 1970 to 23 % 12 %, 40 % and 17 %. The share of electricity thus doubles, benefitting mostly the residential/commercial sector (see discussion of energy distribution to users). Coal delivery decreases by one half. The share of gas almost triples. It replaces mainly liquid fuel previously used in the residential/commercial and industrial sectors. The 17 % share of liquid fuels goes mainly to the transportation sector.

Concentrated waste heat

In the alternative scenario, the heat rejected in concentrated form from conversion processes triples until 2025 (.28 Gtce in 1970, .88 in 2025). However, in the standard case, this waste heat increases by a factor of twenty-one, or to more than four times the total primary energy input in 1970 (.28 Gtce in 1970, 5.89 in 2025)!

Conclusions

The conclusions from the simulations for the different regions are similar and related, and they will therefore be drawn together in the next section following the discussion of the final (Middle East) scenario.

Energy Scenario for the Middle East *

Many of the oil producing nations of the Middle East face a severe long-range dilemma: (1) at present (and constantly increasing!) rates of exploitation, their oil reserves will only last for a few decades; (2) except for oil and gas, they have no viable resource base which could support their economy in the long run. On the other hand, presently oil-importing regions face the prospect of gradual conversion to energy systems not based on petroleum. The preceding scenarios have shown that neither thenuclear-based nor the coal-based energy system are pretty prospects. The scenario results also point to the advantages of a gas-based energy system: efficiency and relatively low cost of generation and transportation, and simplicity, efficiency, and environmental advantages of gas use. Hydrogen, in particular, offers significant advantages (see brief on the hydrogen economy).

Hydrogen can be generated from water by either electrolysis or perhaps more efficiently by the application of heat in the presence of catalysts (Marchetti processes). Both electricity or heat can be generated by collecting and using solar energy - an energy form of which there exists an abundant and permanent supply in the countries of the Middle East.

The energy density of sunlight is relatively low. Outside of the earth's atmosphere it amounts to about 1400 Watts/m^2 . The annual average of solar energy received on the ground in Middle Eastern countries is somewhat better than 200 Watts/m^2. At an overall efficiency of 30 percent for the generation

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* the term 'Middle East" here stands for Region 7 of the Mesarovic-Pestel world model, i.g. the oil-exporting nations of North Africa and the Middle East.

of hydrogen[8], a solar plant with a collector area of some 17 km^2 (a little more than 4 by 4 km!) would provide a continuous hydrogen output corresponding to 1000 MWe. One thousand of such plants would be needed to produce hydrogen with an energy content equivalent to 10^9 (billion) metric tons of coal equivalent (=1 Gtce), approximately the present level of oil exports from the Middle Eastern countries. These plants would cover some 17000 km^2 of land area, or roughly an area 130 times 130 km square. Distributed over a dozen countries, the project does not appear infeasible. Cost estimates for such plants usually run between $ 1000 and $ 2000 per kWe[9].(In the present scenario analysis we have applied an investment estimate of $ 430/kWe of hydrogen produced ($ 350 and $80 in agreement with the previous investment assumptions)).

In the following scenario it has been assumed that the Middle East gradually builds up a hydrogen production capacity for export corresponding to somewhat more than 2 Gtce per year, in 2025. Oil export is gradually reduced to a fraction of the present level. The domestic economy remains almost entirely oil-based, however. To simplify the analysis, energy forms other than solar (resp. hydrogen) and oil are not considered.

Conversion efficiencies (exception: solar to electricity here assumed as 20 %, instead of (earlier) 15 %), user efficiencies, the prices of primary and secondary energies, and the capital investment costs of

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[8] Walter E. Morrow, "Solar Energy:Its Time is Near". Technology Review, December 1973, p. 31 - 43

[9] Morrow, op.cit.

energy conversion plants correspond to the values listed and used previously. In the following, the time-dependent input scenarios will be discussed:primary energy inputs, primary energy exports, energy allocations to the different conversion processes, and energy distribution to (domestic) users. The full scenario listing is found in the data appendix.

Primary energy inputs and exports

The scenario assumes that oil production in the region supplies all of the primary energy demands of the domestic market, and, in addition foreign markets through oil exports which peak around 1990. Hydrogen produced in solar plants is exclusively produced for export, entering the market around 1985.

The crude oil input into the domestic economy follows the demand prediction for the region, assuming a 9 % annual growth of GNP (see chapter 3 on regional energy demand) over the simulation period. This function is modified after 2010 by assuming that primary energy demand is then held at 10 kW per capita. The demand climbs from .09 Gtce in 1970 to 1.3 in 2000 and 2.9 in 2025. The regional primary energy demand is shown in Fig. 4.19.

Oil export starts at the historic level and climbs until 1985, then falling to one sixth of the 1970 level by 2025. (1.19 Gtce in 1970, 1.64 in 1985, 1.1 in 2000, .2 in 2025).

Beginning in 1985, the intercepted solar energy climbs steeply from 1.3 Gtce in 1985 to 16.7 Gtce in 2025. This solar energy is used with an overall efficiency of 14 % for the production of hydrogen (note that this

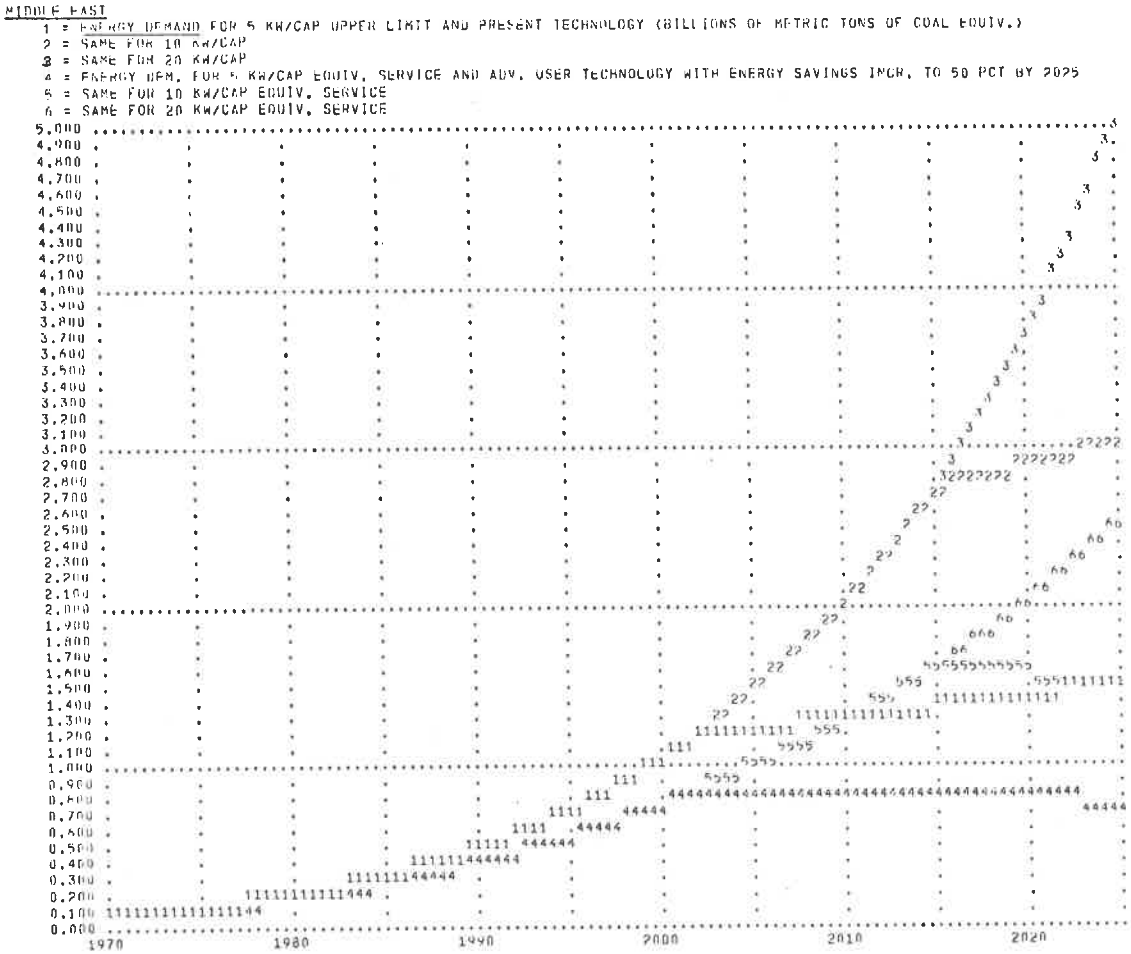

Fig. 4.19 - Regional energy demand for the Middle East

efficiency estimate is conservative; the overall efficiency could possibly as high as 30 %[10].

No primary energy inputs other than solar energy and oil are considered.

Energy allocations to the different conversion processes

In the present case the allocation fractions control (a) the flow of oil through the domestic economy, and (b) the production of hydrogen. We have here formally assumed that hydrogen is generated by electrolysis using electricity from solar plants. This is probably not the best approach; the direct generation of hydrogen using concentrated solar heat seems to have significant advantages over the electrolysis approach. However, the results would not be much different; they can be used for both methods.

Oil is refined with a 5 % energy loss. 5 % of the input energy are converted to liquid fuels, the remaining 10 % to gas. 3 % of the gas produced is used for chemical products.

Of the liquid fuel produced, 40 % is burnt in central power plants, 10 % goes to chemical industry for petro-chemical products, and the remaining 50 % flows into the user sector. Power plants use standard combustion power cycles (present technology).

Of the total electricity generated (by combustion power plants and solar plants), an increasing share is used for the production of hydrogen, beginning 1985 (40 % in 1985, 70 % in 2000, 80 % in 2025). All of the

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[10] Morrow, op. cit.

hydrogen generated goes to export. The conversion efficiency is 20 % from solar to electrical energy, and 70 % from electrical to hydrogen.

Energy distribution to users

Only three energy forms appear in the domestic user sector: electrical energy, gas, and liquid fuel.

A constant 60 % of the electrical energy is assumed to be used in the residential/commercial sector, the remaining 40 % go to the industrial sector.

50 % of the gas are taken by the residential/commercial sector, the remaining 50 % go to the industrial sector.

Of the liquid fuels produced, 20 % are used in the residential/commercial sector, 50 % in the industrial sector, and the remaining 30 % in transportation.

Results of the simulation

The full results of the simulation using this input scenario are given in the data Appendix. They will now be discussed in some detail. Figs. 4.20 and 4.21 are excerpted from the complete data sets. Table 4.3 summarizes the results.

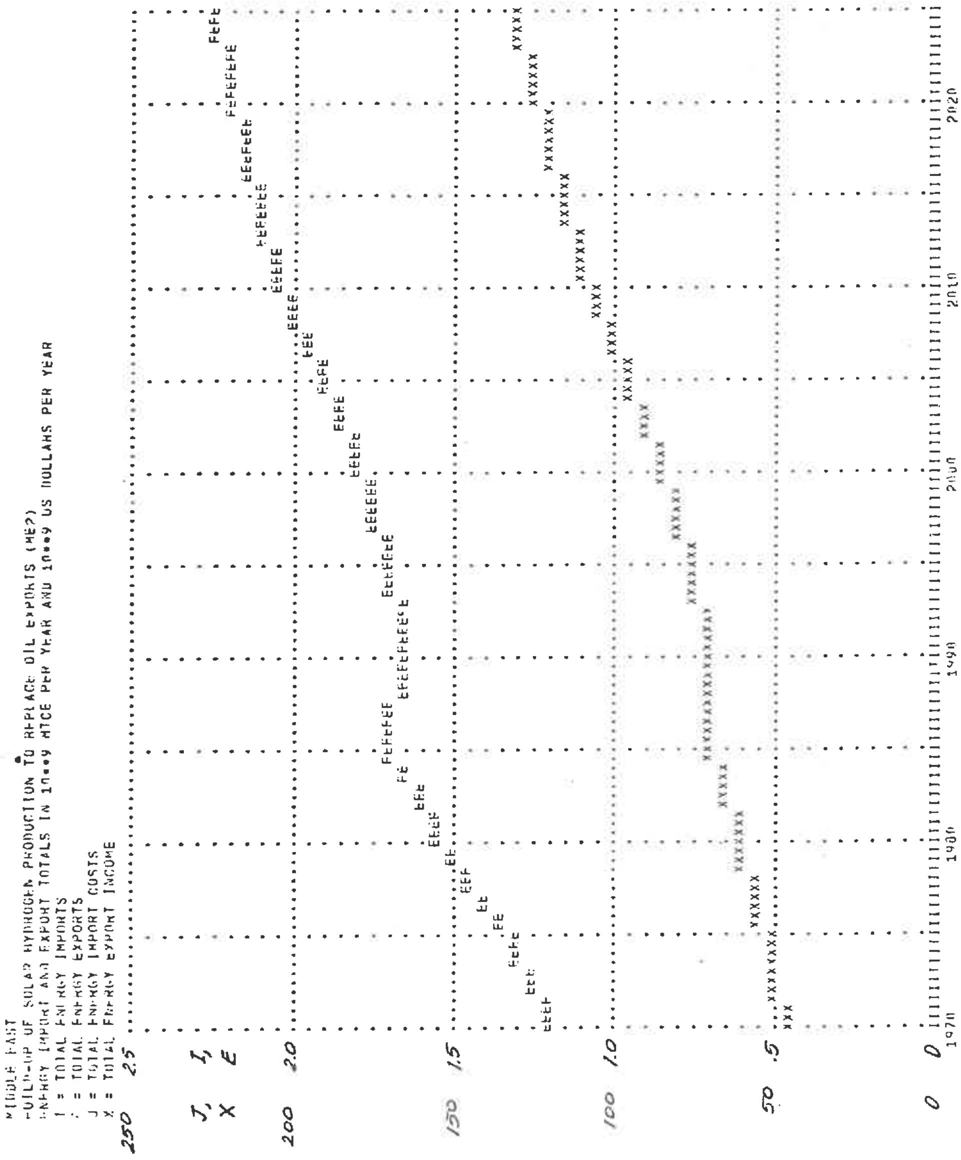

Fig. 4.20 - Energy export for the "solar hydrogen" scenario for the Middle East

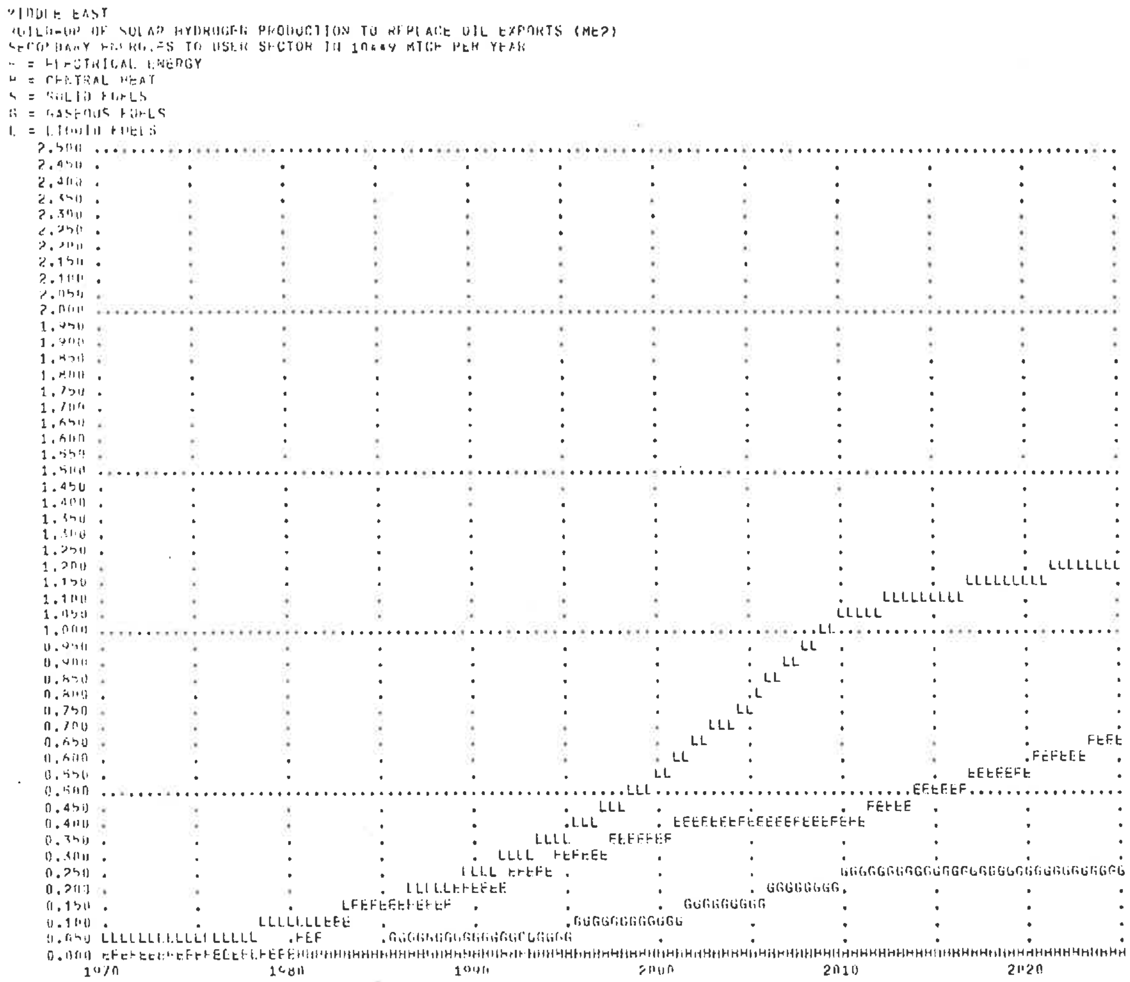

Fig. 4.21 - Secondary energy outputs for the "solar hydrogen" scenario for the Middle East

ESP - ISI/SRC January 1974
SUMMARY OF RESULTS
MIDDLE EAST ENERGY SYSTEM

		"solar hydrogen" scenario (ME2)	units
Oil Consumption in Region	1970	.09	10^9 tce/yr
	2000	1.30	"
	2025	2.90	"
Annual Oil Export	1970	1.19	"
	2000	1.10	"
	2025	.20	"
Annual Hydrogen Export	1970	.0	"
	2000	.69	"
	2025	2.06	"
Export Revenues per Year	1970	47.60	10^9 \$/yr
	2000	85.41	"
	2025	131.81	"
Number of 1000 Mwe Plants	1970	116	
	2000	4034	
	2025	10288	
New Plants per Year	1970	16	
	2000	(291)	
	2025	192	
Capital Investment per Year	1970	1.71	10^9 \$/yr
	2000	(53.89)	"
	2025	42.94	"
Cumulative Capital Investment	1970	12.81	10^9 \$
	2000	782.81	"
	2025	2026.70	"
Energy Mix to Users elec/gas/liq.	1970	17/17/66	%
	2000	36/12/52	%
	2025	31/13/56	%
Total Energy to Users in Region	1970	.06	10^9 tce/yr
	2000	1.06	"
	2025	2.18	"
Energy Cost to User per Year	1970	6.82	10^9 \$/yr
	2000	170.91	"
	2025	325.71	"
Cost to User per Unit of Energy	1970	113.6	\$/tce
	2000	161.2	"
	2025	149.2	"

Table 4.3 - Summary of Results for the Middle East solar hydrogen scenario

The fact that we are here presenting only one scenario for the Middle East should not be understood as an implication that there exists only one option. There do, in fact, exist quite a number which deserve attention. This must be left to future investigations.

Energy exports

The oil export of the region increases from 1.19 Gtce in 1970 to 1.64 in 1985, dropping thereafter to 1.10 in 2000 and .20 in 2025. Correspondingly, the export revenues from oil increase initially, and then decrease to a low value. Revenues from increasing hydrogen exports more than compensate for revenue losses from falling oil export. Hydrogen exports climb from .02 Gtce in 1982 to .69 in 2000 and 2.06 in 2025.

Total exports climb from 1.19 Gtce in 1970 to 1.79 in 2000 and 2.26 in 2025, corresponding to export revenues of \$ 47.60 $* 10^9$ (billions) in 1970, 85.41 in 2000, and 131.81 in 2025. The reason for the more than proportional increase in revenues is the higher unit price of hydrogen.

Number of 1000 MWe conversion plants and capital investment

The number of 1000 MWe conversion plants in the region climbs steeply from 116 in 1970 to 4034 in 2000 and 10288 in 2025. Most of these plants (some 6000 by 2025) are conversion plants of the oil-based energy system producing for domestic demand (refineries, power stations). The remainder consists of somewhat more than 2000 solar electric power plants, and somewhat less than 2000 plants generating hydrogen from electricity. If these two plants are combined, we would deal with some

2000 solar hydrogen generating plants of an individual plant capacity af 1000 MWe. These plants would together represent a capital investment of some 1000 billion dollars (at the, perhaps optimistic, investment cost of $ 500/kWe). If this generating capacity is built up over 40 years, the yearly capital investment requirements to build some 50 plants annually would be approximately $ 25 billion.

Due to the rapid expansion of the domestic oil-based economy and the solar hydrogen generating capacity, the total number of conversion plants to be built each year increases from 16 in 1970 to a peak of 337 by 2020 and then decreases again to 192 in 2025. Note again that refineries, power plants, solar electric plants and hydrogen generating plants are all counted separately, even though we would probably partly deal with integrated units combining several functions. Annual investment in conversion plants increases from $ 1.71 billion in 1970 to 56.28 in 2005, and then decreases again to 42.94 in 2025.

Total energy to user

The secondary energy supply to the regional user increases from .06 Gtce in 1970 to 1.06 in 2000 and 2.18 in 2025. For this energy the user pays $ 6.82 billion in 1970, 170.91 in 2000, and 325.71 in 2025. The respective unit prices of secondary energy are $ 113.6/tce in 1970, $ 161.2/tce in 2000, and $ 149.2/tce in 2025.

During the scenario period, the energy mix to the user changes from 17 % electricity, 17 % gas, 66 % liquid fuel in 1970 (estimate) to 36 %/12 %/ 52 % in 2000, and to 31 %/ 13 %/ 56 % in 2025.

4.3 Evaluation of Scenarios

Introduction

In this section we shall discuss some basic aspects of policy analysis, evaluation, and selection, using scenario analysis and simulation models. These considerations will be applied to the evaluation of the scenario results given in the previous section. Some tentative conclusions will be drawn from these simulation results. We shall also discuss the general approach to comprehensive scenario analysis and evaluation and apply it to a (subjective) rank-ordering of energy policy alternatives for developed and oil-exporting regions.

The general approach to policy evaluation using simulation models consists of the following steps:

(1) A trial policy is chosen. This may be a "pure" or a "mixed" policy (examples in the present context are, respectively, an energy system entirely based on oil as a primary energy, or one based on a mix of oil, gas, and coal).

(2) The policy is translated into a scenario input to a simulation model (this model may have any degree of complexity, from a simple mental model to a sophisticated computer model).

(3) Certain state variables ("indicators", "monitor variables") are observed during the simulation and recorded.

(4) The scenario results, as given by the indicators, are evaluated using objective and subjective criteria. A combined measure of (subjective) utility, disutility, satisfaction or dissatisfaction is derived.

(5) Results from the different scenario simulations are compared and the most satisfactory alternative is selected.

These steps will now be discussed in more detail.

Option trees

The task of planning (whether regional energy system or oil exports) requires consideration of different options at various levels of concreteness; i.e. the study of a hierarchy of options followed by layers of more concrete strategy options, and finally detailed implementation options. The distinction between policies, strategies, and implementation is here merely for the sake of simplifying the discussion; generally more layers will have to be considered. As each policy is usually achievable by one or several members of a set of strategies, and each strategy by one or several different implementations, the hierarchy of options has a tree-like structure. Note that the options are rarely mutually exclusive; very often a satisfactory solution requires the simultaneous pursuit of several competing paths.

To make matters more concrete, consider the simplified option trees for developed, oil importing regions (Fig. 4.22) and for developing, oil-exporting regions (Fig. 4.23). These option trees serve as framework for scenario design and evaluation.

The objective of balancing energy supply and demand of developed regions (Fig.4.22) can be attained by pursuing several policy options:

(1) by providing secondary energy in the form of liquid fuels:

(2) by providing gaseous fuels;

(3) by providing electricity, and

(4) by reducing energy consumption.

There are several options and sub-options for each of these policies: liquid fuel may be provided by importing petroleum, and by liquefaction of coal, using the heat of combustion of coal and of nuclear reactors.

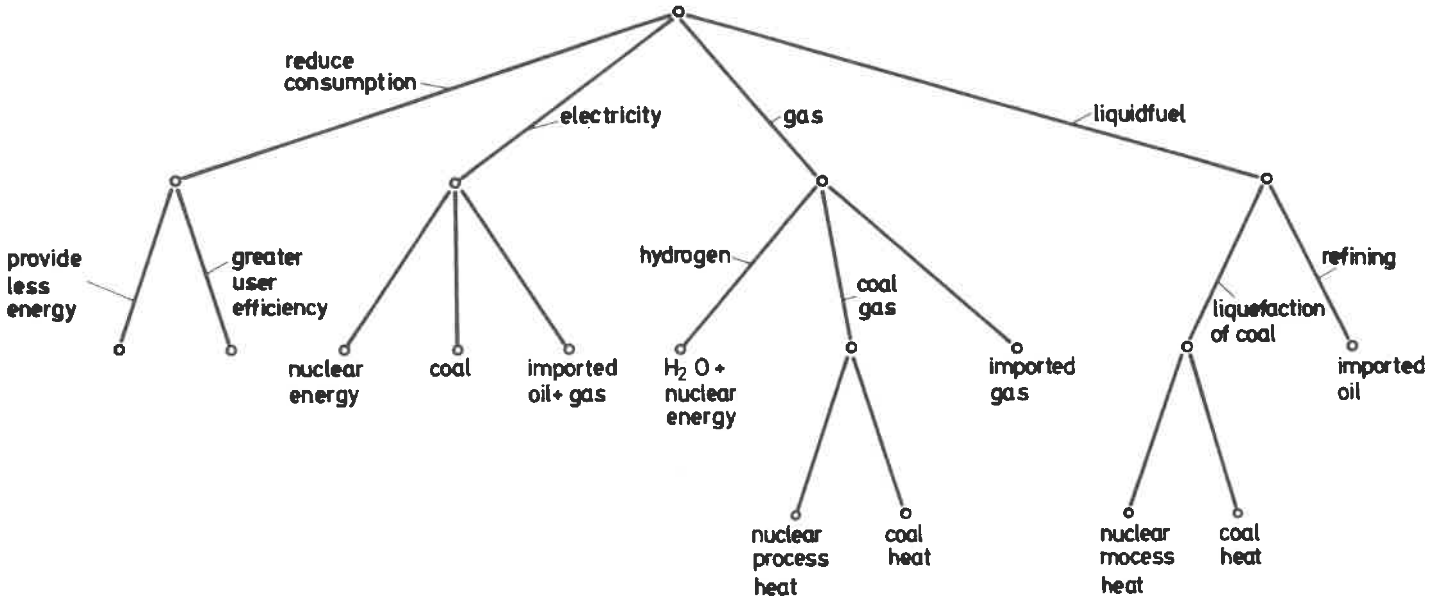

Fig. 4.22 Option tree for energy system of developed region

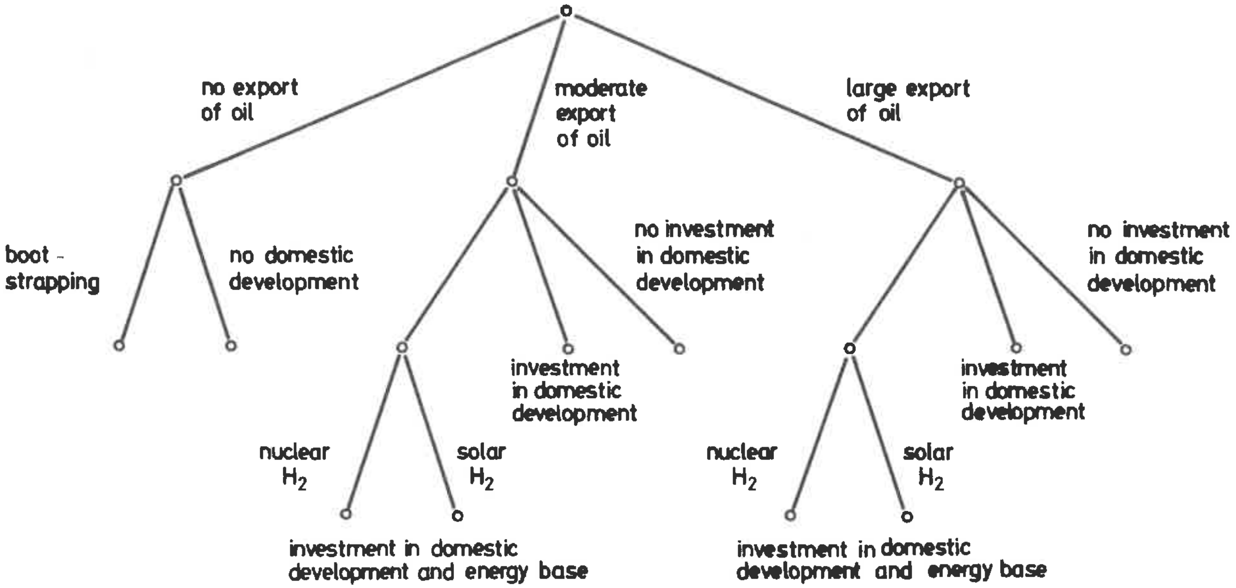

Fig. 4.23 Option tree for oil exporting region

Similarly, gas may be provided by importing it, by gasification of coal (using heat from coal combustion and from nuclear reactors), and by generating of hydrogen in high temperature nuclear reactors. Electricity may be generated by thermal processes using combustion of imported oil or gas, and of domestic coal, and by nuclear reactor heat. Finally, energy consumption may be reduced by increasing the efficiency of energy use, and by simply providing less energy.

Note that these options are generally not mutually exclusive and may be activated simultaneously to varying degrees. This is shown in Figs. 4.24 and 4.25 for the Western European scenarios of the previous section. The options chosen in those scenaraios are emphasized by bands in the option tree; the width of the bands correspond roughly to the emphasis on this particular option in the respective scenario. The difference in the two scenarios should be obvious.

The option tree for the oil-exporting regions is quite different (Fig. 4.23). Here the objective is an oil export rate which insures the greatest benefit to the region. The policies open to the region are (in gross simplification):

(1) a high export rate;
(2) a moderate export rate;
(3) no oil exports.

As a consequence of corresponding export revenues, the region in the first two cases has the option (a) not to invest in domestic development; (b) to invest in development of a domestic industry based entirely on the domestic (nonrenewable) oil and gas reserves; (c) to invest in its own industrial development and at the same time development of a

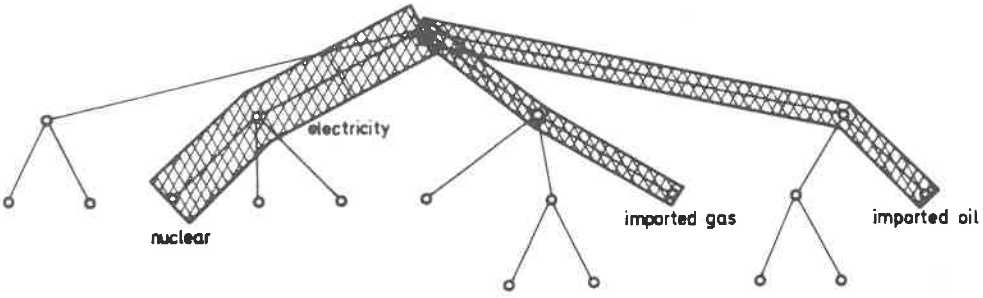

Fig. 4.24 Option emphasis, "standard" scenario for Western Europe

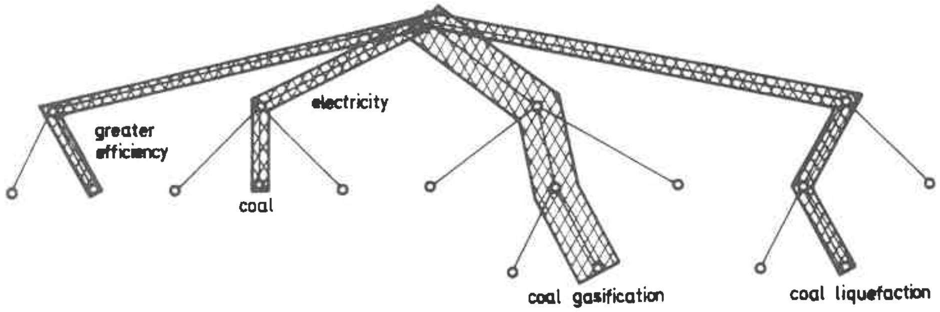

Fig. 4.25 Option emphasis, "alternative" scenario for Western Europe

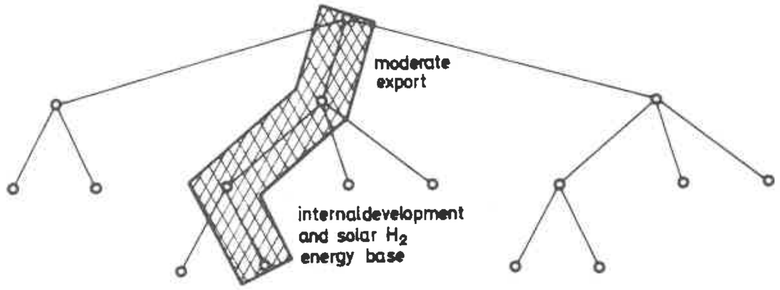

Fig. 4.26 Option emphassis, "solar hydrogen" scenario for the Middle East

renewable energy resource base, with the options "hydrogen generation by solar energy" and "hydrogen generation by nuclear energy". The options in the last case are "no domestic development" or "gradual development by bootstrapping without exports or external help". The emphasis in the solar hydrogen scenario studied in the previous section is again indicated by bands in Fig. 4.26.

Option trees and scenarios

Note that we have used two quite different option trees as a guide for designing scenarios which were then computed using an identical simulation program: option tree and simulation program therefore are not related. The option tree shows, among other things, the context-dependence of the scenario.

Following the simplified schemes of Fig. 4.22 and Fig. 4.23, the number of "pure"scenarios (where one and only one option is implemented) is twelve for the case of the developed regions, and ten for the case of the oil-exporting region. In the case of the developed region, it would be quite absurd to pursue a "pure" policy, relying on only one option to fulfill the objective. Obviously, in practice a "mixed" policy would have to be pursued, requiring the study of "mixed" scenarios where several options are activated simultaneously with varying degrees of emphasis. At any point in time, a given "mixed" scenario corresponds to a point in 12-dimensional space in the first, and 10-dimensional option space in the second case. Obviously, the search for an (in some sense) "optimum" or even just "satisfactory" solution requires some organized (preferrably analytical or numerical) search effort. Provided a criteria function can be specified, optimization is possible with the linear ESP-model, but has so far not been applied.

Decision criteria

In either the manual(and heuristic) or the analytical or computational search for an input scenario giving "optimal" or "satisfactory" results, decision criteria are required for the evaluation. The set of decision criteria is context-dependent and reflects the preferences and problem-awareness of the decision-maker. The set explicitly or implicitly, concretely or vaguely, represents a desired system state, against which the system state implied by the monitored state variables of the simulation (monitor variables, indicators) is measured. The desirability of each scenario is thus judged in either a qualitative, fuzzy manner (the usual procedure in decision-making), or in a more quantitative manner using cost functions or utility analysis. We shall later use the more fuzzy concept of "dissatisfaction" to derive some qualitative measures for the relative desirability of different scenarios.

In order to discuss the results of the simulations in a more or less systematic fashion, we use two different sets of decision criteria for the developed regions, and the oil-exporting region, respectively (Tables 4.4 and 4.5). It is stressed again that the selection of these criteria is subjective: some decision-makers will deal with only a subset of those given, while others may include other criteria and delete some of those listed. Most important, different decision-makers in different contexts will attach different degrees of importance ("weight") to the different criteria. Discussion of these points and the evaluation process itself are taken up again later.

Table 4.4 - Decision Criteria with Respect to the Energy System of Developed Regions

- Adequacy of secondary energy supply (volume and mix)
  - to residential/commercial sector
  - to industrial sector
  - to transportation sector

- Availability of energy supply
  - long range resource availability; exhaustion
  - security of supply: independence or assured cooperation

- Costs
  - extraction investments and operating costs
  - conversion " " " "
  - transportation " " " "
  - distribution " " " "
  - user technology " " " "
  - cost of primary energies
  - cost of secondary energies

- Safety
  - immediate dangers through harmful pollution
  - risks of accidents and sabotage
  - long range dangers
  - synergisms and sumulative effects

- Environmental aspects
  - ecological effects
  - climatological effects
  - geophysical aspects

- General societal aspects
  - structural changes: industry, employment, markets
  - international relations;trade, cooperation
  - overall system efficiency
  - special problems

Table 4.5 - Decision Criteria with Respect to the Energy System of Oil-Exporting Regions

- Independence from foreign domination
- Present regional welfare
- Welfare of future generations
- Capital investment required

The two sets of decision criteria for the two cases can be formally derived as subsets of a much more general set of criteria covering the decision behaviour of regional decision-makers. The possibility of this approach is only pointed out here; it will not be pursued . In deriving sets of decision criteria, one should make an attempt to obtain "orthogonal" components; i.e. criteria which are each independent of any of the others. Cluster analysis will help in this effort, but a clean separation may not always be possible. No claim of orthogonality can be made for the two sets of decision critera given in Tables 4.4 and 4.5. Each member of a subcritera set for a given decision criterion should again be independent of each other member, within the same subset.

Tentative conclusions from the simulations

We will use the decision criteria of Tables 4.4 and 4.5 as guidelines in evaluating the results of the simulations for the United States, Western Europe, and the Middle East. The ESP simulation program does not provide indicators (monitor variables) for all of the decision aspects listed. Indicators on safety, for example, would have to come from a separate investigation; indicators on environmental and pollution aspects could be added to the simulation model.

In the following we shall refer to the "standard" scenarios for the United States and Western Europe as the "nuclear-electric" scenario, to the "alternative" scenarios for both regions as "gas" scenarios, and to the Middle East scenario as "solar hydrogen" scenario.

The simulations undertaken so far with the energy system planning model (five of which have been reported here) have been of an exploratory nature. For lack af available information some of the input data are crude and perhaps inaccurate. Any conclusions drawn are therefore tentative and must await further confirmation. Nevertheless, certain trends seem to emerge which will not be greatly affected by a more accurate data base. Since the model is a linear one, any error in the input data will be reflected in a proportional error component in the output, with a constant proportionality factor. An idea of the magnitude of these factors can be had from the equations of the aggregated energy system planning model (ESPAG) discussed in section 4.4.

Evaluation of the Scenarios for the United States and Western Europe

Adequacy of secondary energy supply

In all four scenarios the secondary energy supply to the user sector appears to be adequate. The total amount of secondary energy provided by both the nuclear-electric, and by the gas scenarios is comparable, despite vast differences in the amounts of primary input energy. However, significant differences appear in the mix of energies to the user. In the nuclear-electric scenarios the share of electricity increases vastly at the expense of gas and liquid fuels (to 82 % (WEU), resp. 59 % (US)). This would imply major structural changes in the user sector, some of them, like the electrification of personal transportation, being extremely unlikely. In the gas scenario for the United States the liquid fuel input drops somewhat while the input of gas and of electrical energy increase. In the gas scenario for Western Europe the shift to gas use is much more pronounced, even though the share of electricity also increases significantly. In both gas scenarios the shift to gas is gradual and only partial, as the gas share increases only to about 40 % of the total energy input into the user sector. Major dislocations are therefore unlikely.

Conclusion: A gas-based energy system can supply the necessary energy amount and mix to the user sector using a much smaller primary energy input than the nuclear-electric energy system. The latter system also provides a particular unsatisfactory energy mix.

Availability of energy supply

All four scenarios start with the historic conditions of 1970 - mainly oil-based energy systems - and gradually develop along the diverging paths of the "standard" and "alternative" scenarios. As a result of resource limitations the oil-based energy system obviously can be neither a permanent, nor even a long-range solution (for a time-horizon of more than three decades). A coal-based energy system fares somewhat better. The developed regions of North America and Western Europe have coal reserves which - at moderate rates of exploitation - could support them for another century. During this time, transition to a more permanent energy base would perhaps be possible. A nuclear energy system based on the conventional reactor would run out of fuel by the time the oilwells dry up (see chapter 2 on resources); this again is not a permanent, nor even a long-range solution. The breeder reactor offers a way out of this dilemma. Of the major sources of primary energy considered here, it is the only one which offers a reasonably long-range solution to the question of energy supplies. It does so at the cost of some serious and as yet unresolved hazards (see the brief on the breeder reactor).

In the "gas" scenario for the United States, solar and geothermal energy, and the energy in wood, wastes, and other biomatter play a small but significant role. The contributions of these renewable energy sources are potentially great; they could, if properly harnessed, cover the future energy needs of the world. The engineering effort needed to develop these resources appears to be smaller than that needed for the development or safe breeder or fusion technologies.

The question of security of supply can be settled by either a policy of energy independence, or a policy of reliable long-range cooperation. Both "gas" scenarios assume eventual depletion of foreign oil-reserves. Primary energy inputs therefore eventually become independent (or almost so) of foreign suppliers. However, until this measure of independence can be achieved (at most in two to three decades in the case of Western Europe) cooperation with oil-importing regions is an essential precondition to reasonably stable economic development.

Conclusions: Oil is not suited as a long-range energy base; coal will serve much better; and the breeder offers almost unlimited energy supplies at a cost. The for all practical purposes equally unlimited and renewable supplies of geothermal, solar, and biomatter energies deserve more attention.

Costs

All electrical energy systems labor under a double handicap: high costs of electricity generation and transmission, when compared to other energy forms. In addition, transmission losses are quite significant (of the order of 3 percent per 100 km in high-voltage lines). Worst of all, thermal electric power generation is limited by the laws of thermodynamics to the relatively low efficiencies of thermal power cycles (some 35 % in the better present-day plant; approximately 55 % appear possible using advanced thermodynamic cycles). These limitations explain the poor results of the nuclear-electric scenarios on all cost counts, with the possible exception of primary energy costs: nuclear fuel is relatively cheap.

The overall conversion efficiencies of energy systems avoiding (as far as possible) thermo-mechanical conversion cycles are considerable better. As a result, the primary energy input is smaller, the plant inventory is correspondingly smaller, less energy is wasted, investments for dissipation of this energy (cooling towers and equipment) are smaller. For the same output of secondary energy, the capital cost of necessary conversion plants is smaller by a factor of about four. Gas generation is more efficient than the generation of liquid fuels.

Conclusions: The lower costs of primary energy input for a nuclear-electric energy system are more than offset by significant cost disadvantages of the electricity generation and transmission system having overall energy losses of some 65 to 75 %. A gas-based energy system is significantly more cost-efficient. Future energy systems should restrict electricity generation and liquid fuel production to a minimum, and supply gas for all remaining energy needs.

Safety

Safety aspects are not directly included in the simulations. Their potential scale can be inferred from the number of the conversion plants and the magnitude of energy flows of the different kinds. While safety risks associated with the electrical energy system, with the liquid fuel system, and with geothermal and solar energies are minimal, serious attention must be paid to potential hazards of the gas and nuclear power systems. Gas systems, including hydrogen systems, have over decades established a good safety record. A potential problem may be small hydrogen storage systems.

Nuclear power systems - whether conventional reactor, breeder reactor, or fusion reactor - pose safety problems of a different order of magnitude and difficulty. The safety problem here has essentially five aspects: (1) emission of radioactive gasses (perhaps the least serious threat, except in the case of radioactive tritium pollution from fusion processes); (2) possible failure of cooling systems, having as a result the melting down of the core and serious radioactive contamination of the surrounding area; (3) transportation and storage of spent and unspent fuels and radioactive wastes; (4) control of all stocks to prevent sabotage, theft, unauthorized use, and possible nuclear blackmail (9 kg of plutonium, a physics degree, and a small laboratory suffice for the production of an atomic bomb; each breeder contains enough plutonium to make several hundred atombombs);(5) permanent safe storage of radioactive breeder wastes with a half-life of many thousand years[1].

Both nuclear-electric scenarios would imply several thousand breeder reactors per region by the year 2o25. The consequences of such a development are frightening indeed - even if a perfect safety record is assumed and we simply consider the size and reach of the control apparatus necessary to maintain this record.

Conclusions: The problem of safety and control is at least an order-of-magnitude more severe for a nuclear energy system than for systems based on other energy forms. As the amount of secondary energy supplied by non-nuclear systems is competitive, at lower overall cost, the large scale adoption of nuclear energy systems appears unwise.

Environmental aspects

Under this heading we here discuss effects of energy system which pose no immediate and direct dangers to man, but may significantly affect the environment surrounding him by causing changes in ecological

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[1] Jon Tinker, "Breeders:risks man dare not run", New Scientist, March 1973, p. 473 - 476

systems, the local, regional, or global climate, or in the natural geophysical or vegetative character of the countryside.

Surface mining of coal on a large scale can alter the character of large land-areas. This must not necessarily be to the detriment of the landscape (US strip-mining practices); restoration of open pit or strip mines to attractive recreational or agricultural areas is possible and should be enforced by proper laws (West Germany). In both "gas" scenarios the level of coal production would have to be increased significantly by 2025 (by a factor of five in the United States, by a factor of nine in Western Europe). Much of this mining effort would have to be underground, especially in Western Europe; a significant amount of coal gasification could probably be in situ.

The large-scale use of coal would necessitate effective control of sulfur dioxide emissions. This can be done most effectively and economically during the gasification process. Transmission of the gas would be in underground pipelines with a minimum impact on the environment.

The dissipation of heat generated by large electric powerplants of any kind poses local environmental problems. Water cooling possibilities (rivers, lakes) have reached their limits in many locations, and the transition to wet or dry cooling towers becomes necessary. The effects of large cooling towers on the local climate are as yet not well establisched. A relatively dense spacing of these cooling towers, as it would be required in a few decades in the nuclear-electric economy, could conceivably have adverse affects on the regional or global climate[2].

In both nuclear-electric cases, the amount of concentrated waste heat produced is truly enormous by 2025: in the United States it has climbed to almost 14 times the (not insignificant) amount of 1970; and in Western Europe to 21 times the 1970 amount. Apart from climatological considerations, this evokes the spectre of at least a twentyfold increase in the number of large cooling towers (probably more, as many existing processes have fresh water cooling without large cooling structures, while the fresh water cooling capacity has now reached its limits in many locations. This implies an increasing share of (much larger) dry cooling towers.)

Conclusions: Both large scale (open pit) mining operations required in a coal-based economy and the necessary dissipation of very significant amounts of rejected heat from the generation of electricity pose substantial environmental problems. Electricity generation should therefore be kept at a minimum.

General societal aspects

The simulations produce only a few indicators relevant to general societal aspects: such as energy costs and primary and secondary energy prices.Using these indicators, one could speculate on possible

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[2] H. Flohn, "Produzieren wir unser eingenes Klima?" Meteorologische Rundschau 23, 1970, p. 161

consequences. We will here only indicate a few.

All of the scenarios are to a greater or lesser degree suboptimal. The most serious criticisms are:

(1) Nonrenewable energies are used at a high rate when competitive renewable energy forms are available. (i.e. present use of oil, gas, and coal instead of solar, geothermal, or bio-matter energies).

(2) As the energy requirements of the end user can be most efficiently served by different energy forms, concentration on one particular energy form ("all-electric economy") is wasteful.

(3) Energy independence of a given region may have to be bought by inefficient energy use and corresponding problems of waste heat dissipation (hypothetical case: a decision to achieve independence from oil imports by switching to a nuclear-electric economy). At the same time a region depending on energy exports is deprived of its means of further development.

(4) Possibilities of combined or cascaded energy systems are seldom considered (example of cascaded processes where each process uses the rejected heat of the previous process: reactor heat → gasification of coal → electricity generation → space heating; example of a combined system: waste disposal - sewage plant - water purification - gas production - electric power generation - space heating).

(5) The focus is on providing increasing amounts of energy, not of energy <u>service</u>. It is a fact that the efficiencies of most

energy use processes can be increased substantially, and that in many cases different, but more efficient processes can be substituted.

(6) The implicit assumption that (especially in the developed societies) ever increasing amounts of energy per capita must be provided is certainly fundamentally wrong. There is a point (and it may be reached soon in some regions) where the marginal utility gained from an additional unit of energy is more than offset by the marginal disutilities of increased cost, decreased safety, increased environmental damage, and decreased social and political stability.

Conclusions: The energy system must be viewed as a part of the complex and dynamic societal system. Every effort should be made to avoid the pitfalls of suboptimality which always accompany the "simple solution".

We shall return to a more formal approach to the evaluation of the simulation results below. Before doing so, the results of the Middle East scenario simulation will be discussed in the light of the applicable decision criteria.

Evaluation of the solar hydrogen scenario for the Middle East

Independence from foreign domination

Independence from foreign domination requires first and foremost development of the region to the point where it becomes self-supporting as far as basic products are concerned. It further requires a secure resource base which can support the domestic economy in the long run.

Oil export can, over the next decades, supply the revenues for supporting a high rate of internal development. It cannot provide a permanent resource base. Exhaustion appears inevitable later in the next century.

The export of hydrogen could provide a permanent source of revenues. None of the developed regions has similarly favorable conditions for this particular energy industry.

Present regional welfare

The interests of the present generation favor a pace of development which provides quick improvement of the quality of life of the individual without disrupting his social and cultural environment. Achievement of this goal requires high revenue income from exports.

Welfare of future generations

As usual, the welfare of future generations is at odds with that of the present. A rapid pace of exploitation of oil and gas resources not only deprives future generations of the region of a source of income, it also deprives future generations of the world of valuable hydrocarbons which they will need for their chemical and pharmazeutical industries. The build-up of a hydrogen resource base would be in the interests of future generations, as it would permit the restriction of oil and gas reserves to future non-energy uses, before they become permanently exhausted.

Capital investment required

The capital investment required for the build-up of the solar hydrogen system (around 50 billion dollars per year) will be of the order of the investment required by each of the developed regions to build up its own energy system if hydrogen import from another region is not possible. There should thus be sufficient mutual interest in joint ventures between regions to build up this energy resource base.

A systematic approach to evaluation

The immense number of different scenarios (literally infinite, as the parameter inputs can vary on continuous scales) which can be investigated with a simulation model such as the present one, necessitate some evaluation procedure which would make it possible to focus on the more satisfactory scenarios. This evaluation would have to take into account all the decision criteria which are felt to be relevant to the search. Rarely (as in the case of cost or physical standards) can objective criteria be applied in this evaluation; most decision criteria repuire subjective evaluation of the indicators (monitor variables) from the simulation output.

This subjective evaluation procedure can be formalized by assigning subjective weights to the different decision criteria, subjectively quantifying the "dissatisfaction" of the decision-maker with respect to a given decision criterion, multiplying dissatisfaction and corresponding weight, and computing the sum of all weighted dissatisfactions ("overall dissatisfaction"). Scenarios giving small overall dissatisfactions are then of greatest interest to the decision-maker and merit further investigation.

Formally: Let i be the index of the i-th of I decision criteria, d_i the respective dissatisfaction, w_i the corresponding weight of the decision criterion, and D the overall dissatisfaction. Then

$$D = \sum_{i=1}^{I} w_i d_i$$

This procedure has been applied to tentatively evaluate the options for the developing regions and the oil-exporting region, using the option trees of Figs. 4.22 and 4.23, and the decision criteria of Tables 4.4 and 4.5. The results are tabulated in Tables 4.6 and 4.7. Note that the criteria weights and the individual dissatisfactions reflect the intuitive "fuzzy" assessments of a particular individual; other individuals will arrive at different assessments. There are no "right" or "wrong" answers. The dissatisfaction assessment could probably be considerably improved by applying a Delphi technique.

The assessment can be refined by disaggregating decision criteria into (more or less) orthogonal components (subcriteria), splitting the criterion weight into subweights for each of the subcriteria, and then applying the previous procedure to arrive at the dissatisfaction d'_i*.

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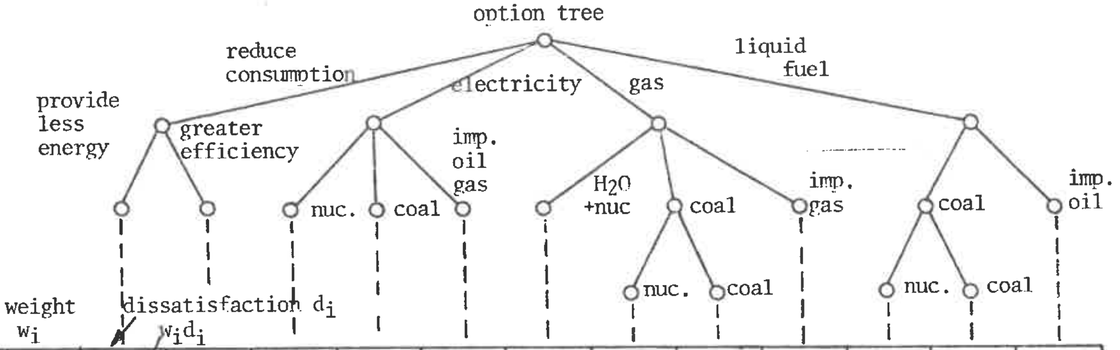
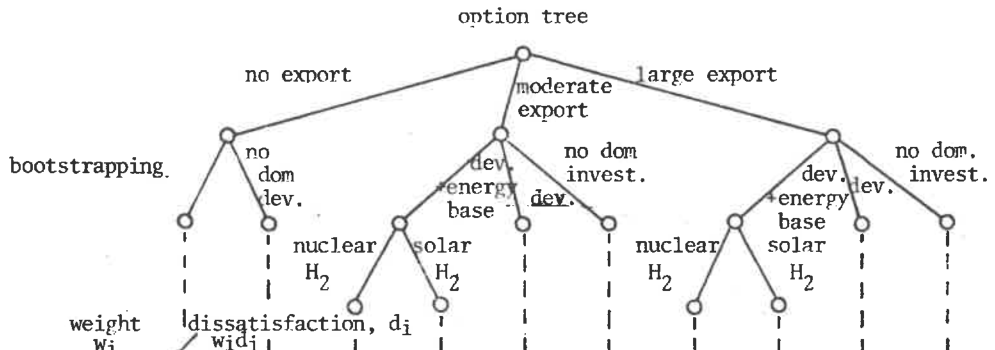
* As an example consider the decision criterion "safety" of Table 4.4. It has the subcriteria "immediate dangers through harmful polluction", "risks of accidents and sabotage", "long range dangers", and "synergisms and cumulative effects".



decision criterion c_i	weight w_i	dissatisfaction d_i $w_i d_i$											
adequacy of (secondary) energy supply	2	.8 1.6	.1 .2	.5 1.0	.5 1.0	.5 1.0	.2 .4	.2 .4	.2 .4	.2 .4	.1 .2	.1 .2	.1 .2
availability of (primary) energy supply	8	.0 .0	.0 .0	.1 .8	.5 4.0	.8 6.4	.0 .0	.3 2.4	.3 2.4	.8 6.4	.3 2.4	.3 2.4	.8 6.4
costs of energy system and energy supply	2	.1 .2	.3 .6	.6 1.2	.6 1.2	.7 1.4	.3 .6	.4 .8	.4 .8	.3 .6	.5 1.0	.5 1.0	.3 .6
safety of energy system	4	.0 .0	.0 .0	.1 4.0	.0 .0	.0 .0	.6 2.4	.5 2.0	.0 .0	.0 .0	.5 2.0	.0 .0	.0 .0
environmental aspects of energy system	1	.0 .0	.0 .0	.5 .5	.6 .6	.1 .1	.2 .2	.4 .4	.4 .4	.0 .0	.4 .4	.4 .4	.0 .0
overall dissatisfaction $D = \sum w_i d_i$ rank →		1.8 2	0.8 1	7.5 9	6.8 6	8.9 10	3.6 3	6.0 5	4.0 4	7.4 8	6.0 5'	4.0 4'	7.2 7
H_2 imports permanently available rank →		3	1	9	7	10	4	6	5	1.0 2	6'	5'	8

dissatisfaction: 0 1
(none) (severe)

Table 4.6 - Scenario evaluation for energy system of developed regions



decision criterion c_i	weight w_i	dissatisfaction, d_i $w_i d_i$									
independence from foreign domination	8	.0 .0	.5 4.0	.2 1.6	.2 1.6	.3 2.4	.7 5.6	.3 2.4	.3 2.4	.5 4.0	1.0 8.0
present regional welfare	4	.8 3.2	1.0 4.0	.3 1.2	.3 1.2	.2 .8	1.0 4.0	.3 1.2	.3 1.2	.2 .8	1.0 4.0
welfare of future generations	2	.0 .0	.7 1.4	.3 .6	.0 .0	.4 .8	.7 1.4	.3 .6	.0 .0	.4 .8	.7 1.4
capital investments required	1	.1 .1	.0 .0	.7 .7	.7 .7	.3 .3	.0 .0	.7 .7	.7 .7	.3 .3	.0 .0
over-all dissatisfaction $D = \sum w_i d_i$ rank →		3.3 1	9.4 7	4.1 3	3.5 2	4.3 4	11.0 8	4.9 5	4.3 4'	5.9 6	13.4 9
independence assured rank →		3.3 4	5.4 5	2.5 3	1.9 2	1.9 2'	5.4 5'	2.5 3'	1.8 1	1.9 2"	5.4 5"

dissatisfaction: 0 1
(none) (severe)

Table 4.7 - Scenario evaluation for energy policy options of oil exporting region

Formally: Let j be the index of the j-th of J subcriteria of decision criterion c_i, d_{ij} the respective subdissatisfaction, w_{ij} the corresponding subweight of the decision subcriterion. Then

$$d'_i = \sum_{j=1}^{J} w_{ij} d_{ij}$$

Note, however, that $D = \sum d'_j$, as the weights have already been accounted for. This procedure can obviously be repeated as needed, leading to a "dissatisfaction hierarchy".

A procedure such as the present one can help to structure decision problems and make the evaluation procedure more transparent. It should be clearly understood, however, that this is not an "objective" evaluation procedure. Such a thing simply does not exist.

In the evaluation of energy system options for the developed regions (Table 4.6) the assumption was that, starting from the present energy system, the future development was almost exclusively in the direction of each one of the 12 alternatives in turn. With the subjective weights as given, the ranked order of preference for the different energy system option was then as follows:

1 - reduced consumption by increased user efficiency (least unsatisfactory solution)
2 - providing less energy
3 - hydrogen from water and nuclear process heat
4 - (gasification of coal using coal for process heat
liquefaction of coal using coal for process heat)

5 - (gasification of coal using nuclear process heat
liquefaction of coal using nuclear process heat)

6 - electricity from coal-fired power plants

7 - liquid fuel from imported oil

8 - energy system based on imported gas

9 - electricity from nuclear power plants

10 - electricity from powerplants fired by imported oil and gas (most unsatisfactory solution)

A very interesting change in this order results by introducing the Middle East solar hydrogen scenario and assuming that an adequate supply of imported gas (hydrogen) at reasonable rates will always be available. The dissatisfaction with respect to the decision criterion "availability of energy supply" is then reduced to zero in the column for the energy system based on imported gas. This changes the first few entries in the preference ranking as follows

1 - reduced consumption by increased user efficiency

2 - energy system based on imported gas

3 - providing less energy

4 - hydrogen from water and nuclear process heat(all the rest are moved down by one position,deleting (old) position 8)

It is interesting to ponder these (thoroughly subjective and unrepresentative) results in the light of current controversies surrounding the large scale introduction of nuclear electric powerplants. Quite obviously different weights are attached by different groups and individuals to the different decision criteria, and different dissatisfactions are assessed as a result of proposed measures.

A similar subjective evaluation of the options for the <u>oil-producing region</u> (Table 4.7) arrives at the following rank-ordering:

1 - "bootstrapping" (regional development without external aid and interference); no oil exports (most satisfactory solution)

2 - moderate oil exports; investment in regional development and a solar hydrogen industry

3 - moderate oil exports; investment in regional development and a nuclear hydrogen industry

4 - moderate oil exports; investment in regional development only

5 - large oil exports; investment in regional development and a solar hydrogen industry

6 - large oil exports; investment in regional development and a nuclear hydrogen industry

7 - large oil exports; investment in regional development only

8 - no oil exports; no investments in regional development

9 - moderate oil exports; no investments in regional development

10 - large oil exports, no investments in regional development (most unsatisfactory solution)

An interesting change in this rank-ordering occurs if the concern about "independence from foreign domination" is assumed not to exist. The rank-ordering then changes to

1 - large oil exports; investment in regional development and a solar hydrogen industry (most satisfactory solution)

2 - moderate oil exports; investment in regional development and a solar hydrogen industry

or - large oil exports; investment in regional development only

or - moderate oil exports; investment in regional development only

3 - large oil exports; investment in regional development and a nuclear hydrogen industry

or - moderate oil exports; investment in regional development and a nuclear hydrogen industry

4 - "bootstrapping"; no oil exports

5 - no oil exports; no domestic development

or - moderate oil exports; no domestic development

or - large oil exports; no domestic development (most unsatisfactory solution)

From these evaluations for the developed regions and the oil-exporting region the impression emerges that a genuine partnership between these regions, based eventually on the production of hydrogen by solar energy by the presently oil-exporting countries, might well meet the long range interests of all parties better than regionally optimized solutions.It is stressed, however, that we have so far only investigated a limited portion of a rather wide spectrum of possible scenarios. Further study may reveal more satisfactory alternative approaches.

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IV.5. WORLD OIL SYSTEM SUBMODEL

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April 1974

Table of Contents

A Description of the World Oil Model

Page

1. Introduction B 973

2. Model Structure B 980

2.1 Oil Demand B 980
2.2 Oil Supply B 985
2.3 World Oil Balance B 986
2.4 Oil Price B 987
2.5 Deficit Regions B 991
2.5.1 Conservation B 992
2.5.2 Unfilled Deficits B 992
2.5.3 Imports B 993
2.5.4 Independence Policies B 996
2.5.5 Retaliatory Policy B 1000
2.6 Surplus Regions B 1000
2.6.1 Price Manipulation B 1001
2.6.2 Production Limitation B 1002
2.6.3 Oil Revenue Expenditure B 1004
2.7 Final Comments B 1004

APPENDIX A: LISTING OF THE OIL MODEL AND VARIABLE DICTIONARY B 1008

Assessment of the World Oil Crisis

3. Introduction B 1020

4. Standard Cooperative Scenario B 1023

4.1 The Impact of Low World Oil Price B 1023
4.2 Desireable Oil Prices for the Middle East B 1026
4.3 The Impact of Prices on World Economies B 1032
4.4 The World Monetary Implications of Cooperation B 1040

5. Conflict Scenarios B 1053

5.1 Oil Production Limitations B 1053
5.2 Investment Good Price Retaliation B 1063
5.3 Mutual Conflict B 1073

1. INTRODUCTION

World Energy consumption has been increasing at approximately the same rate as world GNP--about 5% per year. World oil consumption has been growing even faster as oil has replaced coal, wood, and other less easily transported and utilized forms of energy. In 1950, oil constituted 30% of all energy consumption in the world; by 1970 this had increased to 48% with the trend pointing steeply upward. Different regions of the world have moved with varying speeds toward oil dominated energy systems. Latin America and the Middle East, endowed with considerable oil reserves and few other energy resources used oil in 1970 for 65% and 70% of their total energy needs, respectively. (The Middle Eastern figure is perhaps lower than one would expect because of considerable and growing natural gas use.) Western Europe and Japan, with few energy resources, have responded to the low cost and easy availability of Middle Eastern oil by granting oil 55.2% and 73.5% of their total energy consumption. Regions with alternatives to oil, even when blessed with considerable oil reserves, have maintained more diversified energy systems. North America relied upon oil for 41.5% of its total energy in 1970 and Eastern Europe required only 27.3%.

With the increased reliance on oil within regions, the dependence of several regions, particularly Western Europe and Japan on imported oil has grown remarkably. In 1970 7.4 billion barrels of liquid fuels were exported from surplus to deficit regions. Although Western Europe and Japan are clearly highly vulnerable to oil export limitations as a result of oil based energy systems and limited alternatives, Southeast Asia may be even more vulnerable. In 1970 that region used oil for 47% of its total energy and its oil imports constituted 7.4% of its total energy consumption. The presence of Indonesia in the region makes that import figure misleadingly small. The economies of the region are fragile, and increased oil prices are biting deeply. The South Korean economy is one of the strongest in the region. But the Korean government recently estimated that oil imports would increase in cost from 10% of total imports in 1973 to 20% in 1974, and that the economic growth rate would fall from 16.9% to 8%, almost entirely as a result of the increased oil prices.[1]

There are three major categories of problems in the area of world oil consumption and production, and these constitute the concerns to be analyzed in this report. First, oil is a nonrenewable resource and will eventually be depleted. The date of exhuastion depends on consumption growth or decline and on ultimate (including undiscovered) reserves. The second problem is short-term. At any time, as the Arab nations have recently proved, export limitations can cripple entire importing regions. The economic impact of supply limitations will depend on the size of the cut-back and the dependence of the importer. Even if short term supply limitations are avoided and ultimate reserve exhuastion is postponed, a third problem is that the enormous magnitudes of the international oil flows coupled with the increasing prices of oil pose incredible international monetary problems.

All three of these problems can be analyzed with the assistance of a computer simulation of world oil consumption and production. Quite clearly, the necessary model will need also represent the economies of the world, since it is the size of the economy which determines the demand for energy. Different assumptions about the possibility of continued rapid economic growth of Japan, for example, lead to different energy demand levels. Moreover, a principal concern here is the impact on economic growth of oil or other energy deficits. The model to be used, then, is not so much a world oil consumption and production model, but a world economic (and population growth) model in which oil production and consumption are given special attention. The model is one of a package developed in the context of the Mesarovic-Pestel World Model project.

Description of the project will not be undertaken here[2]. Some characteristics of the project should, however, be noted. First, the project has regionalized the world. The major differences in world regions have been recognized and incorporated into the models. Ten regions constitute the normal division. These are North America, Western Europe, Japan, the remaining developed Western nations (e.g. Australia, South Africa), Eastern Europe and the Soviet Union, Latin America, the Middle East and North Africa, Main Africa, Southeast Asia, and Communist Asia. Second, elements of the model are being developed in essentially modular fashion, so that, for example, the economic models for the 10 regions can be easily incorporated into models like the present one. Third, conscious attention goes to political options and the value-based decisions which governments can make in efforts to control their environments.

It is largely because of the uncertainty of governmental policy - making that no one can make high probability predictions about the future of the world; it is not the purpose of this report to do so. It is, however, possible to make "if-then" statements with considerable confidence. If we spell out basic assumptions and regional choices in the form of alternative scenarios, we can suggest likely implications of such scenarios.

The basic oil-related problems listed above, and the types of proposals which have recently been put forward for their solution suggest several general scenarios which users of a world oil model would want to explore[3]. These scenarios form central themes around which numerous variations exist, depending upon specific assumptions. The first scenario, or set of scenarios, can be called standard or cooperative. This scenario set posits that no restrictions are placed upon oil exports and that the capital accumulating regions are as well accepted and integrated into the international system as Texas is in the U.S. or Scotland is in Great Britain. That is, capital flows to the oil rich areas, but returns to the oil poor areas as expenditure for goods and investment in established capital. The major variables of interest in this set of scenarios are the price of oil, the size of the capital flows (a function of oil prices), and the proportions of capital which oil selling nations invest in long-term capital of other regions and immediate consumption.

The second scenario set focuses on conflict. There are possibilities for conflictual behavior on the part of both importers and exporters. Exporters can at any time limit exports, raise prices, and "squeeze" importers. Although we are labeling such decisions "conflict behavior," it should be pointed out that the intent need not be negative. In fact the Mideast leaders may feel that limitations on production are the best for everyone. Although we naturally think in terms of Mideast supply limitations, if the Soviet Union or even China become major exporters, other variations on the squeeze scenario will prove possible. The relative economic benefits to exporting regions of selling oil now on demand or of limiting production and waiting until later is a hotly debated issue and is central to the squeeze scenario. So is the economic impact on importers of supply limitations. The weapons available to the oil importers are less certain. The possibility exists of some collective action by oil importers to limit the availability of goods desired by the Mideast or to raise the prices of such goods. Although most commentators have rightfully belittled the likelihood of such action, and events have shown the centifrical behavior of the Western alliance in crisis, the possibility of such action remains. In particular, the Western developed region could manipulate sales and prices of capital goods to the Mideast since they have a relative monopoly on these highly desired goods - even the Soviet Union looks to the West for high technology capital goods.

Many other scenarios can be examined with the oil model. For example, we could focus on efforts of regions to make themselves "independent" in their energy supply. Clearly, the North American region has the greatest and most immediate potential for such independence. Its efforts and the efforts of other regions to increase energy supplies through governmental policies rather than through market mechanisms have implications for the entire world system. Other scenarios can be built around technology and various energy systems. If fusion were to become a commercial and inexpensive energy source either earlier or later than the early 21st century, it could change the oil demand picture considerably.

FOOTNOTES FOR CHAPTER 1

[1] *New York Times*, February 11, 1974, p. 53.

[2] See the various reports on the project prepared for the special meeting on the World Model Project, International Institute for Applied Systems Analysis, Vienna, April-May, 1974. See also Barry B. Hughes, "Current Status of the Mesarovic-Pestel World Model," Case Western Reserve University, Systems Research Center, March 1974.

[3] Several scenarios are explored with this model in Barry Hughes, Mihajlo Mesarovic, and Eduard Pestel, "Assessment of the World Oil Crisis Using the Multi-Level World Model," Systems Research Center, Case Western Reserve University, April, 1974.

2. MODEL STRUCTURE

Figure 1 shows the basic structure of the model. Across the top of that figure is the oil demand determination, across the bottom is oil supply, and the center contains the reconcilation of demand and supply, the feedback of deficits to economic growth, and the options or policies available to importing and exporting nations. Naturally, oil demand and oil supply capability are not necessarily equivalent to each other or to final oil consumption as determined in the middle layer of Figure 1. Let us look at each of the three levels. Except when noted otherwise, data for this study come from Joel Darmstadter, *Energy in the World Economy*, Resources for the Future, 1971, and *U.N. Statistical Series J.*

2.1 Oil Demand

Basic to the level of oil demand for a region is the size of the economy. The economic model from the Mesarovic-Pestel World Model project provides a very good base for the projection of economic growth (without inflation) in each of the 10 regions. Energy demand does not grow at the same rate as GNP, however. In general, energy demand grows faster than GNP in less developed regions and slower in developed regions. The less developed regions require tremendous increases in energy use to create the infrastructure and basic industry of industrialized economies. Frequently these countries require as much as two percent increases in energy use for every one percent increase in GNP. In particular, the communist regions increase their energy consumption during the period of industrialization at a far higher rate than they increase total economic output. More

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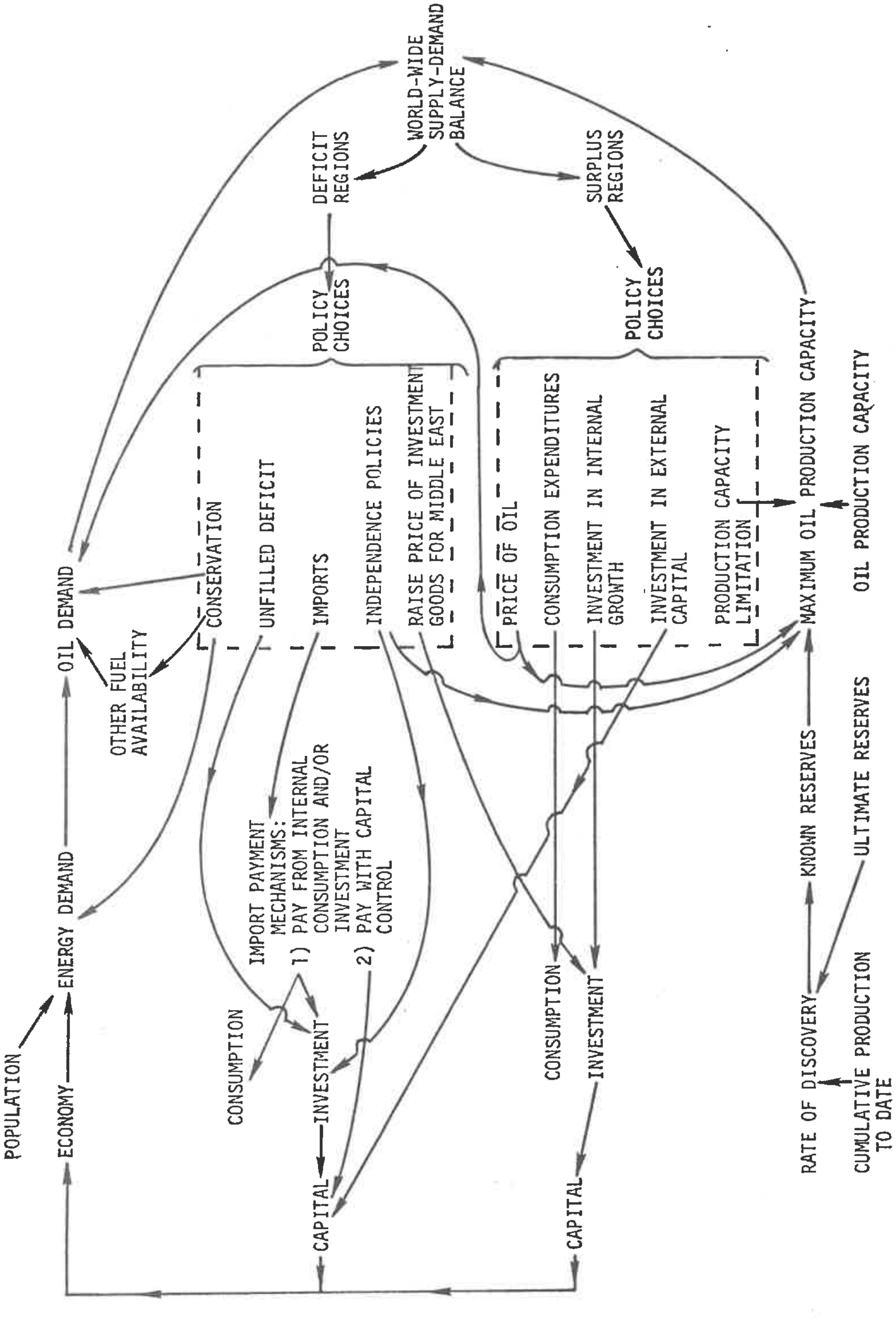


Figure 1

mature and service sector oriented economies, increasingly including Eastern Europe, generally require something less than a one percent increase in energy use for every one percent increase in GNP. Figure 2 shows the relationship between the economic development of a region's economy (as measured by GRP/capita) and the ratio of energy to GRP. Note that the ratio increases dramatically at low levels of GRP/capita, especially for communist regions. The prediction of total energy demand in any time period for a region is thus a function of GRP and population.[1]

Naturally, oil demand is not a constant proportion of total energy demand, and depends on the relative availability and price of oil and other energy sources. Figure 3 shows one estimate by J.D. Parent and H.R. Linden of the future ratio of oil consumption to total energy consumption[2]. That figure is not a simple extrapolation of empirical data. The curve is based on estimates of total world oil supplies and total world energy demand, with the assumption that oil will continue to be a more attractive energy source than other fuels as long as it remains available. Because the assumptions are reasonable, Linden's curve will form the basis for projecting oil demand from total energy demand in the unmodified projection scenario. Clearly, efforts to achieve independence by any region will result in modifications, as will oil conservation measures, oil supply limitations and oil demand elasticity with price. The curve will be modified for various scenarios.

The shape of the curve in Figure 3 largely describes the pattern for each region as well as for the world as a whole. Naturally, each region

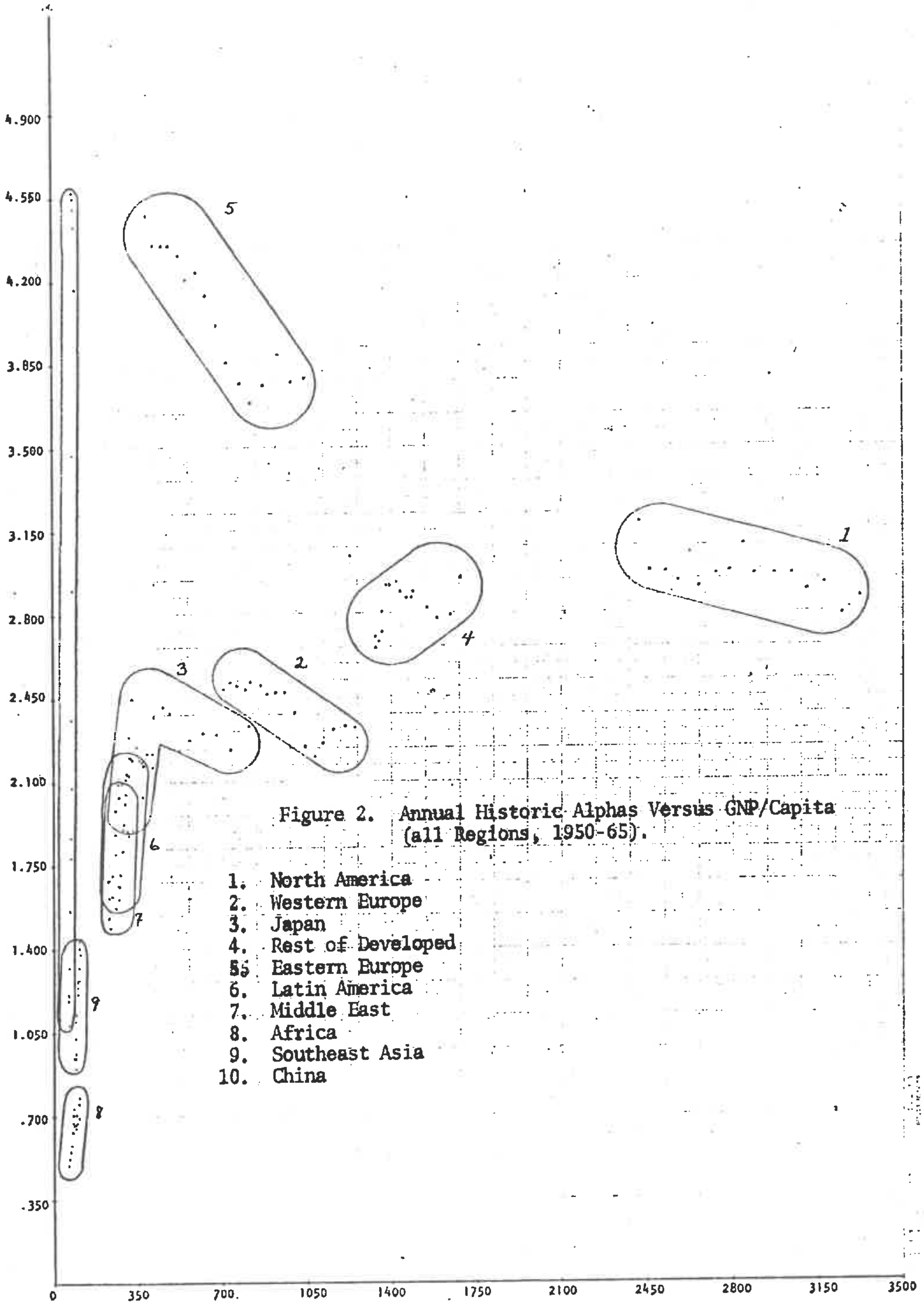


Figure 2. Annual Historic Alphas Versus GNP/Capita (all Regions, 1950-65).

1. North America
2. Western Europe
3. Japan
4. Rest of Developed
5. Eastern Europe
6. Latin America
7. Middle East
8. Africa
9. Southeast Asia
10. China

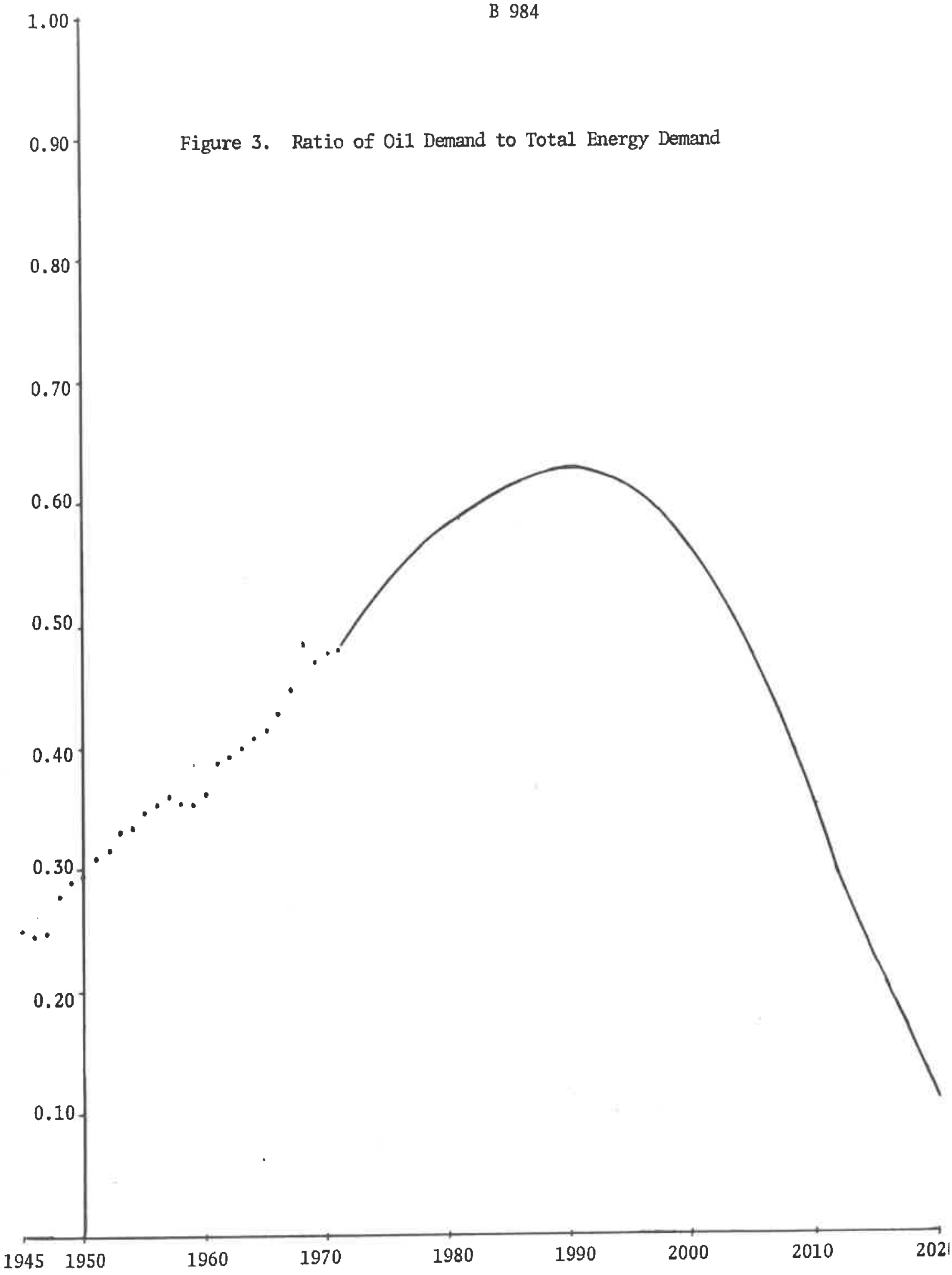


Figure 3. Ratio of Oil Demand to Total Energy Demand

had in 1970 (the base year for the model) a different ratio of oil to total energy consumption than the world value. Thus in order to project oil demand for each region individually, the world curve was shifted upward or downward to pass through the empirical value for 1970.

2.2 Oil Supply

Oil supply for any year is equivalent to oil production capacity, minus any regional production restrictions. Oil capacity in each of the 10 regions has increased at very different annual rates. Although the rate of oil production capacity increase is a scenario variable, the rates of the last decade from the basis for the unmodified projection scenario. Supply elasticity with price will be discussed below.

Naturally, oil production cannot increase indefinitely. Eventually, reserves of the region will near depletion and rates of oil discovery will fall. As ratios of known reserves to annual production begin to decrease, they will dampen investment in energy production capability, eventually leading to decreases in that production.

The major uncertainty in the process is the level of ultimate oil reserves. Geologists have repeatedly made such estimates and repeatedly been wrong. Oil companies are now reprinting advertisements they ran in the 1930s suggesting the near exhaustion of oil--this, of course, was before the major Texas oil discoveries. After hearing "wolf" so frequently, we all treat ultimate reserve estimates gingerly. Presumably, however, the world-wide oil searches and geological exploration of the last decades do allow greater precision in our guesses than earlier. That may explain convergence of estimates of ultimate recoverable world petroleum reserves within the range of two to four trillion barrels.[3] Of this, about 240 billion have already been used and another 780 billion are proved or known recoverable reserves[4]. Reserve estimates depend on assumptions about the efficiency of the extractive process -- presently only about 30% of the oil in place is removed. The above projections assume higher prices and better technology leading to around 40% oil recovery and as much as 60%. Reserve assumptions also depend on the classification of oil in oil shale and tar sands. Now that prices have climbed dramatically, many economic restrictions have been lifted on the exploitation of marginal oil, and we will work with alternative reserve estimates in the three to four trillion barrel range.[5]

2.3 World Oil Balance

Given the oil demand and supply projections, each region will be either a deficit or a surplus region. As Figure 1 suggests, the two types of regions must be treated separately. Any one region can move, of course, between categories over time. The surplus regions are assumed to completely satisfy their own consumption needs first. This is not strictly true--for instance, Latin America is a net exporter of oil because largely of Venezuela, while some countries in South America import Middle Eastern oil. On the whole, however, the assumption holds.

After regional needs are met, surplus oil is available for export (remember that supply limitations are dealt with prior to determination of the final oil supply figure). All deficit nations are assumed to want to import up to the total amount of the deficit, unless as in the case of an independence scenario, an effort is being made to avoid imports. If total world import demand exceeds total world export supply, the unfilled import demand is distributed among all importing countries proportionally to the size of the import demand. This procedure assumes no preferential treatment, selective embargoes, or differential ability to pay in a free market. In so assuming, it significantly and quite reasonably simplifies the model. If total world export supply exceeds total world demand, exports are increased at less than maximum rates. The reduction in capacity or capacity increase is distributed to all exporting regions proportionally to the magnitude of exports.

2.4 Oil Price

It is quite difficult to make accurate statements, much less projections about the price/barrel of oil, and will remain difficult until the present situation stabilizes. In less than five years Middle Eastern oil has increased in selling price from a little over a dollar/barrel to over $10 and as much as $15/barrel in private auctions. North American oil has been significantly costlier to produce and higher priced until recently--the price has incareased from about $3.50/barrel to $5.50 in the same period of time.

In the model computation of oil price, focus has been placed on revenues accruing to the Middle Eastern nations. Since they will remain the dominant exporters, they will largely determine prices. Moreover, it is their accumulated capital which threatens the international monetary order, so that we want the best possible picture of that accumulation. Table 1 shows the revenues accruing to the Middle East per barrel of oil up to 1972. Table 2 shows the resultant capital flows to the Mideast.

The Middle East has clearly proven that oil price is a manipulable variable and thus should be a scenario variable. For the unmodified projection run of the model, oil price for imported oil between 1970 and 1974 is set at the empirical level of royalties and taxes flowing to the Middle East upon the sale of each barrel of oil; after 1974 an annual (non-inflated) increase of 3% is assumed up to a level which maximizes economic growth and capital accumulation of the Mideast. An analysis of this level will be made later.

The "price" of a barrel of oil in 1974 (actually the revenues accruing to the Middle East) was set at $7.00. This is very much lower than the $11.65 posted price of Persian Gulf oil at the beginning of 1974. The posted price, however, means little--it is simply used to calculate royalties and taxes. The Middle Eastern oil exporters consciously set the posted price about 40% higher than the market price at the October, 1973 OPEC Conference[7]. The market price incorporates about $.15 production costs/barrel, about $.50 oil company profits, and the rest is essentially royalties and taxes--about $7.00/barrel. Naturally, all prices and revenue figures are deflated to 1963 prices so that they are comparable to the economic model. Ownership of the major oil companies lies in the hands of Western developed nations, so that profits, and a large proportion of

Table 1. Payments to Major Oil Exporters (cents per barrel of export)

YEAR	KUWAIT	SAUDI ARABIA	IRAN	IRAQ	ABU DHABI	QATAR	OTHERS	TOTAL MIDDLE EAST	LIBYA	TOTAL ME & LIBYA	ALGERIA	NIGERIA	VENE-ZUELA
1955	76.7	82.1	81.8	86.2		83.6	81.8	81.1		81.1			80.7
1960	76.5	75.0	80.1	78.6		86.4	79.3	77.5		77.5			89/2
1961	74.4	75.5	75.8	76.5		83.0	79.3	75.6	62.7	75.6			93.0
1962	74.8	76.5	74.5	76.7	50.9	82.3	79.3	75.7	64.7	75.4			97.2
1963	74.3	78.7	79.7	80.7	36.4	84.2	79.3	77.7	65.1	76.9			98.6
1964	76.9	82.0	80.9	80.1	18.2	84.4	79.9	78.3	62.9	76.7			95.4
1965	78.9	83.2	81.1	81.7	32.5	82.2	80.8	79.5	83.8	80.0			95.6
1966	78.4	83.4	81.4	81.3	75.3	87.3	84.5	81.1	87.0	81.9			95.8
1967	79.3	84.8	82.9	85.2	76.3	87.2	52.3	82.2	101.6	85.1			102.2
1968	80.5	87.8	83.7	90.7	84.5	88.1	72.4	85.0	100.7	87.9	90.3		101.4
1969	80.8	87.1	80.9	91.4	87.3	91.9	77.9	84.3	100.0	87.6	90.4		103.5
1970	82.2	88.3	86.2	95.7	92.0	91.5	83.5	87.4	109.0	91.7	90.7	109.3	109.2
1971	119.7	125.9	124.6	141.5	127.2	126.4	110.1	125.5	178.6	133.3	126.8	172.2	141.1
1972	140.9	143.7	135.8	150.7	143.4	144.5	120.6	140.7	196.6	147.2	187.7	187.0	171.9
TOTAL 1963-1972	91.6	102.1	98.2	105.5	99.0	101.4	91.5	97.7	119.1	101.0			111.2

Source: Zuhayr Mikdashi, "Cooperation Among Oil Exporting Countries with Special Reference to Arab Countries," International Organization, Vol. 28, No. 1 (Winter 1974), pp. 21, 22.

Table 2. Payments to Major Oil Exporters (in million dollars)

YEAR	KUWAIT	SAUDI ARABIA	IRAN	IRAQ	ABU DHABI	QATAR	OTHERS	TOTAL MIDDLE EAST	LIBYA	TOTAL ME & LIBYA	ALGERIA	NIGERIA	VENE-ZUELA
1955	307.0	287.8	90.5	206.5		34.1	9.0	934.9		934.9			596
1960	465.2	355.2	285.3	266.3		54.0	13.0	1,439.0		1,439.0			877
1961	464.3	400.2	301.2	265.5		53.3	13.0	1,497.5	3.2	1,500.7			938
1962	526.3	451.1	333.8	266.6	2.8	55.8	13.0	1,649.4	38.5	1,687.9			1,071
1963	556.7	502.1	398.1	325.1	6.4	59.5	13.0	1,860.9	108.8	1,969.7			1,106
1964	655.0	561.0	469.7	353.1	12.4	65.5	14.3	2,131.0	197.4	2,328.4			1,122
1965	671.1	655.2	522.4	374.9	33.2	68.5	16.4	2,341.7	371.0	2,712.7			1,135
1966	707.2	776.9	593.4	394.2	99.8	92.1	18.5	2,682.1	476.0	3,158.1			1,112
1967	717.6	852.1	736.7	361.2	105.0	101.8	23.6	2,898.0	631.0	3,529.0	191.1		1,254
1968	765.6	965.5	817.1	476.2	153.2	109.5	83.1	3,370.2	952.0	4,322.2	261.8		1,253
1969	812.2	1,008.0	937.8	483.5	191.1	115.2	118.2	3,666.0	1,132.0	4,798.0	298.8		1,289
1970	895.1	1,199.7	1,136.3	521.2	233.1	122.0	150.2	4,257.6	1,294.8	5,552.4	325.0	411.0	1,406
1971	1,399.8	2,148.9	1,944.2	840.0	530.7	197.8	192.6	7,154.0	1,766.0	8,920.0	350.0	915.0	1,702
1972	1,656.8	3,106.9	2,379.8	575.0	550.9	254.8	222.6	8,746.8	1,598.0	10,344.8	700.0	1,174.4	1,948
TOTAL 1963-1972	8,837.1	11,776.3	9,935.5	5,049.4	1,815.8	1,186.7	852.5	39,108.3	8,527.0	47,635.3			13,327

Source: See Table 1.

operating costs returns to those countries from oil expenditures. In 1972 it was estimated that U.S. oil company investments in the Middle East contributed $2 billion to the U.S. balance of payments, even after U.S. imports from the region and oil company expenditures.[8]

The $7.00/barrel price figure only represents Middle Eastern revenues. It cannot be used to accurately determine outflows/barrel of imports for any one region. For the U.S., Britain, and the Netherlands, the net cost is lower, because their oil companies profit on sales of oil throughout the world. Those nations with shipping industries also benefit from transportation of oil throughout the world. For most regions, particularly the underdeveloped regions who must pay the $7.00/barrel Middle Eastern fee, the oil company profits, and transportation costs, the total drain on resources is significantly underestimated by the $7.00/barrel price.

In sum, the discussion that follows will focus on price from the Mideast point of view (taxes and royalties). That price, whether $7.00 or whatever, will be used as a surrogate and reasonably accurate measure for all per barrel capital flows among all regions. The import of these flows on economies will be discussed below. The discussion will turn now to the policies available to deficit and surplus regions and the impact of these policies on the rest of the model.

2.5 Deficit Regions

Figure 1 shows the 5 policies which deficit regions have available to them: conservation or demand reduction, accepting an oil deficit, importing, striving for regional independence, or retaliation against the oil exporting regions by raising investment good prices. Let us look at each in turn.

2.5.1 Conservation

Conservation policies need no explanation. Regions can through conservation reduce total energy demand without an impact on economic growth. This has a duel impact on oil demand, reducing it directly, and freeing other energy for substitution when oil deficits occur. In the current model some conservation occurs automatically as a result of unfilled deficits; that is, energy demand is reduced a fraction of the deficit size. Such conservation is assumed to be short-term, and disappears with the deficits. More significant reduction of demand for oil occurs as a policy within regions. The mechanism for introduction of conservation is manipulation of Linden's curve. A factor for reduction of Linden's curve can be introduced along with the number of years before maximum reduction occurs. The model then gradually reduces oil demand from Linden's curve (shifted to represent initial regional differences) until the full impact of the reduction is felt in the year specified and each year thereafter. This mechanism can be used also to change the initial shape of the oil demand/energy demand ratio away from that specified by Linden.

2.5.2 Unfilled Deficits

This is a non-policy or residual policy most of the time, but when world export supply falls far behind world import demand it can occur in spite of the efforts by regions to reduce demand or increase supply. It has a direct impact on economic growth. The relation described earlier (see Figure 2) between energy need and economic size is used to compute the impact of an energy deficit on economic growth. Economic growth is then reduced to the level allowed by the energy available. The mechanism for manipulating economic growth is the investment rate and that of course cannot fall below zero. If the deficit is so large that investment falls to zero, depreciation of capital in the economy will result in a slight negative growth rate.

2.5.3 Imports

Imports are the primary mechanism for dealing with oil deficiencies. When imports are relied upon, a debt is incurred to oil exporting regions. The payment of this debt will affect the economy of the importer. The impact will vary depending upon the type of repayment requested by oil exporters. Economists are still struggling with the full implications of the large monetary and good transfers. Figure 4 may assist in explaining how the oil model deals with these transfers. Exporting regions have three basic choices in using their earnings. First, they can increase their internal economic investment, which will require significant imports of investment goods. Second, they can increase immediate consumption, importing consumer goods. Third, they can invest their money, accumulating external resources such as land, stocks, gold, etc. Importing regions will be affected in three parallel areas: the production and use of consumer and investment goods and the ownership of capital and other resources. The exact impacts are very complex, however, and do not by any means fall only on the diagonal of Figure 4. To simplify somewhat we can break the money flowing from importing to exporting regions down into two categories.

	Importer Economies		
Exporter Decisions	Sell Consumer Goods	Sell Investment Goods	Give up Ownership of Capital
Consumption Increase			
Investment Increase			
Buy External Capital			

Figure 4

First, a portion of that money will return as demand for goods and services, either consumer or investment. This money will thus reduce the domestic availability of goods. The ultimate impact will be to reduce domestically available consumer goods, whether the exporting region demand is for consumer or investment goods. If the external demand is immediately met by reduction of internal consumption this will clearly be true; if the external demand for goods is partly met by a reduction in internal investment, the impact on consumer goods will be less immediate, but greater in the long run because the economy will not grow as fast. The "strategy" of payment by importing regions will be in large part a question of the political acceptability of reduced income and will vary by region. The oil model subtracts a fraction of this reduced good availability from investment and its complement from consumption of the importing regions. The faction is a scenario variable.

The second general category for the money flowing out of importing regions is money that returns not as demands for goods and services, but as payment for land, stock, and other "capital." This money does not compete for or reduce domestically available goods. Its impact on the availability of such goods might actually be to increase them somewhat as it involves an internal transfer of purchasing power from those who spend high portions of their income (oil purchasers) to those (investment holders) who spend lessor portions. These investments by the Middle East will stand as long term claims upon goods and services of the importing regions, however, and eventually may reduce goods available for consumption.

There has been speculation lately that some money taken out would not return to the oil importing regions, leading even to fears of decreased total money supply and deflation. These speculations hinge on reports of Arab purchases of gold and their placement of large amounts of funds in Swiss and other banks. Yet someone presumably sells the Arabs whatever gold they buy and someone presumably borrows the funds the Swiss banks loan out (if greater loan availability drives interest rates down the banks will invest in higher profit enterprises like oil production). We are not, after all, speaking of amounts of money which can be accepted in currency, hidden under a mattress, and removed from circulation. The money flows distort many monetary structures, but the money does not disappear.

The discussion above did not recognize any distinction between demand by the Mideast for investment goods and demand for consumer goods. The former is more likely at least in the short run than the latter to reduce the level of investment in the economy. In the long run, increased production of investment goods, at the expense of consumer goods, could maintain a high level of investment in oil importing countries, but consumer political strength may retard such a change in production patterns. Thus we do differentiate in the model between the two types of Mideast demand, and our scenarios for economic impact of the monetary transfers assume a greater impact on investment of demand for investment goods than of demand for consumption goods.

A major economic impact issue has been ignored here. Importing regions will be affected differently because the returning capital may not equal the exiting capital--that is, there will be inter-regional transfers among oil importing regions. In this case, for example, inflationary and deflationary affects are possible. The analysis of this issue will require, however, a considerably more complicated monetary sector model than is now available.

2.5.4 Independence Policies

Scenarios for importing regions include movements to increase energy production. There are three variations of these scenarios.

First, regions may strive for complete independence from external energy resources. This is clearly most likely in the case of North America. Second, they may strive not for complete independence, but to increase production sufficiently to avoid actual energy deficits (oil demand which world supply cannot fill). This might be a likely policy for Western Europe or Japan--it would require relatively moderate investments as long as Middle Eastern oil was available, but extensive ones during Mideast cut-backs or in the 21st Century as Mideast oil runs out. The third variation of these policies does not focus on a specific output target, but rather requires an annual investment in energy production of an amount determined by the region (say $5 billion annually for Western Europe). The actual energy produced would depend on the type of energy system (e.g. nuclear or coal) invested in.

All approaches to increased domestic energy production require a specification of the energy system desired. It is assumed that parallel changes will be made on the demand side of the energy system so that substitution of the increased production for oil will be possible. Our standard scenario assumes that 10% of the increased production will be oil, 80% coal, and 10% nuclear. A full energy system based on Hartmut Bossel's energy supply model will later replace this approach.[9]

The increased investment has a cost. This cost must be balanced against the cost of crude oil landed in a coastal port. Since such imported crude oil would need to be refined and transmitted to users, costs of coal or nuclear generated electricity to users are not strictly comparable. A better comparison is with the fuel costs of coal and nuclear energy plus the investment cost in generating plants. In other words, operating costs of the additional plants (coal liquifaction or gassification as well as electric generating) and fuel transmission costs are assumed to be costs that would be borne by the economy even if oil were imported: we are interested in seeing the <u>additional</u> investment costs and balancing these against the costs to the economies of imported oil.

Table 3 shows the energy costs per barrel of energy equivalent for coal and nuclear energy increases, assuming only electric generation processes and not other energy systems. These costs are from U.S. sources and characterize U.S. resources. They underrepresent equivalent costs in most regions of the world. Since North America is the region whose independence opportunities we wish most to examine, this presents no great source of error. The cost for increased oil production has been set at \$1.05/barrel. As in the case of other fuel types, life span of such oil capacity has been considered in arriving at that fiture. One source puts the cost/annual barrel of new wells at about \$4.11, implying an average of approximately four years well life.[10]

All of these costs may seem low. The reader must remember that these costs are for an energy rich area, the U.S. He must also remember that these costs are per unit of energy and not for ongoing capacity--thus these costs are incurred every year in which increased production is desired. Time lags for production capacity increase are not explicitly treated here, but are implicitly handled by restricting the size of annual increases in production. North America is not allowed to achieve independence at any cost in less than 10 years and may achieve it more slowly.

The costs of increased production, like those of imports, are the competing demand of that capacity for consumer and investment goods. The proportions which come from each are scenario variables.

Table 3: Costs of Additional Energy Production

	Coal	Nuclear
Fuel costs/ barrel equivalent	$1.36	$ .86
Fuel costs assuming 30% generating efficiency	4.08	2.58
Investment cost/ annual barrel equivalent for electric generating capacity	21.00	49.40
Investment cost/ annual barrel equivalent assuming 20 year life	1.05	2.50
Annual cost/barrel equivalent	5.13	5.08

Source: Associated Universities, Inc., Reference Energy Systems and Resource Data For Use in the Assessment of Energy Technologies (April, 1972).

2.5.5 Retaliatory Policy

Much discussion of oil consumer cartels has occurred since the success of OPEC in raising oil prices by a factor of four. Although most discussions conclude that retaliation of any type is unlikely and almost certainly unsuccessful, it merits discussion as a potential policy.

Perhaps the spot in the Middle Eastern economy most vulnerable to feedback from the importing nations is the need to import investment goods. Other imports (food, raw materials, etc.) can be secured elsewhere in the world, but high technology investment goods can only come from the Western developed economies, the principal customers of the Mideast.

If the price of these investment goods became tied to the price of oil (or was elastic with it), this would greatly affect the growth of capital accumulation of the Middle East. Such a relationship between the two prices might be retaliation of a consumers cartel, might come about by individual action or financially pressed oil importers, or might be a price distortion as a result of the energy intensiveness of investment goods. We are not, however, talking about an inflationary rise in investment good prices, since the model is in constant 1963 dollars. The price rise would be a relative rise. The implications of such a price relationship will be explored later.

2.6 Surplus Regions

Surplus regions also must make many political decisions. These include the price of oil, since they are unlikely to leave this to market mechanisms and see the price fall to $1/barrel.[11] They also include possible limitations of productive capability, to protect both prices and reserves. Finally, the oil exporting regions must spend their revenues. As noted in the previous section, they can invest these in economic growth, buy consumer goods, and if their revenues are sufficiently large, they can invest outside of the region.

2.6.1 Price Manipulation

The MIddle East and North African region has very considerable control over the price it sets for oil. Chapter 3 will analyze the impact on the Middle East and other regions of various prices. In this section we will look only at the mechanisms related to price in the model.

Historic prices underly the model's operation up to 1975. The basic price in 1975 is $7.21, assuming a 3% increase over 1974. Of course this is deflated to 1963 prices. After 1975 the price grows at an annual rate set by scenario, up to an upper limit also set by scenario.

The price of oil underlies all computations of the dollar value of imports and exports. It affects supply via a supply elasticity supplied by scenario. Supply capacity in any region equals previous supply capability plus normal growth and plus supply increases or decreases with price. This last term utilizes standard elasticity of supply computations where the percentage change in supply equals the percentage change in price times the elasticity factor.

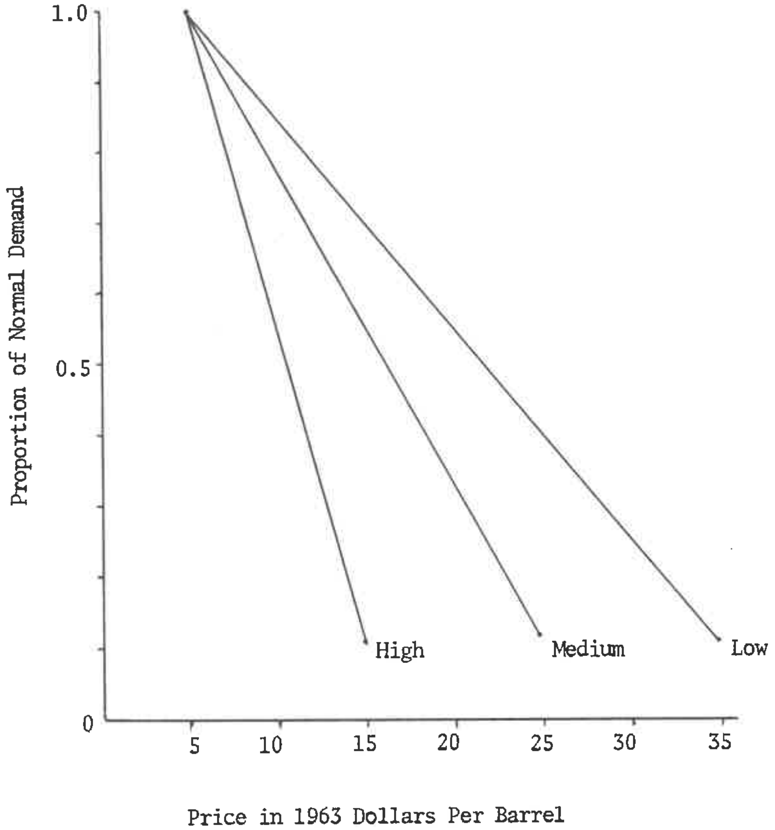
The price of oil also affects demand via a similar but different mechanism. Rather than providing a factor for elasticity of demand, we provide parameters which determine a pattern of demand like that shown in Figure 5. The lines in Figure 5 show us the proportion of normal demand (as specified by Linden's curve, its regional specification, and any modifications of it for conservation) which will exist at any price level. Demand is always "normal" at $5/barrel. This is a price below which demand is unlikely to be greatly affected and other fuels are essentially uncompetitive with oil. The line slopes downward from that point to whatever price at which we feel demand will be reduced to only 10% of normal demand.

The reason that a more complicated approach has been adopted for energy demand elasticity than for energy supply elasticity is that energy demand elasticity is more complicated. There are at least two elements, first the overall reduction in oil and energy demand which results from increased oil prices and second the shift of oil demand to demand for other fuels. This last factor, substitution, involves the supply positions of other energy types and the flexibility of energy use systems. The model will later be coupled to the energy supply model of Hartmut Bossel, and the oil demand elasticity will be an important interface.

2.6.2 Production Limitation

This policy needs no explanation. The Mideast region can place any desired upper limit on oil production. Use of this as a scenario must be cautious, because domestic oil demand in the Mideast grows steadily, and a limit which is too low can result in neglible exports by the early 21st century.

Figure 5. Oil Demand Elasticity



	High	Medium	Low
Elasticity	.45	.225	.15
Slope	- .09	- .045	- .03
Intercept	1.45	1.225	1.15

2.6.3 Oil Revenue Expenditure

There is no reason to repeat the discussion of Section 2.5.3 detailing the possibilities for interregional exchange of funds and the impact of these exchanges on oil importing countries. We should briefly discuss, however, the impact on oil exporting countries.

The model assumes that the first priority in the use of oil revenues is to supplement internally generated investment funds. A limit is placed on the rate of growth which can be obtained; in normal scenarios the Middle East is not allowed to grow at more than 9% annually. The more economically developed and complicated a society is, the more limited an annual growth it can attain, so the upper limit is reduced with growth in GRP/capita. The upper limit begins to decline at $1500/capita and reaches 4.5% at $2500/capita.

Oil generated funds available after investment is increased are divided between immediate consumption and savings. This division is scenario dependent. Consumption expenditure increases immediate consumption, but has no long term impact on the oil exporting region's economy. Savings are assumed to be invested externally and the amount of such investment is monitored. The investment presently neither grows nor depreciates, and some net growth would probably better represent its amount.

2.7 Final Comments

The oil model presented here is more detailed than any other world model.[12] The actual equations can be seen in the listing that follows--a variable dictionary supplements the listing. Two areas exist in which future improvement can and will occur. First, a more detailed monetary sector is desireable. This will also be necessary for other models within the world model project, like the food model. The mechanisms of international good and capital flow should be better represented. Second, no energy type can be examined outside of the entire energy system. Although conscious effort has been here made to represent the central elements of the rest of the energy system, interfacing with Hartmut Bossel's model and future energy model developments is highly desireable.

FOOTNOTES FOR CHAPTER 2

[1] For a full description of the energy demand function and its derivation see Rolf Banerschmidt, Hartmut Bossel, Nhan Chu, Richard Denton, Barry Hughes, and H. Henning Maier, Energy Models: Resources Demand Supply, World Model Report for May 1974 IIASA Conference.

[2] J.D. Parent and H.R. Linden, "A Study of World Crude Oil Supplies," Institute of Gas Technology, mimeo, undated. Actually, the curve they present is the ratio of oil production to energy production, with the assumption on a world basis that production and consumption will be equal. See also H.R. Linden, "Review of World Energy Supplies," paper presented at the 12th annual Congress Mondial An Laz, Nice, 1973.

[3] One of the most useful discussions of ultimate reserves is in M. Hubert King, "The Energy REsources of the Earth," in *Energy and Power*, a Scientific American Book (San Francisco: W.H. Freeman and Co., 1971), pp. 31-43. See also N.B. Anyol, "World Energy Requirements and Supplies, 1970-2000, a Dialogue Discussion Paper at the Center for the Study of Democratic Institutions; Corrado Mazzolini, "Remarks on Liquid Fuel Prospects," Technological Forecasting Dept., Montedison, Milan, Italy; Lewis Weeks, "World Offshore Petroleum Resources," *AAPG Bulletin* 49: 1680-1693.

[4] Parent and Linden, *op. cit.*

[5] For the most part specification of regional reserves was taken from the W.P. Ryman data reported in King, *op. cit.* These data were supplemented by various data sources including U.S. Department of Interior, *U.S. Energy: A Summary Review*, 1972.

[6] *Plain Dealer*, December 24, 1973, p. 1.

[7] *New York Times*, October 19, 1973, p. 61.

[8] Foreign Policy Association, *U.S. Foreign Policy: 1972-1973* (New York: Collier Books, 1972), p. 37.

[9] See Bauerschmidt, *et. al.*, *op. cit.*

[10] M.A. Adelman, *The World Petroleum Market* (Baltimore: Johns Hopkins Press, 1972).

[11] Adelman, *op. cit.*, argues convincingly that the non-monopolistic price of oil is very low.

[12] The heretofore most fully developed world oil model has been that of Houtthaker and Jorgensen. Although we have not seen a detailed description of that model, the analysis provided in "The World Petroleum Model: An Overview" (March 13, 1974) suggests that it does not have as comprehensive a data base or as fully developed an economic base as the model described here. Nor does it focus as explicitly on other energy forms. A very useful review of energy models is Dilip R. Lirage, Robert Ciliano, and John R. Shanko, "Quantitative Energy Studies and Models," prepared for Council on Environmental Quality by Decision Sciences Corporation. See also Milton F. Seanl, ed., *Energy Modeling*, working papers for a seminar on Energy Modeling, Resources for the Future, Inc., March, 1973.

APPENDIX A: LISTING OF THE OIL MODEL

B 1oo9

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PAGE 001    04/04/74    OIL MODEL

110701 REMOVE,52,PERMAN
110703 COMPIL,52,PERMAN
       REAL L1,L2,L3,L4,L5                                              752       2
       REAL K,I,IR,LK,IRN                                               752       3
       REAL INDE,INDYE,IYRRE,LF                                         752       4
       REAL MECON,MECAPR ,MECON3                                        752       5
       DIMENSION K(10),SK(10),Y(10),Q(10),C(10),CR(10),I(10),IR(10),    752       6
     2  YI(10)                                                          752       7
       DIMENSION ECN(10),SECN(10),OP(10),SOP(10),P(10),SP(10),DY(10),   752       8
     2            OCK(10),OCKI(10),OCN(10),ROP(10),R(10),OMN(10),       752       9
     3   OXS(10),OXK(10),OX(10),OMK(10),OM(10),OMP(10),OXP(10),OC(10)752      10
       DIMENSION COP(10),OR(10),OPT(10),COPU(10),SOR(10)                752      11
       DIMENSION POP(10),POPR(10),SPOP(10),ODPC(10),ODACC(10),          752      12
     2   SODACC(10),EGR(10),IRN(10),IN(10),CAPTR(10),CAPUS(10),         752      13
     3   ECUNCO(10),CAPAC(10),OTHEN(10)                                 752      14
       DIMENSION OD(10),ODACPC(10),ODRY(10),YPC(10) ,SCAPAC(10)         752      15
       DIMENSION CAPAC2(10),CAPAC3(10),YG(10),ENDEF(10)                 752      16
       DIMENSION            ROCKL(10),IYRRE(10),OCKLR(10)               752      17
       DIMENSION FINDE(10),INDE(10),INDYE(10),SR(10),RI(10),R1(10),     752      18
     XLF(10),COO(10),COC(10),CON(10),PRMIX(5),ADIE(10), ENDE(10),       752      19
     XSOTHEN(10),ENIN(10),ADIED(10),ENDE2(10),CPC(10),CRN(10)           752      20
       DIMENSION YR(10),ADIEC(10),SADIEC(10),ENSHT(10),RECN(10)         752      21
       DIMENSION SRECN(10),OCKS(10),ENDEF2(10)                          752      22
       DO 1 IYR=1,NDT                                                   752      23
       CALL COMONI(IYR)                                                 752      27
       IC=0                                                             752      30
       ID=0                                                             752      33
       IF (IYR-1) 2,2,3                                                 752      36
C                                                                       752      44
C RESET                                                                 752      45
C                                                                       752      46
3      CONTINUE                                                         752      47
       BBR=SPRD                                                         752      49
       IF (PRI) 30,30,31                                                752      52
   31  PRO=PRI*DEFLF                                                    752      59
       GO TO 32                                                         752      63
   30  PRO=(1.+PROGR)*SPRO                                              752      65
   32  IF (UPLPR-PRO) 33,34,34                                          752      70
   33  PRO=UPLPR                                                        752      78
   34  SPRO=PRO                                                         752      81
       DO 10 J=1,10                                                     752      84
       ENDE(J)=0.                                                       752      88
       DTHEN(J)=SOTHEN(J)                                               752      92
       OTHEN(J)=0.                                                      752      95
       CAPAC(J)=SCAPAC(J)                                               752      98
       CAPUS(J)=0.                                                      752     101
       CAPTR(J)=0.                                                      752     104
       ADIEC(J)=SADIEC(J)                                               752     107
       EGR(J)=0.                                                        752     110
       K(J)=SK(J)                                                       752     113
       POP(J)=SPOP(J)                                                   752     116
       RECN(J)=SRECN(J)                                                 752     119
       ECN(J)=SECN(J)-RECN(J)                                           752     122
       R(J)=SR(J)                                                       752     126
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         P(J)=SP(J)                                              752     129
         P(J)=MIN1F(P(J),R(J))                                   752     132
         ODACC(J)=SODACC(J)                                      752     142
         OR(J)=SOR(J)                                            752     145
         OR(J)=MAX1F(0.0,MIN1F(OR(J),R(J)-P(J)))                 752     148
10       CONTINUE                                                752     164
         GO TO 4                                                 752     172
C                                                                752     174
C INITIALIZE                                                     752     175
C                                                                752     176
2        CONTINUE                                                752     177
         SUMRFS=0.0                                              752     179
         PRO=PRI*DEFLF                                           752     182
         SPRO=PRO                                                752     186
         BB=PRO                                                  752     189
         BHH=PRO                                                 752     192
         DO 8 J=1,10                                             752     195
         OTHEN(J)=0.                                             752     199
         R(J)=RI(J)*RESFAC                                       752     203
         SR(J)=R(J)                                              752     207
8        SUMRES=SUMRES+R(J)                                      752     210
         DO 9 J=1,10                                             752     222
         CAPAC(J)=0.                                             752     226
         CAPUS(J)=0.                                             752     230
         CAPTR(J)=0.                                             752     233
         ADIEC(J)=0.                                             752     236
         RECN(J)=0.                                              752     239
         SOP(J)=OP(J)/(1.0+ROP(J))                               752     242
         OR(J)=R(J)*780./SUMRES                                  752     249
         P(J)=R(J)*240./SUMRES                                   752     254
         R1(J)=R(J)-P(J)                                         752     259
         YPC(J)=YI(J)/POP(J)                                     752     263
         IF (J-5) 104,100,101                                    752     267
     101 IF (J-10) 104,100,104                                   752     275
     100 CALL DATATC(AL,YPC(J))                                  752     283
         GO TO 106                                               752     290
     104 CALL DATATR(AL,YPC(J))                                  752     292
     106 B=YI(J)*AL*4.931/1000.                                  752     299
         OCKI(J)=OCKI(J)*B/ECN(J)                                752     306
9        K(J)=O(J)*YI(J)                                         752     311
         CALL ENDEM(ECN,K,O,POP,LF)                              752     323
4        CONTINUE                                                752     330
         DEL=1.0-1.0/LK                                          752     332
         YTOT=0.0                                                752     340
C                                                                752     343
C OIL CONSUMPTION NEED AND PRODUCTION CAPABILITY                 752     344
C                                                                752     345
         DO 46 J=1,10                                            752     346
         ROCKL(J)=MIN1F(ROCKL(J),.15)                            752     350
         ZR=IYR                                                  752     359
         IF ( ZR-IYRRE(J)) 41,42,42                              752     363
      41 OCKLR(J)=OCKL-ROCKL(J)*ZR/IYRRE(J)                      752     371
         OCKLR(J)=MAX1F(0.,OCKLR(J))                             752     381
         GO TO 46                                                752     389
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   42 OCKLR(J)=MAX1F(0.,OCKL-ROCKL(J))                                752      391
   46 CONTINUE                                                        752      401
      DO 20 J=1,10                                                    752      409
      OCK(J)=MAX1F(0.0,MIN1F(1.0,OCKI(J)+OCKLR(J)-.48 ))              752      413
      OCKS(J)=OCK(J)                                                  752      429
      IF (SLOPF) 12,13,12                                             752      432
   12 OCK(J)=OCK(J)*(SLOPF*PRO+BPF)                                   752      439
      OCK(J)=MAX1F(OCK(J),0.)                                         752      446
   13 OCN(J)=OCK(J)*FCN(J)                                            752      454
      COP(J)=(1.+ROP(J)+(PRO-BBB)/BBB*ELAS)*SOP(J)                    752      459
      COP(J)=MIN1F(COP(J),OR(J))                                      752      470
      OCN(J)=OCN(J)*1.053                                             752      480
      ENDEF2(J)=(OCKS(J)-OCK(J))*ECN(J)*((OCN(J)-COP(J))/OCN(J))*FPRO752      484
   20 ENDEF2(J)=MAX1F(0.,ENDEF2(J))                                   752      495
C                                                                     752      511
C ECONOMIC MODEL                                                      752      512
C                                                                     752      513
  160 DO 26 J=1,10                                                    752      514
      SPOP(J)=(1.0+POPR(J))*POP(J)                                    752      518
      Y(J)=K(J)/Q(J)                                                  752      524
      YTOT=YTOT+Y(J)                                                  752      528
      C(J)=Y(J)*CR(J)-ADIED(J)*(1-FINDE(J))                           752      532
   26 I(J)=Y(J)*IR(J) -ADIED(J)*FINDE(J)                              752      545
   27 DO 11 J=1,10                                                    752      564
      L3=1.-L1                                                        752      568
      L4=1.-L2                                                        752      572
      FA=MAX1F(0.,CAPTR(7)-CAPUS(7))                                  752      576
      I(J)=I(J)-L1*CAPUS(7)*OMK(J)-L2*FA*L5*OMK(J)                    752      585
      C(J)=C(J)-L3*CAPUS(7)*OMK(J)-L4*FA*L5*OMK(J)                    752      601
      IF (I(J)) 5,6,6   ,                                             752      616
    5 C(J)=C(J)+I(J)                                                  752      623
      I(J)=MAX1F(I(J),0.)                                             752      628
    6 SK(J)=DEL*K(J)+I(J)                                             752      636
11    CONTINUE                                                        752      642
      SK1=SK(2)                                                       752      650
      CALL ENDEM(SECN,SK,Q,SPOP,LF)                                   752      653
      IF (ID-1) 152,36,36                                             752      660
C                                                                     752      668
C OIL IMPORT AND EXPORT                                               752      669
C                                                                     752      670
  152 SUMREM=0.0                                                      752      671
      SUMCOP=0.0                                                      752      674
      SUMOR=0.0                                                       752      677
      DO 7 J=1,10                                                     752      680
      SUMREM=SUMREM+R(J)-P(J)-OR(J)                                   752      684
      SUMCOP=SUMCOP+COP(J)                                            752      691
    7 SUMOR=SUMOR+OR(J)                                               752      695
      OMNW=0.0                                                        752      707
      OXSW=0.0                                                        752      710
      IF (OCN(7)-SQUE) 50,50,51                                       752      713
   51 COP(7)=MIN1F(OCN(7),COP(7))                                     752      721
      GO TO 21                                                        752      727
   50 COP(7)=MIN1F(COP(7),SQUE)                                       752      729
   21 CONTINUE                                                        752      735
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B 1o11

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      SUMCOP=0.                                                    752    737
      DO 25 J=1,10                                                 752    740
      SK2=SK(2)                                                    752    744
      SUMCOP=SUMCUP+COP(J)                                         752    747
      OMN(J)=MAX1F(0.0,OCN(J)-COP(J)-OTHEN(J))                     752    752
      OMNW=UMNW+OMN(J)                                             752    762
      OXS(J)=MAX1F(0.0,COP(J)-OCN(J))                              752    766
      OXSW=UXSW+OXS(J)                                             752    775
   25 CONTINUE                                                     752    779
      OXNW=OMNW                                                    752    787
      OXW=0.0                                                      752    790
      SUMREM=MAX1F(0.0,SUMREM)                                     752    793
      RD=  SUMCOP*SUMREM/SUMRES*3.8                                752    799
      RD=(46.+IYR*5.)*(SUMREM/(SUMRES-1020.))                      752    805
      SUMOP=0.0                                                    752    818
      DO 23 J=1,10                                                 752    821
      OXK(J)=OXS(J)/OXSW                                           752    825
      OXK(J)=MIN1F(1.0,OXK(J))                                     752    830
      OX(J)=OXK(J)*UXNW*OXSCEN                                     752    838
      OX(J)=MIN1F(OX(J),OXS(J))                                    752    843
      OXP(J)=PRU*OX(J)                                             752    853
      OP(J)=MIN1F(COP(J),OCN(J)+OX(J))                             752    857
      SUMOP=SUMUP+OP(J)                                            752    868
      SOR(J)=OR(J)-UP(J)+RD*(R(J)-OR(J)-P(J))/SUMREM               752    872
      OPT(J)=UR(J)/UP(J)                                           752    883
      COPU(J)=MIN1F(1.0,OPT(J)/5.)                                 752    887
      SOP(J)=OP(J)*CDPU(J)                                         752    896
      SP(J)=P(J)+OP(J)                                             752    900
      OXW=OXW+OX(J)                                                752    904
23    CONTINUE                                                     752    908
      OMW=OXW                                                      752    916
      DO 224 J=1,10                                                752    919
      OMK(J)=OMN(J)/OMNW                                           752    923
      OMK(J)=MIN1F(1.0,UMK(J))                                     752    928
      OM(J)=OMK(J)*UMW                                             752    936
      OM(J)=MIN1F(OM(J),OMN(J))                                    752    940
      OP(J)=MIN1F(OP(J),COP(J))                                    752    950
      OC(J)=OP(J)+UM(J)-OX(J)                                      752    960
      OMP(J)=PRO*UM(J)                                             752    965
      ODPC(J)=(UXP(J)-OMP(J))/POP(J)*1000.                         752    969
      SODACC(J)=(OXP(J)-OMP(J))        +ODACC(J)                   752    975
      OD(J)=OXP(J)-OMP(J)                                          752    980
      ODACPC(J)=ODACC(J)/POP(J)*1000.                              752    984
      YPC(J)=Y(J)/POP(J)*1000.                                     752    989
      ODRY(J)=OUPC(J)/YPC(J)                                       752    994
      YR(J)=IYR                                                    752    998
  154 YR(J)=INDYE(J)                                               752   1002
      IF (YR(J)-INDYE(J)) 155,155,154                              752   1006
  155 ENDE2(J)=(OMN(J)-OTHEN(J))*(YR(J)/INDYE(J))                  752   1014
      ENDE2(J)=MAX1F(ENDE2(J),0.)                                  752   1023
  224 ENDEF(J)=MAX1F(0.,OMN(J)-OM(J)-OTHEN(J))+ENDEF2(J)           752   1031
      IC=IC+1                                                      752   1050
      IF (IC-1) 119,119,151                                        752   1054
C                                                                  752   1062
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B 1o12

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C INDEPENDENCE: CAPITAL SHIFT (OPTIONAL)                                752     1063
C                                                                       752     1064
  119 DO 150 J=1,10                                                     752     1065
      IF (INDE(J)) 150,150,120                                          752     1069
  120 II=INDE(J)                                                        752     1077
      GO TO (125,135,145,125,135,145),II                                752     1085
  125 ENDE(J)=(OMN(J)-OTHEN(J))*(YR(J)/INDYE(J))                        752     1095
      ENDE(J)=MAX1F(ENDE(J),0.)                                         752     1104
      GO TO 136                                                         752     1112
  135 ENDE(J)=ENDEF(J)                                                  752     1114
  136 OTHEN(J)=OTHEN(J)+ENDE(J)*(1.-PRMIX(1))                           752     1118
      COP(J)=COP(J)+ENDE(J)*PRMIX(1)                                    752     1125
      ADIE(J)=ENDE(J)*(COO(J)*PRMIX(1)+COC(J)*PRMIX(2)+CON(J)*          752     1130
     XPRMIX(3))                                                         752     1131
      GO TO 147                                                         752     1144
  145 ENIN(J)=ADIE(J)/(COO(J)*PRMIX(1)+COC(J)*PRMIX(2)+                 752     1146
     XCON(J)*PRMIX(3))                                                  752     1147
      OTHEN(J)=OTHEN(J)+ENIN(J)*(1.-PRMIX(1))                           752     1163
      COP(J)=COP(J)+ENIN(J)*PRMIX(1)                                    752     1169
  147 ADIED(J)=ADIE(J)                                                  752     1174
      ADIEC(J)=ADIEC(J)+ADIE(J)                                         752     1178
      SADIEC(J)=ADIEC(J)                                                752     1182
  150 SOTHEN(J)=OTHEN(J)*DEPEN                                          752     1185
      RCC=0.                                                            752     1197
      DO 153 J=1,10                                                     752     1200
      RCC=RCC+INDE(J)                                                   752     1204
      IF (INDE(J)-3.) 153,153,160                                       752     1209
  153 CONTINUE                                                          752     1217
      IF (RCC) 151,151,152                                              752     1225
  151 CONTINUE                                                          752     1232
      SK3=SK(2)                                                         752     1234
C                                                                       752     1237
C SQUEEZE:  ECONOMIC IMPACT OF OIL DEFICITS (OPTIONAL)                  752     1238
C                                                                       752     1239
      IF (SQUEEZ-1.)  24,22,24                                          752     1240
   22 DO 225 J=1,10                                                     752     1248
      DY(J)=(SK(J)-K(J))/Q(J)                                           752     1252
      DY(J)=DY(J)-ENDEF(J)/LF(J)*FBF                                    752     1258
      RECN(J)=ENDEF(J)*FBF*ECF+RECN(J)*ESF                              752     1267
      SRECN(J)=RECN(J)                                                  752     1276
      EGR(J)=DY(J)/Y(J)                                                 752     1279
      IRN(J)=(EGR(J)+1./35.)*(Q(J))                                     752     1283
      IRN(J)=MAX1F(0.,IRN(J))                                           752     1289
      CRN(J)=CR(J)+IRN(J)-IR(J)                                         752     1297
      C(J)=CRN(J)*Y(J)                                                  752     1302
      I(J)=IRN(J)*Y(J)                                                  752     1306
  225 SK(J)=DEL*K(J)+I(J)                                               752     1310
      SK4=SK(2)                                                         752     1323
      CALL ENDEM(SECN,SK,Q,SPOP,LF)                                     752     1326
24    CONTINUE                                                          752     1333
      IF (YPC(7)-1500.) 60,60,61                                        752     1335
   60 GMEMAX=GMEMAI                                                     752     1343
      GO TO 64                                                          752     1346
   61 IF (YPC(7)-2500.) 62,63,63                                        752     1348
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B 1o13

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   62 GMEMAX=GMEMAI*(1.-.4*(YPC(7)-1500.)/1000.)                     752     1356
      GO TO 64                                                       752     1367
   63 GMEMAX=.6*GMEMAI                                               752     1369
   64 CONTINUE                                                       752     1373
      ID=ID+1                                                        752     1375
C                                                                    752     1379
C COOPERATION:  CALCULATION OF EXPORTER CAPITAL ACCUMULATIONS (OPTION752     1380
C                                                                    752     1381
      IF (COOP-1.) 36,28,36                                          752     1382
   28 DO 35 J=1,10                                                   752     1390
      CAPTR(J)=OXP(J)-OMP(J)                                         752     1394
      IF (CAPTR(J)) 35,35,29                                         752     1399
   29 IRN(J)=(GMEMAX+1./35.)*Q(J)                                    752     1406
      IN(J)=IRN(J)*Y(J)                                              752     1413
      IN(7)=IN(7)*(1.+(PRO/BB-1.)*OK)                                752     1421
      CAPUS(J)=MIN1F(CAPTR(J),IN(J)-I(J))                            752     1436
      CAPUS(J)=MAX1F(CAPUS(J),0.)                                    752     1449
      CAPAC(J)=(CAPTR(J)-CAPUS(J)*PICEG)*(1.-L5)+SCAPAC(J)           752     1457
      SCAPAC(J)=CAPAC(J)                                             752     1470
      ECONCO(J)=CAPAC(J)/(K(1)+K(2)+K(3)+K(4))                       752     1473
      ECONCO(J)=MIN1F(1.,ECONCO(J))                                  752     1482
      I(J)=I(J)+CAPUS(J)                                             752     1490
      C(J)=C(J)+(CAPTR(J)-CAPUS(J)*PICEG)*L5*L4                      752     1494
      SK(J)=DEL*K(J)+I(J)                                            752     1505
   35 CONTINUE                                                       752     1510
      I(7)=I(7)/(1.+(PRO/BB-1.)*OK)                                  752     1518
      CALL ENDEM(SECN,SK,Q,SPOP,LF)                                  752     1528
      GO TO 27                                                       752     1535
   36 CONTINUE                                                       752     1537
C                                                                    752     1539
C FINAL INDICATOR CALCULATION                                        752     1540
C                                                                    752     1541
      DO 40 J=1,10                                                   752     1542
      YG(J)=SK(J)/Q(J)/Y(J)-1.                                       752     1546
      CAPAC2(J)=1.5*CAPAC(J)                                         752     1553
      CAPAC3(J)=2.*CAPAC(J)                                          752     1557
      ENSHT(J)=OMN(J)/ECN(J)                                         752     1561
      CPC(J)=C(J)/POP(J)*1000.                                       752     1565
   40 ECONCO(J)=CAPAC(J)/(K(1)+K(2)+K(3)+K(4))                       752     1570
      MECON=ECONCO(7)                                                752     1587
      MECON3=2.*MECON                                                752     1590
      ODFF=OMW-OMNW                                                  752     1594
      ODEFS=OXSW-OMNW                                                752     1598
      MECAPR=CAPAC(7)/K(7)                                           752     1602
      Y1234=(Y(1)+Y(2)+Y(3)+Y(4) )/1000.                             752     1606
      Y1R234=Y(1)/(Y(2)+Y(3)+Y(4) )                                  752     1613
      Y6789=(Y(6)+Y(7)+Y(8)+Y(9))/1000.                              752     1621
      Y510=(Y(5)+Y(10))/1000.                                        752     1628
      C1234=(C(1)+C(2)+C(3)+C(4))/1000.                              752     1633
      C510=(C(5)+C(10))/1000.                                        752     1640
      C6789=(C(6)+C(7)+C(8)+C(9))/1000.                              752     1645
1     CALL COMONO(IYR)                                               752     1652
      TURN PROGRAM 27 ON,0                                           752     1662
      STOP                                                           752     1666
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B 1o14

B 1o15

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PAGE 007    04/04/74    OIL MODEL

                 COMMON NDT                                                     752     1669
                 COMMON K,Y,Q,C,CR,I,IR,YTOT,LK,DEL,YI                          752     1670
                 COMMON ECN,DP,P,DY,     UCK,OCKI,OCN,ROP,R,OMN,OXS,OXK,OX,OMK, 752     1671
                2   OM,OMP,OXP,OXSCEN,ADIEC,DEPEN,ENSHT                         752     1672
                 COMMON OCKL,PHO,OXSW,OMW,OXW,OXNW,OMNW,COP                     752     1673
                 COMMON      ODEF,ODEFS,SUMOP,SUMOR,SUMCOP                      752     1674
                 COMMON POP,POPR,ODPC,ODACC,OR,RD,OPT,COPU,SUMREM               752     1675
                 COMMON SQUEEZ,IRN,EGR,ECONCO,COOP,RESFAC,SQUE,ROCKL            752     1676
                 COMMON         MECON,MECAPR,Y1234,Y1R234,Y6789,Y510            752     1677
                 COMMON OD,ODACPC,ODRY,YPC,CAPAC ,CAPAC2,CAPAC3,MECON3          752     1678
                 COMMON PICFG,GMEMAI,YG,ENDEF,FINDE,IYRRE,OTHEN,ENDE2           752     1679
                 COMMON INDE,INDYE,RI,COO,COC,CON,PRMIX,ADIF,ENDE,ENIN,LF       752     1680
                 COMMON FBF,ECF,PRI,CAPUS,CAPTR,FA                              752     1681
                 COMMON SK1,SK2,SK3,SK4,CRN,RECN,ESF,SLOPF,HPF                  752     1682
                 COMMON L1,L2,L5,CPC,UPLPR,DEFLF,PROGR,C1234,C510,C6789         752     1683
                 COMMON ENDEF2,FPRO,OCKS,OK                                     752     1684
                 COMMON ELAS                                                    752     1685
                 END                                                            752     1686

             *                                                                  152     1896

             *PROGRAM END.    0 FORTRAN ERRORS                                  152     1897
                 SUBROUTINE ENDEM(SECN,SK,Q,SPOP,LF)                            752     1899
                 REAL LF                                                        752     1916
                 DIMENSION SECN(10),SK(10),Q(10),SPOP(10),YPC(10),LF(10)        752     1917
                 DO 9 J=1,10                                                    752     1918
                 YPC(J)=SK(J)/Q(J)/SPOP(J)                                      752     1922
                 IF (J-5) 6,4,2                                                 752     1946
               2 IF (J-10) 6,4,6                                                752     1954
               4 CALL DATATC(AL,YPC(J))                                         752     1962
                 GO TO 8                                                        752     1969
              6  CALL DATATR(AL,YPC(J))                                         752     1971
               8 SECN(J)=SK(J)/O(J)*AL*4,931/1000.                              752     1978
               9 LF(J)=AL*4.931/1000.                                           752     2003
                 RETURN                                                         752     2021
                 END                                                            752     2028

             *                                                                  152     2045

*00000000  *00000000   *PROGRAM END.    0 FORTRAN ERRORS                        152     2046
                   END                                                          152     2047

                            0 ASSEMBLY ERRORS

                       004154 PROGRAM OCTAL SIZE

                       001367 EQL TABLE OCTAL SIZE

111407 FIN
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ADIE	R	ADDITIONAL DOLLARS INVESTED IN ENERGY PRODUCTION
ADIEC	R	CUMULATIVE ADDITIONAL DOLLARS INVESTED IN ENERGY PRODUCTION
ADIED	R	ADDITIONAL DOLLARS INVESTED IN ENERGY PRODU
AL		ALPHA FACTOR FOR COMPUTING TOTAL ENERGY DEMAND IN MILLIONS OF METRIC TONS OF COAL EQUIVALENT FROM GRP
BPF		INTERCEPT OF DEMAND ELASTICITY FUNCTION WITH PRICE
C	R	DOMESTIC REGIONAL CONSUMPTION IN BILLIONS OF 1963 DOLLARS
C1234		TOTAL CONSUMPTION OF THE 1ST WORLD
C510		TOTAL CONSUMPTION OF THE 2ND WORLD
C6789		TOTAL CONSUMPTION OF THE 3RD WORLD
CAPAC	R	CAPITAL ACCUMULATED FROM THE SALE OF OIL (AFTER INVESTMENT AND CONSUMPTION PURCHASES)
CAPAC2	R	CAPITAL ACCUMULATED IF RATE IS 1.5 TIMES NORMAL
CAPAC3	R	CAPITAL ACCUMULATED IF RATE IS 2.0 TIMES NORMAL
CAPTR	R	CAPITAL TRANSFERRED INTO THE REGION FROM OIL SALES
CAPUS	R	CAPITAL FROM THE SALE OF OIL USED TO INCREASE INVESTMENT
COC	R	COST OF COAL INVESTED IN 1963 DOLLARS/OIL BARREL EQUIVALENT OF INCREASED CAPACITY
CON	R	COST OF NUCLEAR INVESTMENT IN 1963 DOLLARS/OIL BARREL EQUIVALENT OF INCREASED CAPACITY
COO	R	COST OF OIL INVESTMENT IN 1963 DOLLARS/BARREL OF INCREASED CAPACITY
COP	R	CAPACITY FOR OIL PRODUCTION
COPU	R	FACTOR FOR REDUCING OIL PRODUCTION AS THE LIFETIME OF KNOWN OIL RESERVES (SEE OPT) FALLS BELOW 5
COUP		SCENARIO VARIABLE FOR INTRODUCING COMPUTATION OF MIDEAST CAPITAL ACCUMULATION; ALSO INTRODUCES IMPACT OF CAPITAL ACCUMULATION ON IMPORTING REGIONS (0 WHEN OFF, 1 WHEN ON)
CPC	R	CONSUMPTION/CAPITA IN 1963 DOLLARS
CR	R	PROPORTION OF GRP WHICH GOES TO CONSUMPTION
CRN	R	CONSUMPTION NEEDED TO ACCOMPLISH GIVEN GROWTH RATE
DEFLF		DEFLATION FACTOR TO CONVERT 1974 DOLLARS TO 1963 DOLLARS
DEL		FACTOR FOR DEPRECIATING CAPITAL ANNUALLY
DEPEN		DEPRECIATION FACTOR FOR INCREASED ENERGY CAPACITY
DY	R	THE CHANGE EXPECTED IN GRP
ECF		SCENARIO VARIABLE FOR REDUCING ENERGY CONSUMPTION NEED (SEE RECN) WHEN ENERGY DEFICITS OCCUR
ECN	R	ENERGY CONSUMPTION NEED
ECONCO	R	PROPORTION OF TOTAL CAPITAL OF 4 DEVELOPED REGIONS CONTROLLED BY CAPITAL ACCUMULATED
EGR	R	ECONOMIC GROWTH RATE DESIRED
ELAS		ELASTICITY OF OIL SUPPLY WITH PRICE
ENDE	R	THAT (INCREASING) PORTION OF THE OIL IMPORT NEEDS WHICH IS TARGETED TO BE MET DOMESTICALLY IN THE MOVEMENT TOWARDS REGIONAL INDEPENDENCE
ENDE2	R	THAT PORTION OF OIL IMPORT NEEDS WHICH ARE MET DOMESTICALLY IN THE MOVEMENT TOWARDS REGIONAL INDEPENDENCE
ENDEF	R	ENERGY (OIL) DEFICIT BEFORE EXPANSION OR CONTRACTION OF OIL PRODUCTION BY REGIONS PURSUING INDEPENDENCE
ENDEF2	R	ENERGY (OIL) DEFICIT AFTER EXPANSION (OR CONTRACTION) OF OIL PRODUCTION BY REGIONS PURSUING INDEPENDENCE
ENIN	R	ENERGY INCREASED AS A RESULT OF ADDITIONAL INVESTMENT
ENSHT	R	PROPORTION OF ENERGY NEEDS WHICH MUST BE MET BY OIL IMPORTS
ESF		SCENARIO VARIABLE FOR THE LIFESPAN OF REDUCTION IN ENERGY

		CONSUMPTION NEED AS A RESULT OF ENERGY DEFICITS
FA		OIL INCOME OF THE MIDEAST WHICH IS NOT USED TO SUPPLEMENT INTERNAL GENERAL INVESTMENT
FBF		SCENARIO VARIABLE FOR REDUCING OR INCREASING IMPACT OF ENERGY DEFICITS ON GRP
FINDE		FRACTION OF THE ADDITIONAL INVESTMENT IN ENERGY WHICH COMES FROM NORMAL ECONOMIC INVESTMENT (REST COMES FROM CONSUMPTION)
GMEMAI		INITIAL VALUE OF GMEMAX
GMEMAX		MAXIMUM ECONOMIC GROWTH RATE OF THE MIDEAST
I	R	INVESTMENT
INDE		SCENARIO VARIABLE FOR INDEPENDENCE AT OTHER ENERGY SUPPLY MANIPULATIONS (1 MEANS CALCULATE INDEPENDENCE COSTS, 2 MEANS CALCULATE COSTS OF AVOWING ACTUAL DEFICIT, 3 MEANS CALCULATE ENERGY PAYABLE (SEE ENIN) AT ANY LEVEL OF INVESTMENT INPUT, 4 THROUGH 6 MEANS CALCULATE AS IN 1 THROUGH 3 AND IMPLEMENT)
INDYE	R	THE NUMBER OF YEARS BEFORE INDEPENDENCE IS ACHIEVED
IR	R	PROPORTION OF GRP WHICH GOES TO INVESTMENT
IRN	R	INVESTMENT NEEDED
IYRRE	R	NUMBER OF YEARS BEFORE MAXIMUM REDUCTION (SEE ROCKL) IN LINDEN'S CURVE (SEE OCKL) TAKES PLACE
K	R	CAPITAL
L1		PROPORTION OF THE OIL INCOME WHICH THE MIDDLE EAST USES TO SUPPLEMENT INTERNAL INVESTMENT WHICH DIRECTLY REDUCES CAPITAL AVAILABLE FOR INVESTMENT IN OIL IMPORTING REGIONS
L2		PROPORTION OF THE OIL INCOME WHICH THE MIDDLE EAST DOES NOT USE TO SUPPLEMENT INTERNAL INVESTMENT WHICH DIRECTLY REDUCES CAPITAL AVAILABLE FOR INVESTMENT IN OIL IMPORTING REGIONS
L3		PROPORTION OF THE OIL INCOME WHICH THE MIDDLE EAST USES TO SUPPLEMENT INTERNAL INVESTMENT WHICH REDUCES CONSUMPTION EXPENDITURES IN IMPORTING RATIOS
L4		PROPORTION OF THE OIL INCOME WHICH THE MIDDLE EAST DOES NOT USE TO SUPPLEMENT INTERNAL INVESTMENT WHICH REDUCES CONSUMPTION EXPENDITURES IN IMPORTING RATIOS
L5		PROPORTION OF MIDEAST OIL INCOME NOT USED IN INTERNAL INVESTMENT WHICH RETURNS TO REST OF WORLD AS DEMAND FOR INVESTMENT OR CONSUMPTION GOODS (1-L5 IS PROPORTION USED FOR CAPITAL PURCHASE)
LF		FACTOR FOR COMPUTING TOTAL ENERGY DEMAND IN BILLIONS OF BARRELS OF OIL EQUIVALENT FROM GRP (SEE AL)
LK		LIFE IN YEARS OF CAPITAL
MECAPR		RATIO OF MIDEAST CAPITAL ACCUMULATED TO TOTAL CAPITAL
MECON		PROPORTION OF TOTAL CAPITAL OF 4 DEVELOPED REGIONS CONTROLLED BY MIDEAST CAPITAL ACCUMULATED
MECON3		PROPORTION OF TOTAL CAPITAL OF 4 DEVELOPED REGIONS CONTROLLED BY MIDEAST CAPITAL ACCUMULATED IF SUCH ACCUMULATION OCCURS AT TWICE NORMAL RATE
OC	R	OIL CONSUMPTION
OCK	R	RATIO OF OIL CONSUMPTION TO TOTAL ENERGY CONSUMPTION (OCKL ADJUSTED BY OCKI)
OCKI	R	INITIAL RATIO OF OIL CONSUMPTION TO TOTAL ENERGY CONSUMPTION
OCKL		TIME SERIES VARIABLE REPRESENTING CURVE DEVELOPED BY HENRY

		LINDEN TO REPRESENT THE RATIO OF OIL CONSUMPTION TO TOTAL ENERGY CONSUMPTION ON WORLD BASIS
OCN	R	OIL CONSUMPTION NEED
OD	R	OIL DOLLARS (INCOME OR COST)
ODACC	R	CUMULATIVE NET FLOW OF OIL DOLLARS
ODACPC	R	OIL DOLLARS (INCOME OR COST) ACCUMULATED PER CAPITA IN 1963 DOLLARS
ODEF		TOTAL WORLD OIL IMPORTS MINUS TOTAL WORLD IMPORT NEEDS
ODERS		TOTAL WORLD EXPORTS SUPPLY MINUS TOTAL WORLD IMPORT NEED
ODPC	R	OIL DOLLARS (INCOME OR COST) PER CAPITA IN 1963 DOLLARS
ODRY	R	THE RATIO OF OIL DOLLARS (INCOME OR COST) TO GRP
OM	R	OIL IMPORTS
OMK	R	THE PROPORTION OF TOTAL WORLD OIL IMPORTS TAKEN BY ANY REGION
OMN	R	OIL IMPORT NEED
OMNW		WORLD TOTAL OF OIL IMPORT NEED
OMP	R	TOTAL PRICE OF OIL IMPORTS
OP	R	OIL PRODUCTION
OPT	R	LIFETIME IN YEARS OF KNOWN OIL RESERVES AT CURRENT PRODUCTION RATES
OR	R	KNOWN OIL RESERVES
OTHEN	R	OTHER ENERGY (NON-OIL) PRODUCED BY ADDITIONAL INVESTMENT TO OVERCOME OIL DEFICIENCY
OX	R	OIL EXPORTS
OXK	R	THE PROPORTION OF TOTAL WORLD OIL EXPORTS PROVIDED BY ANY REGION
OXNW		OIL EXPORT NEED OF WORLD
OXP	R	INCOME FROM TOTAL OIL EXPORTS
OXS	R	OIL EXPORT SUPPLY
OXSCEN		OIL EXPORTS SCENARIO VARIABLE SETTING MAXIMUM PROPORTION OF OIL EXPORT NEED OF WORLD TO BE MET
OXSW		WORLD TOTAL OF OIL EXPORT SUPPLY
OXW		TOTAL WORLD OIL EXPORTS
P	R	CUMULATIVE PRODUCTION OF OIL
PICBG		PROPORTION OF ADDITIONAL INVESTMENT IN ECONOMIC GROWTH BY THE MIDEAST WHICH IS PAID FOR BY OIL INCOME
POP	R	POPULATION IN MILLIONS
POPR	R	POPULATION GROWTH RATE
PRI		PRICE OF OIL IN 1974 DOLLARS/BARREL (INPUT)
PRMIX	M	PRODUCTION RATIO MATRIX SPECIFYING PROPORTION OR INCREASED ENERGY PRODUCTION MADE UP BY OIL, COAL, AND NUCLEAR, RESPECTIVELY
PRO		PRICE OF OIL IN 1963 DOLLARS/BARREL
PROGR		ANNUAL GROWTH RATE IN OIL PRICE
Q	R	CAPITAL TO OUTPUT RATIO
R	R	ULTIMATELY RECOVERABLE RESERVES OF OIL
RD		ANNUAL RATE OF DISCOVERY OF OIL
RECN	R	REDUCTION OF ENERGY CONSUMPTION NEED AS A RESULT OF DEFICITS
RESFAC		RESERVE FACTOR TO INCREASE OR DECREASE OIL RESERVES (OIL RESERVES = 2 TRILLION BARRELS WHEN RESFAC = .756; 2.5 TRILLION AT .945; 3.0 TRILLION AT 1.15; AND 4 TRILLION AT 1.5)
ROCKL	R	REDUCTION IN THE RATIO OF OIL CONSUMPTION TO TOTAL ENERGY CONSUMPTION APPLIED TO LINDEN'S CURVE OF THAT RATIO

		(SEE OCKL)
ROP	R	ANNUAL GROWTH RATE IN OIL PRODUCTION CAPACITY
SLOPF		SLOPE OF THE DEMAND ELASTICITY FUNCTION WITH PRICE
SQUE		UPPER LIMIT (SCENARIO VARIABLE) ON MIDEAST OIL PRODUCTION
SQUEEZ		SCENARIO VARIABLE FOR THE INTRODUCTION OF ECONOMIC IMPACT OF OIL DEFICITS (1 WHEN ON, 0 WHEN OFF)
SUMCAP		WORLD TOTAL OF OIL PRODUCING CAPACITY
SUMOP		WORLD TOTAL OIL PRODUCTION
SUMOR		WORLD TOTAL OF KNOWN RECOVERABLE OIL RESERVES
SUMREM		WORLD TOTAL OF REMAINING UNDISCOVERED , RECOVERABLE OIL
SUMRES		WORLD SUM OF ULTIMATELY RECOVERABLE OIL RESERVES
UPLPR		UPPER LIMIT ON THE PRICE OF OIL IN 1963 DOLLARS/BARREL
Y1234		TOTAL GRP OF THE 1ST WORLD
Y1R234		RATIO OF NORTH AMERICA GRP TO OTHER DEVELOPED REGION GRP
Y510		TOTAL GRP OF THE 2ND WORLD
Y6789		TOTAL GRP OF THE 3RD WORLD
YG	R	ECONOMIC GROWTH RATE
YI	R	INITIAL VALUE OF GRP
YPC	R	GRP/CAPITA IN THOUSANDS OF 1963 DOLLARS
YTOT		WORLD GRP

3. Introduction

There are a great many scenarios which can be examined with the world oil model.[1] In this report we want to focus on 2 sets of scenarios. The first scenario set can be called standard or cooperative. This scenario set posits that no restrictions are placed upon oil exports by any region and that the capital accumulating regions are as well accepted and integrated into the international system as Texas is in the U.S. or Scotland is in Great Britain. That is, capital flows to the oil rich areas, but returns to the oil poor areas as expenditure for goods and investment in established capital. The major variables of interest in this set of scenarios are the price of oil, the size of the capital flows (a function of oil prices), and the proportions of capital which oil selling nations invest in long-term capital of other regions and immediate consumption.

The second scenario set focuses on conflict. There are possibilities for conflictual behavior on the part of both importers and exporters. Exporters can at any time limit exports, raise prices, and "squeeze" importers. Although we are labeling such decisions "conflict behavior," it must be pointed out that the intent need not be negative. In fact the Mideast leaders may feel that limitations on production are the best for everyone. Although we naturally think in terms of Mideast supply limitations, if the Soviet Union or even China become major exporters, other variations on the squeeze scenario will prove possible. The relative economic benefits to exporting regions of selling oil now on demand or of limiting production and waiting until later is a hotly debated issue and is central to the squeeze scenario. So is the economic impact on importers of supply limitations.

The weapons available to the oil importers are less certain. The possibility exists of some collective action by oil importers to limit the availability of goods desired by the Mideast or to raise the prices of such goods. Although most commentators have rightfully belittled the likelihood of such action, and events have shown the centrifical bheavior of the Western alliance in crisis, the *possibility* of such action remains. In particular, the Western developed region could manipulate sales and prices of capital goods to the Mideast since they have a relative monopoly on these highly desired goods--even the Soviet Union looks to the West for high technology capital goods.

Footnotes

[1] The model itself will not be described here. See Barry Hughes, "A Description of the World Oil Model," Systems Research Center, Case Western Reserve University, April, 1974.

4. Standard Cooperative Scenario

The standard run of the oil model assumes generally cooperative policies on the part of both surplus and deficit regions. That is, surplus regions do not limit oil production and exports and do not adopt extreme pricing policies. Deficit regions do not adopt retaliatory policies in the pricing of their sales to the oil producers. The standard run also assumes that no special efforts will be made by oil importers to achieve independence from external oil supplies; higher prices of oil imports may move some importing regions towards self-sufficiency as a result of the elasticities of demand and supply, but this scenario assumes that no governmental intervention will supplement these market mechanisms. The new wealth of the oil exporters is assumed to allow those regions to grow rapidly and to invest externally, but to cause no greater conflicts than those between Texans and other Americans.

We still must turn our attention to oil pricing. Some have essentially argued that there is no cooperative price--that the lower the price, the better for importers, and the higher the price, the better for exporters. Analysis with the oil model very strongly suggests the opposite--that there is a range of highly satisfactory prices for the Mideast and that this range is better for the rest of the world in the long run than very low prices. Moreover, this range is not the highest possible price.

4.1 The Impact of Low World Oil Prices

Let us look briefly at the world future which might have come had the Middle Eastern nations not raised their taxes and royalty income from oil above the $1.35/barrel of the early 1970s and not restricted production. Oil demand as a percentage of total energy demand has been growing throughout the world and would have continued to rise with such low prices. Thus absolute oil demand would have risen quite steeply. Even with fairly generous assumptions of 2.5 trillion barrels of ultimately recoverable oil in the world (about four times current known reserves), exhaustion occurs in the very early part of the 21st century. Graph 1 shows the resulting pattern of economic growth for the groups of nations known as the first (Western, industrial), second (communist), and third (less developed) worlds. The remainder of the twentieth century is characterized by rapid growth, fueled by cheap energy, although some failures of capacity to keep up with demand affect growth in the 1970s. The exhaustion of oil reserves, although it does not occur all at one time, or at the same time for each region, has a devastating affect on the economies of the world, particularly those of the first and third worlds. This portrayal of the long run impact of $1.35/barrel oil is not a straw man in which ever growing demand is allowed to crash against a barrier of limited resources--the demand curve assumes that other energy forms would be developed and that the proportion of oil in total energy demand would begin decreasing well before the exhaustion of reserves. Without the ameliorating impact of increased oil prices on energy demand and the spur of such prices to supply, even such foresight would be unlikely to succeed. Appendix A to this chapter presents some further data on individual region economies, growth rates, and consumption patterns in the $1.35/barrel price scenario.

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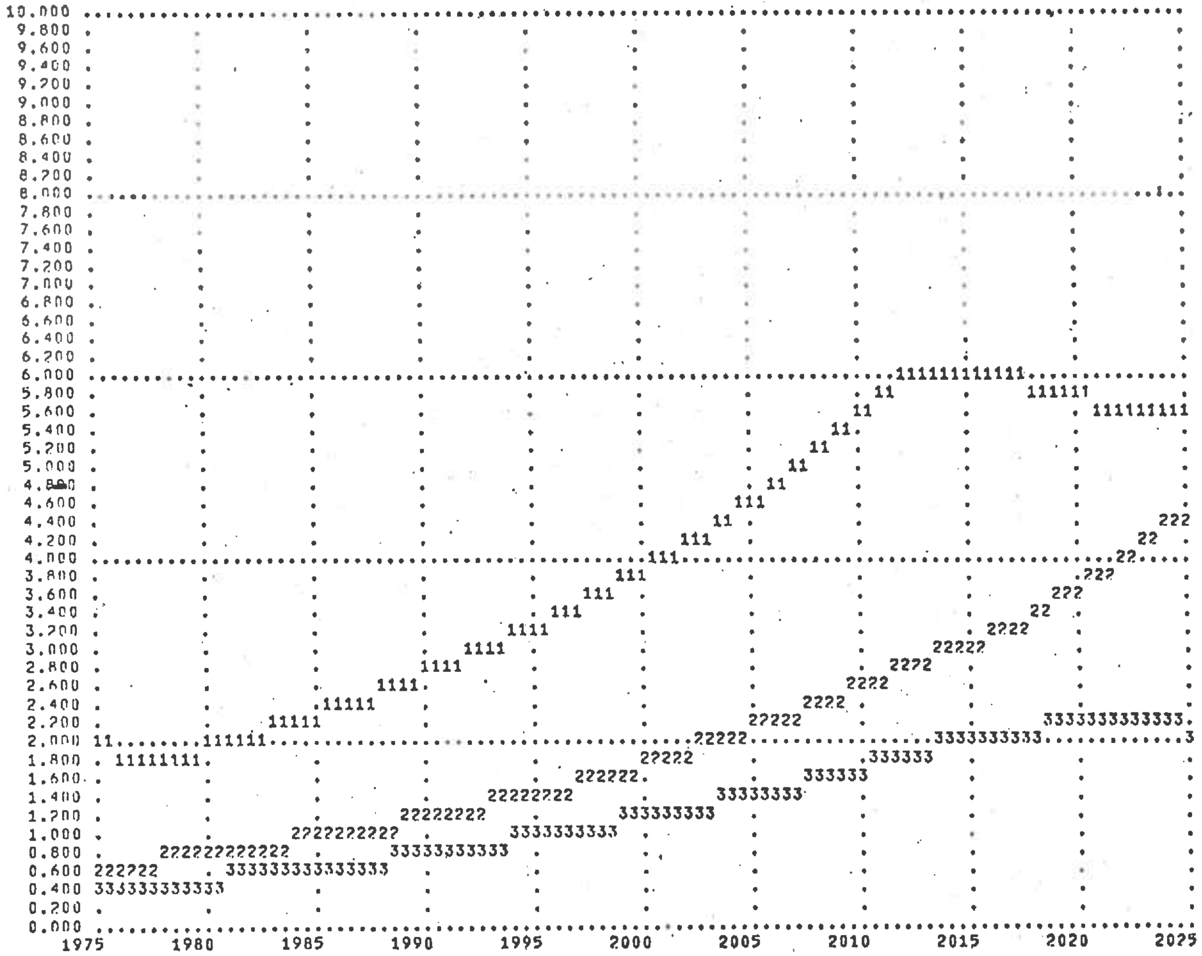
PAGE    5     04/05/74     10:36     SUMMARY ECONOMIC INDICATORS

        Y1234       Y510      Y6789
      10.00000   10.00000   10.00000
       0.00000    0.00000    0.00000
          1          2          3
```



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This discussion does not constitute an argument that the Middle East has done the world a great favor by quadrupling the price of crude oil. Clearly, the recent price increases are having and will continue to have an extremely disruptive impact on the developed economies and a potentially catastrophic one on the underdeveloped world. The model does suggest, however, that in the longer run a price of oil higher than $1.35/barrel will lead to more stable and greater economic growth in most regions of the world. We will look next at the most desirable price range for oil from the Middle East point of view and then return to the impact of such a price on the rest of the world.

4.2 Desirable Oil Prices for the Middle East

There are at least three criteria by which the Middle East can judge the desireability of oil prices:

1. The implications of the price for long run domestic economic growth.
2. The accumulation of capital for foreign investment which results from the price.
3. The impact of the price on the life of Middle Eastern oil reserves.

Clearly, the last criterion, if applied outside of the context of other criteria, constitutes an argument for the highest possible oil price. We will focus here on the first two criteria, realizing that individual Middle Eastern elites may drive the price higher than the optimum so determined in order to save the oil for future generations. The first two criteria are optimized in very much the same range, since both depend on maximal sustained capital inflow. For ease of result presentations, then we will focus on the price structure which maximizes Middle Eastern GRP in 2025. That is the approximate year in which, according to many of our scenarios, oil demand has been reduced to petrochemical and other non-fuel demand.

The optimal oil price for the Middle East depends on at least four variables:

1. The rate of increase in price to the optimal level.
2. The elasticity of world supply of oil and other forms of energy with oil price.
3. The elasticity of world demand for oil and other energy forms with price.
4. The possibility of a relationship between the price of oil and the price of the investment goods which the Mideast must import to achieve rapid economic growth.

It should be noted that all four of these variables are scenario dependent. The rate of price increase is a varible as much under control of the Middle Eastern countries as is the final price for oil. Demand and supply elasticity are to some considerable degree economic variables determined by the size of economies, the existing energy systems, and the technological and resource alternatives for those systems. They are also greatly affected, however, by political decisions on taxation, investment, and import/export control. Thus scenarios such as North American independence, massive efforts to conserve energy, or fairly rapid introduction of inexpensive fusion power will set the level of supply and demand elasticity.

The fourth variable should not be interpreted as an inflationary effect. The economic model which underlies the oil model in constant 1963 dollars and price rises in oil are relative and not inflated. Similarly, an increase in the cost of investment goods would be relative to the price level of the economy as a whole. Such an increase could occur in two ways. First, it might result from a distortion of the price structure as a result of the sharply rising cost of energy and the energy intensiveness of certain goods like invstment goods. Second, it might represent a retaliation of Western industrialized economies for high oil prices, and take the form of an export tax on goods (primarily capital goods) delivered to the Middle East. This could come about by collaboration of oil importers or through individual action to achieve some semblance of a balance in payments. Under normal conditions we assume that such a rise in the cost of investment goods is unlikely, but as a possible scenario it deserves investigation.

We can begin our analysis of the optimal price range of oil for the Middle East by positing a seemingly reasonable level for these scenario variables, look at the optimal oil price range in that context, and then analyze the sensitivity of the optimal oil price range to the variables. We will set energy supply elasticity quite high (as most analyses have), although ultimate reserves and their discovery rate bound the elasticity of oil supply in the short run. We will establish a moderate level of energy demand elasticity, a 3% annual increase in oil prices up to the optimal, and an absence of impact of oil prices on Mideast investment good cost. In other words, our basic scenario is business as usual, in which regions make little effort to cut energy consumption (lower demand elasticity), try instead to increase alternative energy sources, and do not either individually as is cannot raise the price of investment goods to the Middle East.

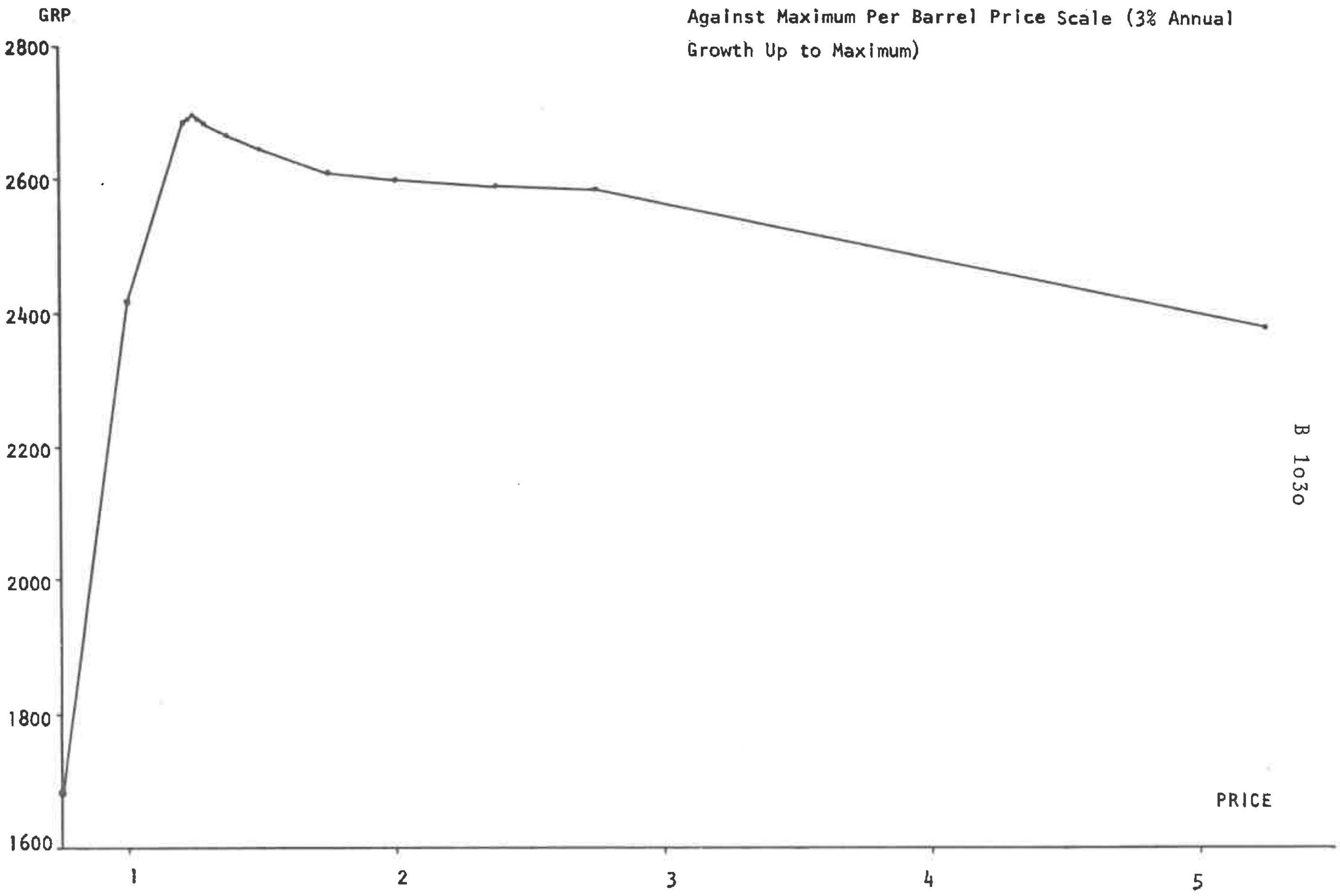
Under these conditions we find the relationship between final price and GRP of the Middle East in 2025 to be that portrayed in Graph 2. An optimum price appears to be in the range of prices number 1 and number 2, with the extent of the optimum range considerably greater on the upward side of the price than on the downward side. Graph 3 shows the relationship between accumulated capital and the final price of oil. Again the optimal price appears to be in the same range, with the range lower on the downward side than on the upward, in contrast to Graph 2.

In this report we are not presenting actual prices, but using price numbering system from 1 to 5. There are several reasons for this. First, we do not wish to overemphasize the accuracy of the oil model by putting forward an exact price at this time. Second, any price we put forward now could raise a storm of controversy which would detract from more general consideration of the model. Finally, some aspects of the analyses with the world oil model will be retained as proprietary information.

Although the model suggests quite strongly that aside from reserve life span considerations the optimal price is in the 1 to 2 range, we naturally want to know how sensitive that finding is to the business as

Graph 2

Mideast Gross Regional Product In the Year 2025 Against Maximum Per Barrel Price Scale (3% Annual Growth Up to Maximum)



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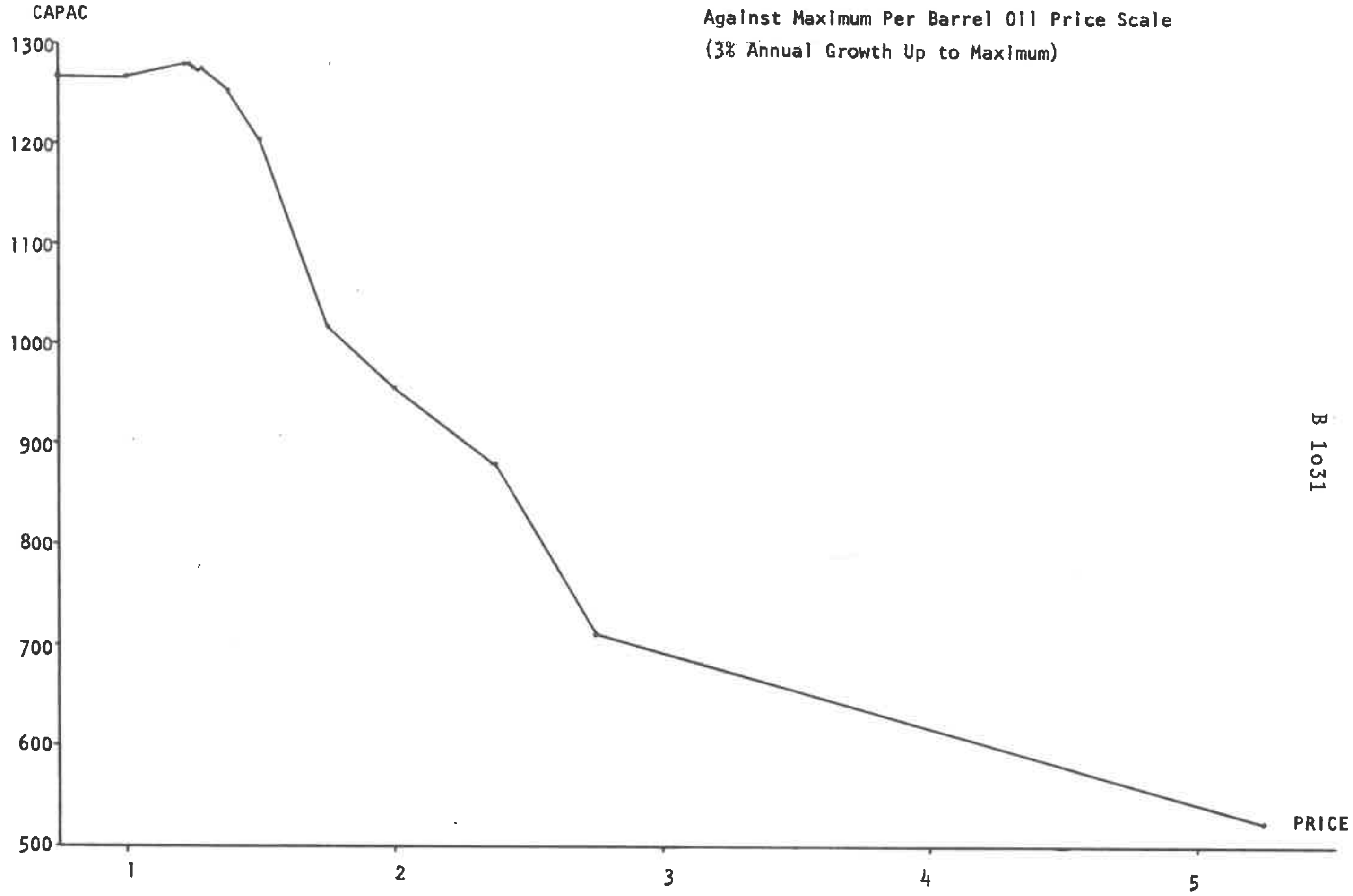
Graph 3

Mideast Accumulated Capital in the Year 2025
Against Maximum Per Barrel Oil Price Scale
(3% Annual Growth Up to Maximum)



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usual scenario assumptions laid out above. First, let us look at the impact of rate of price increase on the optimal price range. Graph 4 portrays the optimal price when annual oil price growth rates of 1%, 3%, 5%, and 8% are introduced. Although the tendency is for higher growth rates to lead to lower optimal prices, a result perhaps comforting to the rest of the world, the differences are not marked.

Graphs 5 and 6 show the impact of assumptions about supply elasticity and demand elasticity on the optimal price. Supply elasticity has relatively little impact. Thus scenarios positing massive expansions of other energy sources (which will generally be very expensive) will have quite moderate effects on Middle Eastern price, although the optimal price will come down somewhat with greater elasticity. As can be seen from Graph 6, the level of demand elasticity is especially important, and optimal price is quite sensitive to it. Thus energy conservation scenarios will be especially powerful in their implications for the model.

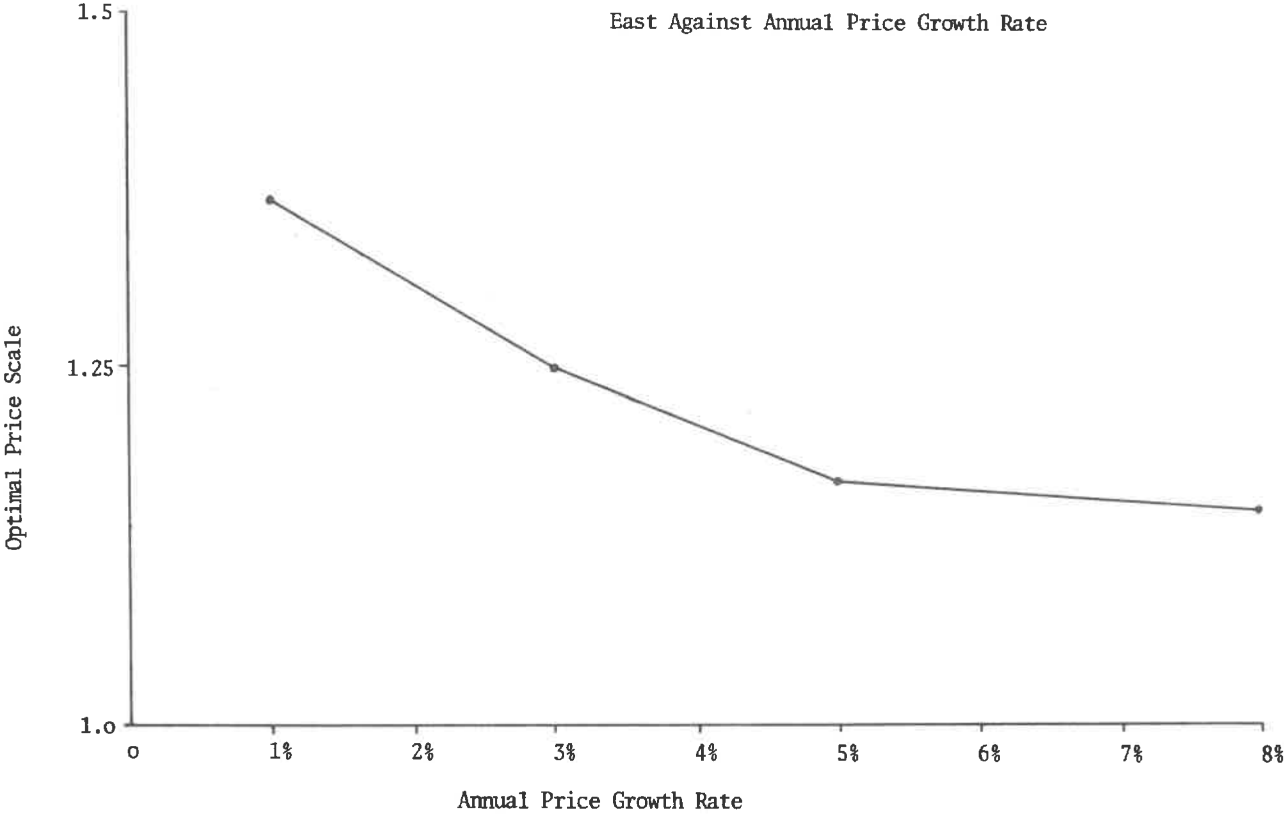
Finally, Graph 7 shows the sensitivity of optimal price to relationships between price and investment good cost. Again, there is no great sensitivity of optimal price to such a relationship, although the stronger relationships do lower that price.

4.3 The Impact of Prices on World Economies

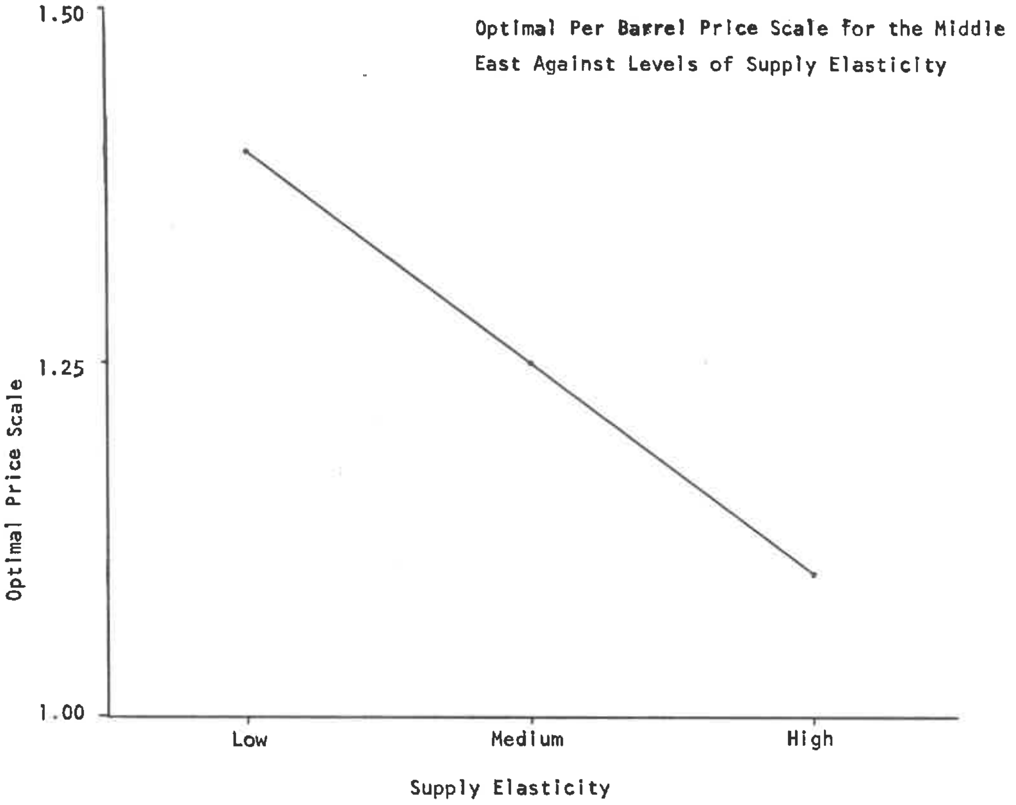
With this analysis of price optimality from the point of view of the Middle East, we can return to implications for the rest of the world.

Graph 4

Optimal Per Barrel Price Scale for the Middle East Against Annual Price Growth Rate

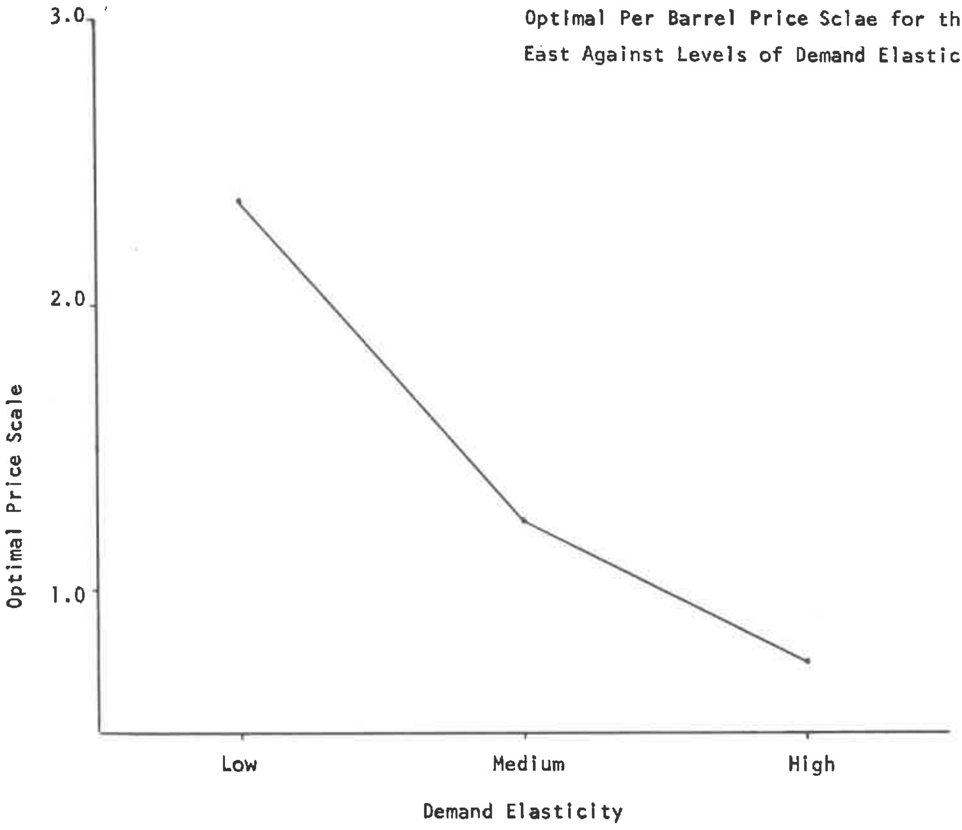


Graph 5



Optimal Per Barrel Price Scale for the Middle East Against Levels of Supply Elasticity

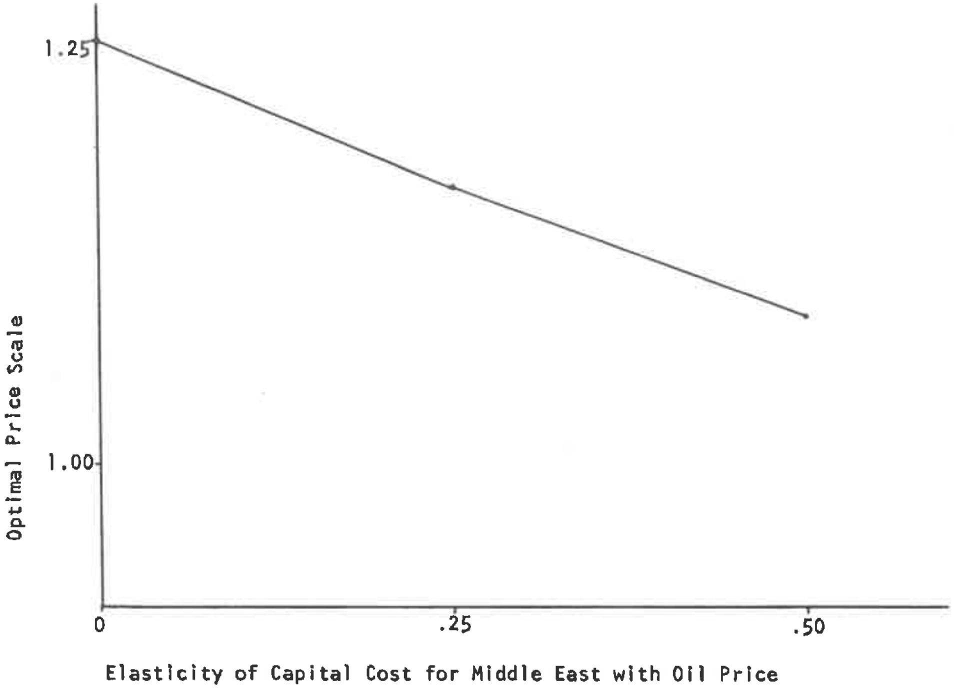
Graph 6



Optimal Per Barrel Price Sclae for the Middle East Against Levels of Demand Elasticity

Graph 7

Optimal Per Barrel Price Scale for the Middle East Against Rates of Capital Cost Increase for the Middle East

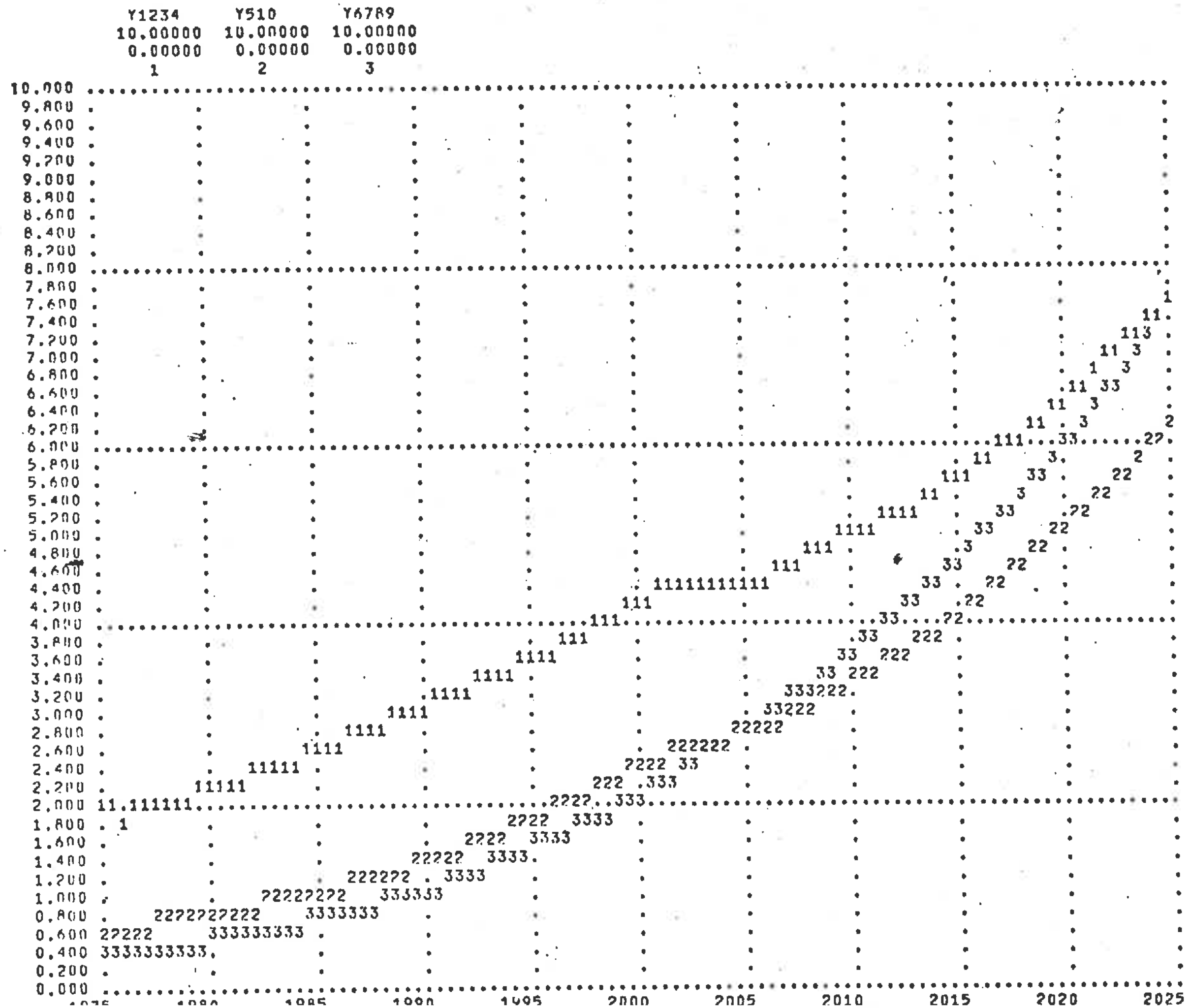


Graph 8 shows the economic growth pattern of the three worlds, given the earlier scenario levels of elasticities, and optimal oil pricing from the Middle Eastern viewpoint. That is, prices underlying Graph 8 increase at 3% annually to the middle of the 1 to 2 range. A comparison of Graphs 1 and 8 proves that oil pricing is not completely competitive or zero-sum, but that the world as a whole can benefit in the long run from increased oil prices. We must reiterate our recognition that the sudden jumps of price in the early 1970s are unfortunately and very significantly disruptive -- see Graph 8. Moreover, they may well lead to a second disruption of the developed world, especially of North America, in the early 2000s. The reason is that the sudden increase will lead to dramatic expansion of supply of oil in that region, at a cost which is competitive with imports and which impedes reduction of demand. The exhaustion of North American oil reserves in the early 2000s thus could become a temporarily disrupting factor, ameliorated by the continued availability of some Middle Eastern supply. Appendix B to this chapter presents further data from the Middle Eastern optimal price scenario.

Although the 1 to 2 range of oil prices is highly desireable from the point of view of the Middle East, and proves better than very low prices in the long run for the rest of the world as well, it might still be expected that other regions would have quite different optimal price ranges. Graph 9 suggests otherwise. An analysis of the GRP in 2025 of the four major developed regions against the final price of oil leads to the surprising result that Western Europe and Japan, the major oil importers

Graph 8

PAGE 19 04/05/74 10:36 SUMMARY ECONOMIC INDICATORS



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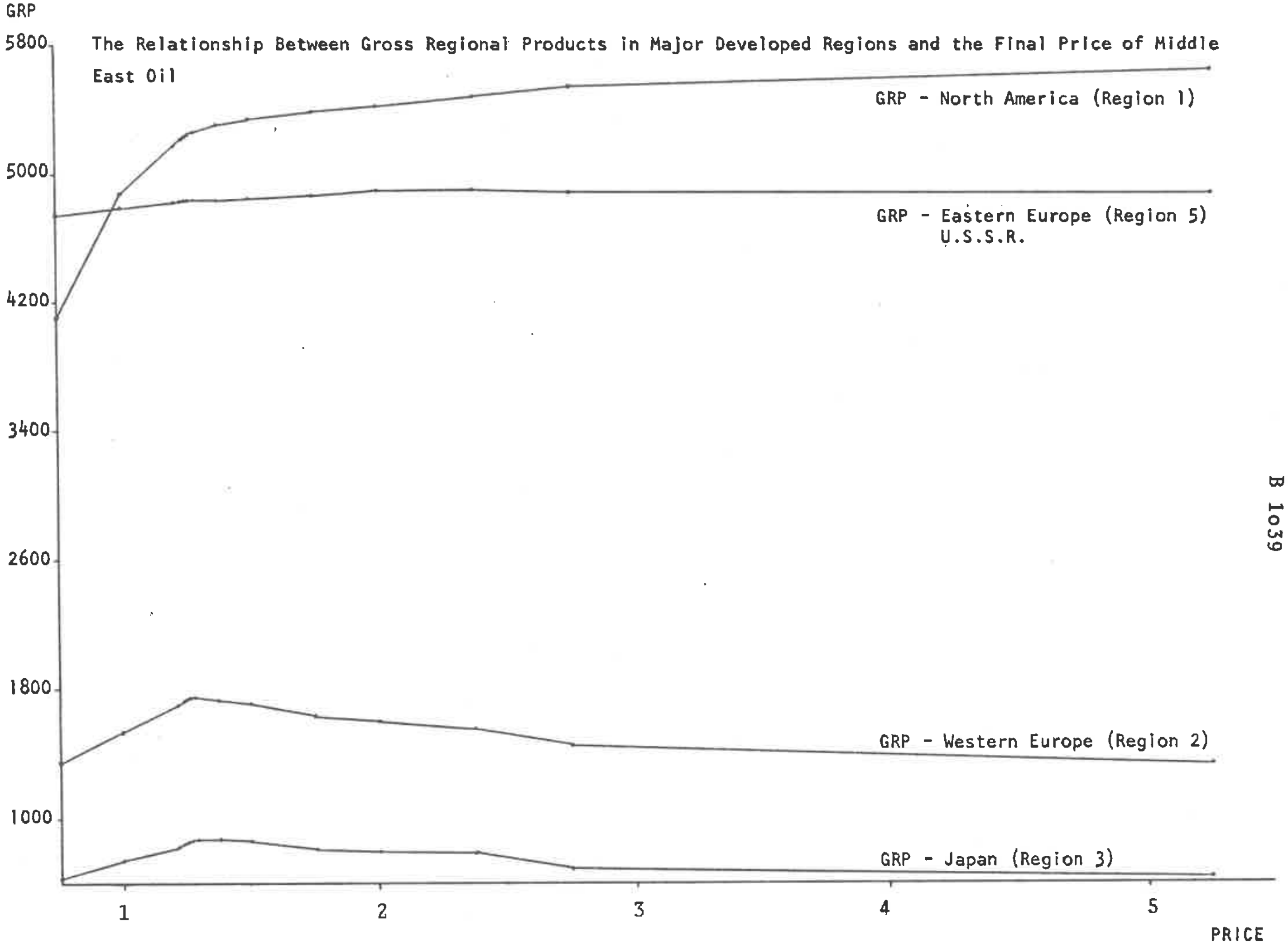
Graph 9

The Relationship Between Gross Regional Products in Major Developed Regions and the Final Price of Middle East Oil



will also do better with prices in that same range than with other prices. The reason is that major exporting regions and major importing regions both gain by having oil reserves last until other energy forms can replace them. A scenario with rapid introduction of cheap fusion power or any other major energy source would not require higher oil prices to elicit oil supply and curb demand. Such scenarios are possible, but unlikely.

Interestingly, North America and Eastern Europe are characterized by different price/GRP relations than either the major exporting region or the two major importers. Eastern Europe's oil reserves are adequate for internal use but never allow it to be a major exporter. Thus price of MIddle East oil has little affect. North America has the potential for some exports after filling internal demand. Thus somewhat higher prices are desireable for it. Yet this export capability would be exhausted by the early 21st century.

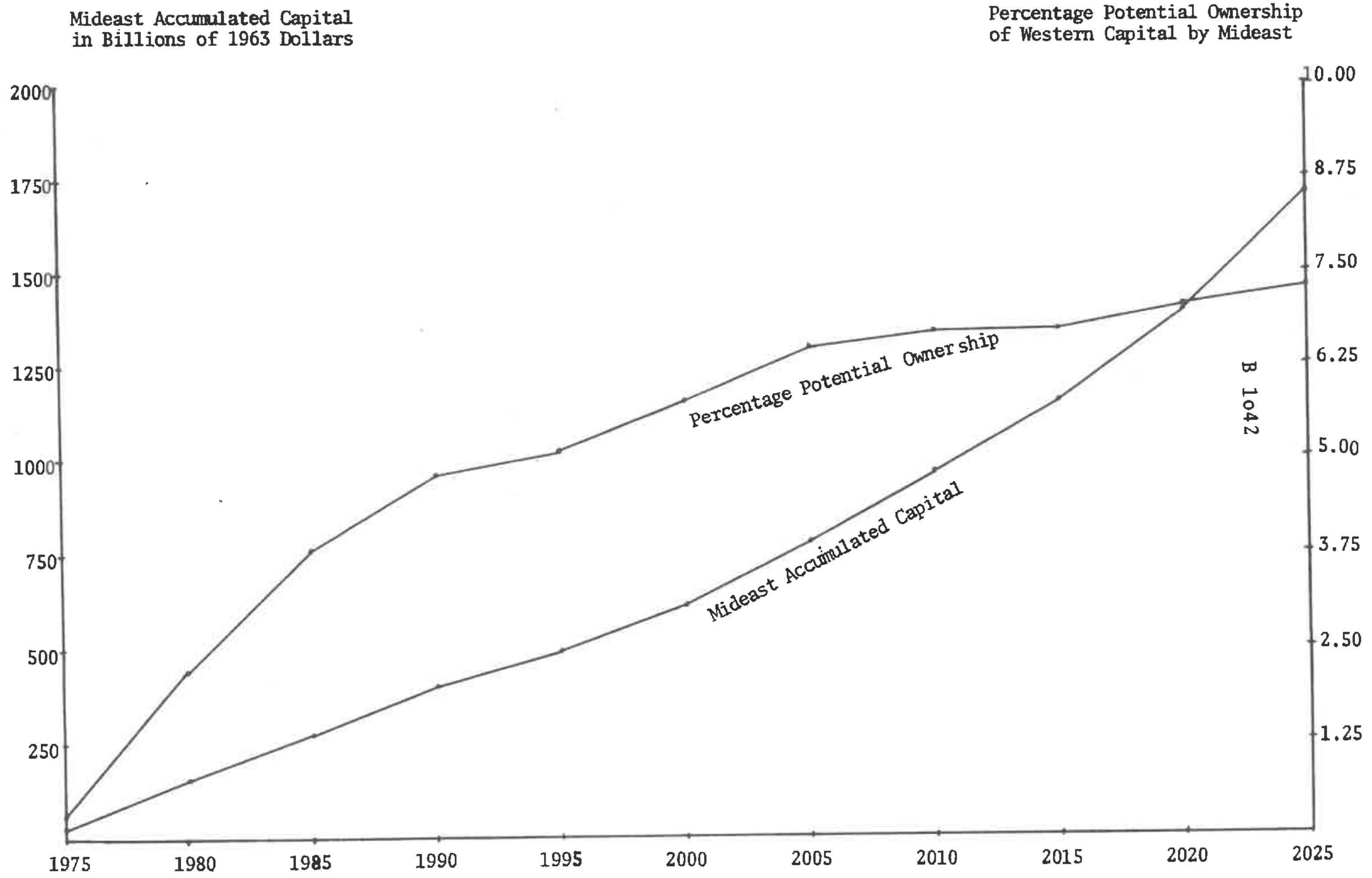
4.4 The World Monetary Implications of Cooperation

The higher oil prices of the last year have lead to repeated warnings of the impact on the world monetary system. Estimates of the capital flow to the Mideast in 1974 have reached \$100 billion.[1] The oil model suggests that although the amounts involved are very substantial, they are not nearly as large as such panic predictions. Moreover, after investment by the Mideast nations in their own economic growth, excess revenues available for external investment or immediate consumption will not even be half so large in any year through 1980. Graph 10 shows the accumulation of capital by the Mideast through 2025. Although the amount is large, 1.71 trillion 1963 dollars, it is not so large in comparison to the developed world economies at that time. In fact, the total amount of capital accumulated by the Mideast through 2025 will be equal to only 21% of the Western developed world's GRP in 2025, and only 7% of their accumulated capital. Thus even with considerable Middle Eastern frugality, the world would not be owned by sheiks in 2025. Graph 10 also shows the proportion of total Western developed world capital which could be owned by the Middle East with accumulated oil revenues throughout the period.

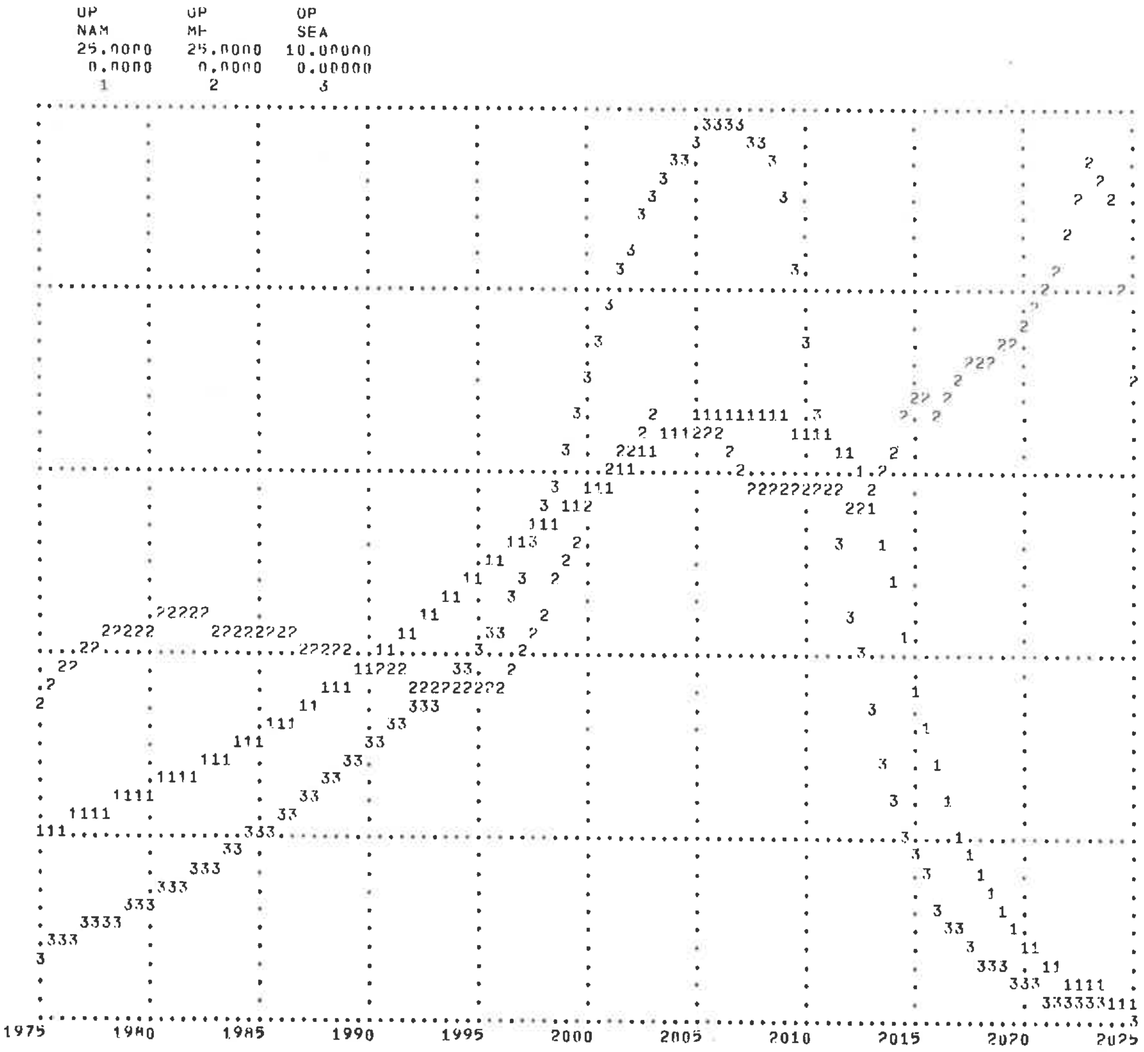
Thus a world willing to cooperate on the oil problem would not be so bad a place. Economic growth for all regions is quite possible. The Middle East is clearly in a most enviable and powerful position, but policies pursued in its own self interest are not likely to destroy the rest of the world. Problems of short term dislocations because of the rapid increase in oil prices will remain. These will be especially severe for LDCs, and resources to pay increased oil bills are badly needed by them. Alternating strength and weakness in the OPEC cartel, with associated price changes, could also have disruptive results.

Further data on the cooperative scenario can be seen in Graphs 11 through 14. These graphs will form the basis for our comparison of scenarios and merit explanation. Graph 11 shows the rate of oil production (OP) in billions of barrels annually for North America (NAM), the Mideast (ME), and Southeast Asia (SEA), a potential oil exporter. Note the rapid increase

Graph 10. Monetary Implications of Oil Cooperation



PAGE 11 04/15/74 14:24 SUMMARY OIL VARIABLES



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PAGE   12      04/15/74      14:24      SUMMARY OIL VARIABLES

              OP          OP          OP
              NAM         ME          SEA
1975          5.0398      8.4998      0.73396
1976          5.2678      9.5640      0.84056
1977          5.5048     10.1775      0.95154
1978          5.7523     10.4153      1.06433
1979          6.0110     10.6233      1.18555
1980          6.2814     10.8064      1.31567
1981          6.5638     10.9570      1.45471
1982          6.8590     11.0779      1.60306
1983          7.1675     10.8096      1.73764
1984          7.4899     10.8735      1.90286
1985          7.8268     10.5647      2.04871
1986          8.1790     10.5803      2.23151
1987          8.5464     10.2419      2.38867
1988          8.9307      9.9058      2.55060
1989          9.3323      9.8816      2.76019
1990          9.7520      9.7004      2.95667
1991         10.1904      9.5430      3.16296
1992         10.6487      9.3696      3.37207
1993         11.1277      8.8875      3.51611
1994         11.6282      8.8987      3.76843
1995         12.1511      8.9778      4.03979
1996         12.6975      9.1528      4.34229
1997         13.1826     10.2341      4.94214
1998         13.5779     11.3595      5.58447
1999         13.9851     12.6089      6.31030
2000         14.4045     13.9956      7.13049
2001         14.8364     14.9966      7.83972
2002         15.2815     15.7705      8.48975
2003         15.7268     16.3774      9.09668
2004         16.0918     16.3047      9.41089
2005         16.3804     16.1465      9.66870
2006         16.5957     15.9524      9.88550
2007         16.5723     15.2134      9.75806
2008         16.4048     14.4934      9.57666
2009         16.4194     14.5571      9.14868
2010         16.2852     14.5125      7.43188
2011         16.0674     14.5137      5.83667
2012         15.6565     14.3215      4.51978
2013         14.3682     14.3813      3.38287
2014         12.0234     15.7407      2.46741
2015          9.3225     17.0356      1.79388
2016          7.0327     16.7637      1.31400
2017          5.2714     17.8340      0.97478
2018          3.9574     17.9282      0.73390
2019          2.9851     18.6865      0.56096
2020          2.2657     18.9121      0.43484
2021          1.7309     19.8877      0.34131
2022          1.3308     21.6323      0.27071
2023          1.0296     23.4346      0.21655
2024          0.8012     22.6416      0.17440
2025          0.6268     17.5000      0.14109
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Graph 12

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PAGE    2     04/17/74     15:35     WORLD OIL DEFICIT

          ODEFS
          6.05298
         -7.63086
            1
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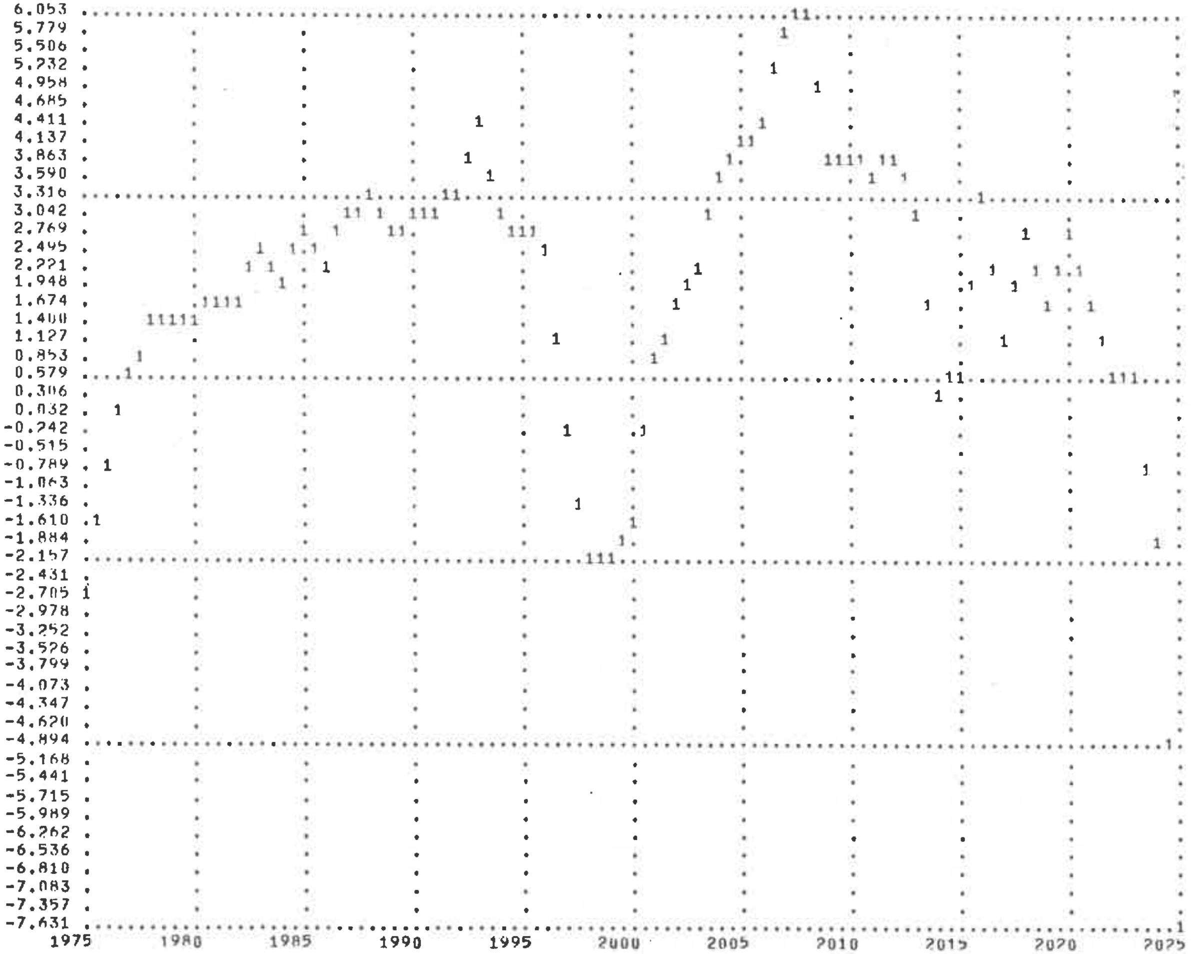

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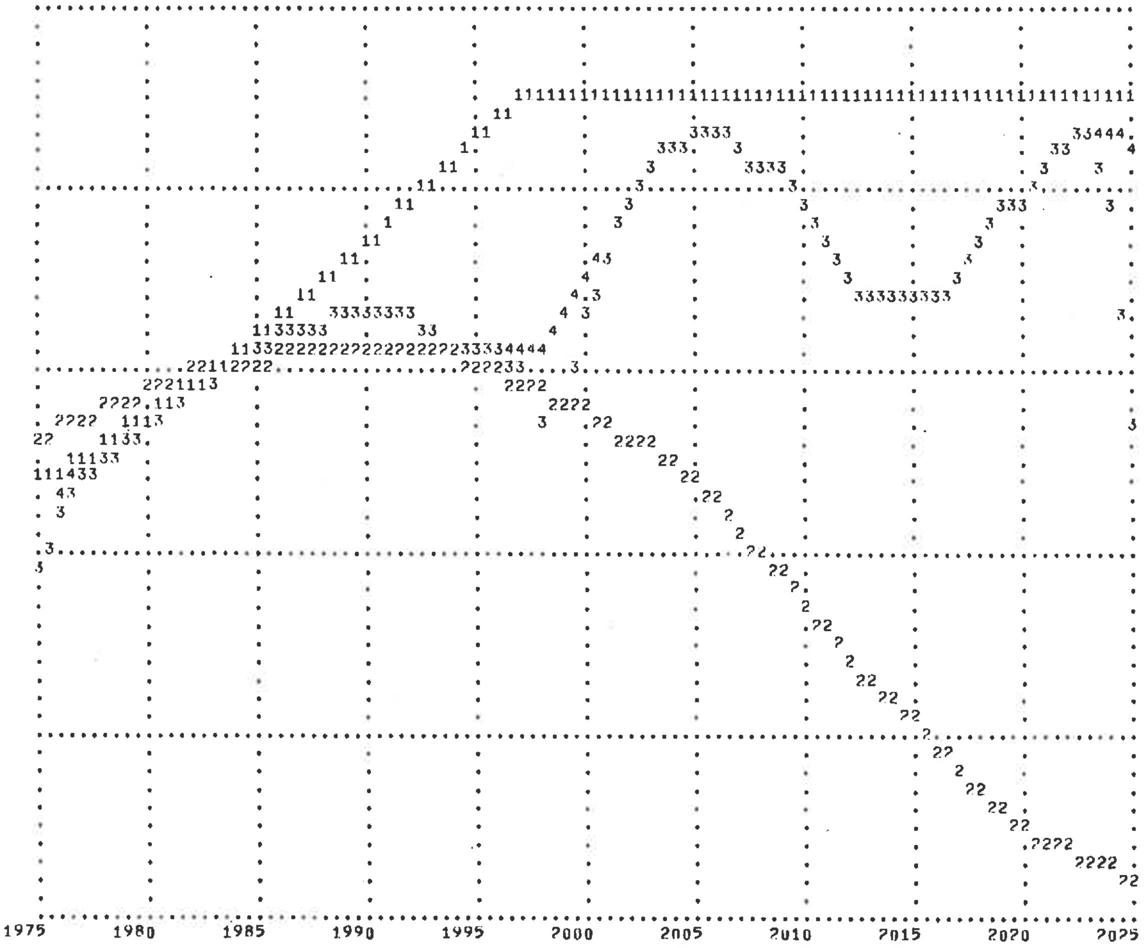
PAGE     3     04/17/74     15:35     SUMMARY OIL VARIABLES

          PRO      OCKL      UMNW      OMW       UDEFS     RD       SUMREM   SUMOP    SUMOR    SUMCUP
1975    4.75842  0.529984  12.1404    9.5942  -2.54614  51.0029  1479.50  21.9834   780.00  21.9834
1976    4.90369  0.539978  11.8091   11.1006  -0.70862  54.0742  1428.50  24.2642   809.02  24.2642
1977    5.05066  0.549988  12.0461   12.0459   0.74280  56.6719  1374.44  26.0781   838.83  26.8213
1978    5.20215  0.559982  12.5376   12.5371   1.35144  58.7891  1317.78  27.5083   869.42  28.8599
1979    5.35815  0.569977  13.0217   13.0215   1.46448  60.4199  1258.97  29.0005   900.69  30.4653
1980    5.51880  0.579987  13.5642   13.5640   1.58093  61.5723  1196.56  30.5620   932.11  32.1436
1981    5.68433  0.589981  14.1003   14.1001   1.71338  62.2510  1136.97  32.1865   963.11  33.9014
1982    5.85474  0.599991  14.6260   14.6255   1.84595  62.4766  1074.75  33.8838   993.17  35.7305
1983    6.03027  0.599991  14.7598   14.7595   2.56250  62.2646  1012.23  35.0791  1021.77  37.6416
1984    6.21106  0.609985  15.2478   15.2478   2.07471  61.6445   949.97  36.9102  1048.97  38.9844
1985    6.39734  0.609985  15.4260   15.4258   2.84839  60.6455   888.31  38.2002  1073.69  41.0498
1986    6.58923  0.619980  15.9436   15.9434   2.33594  59.3057   827.72  40.1641  1096.13  42.5000
1987    6.78687  0.619980  16.0684   16.0679   3.16675  57.6533   768.41  41.5488  1115.28  44.7158
1988    6.99036  0.619980  16.1587   16.1587   3.29004  55.7295   710.75  42.9805  1131.38  46.2705
1989    7.19995  0.629990  16.6021   16.6021   2.71240  53.5732   655.02  45.1641  1144.13  47.8779
1990    7.41589  0.629990  16.6147   16.6143   3.19458  51.2236   601.44  46.7002  1152.53  49.8955
1991    7.63831  0.629990  16.5781   16.5781   3.23657  48.7217   550.22  48.2861  1157.03  51.5225
1992    7.86743  0.629990  16.4863   16.4863   3.39551  46.1025   501.50  49.9160  1157.47  53.3125
1993    8.10352  0.619980  15.8877   15.8875   4.40991  43.4043   455.41  50.7559  1153.66  55.1670
1994    8.34644  0.619980  15.6746   15.6743   3.01001  40.6602   412.01  52.3555  1146.31  55.3662
1995    8.59668  0.609985  15.5503   15.5503   2.87866  37.9043   371.36  53.1396  1134.59  56.0195
1996    8.85449  0.599991  15.4307   15.4304   2.64673  35.1631   333.46  53.9141  1119.38  56.5615
1997    9.00000  0.589981  15.4663   15.1570  -0.30945  32.4629   298.30  54.6885  1100.63  54.6885
1998    9.00000  0.579987  15.6199   13.6409  -1.97913  29.8286   265.84  54.3926  1078.38  54.3926
1999    9.00000  0.569977  16.4048   14.1875  -2.21729  27.2803   236.01  54.8740  1053.84  54.8740
2000    9.00000  0.559982  17.8604   16.4048  -1.45532  24.8330   208.74  56.2813  1026.25  56.2813
2001    9.00000  0.539978  18.2808   18.2803   0.98853  22.5010   183.91  57.5635   994.78  58.5527
2002    9.00000  0.529984  19.5371   19.5366   1.63965  20.2949   161.42  58.8564   959.72  60.4971
2003    9.00000  0.519989  20.6489   20.6484   2.17090  18.2202   141.12  60.1328   921.16  62.3037
2004    9.00000  0.499992  21.1357   21.1353   3.79468  16.2827   122.90  60.1904   879.23  63.9854
2005    9.00000  0.479988  21.4619   21.4614   4.15747  14.4854   106.62  60.0742   835.33  64.2324
2006    9.00000  0.459991  21.6582   21.6582   4.39990  12.8320    92.15  59.8379   789.75  64.2383
2007    9.00000  0.429993  21.1577   21.1572   5.94043  11.3147    79.33  58.1406   742.73  64.0820
2008    9.00000  0.399994  20.5327   20.5327   6.05298   9.9314    66.02  56.2266   695.91  62.2803
2009    9.00000  0.379990  20.4126   20.4126   3.87671   8.6790    58.10  55.5283   649.63  59.4053
2010    9.00000  0.349991  19.5586   19.5581   4.60977   7.5502    49.42  53.1816   602.78  57.1924
2011    9.00000  0.319992  18.5801   18.5796   3.67310   6.5402    41.88  50.9614   557.14  54.6553
2012    9.00000  0.289993  17.4717   17.4712   3.93384   5.6385    35.35  48.5791   512.70  52.5127
2013    9.00000  0.259995  16.9082   16.9077   3.16602   4.8406    29.71  45.9277   469.76  49.0947
2014    9.00000  0.239994  17.0903   17.0898   0.40210   4.1362    24.87  44.5967   428.68  44.9990
2015    9.00000  0.219994  17.2974   17.2974   0.70410   3.5209    20.75  43.0801   388.23  43.7842
2016    9.00000  0.189995  16.9824   16.9819   3.44263   2.9836    17.24  39.6367   348.66  43.0801
2017    9.00000  0.169994  17.7134   17.7134   1.17212   2.5159    14.26  37.6670   312.02  38.8389
2018    9.00000  0.139996  18.3770   18.3765   2.86475   2.1149    11.76  34.3945   276.87  37.2598
2019    9.00000  0.119997  19.4443   19.4438   1.84351   1.7696     9.66  32.8896   244.60  34.7334
2020    9.00000  0.099998  19.7358   19.7358   2.75684   1.4735     7.90  31.2090   213.48  33.9658
2021    9.00000  0.089998  20.7695   20.7695   1.64014   1.2220     6.43  30.9302   183.75  32.5703
2022    9.00000  0.079998  21.3711   21.3706   0.60278   1.0099     5.22  30.5596   154.04  31.1621
2023    9.00000  0.069998  21.6333   21.6328   0.71655   0.8312     4.23  30.1123   124.50  30.8291
2024    9.00000  0.059999  21.6250   19.6743  -1.95068   0.6815     3.41  27.6240    95.22  27.6240
2025    9.00000  0.049999  21.1958   13.5649  -7.63086   0.5559     2.73  21.1206    68.28  21.1206
```

Graph 13

```
PAGE   13     04/15/74     14:24     SUMMARY OIL VARIABLES

    PRO        OCKL        OMW        OMNW
 10.00000   1.000000   25.0000    25.0000
  0.00000   0.000000    0.0000     0.0000
    1          2          3          4
```



B 1o47

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PAGE   14      04/15/74      14:24      SUMMARY OIL VARIABLES

              PRD       OCKL        UMW        OMNW
1975        4.75842   0.529984    9.5942    12.1404
1976        4.90369   0.539978   11.1006    11.8091
1977        5.05066   0.549988   12.0459    12.0461
1978        5.20215   0.559982   12.5371    12.5376
1979        5.35815   0.569977   13.0215    13.0217
1980        5.51880   0.579987   13.5640    13.5642
1981        5.68433   0.589981   14.1001    14.1003
1982        5.85474   0.599991   14.6255    14.6260
1983        6.03027   0.599991   14.7595    14.7598
1984        6.21106   0.609985   15.2478    15.2478
1985        6.39734   0.609985   15.4258    15.4260
1986        6.58923   0.619980   15.9434    15.9436
1987        6.78687   0.619980   16.0679    16.0684
1988        6.99036   0.619980   16.1587    16.1587
1989        7.19995   0.629990   16.6021    16.6021
1990        7.41589   0.629990   16.6143    16.6147
1991        7.63831   0.629990   16.5781    16.5781
1992        7.86743   0.629990   16.4863    16.4863
1993        8.10352   0.619980   15.9875    15.8677
1994        8.34644   0.619980   15.6743    15.6746
1995        8.59668   0.609985   15.5503    15.5503
1996        8.85449   0.599991   15.4304    15.4307
1997        9.00000   0.589981   15.1570    15.4663
1998        9.00000   0.579987   13.6409    15.6199
1999        9.00000   0.569977   14.1875    16.4048
2000        9.00000   0.559982   16.4048    17.8604
2001        9.00000   0.539978   18.2803    18.2808
2002        9.00000   0.529984   19.5366    19.5371
2003        9.00000   0.519989   20.6484    20.6489
2004        9.00000   0.499992   21.1353    21.1357
2005        9.00000   0.479983   21.4614    21.4619
2006        9.00000   0.459991   21.6582    21.6582
2007        9.00000   0.429993   21.1572    21.1577
2008        9.00000   0.399994   20.5327    20.5327
2009        9.00000   0.379990   20.4126    20.4126
2010        9.00000   0.349991   19.5581    19.5586
2011        9.00000   0.319992   18.5796    18.5801
2012        9.00000   0.289993   17.4712    17.4717
2013        9.00000   0.259995   16.9077    16.9082
2014        9.00000   0.239994   17.0898    17.0903
2015        9.00000   0.219994   17.2974    17.2974
2016        9.00000   0.189995   16.9819    16.9824
2017        9.00000   0.169994   17.7134    17.7134
2018        9.00000   0.139996   18.3765    18.3770
2019        9.00000   0.119997   19.4438    19.4443
2020        9.00000   0.099998   19.7358    19.7358
2021        9.00000   0.089998   20.7695    20.7695
2022        9.00000   0.079998   21.3706    21.3711
2023        9.00000   0.069998   21.6328    21.6333
2024        9.00000   0.059999   19.6743    21.6250
2025        9.00000   0.049999   13.5649    21.1958
```

B 1o48

```
PAGE     9      04/15/74      14:24      SUMMARY OIL VARIABLES

        Y1234       Y          CAPAC      CAPAC
                    ME         MF         NAM
       10.00000    2500.00    2500.00    25.0000
        0.00000       0.00       0.00     0.0000
          1          2          3          4
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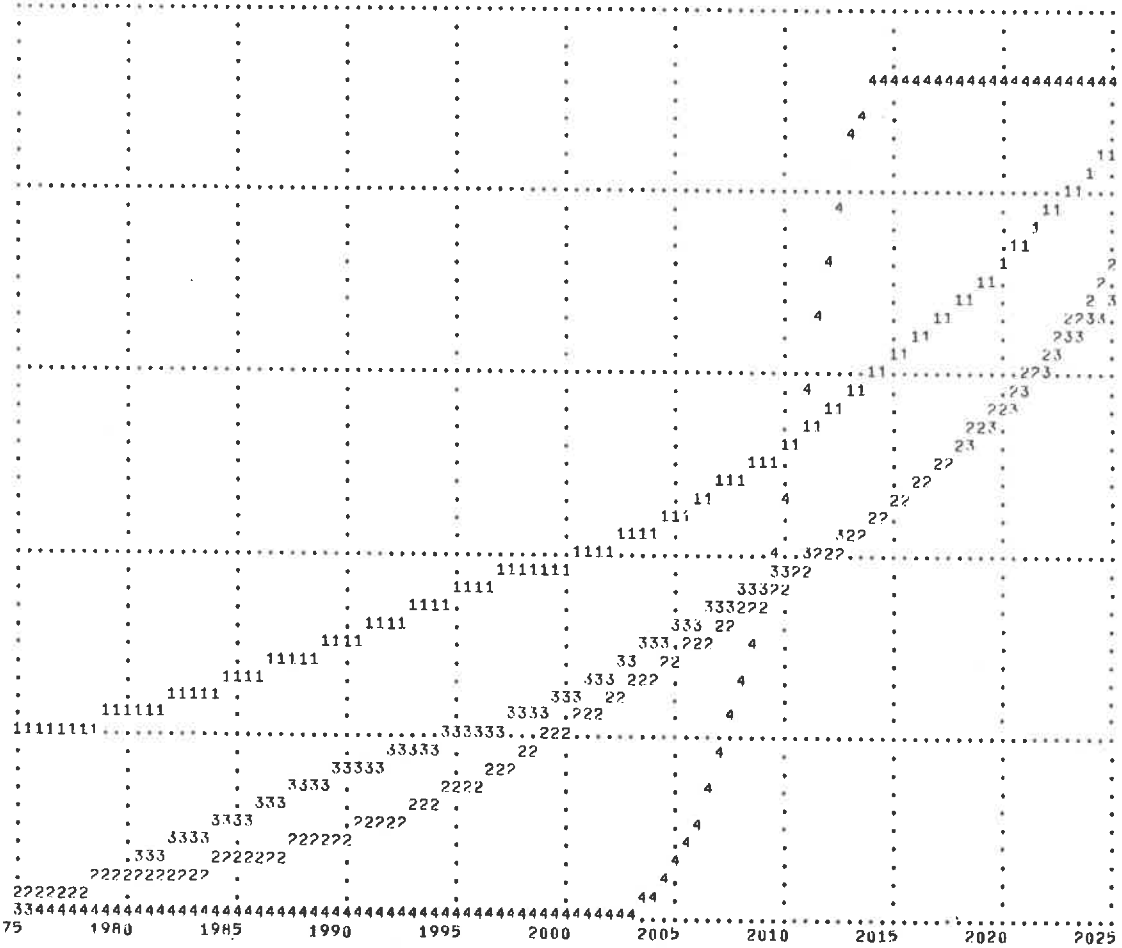

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PAGE   10     04/15/74     14:24     SUMMARY OIL VARIABLES

              Y1234        Y          CAPAC      CAPAC
                           ME         ME         NAM
1975         1.99477      66.09      17.69      0.0000
1976         1.97144      71.44      38.29      0.0000
1977         2.01514      77.85      61.19      0.0000
1978         2.08557      84.68      85.27      0.0000
1979         2.15778      91.92     110.13      0.0000
1980         2.23163     100.16     136.16      0.0000
1981         2.30737     108.76     162.93      0.0000
1982         2.39483     118.33     190.40      0.0000
1983         2.46411     128.83     217.52      0.0000
1984         2.54523     140.24     245.26      0.0000
1985         2.62823     152.53     272.52      0.0000
1986         2.71326     165.68     299.88      0.0000
1987         2.79999     180.25     326.25      0.0000
1988         2.88873     196.23     351.62      0.0000
1989         2.97961     213.56     376.98      0.0000
1990         3.07214     232.20     401.47      0.0000
1991         3.16602     252.73     424.67      0.0000
1992         3.26074     275.09     446.05      0.0000
1993         3.35620     299.82     464.77      0.0000
1994         3.45367     326.26     481.78      0.0000
1995         3.55212     355.56     497.86      0.0000
1996         3.65192     387.05     513.77      0.0000
1997         3.75323     420.05     533.09      0.0000
1998         3.84546     454.53     555.80      0.0000
1999         3.86208     489.83     581.92      0.0000
2000         3.91827     526.53     612.44      0.0000
2001         3.98669     564.00     646.86      0.0000
2002         4.10095     602.20     683.94      0.0000
2003         4.21985     641.14     722.95      0.1116
2004         4.34351     680.77     761.66      0.6446
2005         4.47375     720.47     799.34      1.5454
2006         4.61047     760.84     835.95      2.7666
2007         4.75378     801.88     869.97      4.4344
2008         4.90479     842.94     901.22      6.4631
2009         5.06360     884.64     933.30      8.7249
2010         5.22961     926.36     965.94     11.4722
2011         5.40417     968.70     999.08     14.6863
2012         5.58752    1012.25    1031.66     18.2554
2013         5.77966    1057.56    1064.94     21.4575
2014         5.97852    1104.63    1103.97     23.0103
2015         6.17908    1153.94    1148.59     23.0103
2016         6.38123    1205.47    1192.63     23.0103
2017         6.58984    1259.16    1241.25     23.0103
2018         6.80444    1315.53    1290.94     23.0103
2019         7.02820    1374.50    1344.19     23.0103
2020         7.26013    1436.03    1398.41     23.0103
2021         7.50183    1500.63    1456.75     23.0103
2022         7.75208    1567.59    1522.13     23.0103
2023         8.01147    1638.09    1595.31     23.0103
2024         8.28076    1711.41    1664.47     23.0103
2025         8.52661    1788.06    1710.16     23.0103
```

in North American and South Asian oil production as a result of the higher oil prices and their equally dramatic decrease later as oil reserves dwindle. Graph 12 shows world oil supply situation, either an oil deficit or surplus (ODEFS), again in billions of barrels. The end of the oil shortage of the 1970s can be seen clearly, as price rises cause demand to grow less rapidly and supply to grow more rapidly. A deficit also arises in the late 1990s when oil in many world regions becomes depleted. Again in the 2020s a deficit shows up as Mideast oil dwindles. Graph 13 shows that this last deficit would not deepen significantly if the time horizon were extended, because the oil consumption demand curve of Linden (OCKL) is rapidly approaching zero at that point.[2] Graph 13 also shows the rise in oil prices (PRO). Note also the curves for world oil imports (OMW) and world oil import need (OMNW). For the most part these two overlap because there are no output restrictions and demand does dwindle at much the same rate as oil reserves. In later scenarios we will see more separation of those curves. Finally, Graph 14 shows basic economic and monetary data. It traces the growth of GRP in the first or Western developed world (Y1234), the GRP of the Middle EAst, and capital accumulated (CAPAC) by both the Middle East and North America for oil sales, in billions of 1963 dollars.

We turn now to conflict scenarios.

Footnotes

[1] The Houtthaker and Jorgensen model suggests that Mideast revenues could be as low as $17.7 billion in 1980 and their upper estimate is only $22.8 billion. See "The World Petroleum Model: An Overview" (March 13, 1974). Although the $100 billion figure is unreasonably high, the Houtthaker and Jorgensen range seems improbably low.

[2] For an explanation of that curve and the computation of oil demand in the model, see Barry Hughes, op. cit.

5. Conflict Scenarios

The world of 2025 could stand in marked contrast to that of the scenario in the last chapter. Analysis with the oil model shows that conflictual actions, by either the Mideast or the rest of the world, will be damaging to both actor and target (or innocent bystanders). This chapter will look at the impact of two kinds of conflict. The first is the possibility of oil production limitations by the Middle East. The second is possible retaliation of oil importers against higher oil prices by means of higher prices on capital goods exported to the Mideast. Again it should be noted that Mideast production limitations, although labeled conflict here, could be established without malice.

5.1 Oil Production Limitations

There are an infinite number of possible oil production limitation scenarios and the purpose of the analysis here is by no means to suggest a "likely" or "highly possible" one. Instead, the analysis will suggest the implications of oil production cutbacks in general. We introduced a relatively moderate production cut-back by the Mideast region. In 1975 oil production was cut from about 8.5 billion barrels to 7 billion. The restriction was gradually relaxed until it allowed production of 14 billion barrels in 2015, a level which was held constant thereafter. Without a restriction on production, that is in the standard run, Mideast oil production in 2015 would have been 16.7 billion barrels. The production restriction is thus relatively mild, except in the decade after 2020 when Mideast oil production without a restriction reaches 23.4 billion barrels. This output restriction scenario thus assumes that the restriction would be greatest when Mideast oil was most threatened with depletion. The resultant pattern of oil production for the Middle East, North America, and Southeast Asia (also a potential oil exporter) is traced in Graph 1. The squeeze prolongs the exploding demand based deficit of the 1970s, deepens that of the late 1990s, when many of the world regions are exhausting supplies, and greatly intensifies that of the early 21st century, when North American and Southeast Asian supplies dwindle. Graphs 1 and 2 can profitably be compared with the same data from the standard run--see Graphs 11 and 12 of Chapter 3. Graph 3 shows the magnitudes of the oil production restrictions in another way. The gaps between world oil imports (OMW) and world oil import need (OMNW) are much larger than in the cooperative scenario, especially in the 2020s.

The implications of the restriction for developed world growth are major. Economic output for the first world in the cooperative scenario reached $8.5 trillion. In the squeeze scenario it reaches only a comparatively modest $7.3 trillion. There is no impact on the size of the Middle East economy because the exports are still adequate to finance all economic development which that region is capable of absorbing, and because we are assuming no economic retaliation by importers in this scenario. The squeeze does have negative consequences for the Mideast, however, in that very considerably less capital is accumulated. Graph 4 shows the economic data and the monetary or capital accumulation data. In 2025 the total capital accumulation of the Mideast is $982 billion, as opposed to $1788 billion in the cooperative scenario. Naturally the larger amounts of oil

B 1o55

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PAGE   21      04/17/74      15:35      SUMMARY OIL VARIABLES

          OP          OP          OP
          NAM         ME          SEA
          25.0000     25.0000     25.0000
           0.0000      0.0000      0.0000
            1           2           3
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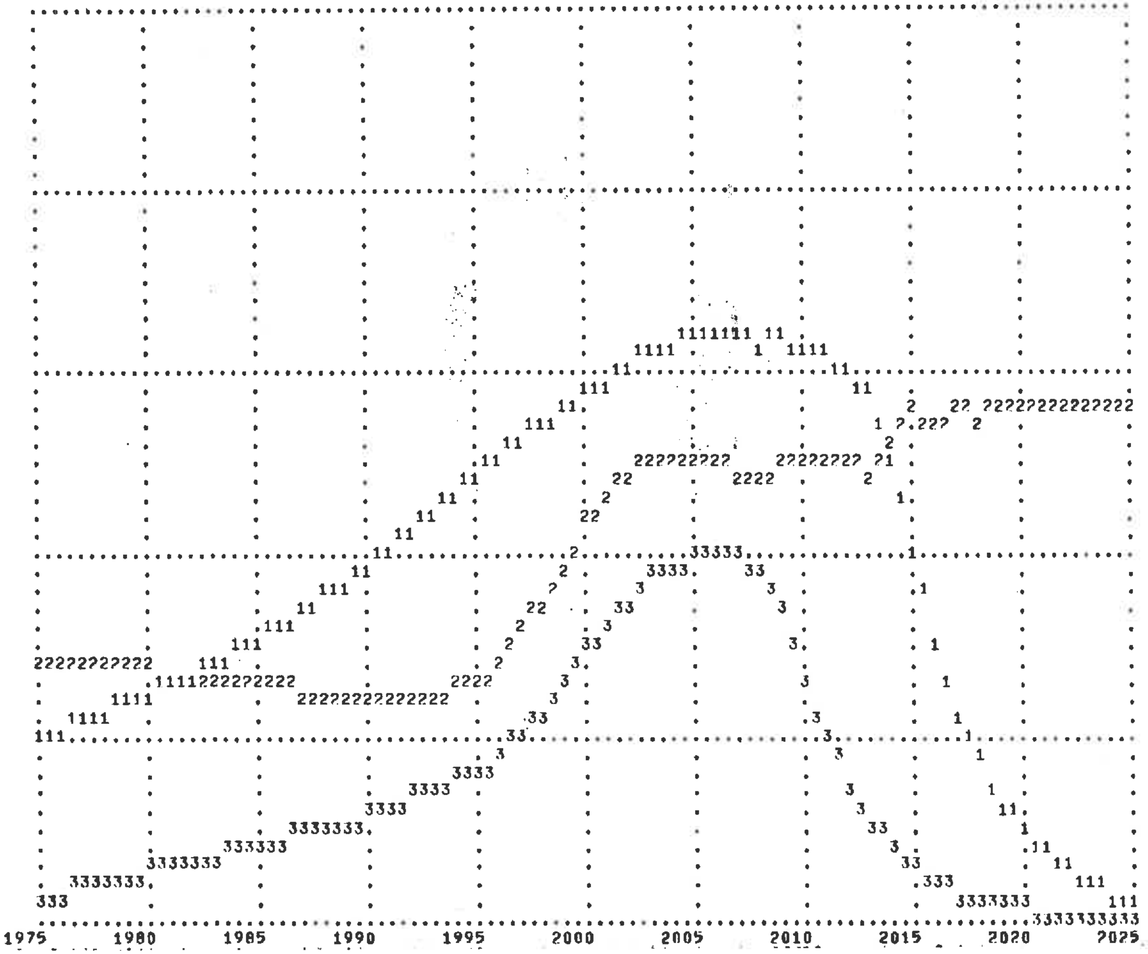

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PAGE    22      04/17/74      15:35      SUMMARY OIL VARIABLES

              OP        OP        OP
              NAM       ME        SEA
1975        5.0396    7.0000    0.7339
1976        5.2676    7.0000    0.8405
1977        5.5045    7.0000    0.9624
1978        5.7521    7.0000    1.1019
1979        6.0107    7.0000    1.2616
1980        6.2810    6.8969    1.4362
1981        6.5635    6.7882    1.5897
1982        6.8586    6.8444    1.7336
1983        7.1671    6.6525    1.8544
1984        7.4895    6.6820    2.0120
1985        7.8263    6.4833    2.1411
1986        8.1782    6.4998    2.3132
1987        8.5459    6.3055    2.4510
1988        8.9302    6.1271    2.5925
1989        9.3318    6.1522    2.7870
1990        9.7515    6.0492    2.9511
1991       10.1899    6.0138    3.1343
1992       10.6482    6.1967    3.3917
1993       11.1270    6.2621    3.6067
1994       11.6274    6.4692    3.8822
1995       12.1504    6.5924    4.1187
1996       12.6968    7.1290    4.5656
1997       13.1819    7.9716    5.1963
1998       13.5771    8.8484    5.8717
1999       13.9844    9.8213    6.6349
2000       14.4038   10.9014    7.4973
2001       14.8027   11.5989    8.1477
2002       15.1929   12.2583    8.7964
2003       15.5659   12.8264    9.4055
2004       15.8359   12.7791    9.7329
2005       16.0352   12.7100    9.9839
2006       16.1685   12.6692   10.1755
2007       16.0508   12.2544    9.9746
2008       15.8320   11.9512    9.5291
2009       15.9299   12.4338    8.3950
2010       15.7803   12.5957    6.5592
2011       15.5068   12.6875    5.0831
2012       15.0645   12.5693    3.8643
2013       14.4148   12.3337    2.8385
2014       12.7839   13.1802    2.0714
2015       10.2537   14.0000    1.5210
2016        7.8073   13.6667    1.1307
2017        5.8541   14.0000    0.8533
2018        4.3810   13.8630    0.6539
2019        3.2889   13.9287    0.5085
2020        2.4822   14.0000    0.4006
2021        1.8849   14.0000    0.3191
2022        1.4405   14.0000    0.2564
2023        1.1079   14.0000    0.2073
2024        0.8572   14.0000    0.1684
2025        0.6670   14.0000    0.1372
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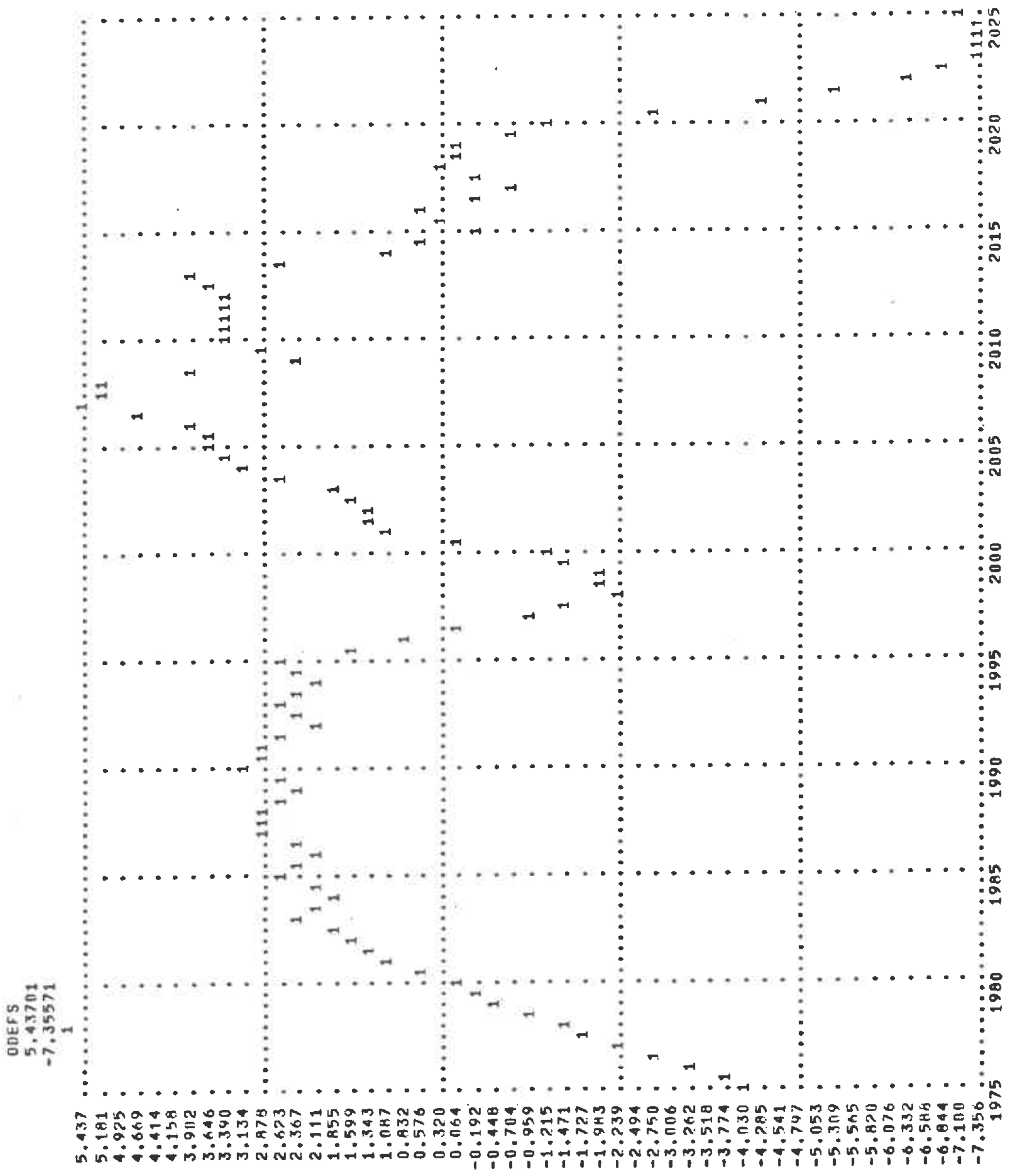
B 1o57

Graph 2

PAGE 25   04/17/74   15:35   WORLD OIL DEFICIT



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PAGE   26     04/17/74     15:35     SUMMARY OIL VARIABLES

          PHO       OCKL       OMNW      OMW       ODEFS      RD       SUMREM    SUMOP     SUMOR    SUMCOP
1975    4.75842  0.529984   12.1406    8.0942  -4.04639   51.0029   1479.50   20.4834    780.00   20.4834
1976    4.90369  0.539978   11.6887    8.5364  -3.15234   54.0742   1428.50   21.6997    810.52   21.6997
1977    5.05066  0.549988   11.2866    9.0295  -2.25720   56.6729   1374.44   23.0615    842.89   23.0615
1978    5.20215  0.559982   10.9275    9.6226  -1.30481   58.7910   1317.81   24.5952    876.48   24.5952
1979    5.35815  0.569977   10.8545   10.3660  -0.48840   60.4219   1259.00   26.3267    910.67   26.3267
1980    5.51880  0.579987   11.1035   11.1035   0.19373   61.5742   1198.59   28.0942    944.77   28.2881
1981    5.68433  0.589981   11.5271   11.5269   1.13550   62.2529   1137.00   29.6245    978.25   30.7603
1982    5.85474  0.599991   11.9390   11.9387   1.67273   62.4766   1074.75   31.2285   1010.88   32.9014
1983    6.03027  0.599991   11.9968   11.9966   2.34338   62.2666   1012.27   32.3682   1042.13   34.7119
1984    6.21106  0.609985   12.3953   12.3950   1.88770   61.6465    949.98   34.1016   1072.00   35.9902
1985    6.39734  0.609985   12.4990   12.4988   2.61060   60.6484    888.36   35.3350   1099.56   37.9463
1986    6.58923  0.619980   12.9016   12.9014   2.12378   59.3047    827.69   37.2041   1124.88   39.3281
1987    6.78687  0.619980   12.9536   12.9534   2.90515   57.6533    768.41   38.5303   1146.97   41.4355
1988    6.99036  0.619980   12.9729   12.9727   3.01636   55.7295    710.73   39.9014   1166.06   42.9170
1989    7.19995  0.629990   13.3030   13.3027   2.46655   53.5732    655.02   41.9795   1181.91   44.4463
1990    7.41589  0.629990   13.2488   13.2485   3.11060   51.2256    601.45   43.4521   1193.50   46.5635
1991    7.63831  0.629990   13.1494   13.1492   2.98584   48.7207    550.22   44.9766   1201.28   47.9629
1992    7.86743  0.629990   12.9973   12.9971   2.13684   46.1045    501.52   46.5459   1205.00   48.6816
1993    8.10352  0.619980   12.4124   12.4121   2.64343   43.4043    455.41   47.4023   1204.56   50.0459
1994    8.34644  0.619980   12.1392   12.1389   2.11926   40.6602    412.00   48.9951   1200.56   51.1143
1995    8.59668  0.609985   12.0093   12.0090   2.57617   37.9023    371.34   49.8125   1192.22   52.3896
1996    8.85449  0.599991   11.9370   11.9368   0.97949   35.1621    333.45   50.5869   1180.31   51.5664
1997    9.00000  0.589981   11.9995   11.0605  -0.93909   32.4629    298.30   50.6914   1164.88   50.6914
1998    9.00000  0.579987   12.1985   10.1016  -2.09705   29.8286    265.84   50.5889   1146.66   50.5889
1999    9.00000  0.569977   13.7480   11.7876  -1.96033   27.2803    236.02   51.3301   1125.91   51.3301
2000    9.00000  0.559982   14.8525   13.7434  -1.10901   24.8325    208.73   52.8789   1101.84   52.8789
2001    9.00000  0.539978   15.5894   15.5891   1.19263   22.5010    183.91   53.9629   1073.81   55.1563
2002    9.00000  0.529984   16.8657   16.8652   1.50439   20.2939    161.41   55.2529   1042.34   56.7578
2003    9.00000  0.519989   17.9419   17.9414   1.94995   18.2212    141.13   56.5293   1007.39   58.4795
2004    9.00000  0.499992   18.3760   18.3755   3.24805   16.2856    122.92   56.6240    969.06   59.8721
2005    9.00000  0.479988   18.6821   18.6816   3.63135   14.4868    106.62   56.5498    928.72   60.1826
2006    9.00000  0.459991   18.8804   18.8799   3.91943   12.8337     92.17   56.3760    886.66   60.2959
2007    9.00000  0.429993   18.4414   18.4409   5.43701   11.3152     79.33   54.8018    843.11   60.2393
2008    9.00000  0.399994   17.8823   17.8823   5.29541    9.9321     68.03   53.0088    799.63   58.3037
2009    9.00000  0.379990   17.7705   17.7700   2.49097    8.6802     58.11   52.3516    756.55   54.8428
2010    9.00000  0.349991   16.9766   16.9761   3.35059    7.5514     49.43   50.1152    712.88   53.4658
2011    9.00000  0.319992   16.0645   16.0640   3.32837    6.5396     41.88   48.0234    670.31   51.3525
2012    9.00000  0.289993   15.4932   15.4929   3.58105    5.6393     35.35   45.7324    628.83   49.3135
2013    9.00000  0.259995   15.1531   15.1528   4.05762    4.8406     29.71   43.1963    588.73   47.2549
2014    9.00000  0.239994   15.2112   15.2109   1.12964    4.1381     24.89   41.9229    550.39   43.0527
2015    9.00000  0.219994   14.9294   14.8745  -0.05493    3.5217     20.76   40.4189    512.61   40.4189
2016    9.00000  0.189995   13.8479   13.8477   0.61609    2.9827     17.24   37.1748    475.70   37.7910
2017    9.00000  0.169994   15.4636   14.8093  -0.65442    2.5165     14.26   34.6279    441.52   34.6279
2018    9.00000  0.139996   16.2251   16.2251   0.28101    2.1127     11.75   32.0771    409.41   32.3574
2019    9.00000  0.119997   17.3501   17.3501   0.15405    1.7679      9.65   30.6597    379.45   30.8140
2020    9.00000  0.099998   17.7041   16.4624  -1.24146    1.4724      7.89   27.8354    350.56   27.8354
2021    9.00000  0.089998   18.5635   14.3169  -4.24658    1.2213      6.43   24.4072    324.20   24.4072
2022    9.00000  0.079998   18.6362   12.4219  -6.21436    1.0075      5.21   21.5610    301.02   21.5610
2023    9.00000  0.069998   18.1592   10.9910  -7.16846    0.8265      4.20   19.4370    280.46   19.4370
2024    9.00000  0.059999   17.3438    9.9880  -7.35571    0.6785      3.39   17.9146    261.86   17.9146
2025    9.00000  0.049999   16.3438    9.2971  -7.04663    0.5530      2.72   16.8374    244.63   16.8374
```

B 1058

B 1o59

Graph 3

```
PAGE   23     04/17/74     15:35     SUMMARY OIL VARIABLES

        PRO        OCKL        OMW        OMNW
      10.00000   1.000000    25.0000    25.0000
       0.00000   0.000000     0.0000     0.0000
          1          2           3          4
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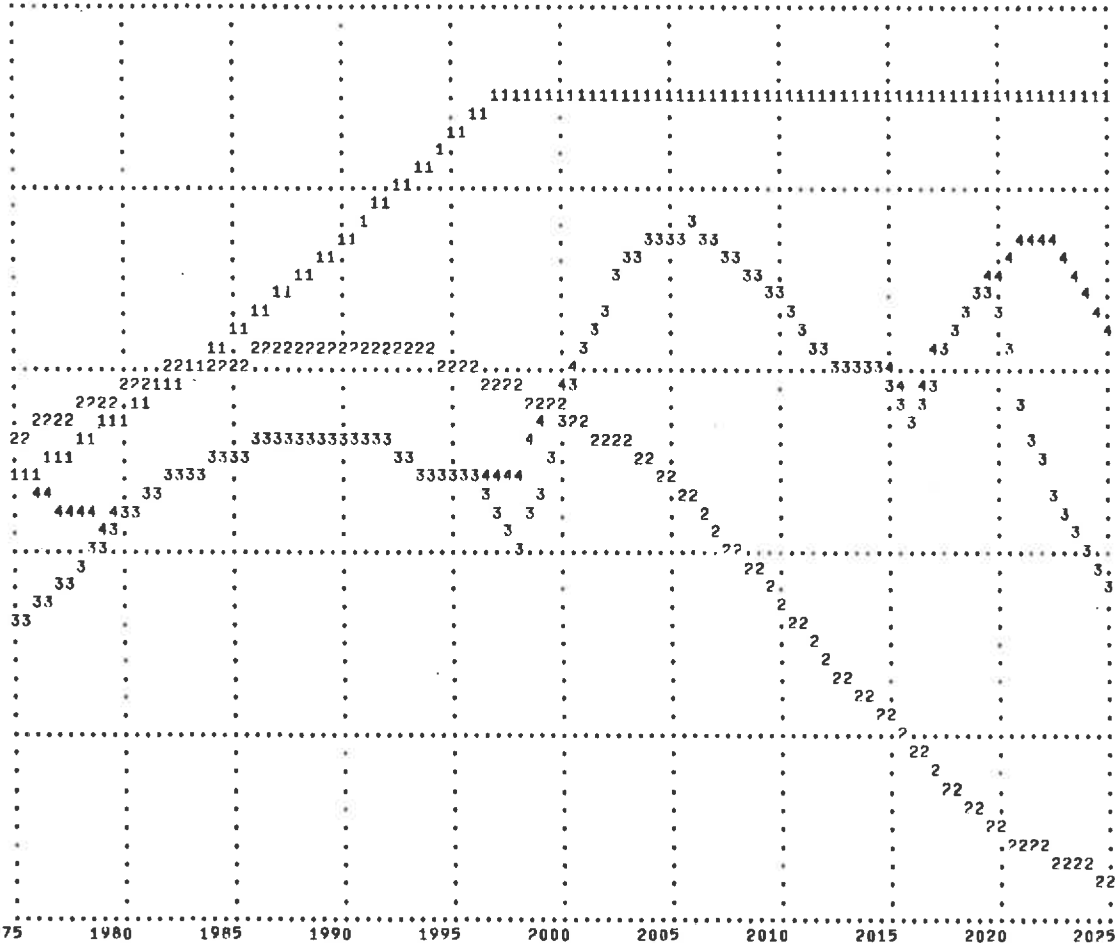

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   PAGE   24     04/17/74     15:35     SUMMARY OIL VARIABLES


              PRO       OCKL       OMW       OMNW
1975        4.75842  0.529984    8.0942    12.1406
1976        4.90369  0.539978    8.5364    11.6887
1977        5.05066  0.549988    9.0295    11.2866
1978        5.20215  0.559982    9.6226    10.9275
1979        5.35815  0.569977   10.3660    10.8545
1980        5.51880  0.579987   11.1035    11.1035
1981        5.68433  0.589981   11.5269    11.5271
1982        5.85474  0.599991   11.9387    11.9390
1983        6.03027  0.599991   11.9966    11.9968
1984        6.21106  0.609985   12.3950    12.3953
1985        6.39734  0.609985   12.4988    12.4990
1986        6.58923  0.619980   12.9014    12.9016
1987        6.78687  0.619980   12.9534    12.9536
1988        6.99036  0.619980   12.9727    12.9729
1989        7.19995  0.629990   13.3027    13.3030
1990        7.41589  0.629990   13.2485    13.2488
1991        7.63831  0.629990   13.1492    13.1494
1992        7.86743  0.629990   12.9971    12.9973
1993        8.10352  0.619980   12.4121    12.4124
1994        8.34644  0.619980   12.1389    12.1392
1995        8.59668  0.609985   12.0090    12.0093
1996        8.85449  0.599991   11.9368    11.9370
1997        9.00000  0.589981   11.0605    11.9995
1998        9.00000  0.579987   10.1016    12.1985
1999        9.00000  0.569977   11.7876    13.7480
2000        9.00000  0.559982   13.7434    14.8525
2001        9.00000  0.539978   15.5891    15.5894
2002        9.00000  0.529984   16.8652    16.8657
2003        9.00000  0.519989   17.9414    17.9419
2004        9.00000  0.499992   18.3755    18.3760
2005        9.00000  0.479988   18.6816    18.6821
2006        9.00000  0.459991   18.8799    18.8804
2007        9.00000  0.429993   18.4409    18.4414
2008        9.00000  0.399994   17.8823    17.8823
2009        9.00000  0.379990   17.7700    17.7705
2010        9.00000  0.349991   16.9761    16.9766
2011        9.00000  0.319992   16.0640    16.0645
2012        9.00000  0.289993   15.4929    15.4932
2013        9.00000  0.259995   15.1528    15.1531
2014        9.00000  0.239994   15.2109    15.2112
2015        9.00000  0.219994   14.8745    14.9294
2016        9.00000  0.189995   13.8477    13.8479
2017        9.00000  0.169994   14.8093    15.4636
2018        9.00000  0.139996   16.2251    16.2251
2019        9.00000  0.119997   17.3501    17.3501
2020        9.00000  0.099998   16.4624    17.7041
2021        9.00000  0.089998   14.3169    18.5635
2022        9.00000  0.079998   12.4219    18.6362
2023        9.00000  0.069998   10.9910    18.1592
2024        9.00000  0.059999    9.9880    17.3438
2025        9.00000  0.049999    9.2971    16.3438
```

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PAGE   19     04/17/74     15:35     SUMMARY OIL VARIABLES

       Y1234      Y          CAPAC      CAPAC
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      0.00000      0.00      0.000     0.0000
       1          2          3          4
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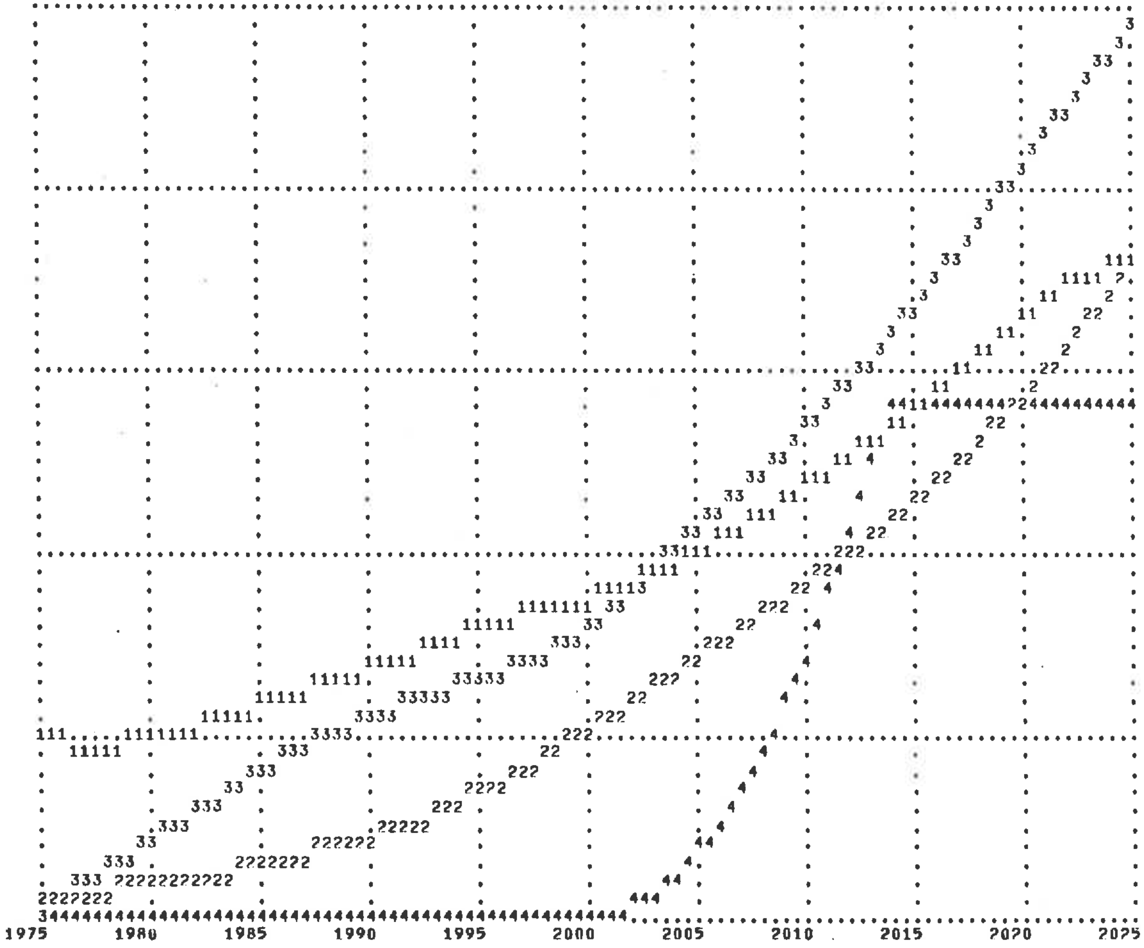

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B 1062

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   PAGE   20     04/17/74     15:35     SUMMARY OIL VARIABLES

              Y1234        Y          CAPAC        CAPAC
                           MF         MF           NAM
 1975       1.98477      66.09      14.124       0.0000
 1976       1.95703      71.44      28.482       0.0000
 1977       1.93906      77.85      43.355       0.0000
 1978       1.93063      84.68      58.558       0.0000
 1979       1.95062      91.92      73.705       0.0000
 1980       1.99997     100.16      88.947       0.0000
 1981       2.06830     108.76     103.867       0.0000
 1982       2.13843     118.33     118.953       0.0000
 1983       2.21014     128.83     133.539       0.0000
 1984       2.28375     140.24     148.258       0.0000
 1985       2.35913     152.53     162.461       0.0000
 1986       2.43652     165.68     176.375       0.0000
 1987       2.51550     180.25     189.391       0.0000
 1988       2.59644     196.23     201.551       0.0000
 1989       2.67932     213.56     213.488       0.0000
 1990       2.76404     232.20     224.438       0.0000
 1991       2.85040     252.73     234.168       0.0000
 1992       2.93781     275.09     243.059       0.0000
 1993       3.02612     299.82     251.152       0.0000
 1994       3.11615     326.26     258.023       0.0000
 1995       3.20734     355.56     263.852       0.0000
 1996       3.29993     387.05     270.797       0.0000
 1997       3.39392     420.05     279.938       0.0000
 1998       3.45630     454.53     291.336       0.0000
 1999       3.48260     489.83     304.930       0.0000
 2000       3.52435     526.53     321.516       0.0000
 2001       3.59735     564.00     340.656       0.3866
 2002       3.70422     602.20     361.922       0.9287
 2003       3.81555     641.14     384.961       1.6101
 2004       3.93121     680.77     407.797       2.6113
 2005       4.05261     720.47     430.023       3.8859
 2006       4.17969     760.84     451.867       5.3931
 2007       4.31262     801.88     472.570       7.2329
 2008       4.45203     842.94     492.383       9.3594
 2009       4.59851     884.64     514.906      11.7805
 2010       4.75146     926.36     538.922      14.6406
 2011       4.91235     968.70     563.844      17.8828
 2012       5.08093    1012.25     588.531      21.4155
 2013       5.25745    1057.56     612.609      25.1177
 2014       5.44189    1104.63     640.125      27.7656
 2015       5.62964    1153.94     671.109      28.6641
 2016       5.81726    1205.47     701.203      28.6641
 2017       6.01001    1259.16     732.562      28.6641
 2018       6.19397    1315.53     763.953      28.6641
 2019       6.39905    1374.50     795.797      28.6641
 2020       6.61157    1436.03     827.938      28.6641
 2021       6.81006    1500.63     859.797      28.6641
 2022       6.96313    1567.59     890.813      28.6641
 2023       7.08960    1638.09     921.562      28.6641
 2024       7.20715    1711.41     951.813      28.6641
 2025       7.32922    1788.06     981.750      28.6641
```

remaining in the ground must be considered by the Mideast as a factor compensating it for the lower capital accumulation of the oil production restriction scenario. It may be, however, that the larger sum, invested in regions which are themselves growing rapidly and which do not dislike Arabs for denying them oil would appear more attractive than smaller sums invested in less healthy and more hostile economies.

There is, of course, also the possibility that conflictual actions by the Middle East would be met by retaliatory actions on the part of importers. We will turn next to the impact of such retaliation. Since the affects of it can become difficult to disentangle from the affects of the oil production limitation, we will look first at the impact of retaliatory action in a scenario free from oil production limitations. Then we will return to the more likely scenario, in which both importers and exporters act conflictually.

5.2 Investment Good Price Retaliation

The basis for this scenario is the possibility of a relationship between the price of Mideast oil and the price of capital goods sold to the Mideast. Again it should be stressed that this relationship is not caused by inflation--the model runs in constant 1963 dollars. Instead the link could arise from price distortions or from retaliatory action. Retaliatory action is highly unlikely because it would require an oil consumers' cartel. Nevertheless, it has become a topic of discussion, and its implications should be worked out. For this scenario we will assume that capital goods prices for the Middle East rise relative to oil prices with an elasticity of .5. That is, capital goods prices will rise one half as much as oil prices.

Graph 5 shows the impact of this scenario on oil production. There is an impact because the increased cost of capital goods decreases the Middle Eastern growth rate and lowers its demand for energy. The impact can also be seen in Graph 6 because the deficit at the very end of the time period is reduced--since Mideast oil demand is less, its reserves last longer and better cover world demand in the last few years. The same phenomenon can be seen in Graph 7, since world oil import need and world oil imports are seldom different.

The most interesting implications of the scenario, of course, are for the economic and monetary variables of Mideast and developed regions. These are reported in Graph 8. The GRPs of both the MIddle East and the first world are slightly reduced by the retaliatory scenario from the standard cooperative run. In the case of the Middle East this is very understandable, because they have to pay higher prices and are likely to buy less. It is more surprising that Western developed region GRPs are also slightly reduced. The reason is that Middle Eastern purchases of investment goods reduce investment good availability in the developed regions and thus reduce growth. Since investment goods are measured in dollars and not in other units, the higher cost of investment goods purchased by the Middle East artificially reduces developed world good availability. If the rise in investment good prices were a result of price structure distortions (investment goods actually did rise in cost relative to the rest of the economy) this affect might be reasonable, because it would reduce developed world investment demand.

B 1o65

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PAGE    9      04/17/74      15:35      SUMMARY OIL VARIABLES

         OP          OP          OP
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         25.0000     25.0000     10.00000
          0.0000      0.0000      0.00000
           1           2           3
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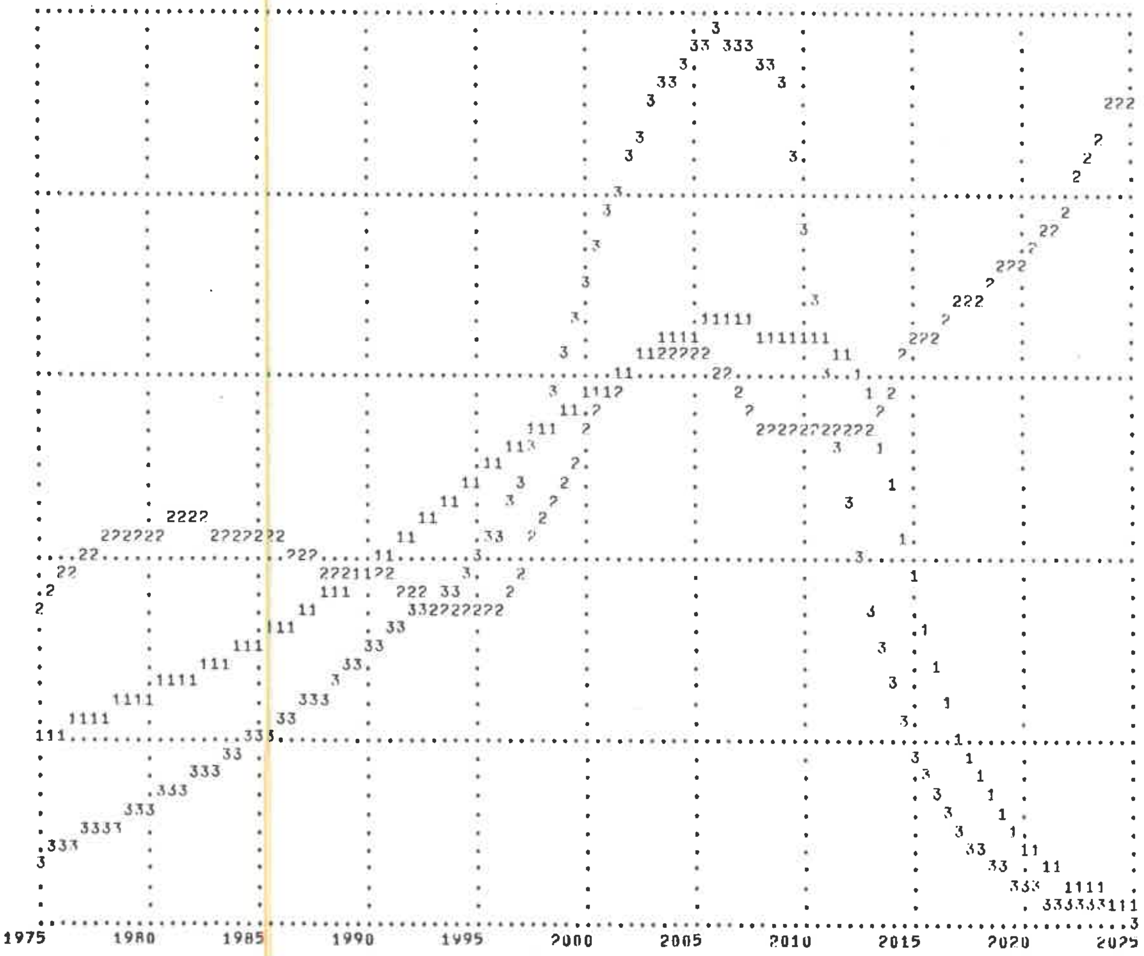

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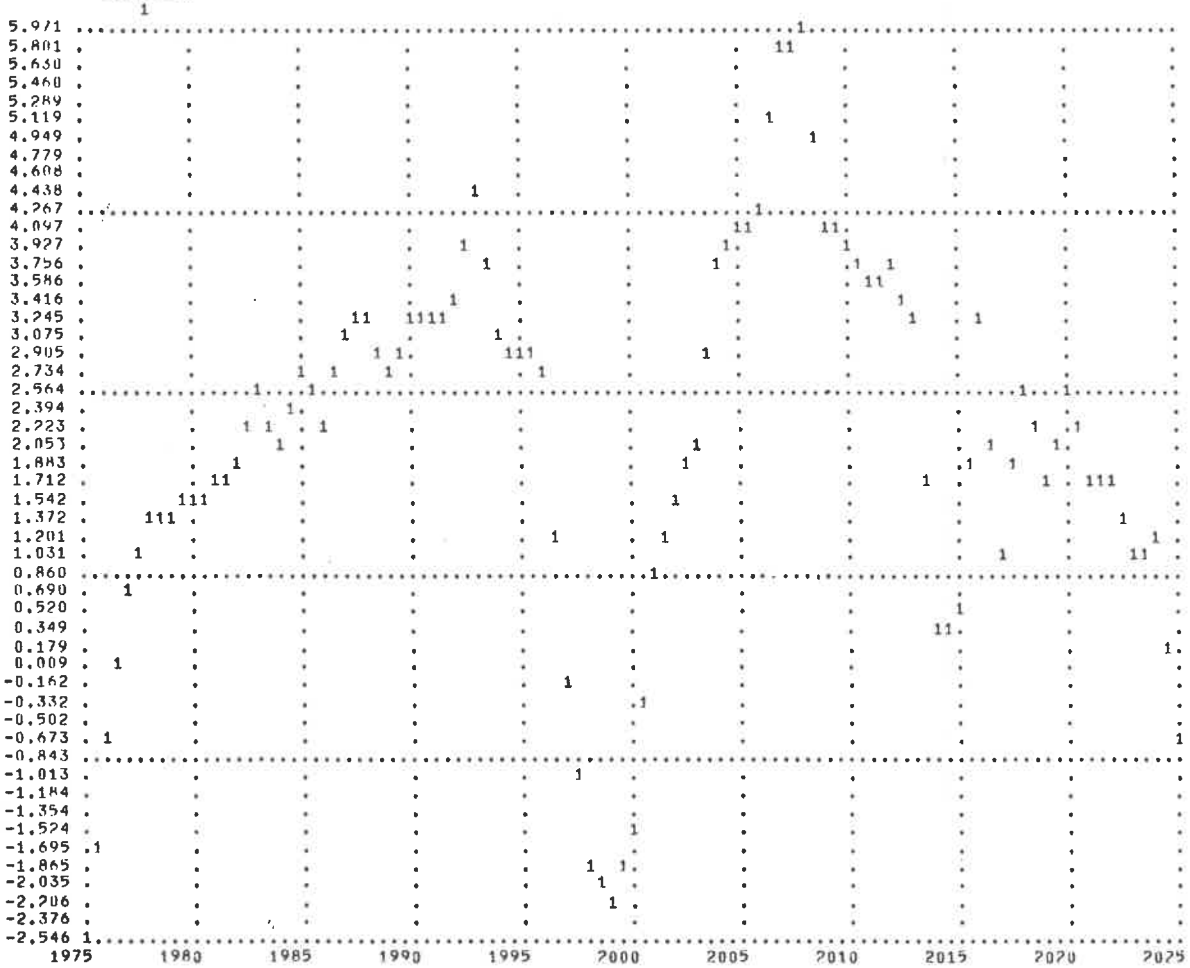
PAGE   10     04/17/74      15:35     SUMMARY OIL VARIABLES

              OP          OP          OP
              NAM         ME          SEA
1975         5.0397      8.4995     0.73395
1976         5.2677      9.5640     0.84055
1977         5.5046     10.1768     0.95151
1978         5.7522     10.4124     1.06424
1979         6.0109     10.6165     1.18539
1980         6.2813     10.7942     1.31540
1981         6.5637     10.9404     1.45438
1982         6.8589     11.0581     1.60263
1983         7.1674     10.7813     1.73691
1984         7.4897     10.8362     1.90179
1985         7.8265     10.5161     2.04718
1986         8.1787     10.5212     2.22949
1987         8.5461     10.1687     2.38593
1988         8.9304      9.8191     2.54718
1989         9.3320      9.7783     2.75555
1990         9.7517      9.5776     2.95044
1991        10.1902      9.4014     3.15503
1992        10.6484      9.2078     3.36188
1993        11.1272      8.7090     3.50409
1994        11.6277      8.6685     3.74677
1995        12.1506      8.7078     4.01074
1996        12.6970      8.8037     4.29272
1997        13.1821      9.8438     4.88586
1998        13.5774     10.9263     5.52087
1999        13.9846     12.1279     6.23853
2000        14.4041     13.4617     7.04944
2001        14.8359     14.4448     7.76111
2002        15.2808     15.1956     8.41113
2003        15.7217     15.7778     9.01855
2004        16.0796     15.6907     9.33325
2005        16.3589     15.5154     9.58740
2006        16.5654     15.3113     9.80249
2007        16.5298     14.5793     9.67505
2008        16.3481     13.8711     9.49414
2009        16.3213     13.8245     9.27173
2010        16.1685     13.7490     7.62085
2011        15.9458     13.7556     6.02344
2012        15.5322     13.5862     4.67407
2013        14.3984     13.5674     3.51178
2014        12.1533     14.8660     2.56165
2015         9.4482     16.1616     1.85916
2016         7.1316     15.9124     1.35603
2017         5.3445     16.9961     1.00415
2018         4.0105     17.1260     0.75345
2019         3.0234     17.8926     0.57394
2020         2.2930     18.1240     0.44344
2021         1.7504     18.9219     0.34704
2022         1.3450     19.7480     0.27457
2023         1.0401     21.1602     0.21912
2024         0.8087     22.5376     0.17609
2025         0.6322     22.6943     0.14229
```

Graph 6

PAGE 13 04/17/74 15:35 WORLD OIL DEFICIT

ODEFS
5.97095
-2.54651
1



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PAGE   14      04/17/74      15:35      SUMMARY OIL VARIABLES

            PRO       OCKL       OMNW       OMW       OREFS      RD        SUMREM    SUMOP     SUMOR     SUMCUP
1975      4.75842  0.529984   12.1406    9.5940  -2.54651   51.0029   1479.50   21.9829    780.00   21.9829
1976      4.90369  0.539978   11.8093   11.1003  -0.70886   54.0742   1428.50   24.2642    809.02   24.2642
1977      5.05066  0.549988   12.0461   12.0459   0.74390   56.6719   1374.44   26.0767    838.83   26.8213
1978      5.20215  0.559982   12.5376   12.5374   1.35388   58.7900   1317.78   27.5039    869.42   28.8579
1979      5.35815  0.569977   13.0217   13.0212   1.46851   60.4219   1258.97   28.9917    900.70   30.4609
1980      5.51880  0.579987   13.5640   13.5635   1.58691   61.5723   1198.56   30.5469    932.13   32.1338
1981      5.68433  0.589981   14.0977   14.0972   1.71667   62.2510   1136.97   32.1660    963.14   33.8828
1982      5.85474  0.599991   14.6187   14.6187   1.84741   62.4766   1074.75   33.8584    993.23   35.7061
1983      6.03027  0.599991   14.7505   14.7502   2.57056   62.2646   1012.23   35.0430   1021.84   37.6133
1984      6.21106  0.609985   15.2339   15.2339   2.08203   61.6436    949.95   36.8604   1049.06   38.9424
1985      6.39734  0.609985   15.4077   15.4077   2.85718   60.6475    888.33   38.1357   1073.84   40.9941
1986      6.58923  0.619980   15.9158   15.9153   2.34229   59.3047    827.70   40.0840   1096.34   42.4268
1987      6.78687  0.619980   16.0308   16.0303   3.17676   57.6533    768.41   41.4482   1115.56   44.6260
1988      6.99036  0.619980   16.1074   16.1074   3.29712   55.7295    710.75   42.8594   1131.78   46.1572
1989      7.19995  0.629990   16.5332   16.5327   2.72363   53.5752    655.03   45.0166   1144.63   47.7402
1990      7.41589  0.629990   16.5249   16.5244   3.20898   51.2256    601.45   46.5254   1153.19   49.7354
1991      7.63831  0.629990   16.4639   16.4634   3.24756   48.7236    550.25   48.0791   1157.88   51.3271
1992      7.86743  0.629990   16.3418   16.3418   3.40649   46.1045    501.52   49.6719   1158.53   53.0781
1993      8.10352  0.619980   15.7278   15.7275   4.40820   43.4063    455.42   50.4805   1154.97   54.8887
1994      8.34644  0.619980   15.4775   15.4775   3.10986   40.6631    412.03   52.0393   1147.88   55.1406
1995      8.59668  0.609985   15.3188   15.3188   2.93262   37.9033    371.36   52.7568   1136.50   55.6895
1996      8.85449  0.599991   15.1558   15.1555   2.82617   35.1650    333.48   53.4756   1121.66   56.3018
1997      9.00000  0.589981   15.1487   14.9714  -0.17725   32.4639    298.30   54.3086   1103.34   54.3086
1998      9.00000  0.579987   15.2939   13.4099  -1.88403   29.8301    265.85   53.9531   1081.50   53.9531
1999      9.00000  0.569977   15.9622   13.7788  -2.18335   27.2822    236.03   54.3447   1057.38   54.3447
2000      9.00000  0.559982   17.3940   15.9351  -1.45898   24.8345    208.75   55.6553   1030.31   55.6553
2001      9.00000  0.539978   17.7788   17.7783   0.92114   22.5020    183.92   56.9053    999.47   57.8262
2002      9.00000  0.529984   18.9810   18.9805   1.58374   20.2959    161.43   58.1582    965.06   59.7432
2003      9.00000  0.519989   20.0781   20.0781   2.11938   18.2217    141.14   59.3926    927.20   61.5127
2004      9.00000  0.499992   20.5117   20.5112   3.73657   16.2856    122.92   59.4150    886.03   63.1533
2005      9.00000  0.479988   20.7808   20.7803   4.10937   14.4895    106.64   59.2529    842.91   63.3633
2006      9.00000  0.459991   20.9229   20.9224   4.33789   12.8330     92.16   58.9834    798.14   63.3213
2007      9.00000  0.429993   20.3823   20.3818   5.86255   11.3152     79.33   57.2637    751.98   63.1270
2008      9.00000  0.399994   19.7202   19.7202   5.97095    9.9326     69.33   55.3301    706.05   61.3018
2009      9.00000  0.379990   19.5513   19.5513   4.12012    8.6799     58.10   54.6025    660.64   58.7236
2010      9.00000  0.349991   18.6699   18.6694   4.03442    7.5508     49.43   52.2344    614.72   56.2695
2011      9.00000  0.319992   17.6685   17.6680   3.58472    6.5419     41.90   50.0225    570.05   53.6074
2012      9.00000  0.289993   16.5444   16.5439   3.80591    5.6400     35.35   47.6055    526.56   51.4111
2013      9.00000  0.259995   15.9277   15.9275   3.26343    4.8406     29.71   44.9414    484.59   48.8051
2014      9.00000  0.239994   16.1133   16.1128   0.35938    4.1366     24.88   43.5830    444.51   43.9424
2015      9.00000  0.219994   16.1680   16.1680   0.55103    3.5207     20.75   42.0361    405.06   42.5869
2016      9.00000  0.189995   15.9082   15.9080   3.27515    2.9840     17.24   38.6016    366.55   41.8770
2017      9.00000  0.169994   16.6460   16.6460   1.01270    2.5192     14.28   36.6123    330.94   37.6260
2018      9.00000  0.139996   17.3423   17.3423   2.67456    2.1149     11.76   33.3525    296.84   36.0273
2019      9.00000  0.119997   18.4131   18.4126   1.69922    1.7689      9.66   31.8237    265.61   33.5234
2020      9.00000  0.099998   18.7046   18.7046   2.61523    1.4733      7.90   30.1235    235.56   32.7393
2021      9.00000  0.089998   19.7002   19.6997   1.79395    1.2214      6.43   29.7876    206.91   31.5815
2022      9.00000  0.079998   20.2563   20.2559   1.83252    1.0078      5.21   29.3789    178.35   31.2119
2023      9.00000  0.069998   20.4727   20.4722   1.02173    0.8295      4.22   28.8794    149.98   29.9014
2024      9.00000  0.059999   20.4282   20.4282   1.17236    0.6791      3.39   28.2983    121.94   29.4712
2025      9.00000  0.049999   20.1870   19.6050  -0.58203    0.5532      2.72   27.0776     94.32   27.0776
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PAGE   11        04/17/74        15:35        SUMMARY OIL VARIABLES

    PRO          UCKL          OMW          OMNW
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   0.00000     0.000000       0.0000       0.0000
      1            2             3            4
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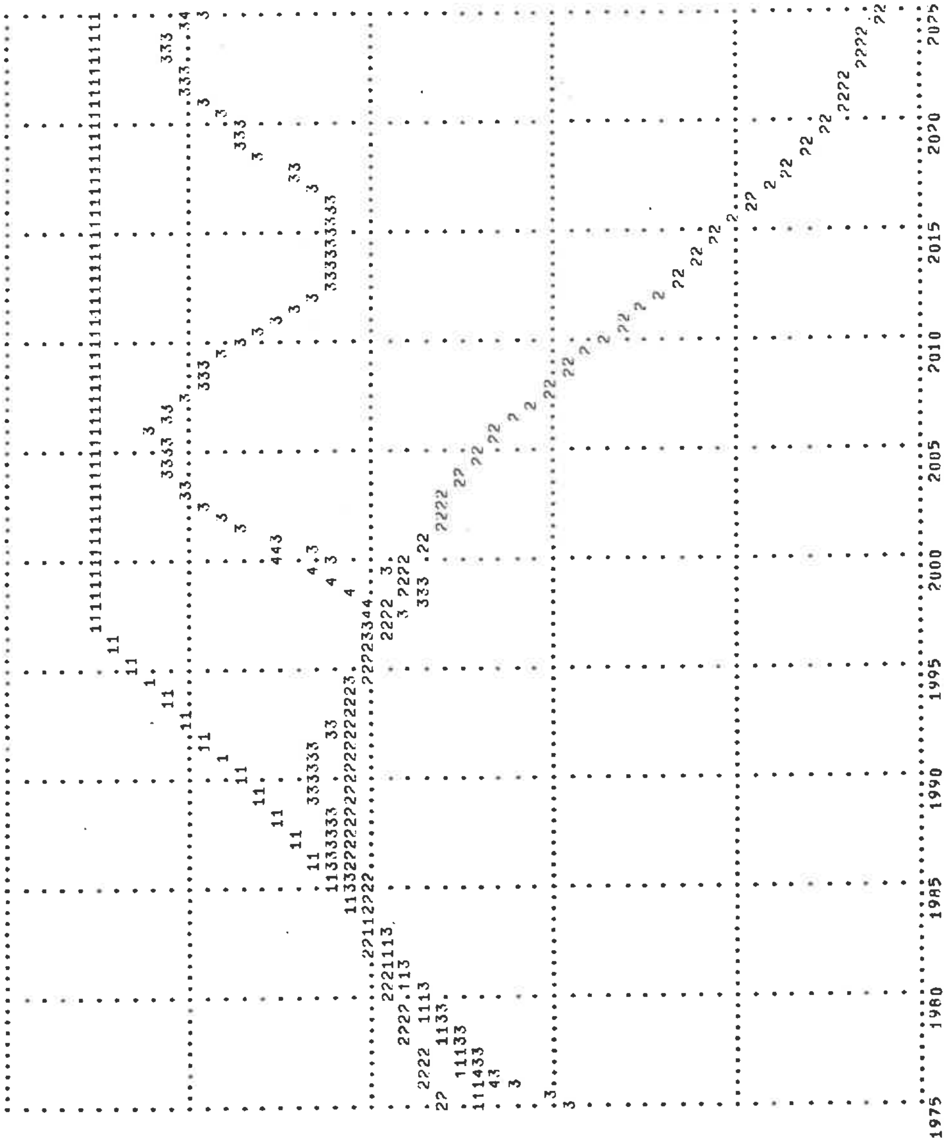

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PAGE  12     04/17/74     15:35     SUMMARY OIL VARIABLES

             PRO      UCKL        UMW       OMNW
1975      4.75842  0.529984     9.5940    12.1406
1976      4.90369  0.539978    11.1003    11.8093
1977      5.05066  0.549988    12.0459    12.0461
1978      5.20215  0.559982    12.5374    12.5376
1979      5.35815  0.569977    13.0212    13.0217
1980      5.51880  0.579987    13.5635    13.5640
1981      5.68433  0.589981    14.0972    14.0977
1982      5.85474  0.599991    14.6187    14.6187
1983      6.03027  0.599991    14.7502    14.7505
1984      6.21106  0.609985    15.2339    15.2339
1985.     6.39734  0.609985    15.4077    15.4077
1986      6.59923  0.619980    15.9153    15.9158
1987      6.78687  0.619980    16.0303    16.0308
1988      6.99036  0.619980    16.1074    16.1074
1989      7.19995  0.629990    16.5327    16.5332
1990      7.41589  0.629990    16.5244    16.5249
1991      7.63831  0.629990    16.4634    16.4639
1992      7.86743  0.629990    16.3418    16.3418
1993      8.10352  0.619980    15.7275    15.7278
1994      8.34644  0.619980    15.4775    15.4775
1995      8.59668  0.609985    15.3188    15.3188
1996      8.85449  0.599991    15.1555    15.1558
1997      9.00000  0.589981    14.9714    15.1487
1998      9.00000  0.579987    13.4099    15.2939
1999      9.00000  0.569977    13.7788    15.9622
2000      9.00000  0.559982    15.9351    17.3940
2001      9.00000  0.539978    17.7783    17.7788
2002      9.00000  0.529984    18.9805    18.9810
2003      9.00000  0.519989    20.0781    20.0781
2004      9.00000  0.499992    20.5112    20.5117
2005      9.00000  0.479988    20.7803    20.7808
2006      9.00000  0.459991    20.9224    20.9229
2007      9.00000  0.429993    20.3818    20.3823
2008      9.00000  0.399994    19.7202    19.7202
2009      9.00000  0.379990    19.5513    19.5513
2010      9.00000  0.349991    18.6694    18.6699
2011      9.00000  0.319992    17.6680    17.6685
2012      9.00000  0.289993    16.5439    16.5444
2013      9.00000  0.259995    15.9275    15.9277
2014      9.00000  0.239994    16.1128    16.1133
2015      9.00000  0.219994    16.1680    16.1680
2016      9.00000  0.189995    15.9080    15.9082
2017      9.00000  0.169994    16.6460    16.6460
2018      9.00000  0.139996    17.3423    17.3423
2019      9.00000  0.119997    18.4126    18.4131
2020      9.00000  0.099998    18.7046    18.7046
2021      9.00000  0.089998    19.6997    19.7002
2022      9.00000  0.079998    20.2559    20.2563
2023      9.00000  0.069998    20.4722    20.4727
2024      9.00000  0.059999    20.4282    20.4282
2025      9.00000  0.049999    19.6050    20.1870
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PAGE    7    04/17/74     15:35     SUMMARY OIL VARIABLES

     Y1234       Y          CAPAC      CAPAC
                 ME         ME         NAM
    10.00000   2500.00   1000.000   25.0000
     0.00000      0.00      0.000    0.0000
       1          2          3         4
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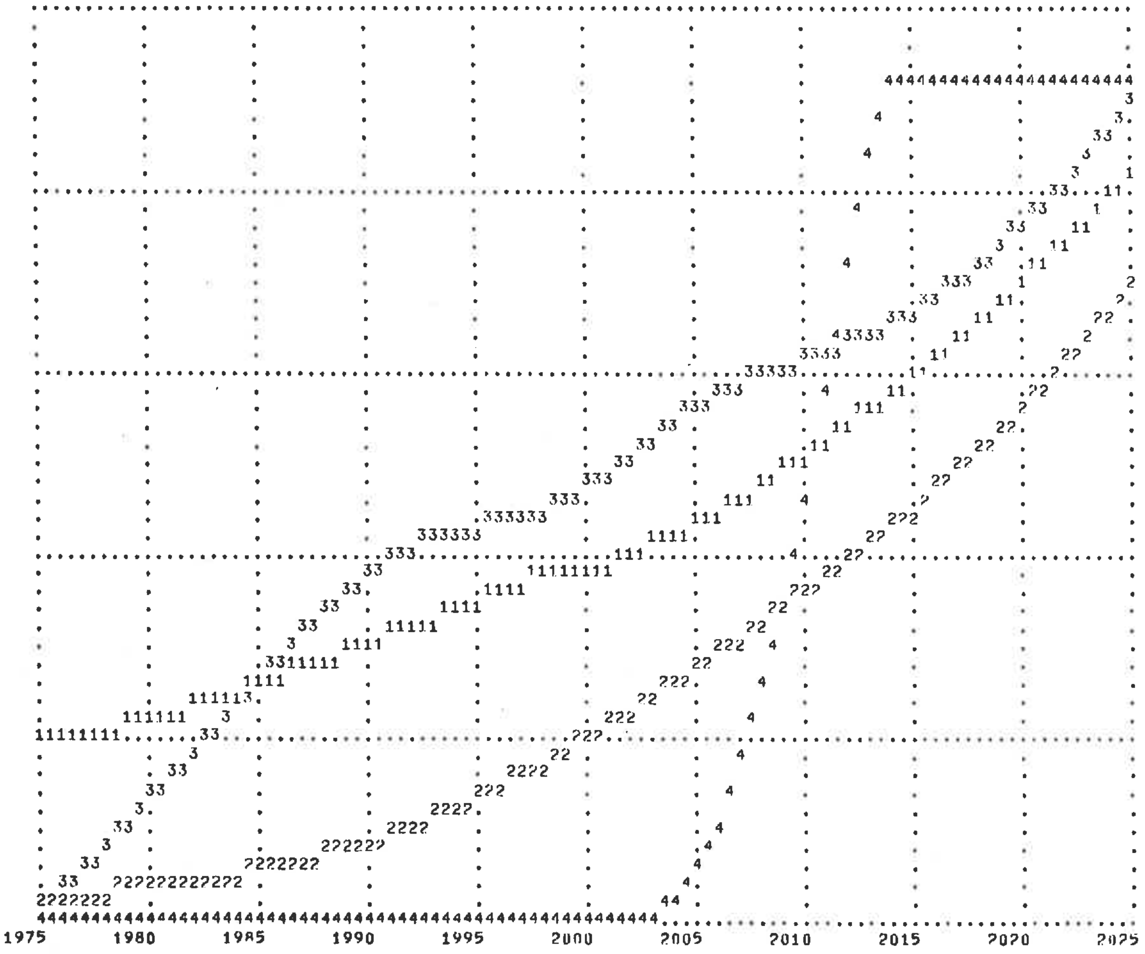

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PAGE    8     04/17/74     15:35     SUMMARY OIL VARIABLES

             Y1234       Y         CAPAC      CAPAC
                         ME        MF         NAM
1975        1.98477      66.09     17.692     0.0000
1976        1.97144      71.44     38.288     0.0000
1977        2.01514      77.72     61.179     0.0000
1978        2.08557      84.29     85.242     0.0000
1979        2.15778      91.11    110.047     0.0000
1980        2.23157      98.72    135.594     0.0000
1981        2.30713     107.08    161.453     0.0000
1982        2.38422     116.67    188.418     0.0000
1983        2.46326     126.32    214.574     0.0000
1984        2.54407     137.09    241.297     0.0000
1985        2.62671     148.36    266.672     0.0000
1986        2.71094     161.11    292.102     0.0000
1987        2.79681     174.73    315.664     0.0000
1988        2.88440     190.14    337.766     0.0000
1989        2.97375     206.70    358.984     0.0000
1990        3.06464     224.81    378.438     0.0000
1991        3.15637     244.81    395.742     0.0000
1992        3.24854     266.54    410.727     0.0000
1993        3.34143     289.86    421.781     0.0000
1994        3.43549     315.07    430.102     0.0000
1995        3.53021     342.45    434.906     0.0000
1996        3.62524     373.09    439.617     0.0000
1997        3.72174     403.33    445.133     0.0000
1998        3.81281     436.46    452.258     0.0000
1999        3.84607     471.59    462.242     0.0000
2000        3.87665     507.80    475.594     0.0000
2001        3.93903     545.05    491.570     0.0000
2002        4.04712     583.75    509.688     0.0000
2003        4.15991     623.02    529.219     0.1475
2004        4.27747     662.83    547.172     0.7088
2005        4.40137     703.58    564.016     1.6289
2006        4.53162     744.42    579.313     2.8604
2007        4.66797     785.78    591.234     4.5255
2008        4.81165     827.61    600.422     6.5382
2009        4.96289     869.52    609.125     8.7461
2010        5.12048     911.89    617.406    11.4209
2011        5.28613     955.13    626.625    14.5574
2012        5.46033     998.39    635.313    18.0454
2013        5.64270    1042.50    642.750    21.3037
2014        5.83142    1089.13    655.234    23.0000
2015        6.02185    1137.34    672.094    23.0000
2016        6.21301    1187.91    687.203    23.0000
2017        6.40942    1240.81    705.688    23.0000
2018        6.61096    1296.34    724.172    23.0000
2019        6.82092    1354.50    745.016    23.0000
2020        7.03894    1415.16    766.016    23.0000
2021        7.26611    1478.25    788.297    23.0000
2022        7.50098    1544.56    812.531    23.0000
2023        7.74463    1613.56    841.187    23.0000
2024        7.99731    1685.59    873.891    23.0000
2025        8.25952    1761.00    905.328    23.0000
```

But since we are positing an increase based on retaliatory action (some sort of export tax), the result is spurious and should be disregarded.

The real burden of the higher capital goods prices would, of course, fall upon the Middle EAst. Although economic growth would be little affected, possibilities for capital accumulation are reduced. Instead of the $1710 billion level of the standard scenario, the Middle East reaches only a level of $905 billion in the retaliatory scenario. Unlike the squeeze or production limitation scenario, larger remaining reserves do not exist to compensate for the lower accumulation.

5.3 Mutual Conflict

Both of the conflict scenarios presented thus far in this chapter primarily hurt the nonacting regions. There are feedbacks to the actor which may be undesireable in the oil production limitation scenario (specifically, lowered capital accumulations). The full range of implications of international conflict behavior is not, however, developed in this model. In general, highly interdependent states, as are the major oil importers and exporters, inevitably find that conflict hurts both actor and intended or innocent target. The last scenario we will briefly present here is that of mutual conflict. Graphs 9 through 12 again present the scenario summary variables. Graph 12, reporting economic and monetary variables, is adequate to show that such mutual conflict could be very damaging. Neither Mideast nor first world grows at the potential exhibited in the cooperative run. Middle East capital accumulation in 2025 is reduced to $404 billion, less than one-fourth of its potential. Again, one conclusion seems obvious: the world as a whole has a stake in a set of mutually desireable and cooperative policies.

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PAGE    6     04/17/74     16:53
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Graph 9

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         OP          OP          OP
         NAM         ME          SEA
         25.0000     25.0000     25.0000
          0.0000      0.0000      0.0000
           1           2           3
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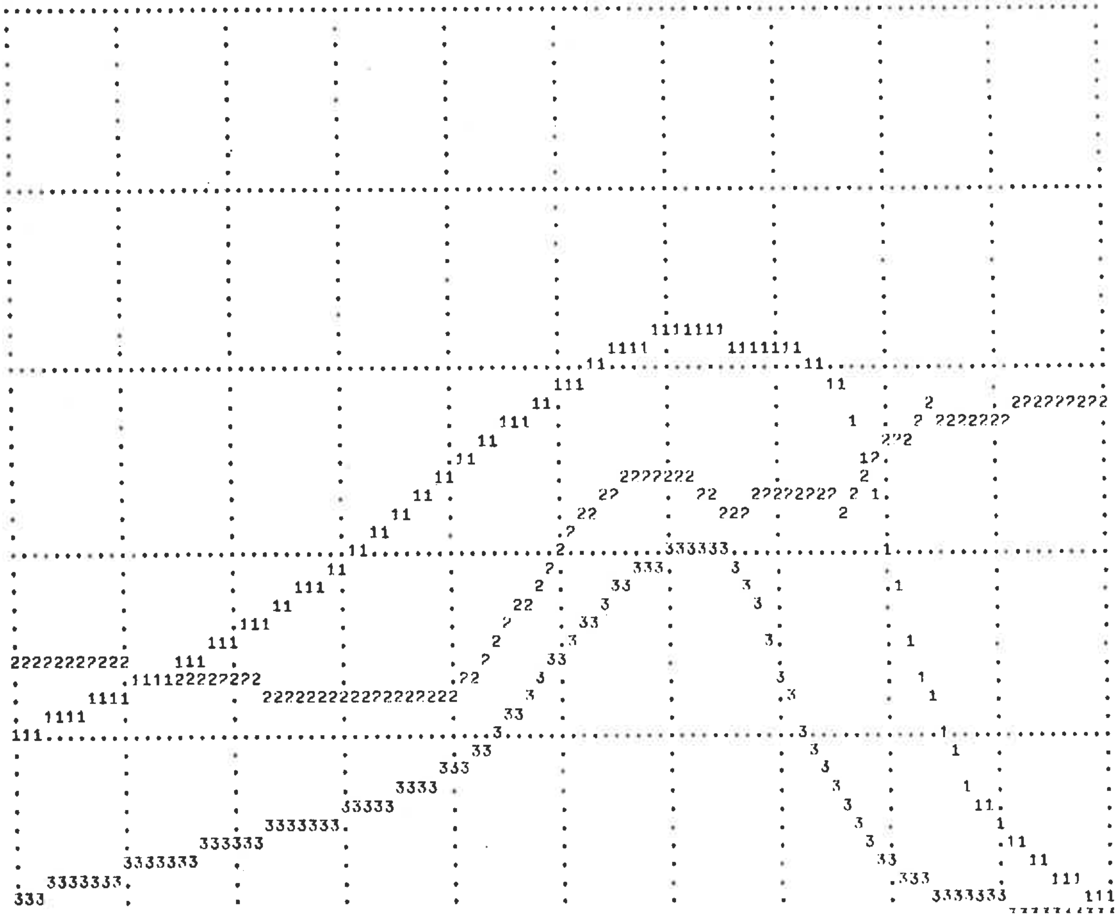

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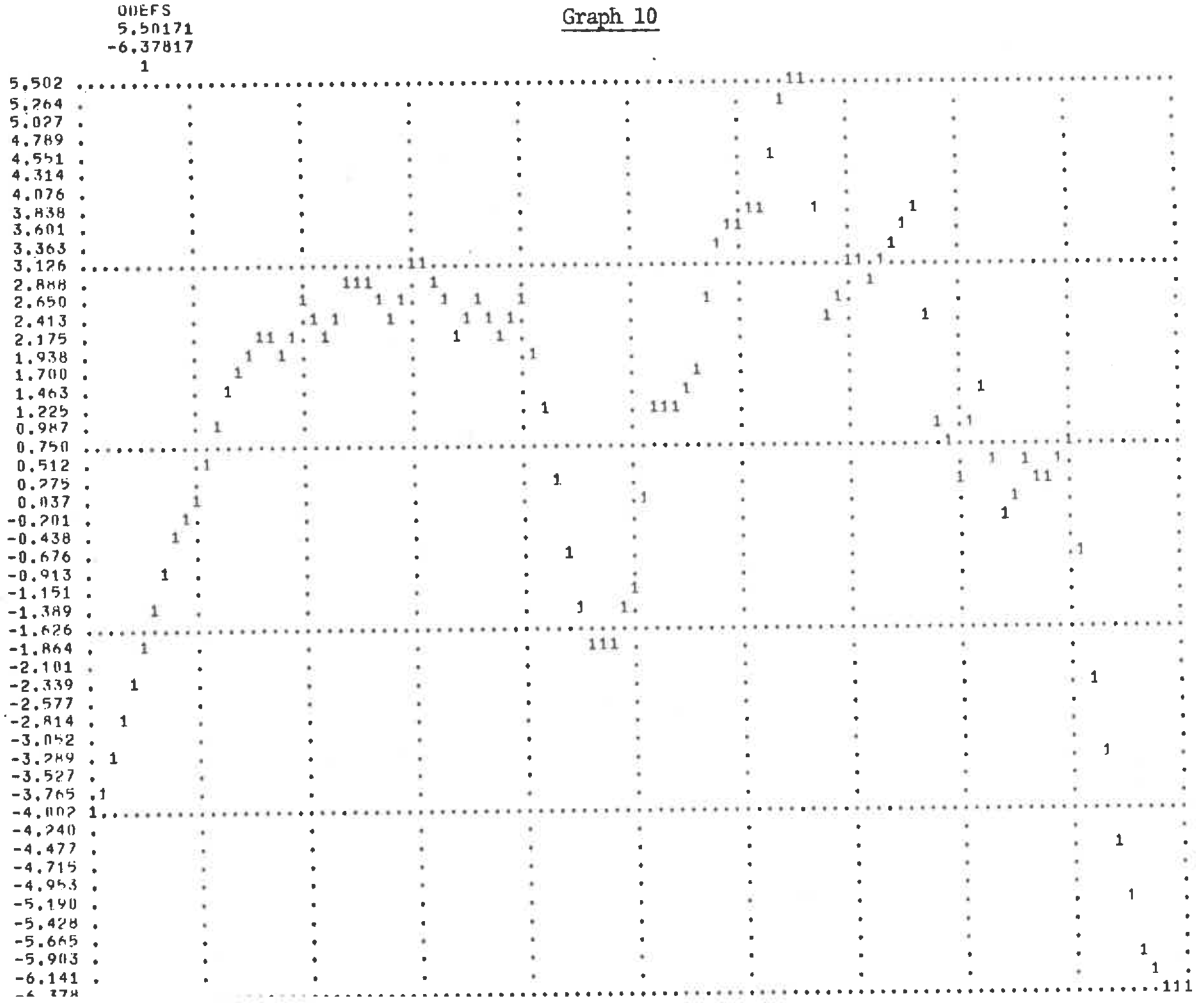
 PAGE     7      04/17/74      16:53

              OP          OP          OP
              NAM         ME          SEA
1975          5.0398      7.0000      0.7340
1976          5.2678      7.0000      0.8406
1977          5.5048      7.0000      0.9624
1978          5.7523      7.0000      1.1019
1979          6.0110      7.0000      1.2617
1980          6.2814      6.8906      1.4358
1981          6.5638      6.7821      1.5888
1982          6.8590      6.8353      1.7327
1983          7.1675      6.6359      1.8531
1984          7.4899      6.6583      2.0102
1985          7.8268      6.4492      2.1388
1986          8.1790      6.4568      2.3104
1987          8.5464      6.2505      2.4474
1988          8.9307      6.0597      2.5881
1989          9.3323      6.0708      2.7814
1990          9.7520      5.9517      2.9437
1991         10.1904      5.8977      3.1240
1992         10.6487      6.0469      3.3730
1993         11.1277      6.0844      3.5812
1994         11.6282      6.2568      3.8484
1995         12.1511      6.3342      4.0758
1996         12.6975      6.7502      4.4760
1997         13.1826      7.5479      5.0944
1998         13.5779      8.3779      5.7565
1999         13.9851      9.2993      6.5046
2000         14.4045     10.3220      7.3501
2001         14.8022     10.9539      7.9968
2002         15.1936     11.5747      8.6702
2003         15.5686     12.1023      9.3176
2004         15.8228     12.1001      9.6206
2005         16.0117     12.0598      9.8845
2006         16.1377     11.9954     10.1130
2007         16.0132     11.5146      9.9805
2008         15.7610     11.0410      9.7886
2009         15.8647     11.4446      8.7283
2010         15.7402     11.5708      6.8654
2011         15.5005     11.6487      5.3241
2012         15.0835     11.5820      3.9731
2013         14.4521     11.3264      2.6930
2014         12.8469     12.1108      2.1012
2015         10.2686     13.2051      1.5385
2016          7.8400     13.1714      1.1415
2017          5.8840     14.0000      0.8601
2018          4.4038     13.6921      0.6583
2019          3.3055     13.8718      0.5114
2020          2.4941     13.6509      0.4025
2021          1.8933     14.0000      0.3202
2022          1.4463     14.0000      0.2570
2023          1.1115     14.0000      0.2076
2024          0.8594     14.0000      0.1685
2025          0.6681     14.0000      0.1374
```

PAGE 10 04/17/74 16:53 WORLD OIL DEFICIT

Graph 10



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PAGE   11     04/17/74     16:53     SUMMARY OIL VARIABLES

          PRO      UCKL       OMNW      OMW       OPEFS      RD        SUMREM    SUMOP     SUMOR     SUMCUP
1975     4.75842  0.529984   12.1404    8.0947  -4.04578   51.0029   1479.50   20.4839    780.00   20.4839
1976     4.90369  0.539978   11.6885    8.5366  -3.15186   54.0742   1428.50   21.7002    810.52   21.7002
1977     5.05066  0.549988   11.2864    9.0313  -2.25525   56.6729   1374.44   23.0625    842.89   23.0625
1978     5.20215  0.559982   10.9275    9.6272  -1.30017   58.7910   1317.81   24.5962    876.48   24.5962
1979     5.35815  0.569977   10.8564   10.3750  -0.48132   60.4219   1259.00   26.3276    910.67   26.3276
1980     5.51880  0.579987   11.1074   11.1074   0.20532   61.5742   1198.59   28.0835    944.77   28.2891
1981     5.68433  0.589981   11.5295   11.5291   1.14575   62.2529   1137.00   29.6089    978.25   30.7554
1982     5.85474  0.599991   11.9375   11.9373   1.67419   62.4766   1074.75   31.2095   1010.89   32.8838
1983     6.03027  0.599991   11.9929   11.9927   2.35229   62.2646   1012.25   32.3369   1042.16   34.6895
1984     6.21106  0.609985   12.3872   12.3872   1.89441   61.6465    950.00   34.0596   1072.09   35.9541
1985     6.39734  0.609985   12.4866   12.4863   2.62048   60.6484    888.36   35.2773   1099.66   37.8984
1986     6.58923  0.619980   12.8799   12.8794   2.12976   59.3047    827.70   37.1309   1125.03   39.2617
1987     6.78687  0.619980   12.9231   12.9231   2.91394   57.6533    768.39   38.4385   1147.22   41.3525
1988     6.99036  0.619980   12.9294   12.9292   3.02307   55.7295    710.75   39.7891   1166.41   42.8115
1989     7.19995  0.629990   13.2427   13.2424   2.47717   53.5742    655.02   41.8408   1182.34   44.3184
1990     7.41589  0.629990   13.1689   13.1687   3.12573   51.2256    601.45   43.2871   1194.09   46.4141
1991     7.63831  0.629990   13.0457   13.0454   3.01025   48.7236    550.25   44.7803   1202.03   47.7910
1992     7.86743  0.629990   12.8662   12.8660   2.22107   46.1025    501.50   46.3135   1205.97   48.5342
1993     8.10352  0.619980   12.2529   12.2527   2.69751   43.4033    455.40   47.1240   1205.75   49.8213
1994     8.34644  0.619980   11.9539   11.9534   2.17236   40.6611    412.02   48.6455   1202.00   50.8184
1995     8.59668  0.609985   11.8020   11.8018   2.63196   37.9033    371.35   49.3711   1194.03   52.0039
1996     8.85449  0.599991   11.7173   11.7168   1.27991   35.1631    333.46   50.0293   1182.56   51.3105
1997     9.00000  0.589981   11.7634   11.0376  -0.72595   32.4639    298.30   50.2217   1167.69   50.2217
1998     9.00000  0.579987   12.0000   10.0933  -1.90662   29.8296    265.84   50.0479   1149.94   50.0479
1999     9.00000  0.569977   13.4807   11.6582  -1.82251   27.2793    236.01   50.6758   1129.72   50.6758
2000     9.00000  0.559982   14.6245   13.5986  -1.02576   24.8325    208.73   52.1025   1106.31   52.1025
2001     9.00000  0.539978   15.3911   15.3909   1.16699   22.5015    183.91   53.0859   1079.06   54.2529
2002     9.00000  0.529984   16.6318   16.6313   1.38672   20.2939    161.41   54.3652   1048.47   55.7520
2003     9.00000  0.519989   17.6592   17.6587   1.81641   18.2207    141.13   55.6553   1014.39   57.4717
2004     9.00000  0.499992   18.0420   18.0415   3.42310   16.2847    122.91   55.7002    976.95   59.1240
2005     9.00000  0.479988   18.2939   18.2939   3.69263   14.4880    106.63   55.6357    937.53   59.3291
2006     9.00000  0.459991   18.4404   18.4399   3.91455   12.8345     92.17   55.4609    896.39   59.3770
2007     9.00000  0.429993   17.9590   17.9590   5.38794   11.3149     79.33   53.8916    853.75   59.2803
2008     9.00000  0.399994   17.3726   17.3721   5.50171    9.9299     68.01   52.0947    811.19   57.5977
2009     9.00000  0.379990   17.2485   17.2480   2.40454    8.6777     58.09   51.4443    769.02   53.8496
2010     9.00000  0.349991   16.4429   16.4424   3.12646    7.5516     49.43   49.2148    726.27   52.3408
2011     9.00000  0.319992   15.5081   15.5078   3.05298    6.5397     41.88   47.1348    684.59   50.1885
2012     9.00000  0.289993   15.3262   15.3259   3.41040    5.6396     35.35   44.8369    644.00   48.2480
2013     9.00000  0.259995   15.0037   15.0034   3.90112    4.8408     29.72   42.2881    604.80   46.1885
2014     9.00000  0.239994   15.0518   15.0515   1.04248    4.1368     24.88   40.9805    567.36   42.0234
2015     9.00000  0.219994   14.7444   14.7439   0.45142    3.5204     20.75   39.5088    530.52   39.9609
2016     9.00000  0.189995   13.5942   13.5940   1.43958    2.9830     17.24   36.2334    494.53   37.6729
2017     9.00000  0.169994   15.2771   15.0728  -0.20435    2.5157     14.26   34.1143    461.28   34.1143
2018     9.00000  0.139996   16.0503   16.0498   0.58032    2.1130     11.75   31.1689    429.69   31.7495
2019     9.00000  0.119997   17.1299   17.1299   0.25122    1.7676      9.65   29.7100    400.63   29.9614
2020     9.00000  0.099998   17.4395   17.4390   0.70898    1.4706      7.88   28.0815    372.69   28.7910
2021     9.00000  0.089998   18.4121   16.2344  -2.17773    1.2177      6.41   25.5684    346.09   25.5684
2022     9.00000  0.079998   18.6938   14.2061  -4.48804    1.0045      5.20   22.5854    321.73   22.5854
2023     9.00000  0.069998   18.3804   12.5193  -5.86133    0.8252      4.20   20.1943    300.16   20.1943
2024     9.00000  0.059999   17.6729   11.2947  -6.37817    0.6754      3.38   18.4360    280.79   18.4360
2025     9.00000  0.049999   16.7368   10.4480  -6.28857    0.5508      2.71   17.1851    263.03   17.1851
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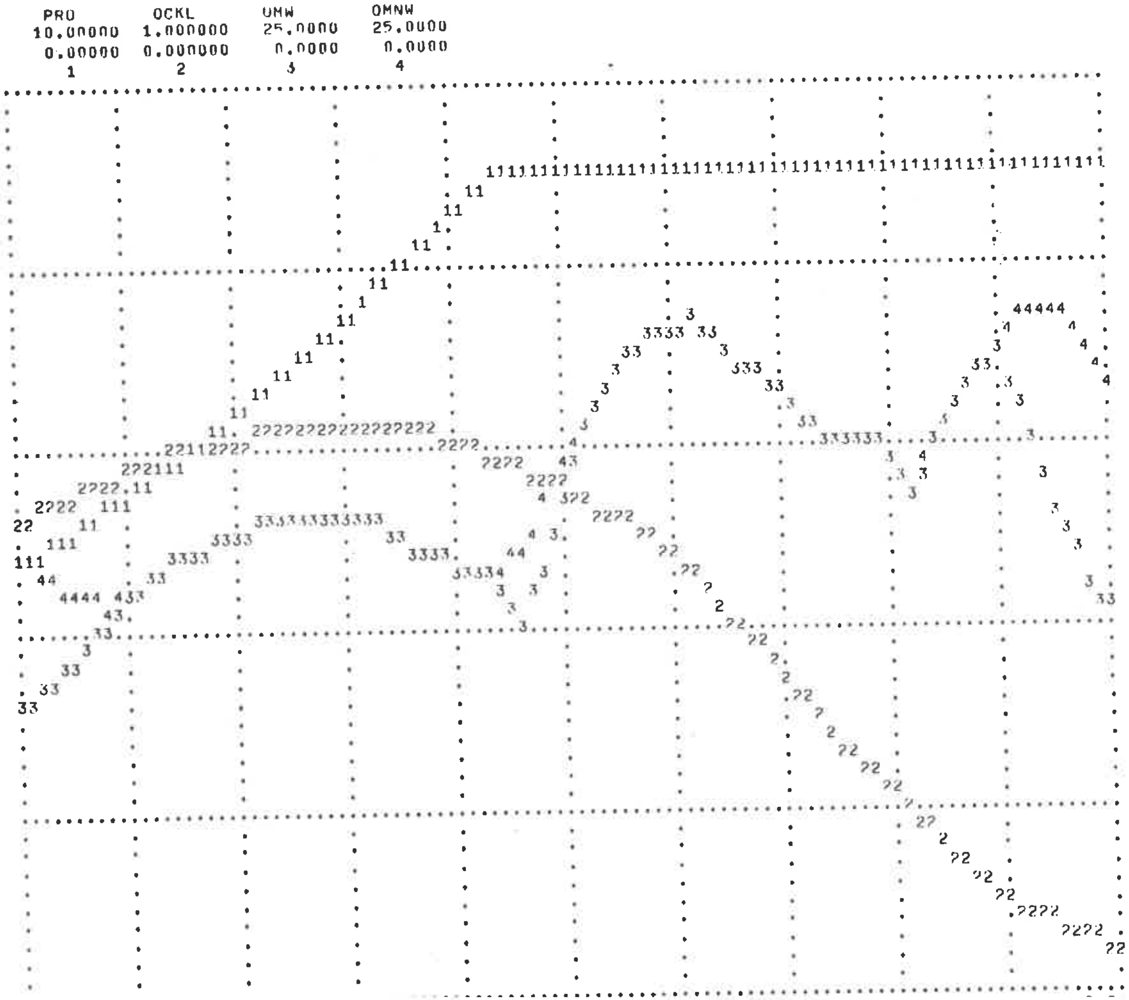
PAGE 8 04/17/74 16:53

Graph 11



B 1o78

B 1o79

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                PRO       UCKL       OMW      OPNW
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  1976       4.90369  0.539978    8.5366   11.6885
  1977       5.05066  0.549988    9.0313   11.2864
  1978       5.20215  0.559982    9.6272   10.9275
  1979       5.35815  0.569977   10.3750   10.8564
  1980       5.51880  0.579987   11.1074   11.1074
  1981       5.68433  0.569981   11.5291   11.5295
  1982       5.85474  0.599991   11.9373   11.9375
  1983       6.03027  0.599991   11.9927   11.9929
  1984       6.21106  0.609985   12.3872   12.3872
  1985       6.39734  0.609985   12.4863   12.4866
  1986       6.58923  0.619980   12.8794   12.8799
  1987       6.78687  0.619980   12.9231   12.9231
  1988       6.99036  0.619980   12.9292   12.9294
  1989       7.19995  0.629990   13.2424   13.2427
  1990       7.41589  0.629990   13.1687   13.1689
  1991       7.63831  0.629990   13.0454   13.0457
  1992       7.86743  0;629990   12.8660   12.8662
  1993       8.10352  0.619980   12.2527   12.2529
  1994       8.34644  0.619980   11.9534   11.9539
  1995       8.59668  0.609985   11.8018   11.8020
  1996       8.85449  0.599991   11.7168   11.7173
  1997       9.00000  0.589981   11.0376   11.7634
  1998       9.00000  0.579987   10.0933   12.0000
  1999       9.00000  0.569977   11.6582   13.4807
  2000       9.00000  0.559982   13.5986   14.6245
  2001       9.00000  0.539978   15.3909   15.3911
  2002       9.00000  0.529984   16.6313   16.6318
  2003       9.00000  0.519989   17.6587   17.6592
  2004       9.00000  0.499992   18.0415   18.0420
  2005       9.00000  0.479988   18.2939   18.2939
  2006       9.00000  0.459991   18.4399   18.4404
  2007       9.00000  0.429993   17.9590   17.9590
  2008       9.00000  0.399994   17.3721   17.3726
  2009       9.00000  0.379990   17.2480   17.2485
  2010       9.00000  0.349991   16.4424   16.4429
  2011       9.00000  0.319992   15.5078   15.5081
  2012       9.00000  0.289993   15.3259   15.3262
  2013       9.00000  0.259995   15.0034   15.0037
  2014       9.00000  0.239994   15.0515   15.0518
  2015       9.00000  0.219994   14.7439   14.7444
  2016       9.00000  0.189995   13.5940   13.5942
  2017       9.00000  0.169994   15.0728   15.2771
  2018       9.00000  0.139996   16.0498   16.0503
  2019       9.00000  0.119997   17.1299   17.1299
  2020       9.00000  0.099998   17.4390   17.4395
  2021       9.00000  0.089998   16.2344   18.4121
  2022       9.00000  0.079998   14.2061   18.6938
  2023       9.00000  0.069998   12.5193   18.3804
  2024       9.00000  0.059999   11.2947   17.6729
  2025       9.00000  0.049999   10.4480   16.7368
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PAGE    4      04/17/74      16:53
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Graph 12

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        Y1234       Y          CAPAC      CAPAC
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        0.00000      0.00      0.000     0.0000
         1          2          3          4
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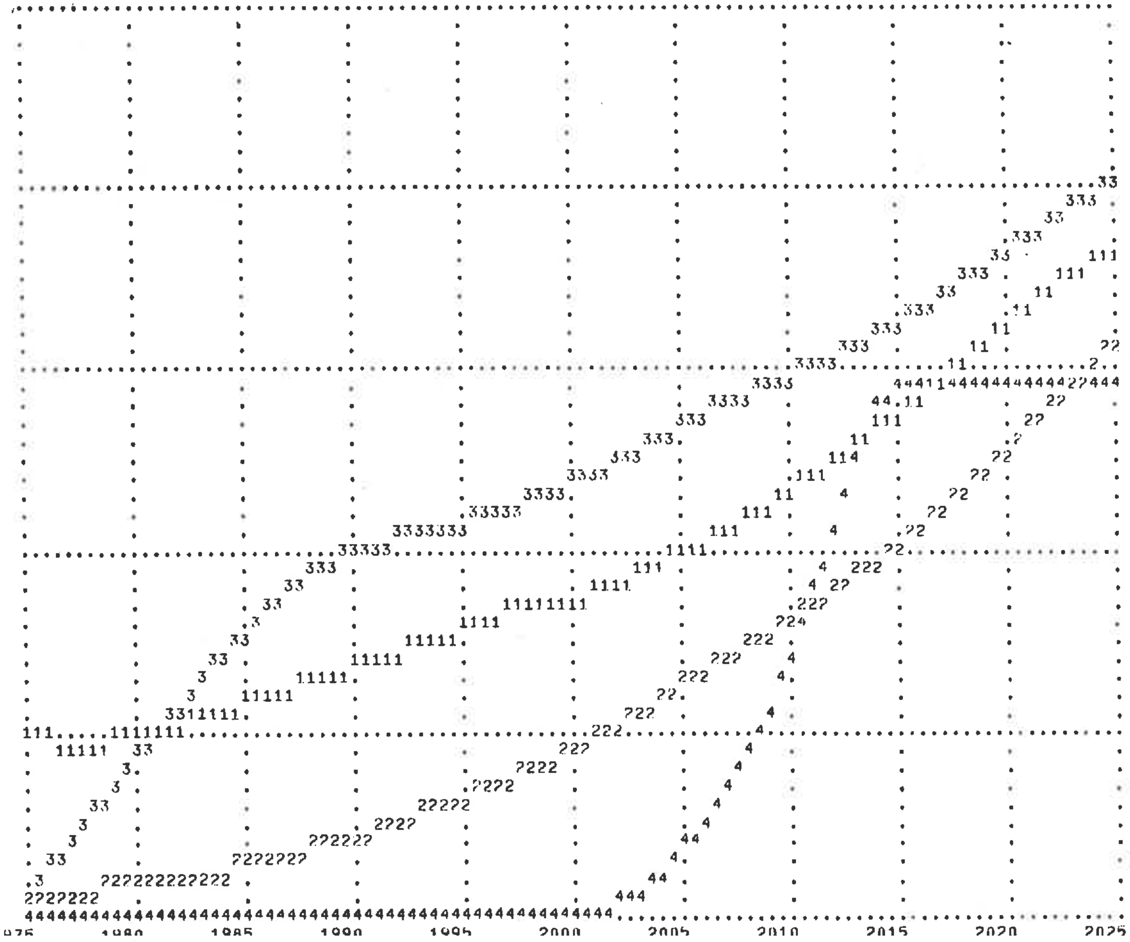

B 1080

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    PAGE    5     04/17/74     16:53

             Y1234      Y          CAPAC      CAPAC
                        MF         ME         NAM
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1976         1.95703     71.44     28.482     0.0000
1977         1.93909     77.72     43.351     0.0000
1978         1.93069     64.29     58.537     0.0000
1979         1.95081     91.11     73.654     0.0000
1980         2.00043     98.72     88.430     0.0000
1981         2.06860    107.08    102.471     0.0000
1982         2.13837    116.67    117.074     0.0000
1983         2.20990    126.32    130.730     0.0000
1984         2.28314    137.09    144.477     0.0000
1985         2.35809    148.36    156.844     0.0000
1986         2.43463    161.11    168.887     0.0000
1987         2.51282    174.73    179.156     0.0000
1988         2.59265    190.14    188.117     0.0000
1989         2.67413    206.70    195.988     0.0000
1990         2.75708    224.81    202.000     0.0000
1991         2.84137    244.81    205.918     0.0000
1992         2.92621    266.54    208.594     0.0000
1993         3.01190    289.72    211.238     0.0000
1994         3.09955    312.45    213.938     0.0000
1995         3.18872    335.01    216.652     0.0000
1996         3.27979    357.06    219.695     0.0000
1997         3.37177    379.81    223.367     0.0000
1998         3.43896    404.66    227.605     0.0000
1999         3.46783    431.66    232.480     0.0000
2000         3.50970    461.04    238.066     0.0002
2001         3.58099    493.07    244.043     0.4069
2002         3.68378    527.34    250.340     0.9700
2003         3.79053    563.59    256.859     1.6741
2004         3.90149    601.45    263.187     2.6833
2005         4.01794    639.22    269.297     3.9561
2006         4.14014    676.80    275.188     5.4547
2007         4.26794    714.19    280.586     7.2799
2008         4.40259    750.20    285.531     9.3608
2009         4.54395    785.02    290.766    11.7415
2010         4.69141    821.69    296.117    14.5837
2011         4.84607    859.58    301.578    17.8379
2012         5.00818    898.59    307.023    21.4038
2013         5.17810    938.33    312.320    25.1538
2014         5.35596    978.14    318.313    27.8916
2015         5.53662   1021.66    325.281    28.7959
2016         5.71704   1070.06    332.320    28.7959
2017         5.90051   1119.66    340.117    28.7959
2018         6.08411   1173.34    347.773    28.7959
2019         6.27979   1227.50    356.922    28.7959
2020         6.48267   1282.19    364.648    28.7959
2021         6.69360   1338.69    372.625    28.7959
2022         6.87488   1397.25    380.539    28.7959
2023         7.02563   1456.69    388.414    28.7959
2024         7.16174   1517.06    396.250    28.7959
2025         7.29773   1578.41    404.055    28.7959
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B 1081

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PAGE     5      04/17/74      16:53


              Y1234       Y           CAPAC       CAPAC
                          MF          ME          NAM
1975          1.98477       66.09      14.124      0.0000
1976          1.95703       71.44      28.482      0.0000
1977          1.93909       77.72      43.351      0.0000
1978          1.93069       64.29      58.537      0.0000
1979          1.95081       91.11      73.654      0.0000
1980          2.00043       98.72      88.430      0.0000
1981          2.06860      107.08     102.471      0.0000
1982          2.13837      116.67     117.074      0.0000
1983          2.20990      126.32     130.730      0.0000
1984          2.28314      137.09     144.477      0.0000
1985          2.35809      148.36     156.844      0.0000
1986          2.43463      161.11     168.887      0.0000
1987          2.51282      174.73     179.156      0.0000
1988          2.59265      190.14     188.117      0.0000
1989          2.67413      206.70     195.988      0.0000
1990          2.75708      224.81     202.000      0.0000
1991          2.84137      244.81     205.918      0.0000
1992          2.92621      266.54     208.594      0.0000
1993          3.01190      289.72     211.238      0.0000
1994          3.09955      312.45     213.938      0.0000
1995          3.18872      335.01     216.652      0.0000
1996          3.27979      357.06     219.695      0.0000
1997          3.37177      379.81     223.367      0.0000
1998          3.43896      404.66     227.605      0.0000
1999          3.46783      431.66     232.480      0.0000
2000          3.50970      461.04     238.066      0.0002
2001          3.58099      493.07     244.043      0.4069
2002          3.68378      527.34     250.340      0.9700
2003          3.79053      563.59     256.859      1.6741
2004          3.90149      601.45     263.187      2.6833
2005          4.01794      639.22     269.297      3.9561
2006          4.14014      676.80     275.188      5.4547
2007          4.26794      714.19     280.586      7.2799
2008          4.40259      750.20     285.531      9.3608
2009          4.54395      785.02     290.766     11.7415
2010          4.69141      821.69     296.117     14.5837
2011          4.84607      859.58     301.578     17.8379
2012          5.00818      898.59     307.023     21.4038
2013          5.17810      938.33     312.320     25.1538
2014          5.35596      978.14     318.313     27.8916
2015          5.53662     1021.66     325.281     28.7959
2016          5.71704     1070.06     332.320     28.7959
2017          5.90051     1119.66     340.117     28.7959
2018          6.08411     1173.34     347.773     28.7959
2019          6.27979     1227.50     356.922     28.7959
2020          6.48267     1282.19     364.648     28.7959
2021          6.69360     1338.69     372.625     28.7959
2022          6.87488     1397.25     380.539     28.7959
2023          7.02563     1456.69     388.414     28.7959
2024          7.16174     1517.06     396.250     28.7959
2025          7.29773     1578.41     404.055     28.7959
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B 1o81