RR-75-2

STUDIES ON ENERGY RESOURCES IN THE IIASA ENERGY PROJECT

Michel Grenon

January 1975

P R E F A C E

This report is a follow-up to the contribution of Professor Michel Grenon to the IIASA Energy Project Status Report (SR-74-1-EN, April 5, 1974), and is aimed at helping to locate the coming IIASA Conference on Energy Resources (May 20-21, 1975) among the various activities of the Energy Project on energy reserves and resources.

Basically, this report was presented during the visit of the Energy Project (December 1-4, 1974), to the Committee for IIASA, USSR Academy of Sciences, Moscow.

Wolf Häfele

Studies on Energy Resources in The IIASA Energy Project

Michel Grenon

Introduction

A crucial point for the transition from a fossil to a non-fossil energy economy is time. Are we in a hurry, and must we shift as fast as possible from coal and hydrocarbons to say nuclear fission? Or else do we have time, not only to choose the best of various possible options (the options being studied in the Energy Project are: nuclear fission, nuclear fusion, solar and geothermal), but also to implement them with optimized devices, such as the fast breeder instead of the lower-performance Light Water Reactor?

Regarding nuclear fission, we can also raise another question: Is it still really on open option, or are we already so heavily committed to it that it is more comparable to coal and hydrocarbons (all the more so if we consider the amount of known uranium reserves, if used only with the LWR) than to solar and/or geothermal?

If we agree that time is a crucial factor for any study on transition such as we are doing in the Energy Project, we realize immediately that time is closely related to, and dependent on, resources (essentially, for our purpose here, coal, hydrocarbons and natural uranium, i.e. non-renewable energy resources).

But the problem of resources, to my mind, can be looked at from two different points of view:

1. Knowing--or expecting to know--the various energy resources, when do we need a new energy option? Or
2. Knowing that in any case we need a new energy option (or two or three new energy options), and that we need a certain amount of time to implement this, do we have enough resources to make the transition as well as possible?

In the first case, I would say that we would like to know the maximum, or ultimate, amount of energy resources. In the second case, we need some kind of acceptable minimum value, assuming a more or less tight planification of energy development.

Thus the author is studying the resource problem, to aid those in the IIASA Energy Project who are investigating energy options, and in close collaboration with them.

Energy Resource Studies

We have divided these studies into three parts, related to the various steps between the energy resources in the ground and the final availability of raw energy materials to the "consumer" (Figure 1).

The first step is the assessment of energy resources. How many resources are really in the ground, or what is the "energy resources capital" for mankind?

The second step is related to the production of energy materials. What are the main problems, and are there global factors introducing limits to the production capability of world energy materials?

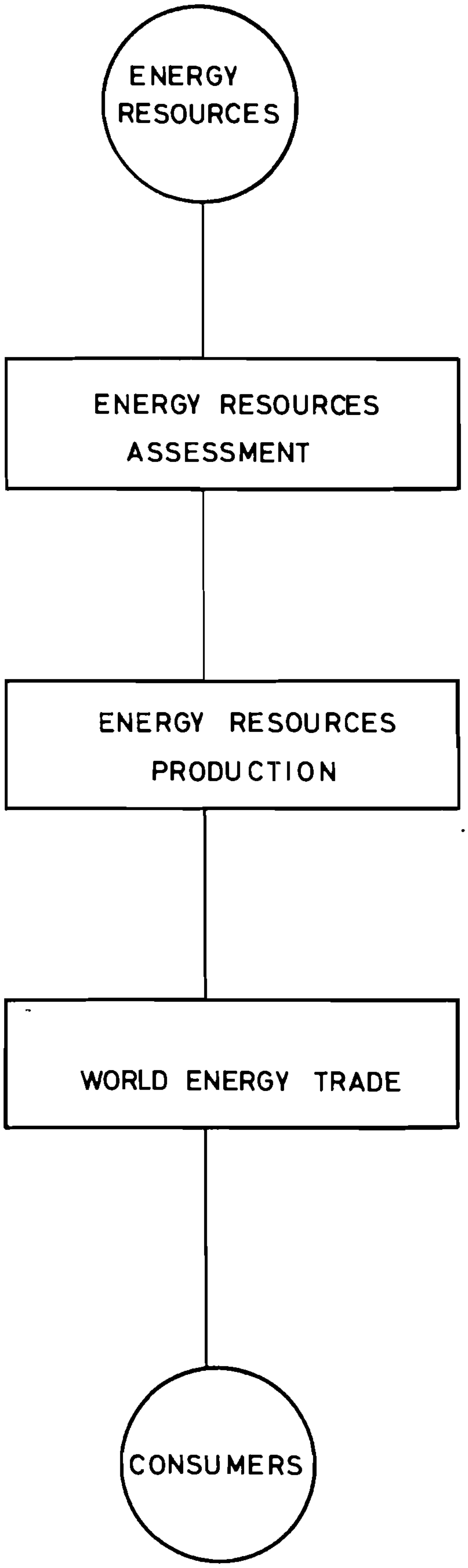
But for the time being, energy users are generally different from energy producers. So a major point for energy consumers is energy trade: can we foresee future conditions of energy trade? This is the third step of our studies.

Before describing our detailed studies of the various steps, it must be stated clearly that these problems, as a whole, would alone require at least an entire Institute like IIASA. So we have concentrated on some major points, or points which appeared to us to have been insufficiently studied. Moreover, we have emphasized as much as possible the methodological aspects, or else, for obvious reasons, the "service" aspect, such as a critical collection of energy resources data for the use of other scientists.

Energy Resources Assessment

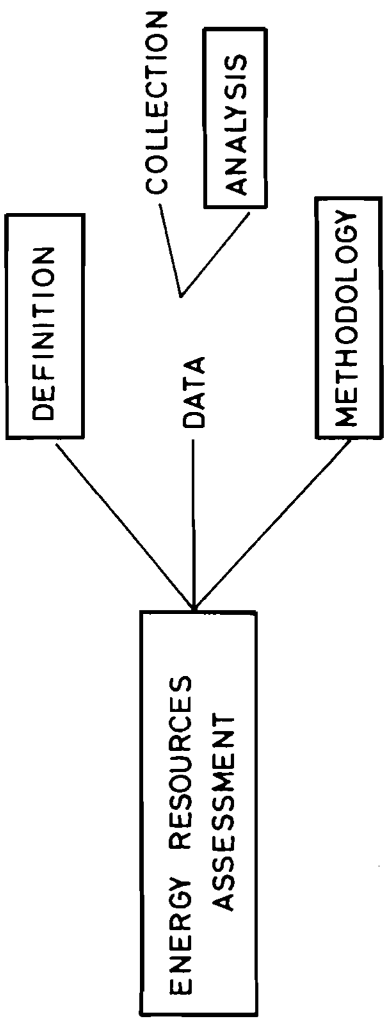
Of the various activities which can be associated with energy resources assessment, we have concentrated mainly on definitions, analysis of data, and methodology (Figure 2).

A first difficulty is related to the definition of energy reserves and/or resources. If we take oil, for instance, the most international of all energy commodities, the U.S.A. distinguishes between two types of oil reserves (drilled or proven, and additional); the French Petroleum Institute has adopted three types (proven, probable, and possible), and even the second type, probable, is subdivided into probable A and probable B; and in the Soviet Union, five types are considered (drilled proven reserves, undrilled proven reserves, discovered possible reserves, undiscovered possible reserves, and hypothetical reserves).



FROM RESOURCES IN THE GROUND TO ENERGY CONSUMPTION

FIGURE 1



ENERGY RESOURCES ASSESSMENT
DEFINITION
DATA
COLLECTION
ANALYSIS
METHODOLOGY

FIGURE 2

It is clear that such a situation makes it very difficult to compare and/or integrate these data on a world basis. The situation is no better for the resources in general, and various definitions and/or representations are used throughout the world, as shown in Figure 3 and 4.

One of the most extensively used classifications is that of McKelvey (upper part of Figure 4) of the USGS. McKelvey distinguishes between identified and undiscovered resources, and between those recoverable under present economic conditions: marginal or paramarginal (at less than 1.5 present economic conditions), and submarginal (at more than 1.5 present economic conditions). In fact, a time in which economic conditions (costs and/or prices) are changing so fast, we are not completely satisfied with McKelvey's classification: we at IIASA are more in favor of Brobst and Pratt's classification into only recoverable and subeconomic resources, with undiscovered resources split between known and undiscovered districts (lower part of Figure 4).

We have not yet definitely made up our mind at IIASA, and we are studying as many classifications as possible in detail, with their positive or negative aspects, so as to adopt finally the most appropriate classification to our needs.

Some preliminary comments on such definitions can be made:

1. Generally, the more detailed the classification, and the more classes are defined, the greater the uncertainties associated with classes of higher rank. As pointed out by King Hubbert, it often happens that the uncertainty of the amount of the higher classes of resources is greater than the known amount of the first class (say, proven reserves), which makes them of low (if not problematic) practical value.
2. The economic limit between reserves and resources on the vertical scale is today very uncertain because of new factors: ecology, land management, availability and management of water resources, and political factors (the difference between costs and price becomes tremendous for oil, for instance for Arabian oil, where price is about 100 times the cost).
3. Which inferior limit must we consider? Lasky, for instance, has proposed taking the content of the Earth's crust. But it is clear that under present economic conditions (and maybe under any economic conditions) some of the Earth's minerals will never be mined. In this case, is it realistic to take such a low limit? At IIASA, for instance (as will be discussed in the next section), we have begun to study the ENERGY CONTENT of energy resources, and especially of mining operations: at first sight,

CONCEPTUAL MODEL OF THE RELATION BETWEEN MINERAL RESOURCES AND MINERAL RESERVES

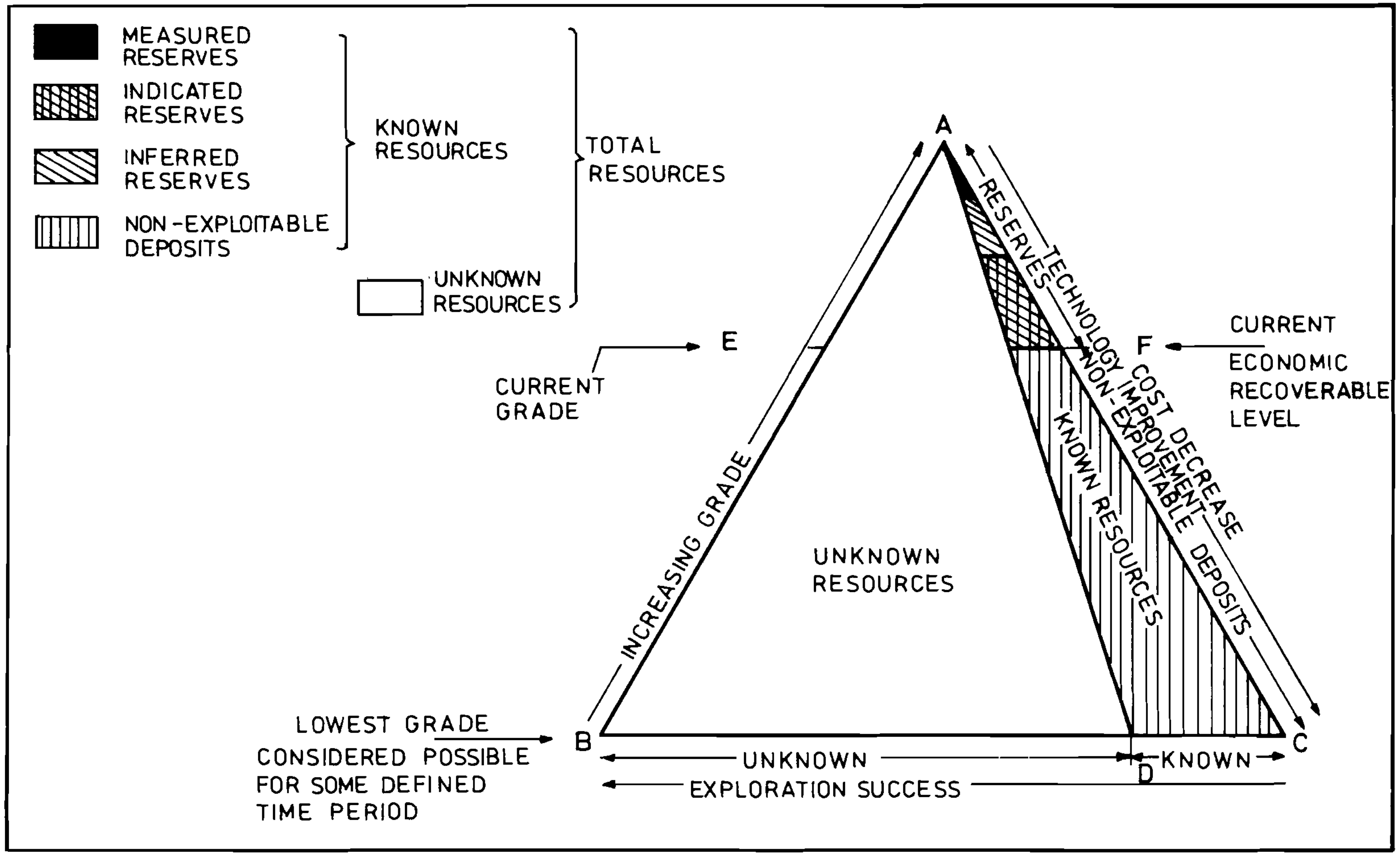
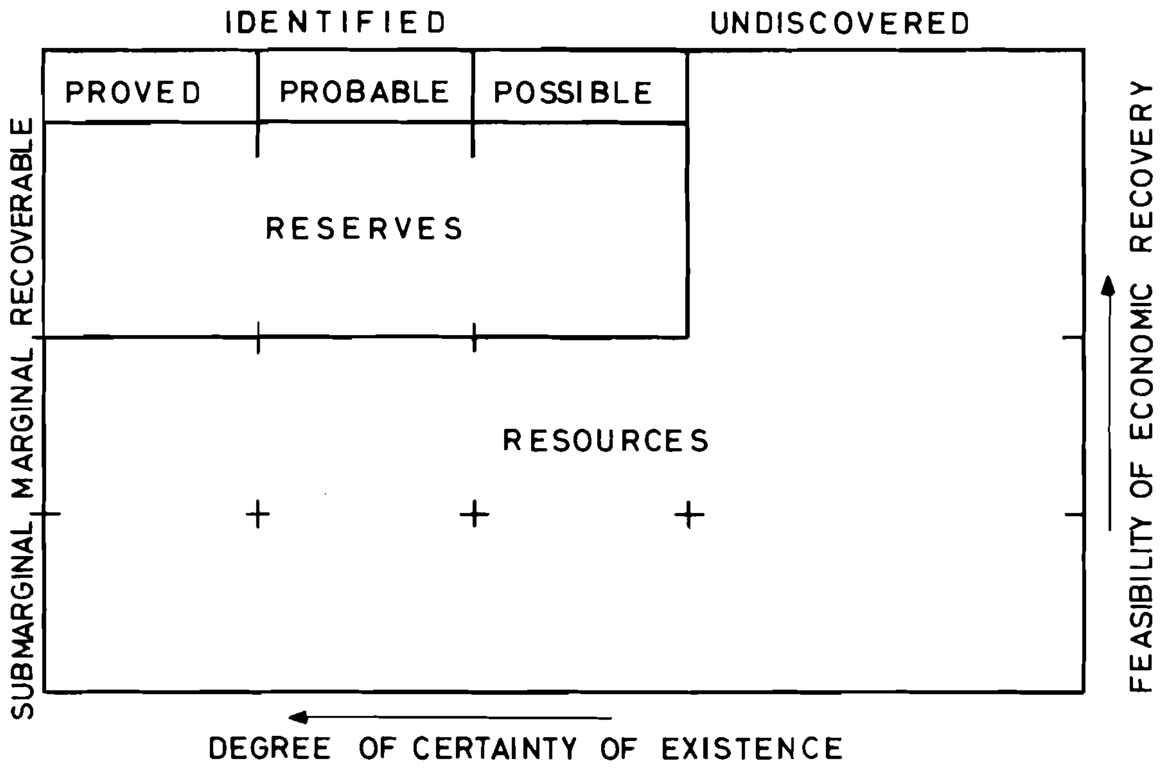
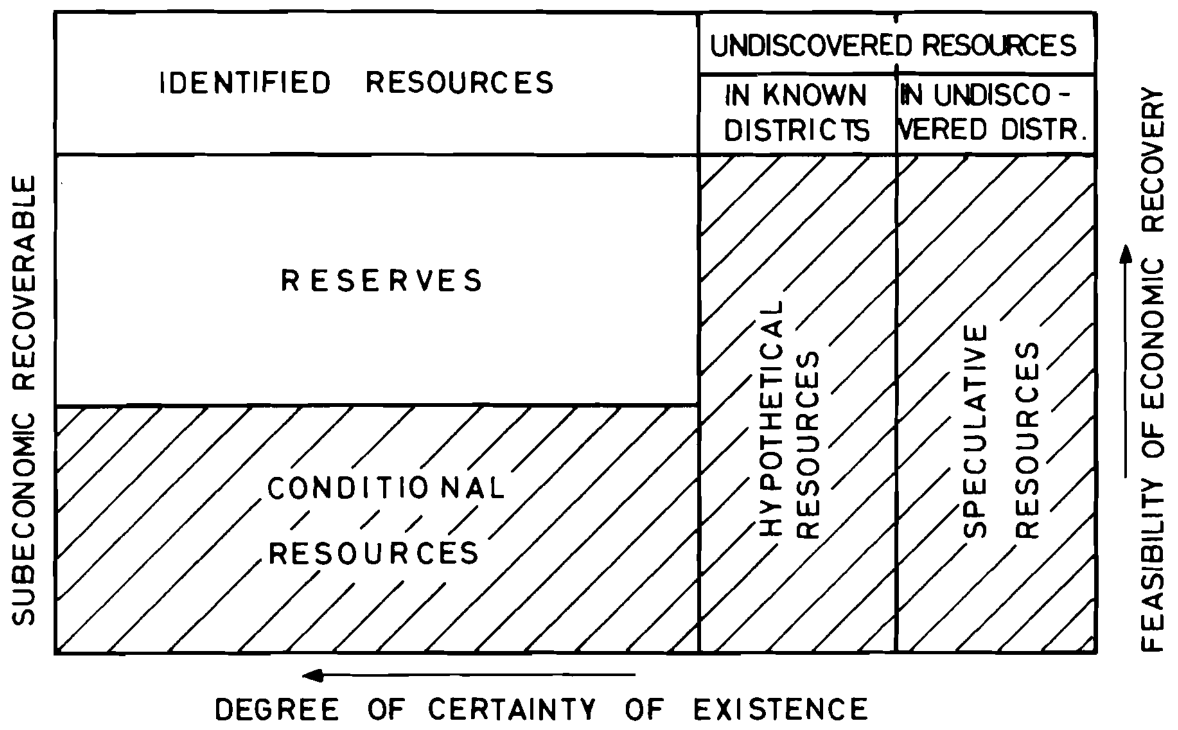


FIGURE 3



DEFINITIONS OF RESERVES AND RESOURCES. MC.KELVEY



DEFINITIONS OF RESERVES AND RESOURCES. BROBST & PRATT

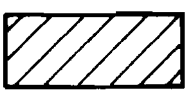
 POTENTIAL RESOURCES: CONDITIONAL + HYPOTHETICAL + SPECULATIVE

FIGURE 4

it is conceivable that some mining operations on low grade minerals (shale oil, uranium, etc.) could consume more energy than could be recovered by simple combustion of the fuels produced. Even without going to such an extreme case, the energy content of mining operations can be used for a comparison between various fuels, and to assign a practical lower limit to the classification of usable energy resources.

Other classifications have been studied for energy reserves and/or resources. A very useful one has been prepared by Tussing for hydrocarbons, with three main classes:

Class I: Giant fields, such as Samotlor in the Soviet Union, Ghawar and Burgan in the Arabian-Persian Gulf, etc., with actual production costs of less than 2 dollars per barrel (1974)*. It is important to remember that these fields represent about 70 to 80% of known reserves today.

Class II: Fields which are far more widely distributed, but for which proven reserves are substantially less than for Class I. Production costs today are between 2 and 5 dollars per barrel.

These reserves are depleted much faster than those of Class I (depletion rates of 5-15%/year, versus 2%), and they must constantly be renewed by fresh discoveries. U.S. fields are a good example of this class.

Class III: This offers the greatest variety and an enormous potential, at production costs above 5 dollars per barrel. We can mention:

a) oil left in the ground after primary and secondary recovery;

b) giant gas fields, very remote (Arctic, etc.);

c) solid hydrocarbons, etc.

As pointed out by Tussing, it seems that for our future oil supply we have the choice mainly between Class I and Class III, with two opposite risks: after having invested billions of dollars for Class III, a lowering of prices for Class I; or else, to avoid this, an over-protection (with economic penalty) of Class III.

Apparently, it would seem that such a classification, with the biggest reserves at two extremes, contradicts Lasky's hypothesis of continously growing resources with decreasing ore grades. Incidentally, a similar contradiction has been found for copper in Chile. What about uranium? Generally,

*Production costs are generally much lower than the limit of $2/bbl; at Ghawar for instance, they are about 10 cents.

people assume that more and more uranium of decreasing grade will be found. Can we consider the giant deposits in Australia as comparable to the giant oil fields already mentioned, and then assume (as advocated by some U.S. specialists) that the class similar to Class II, on which we are living now, is relatively poor, and that we will be obliged to go to very high cost uranium (more than \$30/lb U_3O_8, possibly more than \$50 or even higher) to find very abundant uranium resources again? I think more and more that it is somewhat paradoxical that we engage ourselves, mainly in the Western World, so heavily in nuclear energy (and almost exclusively, for the time being, with Light Water Reactors) and that, finally, we know so little about uranium resources.

Thus we are trying at IIASA to clarify our ideas on these definitions of reserves/resources, and possibly choose a working classification. If we now return to Figure 2, we can point out a second difficulty, related to the choice of data. Various organizations (not many, in fact) publish statistics on energy reserves and (fewer still) on energy resources, such as the United Nations, the World Energy Conference, the U.S. Geological Survey, the Oil and Gas Journal, World Oil, etc. Practically, it is very difficult to work efficiently with such statistics, because their publication is delayed (those of the U.N., for instance) and/or because they are not always coherent. To give an example for oil reserves, there are sometimes very big differences, such as for Algeria's proven oil reserves: 1,090 million tons (Oil and Gas Journal, which generally also includes condensates), 1,420 million tons (World Oil) and 6,000 million tons (World Energy Conference) for 1972-1973.

As a result, we have as a permanent task, in the Energy Project at IIASA, not the collection of data (which is completely beyond the scope and ability of our Institute), but their critical analysis, and the establishing of recommendations for other scientists, trying to assure reliability and coherence.*

Finally, looking again at Figure 2, our third task related to energy resources assessment is to understand, analyze, and compare (and possibly develop our own) methodologies used to estimate energy resources. This is a fundamental task in view of our objective, the first two tasks being more or less prerequisites for this major one. To stress its importance, we can mention that, starting apparently from a similar bank of U.S. oil data, McKelvey and King Hubbert, using two different approaches, arrived at very different figures for ultimate U.S. oil resources: 500 to 1000 x 10^9 bbl (70 to 140 billion tons) for McKelvey, and only 170 to 200 × 10^9 bbl (25 to 29

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*It is worth mentioning that this time-consuming task was initiated by Dr. Kourochkin, who laid the foundation for this long term activity.

billion tons) for King Hubbert. Such a difference can, and must, lead to completely different oil policies. The same, of course, would apply if similar differences were to be found--and sometimes they are--at world level.

To implement our work on comparison of methods for energy resource assessment, we are planning a Conference in a few months' time at IIASA (see Annex for draft of announcement as distributed to various Soviet scientists during the Moscow Meeting). This conference will try to compare existing methods for the assessment of ultimate energy resources.

Production of Raw Energy Materials

This is a very broad field, and we limit ourselves, as shown in Figure 5, to specific problems, related say to large scale mining. Some of these problems, such as large scale mining and land reclamation for coal, will be studied by a joint team of the Water Project and the USGS, whilst the Energy Project plans to participate in such studies.

However, for the time being, we have started a research activity related to the ENERGY CONTENT of mining operations. There are two possible ways of approaching this problem: by input-output matrices (such as those being developed at present by research scientists of the Energy Project for studies on energy demand), or by direct estimates.

As far as we know, there are few studies on this problem. Worth mentioning is the work at Oak Ridge National Laboratory by Bravard, Flora and Portal, on the recycling of some materials (Mg, Fe, Ti and Al), and the work of Brobst and Pratt of the USGS on copper. The latter have developed the general equation:

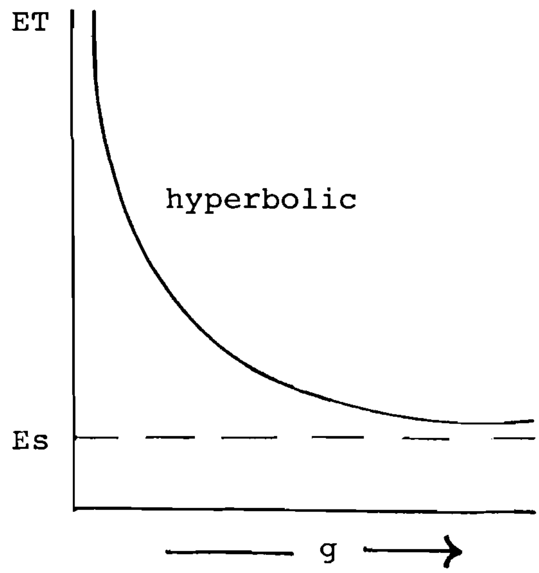
$$ET = Em(T) + Es$$

$$= \frac{Em}{g} + Es$$

where Em = energy to mine and mill one ton of ore

Es = energy to smelt and refine the concentrate to produce one ton of metal

g = grade of the ore



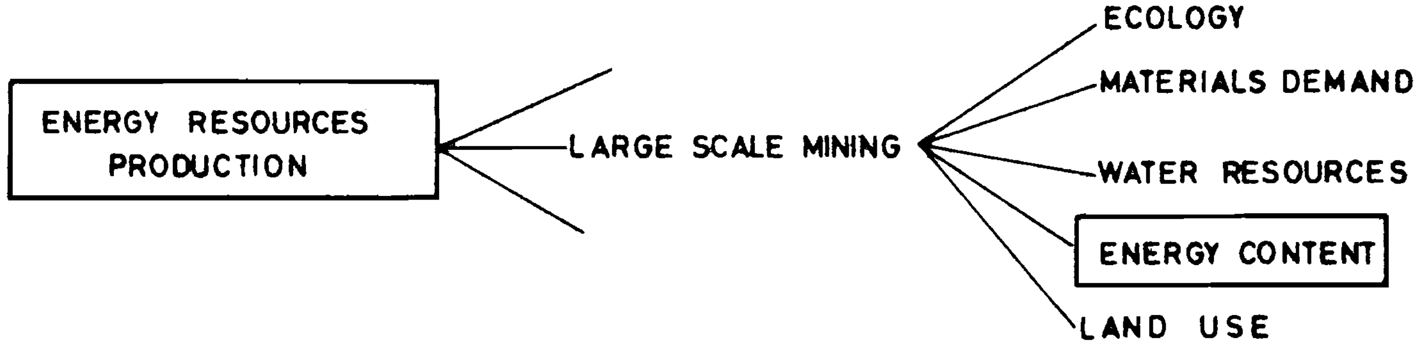
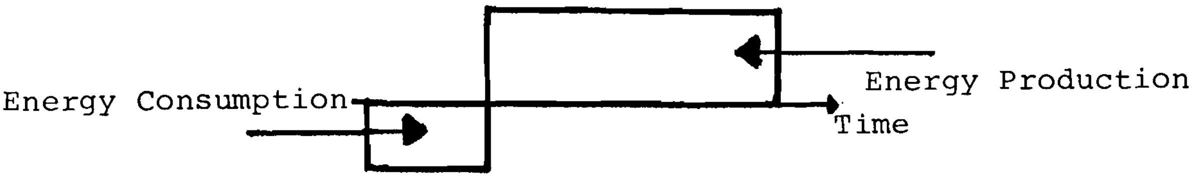

ENERGY RESOURCES PRODUCTION
LARGE SCALE MINING
ECOLOGY
MATERIALS DEMAND
WATER RESOURCES
ENERGY CONTENT
LAND USE

FIGURE 5

T = tonnage of rock

ET = total energy to process
one ton of metal from its ore.

In a broader sense, Chapman and Mortimer have studied the total energy content of nuclear fission, including mining operations, reactor construction and operation, etc. They have designed an energy cycle with two main phases, energy consumption (assumed at a constant virtual power during construction phase) and energy production during power plant operation. Calculations have been applied to two uranium resources: natural uranium at 0.3% or 3,000 ppm ore content (average value of present U.S. uranium exploitation), and low grade uranium for uranium shales at 0.007% or 70 ppm. Although results are some-



what premature, one interesting indication was that with the known technology for the exploitation of uranium shales, present Light Water Reactors are net energy consumers, and never energy producers. Once more, this shows how careful we must be when handling potential resources.

At IIASA, we have started some calculations in connection with energy content for uranium mining, by contacting a number of uranium mining organizations to try to collect real data on energy accounting in mining operations.

Energy Trade

Assuming that ultimate energy resources can be reasonably estimated, and that large scale production problems can be adequately solved, a new problem arises: how many energy commodities will in fact be put on the international market so that consuming countries can really make proper use of them? Many factors have, of course, to be taken into account (including, as was practically demonstrated about one year ago, political factors). We are more especially interested in exploiting two of them, on a methodological basis, say possible energy conservation policies of producers, and "coalitions" of commodity-producers (as shown in Figure 6).

Regarding possible energy conservation policies by producers, which can drastically influence the amount of energy commodities put on the market and how long they can possibly be available, we have started by defining the ENERGY POSITION

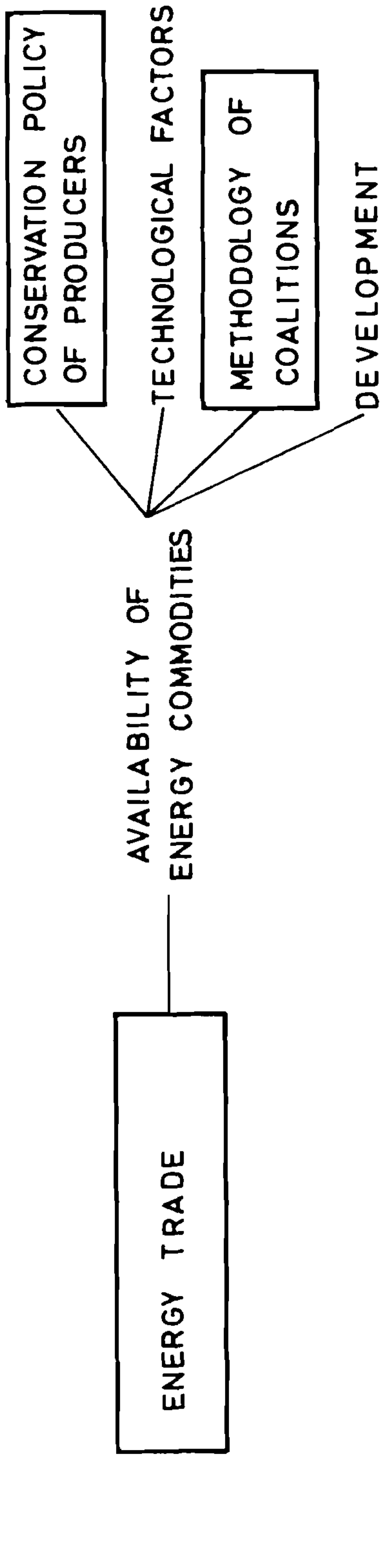

ENERGY TRADE
AVAILABILITY OF
ENERGY COMMODITIES
CONSERVATION POLICY
OF PRODUCERS
TECHNOLOGICAL FACTORS
METHODOLOGY OF
COALITIONS
DEVELOPMENT

FIGURE 6

of various countries*. Generally, a graphical correlation of various countries is considered by plotting energy consumtion per capita versus GNP per capita, as shown in Figure 7. We have developed a somewhat different approach by plotting the energy reserves per capita, or the energy production per capita (depending on the problem being studied), versus the energy consumption per capita. As shown in Figure 8, for energy reserves per capita versus energy consumption per capita, the representation can be applied to various fuels individually, or to the total amount of energy reserves, which can be expressed in absolute values (tce, toe, kwh, etc.). As an example we have used one country, France, in 1973 (▲ absolute values in tce on left scale and ● relative values in years of actual consumption on right scale of Figure 9).

Figure 10 shows the basic diagram used for the classification of the various countries relative to each other, and illustrates the various ENERGY POSITIONS: relative self-sufficiency, importers, exporters, etc. Figure 11 shows trends of possible evolution for one country with time; Figure 12, the relations between time evolution for one country and possible energy policies and/or future objectives; and Figure 13, the representation of trade for an importing energy, to illustrate the flexibility of such diagrams.

The same kind of diagrams can be made for energy production per capita versus energy consumption per capita, as shown in Figure 14. This has been applied (Figure 15) to nine geographical and economic regions, and then (Figures 16 to 19) to four case histories, for France, the Netherlands, Poland and Iran respectively. In fact, for studying their energy positions, we have selected 72 countries out of 178, based on the criterion of producing and/or consuming more than 5 million tons of coal equivalent in 1972 (latest UN energy statistics). Figure 20 summarizes the data of these 72 countries, grouped into nine regions, as already shown in Figure 15.

The last sentence of Figure 20, stating that 19 countries among the 72 studied have more than 50 years of energy reserves at an 8 tce/capita/year rate of consumption, brings us to the question of energy trade. In fact, to have big reserves per capita may mean two quite different things:

1. to have in fact a very big amount of energy reserves, like the USSR or Kuwait; or

2. to consume very little energy indeed, like Indonesia.

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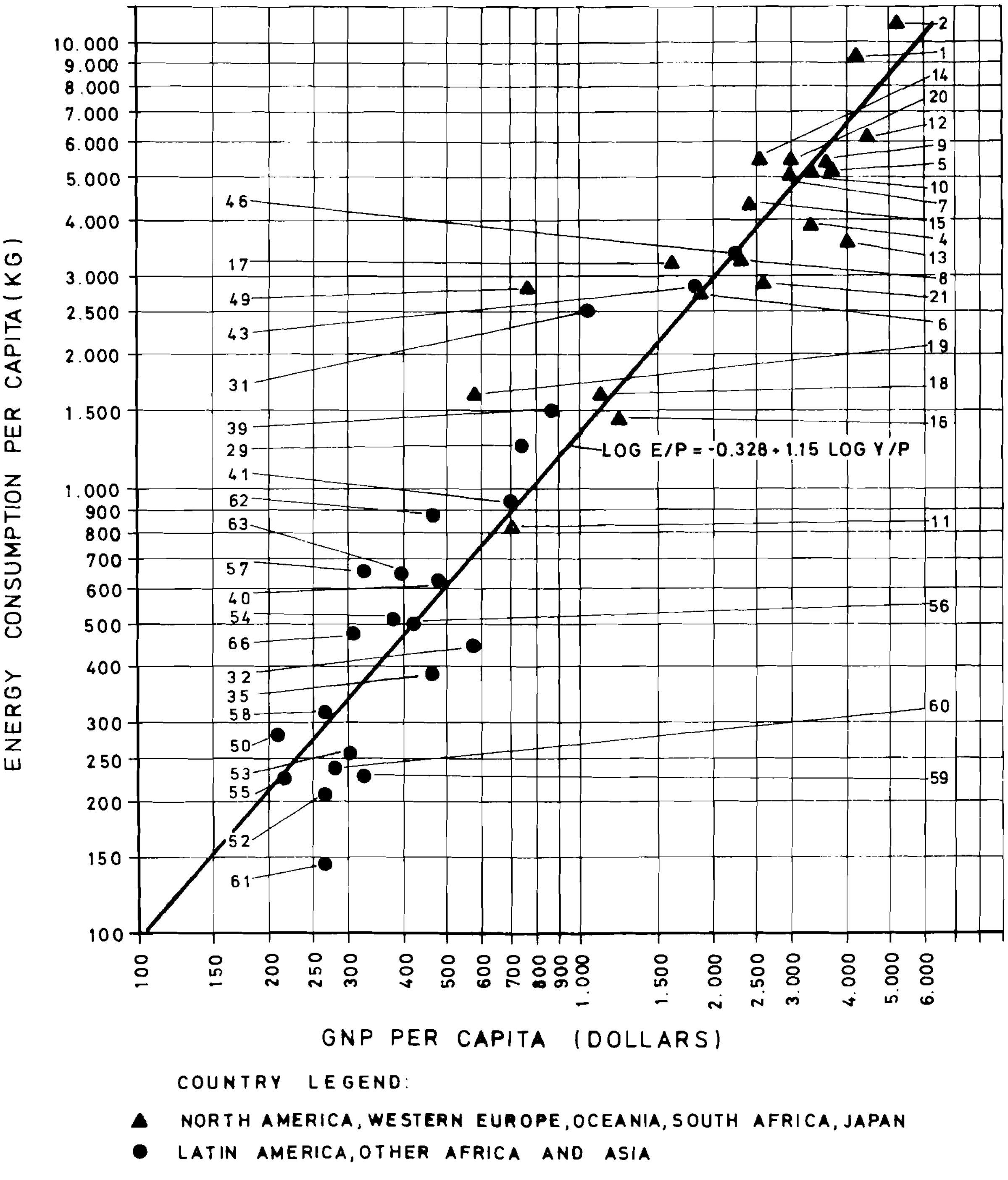
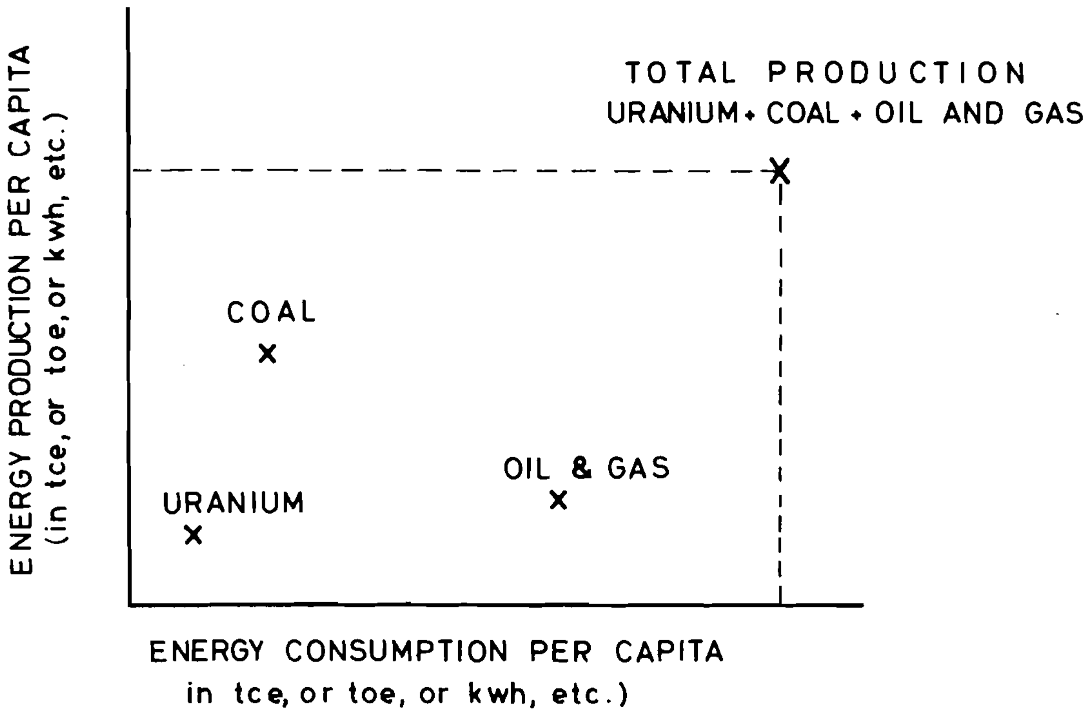
*This work was introduced in the Energy Project Status Report 1974 and developed in internal notes of the Project.

ENERGY CONSUMPTION, POPULATION AND GNP



GNP PER CAPITA AND ENERGY CONSUMPTION PER CAPITA: SELECTED COUNTRIES, 1971

FIGURE 7


TOTAL PRODUCTION
URANIUM + COAL + OIL AND GAS
COAL
OIL & GAS
URANIUM
ENERGY PRODUCTION PER CAPITA
(in tce, or toe, or kwh, etc.)
ENERGY CONSUMPTION PER CAPITA
in tce, or toe, or kwh, etc.)

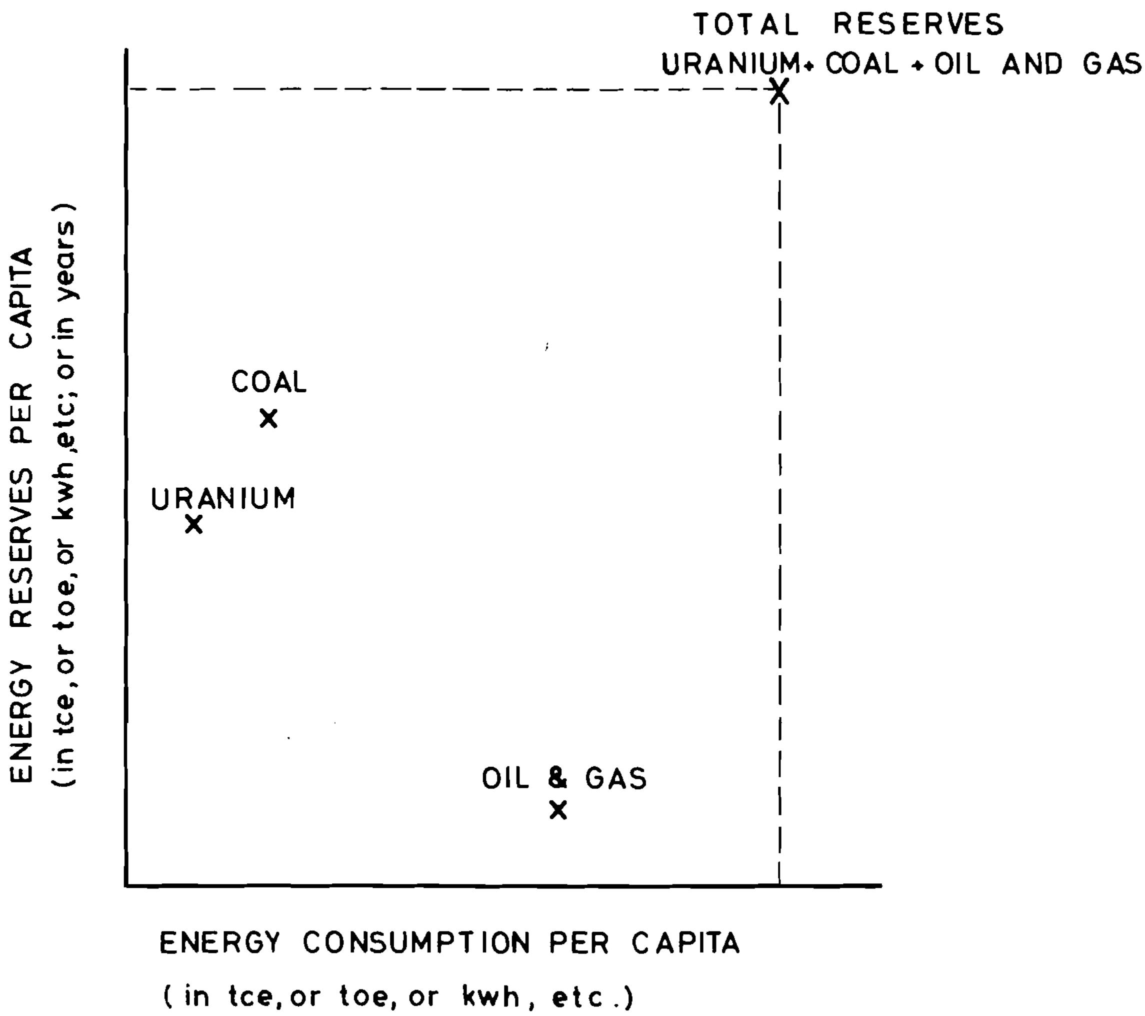

TOTAL RESERVES
URANIUM + COAL + OIL AND GAS
COAL
URANIUM
OIL & GAS
ENERGY RESERVES PER CAPITA
(in tce, or toe, or kwh, etc; or in years)
ENERGY CONSUMPTION PER CAPITA
(in tce, or toe, or kwh, etc.)

FIGURE 8

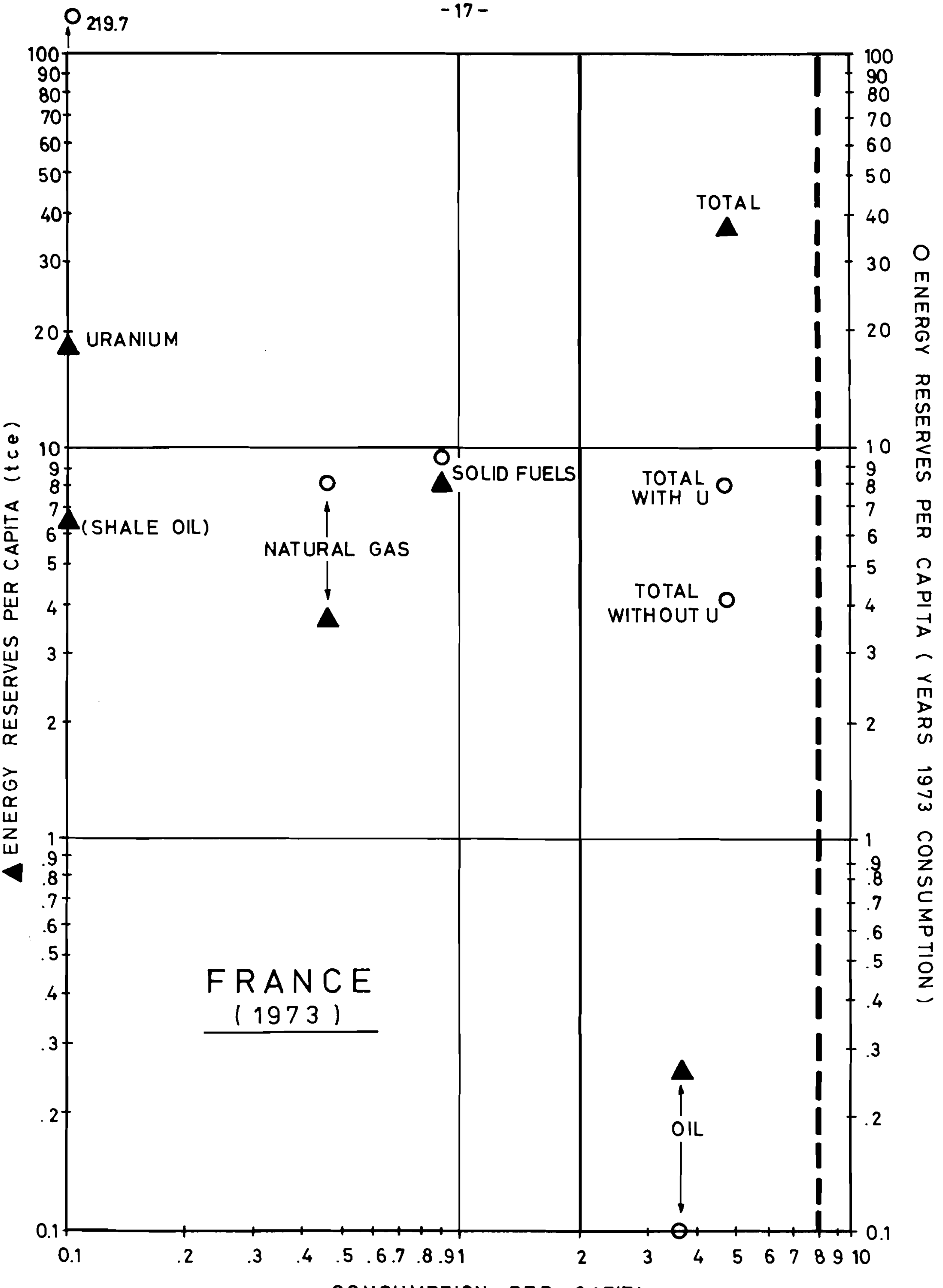

219.7
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
.9
.8
.7
.6
.5
.4
.3
.2
0.1
TOTAL
URANIUM
SOLID FUELS
TOTAL WITH U
(SHALE OIL)
NATURAL GAS
TOTAL WITHOUT U
FRANCE
(1973)
OIL
0.1 .2 .3 .4 .5 .6 .7 .8 .9 1 2 3 4 5 6 7 8 9 10
▲ ENERGY RESERVES PER CAPITA (tce)
○ ENERGY RESERVES PER CAPITA (YEARS 1973 CONSUMPTION)
CONSUMPTION PER CAPITA

FIGURE 9

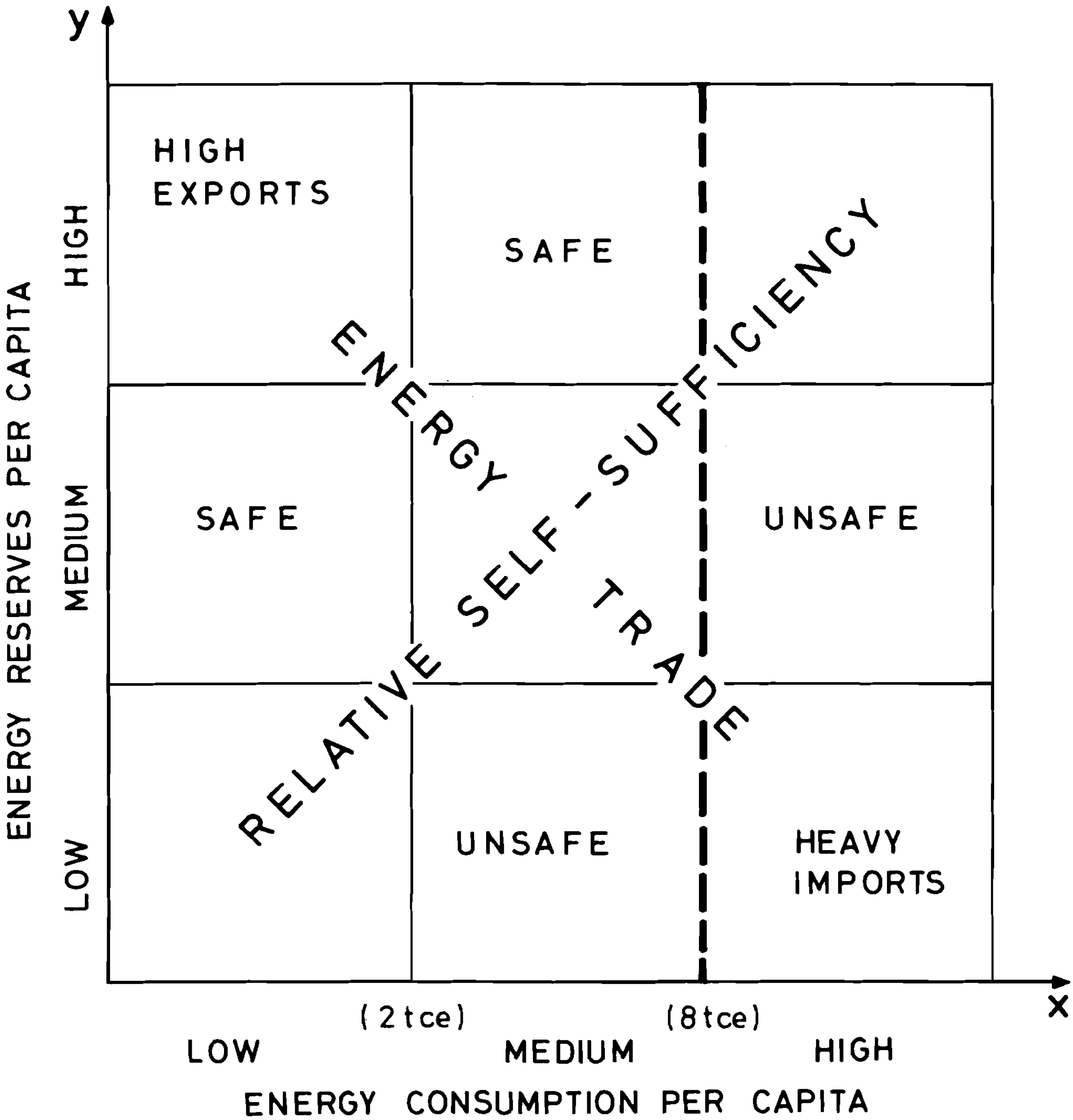
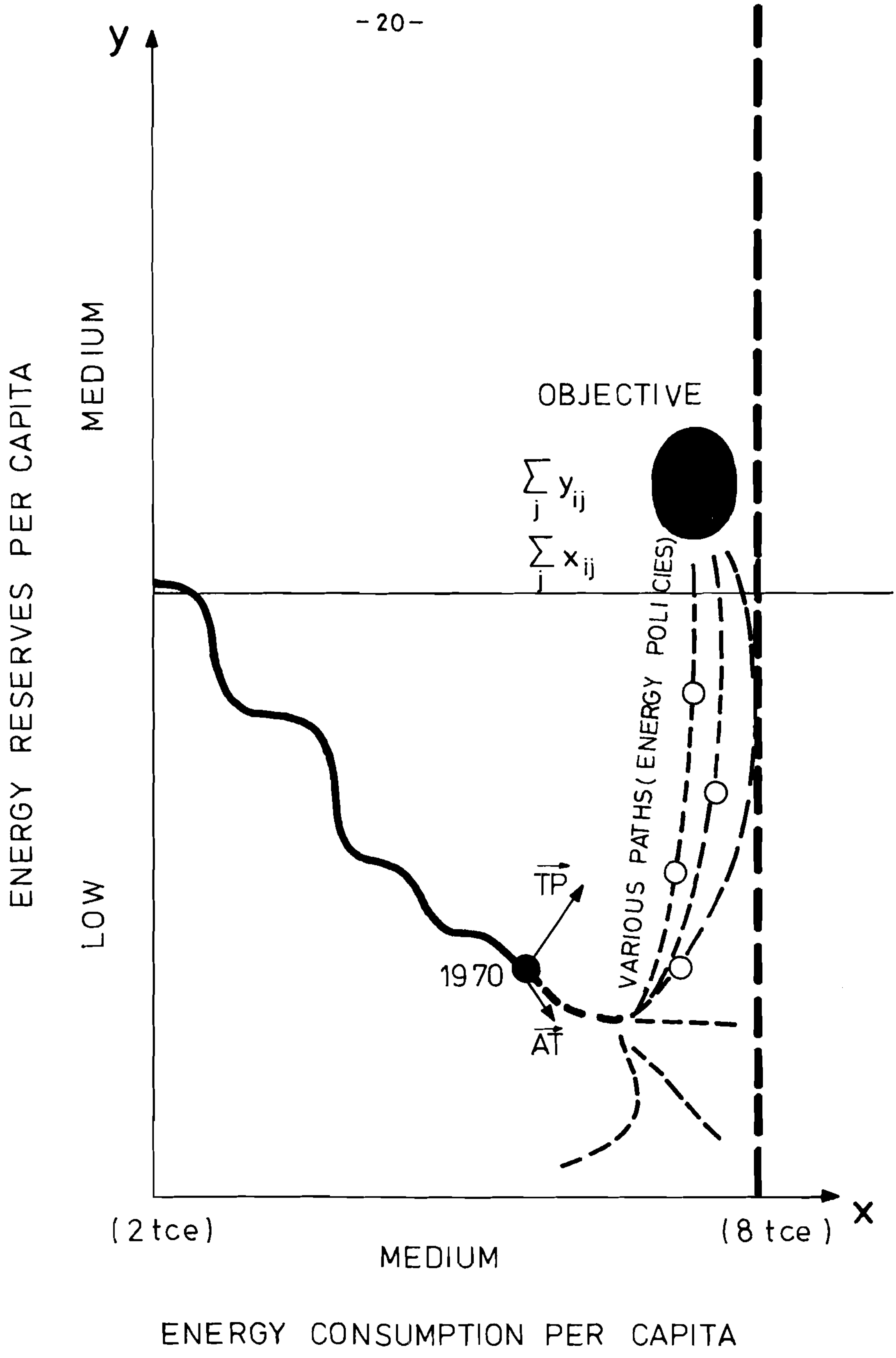

y
x
HIGH
EXPORTS
SAFE
SAFE
UNSAFE
UNSAFE
HEAVY
IMPORTS
ENERGY TRADE
RELATIVE SELF-SUFFICIENCY
ENERGY RESERVES PER CAPITA
HIGH
MEDIUM
LOW
(2tce)
(8tce)
LOW
MEDIUM
HIGH
ENERGY CONSUMPTION PER CAPITA

FIGURE 10

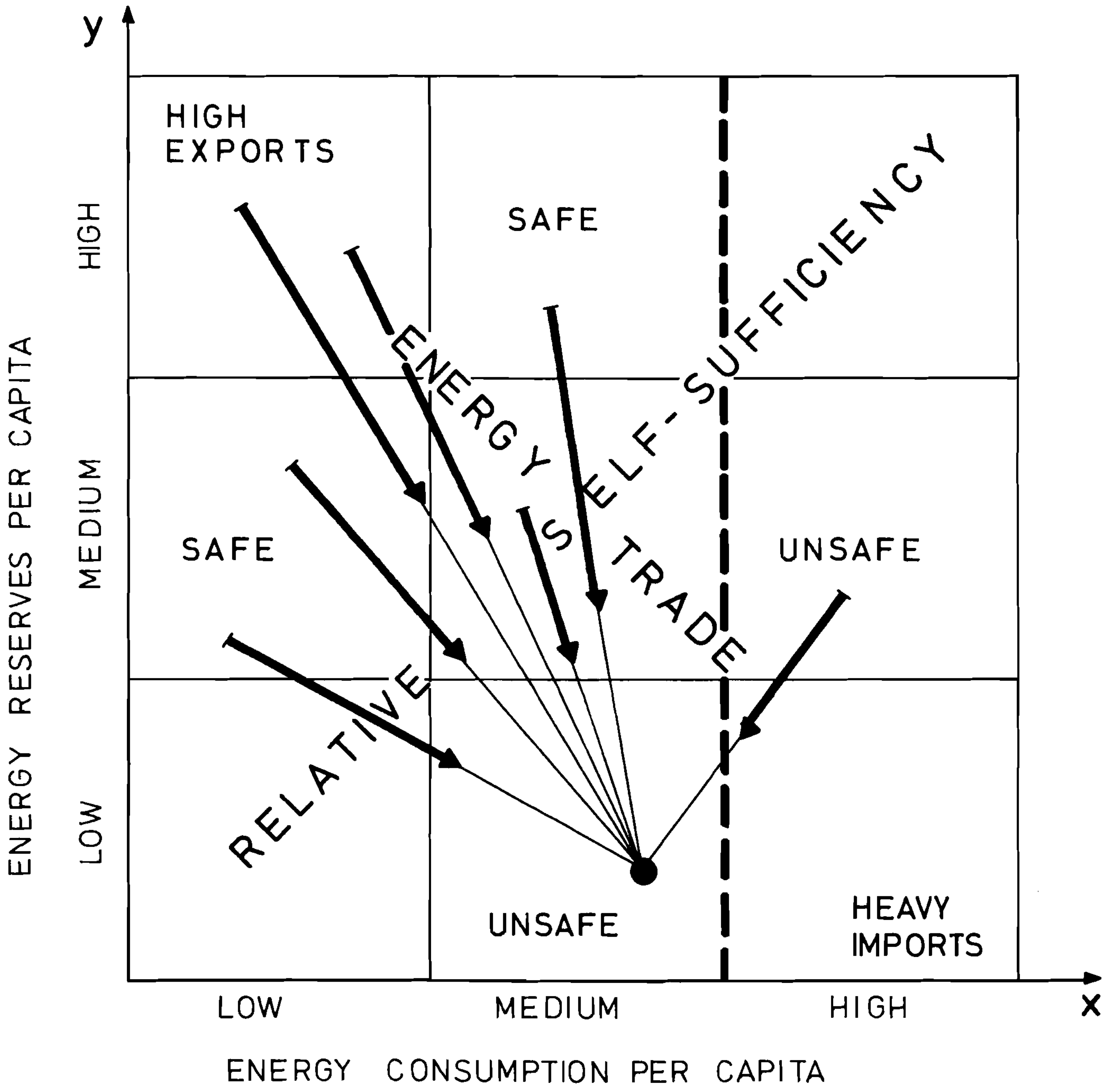
Direction	Meaning	Possible mechanism
$\uparrow$	Increase of reserves	Discovery New technology
$\downarrow$	Decrease of reserves	Consumption Abandon
$\rightarrow$	Decrease of consumption	Technology (i.e. efficiency) Conservation Change of living style Political decline
$\leftarrow$	Increase of consumption	Development "Passivity"

Figure 11.



PRELIMINARY "DECISION MAKING" PROCESS, FOR ONE COUNTRY (1970'S)

FIGURE 12



PATTERN OF TRADE

FIGURE 13

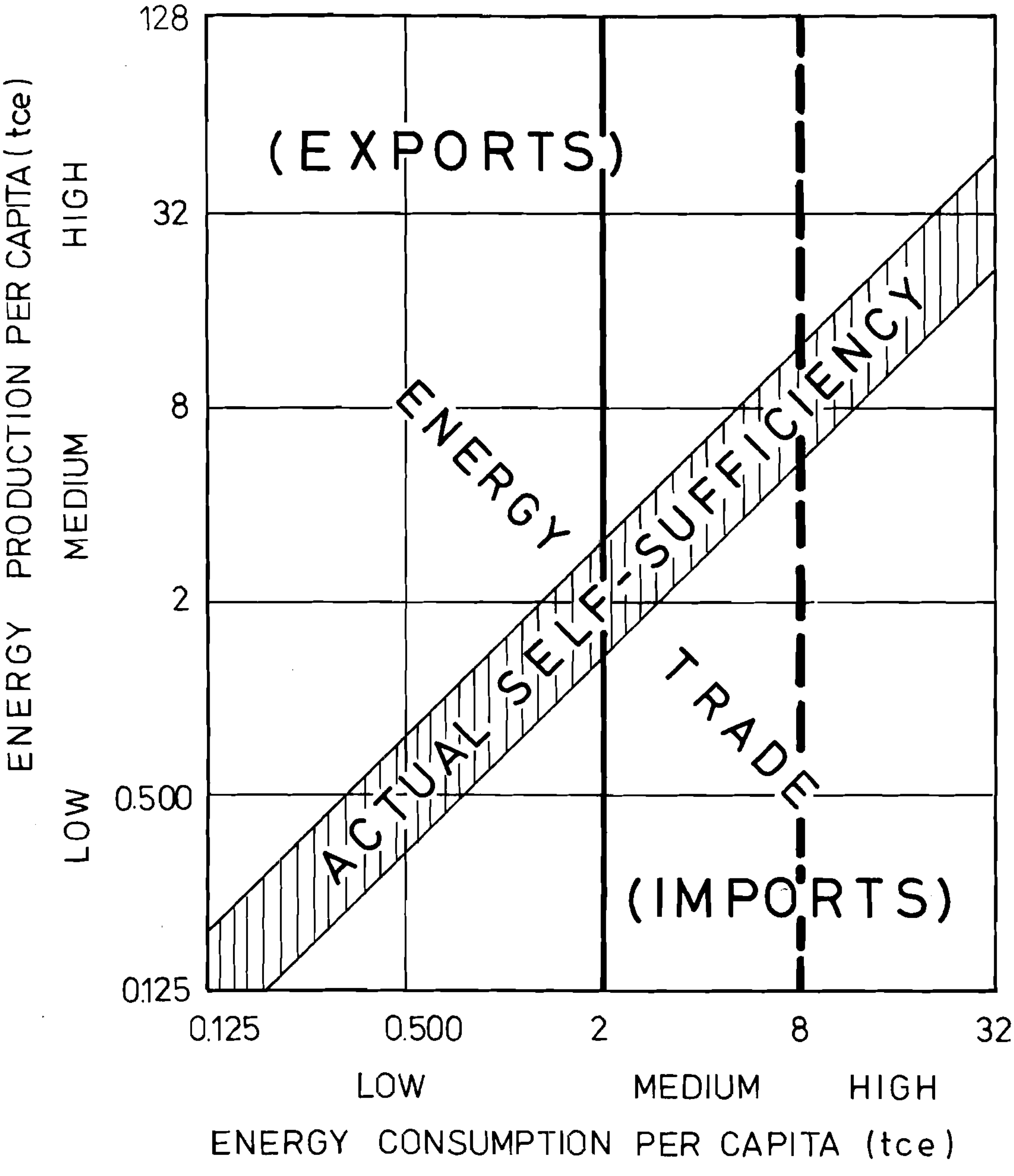
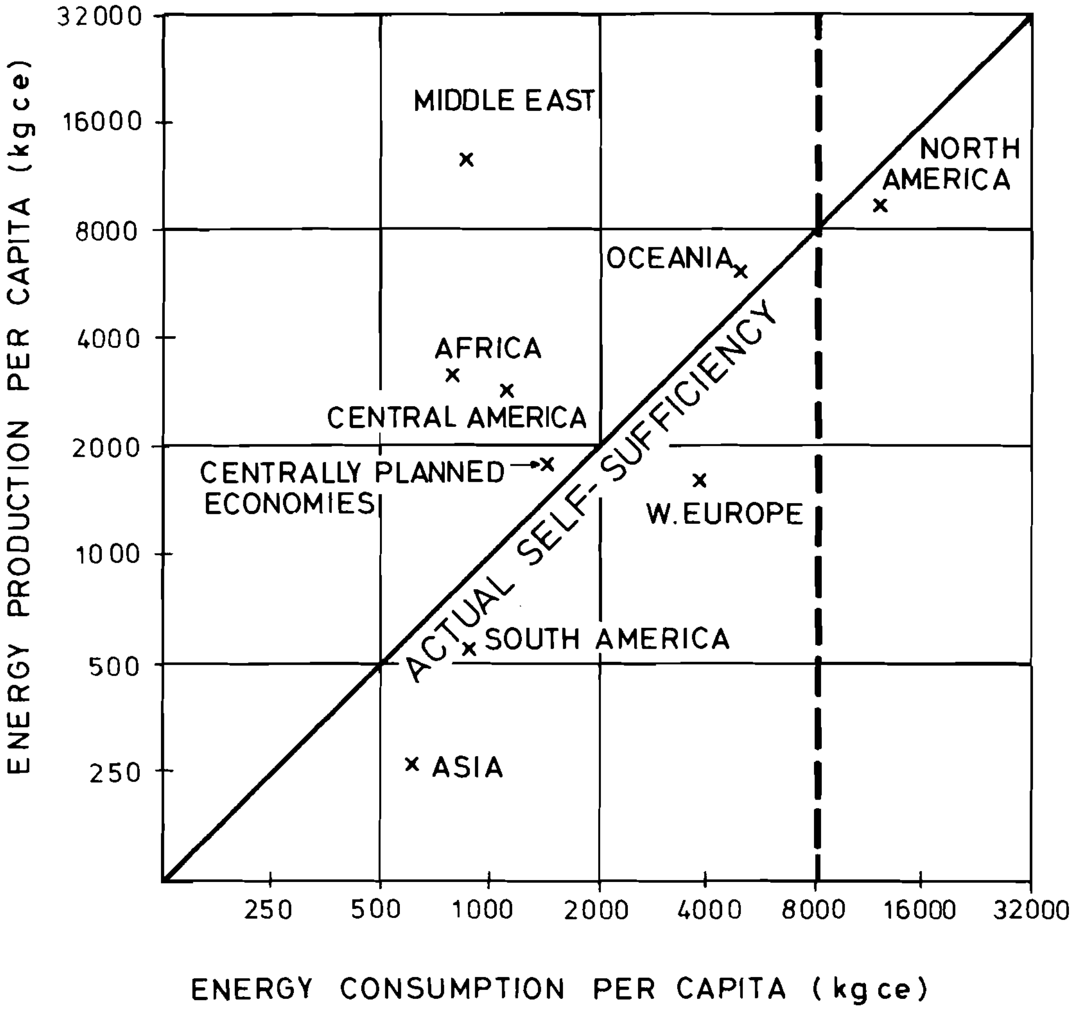
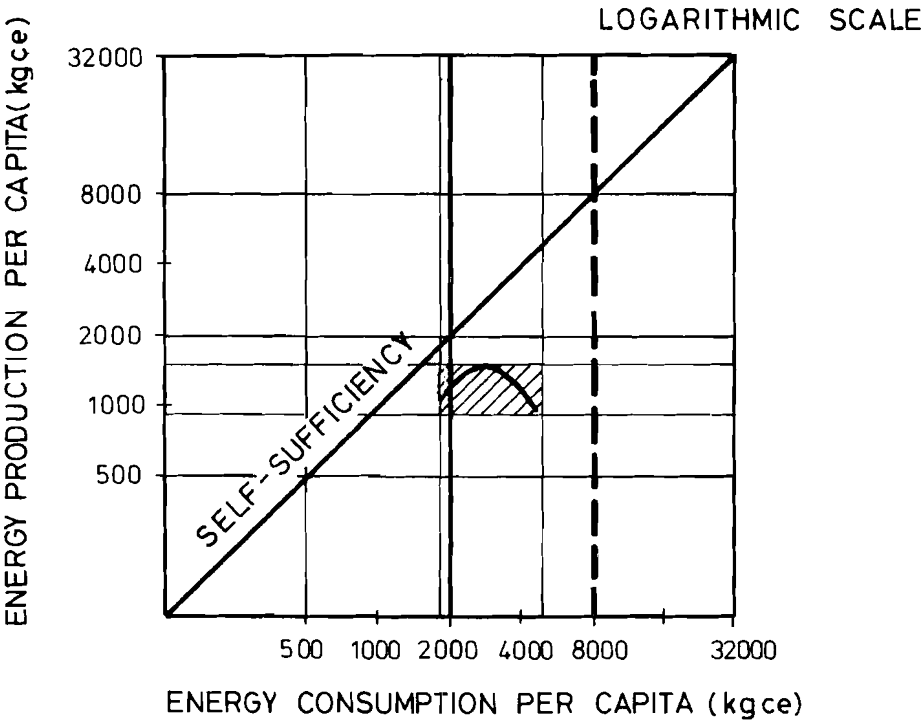

128
32
8
2
0.500
0.125
ENERGY PRODUCTION PER CAPITA (tce)
LOW
MEDIUM
HIGH
(EXPORTS)
ENERGY
ACTUAL SELF-SUFFICIENCY
TRADE
(IMPORTS)
0.125
0.500
2
8
32
LOW
MEDIUM
HIGH
ENERGY CONSUMPTION PER CAPITA (tce)

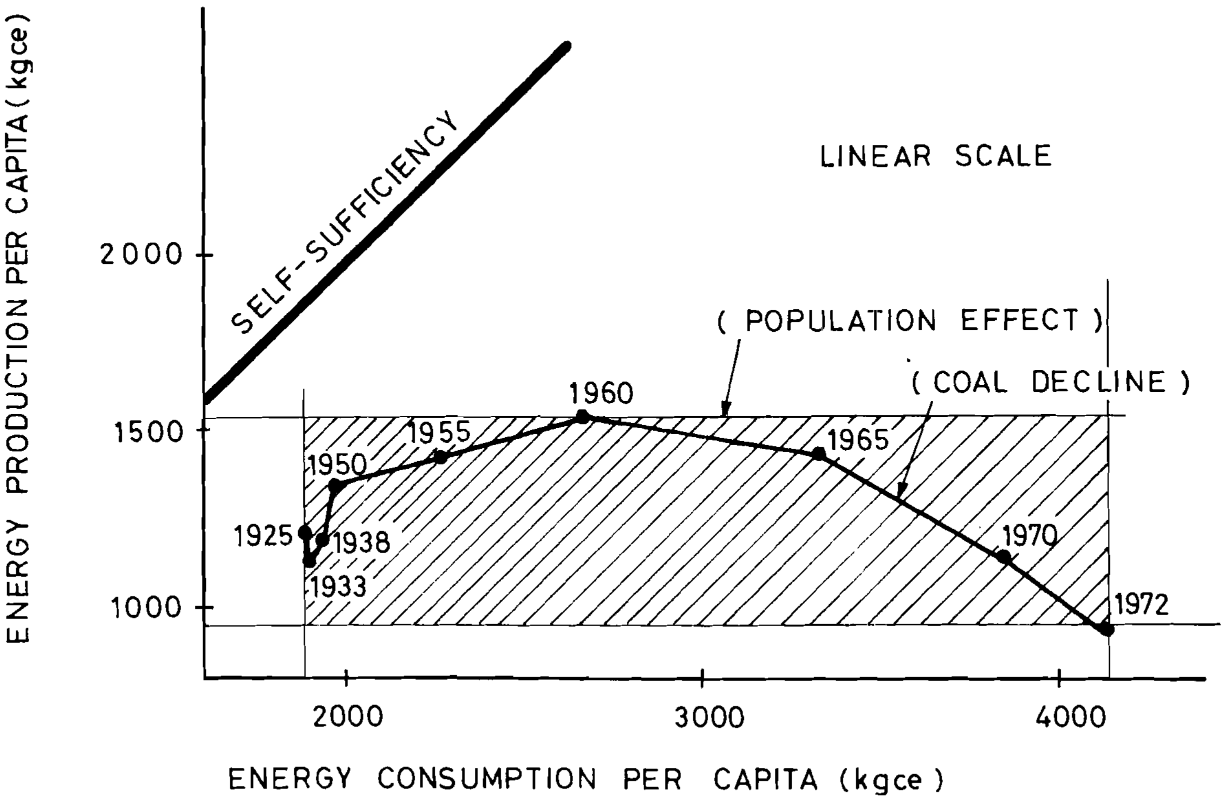
FIGURE 14



DISTRIBUTION OF NINE ENERGY REGIONS (1972)

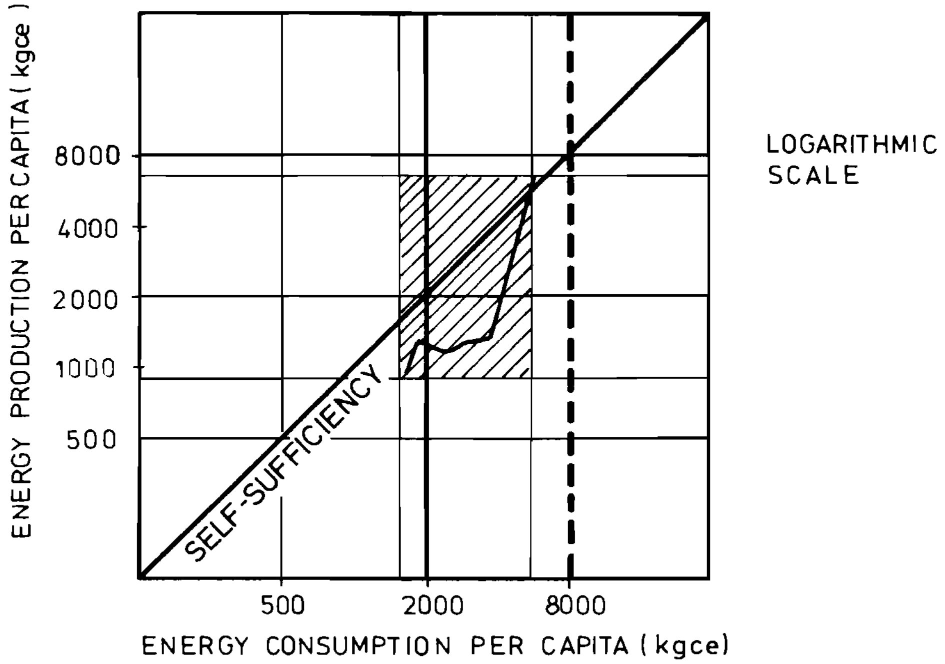
FIGURE 15

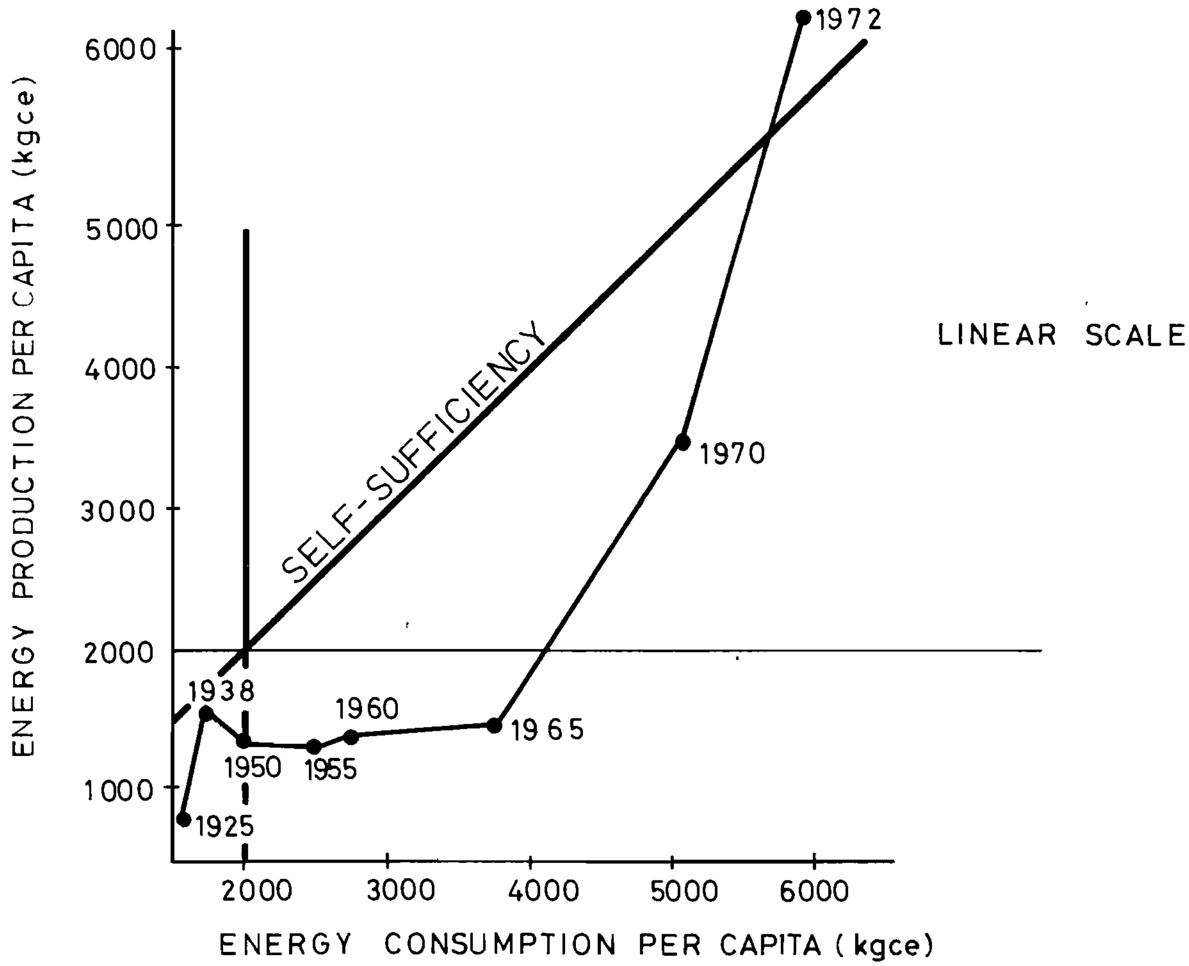




A CASE HISTORY : FRANCE (1925 - 1972)

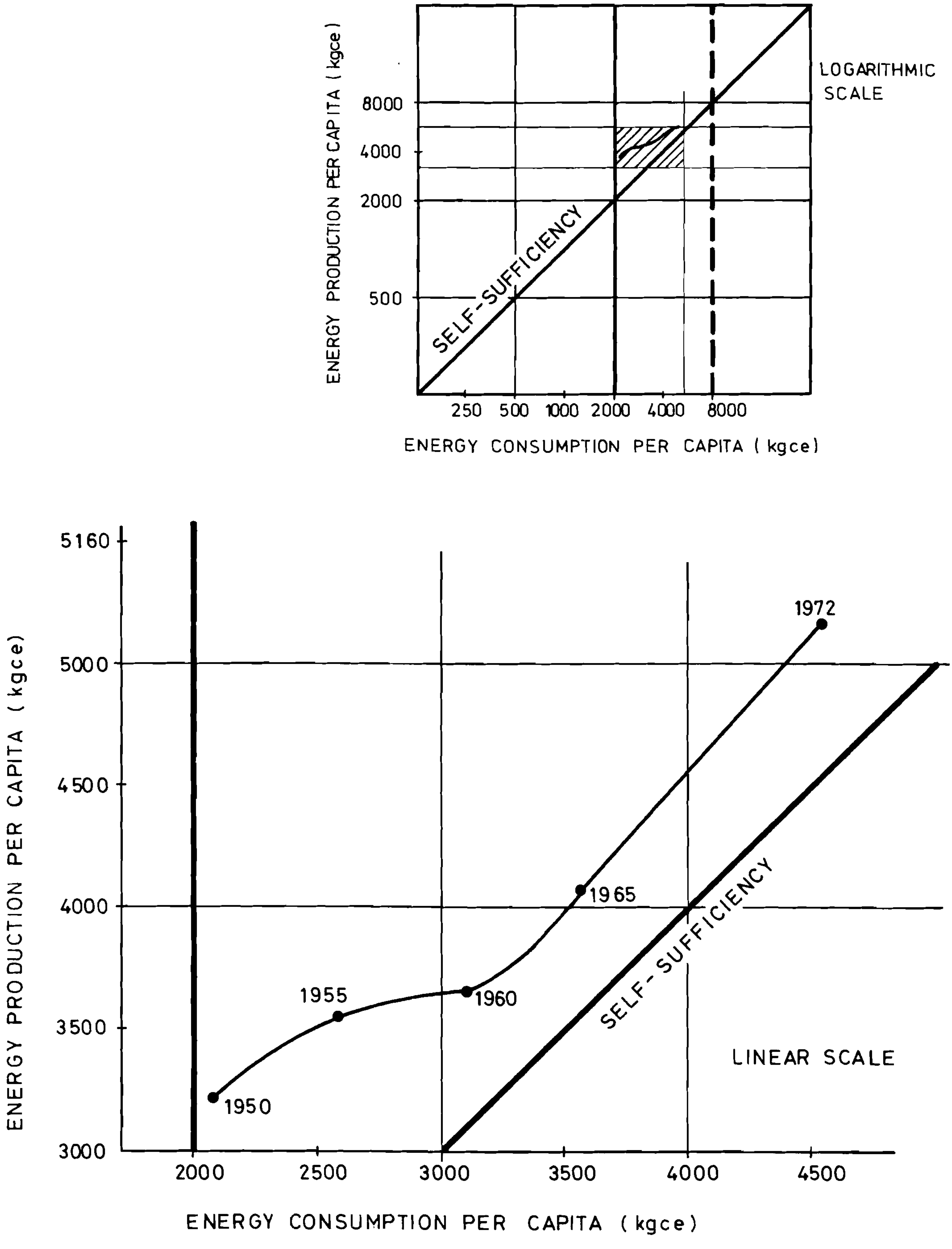
FIGURE 16





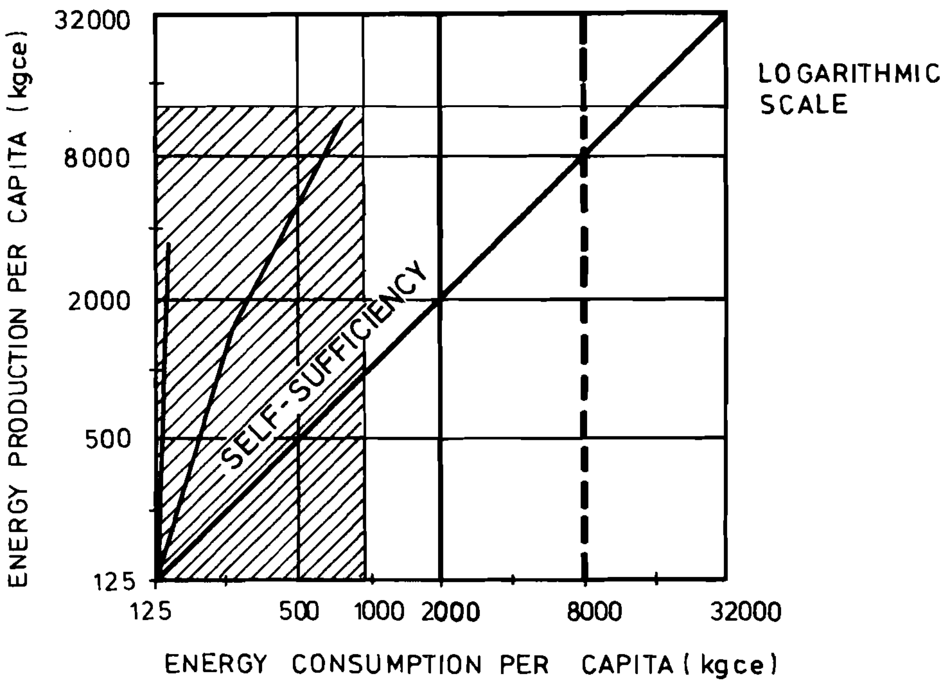
A CASE HISTORY: NETHERLANDS

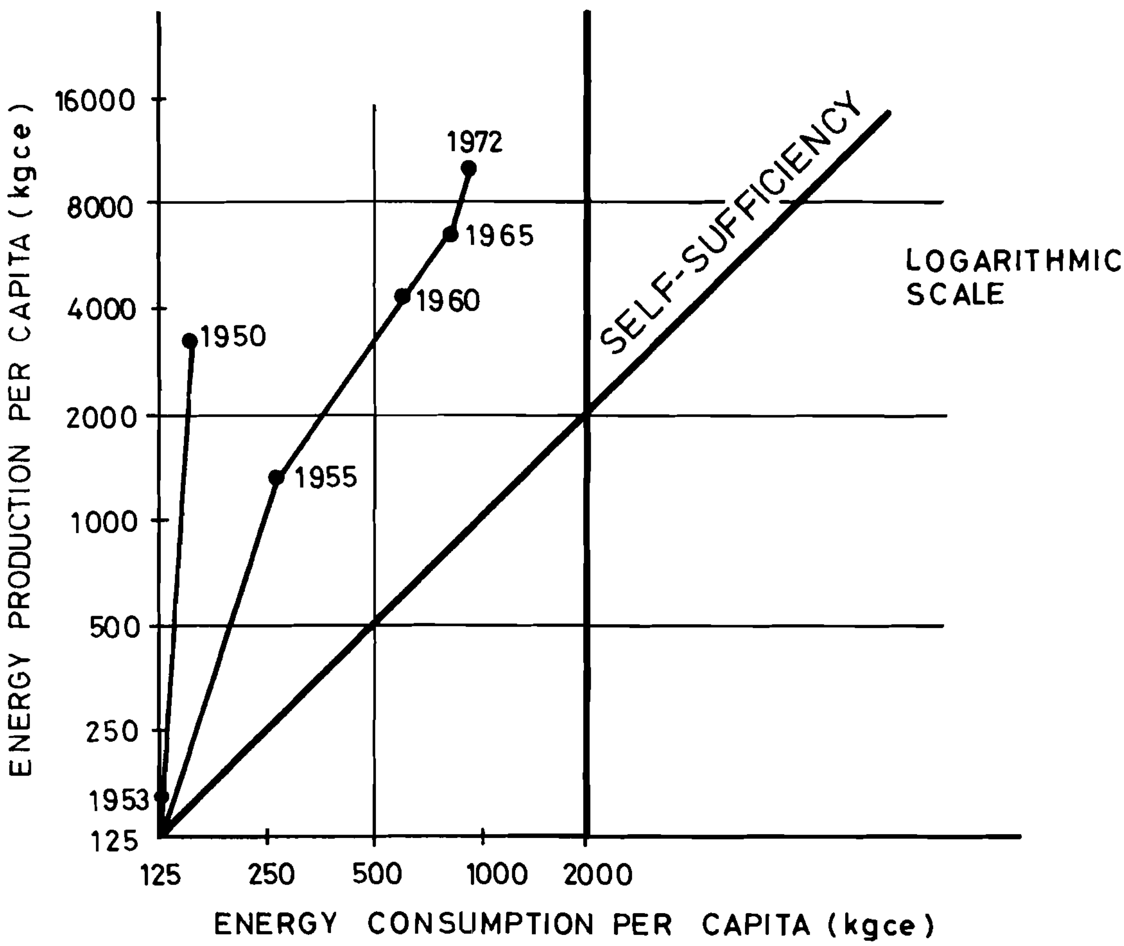
FIGURE 17



A CASE HISTORY : POLAND

FIGURE 18





<u>A CASE HISTORY: IRAN</u>

FIGURE 19

CRITERIA FOR SELECTION:

To produce, or to consume, more than 5 million tons of coal equivalent in 1972

72 countries, grouped in 9 regions, out of 178 countries,

These 9 regions - 72 countries represent:

- 3,255 million people, compared to world: 3,735 million
- 7,531 million tce produced, " " " 7,566 million
- 7,312 million tce consumed, " " " 7,408 million
- 1,096,470 million tce recoverable fossil reserves, compared to world: 1,108,428 million

30 countries have more than 100 years of reserves at present rate of consumption.

19 countries have more than 50 years of reserves at 8 tce/capita/year rate of consumption

Figure 20. Selection of 72 Countries (1972)

This is why we have generally introduced a correcting (or normalizing) factor by assuming for any country a "standard level of consumption" of 8 tce per capita, which we consider as a reasonable standard, and moreover as a reasonable objective for many countries which are at present far from such a level of consumption. It is our opinion that such a standard level could really be sufficient, and that it can be of the greatest importance for mankind to fix a reasonable limit for further energy consumption per capita instead of increasing or even "boosting" it to U.S. levels of 25 or 30 tce/capita.

From such a principle, what we call the "8 tce/capita index" has been derived, which is the life time of present proven reserves at 8 tce/capita with present population levels of various countries. We will come back to this problem of population levels.

Figures 21 and 22 show the effect of introducing this 8 tce/capita index for a few selected countries, according to two different types of representation.

We have further begun to analyze specifically some problems related to world oil trade and the relative energy positions of various producing countries; some examples will be shown for the OPEC and/or OAPEC countries, although this analysis is extended to other countries as well. Similar analysis has been performed for uranium producing countries.

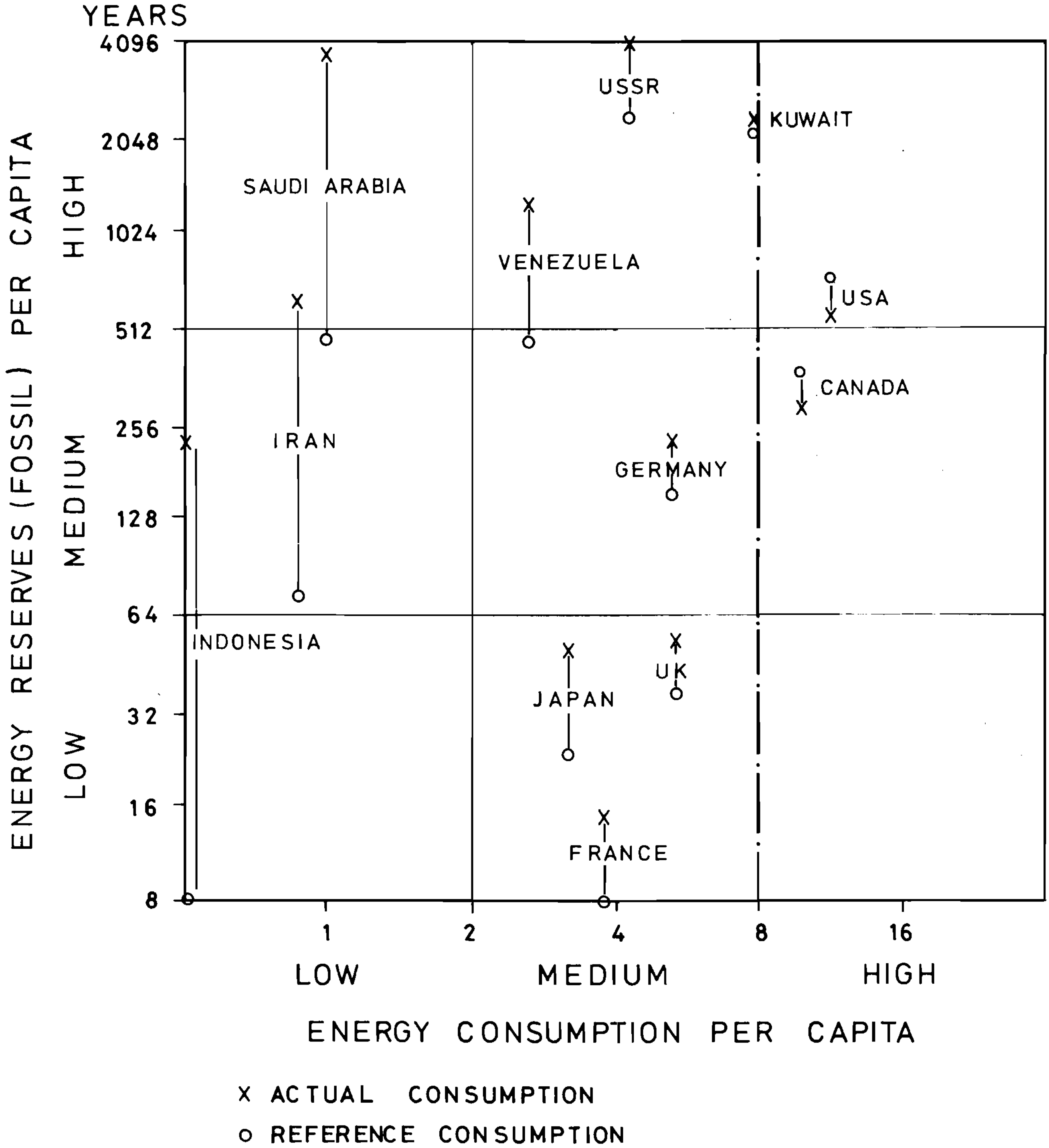
If we apply the 8 tce/capita (roughly equivalent to 6.15 toe/capita) to these oil exporting countries (Figure 23), we see that the relative energy positions of some of them are drastically changed, mainly for Indonesia, Nigeria and Algeria. We think that such considerations will play a growing role in future export and/or pricing policies of oil exporting countries, leading to possible energy conservation policies.

At this point, it is possible to raise two questions:

1. Is 8 tce/capita a realistic assumption for such countries? Figure 24 shows possible growth rates of oil producing countries, and gives the required annual growth rate of energy consumption to reach the 8 tce level starting from existing 1972 levels per capita, or the time to reach this same standard level assuming a uniform growth rate of 10%/yr. For Iran, for instance,

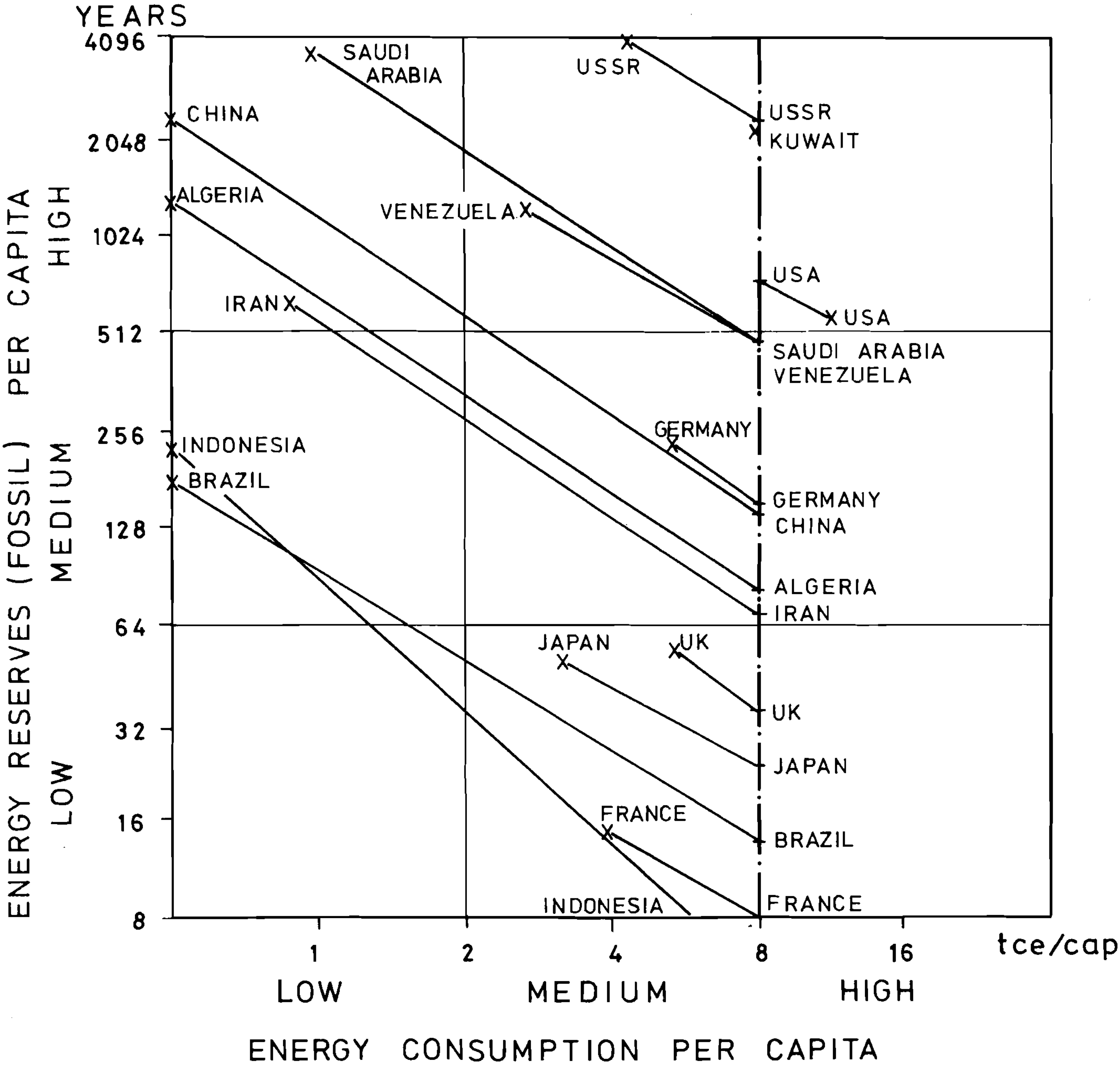
calculations have shown a required growth rate of 9%/yr for 25 years; it is worth remembering that Japan, which is practically without domestic energy resources, had, for two decades, a higher growth rate than this 9% value, and also that Iran has just started a pluri-annual development plan with a net growth rate of the GNP (and hence, more or less of the energy consumption) of slightly more than 25% per year. So we consider that our assumption is not unrealistic, even if not fully applicable to all energy producers.

2. What about population growth, which we have not taken into account so far? Figure 25 shows population forecasts as established by Fremont Felix for the various oil producing countries of the OPEC from 1967 to 2020, and Figure 26 compares such values with similar values for other geographical and/or economic areas of the world. Results illustrate the importance of the population effect for energy producing and for developing countries, a factor which presumably will play an increasing role in future energy policies.



CLASSIFICATION OF A FEW COUNTRIES (FOSSIL) RESERVE PER CAPITA, IN YEARS

FIGURE 21



CLASSIFICATION OF A FEW COUNTRIES
(FOSSIL) RESERVES PER CAPITA, IN YEARS

FIGURE 22

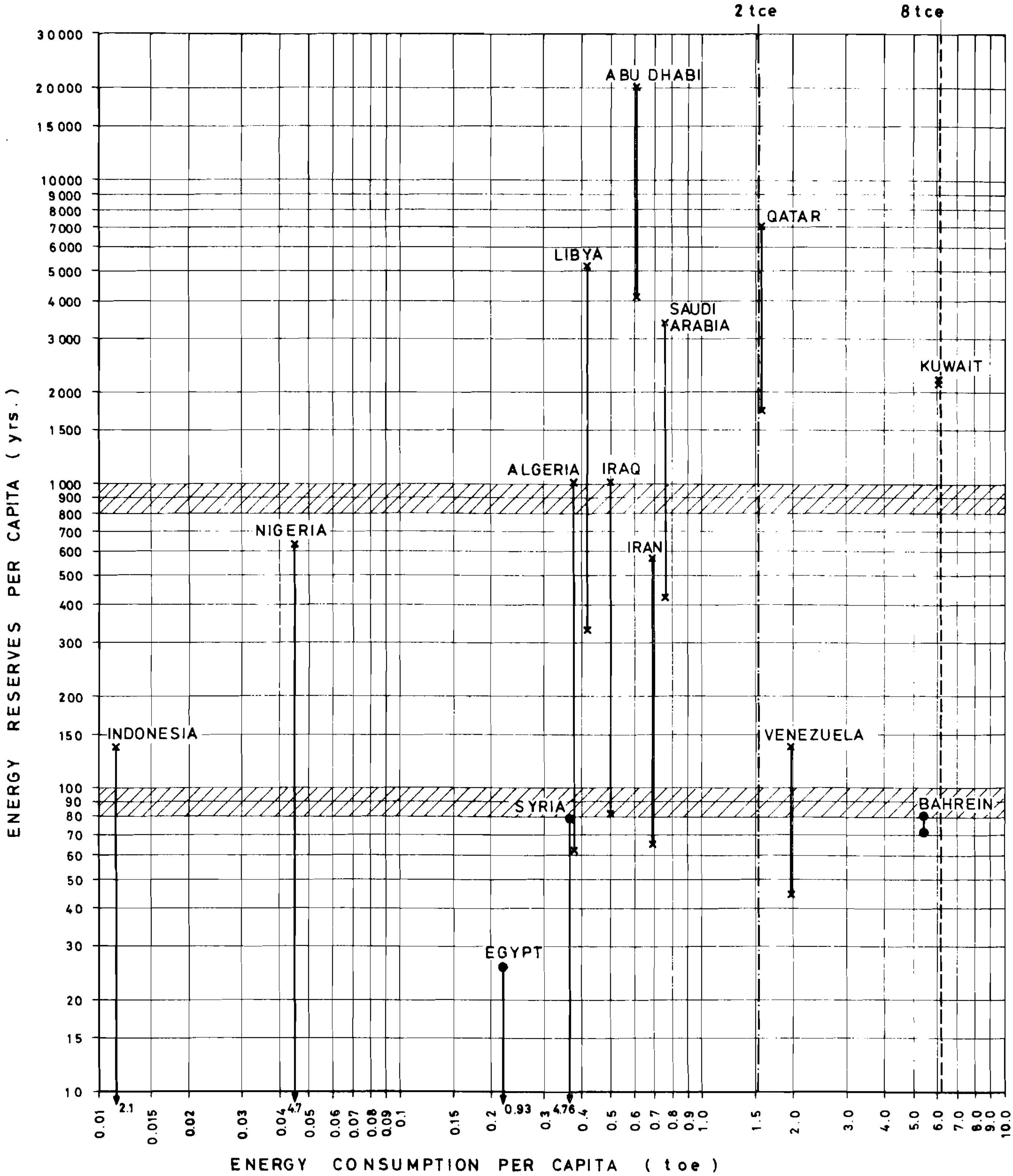

2 tce
8 tce
ENERGY RESERVES PER CAPITA (yrs.)
30000
20000
15000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1500
1000
900
800
700
600
500
400
300
200
150
100
90
80
70
60
50
40
30
20
15
10
ABU DHABI
QATAR
LIBYA
SAUDI ARABIA
KUWAIT
ALGERIA
IRAQ
NIGERIA
IRAN
INDONESIA
VENEZUELA
SYRIA
BAHREIN
EGYPT
2.1
4.7
0.93
4.76
0.01
0.015
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0.15
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.5
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
ENERGY CONSUMPTION PER CAPITA (toe)

FIGURE 23

Country	Energy Consumption per capita (1972) toe	Required annual rate to reach 6.15 toe (= 8tce) in 25 years, in per cent	Time to reach 6.15 toe (= 8 tce) at 10%/year years
Abu Dhabi	12.07	already over	already over
Algeria	0.410	11.5	28
Indonesia	0.103	17.8	43
Iran	0.734	9	20
Iraq	0.493	10.6	24
Kuwait	7.377	already over	already over
Libya	3.391	2.4	6
Nigeria	0.051	21.1	50
Qatar	17.882	already over	already over
Saudi Arabia	0.693	9.1	23
Venezuela	1.903	4.8	11

Figure 24. Possible Growth Rates of Energy Consumption per Capita in OPEC Countries.

	1967	1975	1985	2000	2020
Abu Dhabi*	0.135	0.274	0.423	0.693	1.033
Algeria	16.516	18.11	21.95	24.88	29.15
Ecuador	5.89	7.05	9.26	12.50	16.70
(Gabon)	(0.485)	(0.501)	(0.536)	(0.577)	(0.614)
Indonesia	116.00?	131.0	155.8	192.50	234.50
Iran	27.892	32.39	40.25	52.10	66.25
Iraq	9.35?	10.40	12.92	16.53	21.03
Kuwait	0.570	0.790	1.222	2.00	2.98
Libya	1.869?	2.30	3.10	4.29	5.79
Nigeria	63.87?	72.60	87.10	106.60	130.10
Qatar	0.100?	0.114	0.176	0.289	0.430
Saudi Arabia	7.23	7.90	9.02	10.49	12.10
Venezuela	10.035	12.04	15.78	21.48	28.71
Total**	259.467	294.968	357.001	444.352	575.773

* (Trucial Oman)

? Figures given in the tables do not correspond with detailed figures per country for 1967.

** (Not including Gabon)

Figure 25. <u>OPEC Populations (millions inhabitants)--according to Fremont Felix</u>

	1967	2000	2020
Belgium*	9.92	11.62	12.28
Denmark	4.839	5.85	6.24
France	49.55	66.60	73.60
Germany	57.70	76.20	83.30
Ireland	2.899	3.12	3.20
Italy	52.35	62.60	66.50
Luxemburg*	-	-	-
Netherlands	12.873	17.38	19.42
United Kingdom	55.07	65.50	69.60
"9-Europe"	245.20	308.87	334.14
U.S.S.R.	235.5	330.8	372.0
U.S.A.	203.21	285	322.5
Ratio $\frac{\text{9-Europe}}{\text{OPEC}}$	0.946	0.696	0.61

*Luxemburg is included in the figures for Belgium.

Figure 26. DEVELOPED COUNTRIES Populations (millions inhabitants)--according to Fremont Felix

Finally, the next step is to try to assess what may be the effects of possible energy conservation policies on world energy trade. Incidentally, it is worth mentioning that, whilst we were doing such studies, two countries, France and Canada, adopted energy conservation policies for uranium, in line with some of our assumptions. For France, for instance, we can say that it seemed unreasonable to have an exporter position--with 0.71 kg U/capita of reasonably assured reserves or 2.05 kg U/capita total reserves, giving, at best, five years of total energy consumption at 8 tce/capita--and simultaneously engage in an ambitious nuclear program, sometimes summarized by the slogan "all nuclear, all electric...." Such recent decisions prove that our considerations are not purely theoretical.

To explore various possibilities of energy conservation policies, we have developed different scenarios for energy producing countries, assuming various growth rates of domestic energy consumption, commitments of energy contracts, growth rates for population, rates of discoveries for new reserves, etc. One purpose of such calculations is to see whether it is possible to find "indicators" such that, if say less reserves are found than expected or required for a given scenario, changes in exporting policy can be forecasted. As an example, one sample case for Iran is given. This is summarized in Figures 27 and 28. According to such a scenario, Iran would have to discover 79×10^9 bbl of oil in the next 27 years, say roughly 3×10^9 bbl per year at an average, to be able to fulfil present commitments and meet a growing domestic energy demand, and still have oil reserves equivalent to 30 years of the total domestic energy consumption in the year 2000, by the year 2000. If during the next ten years, for instance, new oil discoveries were much less than 3×10^9 bbl/year, all other conditions being equal, one of the objectives would probably have to be changed.* Figure 28 shows similar conclusions in a somewhat different way.

Such models will be refined in coming months, aiming at a better understanding of possible forecasts for world energy trade.

Finally, a small effort has been initiated on the methodology for studying energy or mineral commodities "coalitions", on the basis of games between consumers and producers. One problem studied is the attempt to judge different coalitions by different factors, such as energy position, relative part

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*These calculations are illustrative and based on very simple assumptions (as for instance, not taking into account natural gas reserves or utilization, etc.).

SCENARIO FOR A DEVELOPMENT AND CONSERVATION POLICY

Present Oil Reserves (1973): 70×10^9 bbl

Production $\sim$ 2×10^9 bbl

Assumption on Supply: 2×10^9 bbl/yr for 20 years

Domestic Consumption: 0.125×10^9 bbl Oil equivalent in 1973 (all Energy)

Assumptions on Consumption:

+ 15%/yr until 1990

+ 7%/yr between 1990 and 2000

New Discoveries Necessary to keep 30 Years of Domestic Consumption after Year 2000:

$\boxed{79 \times 10^9 \text{ bbl}}$

Figure 27. Iran.

I R A N

SCENARIO FOR A DEVELOPMENT AND CONSERVATION POLICY

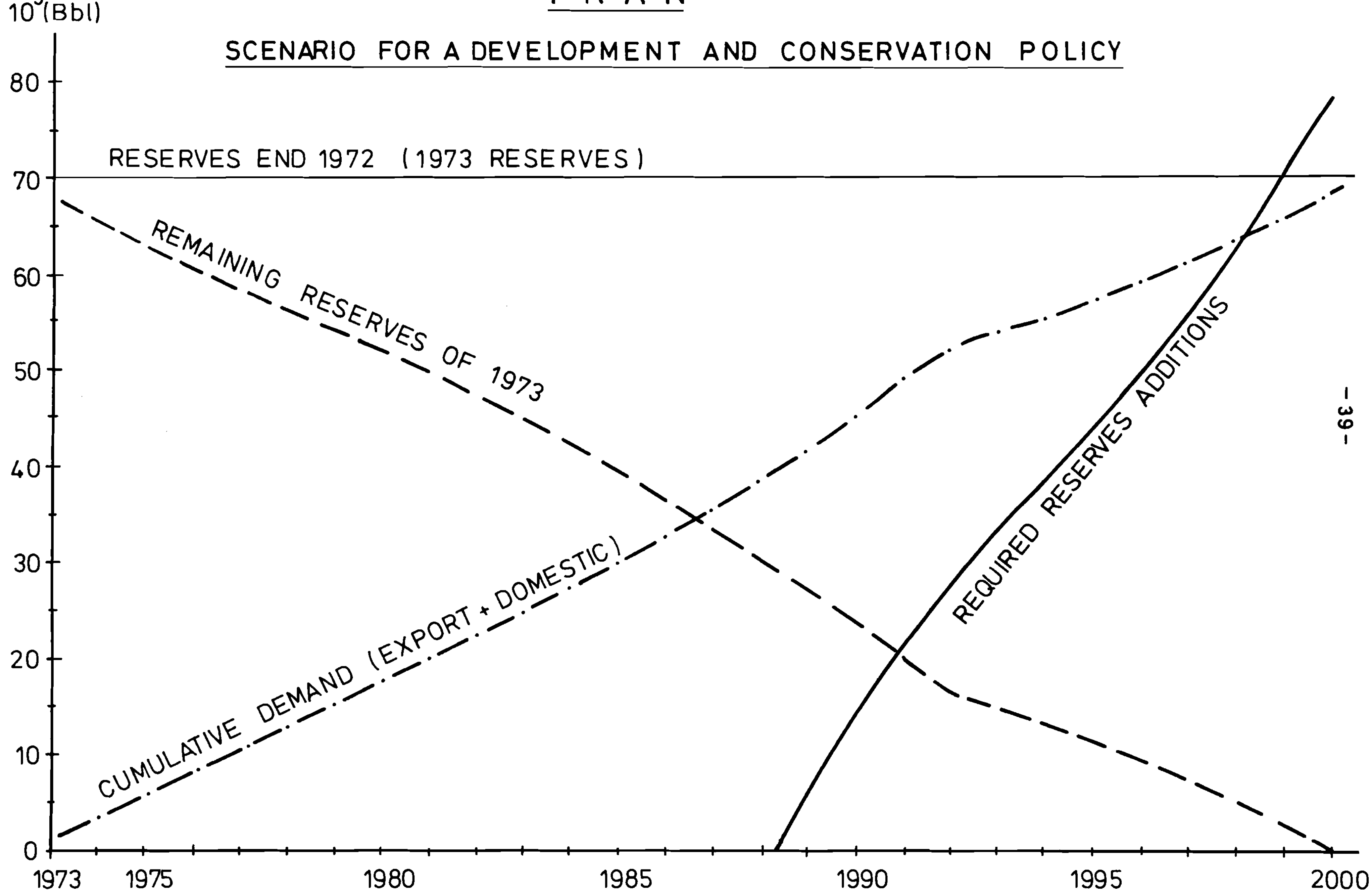

FIGURE 28

of trade in GNP or in the balance of payments, internal factors, such as singleness of coalition objective, etc.

ANNEX

ENERGY RESOURCES CONFERENCE

The IIASA Energy Project plans to host a Workshop on Energy Resources on May 20-21, 1975, These two days will be devoted to discussions of papers and a third day may be available for the extension of discussions and/or small specialized meetings.

For the main objective of the Energy Project, namely the comparison of long term energy options (nuclear, solar, geothermal, fusion and large scale use of coal), it is clear that one of the critical points is the time we have to compare, select and implement a single option, or various options. This length of time depends on three main factors:

- real amount of energy resources
- problems related to large scale production of these resources (especially in view of low grade ores, such as low content oil shales or diluted uranium rocks)
- availability of these energy resources to world trade.

Although the Energy Project is interested in a better understanding of these points, it has been considered that the most appropriate of them for the planned workshop was the assessment of energy resources.

A brief survey of world estimates will be discussed, but the main emphasis will be an a comparison and, if possible, coordination of the various methods, such as statistical, analogical, etc., for the most important energy resources--mainly hydrocarbons and fissile (uranium and/or thorium), but also coal. It is proposed that the different models which have been developed will be discussed and compared.

In addition to such comparisons, it is expected that the workshop will help to define or better judge the effort which would be necessary for more reliable energy resource estimates so that the energy planners have a better tool to study long term prospects, as well as short or medium term transitions.

Michel Grenon

TENTATIVE OUTLINE OF THE CONFERENCE

I. Quick survey of the most recent world estimates.

II. Coal resources assessment models.

III. Petroleum resources assessment models:

a) regional
b) world-wide

IV. Fissile resources assessment models:

a) regional
b) world-wide.

V. Comparisons and common points of various models.

VI. What can be done to improve the situation.