

PERSPECTIVES ON SOME RESOURCE ANALYSIS TECHNIQUES AND METHODS

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INTRODUCTION

Economic growth as well as social well-being are, to a large extent, associated with the structure of resource base and, as such, their study from different standpoints has been a major concern of scholars, particularly the geo-scientists. With very fast growth of population and introduction of sophisticated technology leading to speedy depletion of resources, there has developed an imbalance in terms of requirement and availability of resources at present level and more so in future context. Thus, a knowledge about the real situation as to the quantum of existing and potential resources, their structure and process is very essential particularly to cope with the development on planned lines.

This paper aims at bringing into focus some techniques of resource analysis, also pointing out their drawbacks and suitability. Obviously, with the application of remote sensing enormous data is being poured in from different sources which will have to be perused through more scientific and rigorous methods. The present attempt is limited in the sense that it simply demonstrates some aspects of analysis deriving materials from scattered places, making them cohesive and more meaningful.

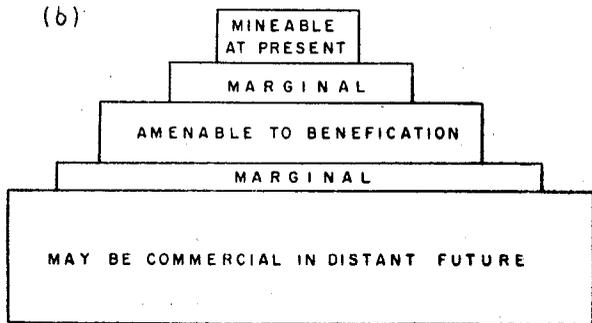
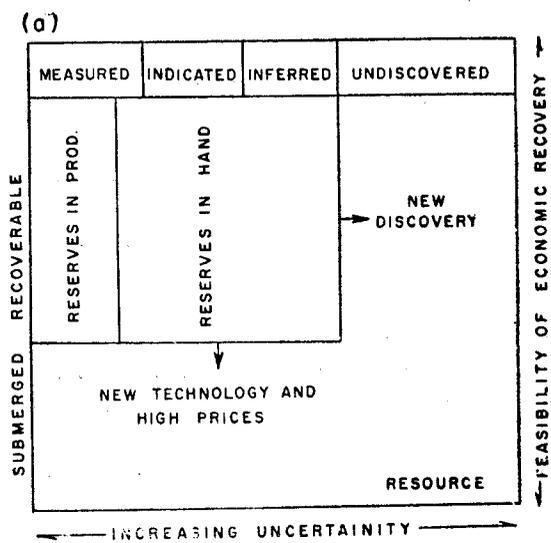
THE TECHNIQUES

It may be underlined that there is hardly any technique dealing with assessment of resources at a particular point of time or in a projected perspective which can be claimed as most reliable and widely acceptable. In fact, it is an uphill task to make an estimate of resources on desired lines and, more often than not, any attempt in this

respect becomes subject to question in due course.¹ In general, there are observed variations in estimates because of differences in specifications used in the investigations which in turn are influenced by envisaged future intensity of extraction linked with unknown economic forces and technological advances. Similarly, changes in figures are found to be associated with estimation techniques and economic values. To exemplify, in U.S.A. the manganese reserves, as based on 25% metal content account for 1 million tonne but these will amount to 100 million tonnes if reserves with 5% metal content are taken into account. Estimates also tend to reflect the views of the individual or organization² making the assessment, which may be pessimistic or optimistic. This necessitates an enquiry into motivation for the estimate before examining the available data for certain analysis. Moreover, usually, there are invariably discovered some sort of discrepancies for certain confusions as to the concept of resources and reserves. It is not out of place, therefore, to briefly mention the subtle differences in the criteria which distinguish developed and potential resources and variety of reserves, viz. measured, indicated and inferred. The 'developed resources' may be defined as the resources which are under use at the present level of demand and technological development, while the 'potential resources' are those which are likely to be used in near future (within 20-30 years) following availability of sufficient demand and requisite technology. Thus, the latter may include stocks of resources in a condition or situation which makes exploitation under known or expected technological processes extremely unlikely.

With regard to reserves, there are certain criteria, e.g. accessibility that should be satisfied for exploitation purpose. Thus considering the degree of certainty with which they can be exploited reserves are classified into 'measured', indicated and inferred types (Fig. 1a). Accordingly, 'measured reserves' (also termed proved reserves) are calculated on the basis of geological observations coupled with drilling sample analysis showing almost a certainty of recovery under existing techno-economic situations. 'Indicated reserves' refer to already known deposit, more or less as per

above process, but their probable recovery is subject to possible technical and economic development over the next two or three decades. The last category, i.e. 'inferred reserves' belong to yet unknown deposits whose estimates are based almost entirely upon the knowledge of the general geological characteristics of the area or region in question.³ As a matter of fact, most of the accessible and good quality reserves are nearing exhaustion. The second layer under production is definitely much less in quantity as compared to the third layer which although



MINERAL DEPOSITS AND MINERAL RESOURCES
(After R. Smith)

FIG. 1

with a vast potential, does not appear to be in the range of availability under existing economic and technological circumstances. The other diagram (Fig. 1b) reveals that as costs are reduced and technological advances made, the mining of leaner ores becomes possible with the ultimate reserves being very large. However, it is too glaring to be ignored that the man's immediate problem is that of discovering and developing new surface supplies in limited period, even if it means much strain and conscious planning.

In view of the foregoing it may be deduced that by and large more credibility is attached to the proven reserves which fall within man's zone of activity. Compared to other resources, the problem of making an accurate evaluation of mineral reserves is a more complicated task, as it is governed by a number of interrelated factors, such as physical characteristics, viz. type, richness, size of reserves, geographical location vis-à-vis transportation cost, efficiency of existing or available technology, mining, production and processing (benefication) cost, utilization and demand pattern, national and international policies, etc. For this reason reserves in most of the cases are nothing more than mere estimates which are subject to change with constant changes in the aforesaid factors both in spatial and temporal contexts.

What should be considered as 'proved reserves', in view of the constraints referred above, is an important question. There have been developed some mathematical models in developed countries but without adding much to the existing knowledge about reserves. Govett and Govett (1972), in this context, suggested a multiple of five as upper limit to raise the U.S. Bureau of Mine's figures so as to cover future discoveries and availability of reserves. This idea, however, does not prove its validity on scientific basis. For example, the multiple, if accepted, is too large for mercury (world

reserves 8×10^8 tonnes). Moreover, the future recovery being based on highly varying technologies available in different parts of world will not be at the same rate all the world over.⁴

It can be inferred from the preceding account that the role of location has been important and it is more so in the case of determining the viability of individual deposits, as may be derived from the account given in sequel.

CONSIDERING THE LOCATIONAL FACTOR AS A KEY ATTRIBUTE

There is no dearth of evidences to establish that the locational attribute of resources has been, and still is, a dominant factor in determination of their respective values and exploitation priorities.⁵ No doubt, the perception and so the utility of natural resources⁶ undergoes temporal changes, but at a given point of time the location of certain resources relative to existing pattern of settlements and economic activity has built-in advantage over other which often reflects in the pattern of their utilization (Chapman, 1979). The cost distance factor, in fact, is of paramount significance particularly in case of resources which are used in bulk as raw materials in industries. For example, the famous Brazilian ore deposits, although known for long, being located far inland in inaccessible area could be utilized only after the quarter of the 20th century. Similarly delayed utilization of the fertile bottom lands in the isolated Ordrusi area of North Western Australia was for the reason of unfavourable location. Even at present petroleum and iron ore deposits in Canada's vast Arctic waste and recently discovered one of the world's largest bauxite deposits in Australia are badly handicapped by their unfavourable location. As observed by Duncan (1967) in this context, the distant materials assume value only in special circumstances i.e., when the element of

scarcity is interposed between the resources and its value. The insignificant use of good quality coal of Eastern Appalachian mountains confirms the fact.

The types and characteristics of different modes of transportation, have also much bearing on exploitation patterns of resources, as becomes evident from analysis of major industrial areas of the world. Lindberg et al explained the relationship between location of the reserves and market as shown in Fig. 2a. It reveals that only much valuable resources like diamond and gold, etc., could be profitably mined at the farthest distance from the market. The range of

distance to which low value materials like sulphate, limestone, kankar etc., could be utilized is very limited while commodities like coal, phosphate, natural gas and petroleum remain generally idle if they are beyond medium distance from the places of consumption. Thus it is important in this context to map the resources categorically with reference to their accessibility zones. Recently, the utilization of certain resources has been highly influenced by introduction of modern transport facilities like oil containers, pipe lines, refrigerations, etc. These have, apart from ensuring safe, quick and intact deliveries, accounted for longer hauls and accordant faster speed of exploitation.

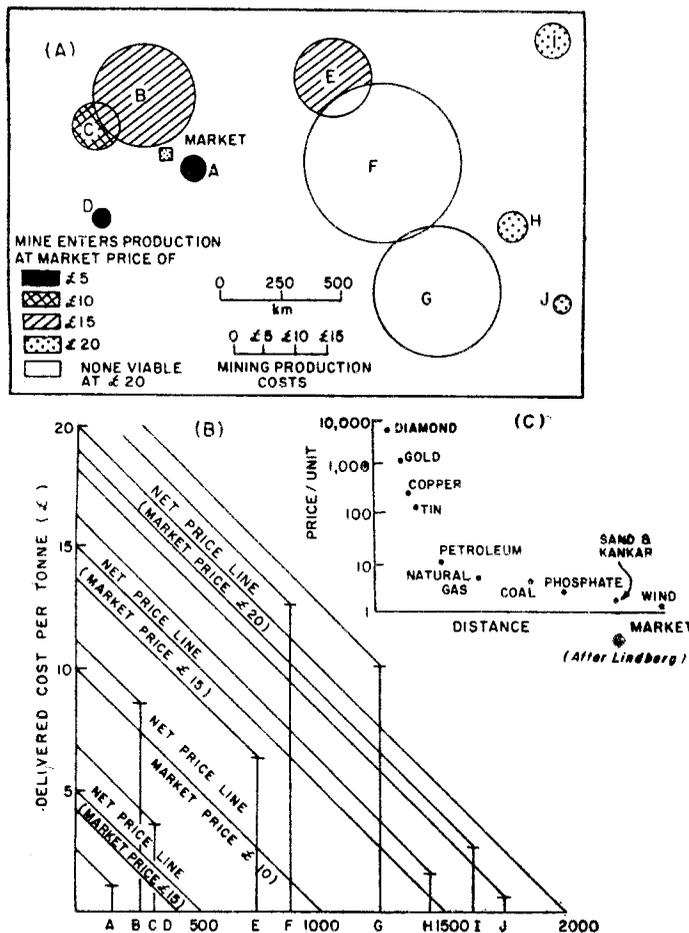


FIG. 2

It is significant to consider accessibility of resources in economic terms.⁷ Apart from the production costs, size and geological occurrence, the transport costs are vital in determining the significance of the location of a deposit in relation to such elements as factories. Hay (1976) provided a model (Fig. 2a and 2b) for location of mining activities whose viability is based on transportation and production costs. The deposits with varying locations from the market have, assumably, also varying production costs.

It may be pointed out that this model has several simplifying assumptions, e.g. linear increase in transport costs with distance, the homogeneity of products from different mines and a simple relationship between supply and demand at different price levels. However, the essential ideas implicit in the model have been found to be valid with reference to international supply of ores and some regional pattern of mineral exploitation (Manners, 1971) in West Africa, Latin America and South East Asia wherein the price increases, declining transport costs and differential production costs could be well marked out. It is relevant to quote Aschman (1970) that the discovery of great mines may be fortuitous event but subsequent exploitation tends to be dependent, to a large extent, on transportation and production costs.

MEASURING ADEQUACY

This is not enough to know as to what resource is located where and in what quantity. But equally significant is to investigate into the fact, if the same is adequate or inadequate for the people of the region or the nation in question. An attempt to solve this problem involves consideration of a host of interrelated points. For example, what is the total population of the area and if its level of consumption is related to standard of living as set forth by per capita income and stage of technological progress. Edward Ackerman (1959) taking

into account such elements formulated the relationship between population and resources as follows :

$$P = \frac{RQ(TASt + Es + Tr + F - W)}{S}$$

- where P = number of people,
 S = Standard of living
 R = amount of resource;
 Q = factor for natural quality of resources;
 T = physical technology factor;
 St = resource stability factor.
 A = administrative technique factor;
 W = frugality element (wastage or intensity of use);
 F = institutional advantage and 'friction' loss element
 Es = scale economies element (size of territory, etc.)
 Tr = resource added in trade.

Beyond doubt, the coverage of the equation is quite impressive, but it is beset with non-availability of some requisite information for a given area and period. Moreover, quantification of some of the factors of equation is rather a difficult task. At least 3 basic elements of equation—population size, the resource technology factor, and standard of living—cannot be treated as independent of one another being closely interrelated. For example, the extent to which the known usable resources are exploited is probably as much a reflection of the number of people or standard of living as it is a determinant of these facts. Also, population size in fact is no more a dependent variable in this equation than the other factors are independent variables, if the effects of other elements like past conditions, the total cultural contexts and unique or accidental occurrence etc., are also examined (Zelinsky, 1966).

Commenting upon the population and resource ratio, Chapman observed that the concept of population pressure serves to

emphasize the complementary nature of the distinction between positive and negative qualities of the environment in the sense that its pressure may crudely be regarded as reflecting a resource-deficit (i.e. constraint) and its absence may be viewed as indication of resource surplus (i.e. an opportunity). Beyond doubt, rising population presses upon all available depleting resources. An analysis of world situation reveals that a large segment (about a sixth) of world population lives adjacent to potential resources of some size but it still exists close to the subsistence level of the technology-deficient densely settled lands. Most of the technology-deficient countries of Africa and Latin America having low population-potential resource ratios fall in this group. Another about a sixth of the world's people live in technologically advanced societies and possess territories affording relatively low ratios of population to potential resources, as exemplified by U.S.A., USSR, Canada, Australia and New Zealand. Still remarkable situation is of a sixth of the world population which relates to the land where industrial organization and technology have permitted it to extend its resource base through world trade. Obviously, the main crisis relating to the first group is that of developing desired level and quantum of technology while the third group faces the vulnerable situation because of highly competing demands from other lands for the resources which they now draw upon outside their own territory.

CALCULATING THE DEPLETION RATE

The question of depletion rate is of crucial importance, as on this is based the future availability and so the regulation of present & future trend of consumption of resources, particularly those which are more dearer because of the small reserves. However, any calculation of the depletion period base on certain rate of consumption is beset with many difficulties and also it does not look

to be very convincing for a number of reasons, e.g. blocking out of considerable amount of resources, especially in case of minerals, on technical (e.g. in pillar form in coal mines) or financial (e.g. price control) grounds⁸ and least possibility of consistency in consumption rate over a period. However, despite such limitations some estimation as to the lasting time, i.e. the number of years to depletion can be made on the basis of static as well as exponential indices.

In the *static index*, the number of years for which reserves will last can be obtained through division of the proved reserves by current annual consumption (Table 1). More rational is to fix the average consumption for a few (3-4) years and project the same for a desired period. A reference year is selected as a base to indicate the existing (proved) amount of the said reserve. An accumulated consumption to the desired year (e.g. 2000 A.D.) assuming the present growth rate to be maintained, is worked out. Thus by deducting the same from the reserve, years to depletion from the reference year (e.g. 1970) are obtained (Table 1).^t For the purpose the following formula can be used :

$$V_n = r(1+i)^n - 1/i$$

where V_n = reserve;

r = consumption;

i = growth rate;

n = number of years to depletion.

The formula was applied and the results were obtained as under in case of World's finite energy reserves by Warren (1973) and Hubbert (1973) et al.

According to them only coal among the fossil fuel reserves which were estimated to be 32,27,000 million tonnes CE, are dependable. But Table 1 shows, even all mineable coal reserves will be exhausted by A.D. 2100, at an annual rate of increase in energy consumption as in 1967-70 period. Thus, oil may last upto 2002 (32 years)

if indicated and inferred reserves and oil from tarsands and oil shales are also included. It is otherwise expected to last 17 years, while natural gas reserves will last a bit longer i.e. upto 2012. Now much will depend upon the renewable energy resources, available only in the form of hydro and wood and charcoal, if the consumption taking into account the present growth rate is

projected, assuming other sources, viz. geothermal, tidal, dung, and agricultural waste etc., to have been fully utilized.

Table 1¹⁰

The world's finite energy reserves, in tonnes × 10⁹ CE projected to A.D. 2000 and to depletion data at 1970 consumption and growth rates :

	Coal	Oil ⁽¹⁾	Natural gas	Uranium	
				breeder	light water
Reserve 1970	2300	344	343	7900	113
Growth rates 1967-70	2½%	7½%	7½%	15%	
Accumulated Consumption upto A.D. 2000, if present growth maintained	106	295	147	280	4
Reserve A.D. 2000	2194	49	196	7620	109
Year to depletion from 1970 ⁽²⁾	130	32	42	84	52

(1) includes oil contained in shale and tar sands

(2) the calculation of number of years to depletion made by the formula produced earlier.

Another formula based on consumption growing exponentially may be put as under :

$$\text{Exponential index}^{11} = \frac{\ln (r \times s) + 1}{r}$$

where *r* = growth rate; *s* = static index.

As the Table 2 computed on the basis of above formula reveals, in case of India,

consumption/production is growing exponentially. Most of the growth rates being faster than that of the population indicate that more people are using resources each year causing a rapid depletion. Thus coal according to static index will last 2300 years on the world scale, but in case of India it will run out in 265 years. However, on the bases of exponential indices (Table 2) with 4.1 and 1.7% growth rates both world and India will run out of coal in about 100 years.

TABLE 2¹²

Resource	Growth rate (% per year)				Exponential Index (yrs.)				
	World	India	World	India	Resource	World	India	World	India
Bauxite	6.4	13.1	31	30	Chromite	2.6	9.6	95	8
Iron	1.3	3.5	93	47	Copper	4.6	1.6	21	8
Manganese	2.9	2.1	46	1.5	Dolomite		2.7		57
Coal	4.1	1.7	111	100	Molybdenum	4.5		34	
Natural gas	4.7	5.4	22	23	Tungsten	2.5		28	
Petroleum	3.9	5.1	20	6					

It must be underlined that static of exponential indices are not unquestionable measures of future resource availability, because these are linked with and influenced by several very complicated and interrelated factors such as grades of ores, production costs, mining technology, elasticity of consumer demand, substitution aspect and, above all, changes in industrial technology. Also, it explicitly does not take into account exhaustion of both internal and external sources, rather, ignoring the intricacy caused by the situation when production exploitation enters export trade. The special role or power of supply¹³, which has been found to be a main determinant of rise and fall in production of certain materials, is not given due attention. Another snag in this technique is that it ignores the effect of price mechanism which may reduce the rate of growth in demand for scarce resources and may also account for substitution, meaning further reduction in demand for the same scavenging of junkyard, forced efforts to find new deposits, use of existing inferior grade mineral, changes in consumption pattern of scarce material e.g. no use of oil in transport, etc., are the other possibilities related with very high rise in price. All these reinforced by unpredictable human reaction will account for changes in the growth and the depletion rates affecting the future availability of resource in question.

One cannot deny that from view point of reality no growth rate should be accepted in long term as trend growth rate, as there may be observed patterns in growth rate rising initially, then reaching a certain maximum and finally taking downward turn. Thus, it is possible that exponential growth rates may persist for a limited period; then having reached their maximum they start to decline adding a few more years to the life span of a resource.

A SIMPLE METHOD

There is another simple but crude method whereby the total requirement and accordant balance position of a fund resource like minerals can be worked out. For example, in the case of manganese resources of India it could be observed that they are likely to dry up any time now, unless more reserves are proved or established. Such an observation is based on the following calculation. Taking the standard of Bokaro steel plant for producing one metric tonne of steel there is required 0.823 metric tonnes of manganese and 2.45 metric tonnes of iron ore. India has known reserves of 4.23×10^9 metric tonnes of iron ore. Dividing it by 2.45 metric tonnes of iron ore will give the amount of steel which can be produced. This comes to about 1724 million metric tonnes. Multiplying this by 0.823 provides the amount of manganese required to produce the steel. This amounts to 1419 million metric tonnes. India's own reserve of manganese ore is 7.7 million metric tonnes meaning shortage of 1411 million metric tonnes, if India continues to produce steel using all its iron ore reserve. Such situation as obtained from the above type of estimates, exists in respect of petroleum, chromite and copper.

The preceding discussion leads to the conclusion that in the context of depletion the consumption rate matters more than anything else. According to an observation, if all the nations were to use minerals at the same per capita rate as the U.S.A., the total consumption would increase about 6 times and as much the world's known reserves of chromite, copper, lead, tin and zinc would exhaust in less than a decade. It is indeed, fantastic that with less than 10% of the free world's population and less than 8% of its land area, the U.S.A. has consumed almost half of the free world's volume of materials.

Obviously, because of its high rate of consumption U.S.A. is experiencing a worsening relationship between its requirements for minerals and energy resources and its means for satisfying its needs. Although this situation is a warning for U.S.A., it can well be visualized in case of many more countries.

An estimation of depletion rate in case of flow resources is rather impossible. Regarding energy sources, excepting hydroelectricity others¹⁴ are at the stage of almost no practical value, as is obvious from their essentially marginal contribution. However, there can be made only some brief observation about their potential. Concerning the water power, if these were to be fully developed all the world over and the plants worked at about 50% of capacity, electricity production will amount to 12×10^{12} kwh or 1500 million tonnes of coal equivalent. In order to produce the equivalent electrical energy by coal approximately 5000 million tonnes (assuming a 30% efficiency) will be needed. For calculating the solar power intercepted by the earth, which is latent in various forms, the solar constant and the area of the earth's diametrical plane are used. The solar power intercepted by a sphere is $I \times r^2$, where I is the solar constant¹⁵ and r is the radius of the sphere. Similarly, the gravitational and interior energy contained in oceanic tides and interior of the earth (obtainable from thermal conduction) have been estimated by Roberts (1973) and, the world's potential energy flow in watts from various sources has been computed by Hubbert (1973).

CONCLUDING REMARKS

While concluding it may be remarked that at the outset despite spectacular recent discoveries only a limited number of places are left to search for most of minerals. Geologists are rather uncertain about the prospects of finding large, new and rich ore deposits. Over reliance on such discovery

would seem unwise in the long term. So the significance of calculating depletion rate and measuring adequacy at present stage is enhanced. Notably, the techniques used for the purpose are more often than not subject to question, because for calculating future prospect they derive basis from the past recovery and trend growth rate which is simple linear projection regardless of uncertainty as to number of points associated with them. Among such points special mention can be made of growth rate of population and its consumption level, effects of new technologies, required availability of energy etc. However, despite these limitations they can be used as guide for estimating exhaustion period of fund resources.

The problem of resource appraisal in a broad sense should not be construed as a mere calculation of its existing (developed) and potential amount. It is rather a complex problem necessitating conceptualization of the role of resource creating factors and the processes involved therein.

It may be mentioned here that even without applying sophisticated methods of calculating depletion rate, there are enough evidences to suggest alarming situation in terms of resource deterioration. It seems to be befitting here to quote some excerpts from Presidents' Material Policy Commission (1952) Report: The U.S. demand by mid 1970s for all minerals will increase by around 90%. An increase of 40-60% is anticipated for the basic metals. . . ., which, if comparatively less, will be balanced by a more than 4 fold increase in the need for aluminium. Total energy need is likely to be doubled. The conclusive remarks were that 'the nature of the problem can perhaps be successfully over simplified by saying that consumption of almost all materials is expanding at compound rate and thus is pressure harder and harder against resources which, whatever else they may be doing, are not similarly

expanding'. In this context, it has to be kept in mind that the possible shortages of many materials will appear in different form if the theory of substitution is accepted. Thereby, the continued use of a particular material becomes uncertain with availability of better alternative. For example, with substitution of copper by aluminium in electrical industry as well as in other places, the position of copper industry will be much more changed. The substitution in some cases looks to be very attractive proposition. It is interesting to note that according to an estimate one unit weight of plastic can replace 9 of steel, 7 of copper, 6 of zinc and 3 of aluminium. However, whole attraction is marred if the economic aspect and the huge requirement of energy for the purpose are considered. For example, taking case of aluminium, in producing its 1 metric

tonne 21000 kwh of electricity is needed which constitutes 20-25% of the total cost of production. Also, in its extraction from bauxite 20 times more energy is required as compared to iron. In order to calculate the energy cost of exploiting a resource, the total energy expended at each stage in mining and refining is divided by the quantity of product finally obtained to derive an energy per unit (P. Chapman, 1973).

Considering the attractive propositions like substitution and the role of market mechanism, a balanced view should be taken and the promises of technology ought to be accepted only after scrutiny of the limitations under which they will have to operate. It is more important to identify the limits of resource development in the problem land.

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NOTES

1. Sometimes figures for certain minerals as available in old records, are far more compared to current figures. For example, in 1929 U.S. coal reserves were estimated to be 320,000 million tonnes but in 1953 it was recorded as only 190,000 million tonnes.
2. There have been published different figures regarding ultimate potential of petroleum in the world in different sources like U.N. Statistical Year Book, World Oil Magazine and a few individual geologists' estimates.
3. In defining and estimating resources, the number of their exposed sides and the number of drilling samples taken into account also matter. As such, the inferred reserves being fully submerged and estimated solely on the basis of geological history are characterized with absolute uncertainty (For detail see Blouel et al. (1956)).
4. Under such limitations U.S. Bureau of Mine's data is often used in world context. For India, Indian Bureau of Mine's data has been used.
5. Nevertheless, the decision to exploit one field rather than other may be related to the interplay of production and transportation costs. For example, the problem of maintaining a supply link between the interior and the coast has strongly influenced the phasing into production of successive Iranian oilfields (Melmaid 1959). Also, in the case of Northern Sea, the distance from the coast line has been found to be very important element affecting the viability of different offshore field (Chapman, 1979).
6. The definition of natural resources that these are 'all the freely given material phenomena of the nature within the zone of man's activity' well indicates the theme of location implied in the 'zone of activity'.
7. The Indian iron ore fields are located in the hinterland of Vishakhapatnam sea port and their supply is received without transshipment in Japan's one of the most modern steel plants installed in the coastal water. The total freight charge comes to be extremely low.
8. So even the measured reserves which are used for calculating the resource depletion rate cannot be taken as quantity which could be extracted to the last point.
9. The initial recoverable reserves and the amount consumed and the remaining for a particular year can be estimated by extrapolating the amount consumed in the said year at the exponential growth rate, obtained over a period in order to produce Eco-doomsters estimate of the probable life of reserve (Earl 1975).

10. Earl, D. E. (1975) : *Forest Energy and Economic Development*, Clarendon Press, Oxford.
11. Exponential indices provide the probable life time of each resource given the exponential rate in consumption with no allowance for substitution.
12. Growth rate % per year is calculated by second formula (exponential Index).
13. There could be observed obvious correlation between the power shortage caused by under capacity running of power houses and drop in the production of materials.
14. These include solar power, tidal power, the gravitational and interior energy.
15. The solar constant is)the quantity of energy which crosses unit area normal to the sun's rays in unit time in free space outside the earth's atmosphere, at a distance from the sun equal to the mean distance to the earth; its value I has been found to be 1.94 calories per minute per square centimetre (Landsbery, 1945) which in terms of power is 0.135 Watts per square centimetre.

APPENDIX

<i>Term</i>	<i>Abbreviation</i>	<i>Conversion Factor</i>
Cal	Calories	Quantity of heat required to raise the temperature of 1g. of water through 1 c. calc. 4.19 Joules.
Kcal	Kilocalories	1 Kcal=4190 Joules (Unit of Work).
CE	Coal Equivalent	Energy equivalent of 1 tonne of coal.ICE— 6.9×10^9 Kcal —5.6 barrels of oil. 8000 kwh 2.3 ² fuel wood (Ory.)

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