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GEOTHERMAL RESOURCES POTENTIAL IN AFRICA AND RECOMMENDATIONS FOR DEVELOPMENT

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1. The increase in oil prices over the past few years has made it more urgent than ever for countries to develop their own indigenous sources of energy as quickly as possible. The developing countries of Africa are now importing about twelve million tons of oil per year for which they are paying approximately one thousand million dollars in foreign exchange. This enormous drain on their economies has seriously affected the progress of development programmes, and made the development of indigenous energy resources a first priority objective.

2. It is highly probable that for some countries in Africa indigenous supplies of geothermal energy could provide a significant portion of power generating requirements, and for others, a significant source of low-grade heat for industrial and agricultural processing. The purpose of this paper, therefore is to:

(a) briefly describe the salient characteristics of geothermal energy;

(b) outline the regions in Africa where it is most likely to be found; and

(c) present a programme for accelerated development.

Characteristics of geothermal energy

Occurance

3. At the present state of technology, the development of geothermal energy involves the location and extraction of underground fluids existing at elevated temperatures and harnessing the energy contained in the fluids for useful purposes. Geothermal fluid is simply groundwater which has become heated during the course of its passage from an infiltration area to an area of discharge. The temperature to which the groundwater is heated depends on the temperature of the rock through which it flows. As earth temperatures increase with depth, at an average rate of about 30°C to 40°C per kilometer, the deeper the water circulates, the hotter it will become. In volcanic regions, the temperature gradient in the earth is much higher than average, and consequently, high temperature groundwater can be found at much shallower depths than in non-volcanic regions. The geothermal fluids may exist in the ground as steam, existing at pressures up to approximately 30 bars and temperatures of 240°C; as hot water ranging in temperature from just above ambient to over 300°C; or a mixture of both steam and water.

4. The presence of boiling springs in close association with recent volcanism is a particularly favourable indication of high temperature reservoirs at depth. These surface features, however, are not infallible indicators of sub-surface conditions. Hot spring areas have been drilled without success, and areas without hot springs have been successfully developed. Geothermal exploration, therefore, involves considerable risk and requires carefully phased planning for its development.

Uses

5. For many countries the most important application of geothermal energy is for power production. For this purpose, the steam, or flash steam from water reservoirs, is produced from wells averaging about 800 m in depth. The steam is passed directly from the well head, or from steam-water separators if

production is from a hot water reservoirs, into turbine-generator units to produce electricity. At present, eight countries - El Salvador, Iceland, Italy, Japan, Mexico, New Zealand, USA and the USSR - have a total installed geothermal generating capacity of about 1200 megawatts. Reservoir temperatures in excess of about 180°C are required for economic power generation.

6. Approximately 1300 megawatts equivalent of low-grade geothermal heat obtained from reservoirs at temperatures below 180°C is being utilized for agricultural applications as well as industrial and space heating. The agricultural applications include greenhouse farming, crop drying, and wood pulp processing.

Capacity

7. The average power capacity of individual geothermal wells ranges from about 5 to 7 megawatts, although some wells have been reported to have capacities as high as 25 megawatts. The minimum economically viable capacity of a well depends on the cost of alternative energy sources but in most cases is of the order of 1 to 2 megawatts.

8. As yet, only two of the 11 producing fields in the work have been developed to full capacity, and it is difficult, therefore, to generalize on the ultimate generating capacities that can be expected from a newly discovered field. Based on limited data, generation capacities could reasonably be expected to range from several tens to several hundreds of megawatts. To date, the largest development in the world is at The Geysers in northern California, which has an installed capacity of 502 megawatts. This field has not been completely developed, however, and the expected ultimate capacity is anticipated to be of the order of 2000 megawatts.

9. The ultimate energy potential of a field, as contrasted to its instantaneous power potential, is a function of its life expectancy and is even more difficult to assess than its power potential because reservoir mechanisms are only poorly understood. However, even in those fields which have been operating the longest, e.g. over 30 years in Italy, although reservoir pressures have fallen, no obvious declines in overall productivity have been experienced.

Power cost

10. The major elements controlling the cost of energy from a geothermal field are:

a) cost of pre-drilling surveys;

b) cost of drilling;

c) average productivity of wells;

d) ratio of successful to unsuccessful wells;

e) cost of effluent disposal;

f) cost of generating plant; and

g) cost of power transmission.

11. Although items (a), (f) and (g) can be predicted with a fair degree of certitude before beginning an exploration programme, only rough estimates for items (b), (c), (d) and (e) can be made prior to drilling about 4 to 6 wells in a new field. Because of these uncertainties, the cost of power from a new geothermal field cannot be predicted with a high degree of accuracy. Nevertheless, estimates of probable power costs can be based on cost data available from producing geothermal fields. The following table compares these estimates with cost estimates for the two most common alternative sources of power, that is, hydro power and power obtained from oil-fired, steam turbine plants.

	Capital Cost	Energy Cost
	US$/kwh	US$/kwh
Geothermal	300-600	0.012
Hydro	600-900	0.015
Oil-fired steam plant	300-500	0.025

12. The cost of geothermal power is not only competitive with most alternative sources, it has a distinct advantage over hydropower in that it can be installed in small increments that correspond to year-by-year increases in demand, and it has a distinct advantage over thermal plant in that geothermal power can be generated at only half the cost of thermal. In addition, if the thermal plant is located in an oil-importing country, a large share of its operating cost must be paid in foreign exchange, which is not true for geothermal plant.

Development problems

13. In addition to the uncertainties intrinsic to exploration and the problem of accurately predicting future costs, there are two other aspects of geothermal energy which, depending on the specific area, may or may not become an obstacle to development. These aspects are related to the chemistry of the thermal fluid.

14. One of these potential problems is the possibility of scaling. High concentrations of carbon dioxide (CO_2) in hot water reservoirs can lead to the precipitation of calcium carbonate in the production wells and surface equipment. This problem is not common, but if it exists, development cannot continue. A method to overcome this problem is being investigated in the United States, but the technology is not yet proven.

15. The other problem related to thermal fluid chemistry is disposal of the water produced from a hot water field after its thermal energy has been extracted. These waters are often saline, and may contain harmful elements such as arsenic and boron. Depending on the location of the field, disposal may or may not be a problem. In some cases, economically feasible and environmentally acceptable disposal can be accomplished by evaporation in existing saline lake basins, dilution with large amounts of fresh water, or discharge to the sea. Reinjection into the reservoir is an alternative solution if surface disposal is not possible.

Geothermal potential in Africa

16. Since 1965, United Nations technical missions have been sent to 13 African countries for the purpose of assessing the possibility of developing geothermal energy, and if appropriate, provide information on how the United Nations could assist in tdevelopment of the resource. Eleven missions returned with positive recommendations, and two governments, Ethiopia and Kenya have requested (and received) follow-up assistance. The evaluations contained in this section of the report are based, in most part, on the information gathered by these technical missions.

17. As can be appreciated from the material discussed in the previous section, the most attractive regions for geothermal development in Africa are in the vicinity of young volcanic centres. Although these centres are located mainly in the northern part of the Rift Valley systems of east Africa, youthful volcanism is also found in Chad, Cameroon and on the islands off the west coast.

18. Geothermal reservoirs will also be found in Africa in regions which, although lacking in recent volcanism, are underlain by geologic structures which permit deep groundwater circulation. These reservoirs will not be as hot at comparable depths as those in volcanic regions, but nevertheless, their waters could be useful for many low-grade heat applications, and in some cases, for power production as well. The Atlas mountains of north Africa, and the southern rift system of east Africa are examples of regions where this type of geologic structure is found.

19. In evaluating the geothermal energy potential of specific African countries, it is convenient to establish two categories: First, those countries expected to have reservoir temperatures above 180 °C, and therefore suitable for power production, at 1500 m depth; and second, those countries expected to have reservoir temperatures ranging between 100 °C and 180 °C, suitable for non-power applications, at 1500 m depth. A depth of 1500 m is chosen because drilling costs tend to rise more rapidly with depth on drilling below 1500 m, and this is well below the average depth needed for production.

20. The criteria used to place a country into one of these two categories are the presence or absence of recent volcanism, the number and temperature of hot springs, and reservoir temperature as indicated by spring chemistry. These criteria are not infallible, and the classification presented here should be considered only as a first approximation, its main purpose being to identify those countries where intensified investigations are particularly justified. Only the confirmation of sub-surface conditions by drilling can give a definitive answer as to the presence or absence of a geothermal resource.

First category countries

21. Based on the above criteria, 14 countries, falling into two geographic groups, have been assigned to the first category, that is, countries which probably have reservoirs existing at temperatures sufficiently high for power production at depths of less than 1500 m. The two geographic groups are east Africa, consisting of 9 countries, and west Africa, consisting of 5 countries.

22. The east African countries are: Ethiopia; the French Territory of Affars and Issas (French Somaliland); Kenya; Tanzania; Uganda; Zaire (eastern); Rwanda; Burundi; and Malagasy.

These countries are placed in the first category because:

a) Recent volcanism is present in all, except Burundi, which is located at the southern edge of a volcanic field.

b) All have springs whose chemistry indicates that the springs are fed from reservoirs well above the minimum temperature of 180°C, except Rwanda, for which available data is inadequate.

c) Drilling has confirmed high temperature reservoirs in the French Territory of Afars and Issas and in Kenya.

23. The west African countries assigned to the first category are: Chad, Cameroon, Canary Islands, Cape Verde, and Sao Tome and Principe. Although no chemical data are available from these countries on which to estimate temperatures, they are included in the first category because of the presence of recent volcanism.

Second category countries

24. Nine countries have been assigned to the second category, that is, countries expected to have reservoirs in the temperature range of 100°C to 180°C, which would provide low-grade heat suitable for non-power application and, in some cases, temperatures sufficiently high for power generation. The nine countries fall into two geographic groups: east Africa, consisting of five countries, and north Africa, consisting of four countries.

25. The five countries of the second category in east Africa are: Malawi, Zambia, Swaziland, Rhodesia, and South Africa. Although no recent volcanism is known in any of these countries, the chemistry of their hot springs, except for Rhodesia for which we do not have adequate data, indicate reservoir temperatures in the range of 130°C to 170°C.

26. The four north African countries assigned to the second category are Morocco, Algeria, Tunisia, and Egypt. Similar to the east African group of second category countries, these north African countries, although essentially devoid of recent volcanic activity, contain numerous hot springs whose chemistry indicates reservoir temperatures in the range of 150°C to 175°C. The chemistry of a few springs in both Morocco and Algeria indicates that considerably higher temperatures may be found at depth.

27. A number of African countries having hot springs with temperatures ranging between 40°C and 60°C, including Libya, Somalia, Sudan, Angola and Niger, have not been included in the above listings because at present there is no evidence to suggest that significantly higher temperature will be found at depths shallow enough for economic development. Additional data, particularly on the chemistry of the springs, is needed. Namibia is worthy of particular mention in the context because both recent volcanism and hot springs up to 80°C have been recorded, but no chemical data is available.

Typical project content, cost and duration

28. Thus far, three African countries have initiated geothermal exploration projects: Ethiopia, the French Territory of Afars and Issas, and Kenya. The Ethiopian and Kenyan Governments are being assisted in this work by the United Nations, and the F.T.A.I. by the French Government. High temperature fluids have been found by drilling in the F.T.A.I., but we have no information concerning productivity. In Kenya, three successful wells have been drilled with a combined production capacity of about 9 megawatts. Surface investigations are being undertaken in Ethiopia and exploration drilling is scheduled to begin within one years time.

Reconnaissance

29. The objective of the reconnaissance phase is to select specific prospect areas for more detailed investigation and one of the most useful techniques as yet developed for this purpose is the examination of groundwater chemistry for evidence of high temperature reservoirs. Although the technique is neither fool-proof nor infallible, it is inexpensive, and combined with background information on regional geology and hydrogeology, can quickly delineate areas for more intensive investigation.

30. Reconnaissance in remote and sparsly populated regions, where geologic conditions indicate hot springs should exist, can be greatly accelerated by aerial infrared sensing surveys which can rapidly locate thermal features for sampling. Such surveys, however, will add a substantial amount to the cost of a reconnaissance survey.

31. The time required for geochemical reconnaissance is mainly determined by the number of available sampling points, and assuming adequate analytical equipment is available, a period of six to eighteen months should be sufficient. The cost of the survey will depend on the capability and capacity of existing personnel and equipment, but in any case, should not exceed US$200,000.

Detailed surface surveys

32. After specific prospect areas have been delineated by a reconnaissance survey, a detailed investigation of the prospect is required in order to select drilling targets. Depending on geologic conditions, such investigations may include drilling shallow holes, that is, to about 100 m, for temperature gradient measurement and microearthquake surveys to delineate fracture zones. The least expensive and most effective detailing technique, however, is an electrical resistivity survey designed to obtain information from at least a depth of 800 m.

33. The cost of a resistivity survey is directly related to the time required for its execution which in turn is dependent on the size of the prospect and its accessibility. If executed by a government geological survey, with its own equipment, costs should not exceed US$2,000 per month. If contracted, costs could be 5 to 10 times this amount.

34. Sophisticated resistivity equipment is now being developed which would be suitable for reconnaissance as well as detailing applications. Such equipment will be ideal for investigating those areas which are geologically favourable for the occurence of geothermal resources, but where there are no direct surface indications such as hot springs.

Exploration drilling

35. After drilling targets have been delineated by the detailed surface surveys, deep exploratory holes are drilled with the objective of identifying a reservoir with sufficient temperature and permeability for economic production. Slim-holes, 2 to 4 inches in diameter, drilled to a depth of 1500 m and at a cost of about US$80,000 to US$150,000 per hole should normally be sufficient for this purpose. Sufficient holes should be drilled to determine the approximate size and uniformity of the reservoir.

Feasibility study

36. If the results of the exploration drilling are favourable, a feasibility study is undertaken to estimate the quantity of reserves, to determine the capital and operating costs of a geothermal power plant, and to compare these projected costs with the cost of developing alternative energy sources. The cost of such a study is about US$100,000.

Development drilling

37. If the results of the feasibility study are favourable, large diameter holes are drilled with the objective of obtaining the rate of production needed for the size of generating plant determined as optimum by the feasibility study. The cost of production holes should range from US$175,000 to US$300,000 per hole.

Plant construction

38. Plant construction can begin when sufficient steam to feed the plant is available at the wellheads. Depending on size and type of plant, costs can run from US$200 to US$400 per kilowatt installed, and construction time from 1½ to 3 years.

Action required for accelerating development

39. As can be seen from the above, an expenditure on the order of 2 to 3 million dollars, invested over a period of about 5 years, is required to establish the presence. or absence, of a geothermal resource in any one project area. Finding this risk capital is a major obstacle for the development of geothermal energy in developing countries. It is difficult to obtain this initial investment for two reasons: First, the banks which are the normal source of investment in the power sector are unwilling to risk their capital on exploration ventures; and second, private investors, the normal source of risk capital, are not particularly attracted to geothermal exploration. Lack of interest on the part of the private investors, whether individuals or companies, is due to the fact that the high rate of return required to attract their investment is normally prohibited by government regulations controlling electricity tariffs.

40. Over the past 10 years the UNDP has endeavoured to alleviate this problem by providing grants for geothermal exploration to six countries, including Kenya and Ethiopia. However, worldwide inflation on the one hand, and the recent financial crisis within the UNDP on the other, have combined to decrease the effectiveness of this assistance programme. The extent of the UNDP financial difficulties is demonstrated by the fact that as a result of recent budget cuts, the UNDP will have only one geothermal expert on the African continent by mid-1976. This is in spite of the fact that need for, and the interest in, geothermal development has never been higher.

41. The developing countries of Africa can adopt two measures which would tend to counteract the problem of obtaining risk capital to initiate geothermal development. The first measure would be to promote co-operation between the various agencies concerned with geothermal development within a country in order to make maximum use of all the scarce resources available. The second measure would be to promote co-operation among countries in the same region, thereby achieving savings of both time and money by the sharing between countries of expertise, laboratory facilities, and expensive drilling equipment.

42. With reference to promoting co-operation within a country, it has been the United Nation's experience that a well organized and efficient geothermal project requires the close co-operation of the national geological survey and the national energy authority. The energy authorities are the logical funding agencies, even for the initial exploration stage, because they generate revenue for capital investment and are the beneficiaries of the results of the project. The geological surveys, which have the expertise for exploration, seldom have funds to undertake work of this magnitude. Due to a poor understanding of each other's problems, obligations, procedures, and objectives, it is rare to see these two potential partners working together in a co-operative effort to implement a well organized and adequately funded project. As geothermal exploration is an expensive and high-risk venture, in order to be successful, both of these organizations must pool their limited resources for maximum benefit. National energy authorities should be encouraged to finance the work of national geologic surveys by pointing out the fact that the fuel oil savings resulting from the operation of only a 30 megawatt geothermal plant would result in a foreign exchange savings of five million dollars a year, that is, twice the cost of the exploration programme. It may be worth noting in this connection that it is i increasingly the practice in the United States for public utilities to raise the funds needed for exploration for natural gas, for example, by a surcharge on the energy prices.

43. With reference to the second measure of promoting co-operation between countries, the UNDP is currently examining the possibility of establishing a regional centre in east Africa for the purpose of assisting participating countries in their exploration programme. If implemented, the regional centre would be designed to:

a) provide highly qualified experts to advise participating governments on the many aspects of geothermal technology;

b) provide specialized field survey equipment to individual governments;

c) provide drilling equipment to be shared among governments;.

d) organize a laboratory to service the requirements of the region;

e) organize and sponsor training programmes both within the region and overseas.

44. Countries interested in participating in such a programme should notify the Regional Representative of the UNDP in Addis Ababa and the Office of Technical Co-operation, United Nations, New York through the UNDP Resident Representative in their own country.