AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

1. SUBJECT CLASSIFICATION

A. PRIMARY
Social Science

B. SECONDARY
Development Planning

2. TITLE AND SUBTITLE.
A Framework for Evaluating Long-Term Strategies for the Development of the Sahel-Sudan Region. Annex 9. Energy and Mineral Resources

3. AUTHOR(S)
Soussou, Joseph E.

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
December 1974	160p.	ARC AFR-309.2-M414-11

7. REFERENCE ORGANIZATION NAME AND ADDRESS
Massachusetts Institute of Technology
Center for Policy Alternatives
Cambridge, Massachusetts 02139

8. SUPPLEMENTARY NOTES (Sponsoring Organization, Publishers, Availability)
This volume consists of working papers for the main report, "A Framework for Evaluating Long-Term Strategies for the Development of the Sahel-Sudan Region", and is not essential to the main summary report.

9. ABSTRACT
Formulation of long-term alternatives for development of the Sahel-Sudan region requires assessment of the region's natural resources and construction of a framework for their more thorough national utilization. This study is concerned with two classes of resources: energy and mineral.

Energy resources are important because they vitally affect the region's economy and ecology. In the face of the rising energy consumption which accompanies development and rising costs initiated by recent oil price changes, balance of trade problems are likely to worsen, thereby hampering the development of the region. The critical ecological impacts are associated with the extensive use of wood as a fuel. In this semi arid region, where the recovery period of vegetation ranges from 10 to over 100 years, the long-term impact of deforestation and brush-fires must be evaluated.

Mineral resources present a completely different type of problem. While insufficient local energy resources and rising prices increase costs of needed imports, additional exploitation of mineral resources and rising mineral prices augment the value of capital needed for development. This study investigates the potential role of minerals--and various means of enhancing it--in the overall development of the region.

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-AAB-223	
12. DESCRIPTORS	13. PROJECT NUMBER
Energy, Mineral Resources, West Africa, Sahel-Sudan	625-11-995-907
	14. CONTRACT NUMBER
	AID/AFR-c-1040
	15. TYPE OF DOCUMENT
	Annex Report

AID 590-1 (4-74)

AFR
309.2
M414
ANNEX 9

A FRAMEWORK FOR EVALUATING LONG-TERM STRATEGIES FOR THE DEVELOPMENT OF THE SAHEL-SUDAN REGION

Annex 9

ENERGY AND MINERAL RESOURCES

Joseph E. Soussou

Center for Policy Alternatives
Massachusetts Institute of Technology

A.I.D.
Reference Center
Room 1656 NS

December 31, 1974

	DOCUMENT INFORMATION SHEET	

1. Performing Organization

CENTER FOR POLICY ALTERNATIVES
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

2. Report Title A Framework for Evaluating Long-Term Strategies for the Development of the Sahel-Sudan Region
Annex 9. Energy and Mineral Resources

3. Descriptive Notes A final report covering the period September 1, 1973 through December 31, 1974.

4. Author(s) Joseph E. Soussou

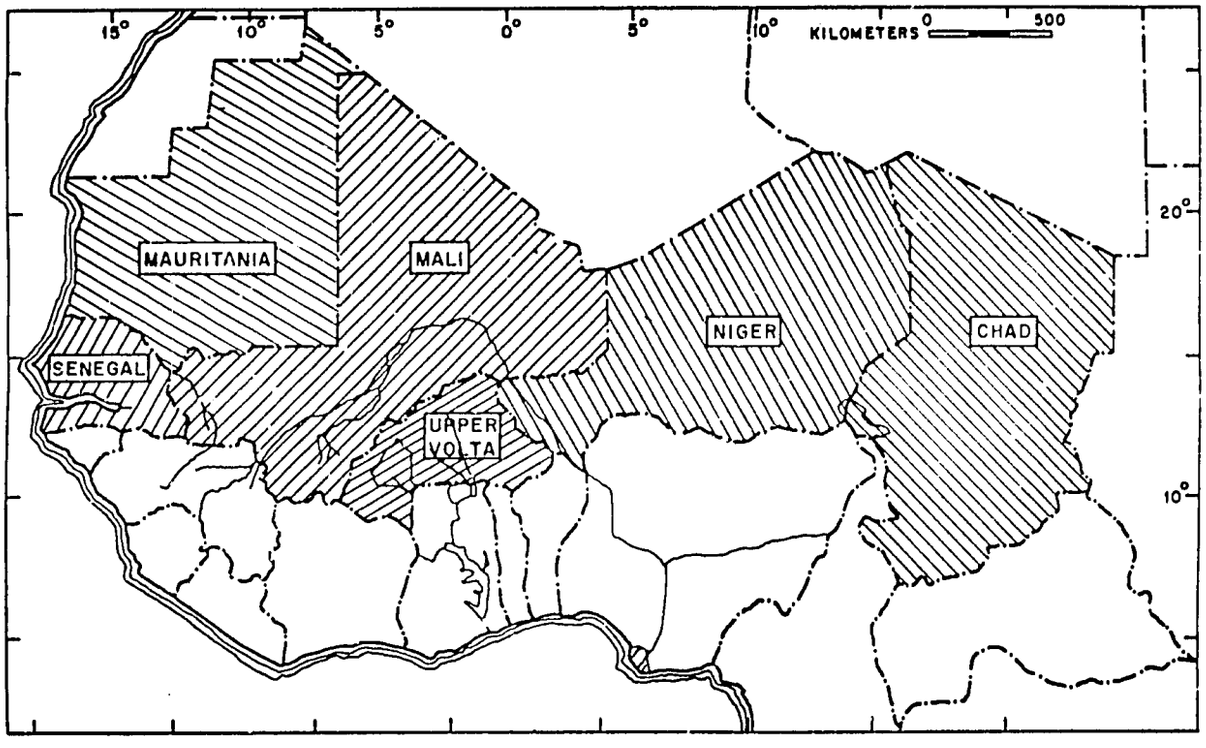
5. Report Date	6. Total No. of Pages	7. No. of Refs
December 31, 1974	160	70

8. Sponsoring Organization	9. Center for Policy Alternatives Report No. CPA 74-9	
United States Agency for International Development	11. Other Report No(s)	12. Price
10. Contract or Grant No. AID/afr-C-1040	13. Supplementary Notes Annex 9 of a two-volume report with ten annexes.	

14. Descriptors

15. Abstract

Energy, Mineral resources, West Africa, Sahel-Sudan



Volume 1. Summary Report: Project Objectives, Methodologies and Major Findings

Volume 2. ISYALAPS, A Framework for Agricultural Development Planning

This work was supported by the United States Agency for International Development under contract afr-C-1040 and was administered by the M.I.T. Office of Sponsored Programs. This report represents tax-supported research.

The contents of this report reflect the views of the Sahel-Sudan Project at the Massachusetts Institute of Technology and do not necessarily reflect the official views or policy of the Agency for International Development.

FOREWORD

This report results from a one-year effort by a multidisciplinary team of analysts to establish a framework for evaluating long-term development strategies for the African Sahel-Sudan area.

By June 1973 it had become evident that the suffering caused by the drought was the most severe the area had experienced in the last half century. A meeting of donor organizations and U.N. agencies, called by the U.N., was held in Geneva to discuss the problem. It was clear that, while the area required immediate assistance to meet the problems of drought relief, there was also need for long-range assistance if the region were to become self-sustaining and begin an era of positive economic development and widespread improvement in the quality of life of its people. The U.S. delegation offered to undertake the first steps necessary to "identify the methodology, the data requirements and the possible alternative lines of inquiry from physical, economic, social and cultural points of view" on which to base "a comprehensive examination of technical problems and the major alternative development possibilities" for the region.* The United States Agency for International Development (A.I.D.) offered to take responsibility for this task and determined that it should enlist the assistance of the academic community in carrying out the work. A.I.D. then approached M.I.T., and a study effort was formally initiated with the signing of a contract covering the period September 1, 1973, through August 31, 1974. This contract was subsequently extended to January 1, 1975.

The goal of the U.S. effort is to develop a methodology for evaluating long-term development strategies for the Sahel-Sudan region. The

---

* Final Report on the Meeting of the Sudano-Sahelian Mid- and Long-Term Programme 28-29 June, 1973, Geneva. Special Sahelian Office, United Nations, New York. Statement by Donald S. Brown.

specific focus of the M.I.T. study has been on the development of an effective framework within which to appraise specific projects and programs. The term framework, in this context, refers to the accumulation, development, organization, integration, and analytical evaluation of information on the natural resources, economic resources, and human resources, including the social and political institutions, of the region. The framework is constructed in such a way that alternative strategies for the region can be identified and evaluated, in terms of both their requirements and their impacts, intended and unintended. The M.I.T. study has not been oriented toward detailed sector studies, prefeasibility studies, or project studies. Nevertheless, in the process of developing a methodology we have examined many kinds of information and a number of specific projects and have identified areas requiring further research to fill information gaps that impede long-range planning and evaluation of specific development proposals.

It is hoped that this framework will assist decision-makers in the Sahel-Sudan countries and in donor organizations in arriving at informed judgments concerning strategies for the long-term (20 to 25 years) social and economic development of the region.

The study was conducted under the direction of the M.I.T. Center for Policy Alternatives and was carried out by a multidisciplinary group. The Summary Report and the volume on agricultural development planning have drawn upon a number of working studies on specialized aspects of the problem prepared by the staff, i.e. (1) Economic Considerations for Long-Term Development, (2) Health, Nutrition, and Population, (3) Industrial and Urban Development, (4) Socio-Political Factors in Ecological Reconstruction, (5) A Systems Analysis of Pastoralism in the West African Sahel, (6) Technology, Education, and Institutional Development, (7) The Role of Transportation, (8) An Approach to Water Resource Planning, (9) Energy and Mineral Resources, and (10) Listing of Project Library Hold-

ings and Organizations Contacted. The basic elements of these studies have been drawn together in the two volumes of the final report.

In addition to M.I.T. personnel, individuals from a number of other organizations participated in the effort. Participants from the University of Arizona, in particular, made major contributions; they had primary responsibility for developing the analysis of the agricultural sector strategy. Professor John Paden of Northwestern University was a major contributor to the work on socio-political factors. Members of the Société d'Etudes pour le Développement Economique et Social (S.E.D.E.S.) in Paris provided valuable insights into various aspects of the Sahel-Sudan area. Several members of the Centre de Recherches en Développement Economique (C.R.D.E.) in Montreal developed sections on monetary policy, urbanization, and relationships between Niger and Nigeria. A list of individuals who participated in the study is included in Volume 1 of this report.

Numerous other individuals acted as consultants to the project, provided advice as the study progressed, and reviewed draft material for the reports. Help and advice were given by officials of the governments of the Sahel-Sudan countries, the Comité Permanent Inter-Etats de Lutte Contre la Sechèresse dans le Sahel (C.I.L.S.S.), members of United Nation organizations, members of the International Bank for Reconstruction and Dévelopment, and, especially, officials of the Secretariat d'Etat and various socio-economic and technical study groups in France. Finally, representatives of A.I.D. arranged meetings in Africa and reviewed the the progress of the study. All this assistance is gratefully acknowledged.

William W. Seifert
Principal Investigator

Nake M. Kamrany
Project Manager

Contributors to this Volume

Joseph E. Soussou Ph.D., Ing.ECP, Research Associate, Department of Civil Engineering, M.I.T.

ACKNOWLEDGEMENT

The author would like to thank Professor Seifert and Professor Cockrum for the numerous discussions he had with them and the many suggestions which helped in the writing of this study.

ABSTRACT

Energy and Mineral Resources

Formulation of long-term alternatives for development of the Sahel-Sudan region requires assessment of the region's natural resources and construction of a framework for their more thorough national utilization. This study is concerned with two classes of resources: energy and mineral.

Energy resources are important because they vitally affect the region's economy and ecology. In the face of the rising energy consumption which accompanies development and rising costs initiated by recent oil price changes, balance of trade problems are likely to worsen, thereby hampering the development of the region. The critical ecological impacts are associated with the extensive use of wood as a fuel. In this semi-arid region, where the recovery period of vegetation ranges from 10 to over 100 years, the long-term impact of deforestation and brush-fires must be evaluated.

Mineral resources present a completely different type of problem. While insufficient local energy resources and rising prices increase costs of needed imports, additional exploitation of mineral resources and rising mineral prices augment the value of capital needed for development. This study investigates the potential role of minerals -- and various means of enhancing it -- in the overall development of the region. The report is divided into three parts.

Part I discusses the role of natural resources in socio-economic development, briefly reviews known energy and mineral resources in the region and specific problems involved in exploiting them.

Part II focuses on energy resources. First, it discusses problems associated with energy use, reviewing present patterns and costs of

energy consumption and supply. It shows that wood provides about 90 percent of consumed energy, while energy consumption from non-wood sources represents less than one hundredth of the present U.S. level on a per capita basis. It also shows that, in developing countries, energy consumption from non-wood sources increases more rapidly as a function of income level than in developed countries. The report draws parallels with historical trends observed in other areas under similar circumstances.

It then evaluates the ecological impact (generally ignored in economic reports) of extensive fuel wood utilization. Brush fires, which have a detrimental ecological impact, also represent a major waste of a resource which could have tremendous economic value.

Several technological solutions are then summarized, including utilization of solar, aeolian, and nuclear energies and energy transmission from coastal boundaries. These are all largely "interesting" technologies which could be useful to the region's development. (This is especially true for production of methane from wasted grasses.) However, the capital and time involved in such technological developments generally exceed the capabilities of developing countries and do not present sufficient economic attraction for any donor to undertake seriously, unless they happen to coincide with its own interest.

The last section of Part II presents mathematical models designed to aid the evaluation of various energy policies. These models, assuming various conditions, yield energy demand projections and the costs associated with each energy policy over the period 1970 to 2000. Because energy use will increase substantially in the future, it will be important for each of the Sahel-Sudan countries to develop national energy policies. They should examine the trade-offs entailed in developing local resources as opposed to importing hydrocarbon fuels. Studies of the consequences of such alternatives will be vital to the formation of realistic economic plans for these nations.

Part III reviews the present state of mineral resources, describes the institutions involved in regional mining research, and assesses current productions, explorations, and potentials.

The principal results and conclusions are:

ENERGY

(1) Wood, representing 90 percent of total energy consumption in the Sahel-Sudan region, will continue to be the principal source of energy until 1990, when other energy sources may exceed it.

(2) Use of wood as a fuel is beginning to have detrimental effects on forests. Upper Volta and, to a lesser degree, Mali may be on the verge of significant deforestation. Desertification has accelerated around urban population centers, where reforestation programs are primarily needed. Such programs may require an estimated 3 million hectares of managed forests by the year 2000, which would cost more than $1.3 billion over thirty years.

(3) It is likely that energy consumption of non-wood sources will become seven to ten times the 1970 level by the end of this century, if the region sustains a moderate growth rate.

(4) Recent oil price increases have made energy a major drain on foreign currencies. This trend is likely to worsen, since the foreign currencies required for energy production and distribution will be increasing at rates between 9 and 11 percent, while exports will grow at a projected rate of less than 6 percent. The estimated projections based on several assumed policy arrangements are summarized in a table. The resultant conclusion points to a serious dilemma regarding the Sahel-Sudan countries.

(5) Local resources can be developed to reduce balance of trade problems. Hydroelectric and geothermal resources should be developed early and coordinated with urban growth. Since these rather limited

resources will offer only a partial solution, local exploitation of known coal deposits -- despite its costly appearance -- should also be considered. Such a Resource Development program would require an annual investment starting at about $20 million and increasing at an annual rate of 10 percent over the next thirty years.

(6) Some of the balance of trade problems could be alleviated if these countries could negotiate special oil pricing agreements or arrange to buy hydroelectric power from the coastal area at long-term stable prices. Alternatively capital investments by national associations of oil producers and industrialized Western powers might be attracted if appropriate special long-term guarantees could be established. If these monies were invested in local energy resource development, short-term impacts would not be significant, but rather dramatic long-term gains could be realized. The advanced technology scenario, which may be the only avenue out of bankruptcy or permanent subsidies, would require an annual investment starting at $50 million and increasing at an annual rate of 10 percent over the next thirty years.

(7) Development of solar and aeolian energy for rural use would have limited economic but possibly significant ecological and social impacts. The principal limitations to the wide use of these technologies appear to be institutional rather than technical.

(8) Aeolian energy sources geared to urban and industrial centers could have large economic impact. Solar energy sources for commercial energy production are still considered "far-out" technologies. Moreover, both types of energy require associated energy storage capacity.

(9) New energy sources using photosynthesis processes -- the most likely of which is artisanal and industrial methane production from grasses and agricultural or urban wastes -- are interesting to consider. The potential energy available from grasses is more than twelve times the present level of utilization of fuel wood. Moreover, methane is advantageous

for storage and transportation. Our models show that development of such resources will be very important, especially if the price of hydrocarbons increases again towards the year 2000. Energy plantations and reforestation are feasible alternatives which should be seriously considered in line with these model projections. Pilot projects within the region are needed to fully evaluate these alternatives.

(10) Exploitation of new resources does not preclude the possibility of finding oil deposits. If oil is found, however, it should be used to assist development of the resources mentioned in (8) and (9) rather than to replace them.

(11) Application of nuclear energy in the near future is unlikely. However, construction of an agro-industrial nuclear complex should be evaluated as a means for developing areas containing several minerals such as manganese, copper, and iron. Such a complex could use high temperature energy to generate electric power and low value energy to desalinate brackish or sea water (if it were available) for irrigation.

(12) Development of increased capacity to formulate and implement energy policies is critical for long-term perspectives of the region. National energy policies should consider the long recovery times occasioned by different forms of land over-exploitation. Balance of trade problems, which could hamper development, should also affect the choice of energy policies. Coordination of urban growth and energy policies is necessary to optimize utilization of local resources. A more refined energy model would be of great value in comparing various energy policies.

MINERALS

(1) The exploitation of mineral resources should not be relied on to stimulate the region's development. Despite an abundance of minerals, deposits are generally of poor to fair quality, i.e. not highly concentrated. Lack of data coupled with high transport and power costs makes it difficult to exploit deposits. Though mineral extraction now produces

about $100 million a year, an increase to $300 million may be expected by 1990. However, only a small fraction of this value represents government or private indigenous earnings, which are reinvested within the region. Therefore current total mineral production is equivalent to only about $1 per capita of foreign assistance.

(2) Although production of uranium is increasing rapidly, and prospects for finding oil are good, it is impossible either to estimate the likelihood of major findings or to base development plans upon exploitation of these potentially high value products.

(3) The economic value of mineral resources could be increased by developing the necessary institutional structures and managerial capacity. Such local institutions, besides actively promoting surveys to further local needs, could suggest integrated regional studies to transform several uneconomical mining projects into a viable association of mining with water, power, industrial and possible agricultural development. In a few instances, such as the case of the Liptako-Gourma, the local institutions undertaking integrated regional studies need strengthening.

(4) Although the region has only a few geologists, it is rather the broad engineering and managerial talents and the institutional capacities which are primarily needed for both mineral and energy resources.

Annex 9: ENERGY AND MINERAL RESOURCES

CONTENTS

Conversion Tables

Part I. GENERALITIES 1

1. Resource Endowment and Development 3

2. An Overview of the Sahel-Sudan Region's Resources 5

3. Management of Resources 9

Part II. ENERGY RESOURCES 13

1. Introduction 15

2. Energy Requirements (Historical Trends) 17

2.1 Historical Background 17

2.2 Patterns of Energy Consumption 20

2.2.1 Residential Energy Use 20

2.2.2 Industrial Energy Use 24

2.2.3 Agricultural Energy Use 26

2.3 Patterns of Energy Production 29

2.3.1 Wood 29

2.3.2 Hydroelectric Power 33

2.3.3 Fossil Fuels 33

2.3.4 Other Sources 36

2.4 Costs 39

3. Energy and the Environment 43

3.1 Deforestation 43

3.2 Brush Fires 44

4. Technological Alternatives 48

4.1 Solar Energy 48

4.1.1 Direct Use 50

4.1.2 Photosynthesis 53

4.2 Aeolian Energy 55

4.3 Nuclear Energy 57

4.4 Energy from Coastal Countries 58

5. Mathematical Models to Analyze Different Energy Policies 60

5.1 Demand Model 61

5.1.1 Description of the Model 61

5.1.2 Demand Projections 61

5.2 Supply Model 70

5.2.1 Description of the Model 70

5.2.2 Energy Supply Policies 75

6. Summary and Conclusions 86

Part III. MINERAL RESOURCES 89

1. Geological Information 91

2. Institutions 93

3. Current Production, Exploration, and Potential 97

4. Summary and Conclusions 101

REFERENCES 103

APPENDIX I. Results from Energy Models 111

APPENDIX II. Summary of Available Data and Information of Mineral Resources (UNECA 1973) 121

CONVERSION TABLES

Volumes

1 cord	$2.12 m^3$
1 bbl	42 gallons
1 bbl	42 x 3.8 = 160 liters
1 stere	$0.65 m^3$
1000 cu. ft.	$18.4 m^3$

Weight Equivalence

1 m^3 wood	725 kg

Energy Equivalence

1 cord of wood	2×10^7 Btu
1000 kg coal or charcoal	25×10^6 Btu
1 kwh	3.4×10^3 Btu (thermal)
1 kwh (32% efficiency) requires	9.4×10^3 Btu
1 bbl crude oil	5.8×10^6 Btu
1 cu. ft. natural gas	10^3 Btu
1000 calories	4. Btu
1000 joules	0.95 Btu
1 hph	2.6×10^3 Btu

Miscellaneous

1 m^3 wood is equivalent to	0.5 m^3 charcoal
1 kg wood is equivalent to	0.25 kg charcoal
1 kw installed produces	8000 kwh/yr (theoretical)
1 kw installed produces	5256 kwh/yr (US 1968)
1 kw installed produces	2470 kwh/yr (Sahel-Sudan, 1970)
1 kw installed equivalent to	1.34 hp

PART I: GENERALITIES

1. RESOURCE ENDOWMENT AND DEVELOPMENT

The principal resources contributing to a country's socio-economic development can be divided into three main categories: human, capital, and physical. Human resources include social structures and traditions, while capital resources reflect institutional and governmental capacity. Physical resources include man-made physical infrastructures as well as natural resources.

Although all three sets of resources are necessary for development, history suggests that physical resources are probably the least important. High economic growth rate may be observed in many regions with relatively modest physical resources -- in countries such as Israel, Japan, or Taiwan and cities such as Las Vegas, for example. Nonetheless, economists generally agree that the presence of natural resources has a positive influence on the rate of economic development. Non-renewable natural resources, when they represent a significant share of exports and thus accrue capital, can be very important assets to developing countries. Moreover, present world-wide shortages of various commodities indicate that natural resources (in the form of food, energy, and mineral production capacity) will undoubtedly have a much greater impact on development than historical precedents may lead one to believe.

However, exploitation of non-renewable natural resources, viewed in the context of long-term development alternatives, may have disadvantages. Apart from drawing in capital, such exploitation often has very few beneficial effects, since it is not usually integrated to the rest of the economy. It may cause such disruptions as a large temporary labor market during some construction phases, or competition for water and energy with other sectors. It may be indirectly subsidized and it may generate capital not for investments but for more consumption of foreign goods.

For most developing countries, this capital is the only realistic alternative to foreign assistance and soft loans. The dramatic price increases achieved recently by the Organization of Petroleum Exporting Countries (OPEC) for oil products and the new price increase for bauxite announced unilaterally by Jamaica may represent interesting avenues for many developing countries. This type of action may transfer capital to developing nations more efficiently and at a larger scale than foreign assistance mechanisms.

Varon and Takenchi (1974) discussed the possibility of third world associations similar to OPEC to increase the relative prices of non-fuel minerals, concluding generally that duplication of OPEC's success is unlikely. Soon after their analysis was published, Jamaica increased the price of bauxite. However, some reports point to softened oil prices and potential rifts within OPEC, and whether or not the price of bauxite can be sustained at its new level is not yet clear.

Only guesses are possible at present. Varon and Takenchi's thorough analysis should nevertheless be summarized. They estimate that by 1980 the price of silver will register a 50 percent increase; zinc will follow with 30 percent; bauxite, nickel, and lead will remain unchanged; copper and iron will decline slightly; and manganese and tin will decline by 30 percent and 20 percent respectively. They argue that more possibilities for group pressure in this area of mineral prices now exist, but that demand for non-fuel minerals tends to be price-elastic in the long run. Stockpiling, recycling possibilities, use of substitutes, and distribution of world reserves among numerous countries stack the odds, they think, against duplicating OPEC oil achievements for non-fuel minerals.

2. AN OVERVIEW OF THE SAHEL-SUDAN REGION'S RESOURCES

The principal mineral resources exploited in the Sahel-Sudan region before this century were precious metals (mainly gold) and salt, which now play a negligible role in the region's economy. Annual production of mineral resources from 1968 to 1970 was valued at about $87 million (UNCTAD 1973), primarily constituted by iron ore from Mauritania ($71 million) and phosphates from Senegal ($11 million). The total GNP of the entire region was about 2.3 billion in 1970. Mineral production therefore accounted for almost 4 percent of the total GNP. Since total exports amounted to only $332 million in 1971, mineral exports represented a significant fraction of all exports (about one-fourth).

Mineral exploitation has been increasing significantly. Exploitation of the deposits of Mali and Senegal may increase iron ore production. SOMIMA produced 1,500 tons of copper concentrates in Mauritania ($10 million until 1971). Niger started exploiting uranium in Arlit in 1971, with an annual production of 750 tons ($12 million) expected to more than double by 1975 (UNECA 1973) and discovery of additional deposits is likely in Niger and other countries of the region. An extensive search for oil is under way with good prospects of discovery in Niger. Other minerals likely to have a significant impact on the region's economy are manganese (in Upper Volta) and bauxite (in Chad, Mali, and Upper Volta).

Present information indicates that the Sahel-Sudan region will probably increase the value of its annual mineral production at the rate of 10 percent a year. Table I.2-1 summarizes mineral production in the Sahel-Sudan region. One general observation: although production is rather limited, data are often inaccurate or non-existent. This table contains data on mineral production for two consecutive years (1970 and 1971) in order to show some of the trends in production.

Table I.2-2 summarizes information concerning the relative value of the exports of minerals. It can be noted that the two principal minerals

TABLE I.2-1

Production of Minerals in the Sahel-Sudan Region

Country	Mineral	Production 1970	Production 1971	Estimated Value (1971) (thousand $U.S.)
Chad	Natron	6,700	7,000	100
Mali	Gold	30	30	(troy ounces) 4
	Salt	3,000	3,000	
	Limestone	2,500		
	Marble	2,500		
Mauritania	Copper	120,000	4,500	650
	Iron ore	9,000,000	8,500,000	71,000
	Monazite conc.	100	0	
	Salt, marine	1,000	1,000	
Niger	Uranium conc.	54	410	12,000
	Tungsten	1	1	
	Tin, metal	66	67	10
	Gold	235	119	(troy ounces) 17
	Cement, hydraulic	35,000	24,000	
	Gypsum	1,500	4,000	
	Salt	4,000	4,000	
	Sand, limestone	30,000	n/a	
Senegal	Fertilizers	1,128,000	1,545,000	19,000
	Cement, hydraulic	241,000	241,000	4,500
	Clays, fuller's earth	3,050	2,810	
	Salt	118,000	123,000	
	Stone			
	Basalt	15,635	25,100	
	Marble	212	350	
Upper Volta	Stone, clay, gravel	n/a	n/a	

Units are metric tons, except when otherwise stated.

Sources: U.S. Bureau of Mines-Minerals 1972; International Monetary Fund 1968; United Nations Economic Commission for Africa 1973; and Agency for International Development 1972.

TABLE I. 2-2

Exports of Minerals

Country	Mineral	Value (Thous. $U.S.)	% of total exp.	Rate of growth of value	Average* annual volume (thous. tons)	Rate of ** growth of volume
Chad	Crude minerals	100.6	0.4	-14.9	1.70	-22.0
Mali	Crude minerals	121.5	0.6	7.1	0.76	1.0
Mauritania	Iron ores	70,730.0	88.1	14.4	8,462.00	15.7
	Non-ferrous	1,007.0	1.3	107.3	120.00	244.0
	Other crude	127.0	0.2	112.5	4.20	84.5
Senegal	Fertilizer crude	10,943.0	7.5	5.0	853.00	9.2
	Other crude	968.0	0.7	25.6	58.00	22.4
	Copper	605.0	0.4	38.2	0.63	17.6

* 1968-1970 averages

** 1963-1970 annual growth rate

Source: United Nations Conference on Trade and Development 1973.

being exploited are iron ores of Mauritania (88 percent of its exports) and the phosphates of Senegal (8 percent of its exports). Other mineral exports are negligible. Comparisons of growth rates of mineral exports show that volumes of exports increased faster than the value of the principal minerals.

In addition to these mineral resources, the Sahel-Sudan region has considerable amounts of untapped non-mineral energy resources which could complement the proven reserves of uranium and the potential reserves of oil. The exploitation of these non-mineral energy sources could play a major role in stimulating industrial development and improving the conditions of life in rural areas. It was argued by B. Guindo (1973) that the lack of energy has been an important factor in suppressing the motivation of foreign investors to establish industrial ventures in west Africa. Hydroelectric energy sources can provide the incentives of abundant and cheap energy. These sources are vitually untapped yet. It has been estimated that less than one percent of the potential hydroelectric energy has been harnessed.

Another important source of energy which is of special interest to the rural areas is solar energy. This region has the highest rate of insolation in the world, and this potential is recognized by west Africans as can be attested by the two solar energy institutes (Niamey and Bamako) and the established Inter-African Solar Energy Association. Unfortunately, the principal bottlenecks to the development of this technology are not technical but institutional. Finally, we should mention geothermal energy sources which are known to exist at least in Chad and Mali, and aeolian energy sources which could play a role similar to that in the U.S. farms before the 1930's Rural Electrification Act.

3. MANAGEMENT OF RESOURCES

Exploitation of mineral and energy resources has been responsive principally to foreign governments or international corporations' initiatives and interests. European countries have actively sought uranium, for instance, in order to diversify and guarantee their fuel supply sources. Development of Mauritania's iron ores was undertaken because the whole development scheme, including construction of the required infrastructure, was attractive to foreign capital.

Exploitation of minerals for the primary benefit of foreign capital does generally contribute to local interests as well, but exclusive reliance on foreign initiative may inhibit other types of development. Additional benefits may accrue when exploitation of mineral and energy resources is undertaken primarily for local interests. For instance, it is then possible to exploit poorer ores either by developing suitable technologies or by justifying the exploitation on indirect socio-economic grounds. It may also be possible to establish priorities in resource development and to consider combining extractive and manufacturing industries with agricultural development programs. Exploitation of the manganese ore of Tambao in Upper Volta, for example, could become feasible if transport facilities were improved and justified by simultaneous agricultural development projects in the same area.

The primary causes of dependency on foreign initiatives and interests are: lack of an overall plan or program for resource development; lack of means (capital and skills) to implement such a program; lack of local processing industries and internal markets which could provide viable alternatives to foreign markets.

The survey and exploitation of mineral and energy resources has been undertaken primarily by the Bureau de Recherches Geologiques et Minieres (BRGM), mostly with French financing (up to $10 million annually, including hydrological research). The second largest promoter of

geological and mining research is the UNDP, which has been committing about $2.5 million annually in the Sahel-Sudan region for a matching local commitment of about $1.5 million. These averages are based on the projects planned in 1971.

A systematic and rational methodology is not yet available for the early stages of exploitation and assessment of mineral resources. The decision to allocate resources to surveys and exploration programs is highly subjective. However, it is possible to decrease progressively the inherent development risks by progressively building up the region's geological information base.

The BRGM has developed several geological maps at different scales. Some of the information and data is unfortunately wrapped in bureaucratic secrecy. Use of ERTS analysis and aerial photography may help accelerate the natural resources surveys and inventories. More detailed geological services are also needed. Multidisciplinary planning teams should be created to act as an interface between the geological services and the capital industry. These teams could interpret the socio-economic value of knowledge accumulated by the geological services and promote its applications when necessary. Conversely, they could provide guidance for the direction of geological and mining research. Developing local talents to constitute such a team is more important than developing local skills for the required scientific tasks.

Since exploration and exploitation of mineral and energy resources will remain very dependent on external assistance, it is very important to build up the capability of local planning services to perceive development of mineral and energy resources as an integrated program. This integrated approach is needed in order to formulate policy guidelines for the type of development sought and to establish institutions which can apply them. In the field of energy, for instance, consideration should be given to the relative priorities for large hydroelectric and thermal power

sources, which may supply urban centers and support industrialization programs, and for smaller power sources geared principally to small towns and rural areas, which would benefit more significantly the agriculture sector.

Policies for fuel supplies are also needed. Should an effort be made to diversify to oil, coal, and nuclear fuel? Should hydroelectric, aeolian, and solar energy sources be developed, and at what cost? What is the relative need for hydroelectric power, water for irrigation, and water for transportation? Questions of this type cannot be answered satisfactorily on solely technical and economic grounds. An overall philosophy of the development process is necessary in order to make these choices.

Multidisciplinary teams are therefore needed at various levels of the administration to formulate questions and provide policy guidelines. The efficiency with which such guidelines could be implemented would depend on the organizational structure.

PART II: ENERGY RESOURCES

1. INTRODUCTION

The energy crisis has shaken international trade patterns. Various agencies have tried to assess how changes in price structure would affect the world economy in the long run. It is generally agreed that developing countries would be the most severely hampered in their development, unless drastic changes take place in their international assistance relationships (Pollack 1974).

Energy sources have a critical bearing on a country's development. However, energy self-sufficiency and availability of domestic energy sources are not absolute necessities for economic development, as can be observed in the case of Japan. Their presence may help accelerate economic development; Europe's early industrialization based on the availability of coal, and the OPEC countries' present high rate of industrialization are cases in point.

The Sahel-Sudan countries have very few resources. Uranium was found in Niger. Limited potential exists for the development of hydroelectric power on the region's principal rivers. No oil in exploitable amounts has been discovered yet in any part of the region, although there are indications that it could be found soon in Niger.

The principal resource that these countries have in abundant supply is sunlight which is used wherever water is available to produce food, other agricultural products, and wood (through photosynthesis).

From 1961 to 1971, the Sahel-Sudan region showed a 6 percent growth rate of per capita energy consumption (UNSSO 1974). This consumption has required imports of $32.6 million for fuel alone out of a total import expenditure of $452 million, or about 7 percent of total imports and 10 percent of total exports.

Modernization of agriculture, industrialization, and more generally, improvements in the quality of life will require tremendous increases in energy use, at a time when the cost of energy has increased drastically

and traditional energy sources such as wood are being depleted. Formulation of overall energy policies is needed, thus, to support development programs.

The purpose of this study is to determine the role of energy use in the region's development. First, historical trends for energy consumption and supplies will be analyzed. Then, we will focus on the impacts of energy use on the environment. Next, several technological alternatives will be presented, and mathematical models will be constructed to evaluate some of them. Finally, the principal alternative energy policies will be compared.

2. ENERGY REQUIREMENTS (HISTORICAL TRENDS)

2.1 Historical Background

Energy use indicates a country's level of development. Highly industrialized countries have a higher rate of energy consumption per capita than developing nations. Although increased use of energy does not necessarily mean a higher standard of living, per capita energy consumption and per capita income levels of various countries correlate well statistically (see Figure II.2-1). Figure II.2-1 shows more variability at the lower end of the scale, i.e., for the developing countries. Statistical correlation also clearly changes in the vicinity of $250 income levels. These observations could have been predicted intuitively. The patterns of energy consumption in industrialized countries tend to be relatively similar, and their variations in time are progressive. In developing countries, where energy consumption reflects more dramatically the variations in development policies, the growth rate of energy consumption is more subject to quantum jumps. The same trends can also be observed for other years.

U.N. world data for 1965 through 1971 show that the growth of energy consumption per capita over the entire range of income levels increased at 1.4 times the growth rate of GDP per capita. However, this ratio is closer to 3.0 for income levels smaller than $250.

It may also be interesting to draw a parallel with the pattern of energy consumption in the United States since 1850. Historical records (Eliasberg et al. 1971) demonstrate that the correlation between energy consumption and income levels has changed with time. Therefore, these statistical correlations should be used very cautiously and only provide a first estimate of energy consumption patterns in the Sahel-Sudan countries. From United States historical trends shown in Figure II.2-2 (Hottel et al. 1971) we note that in 1850, over 90 percent of the energy in the U.S.

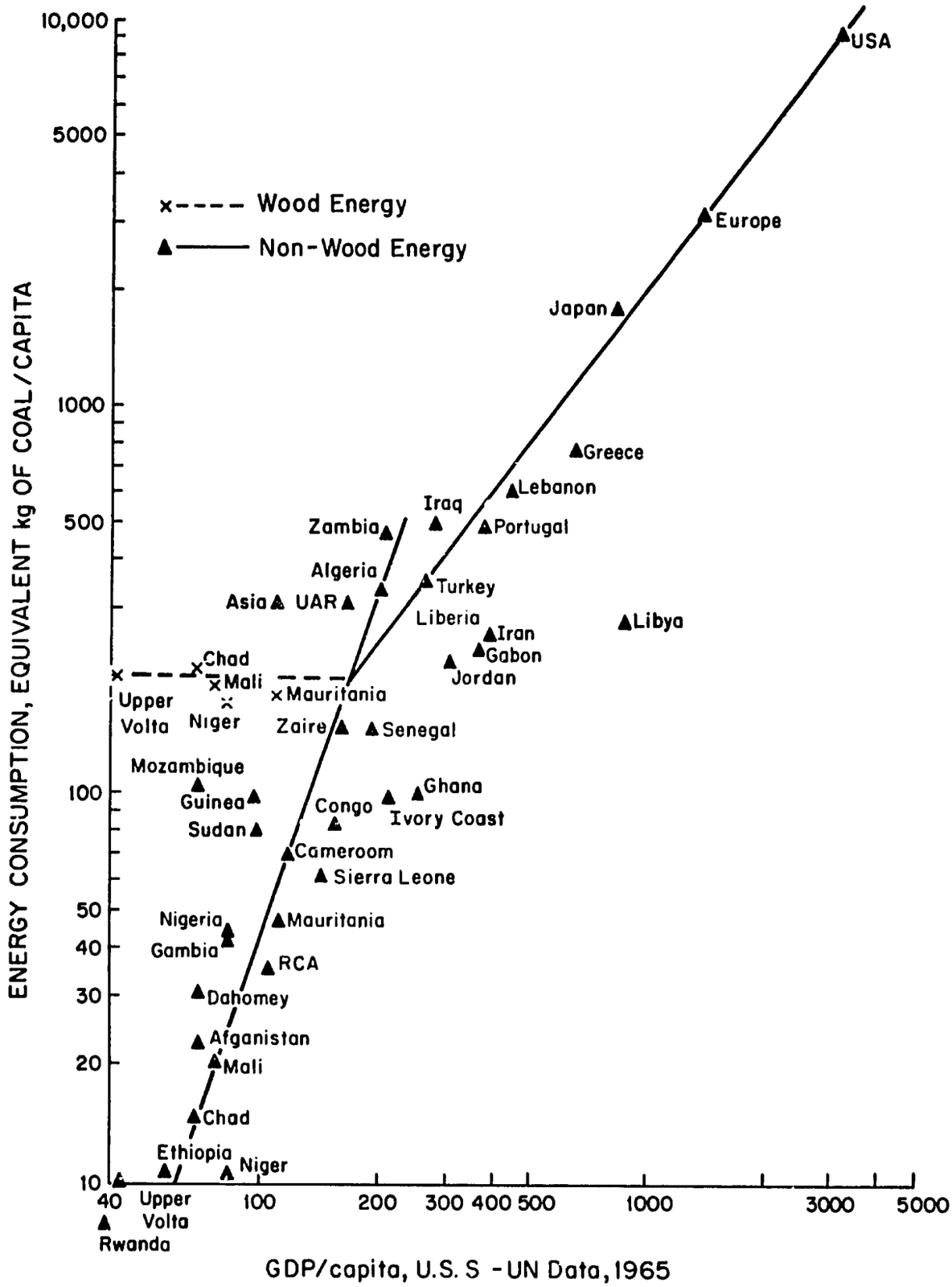


FIGURE II.2-1 Statistical Correlation between Energy Consumption and Income

Source: U.N. 1970

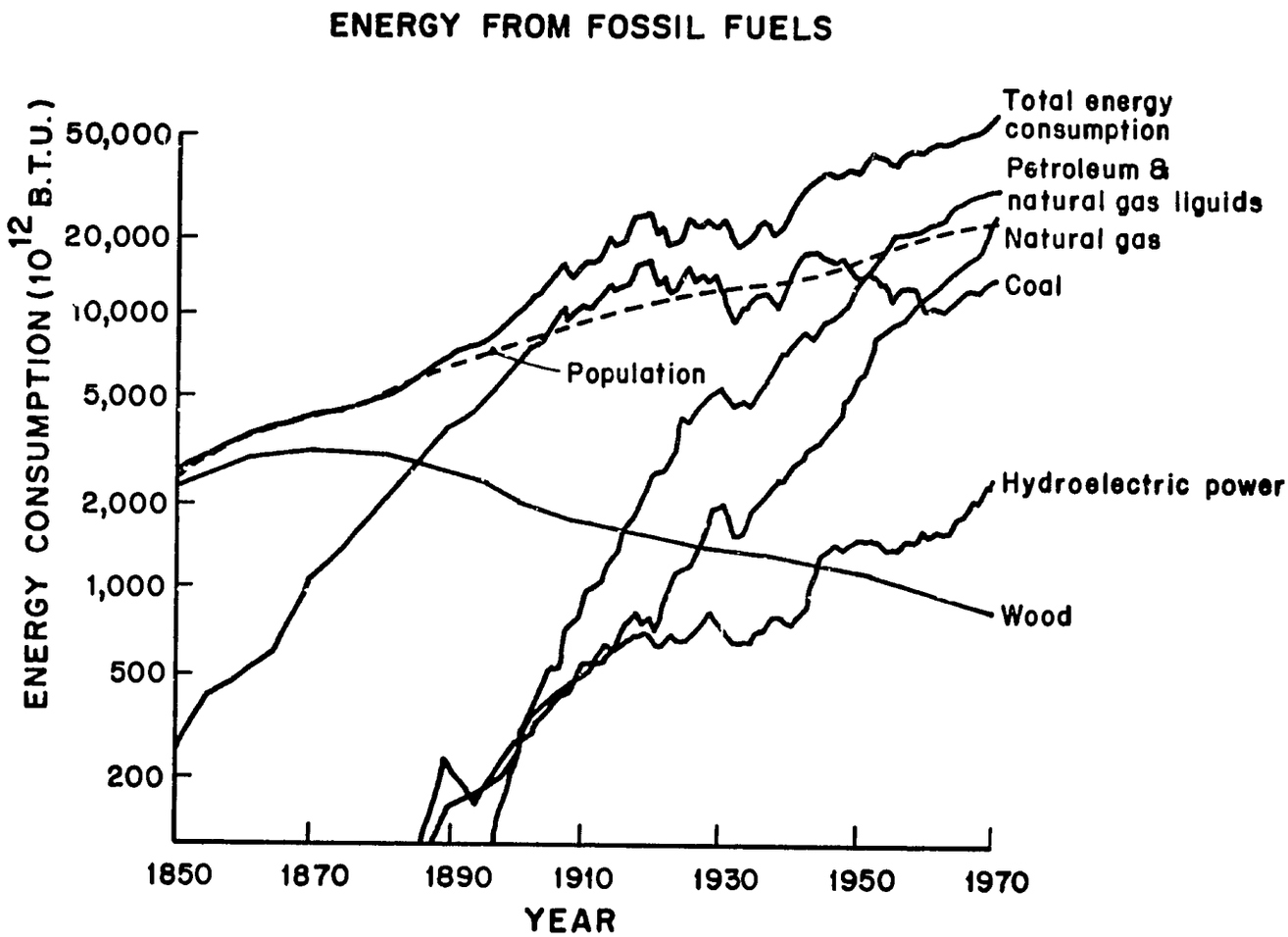


FIGURE II.2-2 Growth of Energy Consumption in the United States (1850-1970)

Source: Hottel et al. 1971

was obtained from wood, the same breakdown observed currently in the Sahel-Sudan countries. Between 1850 and 1880, the annual growth rate of total U.S. energy consumption per capita was 2.3 percent; from 1945 to 1970 it decreased to 1.5 percent. These rates become 9.2 percent and 1.5 percent if we account only for energy sources other than wood. Per capita wood consumption in the United States in the 1850's and in the Sahel-Sudan countries now is used only to provide some perspectives. However, environmental conditions, degree of industrialization, and cultural habits were very different. These differences are dramatized, for instance, by data showing that the United States in 1850 had a per capita consumption of wood 15 to 18 times that prevailing in 1970 in the Sahel-Sudan countries, where there is almost no need for space heating.

2.2 Patterns of Energy Consumption

Various factors contribute to increased energy consumption as income level rises. To better understand these increases, we describe energy use in the principal consumption sectors: residential, industrial, and agricultural. The transport sectors are included in the industrial sector, while the commercial sector is not considered, except as a part of the residential and industrial sectors.

2.2.1 Residential energy use: By and large, cooking is the principal use of energy in this sector, followed by lighting. Space heating, water heating, and refrigeration are almost nonexistent. Use of appliances, such as radio and television, lighting, and refrigeration is expected to increase, especially in urban areas, as the income level rises. In rural areas, increased residential energy consumption will be tied primarily to population growth. Since urbanization rates are high, we expect a large fraction of increased energy use to be absorbed by the urban residential sector. Data is needed to correlate increased residential

energy with income levels).

The principal fuel source used for residential consumption is wood. Other fuels are cow dung and charcoal in the rural areas; and charcoal, gas, oil, and electricity in urban areas. Although detailed statistics on energy use are difficult to obtain, estimates for wood consumption are available from various sources. Moumouni (1973) estimates that 500 kilos of wood per capita per year (i.e., 0.7 cubic meters) are used for fuel in the Sahel-Sudan countries. One kilo per capita per day (or 0.5 cubic meters per year) is also widely used as a rule of thumb. (Table II.2-1 shows the 1968 production of wood for fuel, including use of wood in the form of charcoal.) A publication of Mauritania's Ministry of Industrial Development (1973) shows 70,000 tons of charcoal used in 1970, requiring about 400,000 cubic meters of wood. These figures would indicate that as much as 80 percent of Mauritania's fuel wood is used in the form of charcoal. Statistics from the government of Senegal (1972) show that 128,000 tons of charcoal were produced, or 35 percent of the total wood production. The large percentage of charcoal production is partly explained by the fact that charcoal produces twice as much heat per unit weight as wood and burns more uniformly. These advantages are important when transport cost is a critical component of the total cost. Note that the total consumption of fuel wood is 12.6 million cubic meters, or 126 trillion Btu.*

Bottled gas and kerosene are also used to some extent in urban areas. Electricity is primarily restricted to cities. The electricity consumptions of the six countries are presented in Table II.2-2. Total electricity consumption represents about 480 million kwh, which would require production of about 4,8 trillion* Btu from thermal sources. Note also that Senegal consumes about 10 times more electricity (reflecting its

*Note: billion = 10^9; trillion = 10^{12}.

TABLE II.2-1

Annual Consumption of Fuel Wood

	Total ($x\ 10^6 m^3$)	Per Capita (m^3)
Chad	2.60	0.70
Mali	2.36	0.47
Mauritania	0.46	0.45
Niger	2.00	0.50
Senegal	1.90	0.48
Upper Volta	3.20	0.60
TOTAL	12.55	

Source: Yearbook of Forest Products 1969

TABLE II.2-2

Annual Electricity Consumption (1971)

	Consumption on 10^6 kwh	Capacity (MW)
Chad	42.7	30
Mali	33.4	20
Mauritania	16.5	36
Niger	36.8	15
Senegal	320.0	108
Upper Volta	29.2	14
Total	478.6	223

Sources: Commission des Communautes Europeennes 1972; and United Nations Special Sahelian Office 1974.

higher rate of industrialization and urbanization) than each of the other Sahel-Sudan countries.

An estimated breakdown of Senegal's energy consumption (excluding wood) among various sectors shows that in 1970, the main non-wood energy source was oil, 30 percent of which was used to produce electricity, 38 percent for transportation, and 28 percent for industry. Electricity was subdivided into one quarter for residential use and three quarters for industrial use. In the final analysis, industry consumed 50 percent of the non-wood based energy, transport about 38 percent, and domestic use 12 percent (Senegal 1972). However, when we include wood, residential energy use represents over 90 percent of total energy consumption in the Sahel-Sudan countries, by comparison to only 20 percent in the United States.

2.2.2 Industrial energy use: Industry is still at an embryonic stage in the Sahel-Sudan countries, with the possible exception of Senegal. This condition is reflected in the region's almost negligible electrical consumption by comparison to Senegal's relatively larger level of use. Although we have no measure for energy intensiveness of the region's typical industries, we will note that industry in the United States uses 60,000 Btu's per dollar of value added (Ford Foundation 1974). Figure II.2-3 shows that a crude statistical analysis relates energy consumption from non-wood sources to the size of industry (given as a percentage of the population employed in the industrial sector). Overall electrical consumption represents an average of 21 kwh per capita. In 1970, about three-quarters of Senegal's electrical use was industrial, the remainder being primarily residential. Moreover, industry directly consumed 28 percent of oil products, included in a total of 50 percent of all energy generated by fossil fuels.

Transport has been lumped with the industrial sector since it represents the principal type of energy consumption within it. The

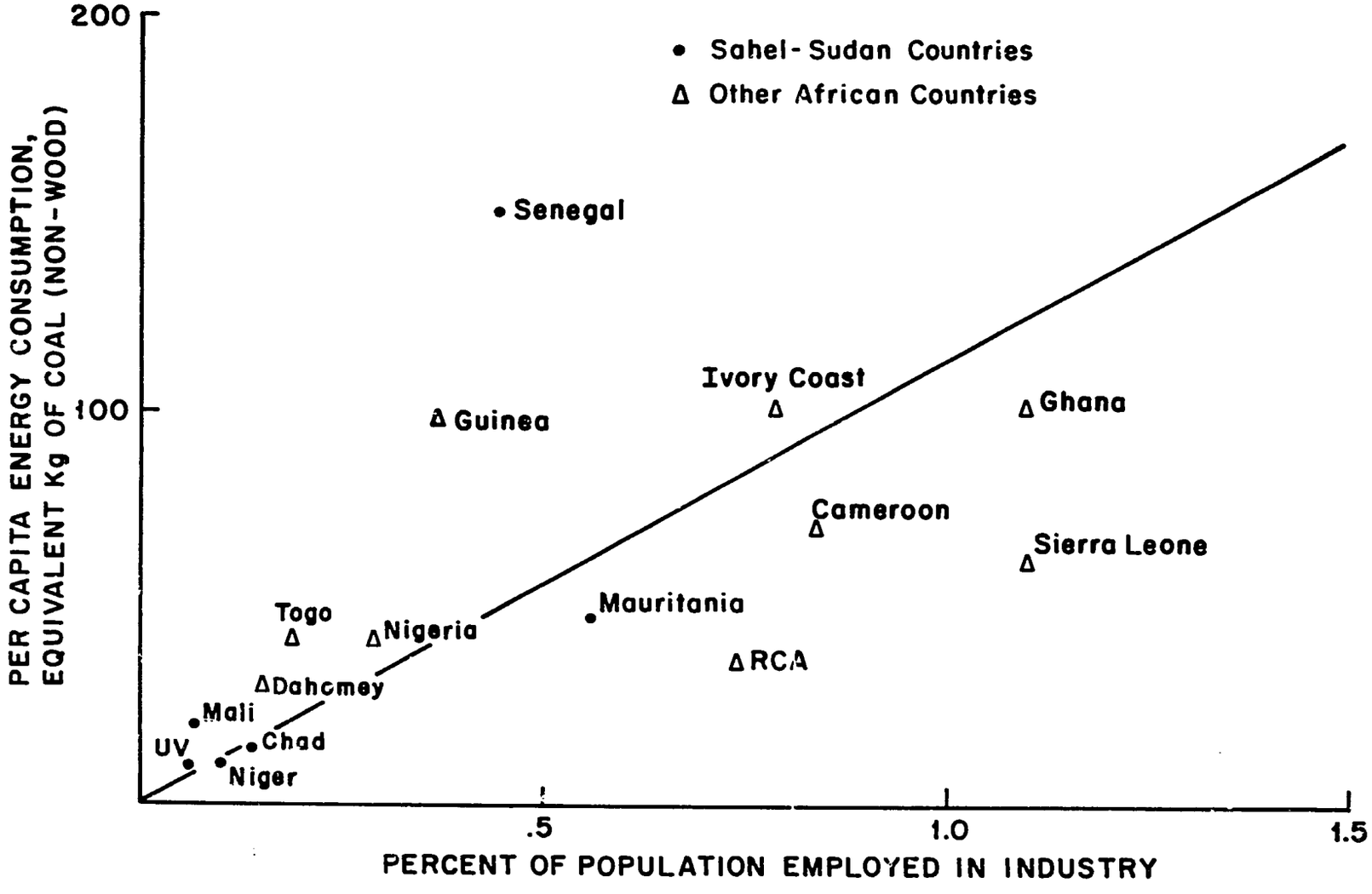


FIGURE II. 2-3 Statistical Correlation between Energy Consumption and a Measure of Industry Size

transport sector's growth rate is an estimated two to three times that of the real GDP, slowing progressively until it keeps pace with the GDP for income levels larger than $500. The size of the transport sector may be estimated by the available number of vehicles (one for 60 people in Senegal, one for 400 people in Chad), and the number of tons/kilometers carried on the principal road axes and by air. Table II.2-3 estimates present petrol and diesel fuel use in road transportation. In Senegal, transport consumed 38 percent of fossil fuels in 1970.

2.2.3 Agricultural energy use: Although this sector uses very little energy at present, increases in agricultural productivity will greatly increase energy use (see Figure II.2-4). Agricultural energy use, however, will be a relatively small percentage of total energy consumption at all stages of development. We note that even the highly mechanized and energy-oriented United States agriculture represents about 2 percent of total U.S. energy. Most of the energy in the Sahel-Sudan countries at present is human energy, which is difficult to evaluate. Use of animal energy is expected to increase. For reference, we note that in 1850 the total U.S. animal energy use was about 240 hph (or 180 kwh) per capita, about twice as much as all other mechanical energy use. Although the level of reliance on animal power in the present west African agriculture system has not been evaluated, indications are that it is low.

Figure II.2-4 may be used to relate energy requirements for agriculture. Our estimates, based on Table 12 of UNCTAD (1973), are that the 1970 total agriculture output of the Sahel-Sudan countries -- which was subdivided into 3.5 percent meat products, 70.7 percent food crops, and 25.8 percent cash crops -- was equivalent to 2,470 calories a day per capita. Beef production required an estimated energy input of 0.5 calorie/calorie of food. These estimates suggest that the present agriculture system averages 0.07 calorie/calorie produced. Therefore, agriculture production absorbs 173 K calories/day/capita, or 43 Btu/day/capita.

TABLE II.2-3

Annual Oil Consumption for Transportation (1970)

	Petrol ($1000'sm^3$)	Diesel ($1000'sm^3$)
Chad	15.1 (e)	--
Mali	51.9 (e)	10.0 (e)
Mauritania	10.5	59.9
Niger	14.3	15.1
Senegal	84.3	18.0
Upper Volta	18.2	8.9
Totals	194.3	111.9

(e) = estimated

Source: International Road Foundation 1973

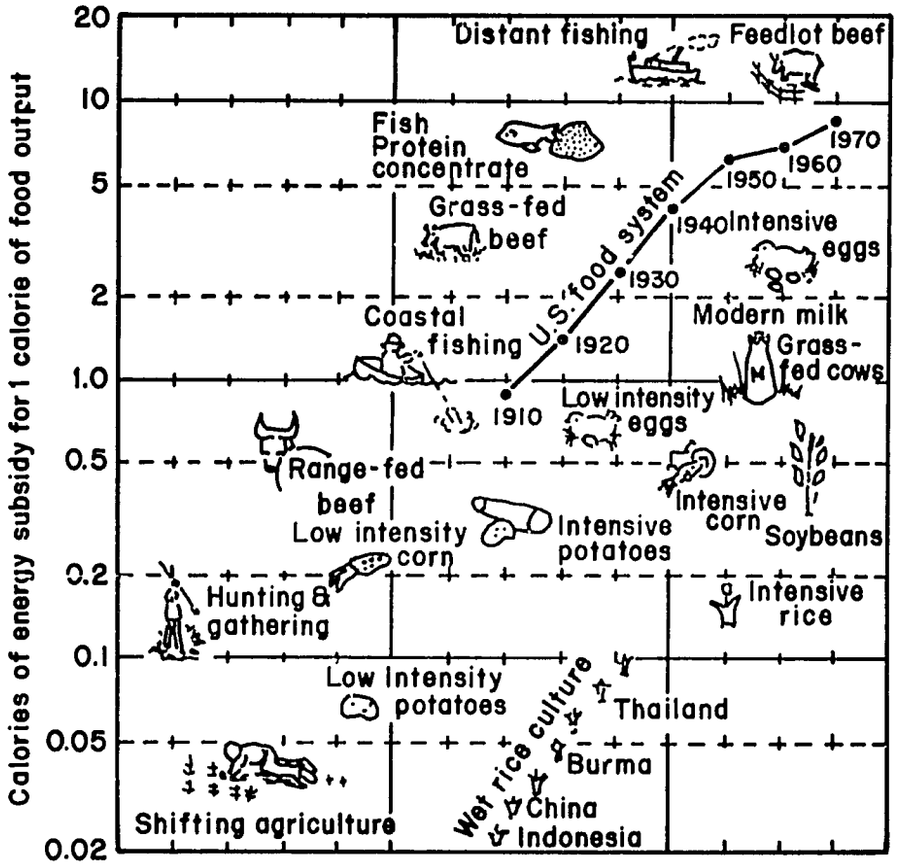


FIGURE II. 2-4 Energy Used in Food Systems

From Steinhart and Steinhart (1974) Copyright 1974, American Association for the Advancement of Science.

In order to increase individual productivity, larger inputs of energy into the agriculture system will be required, as the evolution of the United States food production system suggests. Figure II.2-4 also shows that the process of modernizing the agricultural production system is likely to be time-consuming; with a rate double that achieved by the United States in the first part of this century, more than fifty years will be necessary to duplicate the present U.S. food production system, and at least 25 years will be needed to duplicate that of 1915. (The agricultural production system of 1915 may be considered as a transition point, when food and other agriculture production started demanding more energy than they yielded). If a high agricultural modernization rate is achieved, the total energy input to agriculture in the Sahel-Sudan region should increase at least tenfold within 20 years. More accurate estimates of energy needs in agriculture could be obtained by a less aggregated analysis using, for instance, the data of Table II.2-4.

2.3 Patterns of Energy Production

As previously mentioned, the major energy source of the region is wood. The two principal sources of non-wood energy are imported oil and hydroelectric power.

2.3.1 Wood: Wood is one of the region's principal resources, at least in the southern zones. Its importance is shown in Table II.2-5 which indicates that energy derived from wood represents 54 percent of the total energy in Senegal, and 95 percent of the total energy in Upper Volta. Table II.2-6 compares the areas of existing forests with the areas needed to provide fuel wood for the 1970 population level. From these figures, it would appear that Upper Volta is on the verge of depleting its forests, while Mali and Senegal may have already reached critical consumption levels in some areas. Going back to Figure II.2-1, we can plot total energy consumption by using the percentages determined in Table

TABLE II.2-4

Fuel Required for Crop and Livestock Production in the United States

	gallon/acre		
	gasoline	diesel	Zp-gas
Corn	9.50	6.35	11.40
Soybeans	9.00	6.50	10.80
Small grains (oats, barley, wheat, rye)	4.25	3.00	5.10
Hay (field cured, 3 cuttings, bailed)	12.00	8.65	14.40
	gallon/animal		
Swine (1 pig to market)	0.40	0.30	0.50
Dairy (cow milking 12,000 lb/yr)	1.35	1.00	1.60
Beef-steers-400 to 1200 # cows-winter & raise calf to 400 lb.	0.90	0.65	1.10
Cleaning beef feedlots (no bedding, per animal marketed)	1.25	0.90	1.50
Cleaning dairy lots (with bedding, per cow/yr)	6.75	4.85	8.10
Cleaning swine confinement finishing barn with liquid manure system/per pig raised to market	0.40	0.30	0.50

Source: Hull 1974

TABLE II.2-5

Energy Consumption (per capita)

	Fossil & Hydro (10^6 Btu)	Wood (10^6 Btu)	Wood as % of Total
Chad	0.44	6.44	93
Mali	0.55	4.30	89
Mauritania	1.56	4.30	73
Niger	0.36	4.60	93
Senegal	3.80	4.40	54
Upper Volta	0.26	5.50	95

TABLE II.2-6

Requirements for Fuel Wood

	Required Forests 1970 (1,000 ha)	Present Forests (1,000 ha)
Chad	1,800	16,000
Mali	2,500	4,500
Mauritania	500	9,800
Niger	2,000	14,000
Senegal	1,900	5,300
Upper Volta	2,500	2,000

II.2-5. This plot shows that GDP per capita has almost no influence on total energy consumption for income levels lower than $300.

2.3.2 Hydroelectric power: This energy source represents a large but as yet untapped potential. Mali, the only Sahel-Sudan country to have developed any hydroelectric potential, obtains about 2.5 percent of its electricity from hydroelectric power. About 6,800 kw are generated near Bamako, and 1,350 kw at Markala near Segou. Both power stations are on the Niger. Another plant at Felou on the Senegal River (near Kayes) provides 725 kw.

However, the potential is much larger. It has been estimated that less than 1 percent of the region's hydroelectric power potential has been developed (U.N. 1963). The Manantali Dam on the Senegal River could provide 100 MW, or up to 800 million kwh per year, while the Selingue Dam on the Sankarani River, a tributary of the Niger River, could have a capacity of 40 MW. Both of these sites are in Mali. Although many other projects are possible, especially in Mali, they are less likely to be constructed in the near future.

We made a crude estimate of an upper limit of the potential for hydroelectric power by considering an average annual flow of 700 m^3/second for the Senegal River, and of 1,300 m^3/second for the Niger River, and an average drop of 500 meters for both rivers within the countries of interest. This estimate yields a potential 10,000 MW, not including the Volta Rivers. Because of economic and technical constraints, geographical considerations, and trade-offs with irrigation and navigation requirements, we will assume that less than 10 percent of this hydroelectric potential is feasible. The upper limit for all hydroelectric and geothermal energy in the region will be put at 1,000 MW. Table II.2-7 summarizes the presently known potential sources of hydroelectric power.

2.3.3 Fossil fuels:

—Oil and natural gas: Sedimentary basins in which oil and

TABLE II.2-7

Hydro-Electric Potential

		Power output at 8000 hrs operation/year	
Senegal River			
Manantali (Bafing)		144	MW
Gourbassi (Faleme)		13	MW
Galougo (Senegal)	alternates	187	MW
Badoumbe (Bakoye)	alternates		
Dioubele (Bakoye)			
Petit Gouina (Senegal)			
Felou (Senegal)		0.7	
Niger River			
Sotuba		12	MW
Selingue		40	MW
Dyodyonga (Mekrou)		14	MW
W		84	MW
Kandadji		300	
Others			
Kou Falls		0.25	MW
Banfora Falls (Komoe)		1.6	MW
Dedougou (Black Volta)		3.1	MW
In adjoining countries			
Akossombo (Ghana)		768	MW
Konkoure (Guinea)		125	MW

natural gas may occur cover a large part of the region, with the exception of Upper Volta. Although exploration has been conducted in the region for over twenty years, very little oil has been found.

There are indications of natural gas in an area north of Lake Chad, and of oil in the basin of Doba to the south (U.N.E.C.A. 1973). Several oil companies are still conducting surveys and explorations.

Exploitation of Mali's oil, the largest known deposit (50 million tons at Tin Fouye) was to be started in 1970. Further explorations are still being conducted.

Although an active prospecting program is underway in Mauritania, current indications appear negative.

Niger also has an active prospecting program. The strong interests shown by some companies may be interpreted as positive signs.

Senegal has found some natural gas near Dakar. Most of the exploration for oil is conducted offshore. Some oil found offshore near Casamance is not yet exploitable. Senegal possesses the region's only oil refinery (near Dakar), which processes 500,000 tons of imported crude a year and yields 12,000 barrels of refined products daily. Current plans include increasing its capacity. The refinery's production supplies most of the country's needs. In 1970, 25 percent of this production was exported.

Since Upper Volta has the fewest prospects for discovering oil, no prospecting programs are being conducted there.

—Coal: Small deposits of coal, not exploited at present, are known to exist in the Agamar area of Mali (400 million tons), and at Anou Araten and Agades in Niger (4.5 million tons). Explorations are being conducted in Mali to find better quality coal deposits.

—Nuclear energy minerals: Prospecting for uranium and thorium is under way in most of the region. In Chad, over twelve locations containing some uranium have been found. Prospecting has started recently in Mali. Mauritania uncovered not far from Akjoujt about 1,850 tons of

manazite (averaging about 4 percent yttrium oxide and thorium oxide), which was exploited at a rate of 100 tons/year for several years until present market conditions halted further exploration. Uranium is one of Niger's principal exports; estimates suggest that by 1975, it will account for over 50 percent of the total value of exports (over 1,500 tons a year). The Arlit deposits are estimated at 10,000 tons, containing 2.5 percent uranium. Exploitation's principal problem is lack of transport infrastructure, which adds about $2 per kilogram to the cost of Arlit uranium delivered to Europe. Use of helium-filled dirigibles may prove economical in this case.

Other sites of uranium deposits, such as Azelik (4,000 tons) and Madouela (6,500 tons), have been found. Active prospecting, still under way, is supported by the French, German, and Italian governments. While the results of explorations in Senegal have so far proved negative, some positive indications have been found in Upper Volta.

Thus we see that the region, possessing very few proven reserves of fossil fuels, must rely primarily on oil imports for its needs. Table II.2-8 shows annual consumption of petroleum products, which totaled about $32 million in 1970. The wide variation shown in unit costs is largely due to transportation and distribution costs. In 1970 about 30 percent of Senegal's oil imports were used to generate electricity. The principal characteristics of electricity production are its high cost (between $0.13 and $0.22 per kwh, retail) and low coefficient of generator use (2,470 kwh per installed kw, i.e., half the coefficient of use of United States power plants). The breakdown of energy consumption and supplies is shown in Figure II.2-5.

2.3.4 Other sources: There are other potential sources of energy. Although experiments with marine energy are being conducted near Abidjan, geothermal and marine energy do not seem to hold great potential so far. Aeolian energy, however, is feasible in most of the

TABLE II.2-8

Annual Consumption of Petroleum Products (1970)

	Quantity (Metric Tons)	Thousands of tons of coal equivalent	Value (thousands $ U.S.)	Unit cost ($U.S./ton)
Chad	69,345	87	8,581	124
Mali	71,300	99	3,975	56
Mauritania	116,551	156	3,782	32
Niger	51,623	75	2,239	43
Senegal	416,870	523	9,549	23
Upper Volta	50,843	69	3,774	74
Totals	776,532	1,009	31,900	41

Source: UNSSO 1974.

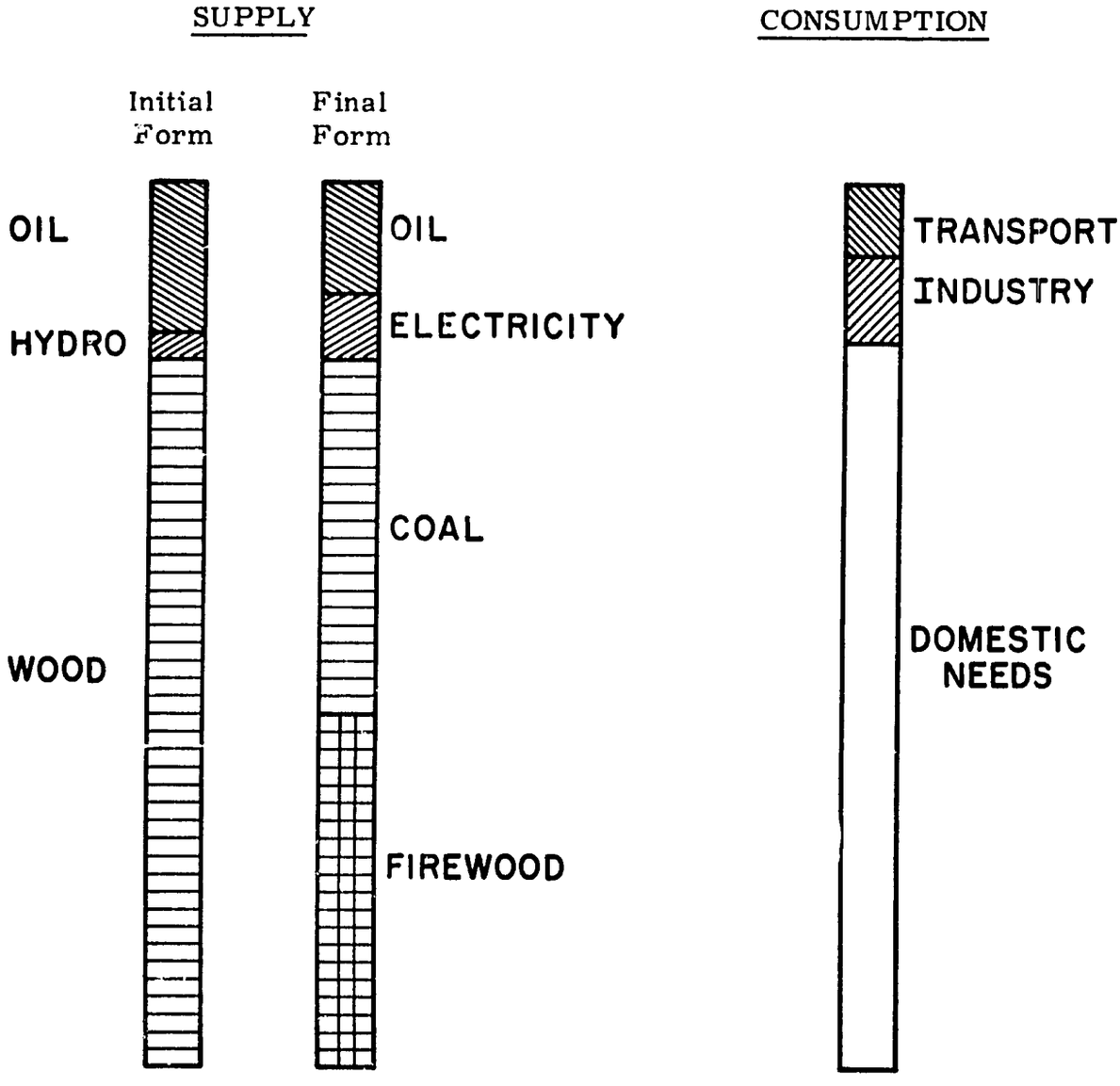


FIGURE II.2-5 Present Pattern of Energy Consumption and Supply

region since the annual average speed of the wind is from 2 meters to 4 meters/second between the 12th and 18th parallel, except in the southern half of Senegal. Below these average velocities, wind energy is difficult to harness. Since the power generated by a windmill increases as the cube of the wind velocity, it is important to try to locate areas where the velocity is higher (10 m to 20m/sec). Higher wind velocities require greatly increased stiffness and strength in power station design, while lower wind velocities may require large storage capacity for electrical power. The areas where aeolian energy production may be feasible are shown in Figure II.2-6.

Geothermal energy sources are possible in at least two areas: first, in Mali between Mopti and Tombouctou and second, in the northern part of Chad in Tibesti. This latter area was studied by German scientists in 1967.

Solar energy also has great potential. The average duration of insolation is between 8 to 10 hours a day in most of the region located between the 12th and 20th parallels. Under these conditions, the average solar energy impacting the area is about 560 calories/cm^2/day. In a similar type of insolation, Hottel (1971) estimates that the electric power production could be about 30 W/m^2 on a 24-hour basis. Figure II.2-6 also shows areas with a given duration of insolation.

2.4 Costs

Energy consumption of fossil fuels is growing observably faster than consumption of fuel wood. It is also clear that all of the fossil fuels are imported and that hydroelectric power constitutes only a small fraction of modern energy consumption. Thus, the trend will be toward increased dependency on foreign sources and a heavier cost for imports.

Another important observation is that because of the distribution costs related to low consumption levels and low population density, the

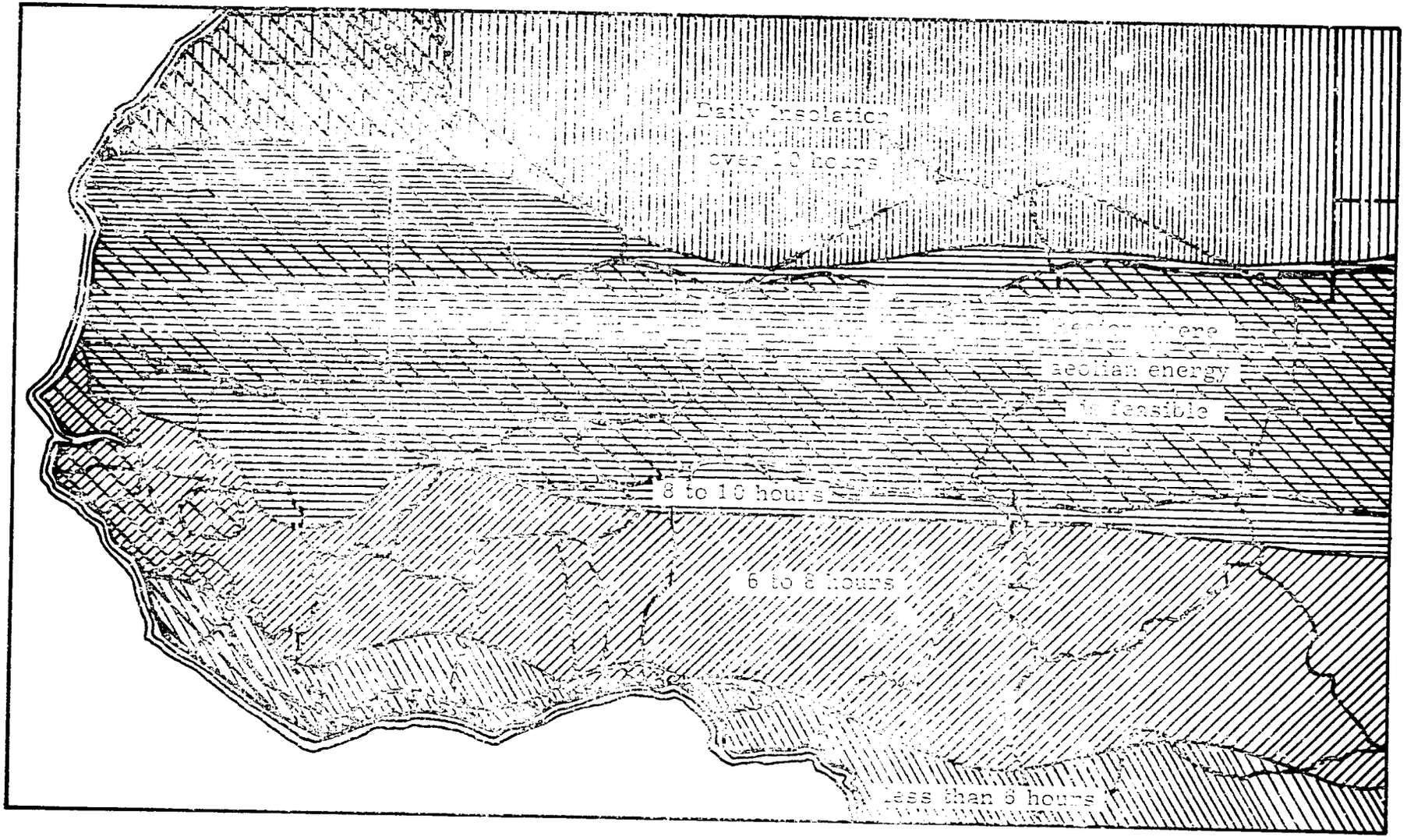


FIGURE II.2-6 Regions where solar and aeolian energy sources may be feasible.

Source: Organization of African Unity 1973.

cost of imported fuels is usually much higher in the Sahel-Sudan region than in industrialized countries.

A summary of the retail costs of different forms of energy in this region is presented in Figure II.2-7. which shows that fuel wood, a local resource, is the cheapest form of energy. Annual expenditure for fuel wood, at 7 to 10 CFA per kilo, amounts to about 4,000 FCFA per capita. An estimate of non-wood energy consumption adds a third more to this annual per capita expenditure for energy.

The price of electricity varies from $0.03 to $0.24 per kwh. Production costs, as projected by Senegal-Consult (1970) for the Manantali dam, are $0.05/kwh. Distribution costs are not included, and over 75 percent of construction costs are charged to irrigation and navigation.

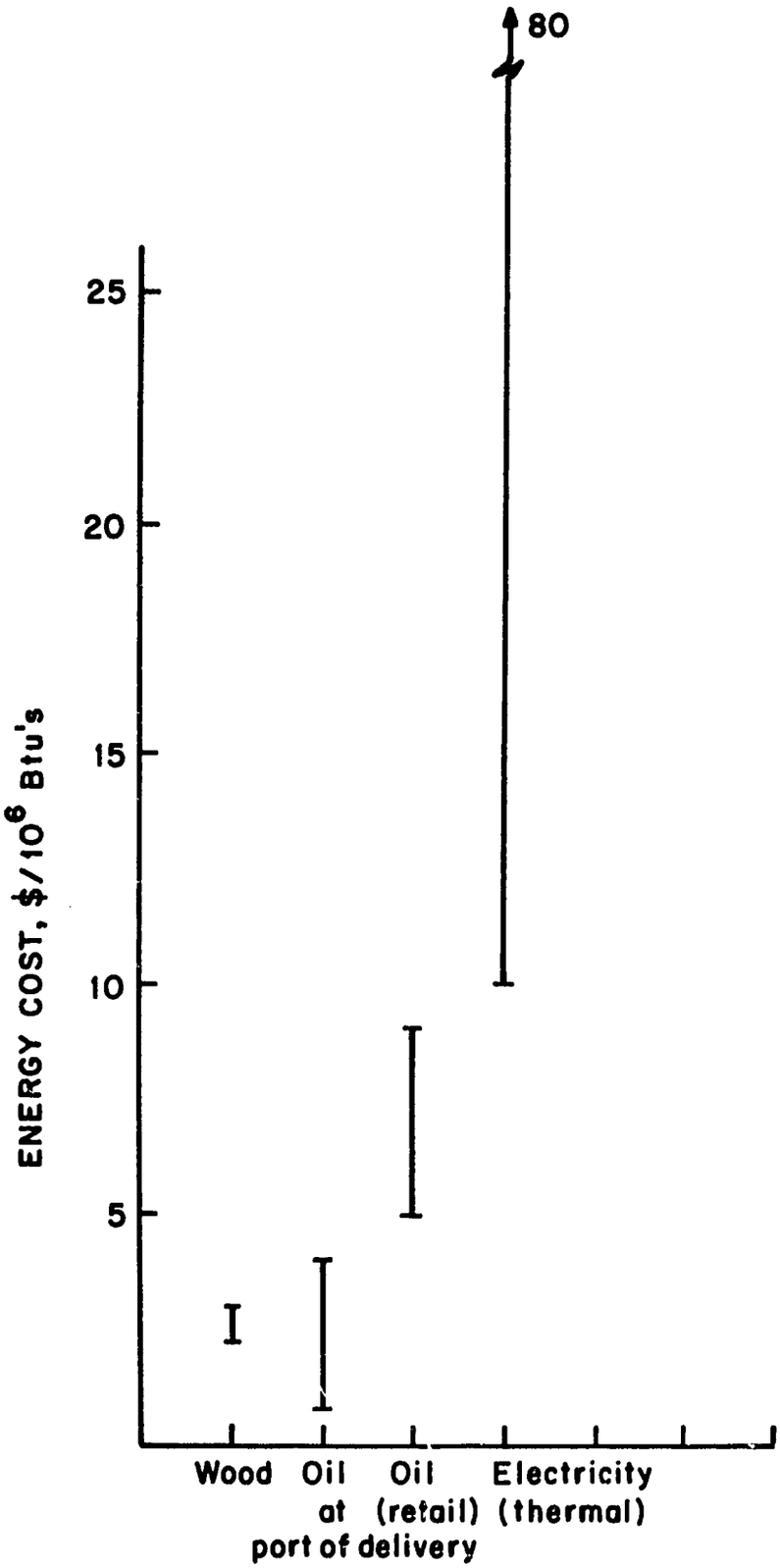


FIGURE II. 2-7 Energy costs in the Sahel-Sudan region (1970).

3. ENERGY AND THE ENVIRONMENT

At its present low level of energy consumption, the Sahel-Sudan region is not likely to be affected in the foreseeable future by most of the ecological impacts which greatly concern industrialized countries. Thus, air and water pollution, thermal pollution, safety and reliability of nuclear reactors, scars left by strip mining, etc., are all likely to have a very low priority in any development plan for the region. However, one ecological impact associated with energy production should not be neglected -- the region's desertification.

Damiba (1973) notes that deforestation of the region is progressing rapidly; in heavily populated areas, "wood merchants go to look for their products some 60 to 80 kilometers from the center." Another important cause of desertification is the widespread practice of making brush fires, which accelerates soil erosion.

3.1 Deforestation

As Section 2.2 indicates, per capita annual wood consumption is estimated between 0.45 and 0.7 m^3. In other words, assuming that one hectare of forest in the woodland zone of the Sahel-Sudan countries has a potential annual productivity of 3,250 kg only 30 percent of which is achieved, each hectare produces an average of 1,000 kg. This amount will provide fuel wood for an average of two people. The government of Mauritania projects a 1.5 percent annual increase of the per capita wood consumption (Ministere de la Planification et du Developpement Industriel 1973).

In order to make a conservative estimate of the need for reforestation programs, we made several assumptions: per capita wood consumption will remain constant; in the year 2000, over 33 percent of the population -- if present trends continue (M.I.T. Interim Report 1974) -- will inhabit the cities; and urban population will obtain its wood primarily from new forests

yielding close to their maximum productivity, or three times the assumed yield of the present unmaintained forests. (We should also note that industrial wood use presently accounts for only 10 percent of total use.)

Under these assumptions, we obtained the data in Table II.3-1, which indicates that to avoid depleting its natural forest resources, the region -- barring major change in its pattern of energy use -- may need about 2.7 million hectares of new forests by the year 2000. Such a reforestation program would cost about $1.3 billion over 30 years. This figure is based on an average cost of $500 per hectare of new forest, which was derived from some of the C.I.L.S.S. reforestation projects (1974).

However, several factors will probably greatly decrease this estimate: some of the wood needed in urban areas will be brought over long distances from existing forests; some forests will be overexploited; and part of the urban population will shift to other fuel sources, such as gas, oil, and electricity. New estimates of other energy sources' availability and costs may greatly decrease these first-order figures for reforestation programs. Nevertheless, this present cost estimate of providing fuel wood without desertification effects is useful in assessing other technological options, which the energy demand and supply models (discussed later) will compare.

3.2 Brush Fires

Cockrum (1974) finds that while fires in the Sahel zone are rarely widespread, in the Sudan zone, the grass is tall, up to 80 cm, and fires are partially responsible for the maintenance of the savanna instead of the natural development of forests. In the woodland belt, widespread fires also occur during the dry season.

Overall, however, these fires have negative ecological impact. First, they tend to prevent or slow down forest development. Second, they

TABLE II.3-1

Estimates of Reforestation Needed by the Year 2000
(x 10^3 hectares)

	Present forests	Unmaintained forests for Rural areas	Maintained forests
Chad	16,000	2,000	330
Mali	4,500	3,000	500
Mauritania	9,800	730	90
Niger	14,000	3,060	510
Senegal	5,300	2,460	410
Upper Volta	2,000	2,000	860
Totals	51,600	13,250	2,700

increase the rate of soil erosion, by removing the groundcover, and accelerate other desertification processes. Third, they waste a natural resource, since the grasses contain nutrients and energy.

On the bases of assumptions made by Matlock and Cockrum (1974), we can estimate the surface areas, where grass is not used intensively. The amount of cultivable land, (or total area allocated to crops) was an estimated 30 percent of the total area of the Sudan and woodland zones. According to data from the Ministere de l'Economie Rurale du Niger (1972), since fallow time has been steadily decreasing, the land actually cultivated at present is about 20 percent of the total available. Therefore, fallow land may be estimated as 80 percent of the cultivable land or 24 percent of the total area. The same Matlock and Cockrum estimates (1974) assume that 10 percent of the total area is left after taking into account wood and livestock. Thus, the areas producing little used grass are about 34 percent of the total surface area of the Sudan and woodland zones, or 327,000 km^2.

Similarly, we can estimate the areas subject to brush fires, including those allocated to livestock. The total surface area of the Sudan and woodland is 963,000 km^2. Since satellite observations claim that 80 percent of this is subject to fires each year, 50 percent of the total, or 481,000 km^2, is a conservative estimate of the burned areas. Therefore, the entire region contains about 400,000 km^2 producing unused grass and/or subject to brush fires.

Bille et al. (1972) show that above-ground herbaceous production is about one ton per hectare in the Sahelian zone of Senegal. However, other areas of the world (such as the United States or Austrialia) with rainfall equivalent to that of the Sudan and woodland zones produce up to 35 tons per hectare. A conservative estimate, based on a 10 ton per hectare annual production from which 5 tons go unused or are burned, yields

a total dry herbaceous waste production of 250 million metric tons. By comparison with barley, a conservative estimate of the caloric content would be about 15,000 Btu/kg (New Alchemy Institute 1973).

Based on these assumptions, the total potentially available energy which is wasted is 3×10^{15} Btu, an amount 24 times the energy produced from fuel wood. One should note, however, that conversion of energy to other forms of fuel will involve energy losses. For instance, conversion to methane will involve about 33 percent loss. Adding energy losses due to fuel distribution, we estimate that as much as 50 percent of this potential energy might be usefully consumed. These additional conservative assumptions would reduce the potential energy available from grasses to 12 times the present level of fuel wood.

Other factors should also be taken into account. For any development plan, decisions about using grass for energy production, for grazing and forage, or for soil improvement would have to be made locally.

This section has emphasized the important ecological impacts of fuel wood use and brush fires, the magnitude of reforestation programs required if such practices continue, and the magnitude of a wasted potential source for energy (1.5×10^{15} Btu), food, and feed (0.38×10^{15} Kcal). Halting this waste and retarding desertification would be among the benefits of a resource conservation program.

The following section will examine some technology-based alternatives which may help counteract these ecological impacts and improve the use of available resources.

4. TECHNOLOGICAL ALTERNATIVES

The previous section demonstrated the potential benefits of developing both an alternative to fuel wood use and a method of using wasted grass. This section outlines several technological ideas which might accomplish these goals.

We will examine first various methods of using solar energy, then the possible use of aeolian energy, and finally the potential use of nuclear energy and of imported electricity from the coastal countries via DC power lines. Geothermal energy sources, presently applicable in only two small parts of the entire region, will not be discussed. Other forms of energy production, such as hydroelectric power generation, are sufficiently known that they do not need special discussion.

State of the art reviews abound (e.g. Hottel et al. 1971, Daniels 1974, N.A.S. 1972, etc...see list of references); we do not wish to add to them. Instead we shall briefly sketch the outlook for the future. Although the region most likely will not have the capacity to develop new energy sources on its own, developed countries may provide technical and economic assistance.

4.1 Solar Energy

Solar energy, one of the region's principal resources, amounts to 0.5 kw per square meter on a continuous basis. Several ways of using this energy are possible. Ideally, complete bookkeeping for each method and established production objectives would be desirable; the optimal mix of the various methods would then be obtained by mathematical programming. Because of many constraints, however, data would be impossible to obtain. Instead, we shall employ a less theoretical, heuristic approach. We will discuss principal methods of using solar energy (summarized in Figure II.4-1) and find their assocted costs and benefits. This section is divided into two parts: direct use,

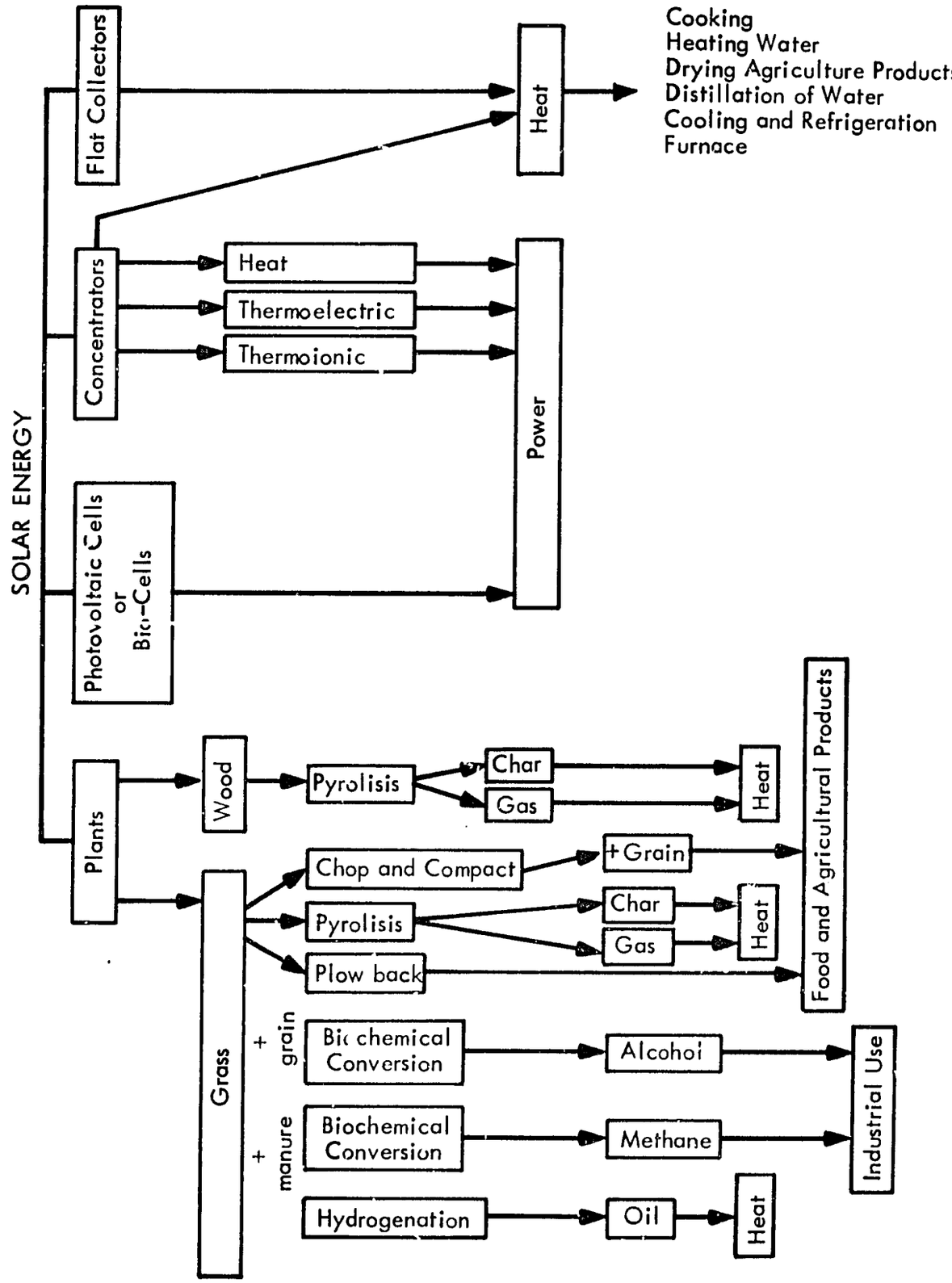


FIGURE II.4-1 Various Utilizations of Solar Energy

and photochemical conversion.

4.1.1 Direct use: Direct use, in this context means rapid conversion of solar energy into a form readily available for other usage. Photochemical conversion integrates available solar energy over a long period of time.

We will further subdivide direct use methods into those producing thermal energy or heat, and those producing mechanical and electrical energy or power.

–Heat: The annual solar energy available in the Sahel-Sudan region is about 200 Kilolangley (Kly) per year, or the equivalent of 2,200 kwh per m^2 per year (or 0.5 kw per m^2) based on 4, 400 hours of insolation. At noon, the solar energy on a bright day equals 1 per m^2, while on a cloudy day it would be only 0.8 kw/m^2.

Methods of directly converting solar energy to usable thermal energy are based on flat-plate or focusing collectors. Flat-plate collectors, easier and cheaper to manufacture, work equally well on hazy and cloudy days. Focusing collectors are more expensive, need adjustments in their orientations, and do not work well on cloudy days. Their advantages are greatest where high temperatures (over 120°C) are needed or to increase efficiency, such as in furnaces and thermal engines.

Estimated costs of collectors are highly variable due to the experimental aspects of most installations. The cost of the large flat-plate collectors reflects the structural stiffness required to withstand severe wind effects. Focusing collectors can be very expensive because of the tolerances required for their construction and the mechanisms needed to control their orientation. Both types require some simple but extensive maintenance to keep a good quality surface.

Solar heat may be directly used for space and water heating, drying, cooking, and water distillation.

Space heating, tried in many experimental systems, costs from $2.5 to $4.5 per million Btu in the U.S. (Hammond et al. 1973; Glaser et al. 1973). This type of utilization, however, holds little interest for the Sahel-Sudan region.

Water heating, used for some time in many countries -- including Japan (over 350,000 units in 1960), Algeria, and Australia -- may help reduce fuel needs for urban domestic use. Prices vary widely ranging from $6 - $120 in Japan to $315 - $400 in France for "family-size" units. Usable life is also variable (U.N. 1962). In the United States solar water heaters are competitive when the cost of fuel exceeds $1 per million Btu ($6 per barrel of crude oil).

Drying is often conducted naturally, by direct exposure to sunshine. Controlled solar drying has, however, some advantages in crop-drying and food-processing (e.g., for unrefined sugar in India).

Cooking is a solar energy application with more potential impact for the region since it requires large quantities of wood. Solar cooking units may be manufactured locally to some extent. But many tests in other parts of the world (such as India) have failed because of costs, sunshine limitation, and other reasons. Kastens (1963) reports, for example, a $0.50 do-it-yourself kit in Buram, or a $2 plastic reflector and an $8 well-designed stove in Lebanon.

Solar stills to produce fresh water have been known for a long time. A glass still of several acres was built in China 100 years ago (UNESCO 1973), and another one in Chile 50 years ago (Spanides 1961). Small distillers (less than 1 m^3/day) charge an estimated $1-$2 per cubic meter of fresh water (U.N. 1962), while large ones (as in Australia) sell water at $0.35 per cubic meter (UNESCO 1973). The U.S. Department of Interior plans a unit which will produce at a cost of about $0.50 per cubic meter. This direct heat application of the sun's energy

is potentially the most interesting method for brackish or salt water areas and for rural areas' drinking water. However, none of these applications is likely to have a major economic impact on the region.

—Power from solar heat: Solar heat can also be used to generate mechanical or electrical power. Egypt used a 10 hp unit at the beginning of the century. Since the cost of fuel is nil, objections to the low efficiency of the conversion cycle are not important; only capital and maintenance expenses per unit output are relevant. The Somor generator, a marketable Italian unit, reportedly averages about $1 per kwh over its life. Even with greatly increased fuel costs, it is unlikely that such devices would cost less than $300 to $500 per kw, or $0.02 per kwh. Unlike conventional power plants, electricity costs from solar heat are not very sensitive to unit size. These devices seem suited to some -- though not many -- applications in the Sahel-Sudan region, where fuel transportation and electricity transmission multiply energy costs by several fold. Pumping water via mechanical energy generated from solar heat is a very interesting possibility. Chinguetti's (1973) experience seems very promising.

—Thermoelectric conversion: Thermocouples provide one method of converting solar heat directly to electricity without using heat engines. Two different metals or semi-conductors are used to make a loop whose two ends are maintained at different temperatures. The cost of electricity from such generators is an estimated $1 per kwh for a one kilowatt unit (U.N. 1962).

Thermoionic conversion also bypasses the heat engine. Involving higher temperature (2,000°C) and a vacuum, however, it appears more costly than the thermoelectric method. In both cases, mass production would change the picture.

—Power from solar light: Photovoltaic conversion. Solar cells converting solar radiation to electricity have been used in the U.S.

Space Program, and schemes involving satellite power stations orbiting the earth have been suggested. Such schemes, however, will probably not be feasible before the last decade of this century. Although other schemes using silicon cells are being discussed, costs range from $400 to $270,000 per kw (UNESCO 1973). NASA's cost estimate in 1972 was $270,000 per kw, although it hopes to reduce this figure to $50,000 per kw by 1978. NSF hopes to achieve $5,000 per kw by 1977 and $500 per kw by 1979 (Rosenblatt 1974). Japan is betting $3.6-$7 billion on its Sunshine project between now and the year 2000: a one MW system should be completed by 1980, 10 MW by 1986, and 100 MW by 1991. Several processes to find inexpensive ways of manufacturing the needed silicon film from sand are under study. Considering the decreased prices of computers and calculators, it would appear that new processes and mass production could make this method of energy production useful to the region in less than two decades. Unfortunately west African countries have no control over this possibility.

—Bio-cells: Chlorophyl donates electrons to certain semiconductors. Work done at the Argonne National Laboratory suggests that duplicating some processes used by plants to convert light into energy may be possible and that artificial leaves may be possible within a decade (Salisbury 1974). Costs may be one percent of present silicon photovoltaic cells (UNESCO 1973).

4.1.2 Photosynthesis: Agricultural crops, livestock, and wood can use the sun's energy naturally to provide energy. Wood in the Sahel-Sudan region costs about 7-10 FCFA per kilo, or $2.5 per million Btu. Reforestation projects are estimated at $500 per hectare, yielding an estimated annual 1,000 kg of wood (potential 3,000 kg in that type of climate). If 1,000 kg produce about 3 million Btu's, wood represents an annual 350 Btu per square meter compared to 7 million Btu

of incident sunlight. Thus only one Btu per 20,000 of the incident solar energy is retrieved in wood.

Algae culture, one method of improving solar energy use, produces not usable energy but food and feed containing proteins (UNESCO 1973) at an estimated average price of $1.70 per kilo of protein content (Kastens 1963).

Single cell proteins (SCP, which can be derived from oil, agricultural waste, and other refuse, also produce food and feed rapidly by making better use of solar energy. Humphrey (1973) mentions the concept -- advanced by a sugar company, Tate and Lyle, Ltd. -- of village-level in addition to high-level technologies. The design includes a $50,000 unit producing three tons a day.

Further research is being conducted in several universities in the United States. One single cell protein process uses wood hydrolysis to produce glucose, which is fermented to produce a yeast strain. Because of the region's large amounts of solar radiation, agricultural wastes, and unused grasses, this technology and methane production from wasted grasses (discussed next) are probably the most interesting. Projected costs of proteins produced by these methods are still high but appear to be cheaper than usual proteins such as beef, pork, or eggs.

—Grass: Earlier we estimated burnt grasses and agricultural wastes. In addition to producing food and feed, these wastes can be used to generate <u>methane</u>, or <u>alcohol</u>, by bio-conversion. The process, well explained in "Methane Digesters for fuel gas and fertilizers" (New Alchemy Institute 1973), produces fuel gas and fertilizers. Since this technology can be developed in small artisanal units, it is extremely useful. Taiwan has 7,500 working simple farm installations, which are associated with pig-raising schemes (Department of Rural Reconstruction); larger units can be used for urban areas. Energy produced can be stored

in the form of gas and carried in bottles. Commercial production does not have to be centralized but can be spread throughout the region. Since this form of energy, obtained almost entirely from local resources, does not require the same enormous infrastructure of distribution lines as electricity, it could be well suited to urban and industrial energy needs as well as farm production. In the United States this technology would be useful primarily for urban wastes. Wise et al. (1974) provide a model for estimating production costs which indicates that if fuel costs exceed $2 per million Btu, this process would be competitive without subsidies. Our model (to be presented in the next section) assumed $6 per million Btu in west Africa. It is important to note that this methane production process generates fertilizers as well.

Alcohol production, more expensive and generally not justifiable for its use as fuel, may be desirable for other chemical applications.

Other efficient uses for grass include: plowing to increase soil productivity, chopping, packing, and distributing it as fuel.

4.2 Aeolian Energy

This is an ancient form of energy production which seems to have originated in Persia before the Arab conquest, when windmills had a vertical axis. Since that time, a great variety of designs and unit sizes have been used throughout the world. Holland's extensive use of windmills has been the most interesting. The United States still used 50,000 units in rural areas in 1950 to generate electricity, pump water, and run sawmills (Wade 1974).

In their present state of development "family-size" units using aeolian energy seem to be more economical than their solar counterparts for mechanical and electrical power production. The reverse is true for heat production. Costs are estimated at over $400 per kw. Quoting costs is difficult, however, because electricity production is highly

sensitive to wind velocities. Power output increases as the cube of the wind velocity, and efficiency drops outside the design wind velocity (Golding 1955). Commercially available 1-3 kw windmill generators produce electricity at about $0.15 per kwh, which is cheaper than the cost of electricity in some parts of the Sahel-Sudan region. Design techniques could reduce costs for small power-generating units by using local materials such as cloth or wood. Despite the obvious advantages of introducing wind power for pumping water, supporting artisanal activities, and conserving wood, the direct economic impacts would be significant only if wind power is used for urban, industrial, and commercial applications. The technology to produce the 100-1,000 kw units which would be needed is less developed than that for 1-10 kw units. Since the United States now shows renewed interest in large production units, 1,000 kw aeolian units will probably be used at an earlier stage than their solar counterparts. During the second world war, a 1,250 kw unit built on Grandpa's Knob in Vermont lost a blade through metal fatigue within a month. NASA, Grumman, and Vertol are now working to design efficient windmill generators using lightweight materials and electronic controls. NASA is starting with a 100 kw unit, then planning 1,000 kw and 5,000 kw units (Business Week, May 11, 1974). Large aeolian units are also being constructed in other countries, such as the USSR. They could be commercially developed in a relatively short time, and could help the balance of trade problems in the Sahel-Sudan region.

Two problems associated with wind energy production are electricity storage and windmill siting. The former is also a problem associated with solar power. The expensive lead batteries used have limited capabilities. New technologies include: compressed air systems, pumped hydraulic storage, super flywheels, and electrolysis of water to produce hydrogen fuel (Wade 1974; Hammond et al. 1973). Site selection requires

extensive meteorological data collection and local wind surveys to take advantage of local topography. Hourly records may be needed for a year or two (U.N. 1962). A list of sources of information about wind machines follows the references at the end of this report.

4.3 Nuclear Energy

Because it generally involves large production units (over 200 MW) using advanced technologies, nuclear energy cannot be considered in the same light as other energy forms. Some characteristics which make it interesting to incorporate in an agro-industrial complex are: highly flexible location since it is not constrained by the transport costs of fuels or the difficulties in finding natural energy resources; the low cost of energy produced; and the possibility of using low value heat energy to produce water at about $0.20-0.30/1,000 gallons, or $0.06 per cubic meter (UNESCO 1973). The concept applies principally to coastal zones where power and desalinated water are produced; the power supports chemical and metallurgical industries while water is used for year-round irrigated farming. Many studies of such complexes (sometimes referred to as NUPLEX) have been carried out. One of them by the Oak Ridge National Laboratory (1968), sees important economic advantages to nuclear energy, especially in developing countries. The study projects internal rates of return higher than 10 percent for a small complex (500 MW). Using an estimate of 200 gallons of water a day to produce the caloric requirements of one person, it estimates a food production cost of $0.03 per day with an initial investment of $165 per person.

UNESCO (1973) notes that "Cost estimates for a projected Egyptian agriculture-based complex are $3.4 billion (70 percent of this for a closed irrigation system. Operation and maintenance $0.8 million per year. Power 140 MW plus 1,450 million gallons/day." Note that current

large plants produce less than 5 million gallons/day.

M.I.T. made a feasibility evaluation for Pakistan showing that such a nuclear complex would provide 275 million gallons per day (12 m^3/sec) to produce 0.5 million tons of food grain and fiber in addition to 400 MW of electrical output (Ahmad 1973). Completion of the project would require about 12 years and a total investment of $323 million with a 10 percent internal rate of return. If no electricity is produced, the water output would triple. This study suggests that to produce food for one person the initial capital investment -- if one-third of it is allocated to electricity production -- could be about $200.

According to a UNESCO Delphi survey, African and international experts do not consider this type of complex of interest to African countries because it still requires a long development period and large amounts of capital, and is principally applicable to coastal countries (UNESCO 1974).

Although the concept of NUPLEX is not likely to be realized in the Sahel-Sudan region, studies of integrated agro-industrial complexes (not necessarily associated with nuclear energy) should be very useful. The Manantali dam is considered the nucleus of such a complex. It will also be much more realistic in the next two decades to consider the Manantali dam as well as other sites and geothermal sources as potential locations for agro-industrial complexes. Concentrating construction of infrastructures in a few chosen areas may be the only way to stimulate exploitation of some of the region's mineral resources and to increase food production.

4.4 Energy from Coastal Countries

Abundant hydroelectric energy is available in the coastal countries. While Nigeria can use most of the energy it produces, Ghana and Guinea are developing projects for 768 MW and 625 MW respectively, amounts

that will greatly exceed their needs for a number of years. As these capacities are more fully utilized, the Sahel-Sudan region could establish long-term contracts, and other sites could be developed. Such developments could be associated with planning of urban centers and agro-industrial complexes. The high cost of electric power transmission could be greatly reduced by using high voltage DC transmission lines. Also the new hydrogen technology, or coal gasification, and similar technologies could be used to transmit energy in a fuel form. Such development will require increased cooperation among the west African countries.

5. MATHEMATICAL MODELS TO ANALYZE DIFFERENT ENERGY POLICIES

Our principal observations from this overview of energy resources in the Sahel-Sudan region may be summarized as follows:

(1) Any development plan will require greatly increased rates of energy consumption. Almost all productivity increases imply increased energy consumption.

(2) The Sahel-Sudan region relies now on two relatively costly sources of energy: imported oil, which is becoming increasingly expensive, and fuel wood, which is contributing to the desertification of some areas.

(3) The region has relatively large amounts of exploitable energy resources which could contribute importantly to its development. However, they are not readily adaptable to conventional energy production systems. Hydroelectric and geothermal resources are not located in the vicinity of large potential markets. Nuclear plants would require large, sudden increases of energy production and very rapid transformation of the agricultural and industrial production systems. Solar and aeolian energy sources would require technological and institutional improvements.

(4) Energy policies are likely to have long-term impacts on the region's development. Political and social considerations regarding supply sources and patterns of consumption will significantly affect balance of trade problems, urbanization and industrialization rates, modernization rates of the agriculture production system, and the region's ecological balances.

Consequently, the region's capacity to formulate energy policies and devise mechanisms to implement them will be very important. This section describes two simple models which may be refined and used as tools to evaluate energy options. The first projects energy demands for various assumptions of development policies; the second projects the costs of various options which may be chosen to supply the energy

requirements.

5.1 Demand Model

5.1.1 Description of the model: The flow chart for the demand model is depicted in Figure II.5-1. This model may be used to project energy consumption growth for assumed sets of inputs which reflect development policy choices. The sets of inputs may not be coherent, and their compatibility has to be tested with other economic models. By utilizing iterative procedures, the model may be used in conjunction with other economic models. It may also help to obtain trends, determine sensitivities, and evaluate qualitatively the impact of policy choices on energy consumption.

The model provides two estimates of total energy projections -- by decades and by country -- for the entire region. Smaller planning subregions could be chosen when more data is available and more accuracy is required. The sectors of energy consumption have been subdivided into: urban domestic wood and non-wood fuels, rural domestic wood and non-wood fuels, transport, industry, and agriculture. Additional consumption sectors may be added, and the chosen sectors may be subdivided into subsectors. However, the level of aggregation chosen at present seems adequate considering the lack of data.

5.1.2 Demand projections: Three runs -- referred to as assumptions (a), (b), and (c) -- were performed with the following input data.

—Population and urbanization: Input data were based on M.I.T.'s interim report (Center for Policy Alternatives 1974) and are shown on Table II.5-1.

—Income per capita: The initial GDP per capita for 1970 -- is shown on Table II.5-1. Two growth rates of GDP per capita were chosen: one percent for (a) and three percent for (b) and (c).

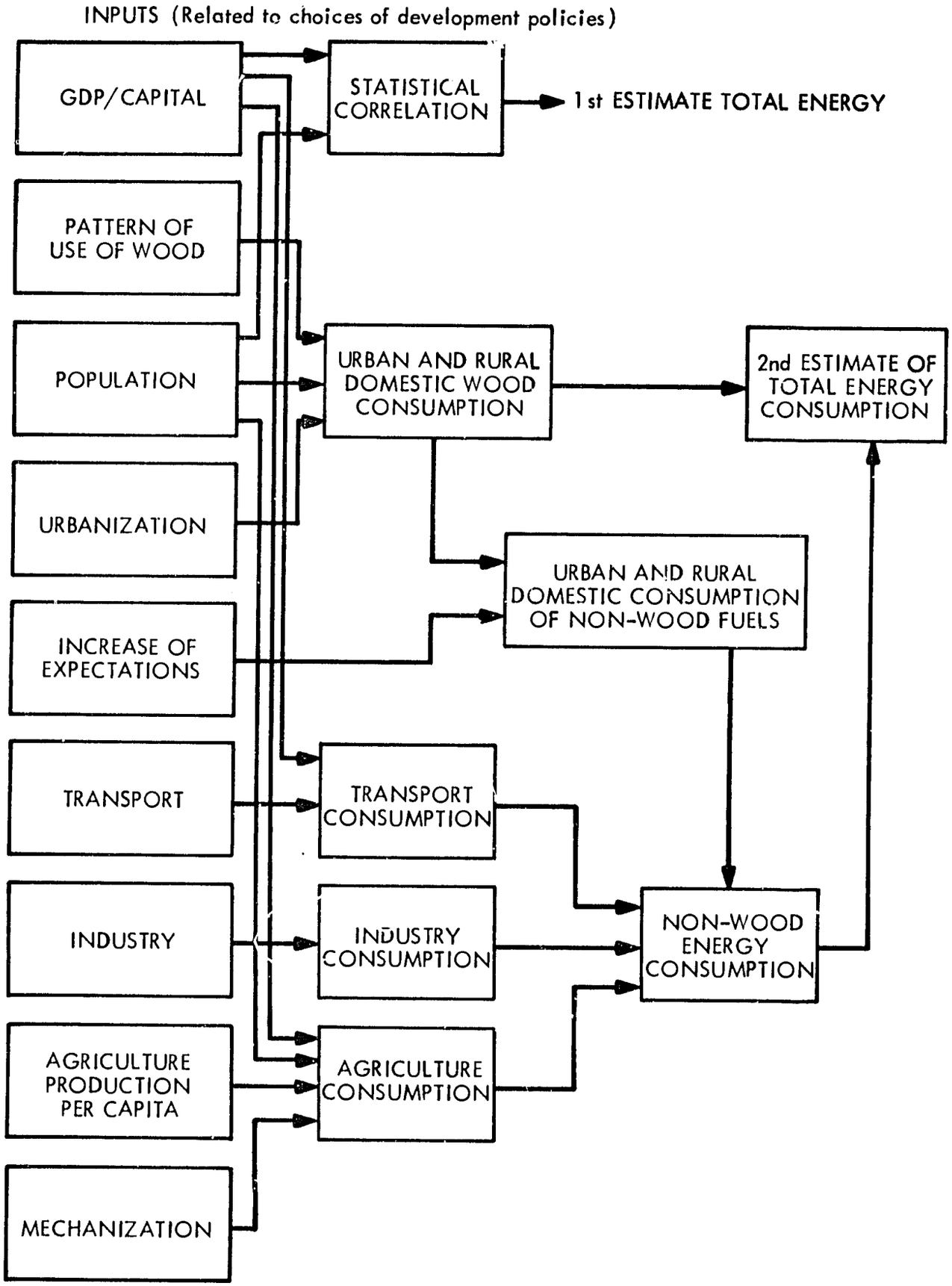


FIGURE II. 5-1 Energy Demand Model

TABLE II.5-1

Population and Income-Input Data for the Base Year 1970

	Population (millions)	Annual Growth Rate (%)	Urban Population (millions)	Annual Growth Rate of Urban Population (%)	GDP per Capita ($US)
Chad	3.68	2.02	0.339	8.1	80
Mali	4.75	2.63	0.472	7.5	70
Mauritania	1.16	2.08	0.053	7.6	140
Niger	3.72	2.67	0.192	9.2	90
Senegal	3.86	2.65	0.095	5.4	230
Upper Volta	5.35	2.23	0.288	8.4	60

—Use of wood: The initial wood consumption per capita in rural areas is based on data from the Yearbook of Forest Products (1969) mentioned in Section 3.1. Per capita wood consumption in urban areas is estimated as only a fraction of rural use. Data for Senegal in 1970 shows that only 1.5 percent of the estimated wood consumption was commercialized. We assume that this commercialized wood represents urban consumption. The same percentage is applied to obtain the urban consumption of other countries. The assumed data (in millions Btu's) on annual per capita consumption of wood in 1970 are shown on Table II.5-2.

Per capita urban wood consumption is assumed to decrease at the annual rate of 2.4 percent. Two assumptions are made on the annual change of per capita rural wood consumption for the three sets of assumptions: (a) and (b) no change; and (c) one percent annual decrease.

We further assumed that a decrease of per capita wood consumption increases consumption of other fuels. However, because of the gains in efficiency, we assumed that only 25 percent of the wood Btu's have to be replaced. This assumption, as well as others which follow, should be revised if the models are refined so that they may be used more effectively in the formulation of development programs.

—Expectations for domestic consumption: In addition to the shift from wood to non-wood fuels, the rate of non-wood domestic energy consumption will presumably increase as the GDP per capita increases. The annual per capita increase rate of non-wood fuel consumption is assumed to be 2.4 percent in both urban and rural areas.

We obtained the initial values of per capita non-wood fuel consumption for 1970 by analyzing data in the 1972 edition of a yearly publication by Senegal's Direction de la Statistique. Our analysis indicates that about 9.5 percent of non-wood energy was used domestically in cities, about 2 percent in rural areas. The same percentages were assumed for

TABLE II.5-2

Per Capita Annual Energy Consumption-
Input Data for the Base Year 1970

	Fuel Wood (10^6 Btu)		Non-wood Fuels (10^6 Btu)	
	Rural Areas	Urban Areas	Rural Areas	Urban Areas
Chad	6.99	1.05	0.010	0.454
Mali	4.70	0.65	0.012	0.526
Mauritania	4.44	1.41	0.033	3.244
Niger	4.78	1.34	0.008	0.662
Senegal	6.05	0.23	0.106	1.273
Upper Volta	5.73	1.53	0.005	0.459

the other countries. The assumed data (in millions Btu's) for annual per capita consumption of non-wood fuels are shown on Table II.5-2.

—Transport: We assumed that energy consumption for transport increases at the rate of 6 percent, which is slightly more than twice the assumed growth rates of the GDP.

—Industry: Two assumptions were made concerning industry's growth rate for the three sets of assumptions: 4.2 percent for (a) and 6 percent for (b) and (c).

—Agriculture: In 1970, the agricultural sector's calorie production per capita was 2,470K calories (estimated from UNCTAD 1973 data). We assumed that production per capita would increase at the rate of one percent a year for policy (a) and 2 percent for (b) and (c). This productivity increase would require a modernization of the agriculture system resulting in increased energy consumption per unit of production. The 1970 rate of energy subsidy to agriculture was an estimated 0.066 calorie per calorie produced; its increase would be three percent for policy (a) and 7 percent for (b) and (c). For reference, this rate was about 5 percent in the U.S. in the first half of this century.

—Statistical correlation: From Figure II.2-1 one deduces a general correlation between non-wood energy consumption and GDP per capita which showed that energy consumption per capita for the least developed countries increases at a rate of about 2.5 times the growth rate of GDP per capita. We compared this statistical correlation with results from the model.

—Summary of sets of assumptions: The principal differences between the three sets of assumptions compared can be summarized as follows:

(a) Modest growth rate of GDP/capita (one percent; constant per capita wood consumption in rural areas; modest industrial growth rate (4.2 percent); small growth rate of agricultural production per capita (one

percent) and of agricultural modernization (three percent). Agricultural modernization is measured by the energy input required to produce a unit agricultural output.

(b) High growth rate of GDP per capita (three percent); constant per capita wood consumption in rural areas; high industrial growth rate (six percent); high growth rate of agriculture production per capita (two) percent) and of agricultural modernization (three percent).

(c) Same as (b) except a one percent decrease in per capita rural wood consumption.

Some of the results for the entire region are shown in Figures II.5-1 and II.5-2. Since these examples are primarily illustrative, differences between countries are not shown. Figure II.5-1 shows total energy needs for the three assumptions (a), (b), and (c). The model's results, compared to the statistical correlations, are less sensitive to changes in inputs. The statistical correlation is extremely sensitive to the growth of GDP per capita; energy consumption projected for the year 2000 varies by a ratio of 1 to 4 for the different assumptions, while the model's projections for the year 2000 differ by less than 40 percent among the three sets of assumptions. The moderate growth assumption (a) shows a sevenfold growth of non-wood energy consumption and 40 percent increase of wood consumption over 20 years. The high growth assumptions (b) and (c) show a tenfold increase of non-wood energy consumption over 30 years, while consumption of wood increases by 40 percent (b) or remains constant (c).

These results show that annual fuel import bills, which stood at $32 million in 1970, are likely to be multiplied 7 to 10 times by the year 2000 to account for growth, and another 3 to 6 times to account for the current trends in price increases. These figures suggest that developing local energy resources may be necessary. This possibility will be evaluated with the supply model. Figure II.5-1 also shows the time delay needed for decreasing the fuel wood consumption.

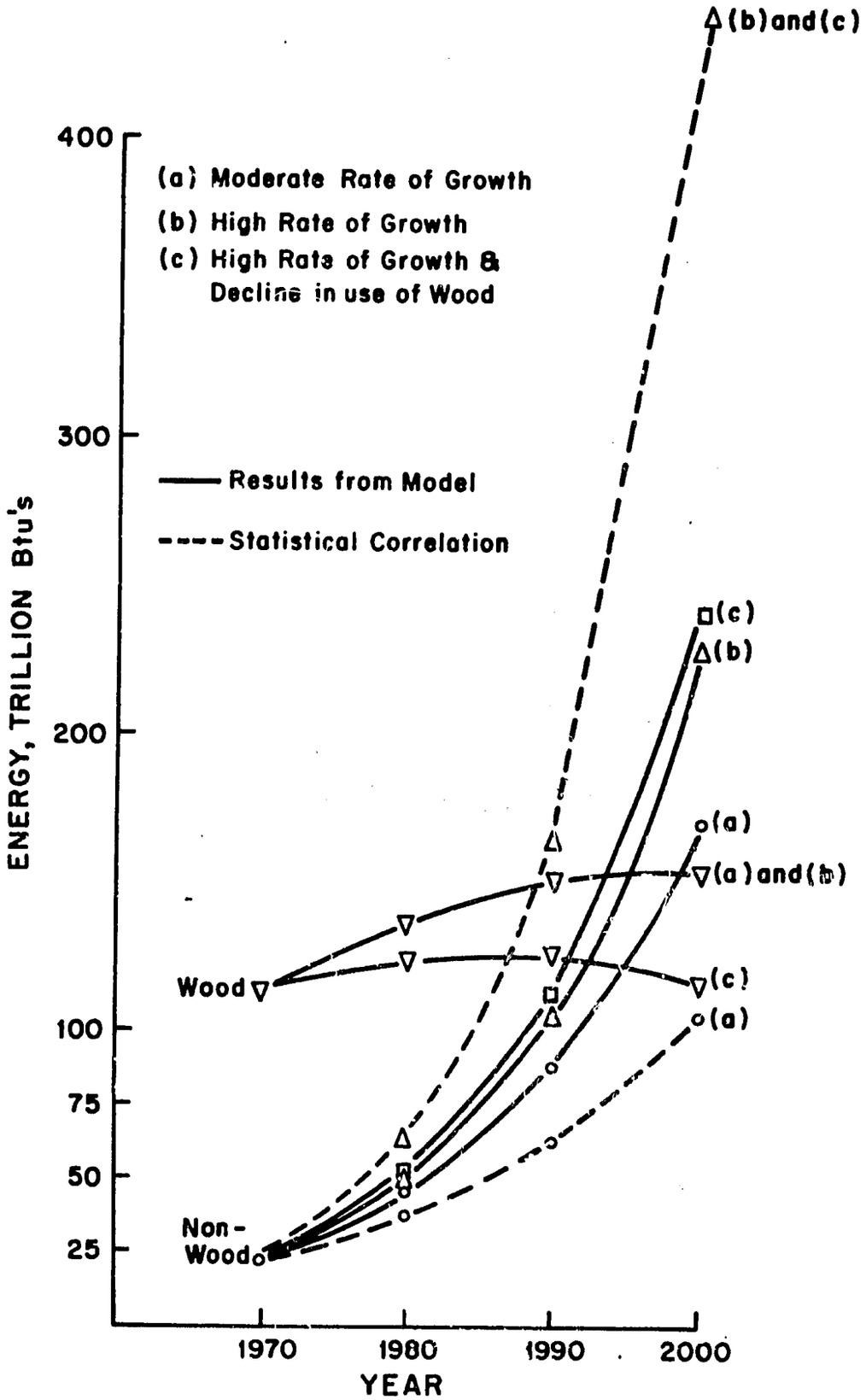


FIGURE II.5-1 Projected Energy Consumption

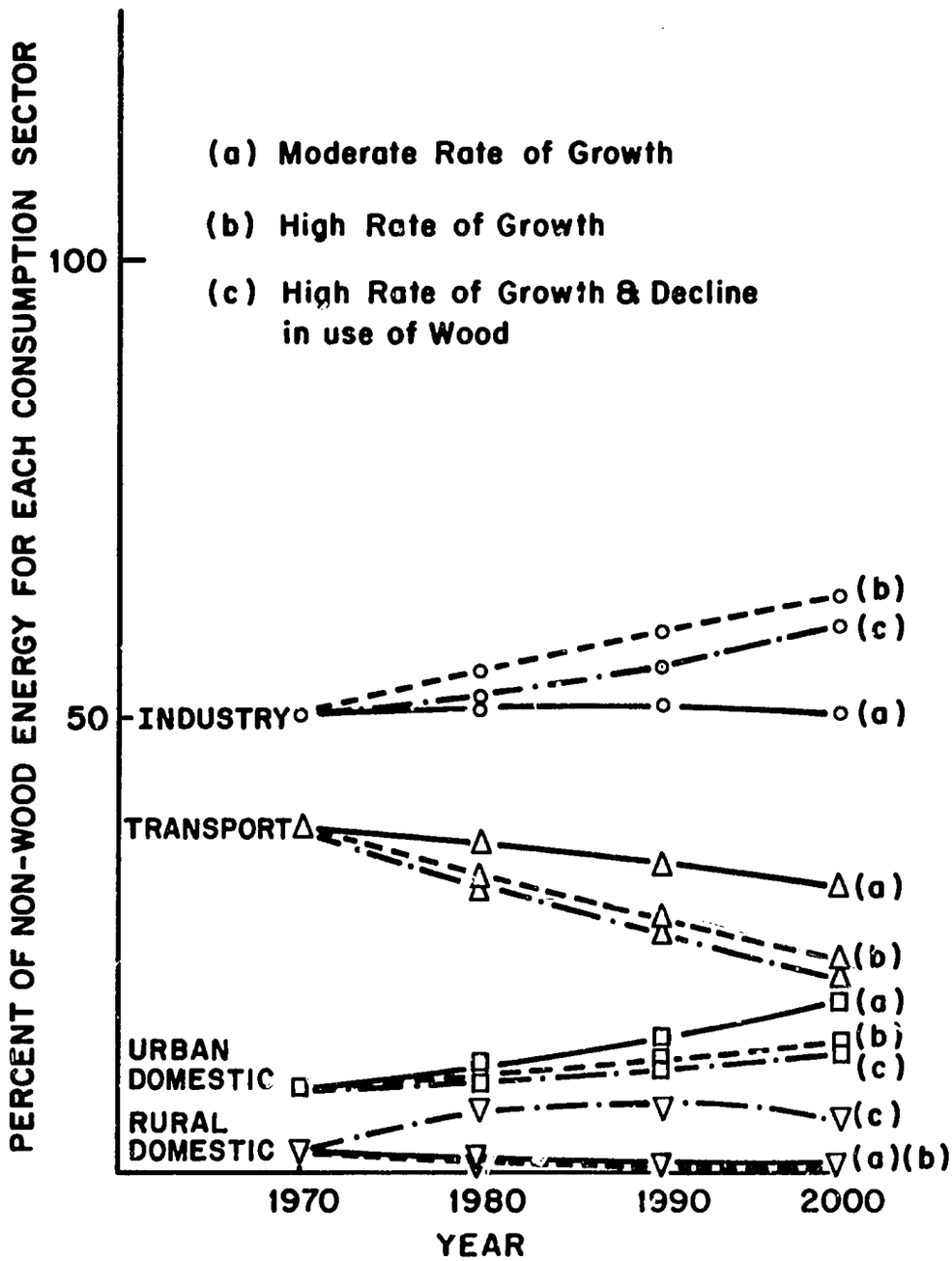


FIGURE II. 5-2 Projected Relative Energy Consumption by Sectors

Figure II.5-2 shows industry as the main sector consuming non-wood energy (50 to 60 percent), while relative consumption by transport declines from 40 to about 25 percent. Urban domestic consumption increases from its present 10 to about 15 percent; rural domestic consumption increases from 2 to 6 percent when the use of wood is actively discouraged, remaining constant otherwise. Finally, agriculture uses a negligible amount of energy for all three sets of assumptions. Variations among the results obtained for different countries showed a strong sensitivity to assumptions concerning urban growth rates.

These results suggest that exploitation of local energy resources -- finding oil, coal, and uranium or tapping hydroelectric and geothermal sources -- will be a critical factor in the region's development. While other sources such as aeolian and solar energy, which are presently geared to small rural consumption units, will have a limited direct economic impact, they may have very significant ecological and social impacts.

5.2 Supply Model

5.2.1 Description of the model: This model uses both the demand model's results and data from different sources about energy costs to project the various costs of providing the needed energy. Price elasticity considerations have not been included at this stage of the modeling.

To a large extent, data about costs are suppositional. Sources of energy such as solar, aeolian, and geothermal have been developed mostly as prototypes or under special conditions. Moreover, it is difficult to assess the costs of energy distribution and marketing. For instance, the official 1970 fuel import cost in the Sahel-Sudan region was $32 million, averaging $1.3 per million Btu. The retail price, however, was $4-$6 per million Btu. The average import cost of oil varied between Senegal, which has a refinery, and landlocked countries like Chad by as much as a ratio

of 1 to 5.

Similarly, the retail price of electricity varied from $0.025 to $0.22 per kwh (see Figure II.2-4), while production and distribution costs averaged about $0.08 with a foreign exchange component of about $0.06 per kwh.

The costs of interest to us at present are: total production and distribution, foreign exchange component, and capital investment. When necessary, the cost of capital is assumed to be 10 percent. Following are estimates concerning each energy source.

—Wood: The estimated cost of wood is about $2.5 million Btu. As wood is depleted around urban centers, the cost of hauling it over greater distances will result in higher prices.

—Oil: In 1970, oil costs averaged $1.3 per million Btu on the foreign exchange. Retail cost varied from $4 to $6. The recent trebling of crude oil prices will result in about $4 per million Btu on the foreign exchange and about $8 per million Btu market price excluding taxes. We will assume -- although we are probably greatly underestimating oil costs -- that these prices will remain constant until the year 2000.

—Solar energy: Solar energy for heat costs about $1.5 - $4.5 per million Btu (Hammond et al. 1973). An average figure of $5 per million Btu will be used for the region. However, for generating electricity, this average will increase to $10.5 per million Btu or $0.35/kwh. We further assumed that half the cost of solar energy is spent as foreign exchange to import components and pay for some of the capital costs, while the remainder is spent locally. Note that the cost of solar energy does not seem to depend on production unit size. We assumed that the investment will cost $400/kw, or $0.20 per kwh.

—Wind energy: Estimates on production costs of wind powered generators which generally require more maintenance than solar

units, vary widely. In many cases such generators show lower production costs since they can produce power during the night and may be used to complement solar units. Production costs vary according to location (average wind velocities), power requirements (storage size), design, and unit size. We will use the figure (similar to that used for solar energy) of $10.5/million Btu or $0.35/kwh, which represents the middle range of the estimated costs for village size production units of about 100 kw. In this case, too, half the cost is attributed to foreign exchange, and capital investment is estimated at $400/kw or $0.20/kwh (i.e., only 2000 kwh a year per installed kw).

—Methane: Methane could be produced either from grasses or from agriculture and urban waste. This technology is being developed in the United States (Wise et al. 1974). Present data show that when the price of U.S. oil goes from about $3.4 to $8 per barrel, methane production from urban wastes becomes economical without any subsidy. One million Btu's of methane obtained from waste will then cost about $2. Since all prices are increased by a factor of at least 2-3 when they are transposed to west Africa, we will guess that the price of such gas will average $6 per million Btu to pay for machinery, capital, and technology, while the capital investment costs will be $60/million Btu a year. This technology, which can be applied with various degrees of sophistication, is being used in Taiwan on small farms. In this report, we emphasize primarily large manufacturing units to satisfy urban needs. We assume rural areas will continue to rely largely on wood. Methane can replace oil and coal in most applications, including transport.

—Electricity: Electricity production depends strongly on production unit size (see Figure II.5-3). Hydroelectric and geothermal power generally have slightly cheaper production costs. However, when electricity distribution is included, the consumer price is about the same as the price of convention oil-fired units. The principal difference

TABLE II.5-3

Summary of the Assumed Costs

	Energy Type		Major Capit. Investment*	Total Costs**	Foreign Exchng Component**
Fuel	Oil	1970	--	4.	1.3
		1975	--	8.	4.0
	Wood		25.	2.5	0
	Solar Heat		50.	5.	2.5
	Solar and Aeolian Electricity		70. ($400./kw)	10.5 ($0.035/kwh)	5.0 ($0.017/kwh)
	Methane from grass and urban & agric. wastes		60.	6.	3.
Electricity	Thermal-Elec. 1970 (oil-coal-10mw)		18.5 ($250/kw)	23.5 ($0.08/kwh)	17.5 ($0.06/kwh)
			18.5 ($250/kw)	35. ($0.12/kwh)	29.5 ($0.10/kwh)
	Hydro Elec. and Geothermal(100 MW)		($400/kw)	($0.05/kwh)	($0.03/kwh)

* $US/Million Btu a year
** $US/Million Btu

Note: The table is subdivided into "fuels" and "electricity" (a higher valued form of energy). Conversion from "fuels" to "electricity" generally involves an efficiency of less than 33 percent.

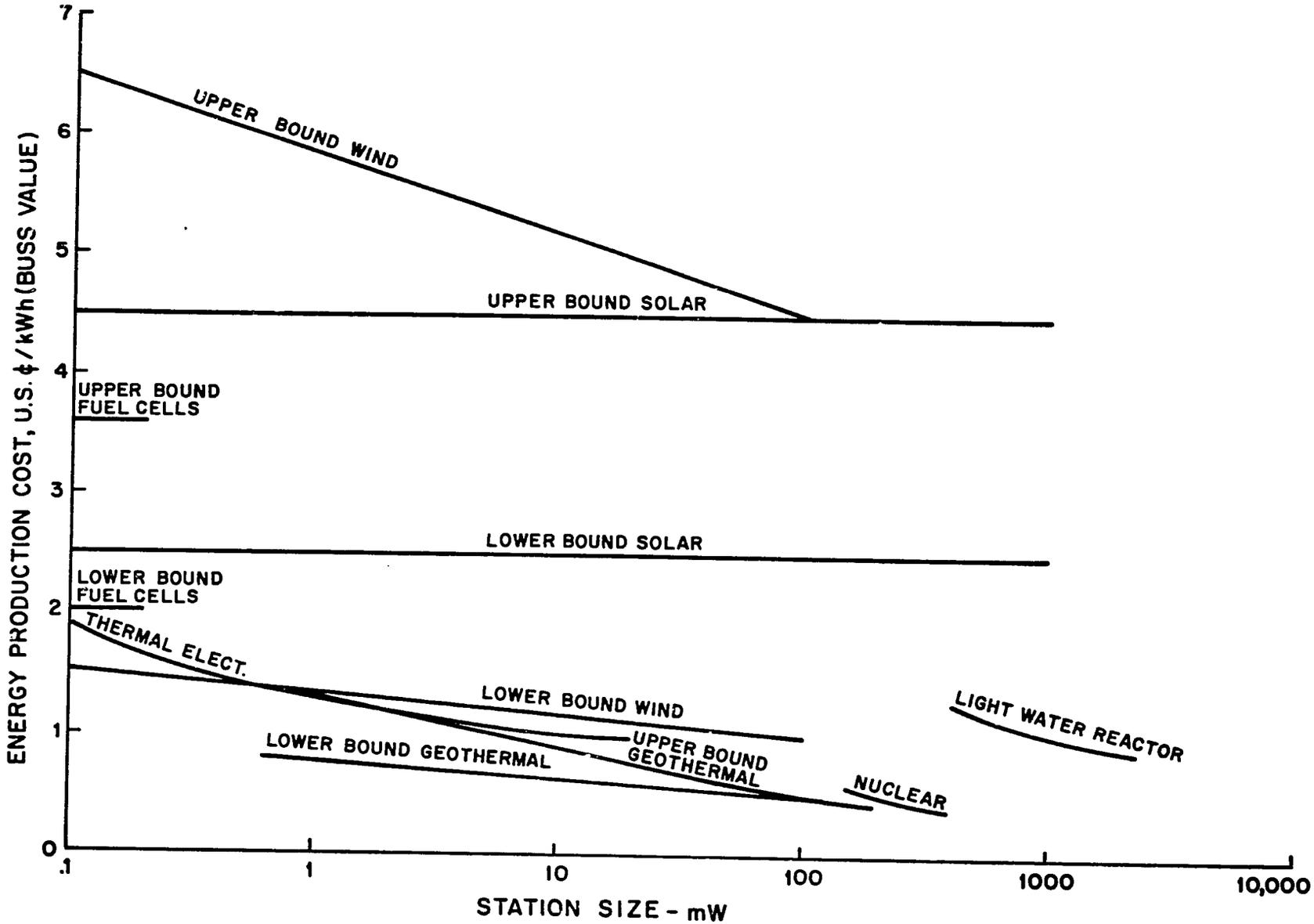


FIGURE II.5-3 Energy Production Costs in the United States

is the high initial capital investments which replace fuel costs.

Figure II.5-3 shows the 1970 relative production costs in the United States for various station sizes and production techniques. These costs require readjustment to be usable in the Sahel-Sudan region. For instance, the U.S. production cost of one kwh averages $0.009 for a 10 MW station, while retail price is about $0.03. However, the retail price of one kwh from the same size station averages $0.12 in the Sahel-Sudan region (see Figure II.5-4). Figure II.5-5 summarizes the U.S. capital investment required per kw capacity. All assumed energy costs are summarized in Table II.5-3.

Oil use cost estimates are biased, since they neglect the current trend of continuously increasing oil prices (which is likely to continue as oil reserves become more scarce toward the end of the century). The costs of hydroelectric and geothermal power are overestimated to compensate for the region's lack of infrastructure and probable inefficiencies.

Nuclear power, which would require larger units (200 to 1,000 MW) is not discussed here. To justify its size, it should be associated with water desalination and an agro-industrial complex. If energy consumption could be rapidly increased by simultaneous development schemes, nuclear power could lower production costs.

We also do not consider potential discovery of fossil fuels (oil, coal, uranium) for local energy production, oil and gas pipelines from north Africa or electric power brought from the coastal areas by high voltage DC line. These potentially interesting ideas are lumped with oil and coal use as "imported energy," whose prices are likely to follow the trends set by oil products.

5.2.2 Energy supply policies: Three principal policies were studied:

Import Policy (A)—High emphasis on fossil fuel imports (continuing current trends).

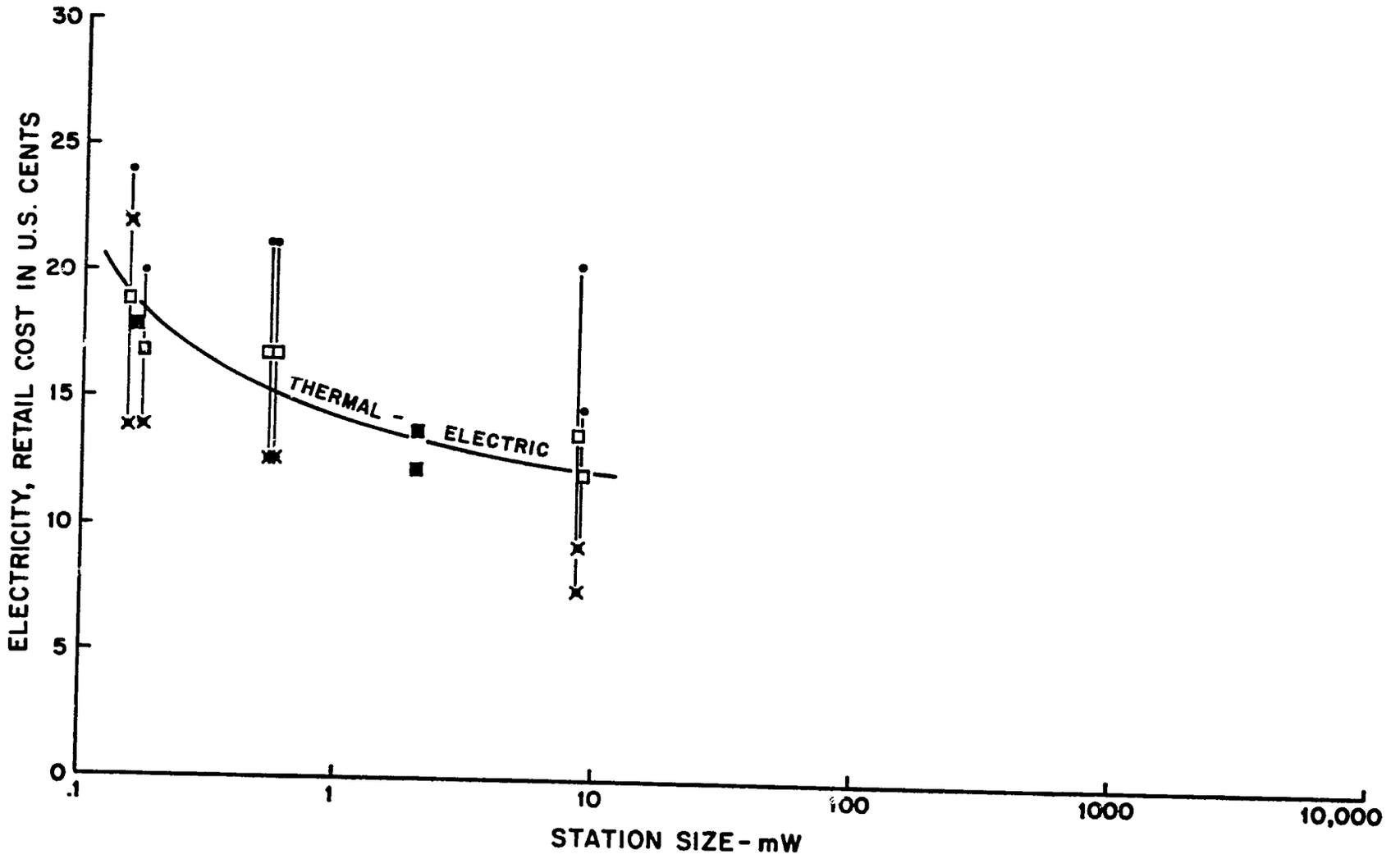


FIGURE II.5-4 Retail Prices of Electricity in the Sahel-Sudan
(as function of station size)

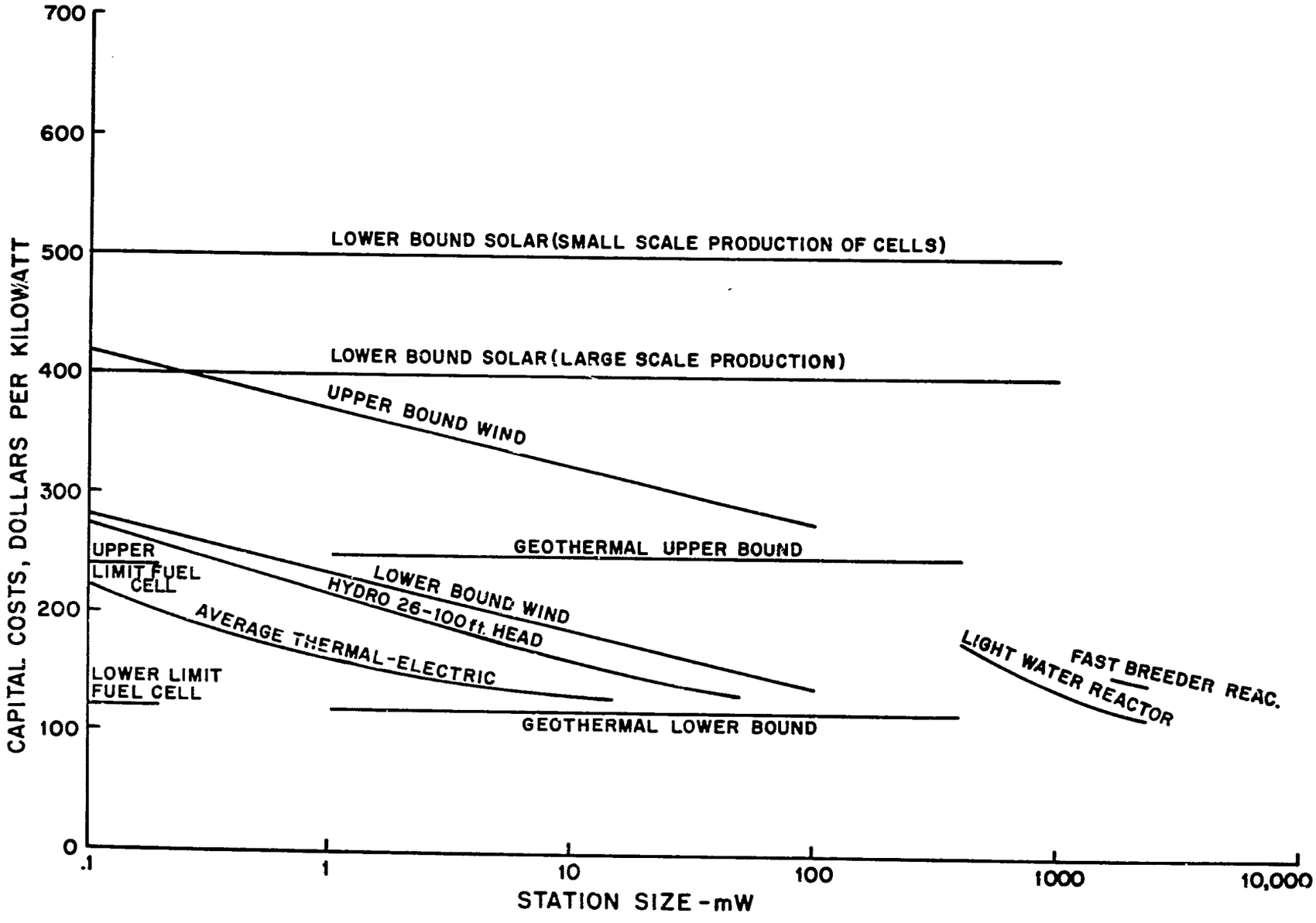


FIGURE II.5-5 Capital Investments for Electricity Production in the United States

Resources Development Policy (B)—Early development of local resources using presently available technologies (i.e. geothermal, hydroelectric, aeolian, and solar resources.

Advanced Technology Policy (C)—Use of advanced technologies as well (methane production from grass and urban and agriculture wastes, large aeolian and solar production units to produce commercial activity.

The detailed assumptions associated with each policy, all relating to consumption of non-wood energies, are:

Import Policy (A): Transport will rely exclusively on imported oil. Industries use 55 percent oil and 45 percent electricity. Electricity (except for 3 MW until 1980, 100 MW until 1990, and 300 MW until 2000, from hydroelectric sources) is generated by thermal-electric power plants. Urban domestic consumption is subdivided into 20 percent oil and 80 percent electricity, while rural domestic consumption relies entirely on oil.

Resources Development Policy (B): Differs from Policy A by exploiting hydroelectric and geothermal resources earlier (250 MW by 1980, 500 MW by 1900, and 1000 MW by 2000). In addition, rural domestic energy supplies (non-wood) are provided by aeolian and solar sources.

Advanced Technology Policy (C): Differs from Policy B by the further assumption of using locally generated methane. Transport and industry switch in part from oil to methane (30 percent by 1980, 50 percent by 1990). Urban consumption switches from 80 percent electricity (1970), to 50 percent (1980), to 40 percent (1990), and finally to 20 per-

cent (2000). Simultaneously methane replaces oil (30 percent by 1980, 50 percent by 1990, and 75 percent by 2000).

The projected annual costs for the various sets of assumptions are presented in the tables of Appendix 1. We will discuss here their salient features.

Figure II.5-6 presents the results of one policy (moderate growth and advanced technologies). All costs are shown as total energy costs and foreign currency requirements. Figure II.5-6 shows (1) the projected fuels costs excluding their use in producing electricity, with oil (or coal) and methane plotted separately; (2) electricity expenditures, with thermal-electric sources (oil, coal) separated from hydroelectric and geothermal sources; (3) costs of solar and/or aeolian energy; and (4) total energy costs (excluding wood). In this case, the total annual cost of energy in the year 2000 will be $2.4 billion, while foreign currency requirement will be $1.44 billion. Our very crude estimates of capital investments (included in the tables) do not include the required construction of refining storage and distribution facilities for the various types of fuels and energies. They account only for power production facilities. In this policy, investments required are estimated at $6.4 billion. The results of these principal assumptions are summarized in Table II.5-4.

To grasp the meaning of these billions of dollars, we compared them to economic projections. For the entire region, the 1968-1970 annual average value of commodities exported was $323 million, compared to $416 million for imports (UNCTAD 1973). We will assume a 6 percent annual average growth for the value of exports. The GDP for the whole region in 1970 was estimated at $2.33 billion; we will use both one percent and 3 percent growth rates of GDP per capita. Under these assumptions, we find that the foreign exchange component of energy cost represents 45 percent of the total value of exports, or 35 percent of the total

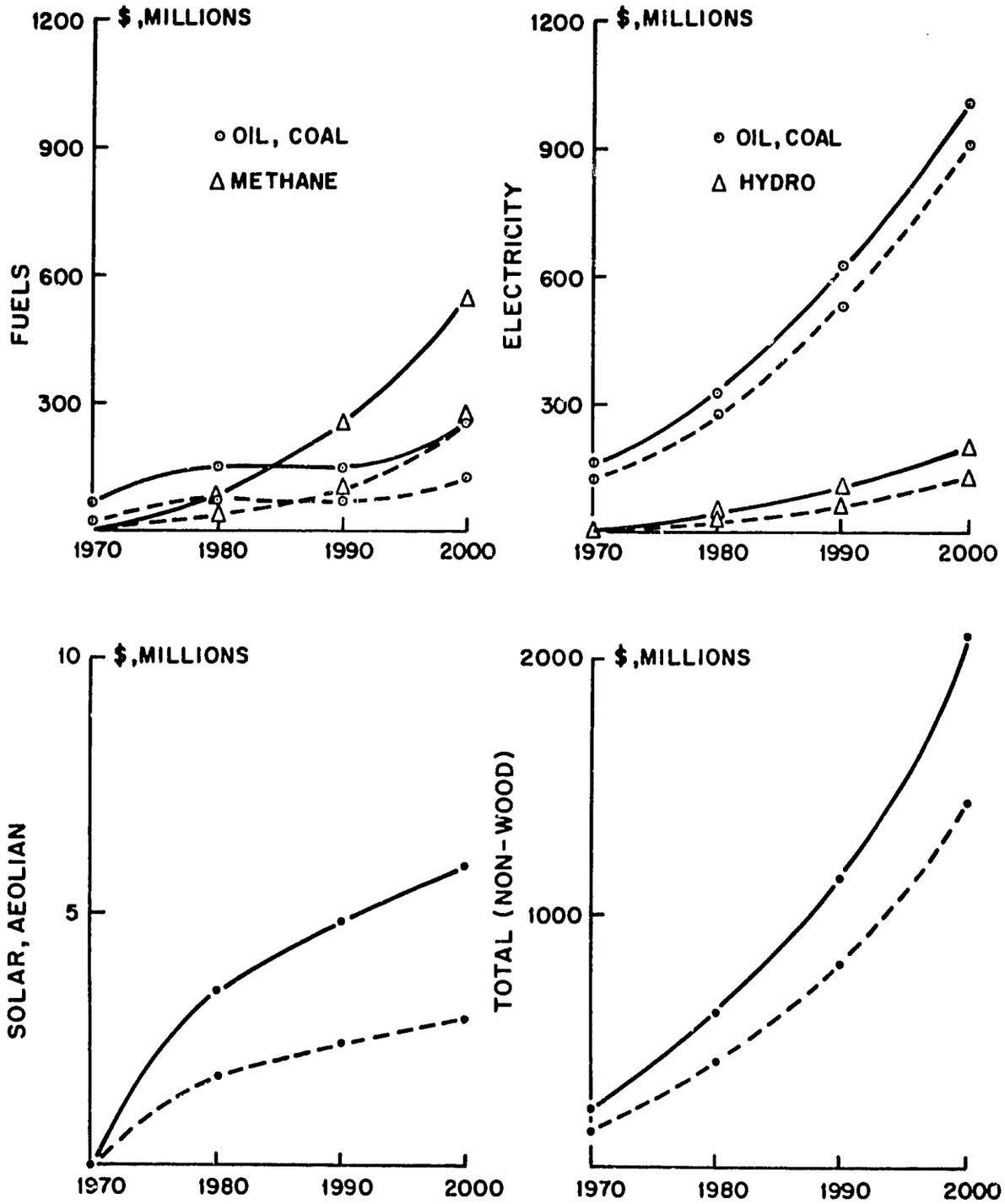


FIGURE II. 5-6 Typical Results from an Energy-based Policy: Moderate Growth and Advanced Technologies-Annual Energy Costs. Continuous lines=total costs; Dotted lines=foreign exchange components

TABLE II.5-4

Estimates for Various Energy Policies

	Energy Consumption in 2000*	Annual Energy Costs in 2000*	Foreign Exchange Component of Costs in 2000*	Cumulative Investments until 2000 ($ billions)
Moderate Growth Imports Policy	7.2	10.3	15.2	1.3
Moderate Growth Local Resource Development	7.2	12.1	13.9	1.3
Moderate Growth Advanced Technology	7.2	9.1	9.9	6.4
High Rate of Growth Imports Policy	10.3	18.4	21.8	1.6
High Rate of Growth Local Resource Development	10.3	17.4	20.3	2.4
High Rate of Growth Advanced Technology	10.3	14.2	16.2	9.3

*Multiples of 1970 values.

value of imports for the average values of 1968-1970. In this estimate, the $32 million annual fuel cost represents only 22 percent of the foreign exchange component for the cost of generating and distributing energy.

Figure II.5-7 (the ratio of the foreign exchange component of energy production to the value of exports, growing at 6 percent) shows sudden increases due to changing oil prices in 1973. It also indicates that the cost of energy represents a continuously increasing share of the value of all exports, in spite of the assumed constant price for oil beyond 1973. The foreign exchange component cost of energy eventually exceeds the value of all exports. However, this figure is useful only for the trends illustrated and not for the absolute values of the variables. It shows that given a high growth rate of GDP (5.5 percent), the foreign exchange cost of energy grows at about 11 percent a year over 30 years and at about 9 percent given a 3.5 percent rate for GDP. Figure II.5-7 suggests that Policy (B) (developing hydroelectric, geothermal, and other energy sources using well known technologies) offers some improvement over Policy (A) (imports). However, a progressive shift to an Advanced Technology Policy (C) appears to be necessary in order to significantly reduce the deteriorating rate of the balance of trade. Such an Advanced Technology Policy would require very large capital investments of over $7.5 billion (when reforestation programs are included) over a thirty year period. These capital investments for energy production and distribution may be estimated to start at an annual rate of $50 million and grow at an annual rate of 10 percent over the next thirty years. The Sahel-Sudan region could not finance such investments on its own, but this may be the only alternative out of bankruptcy or permanent subsidies. Moreover, these are long-term investments and the cost of capital has been included in the projected energy costs. Thus, if special long-term guarantees can be established, it may be feasible to attract foreign investments into the

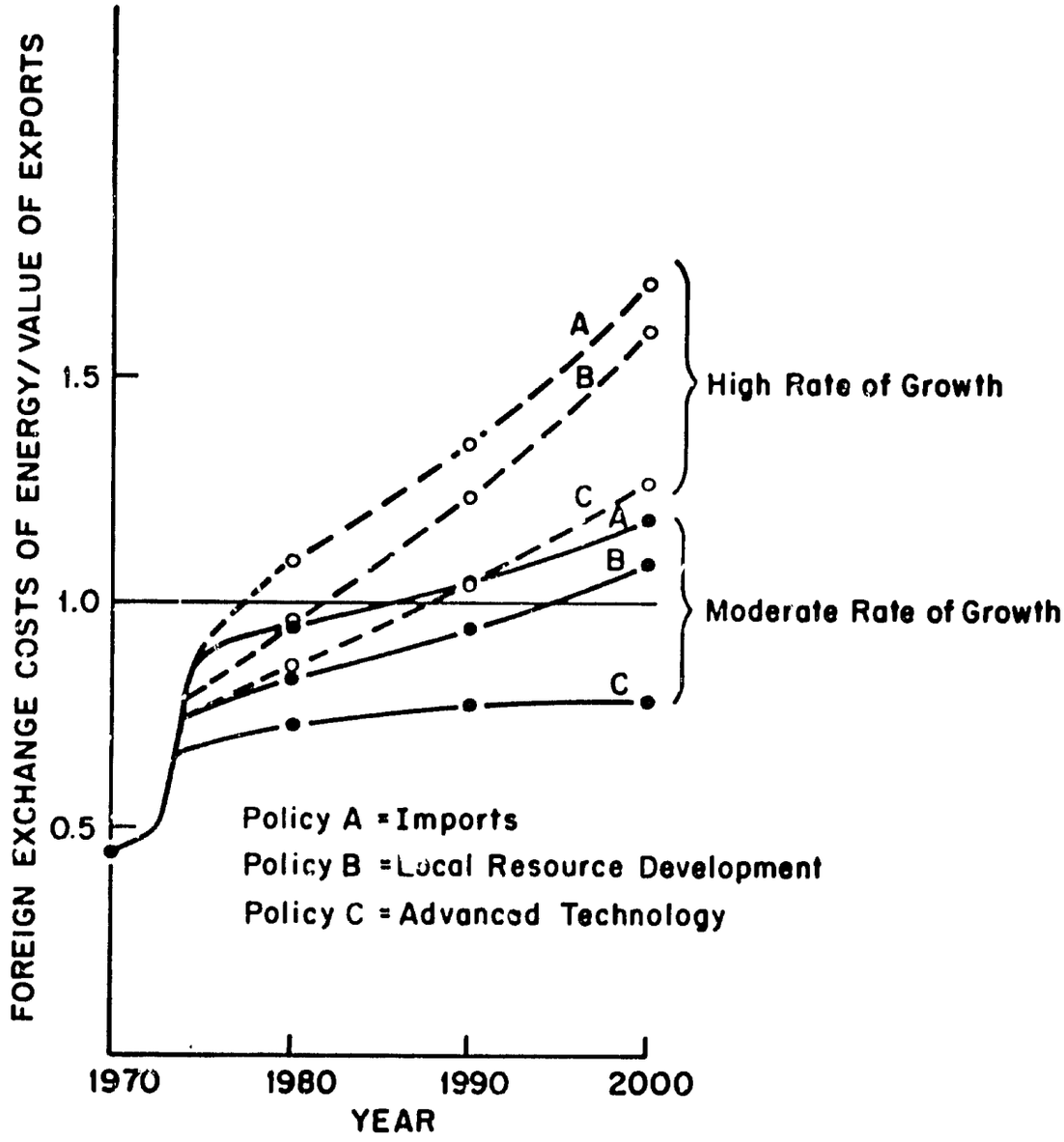


FIGURE II.5-7 Ratio of foreign exchange energy costs to the total value of exports (value of exports assumed to grow at an annual rate of 6 percent).

energy production sector from joint ventures associating some of the oil-producing countries and some of the industrialized Western powers.

Figure II.5-8 shows that the energy sector's relative share in the total GDP represented about 10 percent in 1970 but could represent 40 percent (Policy A) or 25 percent (Policy B) in the year 2000. Here again, the actual percentages are not significant. The trends indicate an increasingly important energy sector, with time. Moreover, Policy (A) (relying on imports) gives the energy sector an inflated value compared to Policy (C) (local resource development with advanced technologies).

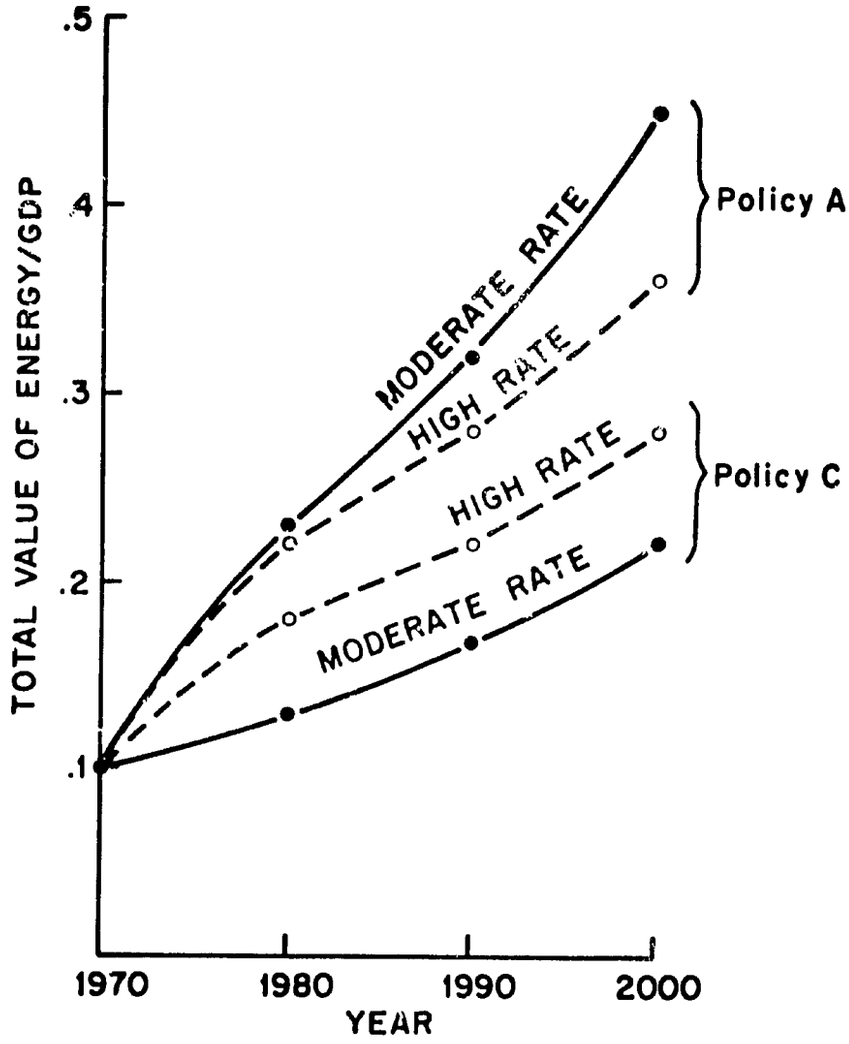


FIGURE II. 5-8 Ratio of total energy value to the gross domestic product.

6. SUMMARY AND CONCLUSIONS

These initial estimates of energy production and consumption's relative economic and ecological impacts over the next 30 years illustrate primarily a method of approach which is useful in long-term development planning. From these examples one can extract some qualitative findings:

(1) Wood, representing 90 percent of total energy consumption in the Sahel-Sudan region, will continue to be the principal source of energy until 1990, when other energy sources may exceed it.

(2) Use of wood as a fuel is beginning to have detrimental effects on forests. Upper Volta and, to a lesser degree, Mali may be on the verge of significant deforestation. Desertification has accelerated around urban population centers, where reforestation programs are primarily needed. Such programs may require an estimated 3 million hectares of managed forests by the year 2000, which would cost more than $1.3 billion over thirty years.

(3) It is likely that energy consumption of non-wood sources will become seven to ten times the 1970 level by the end of this century, if the region sustains a moderate growth rate.

(4) Recent oil price increases have made energy a major drain on foreign currencies. This trend is likely to worsen, since the foreign currencies required for energy production and distribution will be increasing at rates between 9 and 11 percent, while exports will grow at a projected rate of less than 6 percent. The estimated projections based on several assumed policy arrangements are summarized in a table. The resultant conclusion points to a serious dilemma regarding the Sahel-Sudan countries.

(5) Local resources can be developed to reduce balance of trade problems. Hydroelectric and geothermal resources should be developed early and coordinated with urban growth. Since these rather limited resources will offer only a partial solution, local exploitation of known

coal deposits -- despite its costly appearance -- should also be considered. Such a Resource Development program would require an annual investment starting at about $20 million and increasing at an annual rate of 10 percent over the next thirty years.

(6) Some of the balance of trade problems could be alleviated if these countries could negotiate special oil pricing agreements or arrange to buy hydroelectric power from the coastal area at long-term stable prices. Alternatively capital investments by national associations of oil producers and industrialized Western powers might be attracted if appropriate special long-term guarantees could be established. If these monies were invested in local energy resource development, short-term impacts would not be significant, but rather dramatic long-term gains could be realized. The advanced technology scenario, which may be the only avenue out of bankruptcy or permanent subsidies, would require an annual investment starting at $50 million and increasing at an annual rate of 10 percent over the next thirty years.

(7) Development of solar and aeolian energy for rural use would have limited economic but possible significant ecological and social impacts. The principal limitations to the wide use of these technologies appear to be institutional rather than technical.

(8) Aeolian energy sources geared to urban and industrial centers could have large economic impact. Solar energy sources for commercial energy production are still considered "far-out" technologies. Moreover, both types of energy require associated energy storage capacity.

(9) New energy sources using photosynthesis processes -- the most likely of which is artisanal and industrial methane production from grasses and agricultural or urban wastes -- are interesting to consider. The potential energy available from grasses is more than twelve times the present level of utilization of fuel wood. Moreover, methane is advantageous for storage and transportation. Our models show that

development of such resources will be very important, especially if the price of hydrocarbons increases again towards the year 2000. Energy plantations and reforestation are feasible alternatives which should be seriously considered in line with these model projections. Pilot projects within the region are needed to fully evaluate these alternatives.

(10) Exploitation of new resources does not preclude the possibility of finding oil deposits. If oil is found, however, it should be used to assist development of the resources mentioned in (8) and (9) rather than to replace them.

(11) Application of nuclear energy in the near future is unlikely. However, construction of an agro-industrial nuclear complex should be evaluated as a means for developing areas containing several minerals such as manganese, copper, and iron. Such a complex could use high temperature energy to generate electric power and low value energy to desalinate brackish or sea water (if it were available) for irrigation.

(12) Development of increased capacity to formulate and implement energy policies is critical for long-term perspectives of the region. National energy policies should consider the long recovery times occasioned by different forms of land over-exploitation. Balance of trade problems, which could hamper development, should also affect the choice of energy policies. Coordination of urban growth and energy policies is necessary to optimize utilization of local resources. A more refined energy model would be of great value in comparing various energy policies.

PART III: MINERAL RESOURCES

1. GEOLOGICAL INFORMATION

West Africa is a plateau with an average altitude of less than 400 meters. Its geological composition and history are summarized in this section (Organization of African Unity 1973; Diagne 1972).

The plateau is composed of a large (about 2,000 miles in diameter) craton, mainly granitized, which belongs to the two oldest Precambrian cycles (Precambrian D and C). This crystalline formation -- exposed in Sierra Leone, Liberia, Ivory Coast, Togo, Dahomey, Nigeria, and northern Niger -- is bordered by volcanic or sedimentary deposits which were transformed and folded at the time of several orogenies. With principal mineral resources including gold, diamond, manganese, iron, tin, and chromium, the formation is generally subdivided into four areas:

(1) The sourthern area (covering part of Senegal, southern Mali, and coastal countries) contains gold, small diamonds, graphite, and tin.

(2) The western area (covering eastern Senegal and western Mauritania) composed of gneiss with ferruginous quartzites, contains iron, gold, diamonds, and chromite.

(3) The least known northern area (covering part of the Sahara) contains iron and copper.

(4) The eastern area (covering Nigeria and Togo primarily) contains several minerals.

The granitic precambrian craton surrounds a wide basin covered by marine deposits which were formed until the middle of the tertiary period. This sedimentary basin contains phosphates and hydrocarbons. Known phosphate deposits are located in southern Mauritania, Senegal, and northern Mali near Gao. Oil and natural gas are now being actively sought. The basin also contains lateritic formations, which contain the oxides of various elements (aluminum, iron, manganese, titanium, and phosphates), and copper.

More details may be found in Mestraud (1973) and in publications of the Bureau de Recherches Geologiques et Minieres (BRGM).

2. INSTITUTIONS

Geological mapping of west Africa has been undertaken primarily by the BRGM and the Association of African Geological Surveys (ASGA). BRGM prepared a 1:2,000,000 geological map of west Africa; ASGA published a 1:5,000,000 geological map of Africa in 1963. Separate geological maps were prepared by the geological services of each country: Chad, 1:2,000,000 (1963); Mauritania, 1:1,000,000 (1965); Niger, 1:2,000,000 (1966); and Senegal, 1:500,000 (1963). More detailed geological surveys have been recently conducted for the geological services. However, many of them are being released slowly. Many more detailed surveys still need to be constructed.

Professionals in geological and mining research are scarce in the region. Table III.2-1 lists institutions related to this field, including the numbers of scientists and engineers, but does not provide a breakdown between Africans and foreigners.

Every government has an official geology or mining department, for which BRGM is the principal technical support. While ORSTOM undertakes fundamental research, the BRGM is oriented more toward applied research, surveys, and cartography. The University of Dakar curriculum includes geology and mining. The Free University of Berlin has a station in Chad with two teachers and five students.

Attempts to promote integrated regional development are being conducted by local institutions such as the "Autorite de developpement integre du Liptako-Gourma" and the "Organisation pour la mise-en-valeur du fleuve Senegal" (O.M.V.S.). In the Liptako-Gourma region, mineral resources include manganese in Upper Volta and Mali (estimated to yield an annual production of 900,000 tons); phosphates in Mali; iron, copper, molybdenum, and kaolin in Niger; and cement limestone in Upper Volta

TABLE III.2-1

Geological and Mining Research Institutions and Personnel

	Personnel	Geologists, Research Scientists or Engineers
Chad		
Direction des Mines et de la Geologie	24	2
Station Allemande de Bardai Universite Libre de Berlin	8	2
Mali		
Direction Nationale de la Geologie et des Mines	n.a.	n.a.
Societé Nationale de Recherches et d'Exploitation des Resources Minières (SONAREM)	590	60
Direction de l'Hydraulique et de l'Energie	76	21
Mauritania		
Bureau Hydrogeologique	3	2
Direction des Mines et de la Geologie	7	3
Niger		
Bureau de Recherches Geologiques et Minières (BRGM), Niamey	10	2
Direction des Mines et de la Geologie	31	11
Senegal		
Bureau de Recherches Geologiques et Minières (BRGM), Dakar	68	5
Laboratoire du Batiment et des Travaux Publics, Dakar	30	2
Université de Dakar, Departement de Geographie	8	2
Direction des Mines et de la Geologie (DMG), Dakar	43	7

(Continued)

Office de la Recherche Scientifique et Technique d'Outre-Mar (ORSTOM)		
- Paris office	110	5
- Centre de Pedologie de Dakar Hahn	86	n.a.
Upper Volta		
Direction de la Geologie et des Mines (DGM)	75	9

Source: UNESCO 1970

(Kafando 1974). From the outset, the Liptako-Gourma Authority's plans to develop these mineral resources are integrated with the exploitation of hydraulic, agropastoral, energy, and fishery resources. Similarly, the O.M.V.S. combines interactions between agriculture, transport, energy production, mining, and industrial development. Unfortunately, these institutions lack resources and are in dire need of reinforcement.

In addition, international agencies have been actively involved in mineral and geological programs (such as surveys and strengthening of services). They include the United Nations Development Program (UNDP), the French Fonds d'Aide et de Cooperation (FAC) operating primarily through the BRGM, the French Atomic Energy Commission (CEA), the Canadian International Development Agency (CIDA), the World Bank (IBRD), and the U.S. Agency for International Development (U.S.A.I.D.).

3. CURRENT PRODUCTION, EXPLORATION, AND POTENTIAL

Appendix 2 provides a summary of available data of the region's mineral resources (UNECA 1973). This section will only review each country's principal resources (based on U.S. Bureau of Mines-Minerals 1972, IMF 1968, and Petroleum Intelligence Weekly 1970).

Chad produces primarily natron (7,000 tons near Lake Chad) which is used for cattle feeds, medicines, soap, and tanning. Some salt was exported to Libya and Sudan. Known mineral deposits include gold (Guera and Guaddai), bauxite (poor quality), kaolins (240,000 tons at Aboudeira, being evaluated for insecticide production), rare earth minerals and uranium (Guera), and iron. Although permits for oil exploration were given to CONACO, SIREP, and SHELL, no exploratory drilling has yet been done.

Mali produces some gold (30 ounces/year), salt (300 tons/year), and construction materials. A government agency (SONAREM) organizes and undertakes mineral exploration. Known mineral deposits include bauxite in western Mali (820 million tons at 43 percent), gold deposits (potential 1 ton/year, credits advanced by URSS), iron ores (500 million tons in an area near the projected Manantali dam), manganese (3.5 million tons which could be exploited with the Tambao deposits), and lithium oxide (300,000 tons at 6.7 percent). More important are the deposits of phosphate rocks (20 million tons at 30 percent phosphate pentoxide) which are being evaluated for the production of super phosphates. Uranium was explored by a group from Hamburg University, West Germany. Friedrich Krupp Saarbergwerke has exploration permits. Texaco has an exploration permit for oil in the northern part of Mali.

Mauritania produces iron ores (9.1 million tons) which represent almost 90 percent of the value of exports ($70 million). Most exports go to the United Kingdom and the EEC countries, some to Japan. Production decreased by 10 percent in 1971 because of a labor problem and world

market conditions. MIFERMA, the company exploiting iron ores, represents several interests with the Mauritanian government holding a 5 percent share. The total direct and indirect government revenues derived from MIFERMA were estimated at $13 million in 1972. The company already operating four sites (which will last about twelve years at present rates of exploitation) is surveying iron deposits near Zouerate which have been estimated as 2 billion tons at 37 percent. It may build a beneficiation plant to produce 4.5 billion tons of high grade concentrate. Copper production has experienced several problems (engineering, labor, etc.). Production, which should average about 50,000 tons a year over a period of 18 years, was less than 8,000 tons in 1971. An industrial steel-copper complex is being planned, at a cost of $25 million, to produce 1 million tons of steel and 30,000 tons of copper over a five year period. This industrial complex will require a new urban infrastructure, as well as sources of energy and water. Phosphates are being studied for the production of fertilizers. Production of monazite has been discontinued because of world prices. Texaco's exploration drilling for oil has been unsuccessful until now, but AGIP is about to start drilling; Planet Oil and SHELL also have exploration permits; ESSO and AMOCO are surveying offshore possibilities.

Niger exploits uranium at Arlit (750 tons to be doubled to a yearly 1,500 tons by 1975). The government of Niger has a 16.75 percent share in SOMAIR, the production company; France, Germany, and Italy also own shares. Other deposits are being explored with French and Japanese interests. Transportation costs are high for all of these deposits. Cassiterite (tin) is exploited by Societé Miniere du Niger near Agades. Concentrates are shipped to Nigeria and Belgium. Cement capacity is 45,000 tons and gypsum is also mined. Coal deposits (30 million tons) in the same region where cassiterite is found are not economically exploitable.

Exploration programs for copper and diamonds are being conducted. Manganese, lithium, and molybdenum deposits were found northwest of Niamey, but lack of transportation facilities makes exploitation uneconomical. TEXACO and CONTINENTAL have conducted oil surveys but no exploration drilling as yet.

Senegal produces mainly phosphate rock and fertilizers (1.5 million tons). Two companies mine two types of phosphate: calcium phosphate (1.4 million tons) and aluminum phosphate (150,000 tons). Oil was found offshore but not in exploitable quantities. A refinery (12,600 barrels per day) supplies most of the country's needs and a larger refinery is being planned. Titanium was extracted on the beaches of Casamance until 1965, when the reserves declined. Attapulgite is also produced (about 3,000 tons a year) and used in oil drilling. Iron ore (700 million tons at 60 percent) is present in eastern Senegal. Exploitation will require transportation facilities and a power source (possibly Manantali).

Upper Volta has no significant mineral production. However, important manganese deposits (13 million tons of manganese oxides at 54-55 percent) and iron ores (containing vanadium pentoxide and titanium dioxide) exist near Tambao. Bauxite deposits are evaluated at 1-1.5 million tons containing 80 percent alumina. Copper and molybdenum deposits are also known. Non-metal deposits include limestone, granite, and marble.

In summary, mineral production -- which concentrates now on iron, uranium, and phosphates -- represents about $100 million a year. Probable expansion will include a few other minerals (such as manganese, copper, aluminum, phosphates, and gold). Based on the MIFERMA case in Mauritania, one may estimate that 20 to 30 percent of the minerals' value represent local earnings (public and private). Examination of the lists of known deposits shows that mineral production could potentially

increase to a value of $300 million, or a considerably greater amount by 1990 if oil is found. This increased production would occur as transportation and power sources are developed, and as surveys and studies are completed. Since the unknowns in the field of mineral development are too numerous to make analysis meaningful, our projections can only be considered as a reasoned guess.

4. SUMMARY AND CONCLUSIONS

Conclusions we have drawn from this review of the Sahel-Sudan region's principal mineral resources include:

(1) The exploitation of mineral resources should not be relied on to stimulate the region's development. Despite an abundance of minerals, deposits are generally of poor to fair quality, i.e. not highly concentrated. Lack of data coupled with high transport and power costs makes it difficult to exploit deposits. Though mineral extraction now produces about $100 million a year, an increase to $300 million may be expected by 1990. However, only a small fraction of this value represents government or private indigenous earnings, which are reinvested within the region. Therefore current total mineral production is equivalent to only about $1 per capita of foreign assistance.

(2) Although production of uranium is increasing rapidly, and prospects for finding oil are good, it is impossible either to estimate the likelihood of major findings or to base development plans upon exploitation of these potentially high value products.

(3) The economic value of mineral resources could be increased by developing the necessary institutional structures and managerial capacity. Such local institutions, besides actively promoting surveys to further local needs, could suggest integrated regional studies to transform several uneconomical mining projects into a viable association of mining with water, power, industrial, and possibly agricultural development. In a few instances, such as the case of the Liptako-Gourma, the local institutions undertaking integrated regional studies need strengthening.

(4) Although the region has only a few geologists, it is rather the broad engineering and managerial talents and the institutional capacities which are primarily needed for both mineral and energy resources.

REFERENCES

Agency for International Development 1972. In-house report "Development and Management of the Steppe and Brush-Grass Savannah Zone Immediately South of the Sahara." October.

Ahmad, A. P. 1973. "Nuclear-Powered Agro-Industrial Complex Designed for Pakistan." M.I.T. Department of Electrical Engineering. B.S. thesis. June.

Bille, J. C.; and Poupon, H. 1972. "Recherches Ecologiques sur une Savanne Sahelienne." La Terre et la Vie. Vol. 26 (3).

Business Week 1974. "Back to Windmill to Generate Power." May 11.

Chinguetti 1973. Etablissements Mengin-Montargis. France.

Comité Permanent Inter États de Lutte contre la Secheresse dans le Sahel (C.I.L.S.S.) 1974. Project Inventory of the west African Countries stricken by Drought. January.

Cockrum, E. L. 1974. "An Ecological View of the Sahel-Sudan Region of Sub-Saharan West Africa."

Commission des Communautés Europeenés 1972. "Les Conditions d'Installation d'Entreprises Industrielle." December.

Damiba, P. C. 1973. "The Drought in Tropical Africa: Analysis and Policy." 19th International Conference of D.I.A.O. Lome, Togo. July.

Daniels, F. 1974. "Direct Use of the Sun's Energy." Yale University.

Department of Rural Reconstruction (Taiwan). "How to Get Rich Raising Pigs."

Diagne, P. 1972. "Pour l'Unite Ouest-Africaine." Anthropos.

Eliasberg, V. F.; Lerner, J.; and Landsberg, H. H. 1971. Energy in the American Economy 1850-1975.

Ford Foundation 1974. "Exploring Energy Choices." Preliminary Report.

Glaser, P. E.; and Burke, J. C. 1973. "New Directions for Solar Energy." Science and Public Affairs. October.

Golding, E. W. 1955. "The Generation of Electricity by Windpower." London.

Guindo, M. B. 1973. "Le Role de l'Energie dans la Planification du Developpement Economique." United Nations. Institut Africain de Developpement Economique et de Planification. IDEP/ET/CS/2497-23. Dakar. February.

Hammond, A. L.; Metz, W. D.; and Maugh, T. H. 1973. "Energy and the Future." AAAS. Washington, D.C.

Holly, F. M. 1974. "House Windmill Power." Christian Science Monitor. June 7.

Hottel, H. C.; and Howard, J. B. 1971. New Energy Technology. M.I.T. Press. Boston.

Hull, D. O. 1974. "How to figure farm fuel needs." Farm Journal. 98(1):41.

Humphrey, A. E. "Production of Food and Feed by Fermentation." University of Pennsylvania.

Idnani, M. A. 1963. "Bio-Gas Plants--their installation, operation, maintenance, and use." Indian Council of Agricultural Research. New Delhi.

International Monetary Fund 1968. "Surveys of African Economies." Vol. 3. Washington, D.C.

International Road Foundation 1973. World Road Statistics 1971-1972. Washington, D.C.

Kafando, T. 1974. "The Case of Liptako-Gourma" ceres, Jan.-Feb. pp. 45-48.

Kastens, M.L. "Introduction to the Utilization of Solar Energy." Edited by Zarm, A.M. and Erway, D.C. Chapter 10, The Economics of Solar Energy. McGraw Hill, Inc. New York. 1963.

Massachusetts Institute of Technology 1974. Interim Report. Sahel-Sudan Project. Center for Policy Alternatives. March 15.

Matlock, W. G.; and Cockrum, E. L. 1974. Internal progress report. M.I.T. May.

Meinal, A.; and Meinal, M. 1973. "The Village Energy Center: A New Option for Solar Energy Utilization by Sahel Communities?" Optical Sciences Center. University of Arizona, Tucson, Arizona. July.

Mestraud, J. L. 1973. "International Atlas of West Africa." Organization of African Unity.

Ministere de la Planification et du Developpement Industriel 1973. Developpement Rural. Mauritania.

Moumouni, A. 1973. "Prospects of Solar Power." Ambio. Vol. II. No. 6.

National Academy of Sciences 1972. "Solar Energy in Developing Countries: Perspectives and Prospects," A report of an Ad Hoc Advisory Panel of the Board on Science and Technology for International Development Office of the Foreign Secretary. Washington, D.C. March.

New Alchemy Institute 1973. "Methane Digesters for fuel gas and fertilizers." Santa Barbara. Spring.

Niger (Republique du), 1972. Ministere de l'Economie Rural, Direction de l'Agriculture. Rapport Annuel. tome II: "Statistiques."

Oak Ridge National Laboratory 1968. Nuclear Energy Centers. "Industrial and Agro-Industrial Complexes." ORNL-4290. Tennessee. November.

Organization of African Unity 1973. "International Atlas of West Africa.

Petroleum Intelligence Weekly 1970. Vol. 9 No. 22. June. Mali.

Pollack, G. A. 1974. "The Economic Consequences of the Energy Crisis." Foreign Affairs. Vol. 52 No. 3. April

Rosenblatt, A. I. 1974. "Energy Crisis Spurs Development of Photovoltaic Power Sources." Electronics. April 4.

Salisbury, D. F. 1974. "Energy from Leaves?" Christian Science Monitor. July 3.

Senegal Consult 1970. "Feasibility Survey for the Regulation of the Senegal River, Design of a System of Water Management Planning in the Upper Senegal River Catchment." Vol. 1-9.

Senegal 1972. Direction de la Statistique. "Situation Economique du Senegal." July.

Spanides, A. G. 1961. "Solar and Aeolian Energy" Proceedings of the International Seminar on Solar and Aeolian Energy. Greece. September.

Steinhart, J. S.; and Steinhart, C. E. 1974. "Energy Use in the U.S. Food System." Science Vol. 184, No. 4134, pp. 307-316, Fig. 5 April 19. Article based on Energy Sources, Use and Role in Human Affairs, by C. and J. S. Steinhart, Duxbury Press, North Scituate, Mass., 1974.

United Nations 1963. U. N. Secretariat, "Situation, Trends and Prospects of Electric Power Supply in Africa."

United Nations 1970. U. N. Statistical Yearbook 1969. New York.

United Nations Conference on Trade and Development 1973. "Selected Statistical Tables on the Six drought-affected African countries." June 27.

United Nations Department of Economic and Social Affairs 1962. "New Sources of Energy and Energy Development." Rome. August 1961. New York.

United Nations Economic Commission for Africa 1968. "Electric Energy Survey for Africa." U.N. Economic and Social Council. June 26.

United Nations Economic Commission for Africa 1973. Report E/CN. 14/ECO/66. Addis Ababa. November 9.

United Nations Educational, Scientific and Cultural Organization 1970. "Survey on the Scientific and Technical Potential in the countries of Africa."

United Nations Educational, Scientific and Cultural Organization 1973. "Technical Notes of Selected Technologies for African Development." UNESCO/NS/ROU/300.

United Nations Educational, Scientific and Cultural Organization 1974. "Results of a UNESCO Delphi survey on technologically feasible futures for Africa." SC/CASTAFRICA ref. 2. Dakar. January.

United Nations Special Sahelian Office 1974. Energy ST/SSO/22. March.

United States Bureau of Mines-Minerals 1972. Yearbook, 1971. Washington, D.C.

Varon, B.; and Takenchi, D. 1974. "Developing Countries and Non-fuel Minerals." Foreign Affairs. April.

Wade, N. 1974. "Windmills: The Resurrection of an Ancient Energy Technology." Science. Vol. 184. June.

Wise, D. L.; Sadek, S. E.; and Kispert, R. G. 1974. "Fuel Gas Production from Solid Waste." Dynatech R/D Company. Cambridge, Massachusetts. January.

Yearbook of Forest Products 1969.

Windmills: Suppliers and Sources of Information (Holly 1974)

Alternative Sources of Energy, Route 1, Box 36B, Minong, WI 54859

Automatic Power, Inc., 205 Hutcheson Street, Houston, TX 77003.

Braden Aeromotor Corporation, Broken Arrow, OK 74012

Bucknell Engineering, 10717 Ruch Street, South El Monte, CA 91723

Demster Industries, Box 848, Beatrice, NB 63810

Dynatechnology, Box 3263, Sioux City, LA 51102

Environmental Data Service, National Climatic Center, Federal Building, Asheville, NC 28801

Sencenbaugh Wind Electric, Box 11174, Palo Alto, CA 94306

VITA, 3706 Rhode Island Avenue, Mt. Rainier, MD 20822

Windworks, Box 329, Route 3, Mukwango, WI 53149

APPENDIX I

Results from Energy Models

TABLE 1

Projection (a): Moderate Growth-Yearly Consumption

	1970	1980	1990	2000	
Non-Wood Energy	23.4	44.9	86.7	169.5	trillion BTU's
Transport	38.0	35.8	33.4	30.8	%
Use in Transport	8.9	16.1	28.9	52.2	trillion BTU's
Industry	50.5	50.9	50.9	50.3	%
Use in Industry	11.8	22.8	44.1	85.2	trillion BTU's
Urban Domestic	9.5	11.7	14.6	18.2	%
Use in Urban Domestic	2.2	5.3	12.6	30.9	trillion BTU's
Rural Domestic	2.0	1.5	1.1	0.7	%
Use in Rural Domestic	0.5	0.7	1.0	1.2	trillion BTU's
Urban Domestic Wood	1.7	2.8	4.7	8.1	trillion BTU's
Rural Domestic Wood	110.9	131.0	146.5	145.2	trillion BTU's

TABLE 2

Projection (c): High Rate of Growth - Yearly Consumption

	1970	1980	1990	2000	
Non-Wood Energy	23.4	52.4	112.8	241.0	trillion BTU's
Transport	38.0	30.7	25.7	21.7	percent
Use in Transport	8.9	16.1	29.0	52.2	trillion BTU's
Industry	50.5	52.0	55.5	59.8	percent
Use in Industry	11.8	27.2	62.6	144.2	trillion BTU's
Urban Domestic	9.5	10.0	11.2	12.8	percent
Use in Urban Domestic	2.2	5.3	12.6	30.9	trillion BTU's
Rural Domestic	2.0	7.3	7.6	5.6	percent
Use in Rural Domestic	0.5	3.8	8.6	13.5	trillion BTU's
Urban Domestic Wood	1.7	2.8	4.7	8.0	percent
Rural Domestic Wood	110.9	118.0	120.0	180.0	trillion BTU's

TABLE 3

Energy Demand Projection (a) with Import Policy (A)

Yearly Expenditures(In U.S. $ x 10^6)

	1970	1980	1990	2000
Annual Costs of Fuel (excl. generation of electricity)	65.	243.	454.	851.
Foreign Exchange Component	21.	121.	227.	426.
Thermal Electric Energy	166.	505.	1,000.	2,065.
Foreign Exchange Component	124.	426.	843.	1,740.
Hydro-Electric and Geothermal Energy	0.6	0.6	20.	61.
Foreign Exchange Component	0.4	0.4	12.	37.
Solar and Aeolian Energy				
Foreign Exchange Component				
Methane Production				
Foreign Exchange Component				
Total Costs of Energy	232.	748.	1,474.	2,977.
Foreign Exchange Component	145.	547.	1,082.	2,202.
Cumulative Investments	0.	136.	437.	1,260.

TABLE 4

Energy Demand Projection (a) with Local Resources Policy (B)

Yearly Expenditures (In U.S. $ x 10^6)

	1970	1980	1990	2000
Annual Costs of Fuel (excl. generation of electricity)	65.	243.	454.	851.
Foreign Exchange Component	21.	121.	227.	426.
Thermal Electric Energy	166.	387.	810.	1,731.
Foreign Exchange Component	124.	327.	682.	1,459.
Hydro-Electric and Geothermal Energy	0.6	51.	102.	204.
Foreign Exchange Component	0.4	31.	61.	122.
Solar and Aeolian Energy	0.0	3.4	4.8	5.9
Foreign Exchange Component	0.0	1.7	2.4	2.9
Methane Production				
Foreign Exchange Component				
Total Costs of Energy	232.	685.	1,370.	2,792.
Foreign Exchange Component	145.	480.	973.	2,016.
Cumulative Investments	0.	208.	553.	1,250.

TABLE 5

Energy Demand Projection (a) with Advanced Technology Policy (C)

Yearly Expenditures (In U.S. $ x 10^6)

	1970	1980	1990	2000
Annual Costs of Fuel (excl. generation of electricity)	65.	144.	143.	255.
Foreign Exchange Component	21.	72.	72.	128.
Thermal Electric Energy	166.	332.	633.	1,082.
Foreign Exchange Component	124.	280.	534.	912.
Hydro-Electric and Geothermal Energy	0.6	51.	102.	204.
Foreign Exchange Component	0.4	31.	61.	122.
Solar and Aeolian Energy	0.	3.4	4.8	6.0
Foreign Exchange Component	0.	1.7	2.4	2.9
Methane Production	0.	79.	257.	551.
Foreign Exchange Component	0.	40.	128.	276.
Total Costs of Energy	232.	610.	1,140.	2,098.
Foreign Exchange Component	145.	424.	797.	1,441.
Cumulative Investments	0.	947.	2,990.	6,370.

TABLE 6

Energy Demand Projection (c) with Import Policy (A)

Yearly Expenditures (In U.S. $ x 10^6)

	1970	1980	1990	2000
Annual Costs of Fuel (excl. generation of electricity)	65.	289.	596.	1,209.
Foreign Exchange Component	21.	144.	298.	605.
Thermal Electric Energy	166.	574.	1,291.	2,994.
Foreign Exchange Component	124.	484.	1,088.	2,523.
Hydro-Electric and Geothermal Energy	0.6	0.6	20.	61.
Foreign Exchange Component	0.4	0.4	12.	37.
Solar and Aeolian Energy				
Foreign Exchange Component				
Methane Production				
Foreign Exchange Component				
Total Costs of Energy	232.	862.	1,907.	4,264.
Foreign Exchange Component	145.	628.	1,398.	3,164.
Cumulative Investments	0.	173.	591.	1,570.

TABLE 7

Energy Demand Projection (c) with Local Resource Policy (B)

Yearly Expenditures (In U.S. $ x 10^6)

	1970	1980	1990	2000
Annual Costs of Fuel (excl. generation of electricity)	65.	257.	527.	1,101.
Foreign Exchange Component	21.	128.	264.	55 .
Thermal Electric Energy	166.	457.	1,101.	2,660.
Foreign Exchange Component	124.	385.	928.	2,242.
Hydro-Electric and Geothermal Energy	0.6	51.	102.	204.
Foreign Exchange Component	0.4	31.	61.	122.
Solar and Aeolian Energy	0.0	19.	43.	68.
Foreign Exchange Component	0.0	10.	21.	34.
Methane Production				
Foreign Exchange Component				
Total Costs of Energy	232.	783.	1,773.	4,033.
Foreign Exchange Component	145.	553.	1,274.	2,949.
Cumulative Investments	0.	401.	1,087.	2,360.

TABLE 8

Energy Demand Projection (c) with Advanced Technology Policy (C)

Yearly Expenditures (In U.S. $ x 10^6)

	1970	1980	1990	2000
Annual Costs of Fuel (excl. generation of electricity)	65.	153.	151.	279.
Foreign Exchange Component	21.	76.	75.	139.
Thermal Electric Energy	166.	402.	924.	2,011.
Foreign Exchange Component	24.	338.	779.	1,695.
Hydro-Electric and Geothermal Energy	0.6	51.	102.	204.
Foreign Exchange Component	0.4	31.	61.	122.
Solar and Aeolian Energy	0.0	19.	43.	68.
Foreign Exchange Component	0.0	10.	21.	34.
Methane Production	0.0	87.	312.	728.
Foreign Exchange Component	0.0	44.	156.	364.
Total Costs of Energy	232.	712.	1,532.	3,290.
Foreign Exchange Component	145.	500.	1,093.	2,355.
Cumulative Investment	0.	1,246.	4,117.	9,312.

APPENDIX II

Summary of Available Data and Information on Mineral Resources

Source: United Nations Economic Commission for Africa, 1973. "ECA On-Going Activities and Proposed Role in Medium and Long-Term Programs in the Drought Affected Countries of the Sahel-Sudan.

CHAD

Exploration:	Under 1966-70 Plan, FAC loans and BRGM exploration.
	USSR: aid program for geological exploration from 1968.
	1970; private concession for wolfram, cassiterite and scheelite granted for entire country.
Potential Resources:	
Bauxite:	Indications in Kore region but low quality, no commercial value.
Beryl:	Yedri, Calami and Bardagué in pegmatites.
Colombite, tin tungsten:	Tibesti region, little explored, Cassiterite indications here and Pala-Léré but not economic size.
Diatomite:	Large, pure reserves in Kahem and Borkou regions: no economic interest because of distance and absence of local markets.
Gas:	Indications North of Lake Chad.
Geo-thermal:	Tibesti sources: 1966-67 studied by German group.
Gold:	Alluvial; assessment of Pala and Léré for artisanal production. Veins at Irriba.
Kaolin:	(UNDP) Aboudeira (res. 240,000 t good quality); deposit to be used in manufacture of insecticide.
Kyanite:	Hadjer Lélé; indications but no economic interest because of distance.
Limestone:	Scattered poor deposits and absence fuel, therefore, little value, under study for cement works by UN/TA.

Natron:	N.E. shore of lake 2 varieties: black/white.
Non-metals:	Talc, diatomite, sand, clays, limestone south of 16th parallel.
Oil:	(CONACO): W & SW region (SIREP): Ounainga-Kebir region. (SHELL): Prospecting to commence 1972. Favorable indications in Doba basin.
Platinum:	In Léré: indications with Cu, Cr, Ni. 1969 study intensified.
Rare Earths:	Carbonite Hills near Goveyoudom, East of Pala-Fianga road. Sample taken for analysis.
Uranium:	Ennedi indications and 12 others listed by a geological survey: (Misky, Ydri and Bali massifs); require feasibility studies.
Wolfram:	Yedri: good deposits but evaluation problems; possible development with other minerals.

Production:

Natron:	20 basins N.E. of Bol. Production suspended end of 1970 since accumulated stock equals 3 years consumption. Markets: internal plus Nigeria, Cameroon, CAR for livestock.
Salt:	Proposed to increase production.
Limenite:	Produced near Hadjer-el-Bigli for local consumption.

MALI

Exploration:

SONAREM:	Government agency responsible for mineral exploration.
USSR:	Program of assistance to SONAREM continuing 1971-72.
UNSF:	Mineral Survey in Western Region, commenced November 1971, investigating indications. Liptako Gourma: Mali, Niger, Upper Volta.
1970-72 plans:	3.9 billion CFA F. investments in mineral sectors: priority to prospecting.
Potential Resources:	BRGM (1967) and USSR prospection have found indications of U, Cu, Al, Fe, Mn, Li, Au, diamonds, phosphates, and oil but none in exploitable quantities: hopes for further reserves but transport costs critical.
Atomic Minerals:	Krupp exploration and exploitation permit from 1969. Kayes and Kidal regions have been rejected.
Bauxite:	Bamako (Mandingue Plateau): 800 Mt 43 percent.
Coal:	Agamar region 400 Mt: exploration to increase quantity and quality of reserves in progress.
Copper, Lead, Zinc:	Low grade deposit discovered at In Darset: too remote for immediate development. Indications of deposits at Kontoukou-Donkolo (Liptako-Gourma).
Diamonds:	1967 Selection Trust relinquished permit· negative results.
Gold:	Deposits in 3 regions. (i) Faleme (West), (ii) S. Yanfolila (Kalana), (iii)Adrar, Iforas (N.E.). July 1972: USSR gave 15 billion CFA F. credit for exploitation of Yanfolila deposit.

Iron:	1,000 Mt, 56-65 percent: Kita region.
Manganese:	Near Ansongo, 10 Mt. 43-46 percent, reported 1968.
Oil:	(Texaco, Sonarem) Taoudenit; investigation wider 1970-72 plan. (Mobil) Adrar des Iforas: request made for permit. USSR abandoned its exploration work.
Phosphates:	Tamaguelett (Tilemsi). Reserves: 11,400,000 mt. 27.5 percent P_2O_5 = 53 percent Mali's total phosphate reserves. Quality inferior to deposits in Togo or N. Africa. Transportation to industrial areas a problem. (Ste Klockne Industrie Anlangen) study into fertilizer production.
Salt:	Taoudenit: evaluation wider 1970-72 plan.
Zinc:	Tessalit (reserves 150-200 t, 7-10 percent Zn.): too remote for immediate development in spite of high tenor.

Production:

Gold:	1,000 kg/yr possible production: artisanal from Kenieba area; placers in Falémé River.
Kaolin:	At Sankaréné and Yanfolila for ceramics factories.
Marble:	From Bajoulabe area.
Salt:	At Taoudenit (reserves 23 Mt): 1967 studied as basis chemical plant.

MAURITANIA

Exploration:

UNSF:	Exploration Eastern dorsale Regueibat.
UNSF:	Strengthening of the geological service and mineral exploration, 1970-72.
DMG:	Study western dorsale Regueibat with FAC loan.
BRGM:	Atar region (copper-nickel indications follow-up) and Hodh region (geological/minerological survey).
SNIM:	(Societe Nationale Industrielle et Miniere) State company to be created to prospect for, exploit and process mineral products.

Potential Resources

Beryl and Chrome:	Amsaga: investigation by BRGM.
Flourine:	Vein discovered in Bou Naga region 1967.
Gold:	To be recovered as by-product Akjoujit copper: at 1/28 oz/m.t. of ore.
Gypsum:	Nouakchott (reserves 4,000 Mt): plaster production project. N'Drahamcha Sebkha deposits (reserves 1.4 Mt): 1969 cement works proposed but no interest from private sector shown.
Nickel:	Tasiast: geological survey.
Oil:	Offshore exploration since 1968 by ESSO and AMOCO; Taoudeni basin concession 1970 to Tenneco; Shell/Mauritania agreement to prospect; Planet oil granted licence; Agip granted 25 yr. licence in 1971.

Phosphates:	Cive (Kaedi region: reserves 4 Mt 50-70 percent): Somirema prospection artisanal production for agriculture planned.
Sulphur:	Cuprit, near N'Drahamcha; not yet evaluated.
Under Development:	3/4 industrial investment in the mining sector.
Copper/Steel:	Nouakchott. Studies to be undertaken by S.N.I.M. with object of forming copper/steel industrial complex. Cost 100 billion CFA F. Production Capacity: 1Mt steel, 30,000 t Cu, within 5 years. Employment for 6,000 people.
Iron/Steel:	Cap Blanc. Suitable site for steelworks.
Rare Earths:	Bou Naga (reserve 1,200 t 4.4 percent): Somirema (Govt./Pechiney-St. Gobain) experimental production 1968/69, planning production yttrium 20,000 t/yr, but operations suspended due to world market conditions.
Production:	Mining production accounts for 55.4 percent of total industrial output.
Copper:	(SOMIMA) Akjoujit; Reserves 487,613 t. Cu, metal 231,537 t in oxides (2.58 percent): 256,256 t in sulphides (1.76 percent). 1971 production hampered by technical problems. Treatment plant suffered major setbacks. Deposit difficult to develop due to high temperature and dust.
Iron Ore:	(MIFERMA) Tazadit, Rouessa: reserves more than 2000M mt 37 percent Fe. F'Derrick: Other deposits: Kedia d'Idjil (Fort Gouraud): Res: 200 Mt. 60-67 percent Fe. Leglitat el Khader: Res. 18 Mt. 51 percent. Miferma to cut production by 10-15 percent due to current problems facing world's iron and steel industry.

Salt: Studies in progress of N'terert deposit (reserves 150,000 t) for use in Akjoujit copper operation by Somima; of Idjil deposit (reserves 11,500,000 mt) for use in fishing industry by DMG.

Exports:

Iron:

Major consumers:	France:	20.6 percent
	UK:	18.9 percent
	Benelux:	14.9 percent
	Italy:	12.9 percent
	W.Germany:	12.8 percent
	Japan:	11.7 percent

NIGER

Exploration

UNDP/SF:	Mineral exploration of Air and Liptako regions. Field work completed March 1971. Phase II 1971-73. Aerial Survey.
BRGM:	Prospecting program in Zinder region.
US Steel:	Concessions in Liptako and Zinder-Maradi regions.
Canada:	Financing aerial survey programs in Liptako and Zinder regions.
Germany:	Government supports uranium prospecting.
Essex Iron Company:	Makalonchi region. 110,000 km^2 concession (Sn, Ni, Cu, U, Pb, Zn, Fl). Permit not renewed - discouraging results.

Potential Resources

Liptako Region:	Joint Mali, Niger, Upper Volta scheme.
	Concessions on most promising areas put out to tender, e.g. Kourki copper concession taken up by US Steel.
Atomic Minerals:	CEA licenses 3 major areas for U, Th, Be, Lithium in Djado; Arlit-Madouela; Tegguida N'Tessoum.
Beryl:	Air region: at present prices and transport costs, deposits not economically exploitable.
Chrome, Tungsten:	Object SF research.
Coal:	Agades: drilling to assess since 1968 by SF. Anou Araten reserves 4.5 Mt.

Copper:	SF further study Guissat (Air region) indications; Japanese exploration north-east of Niamey. Kourki, 1971-73 economic value of deposit to be determined. Firogoun: deposit discovered.
Diamonds:	(Huntings Geology and Geophysics Ltd.) Air lit. To carry out 5 year exploration program on Bishop. Oil and Refining Co.'s concession.
Gold:	South Maradi: indications found in Goulbi and Goulbi N'Gabi alluvials 1970-71.
Gypsum:	(SMDN) 50,000t reserves to supply Malbaza cement works. Tahoua: exploration.
Iron:	Say region; reserves 200-600 Mt 49 percent Fe. high phosphorous and silica: Austrian aided exploration and possible participation in exploitation. Dyabou River; geological reserves 180 Mt 49.5 percent Fe. Kolo; reserves 89 Mt 42.3 percent Fe.
Kaolin:	Youri, Say. Samples sent to Japan and Czechoslovakia. Also to UNIDO.
Manganese:	(Liptako-Gourma) Ofalikin. 3 Year, $1.135M project to locate largest deposits.
Marble:	Ayorou-Italian research program. Air (S.E.) - German mission.
Molybdemum:	Kourki: BRGM abandoned permits but UNSF further investigation from 1969.
Oil:	(Texaco): Agadem region, 245,000 km^2 area seismic tests. (Continental): Sth Niger, 290,000 km^2 area seismic tests commencing September 1971. (Bishop): Djado and Talak area. 110,000 km^2, 85,000 km^2. Obtained geological data from Petropar.

(Global): Dosso area 65,000 km^2 area. Seguedine 90,480 km^2 area.

Phosphates: Tahoua: exploration and trials abandoned because of lack of results.

Tin: (SMDNC) El Mecki, Taradji) Study of beneficiation techniques by COMETAIN.

Tarouadji: UK Government research into concentration methods.
(Cometain) Air. Geochemical prospection.

Zinc: Firgoun: encouraging indications found by UN.

Under Development

Uranium: Azelik: reserves 4,000 mt. U_3O_8. Most of its reserves cannot be exploited at present.

Other locations:
Madouela, reserves 6,500 t U_3O_8;

Imouraren, Arlette, Ariege, Artois; Secondary deposits at Ariare, Arlequin, Arnold.

To meet W. Germany's atomic energy needs in 1980's Urangeselleschaft has 8.5 percent capital stake in development.

(CEA) Akokan. 30,000t deposit discovered at depth 250m. Feasibility study to be launched into possibility of full scale exploration program. (France/Japan/Niger) Akonta. Deposit discovered, decision regarding development to be taken soon. (Niger/CEA/RFA) Djada. Negotiations for research program.

Production

Gold: From Sirba valley; moved from alluvials to primary deposits. SF to investigate 1968.

Natron: From south-east for local consumption.

Salt: Scattered production by artisanal evaporation from several salines, e.g. Foga, Séguédine: modernization limited by transport problems, marketing.

Tin: SMDN (75% government) through jobbers at El Mecki, Tarraouadji and Timia. Known deposits too small and scattered for industrial scale production: UNSF attempts to locate primary deposits may allow development.

1971/72: Cometain research into beneficiation techniques.

Uranium: Most important mining activity.

(SOMAIR) Arlit: reserves 10,000 mt. 2.5 percent metal: 5th largest reserve in western world. Production commenced February 1971. Franco/German/Italian development. Open-pit mining doesn't require trained staff. Transport a serious problem: 200 km. from sea: road/rail link to be built. Investment 59m.

Production capacity of plant to be doubled to 1,500mt/yr by 1974: Pechiney-Ugine-Kuhlman awarded the contract. France is looking for supplies of uranium for its nuclear power stations.

<u>Major Exports</u>

Uranium: Expected to constitute c. 50 percent value of all exports from mid-1970's.

SENEGAL

Government:	5 year plan. 1969/73. Exploration program with USSR aid. Eastern and Bakel Regions (Au, Cr, D) previously studied by UNSF Phase II, completed 1969.
Exploration:	
BRGM:	Exploration program.
Canada:	1968 offer technical assistance for electromagnetic survey eastern Senegal.
Potential Resources	
Aluminum:	UNOID Aluminum plant project. CSPT exploration program.
Atomic Minerals:	Negative results CEA exploration in the Ferlo.
Chromite:	Lenses discovered by UNSF, BRGM: Gabou region.
Copper:	Gabou, reserves 250,000 mt. metal. Other deposit in E. Senegal. Under UNSF evaluation.
Diamonds:	UNSF found no placers of economic levels from study; Falémé gravels: Daléma Basin remains for study.
Gold:	Falémé gravels, reserves 22,700 kg. UNSF; indications suggest 87.5 t. ore around Moura, in Daile and Makabingui River basins: scattered, low grades, limited water. USSR to give technical and financial aid for follow-up.
Iron:	E. Senegal. La Falémé, Gabou, reserves; 700 M.mt. 60 percent Fe. Total reserves 1200-1300 M.mt. 60 percent Fe. 2 problems facing possible development: 1. Energy source must be located. 2. 700 km. railroad to coast required.

Molybdenite:	SF and BRGM studied indications, without economic results (1969).
Oil:	ESSO, Copetao, Shell, South and offshore. Non-exploitable deposits as yet.
Sulphur:	Prospection by Texas Gulf and Total, on and offshore, into deposits revealed by oil research.
Titanium:	High chrome content deposits: production ceased 1964 because of technical and marketing problems.

Under Development

Iron/Steel:	(Senegal Steel Industry) 40,000 mt/yr plant to be developed. Cost 0.5 billion CFA F. overseas financing.
Iron:	(UNIDO) Thies, 70 km from Dakar. Foundry to be developed at .32 billion CFA F. cost.
Production:	Previously Senegal dependent upon agriculture. Deposits of Fe, Cu, Marble, P, will transform it to a mining company.
Attapulgite:	In Pour region for export. Production capacity 12,000 t/yr.
Basalt:	Production and crushing for local market from Cap Vert and Thies region.
Illmenite, rutile and zircon:	Periodic production to 1964: ceased due to marketing and technical difficulties.
Limestone:	From around Rufisque, reserves of millions of tons.
Marble:	From Ibel and Boudafassi.
Oil refinery:	Dakar: 12,000 b/d capacity; extension wider study.
Phosphates:	(CSPT). Taiba. Calcium phosphate: res: 40 M.t. Dep: 15-20 m. deep.

Open cast mining.
(SSPT): Thies. Aluminium phosphate; res: 50M.t 29.5 percent, 1/2 exported, 1/2 used in fertilizer production.

Increase in production limited by market situation.

Salt: Kaolock Salines. 80 percent production exported: further increase possible if W. African market justifies.

Sand: C. 100,000 t/yr. for building industry.

Major Exports

Phosphates: Approximately 8 percent all exports by value.

UPPER VOLTA

Exploration

UNSF:

UPV4: Mineral and Groundwater survey: completed 1968.

UPV6: Mineral exploration in the northeast: completed 1970.

UPV 10: Studies in connection with mineral studies in the northeast: 1969-70. Mineral exploration in the north: 1971-74.

Liptako-Gourma: joint Mali, Niger Upper Volta development. Investment in Phase II: .702 billion CFA F.

DGM: Exploration program with FAC assistance.

Canada: Aerial geophysical prospection 1970-72 in North and Central areas: 52,000 km^2.

Potential Resources

Bauxite: Kaya, 60 percent alumina content. 3 deposits to south: 5 M t crude Bx.

Calcium: Tin Hrassan. Economic studies halted.

Chromite: Kaume and Arly: DGM investigations into economic significance.

Clays: Foulou (Kongoussi region): drilling by UNSF: estimate reserves, 1-3 M.t white clays.

Copper: Gaoua (Dienemera) 40 M.t 0.8 percent Cu Initial study by UNSF taken over by Charter consortium with a view to development.

Copper, molybdemum: Goron, near Kaya. Prospection.

Diamonds: BRGM exploration of Bourgouriba and tributaries. DGM prospection of indications in Saba, Comoe, Tenkodogo and Eastern Volta regions.

Gold:	SF found in most alluvials but non-commercial except possibly Grangoal and Boromo discoveries.
Graphite:	Korsimoro discovery; French sampling 1967 for concentration process.
Iron:	Tin Edia: Vanadiferous magnetites 40-55 percent Fe: production possible only as by production titanium/vanadium production.
Kaolin:	Studies to be completed prior to exploration.
Lead:	Can region: anomalies found by DGM and further study to be financed by FAC.
Magnetites:	Indications at Oursi: SF recommend investigation (1967).
Marble:	Tiara. 50,000 m^3 good quality. Study by DGM.
Mercury:	DGM investigating at Sibi.
Manganese:	Guibondi and Sanpelga: DGM investigation. Dori and Kaya deposits near Tambao: may be economic in conjunction with development of Tambao.
Nickel/Copper:	Indications at Kaya: SF recommend investigation (1967).
Phosphates:	Tilemsi (Bourem region).
Titanium, Vanadium:	Tin Edia magnetites (Oursi region); reserves 60 M mt 1 percent V_2O_5, 8-14 percent TiO_5. Known tenors too low for production at current market prices.
Uranium:	CEA exploration program in Northern region; indications at Siby (Cercle de Borano).
Zinc:	Anomalies found at Tiebele (Po region) by DGM: further study to be financed by FAC.

Under Development

Limestone:	Tin Hassan reserves: 6M mt. 46 percent CaO, 3 percent MgO. Exploitation for cement works in association with Tambao manganese. Construction cost: $71M.
Manganese:	(BRGM) Tambao; reserves 16 M. t 54 percent Mn. UNSF designed development project; railway and cement works, 734,000 mt/yr. Mine development costs: $3M. Transport development costs 28M., includes 200 mile railroad. Complete 1975.