Urban Design and Energy Conservation for Nairobi

By

Stanley Kebathi
A.B. (University of Nairobi) 1974
M.Arch. (University of Nairobi) 1976
M.Arch. (University of California) 1978

THESIS

Submitted in partial satisfaction of the requirements for the degree of

MASTER OF CITY PLANNING

in the

GRADUATE DIVISION

of the

UNIVERSITY OF CALIFORNIA, BERKELEY

Approved: R. L. Meier
....
....
Donald Appleyard
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Chairman Date

Committee in Charge

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TABLE OF CONTENTS

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Special thanks to Joyce who not only made sure there was enough energy sources at home for my bodily needs but also read the manuscripts and made very useful comments.

LIST OF FIGURES

LIST OF TABLES

TO MY PATIENT WIFE, NJERI

INTRODUCTION

Increasingly, the newspaper front pages are filled with topics that spell out doom for many a developing country. Political instability in the Middle East and now in Afghanistan are all indications of possible future constraints on fossil fuel availability for oil importing countries. Saudi Arabia and Iran are the major sources of oil for Kenya and many other countries. Possible invasions of these countries by the Soviets would present serious difficulties to many a small nation of the developing world. Many of them have now come to depend on oil as the main source of the enormous amounts of energy they need for their development.

Energy in its various forms is becoming the most critical commodity in this century. The world oil reserves are rapidly being depleted and as the demand for it mounts the OPEC nations raise their oil prices even higher. It is the developing countries which suffer most in these price increases because they must suspend development projects in order to import the essential oil. Eventually the oil may stop coming at all due to unstable world situation or due to the ultimate depletion of the fossil fuels. Meanwhile large amounts of money is being invested in the exploration and development of alternative energy sources notably in the United States. A few more years and the word "synfuel" will become a household word.

Will the third world energy importers also import synfuels from other countries? Alternatives must be found that make these countries less dependent on imported energy.

Kenya is energy defficient but being a developing country, its rising standards of living depend upon greater use of energy for industrial, commercial and domestic purposes. This makes it critically vulnerable to the ever-increasing prices of oil and also contributes to drain of valuable foreign exchange. The country's various resources are depleting rapidly and its energy consumption is rising at the rate of 8% per year and as oil prices mount, serious balance of payment deficits decelerates the economic growth momentum, threatening to lower the standards of living for Kenyans as inflation mounts.

It is the large cities such as Nairobi which will feel the effects of such eventualities the most. Growing at a rate of 6½% per year, and with a population of just under a million and expected to reach over 3 million by the turn of the century, Nairobi's energy needs are rising rapidly. The city does not have any major sources of energy, food or water. These must be imported from other countries or from the countryside. Yet as the world oil supplies decline, the demand for food in the country increases with the population and the known water resources are expected to be fully exploited within the next 15 to 20 years.

Due to the unprecedented increase in population, as in other large metropolises in the developing world, Nairobi has a high likelihood for encountering severe critical shortages of energy and food resources. Only recently, the major institutions in the city such as the University were affected seriously by a shortage of cooking gas due to a faulty manufacture of low-pressure-gas at the only oil refinery in Kenya. The urban population, unlike the rural population, depends more heavily on commercial forms of energy, which also are in high demand for industrial processes.

If Nairobi is going to be able to support the 3 million people expected to be living there by 2000, its energy needs must be planned to meet the expected demand. As the major consumer of energy in the country, the city must lead the way in developing more efficient ways of utilizing the available energy sources, and in developing alternative sources of energy. Its location, its status, its wealth of education, as well as the availability of a large pool of manpower make it both a suitable experimentation ground and a model to be emulated by other aspiring towns within the country.

Technical, organizational, substitutional, and other techniques that result in higher energy-conserving systems will have to be adopted if the city is to meet its expected food and energy demand in the future. Resource-conserving, urban designs that improve the quality of life and that are labor-intensive with extremely careful handling of available local materials, using solar collectors to minimize dependency on other forms of household energy sources, have to be developed not only for higher and middle income, but also for the lower income settlements within the city.

It seems then that time has come for urban planning strategies to change from the traditional land-use approach and to face the energy issues more directly. Urban systems ranging from transportation down to the individual house designs and even further to the designs of energy consuming household gadgets, must be modified to be as energy-efficient as possible and conserve as much as possible, to recycle waste and utilize more renewable sources of energy and less of the imported sources. Planning regulations and bylaws must then be modified to make provision for the new innovations.

A thesis like this then can not attempt to do all that has to be done to make a city energy self sufficient. Much has to be done on the political level. More rigorous study of the energy needs and resources, and their relationships with the various urban systems has to be carried out. Even more importantly, urban systems have to be designed in such a way that innovations can keep up with new discoveries meaning that no proposals can ever be final. All that is possible then, and within the scope of this thesis is to describe the prevailing conditions related with energy use in Nairobi, consider various examples of fossil-energy substitution from other parts of the world and make suggestions and proposals as to how the city might attempt to view its future energy needs. If the thesis provokes critical thought and stimulates action from those involved in the planning of energy resources and urban growth in the country, its purpose will have been successfully achieved.

The population of the country and its relationship to the energy situation is briefly described in chapter one and chapter two considers the city of Nairobi and its energy needs and available resources. The consumption patterns of energy in Nairobi are analyzed in chapter three.

Chapter four considers various alternative methods by which the city of Nairobi could improve its energy resources, and its energy efficiency. An attempt is also made to consider a suitable energy efficient urban structure. Chapter five presents a possible approach at designing an energy-efficient urban community seeking to provide as much of its energy needs through conservation, use of renewable energy sources and recycling of waste.

1

POPULATION DYNAMICS AND ENERGY NEEDS IN KENYA

1.01 GROWTH OF THE POPULATION

While the world population is expected to double in 35 years,[1] that of Kenya is expected to double in 21 years. It is growing at a rate of 3.5 per cent per year. The population has risen from about 4 million in 1931 to 15.3 million in 1979. Table 1.01 indicates the growth in this period.

Table 1.01

Population Size and Growth Rates from 1931-1979 Selected Years

YEAR	POPULATION	ESTIMATED GROWTH RATE
1931	4,000,000	—
1948 (CENSUS)	5,405,966	2.3
1951	6,200,000	2 5
1962 (CENSUS)	8,636,263	3 2
1969 (CENSUS)	10,942,705	3 3
1974	12,900,000	3 5
1979 (CENSUS)	15,322,000	—

Source: Physical Planning Department - Ministry of Lands and Settlements

[1] Kingsley Davis. "World Urbanization 1950-1970" Volume 1 University of California, Berkeley, 1969.

This high growth rate is attributed to a decline in death rate, a sustained high birth rate and a youthful structure. Traditional views that do not favor small families have hindered the efforts of the family planning programs and increased medical services have greatly reduced infant mortality. Table 1.02 shows the composition of the 1969 census by age.

From the 1969 census it can be observed that 51% of the population was under 15 years which further indicates the likelihood that the growth rate could rise even further to produce an estimated population between 28 and 34 million by the year 2000. It is also reported that Kenya has a fertility rate of about 8.1 children per child-bearing woman, a rate that is one of the highest in the world. This only indicates that the governments family planning program adopted more than 15 years ago has had very little effect on the Kenyan women. In fact the fertility has been rising from 6.8 in 1962 to the current rate and appears still to be rising further.[2]

The impact of such a high growth rate on the living standards, income levels, employment and need for social and economic services as well as the distribution of human settlements in the country can only be guessed at best.

[2] "The Weekly Review" Stellascope Ltd. Nairobi. September 7, 1979.

Table 1.02

Structure of 1969 Population-five year age group

AGE GROUP	MALE	FEMALE
0 - 4	1,058.1	1,046·4
5 - 9	916 6	893.4
10 - 14	714.7	663·8
15 - 19	560 2	544·8
20 - 24	428 0	450·1
25 - 29	3496	411 ·2
30 - 34	280 9	299 2
35 - 39	252 1	264·8
40 - 49	3664	365·8
50 - 59	2 71	241·3
60 AND OVER	308·5	279·4
TOTAL	5,482 4	5,460·3

Source: Central Bureau of Stat'stics

Whether the country will be able to meet the challenge in the year 2000 will very much depend on the planning that is implemented in the years ahead.

1.02 DISTRIBUTION OF THE POPULATION

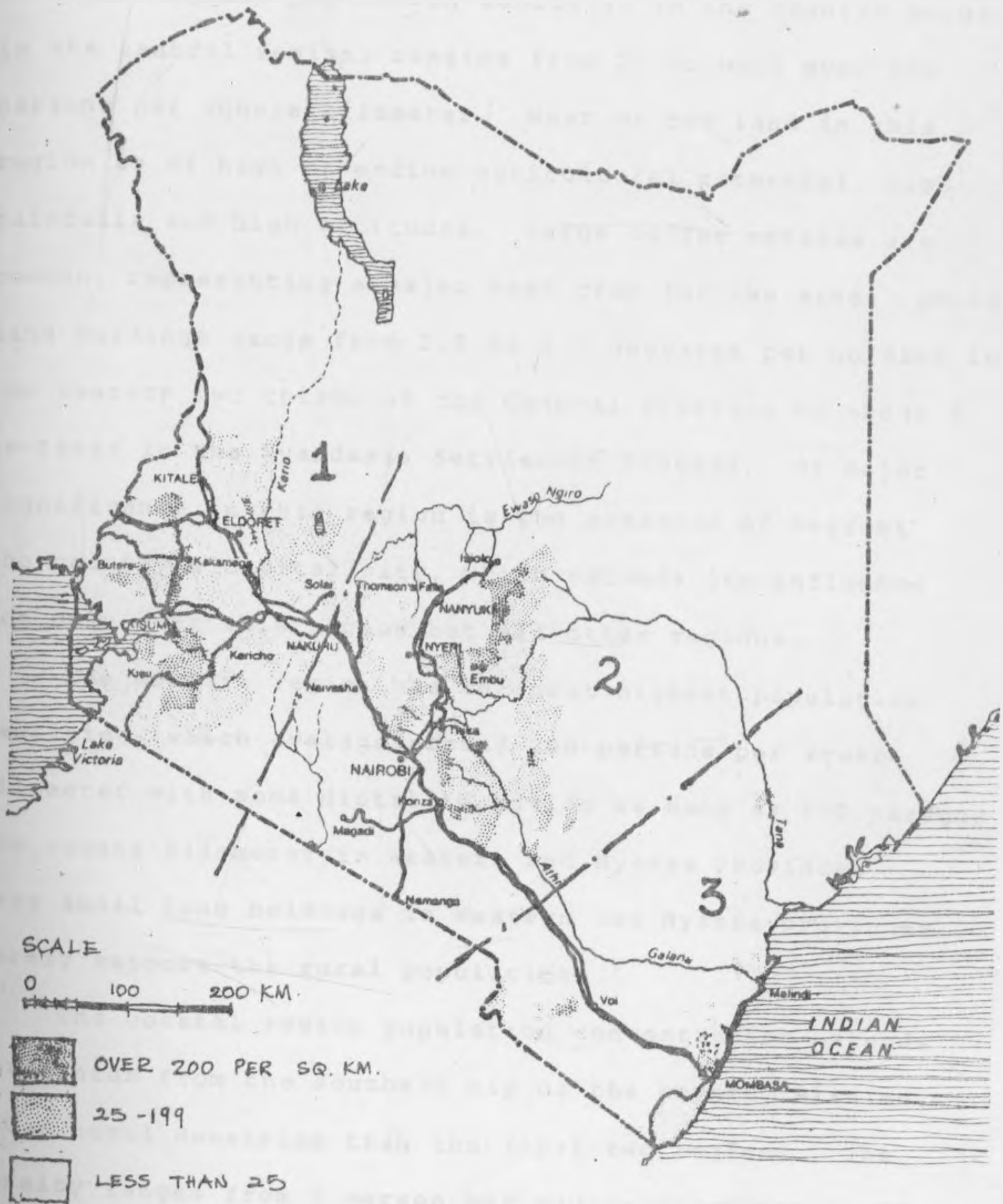
About 90% of the entire Kenyan population lives in rural areas. And yet of the total land area, only about one third is agriculturally productive while 70% of the total land is suitable only for rangeland. Thus the entire population lives in a small proportion of the total land area at extremely high densities. Figure 1.01 shows this distribution.

From the 1969 population data, about 65% of the people lived at a density of over 100 persons per square kilometer, 43% at a density of over 200 and 21% at a density of over 400 persons per square kilometer. A density of 100 persons per square kilometer represents an average land holding of 1 hectare per person, and a density of 400 persons per square kilometer represents an average land holding of 1/4 hectare per person. With the current highly uneven land distribution patterns, many people have no land to depend on for their livelihood.

The actual population distribution in the country as indicated in figure 1.01 is in three main distinct concentrations, one in the western part of the country

Figure 1.01

Population Distribution in Kenya-Density Shown for 1969



Source: City Council of Nairobi

(marked 1), another in the dense strip stretching north-eastwards from Nairobi (marked 2) and a third one along the coast concentrated around the main seaport of Mombasa (marked 3).

The highest population densities in the country occur in the central region, ranging from 20 to well over 600 persons per square kilometer. Most of the land in this region is of high or medium agricultural potential, high rainfalls and high altitudes. Large coffee estates are common, representing a major cash crop for the area. Small land holdings range from 2.5 to 2.7 hectares per holding in the eastern two thirds of the Central Province to about 8 hectares in the Nyandarua Settlement Schemes. Of major significance in this region is the presence of Nairobi the country's capital city, which extends its influence not only over this region but all other regions.

The Western region has the next highest population densities, which average around 200 persons per square kilometer with some districts having as many as 500 persons per square kilometer in Western and Nyanza Provinces. Very small land holdings in Western and Nyanza provinces barely support the rural populations.

The coastal region population concentration extends northwards from the southern tip of the country with much lower rural densities than the first two regions. The density ranges from 1 person per square kilometer to 25 persons per square kilometer. The entire population in the Coast Province was one million in 1969, and a quarter of them lived in Mombasa.

Historical influences of early coastal settlements have made Coast Province one of the most urbanized areas in the country. In 1969 while 8.6% of the total population lived in this province, it contained 26.2% of the total urban population. Within the province about 30% of the population was urban with most of them living in Mombasa. The rural population lives in small holder farms growing subsistence food crops as well as coconuts, cashew nuts, sisal cotton and coffee.

1.03 RURAL URBAN MIGRATION

An increasing volume of internal migration is a well established feature of the Kenyan population. The contemporary regional imbalances in economic growth underline these economically motivated migrations. The movements fall into two distinct categories, the first being rural to rural migrations from more developed to less developed farming areas, and the second being rural to urban areas caused by the increasing pressure on rural resources and the seemingly apparent opportunities in the expanding urban areas of the country. Table 1.03 indicates the migration patterns in 1969.

Table 1.03

Rural-Urban Migration as a Percentage of Total Migration 1969

PROVINCE OF ORIGIN	MIGRATION TO NAIROBI		MIGRATION TO MOMBASA		MIGRATION TO OTHER NINE TOWNS		TOTAL RURAL-URBAN MIGRATION	
	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE
NAIROBI	—	—	1.7	1.6	1.6	1.4	3.3	3.0
NYANZA	23.8	18.6	7.8	6.3	9.5	7.8	41.1	32.7
WESTERN	28.2	21.5	6.1	4.8	11.2	10.1	45.5	36.4
RIFT VALLEY	6.6	5.0	1.1	0.8	3.5	2.9	11.2	8.7
CENTRAL	30.6	21.3	2.8	1.7	5.7	4.8	39.1	27.8
EASTERN	35.9	27.7	15.4	13.0	3.2	2.8	54.5	43.5
COAST	8.2	8.2	48.7	40.3	2.3	2.6	59.2	51.1
NORTH EASTERN	7.2	5.8	3.9	2.8	2.3	1.9	13.4	10.5
TOTAL	20.8	14.4	7.9	5.6	5.5	4.6	34.2	24.6

Source: H. Rampel: An analysis of the information on interdistrict migration provided in the 1969 Kenya census. Working Paper No. 142 I.D.S. 1974.

The 1969 migration data indicates that 34 percent of all males and 25% of all females who migrated moved to major urban centers. In the period from 1948 to 1969 as much as 60 percent of the total growth of urban population was accounted for by rural-urban migration while the rest was due to natural increase. The annual growth rate of Nairobi and Mombasa are higher than the rate of natural increase showing that these cities are receiving a substantial number of people from other regions. Nairobi and Mombasa being the largest cities already have extremely high average population densities, but the concentration of services, social amenities and employment opportunities act as a pull factor for those being displaced from their rural setting.

The high relative development of services in Nairobi has resulted in a major migration from all the regions into the city. About 70 per cent of the total urban population during the last two decades has been located in Nairobi and Mombasa, but while 90 per cent of the increase in the total urban population between 1962 and 1969 occured in these two cities, 70 per cent of it was in Nairobi alone.

Table 1.04 shows the populations of the main cities and towns and it can be seen that the primate city of Nairobi exceeds the other urban areas in size by a wide margin.

Table 1.04

<u>Population of Ten Largest Towns in Kenya</u>

TOWN	1962	1969	ANNUAL GROWTH RATE	1979
NAIROBI	266,794	509,286	97	835,000
MOMBASA	179,575	247,073	4.7	342,000
KISUMU	23,526	32,431	4.7	150,000
NAKURU	38,181	47,151	31	93,000
MERU		52,900	20	73,000
ELDORET	19,605	18,196	11	50,000
THIKA	13,952	18,387	4.0	41,000
NYERI		22,600	49	36,000
KAKAMEGA		18,300	5.7	32,000
KISII		6,100		31,000

Sources: 1) Human Settlements in Kenya. Planning Department - Ministry of Lands and Settlement.

2) Weekly Review November 30, 1979.

The conditions of life for those who migrate into the urban areas do not always improve in the process. Kaplan Irving indicates that since 1960 "the growing numbers of migrants who flocked to the cities in search of economic opportunities and the excitement and convenience of urban life were often worse off than they had been in the countryside."[3]

The problems experienced in the larger cities particularly in Nairobi can be categorized as follows:

(i) housing shortage, and the spread of squatter developments. While 26,000 new housing units were built per year between 1970 to 1974, the dificit being compensated for by illegal squatter settlements.

(ii) high shortage of public utilities and services particularly for the lower income earners.

(iii) high unemployment and underemployment resulting in illegal means of raising income such as violent robberies, illicit trade, prostitution, unauthorized hawking and street vending.

(iv) street congestion during rush hours and poor public transportation which greatly reduce the efficiency of the larger cities.

[3] Kaplan Irving. "Area Handbook for Kenya" 1976.

(v) urban sprawl, as housing and other developments seek more open locations, threatens the agricultural developments around the cities.

In the past the government has emphasized rural development and tried to discourage rural-urban migration by the popular motto "Back to the Land." However, the rural dwellers having difficulties in maintaining their large families from their agricultural crop are increasingly turning to the cities as an alternative way of acquiring the necessities of life. Urban life is becoming more important and has therefore got to be a major part of the government's planning policies.

1.04 RELATIONSHIP BETWEEN POPULATION DYNAMICS AND ENERGY NEEDS

These population trends are not without effect on the energy balance in the country. First the natural increase in population is accompanied by a proportionate increase in demand for the basic life necessities including food and fuel. Available food and water resources must keep up with the increasing demand or else the population becomes undernourished and exposed to greater health hazards. Large amounts of resources will be required to provide not only food and water but also the industrial growth necessary to support the growing population. A greater demand will be made on the natural environmental resources particularly agricultural land, the forests and the rivers. More residential and industrial buildings must accompany the population increase, making further demands on the environment. Transportation needs will rise and energy has to be provided to meet the new demand.

Secondly the interegional population movements which occur to equalize the pressure on land, will constantly increase the pressure in the more suitable areas of the country. The wetter parts will get a bigger share of the population. This will in many cases be the areas with natural forests. Thus deforestation and eventual soil erosion may increasingly be experienced as population movements increase.

The third factor affecting the energy balance is the rural urban migration. Urbanization is accompanied by a change in consumption habits. Food becomes more processed and cooking fuel has now to be bought rather than just collected. The process of urbanizing the migrants takes some time to be completed and the low income migrants continue to import the traditional non-commercial, but now commercialized, forms of fuel such as wood and charcoal. Construction processes and dwelling types differ from those in the rural areas and more commercial energy must replace the rural social networks. The city has thus to depend on the countryside for the supply of food and energy and most of the imported energy from other countries will mainly be consumed in the urban areas where systems of distribution already exist.

It is clear then that the population dynamics briefly analyzed above have major repercussions on the energy balance in the country. The greater pressure is experienced by the urban areas which do not have other resources.

The largest city is the most likely to be hardest hit by food and energy shortages. Nairobi can therefore act as a study model for the rest of the country to stimulate questions and set new directions for the development of other towns in Kenya and possibly even other cities in Africa.

2

ENERGY RESOURCES AND CONSUMPTION IN NAIROBI

2.01 THE CITY AS AN ECOSYSTEM

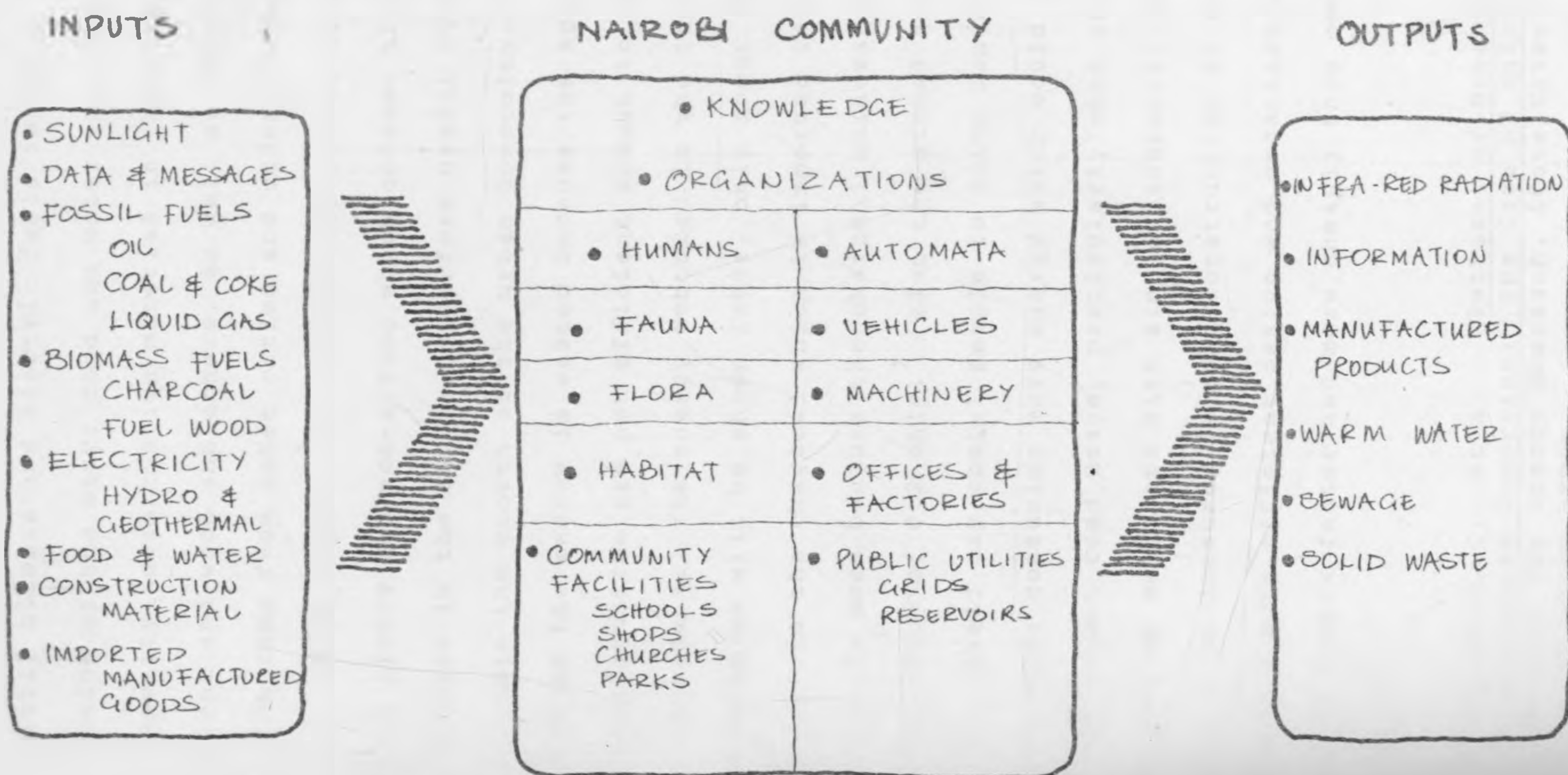
The higher rate of rural-urban imigration into Nairobi than to other towns indicates that the demand for food and energy is also rising faster in Nairobi. The standard of living for the society will depend on the availability of these resources. So far the city has suffered several temporary shortages not only of the imported oil products but also of locally grown food. Since such shortages are becoming increasingly more frequent, it seems appropriate to consider more critically the flows of these resources through the city so as to determine the areas where the consumption habits could be modified to minimize the demand. Secondly it is necessary to understand how the energy flow is affected by the disposition of the various urban activities, and policies could be adopted to conserve energy.

Figure 2.01 is an attempt to depict the city as an urban ecosystem[1] into which various inputs enter, go through a process of transformation in the city and are passed out of the system in the form of useful outputs and waste. The ecosystem receives energy from the sun in the form of solar radiation; data and messages from other places;

[1] Meier, Richard L. Planning for an Urban World. MIT Press, 1974.

Figure 2.01

The Nairobi Ecosystem as an Energy Consumer



fossil, biomass and electric fuels imported from locations outside of the city; food and water imported to support the community; construction material in the form of high-energy cement and wood and others, as well as manufactured goods which come from other cities and other countries.

These inputs are received by agents of transformation, both living and non-living which consume the energy embodied in the inputs to perform useful functions which maintain the growth of the urban community. At this stage much of the energy is wasted because the agents of transformation are not efficient enough to utilize to full advantage all the energy embodied in the inputs. For example as will be shown later, only about 20% of the energy in the charcoal which is imported into the city is actually used because the charcoal burners (jiko) have an efficiency of 0.2 only.[2] Also the actual design of the city itself may compel people to drive longer distances to work thus consuming more energy which could be saved. Inefficient road usage, particularly when congestion is caused by many cars with single occupants, requires that energy be consumed in road construction in situations where a more efficient design and organization might have moved people faster and more cheaply thus consuming less energy.

[2] McGranahan, C., et al. Patterns of Urban Household Energy in Developing Countries: The Case of Nairobi. The Institute for Energy Research, State University of New York at Stony Brook.

The energy that is not efficiently captured is passed out of the ecosystem as infra-red radiation back to the atmosphere while the rest appears as valuable stored information, manufactured goods, warm water sewage and solid waste. In most instances the warm water, sewage and solid waste are forced out of the system as waste. This also represents a certain amount of energy loss which could be minimized by recycling or by using more efficient conversion methods.

While some of the inputs into the city such as sunlight and messages are not readily measurable, others such as fuel wood and charcoal can only be measured in terms of a countrywide perspective. In the analysis that follows, patterns of countrywide energy production and consumption are given where no specific information is available for Nairobi alone. The analysis will be limited to fossil fuels biomass fuels and electric fuels.

2.02 FOSSIL FUELS

(i) Oil

A list of energy resource inputs into Nairobi would be headed by fossil fuels. A 14-inch diameter pipe delivers 1.2 million tons of oil each year[3] to the city from the

[3] Schipper, Lee and Mbeche, Oyuko. Energy Demand and Conservation in Kenya. Beijer Institute of Energy and Human Ecology. Berkeley, California, 1979.

Changamwe Oil Refinery in Mombasa, four hundred and fourty eight kilometers away on the Kenyan coast. Its construction drastically reduced the number of tankers from the fleet that used to bring the oil to the city and many have since been converted to regular delivery trucks. Much of this oil goes to petrol pumps in the city and in the surrounding towns. The rest is required to run the industrial machinery in the city. On the whole Kenya imports about twelve million barrels of oil per year (1978) equivalent to only a single week's consumption in Canada.[4] In 1978, this relatively small quantity of oil accounted for about 85 per cent of the commercial energy consumed by Kenya. More than three quarters of this oil was consumed in essential economic sectors like industry, agriculture and public transport. The rest was consumed by private transportation.

Table 2.01 shows the relative importance of oil compared to other comercial energy sources. The sales of petroleum fuels by consumer categories is given for four selected years in table 2.02. Consumption has been increasing and will continue to rise as each of the consuming sectors expands with the growing economy. From the table it is clear that Kenya heavily depends on petroleum as a source of energy. This situation is not likely to change because of two major resons: first, most

[4] The Weekly Review, Nairobi, July 27, 1979.

Table 2.01

Consumption of Energy Expressed in Terms of Primary Sources

FORM OF ENERGY	OIL EQUIVALENT ('000 TONNES)		PERCENTAGE ANNUAL RATE OF INCREASE	PERCENT OF TOTAL ENERGY CONSUMED		FORECAST 1983	
	1973	1977	1973 - 77	1973	1977	OIL EQUIVALENT ('000 TONNES)	PER CENT SHARE
COAL AND COAK	50.0	43.8	-2.9	3.2	2.3	36.3	1.5
OIL	1,359.9	1,605.90	4.2	86.0	85.0	2,085.3	84.7
ELECTRICITY	170.4	232.6	8.1	10.8	12.4	339.0	13.8
TOTAL ENERGY	1,580.3	1806.5	4.5	100.0	100.0	2.460.6	100.0

Source: Mbeche Oyuko O. Energy Use in Kenya. University of Nairobi, 1980.

Table 2.02

Net Sales of Petroleum Fuels by Consumer Category in Kenya in Selected Years

('000 TONNES)

	ITEM DISPOSITION	1968	1971	1974	1977
1.	AGRICULTURE	35.1	65.7	57.6	64.0
2.	ROAD TRANSPORT	128.8	276.4	336.5	428.0
3.	RAIL TRANSPORT	351.9	239.4	91.4	89.8
4.	MARINE	157.5	115.4	196.3	132.4
5.	AVIATION	50.7	113.1	275.4	324.2
6.	POWER GENERATION	57.5	88.5	94.4	124.4
7.	INDUSTRIAL AND COMMERCIAL	87.2	187.7	295.8	360.7
8.	GOVERNMENT	30.2	53.5	40.8	48.7
9.	UNLOCATED ESTIMATE	9.0	-71.7	-162.0	-69.4
10.	TOTAL SALES	908.0	1,068.1	1,226.2	1,502.8

Sources: (1) East African Statistics of Energy and Power, 1966-1973

(2) C.B.S. Unpublished working papers.

of the petroleum fuels are used in industrial and transportation sectors where there exist no other economically viable close substitutes for these fuels in the near future; second, Kenya's potential for the production and supply of electricity will always lag behind the demand.

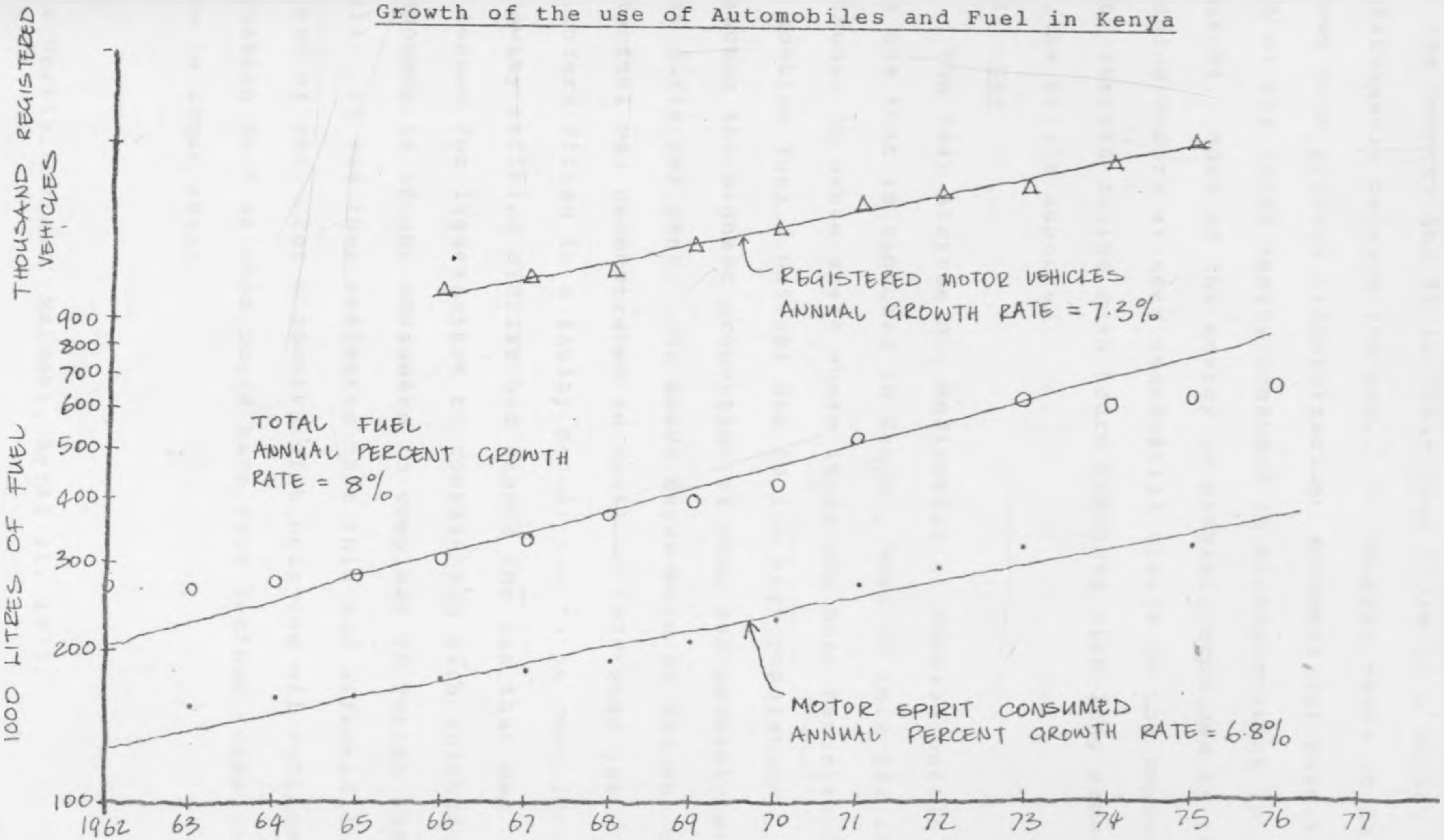
This state of affairs is alarming when it is realized that the world oil supplies are diminishing rapidly. The International Energy Agency estimates that the world oil demand will exceed production capacity by 1990.[5] From then on, supplies must decrease and diminish probably within the next 25 to 30 years. Developing countries like Kenya will experience difficulties since they will take longer to convert to synthetic fuels, another technology yet, that many of them will have to pay a high price to buy from the developed countries like the United States which is already investigating the possibilities of large scale synthetic fuel production.

Since Nairobi has a higher per capita income than the national average meaning that car ownership is also higher in Nairobi, and since about 60% of the country's industries are in Nairobi, it is likely that close to 50% of the imported oil is consumed in Nairobi. Figure 2.02 shows the relationship between auto ownership and oil consumption

[5] Lonnroth, Mans. "The Energy Link Between the North and the South - More Questions than Answers". The Secretariat for Future Studies, 1979.

Figure 2.02

Growth of the use of Automobiles and Fuel in Kenya



Source: Lee Schipper, et al. "Energy Demand and Conservation in Kenya" 1979.

in the country and it is clear that there is a direct relationship between the two. In Chapter three it is also shown that private transportation accounts for more than 90% of the total energy consumed in transportation in Nairobi. Most of the energy is probably consumed by the running motors at near stand-still speeds in the congested city streets during rush hours together with long commutes to the city's suburbs.

(ii) Gas

The East African Oil Refineries at Mombasa bottle all the gas that is consumed in Kenya. Most of this gas is consumed in urban areas where it is the most favorite form of cooking fuel. Nairobi due to its high population consumes the highest proportion of this gas probably more than fifty per cent. The heavy dependence of Nairobi on this fuel was demonstrated in April of 1978 when gas cylinders filled in a faulty manner had to be recalled.[6] A faulty refining process had caused the gas that was collected for liquefaction to contain too much sulphur compounds in it and consumers to complain of rotten egg smell. It was then estimated that this had affected 400 tonnes of gas. For a country with only one oil refinery a situation such as this could have very serious consequencies in urban areas.

[6] The Weekly Review. Nairobi, April 21, 1978.

It is estimated that some 50 tonnes of gas is consumed every day in Kenya, with the consumption rate growing at about seven per cent annually. The demand is increasing even faster due to increases in charcoal prices causing considerable numbers of people to switch over to gas. Of Kenya's total gas consumption, 80 per cent is used for industrial and commercial purposes while domestic use acounts for the remaining 20 per cent. The consumption patterns in Nairobi by income are considered in Chapter 3.

2.03 BIOMASS FUELS

(i) Woody Biomass Resources in Kenya

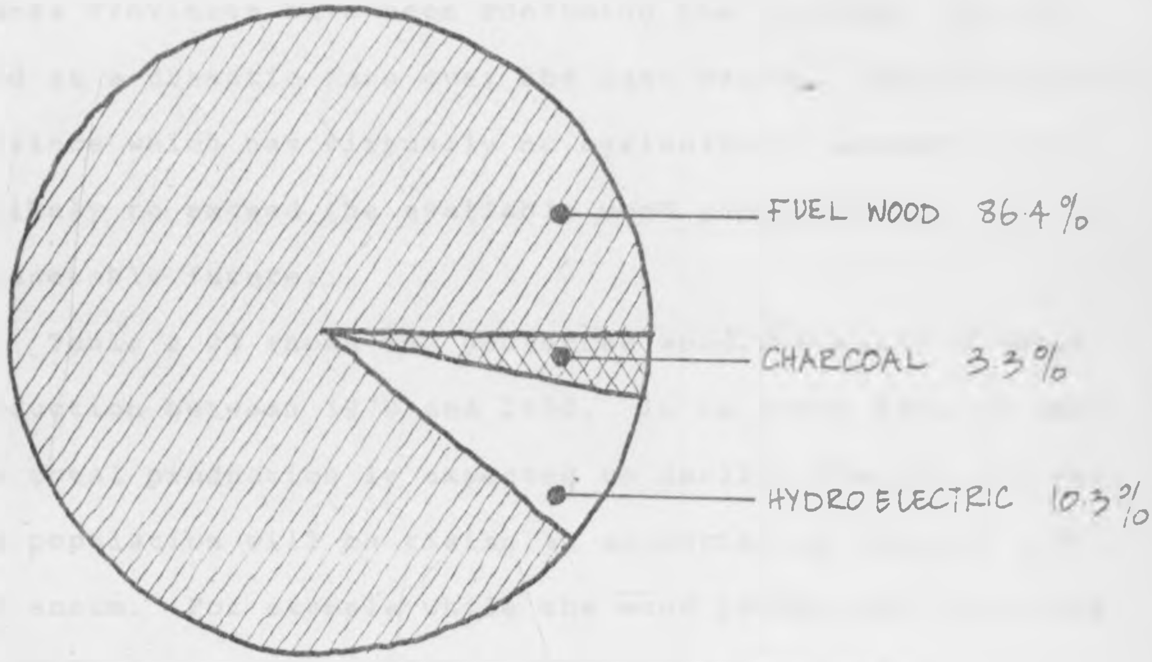
Except for renewable resources, Kenya lacks any other major forms of energy on which its economy would depend. The total energy production in the country in 1976 was estimated to total 3,800,000 tonnes[7] of coal equivalent, where 1 tonne of drywood is equivalent to 0.68 coal equivalent. The main sources can be broken down into fuel wood, charcoal and hydroelectric energy and can be schematically represented as in Figure 2.03.

Kenya has less than 3% of its area gazetted as forest area compared to a world average of 10%, but the rate of deforestation would seem to suggest that the era when firewood was the major source of household energy is soon

[7] Kenya Pipeline Company. The Petroleum Industry and Energy Sector Study. Paper prepared by Mase Economic Services Limited, 1978.

Figure 2.03

Main Local Source of Energy in Kenya



Source: Oyuko O. Mbeche. "Energy Use in Kenya." Department of Civil Engineering, University of Nairobi, 1980.

coming to an end as forests and bushes get cleared to give way to the production of food for the growing population. In many places the only forests left standing are those protected by government necessary to supply the construction and paper industries and to maintain the ecological balance. The main forest reserves are those on Mount Kenya, Aberdares and Mount Elgon.

The actual patterns of production and consumption depend entirely on the rainfall patterns and the population in the various provinces. The relatively sparsely cultivated Coast and Eastern Provinces which receive a reasonably high rainfall have substantial wood resources, while the densely populated and cultivated Central and Nyanza Provinces have been consuming the standing crop of wood at a dramatic rate over the last decade. North-Eastern Province which has virtually no agricultural potential is unlikely to exceed the available wood supply in the foreseeable future.

Table 2.03 shows the projected wood and woody biomass production between 1970 and 2050. It is clear from it that the total production is expected to decline sharply and yet the population will be rising at an estimated rate of 3.6% per annum. For example while the wood production decreases by 36.4 per cent from 1970 to 2000, the population increases by 33 per cent from 11.3 million in 1970 to 34.3 million in 2000. This relationship is graphically demonstrated by the Figure 2.04 which shows a high and a low level of production of wood and woody biomass.

It is clear that the demand is rising faster than the supply. Ssemakula and Western have concluded that based on a low consumption high production Scenario, it is likely that the annual consumption will exceed annual production of wood within 25 years. They also warn that this may not be obvious in looking at the available wood in the rural areas, largely because of the enormous standing mass of woody material that has been accumulated over the preceeding years.

Table 2.03

Potential Annual Wood Production in '000 tonnes and Woody Biomass in '000 tonnes for Kenya

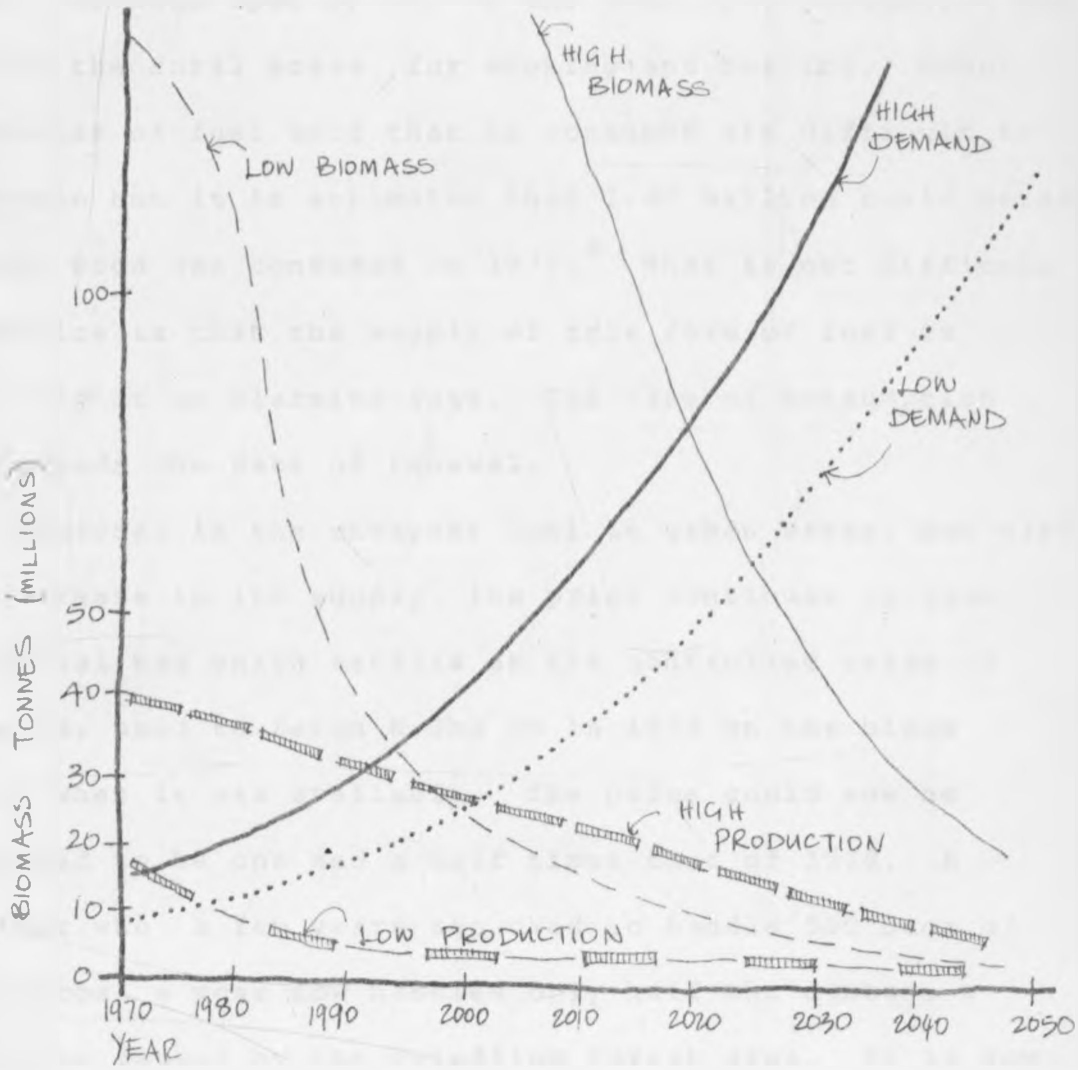
YEAR	WOOD PRODUCTION	WOODY BIOMASS
1970	12,314	156,314
1979	9,106	130,396
1985	7,190	87,509
2000	4,478	46,674
2050	2,047	22,334

Source: Western, David and Ssemakula, James. The Present and Future Patterns of Consumption and Production of Wood in Kenya. Paper for the International Workshop on Energy and Development. Nairobi, 1979.

It is also evident that the existing and planned production of fuel wood from forests is entirely inadequate to meet present and future demand. With a present annual consumption of 15 million cubic meters of wood per annum, and a production of approximately 700,000 cubic meters of fuel wood from forests reserves, the 4.7% contribution to the national level of consumption is minor. Presently only 6% of the forest area is allocated to fuel production and

Figure 2.04

Projection of Woody Biomass Demnad and Supply in Kenya



Source: David Western and James Ssemakula. The Present and Future Patterns of Consumption and Production of Wood-Energy in Kenya, 1979.

it is unlikely that this figure will change sufficiently in the future to the extent that it will be a major source of supply.

(ii) Consumption of Fuel Wood and Charcoal in Kenya

Wood fuel is the most important energy source in Kenya, depended upon by 90% of the country's population who live in the rural areas, for cooking and heating. Exact quantities of fuel wood that is consumed are difficult to assertain but it is estimated that 1.47 million cubic meters of fuel wood was consumed in 1975.[8] What is not difficult to realize is that the supply of this form of fuel is dwindling at an alarming rate. The rate of consumption far exceeds the rate of renewal.

Charcoal is the cheapest fuel in urban areas, but with the decrease in its supply, its price continues to soar. A charcoal bag which retails at the controlled price of K.Shs 18, used to fetch K.Shs 30 in 1978 on the black market when it was available. The price could now be estimated to be one and a half times that of 1978. A retailer who a few years ago used to handle 500 bags of of charcoal a year now handles only half the number, a situation caused by the dwindling forest area. It is now becoming more common for charcoal to be sold in small tins rather than in bags with each tin selling for K.Shs 2.

[8] Earl, D.E. Forest Energy and Economic Development Oxford University Press, 1975.

Charcoal production was estimated at 170,000 tons[9] in 1975 rising to 1.1 million tons[10] by 1980. This last estimate requires 0.74 million hectares of trees, an increase of about 40% on current forest area.[11] If it is also realized that the lower income residents of Nairobi and other urban areas can not afford any other forms of fuel energy it becomes evident that the demand for charcoal and firewood are ever present. This implies that until other forms of cheap energy are developed, the country's environment is in perpetual danger from the pressures of firewood cutters and charcoal burners.

(ii) Consumption of Wood in the Nairobi Area

The three main factors contributing to the depletion of wood production and the reduction of standing biomass are:

(a) An increase in the population at the projected rate of 3.6% per year.

(b) A change from traditional use of fuel wood to charcoal in urban and high density agricultural areas.

[9] Githinji, P.M. Kenya's Energy Needs, Possible Supplies and Impacts on the Environment. UNEP/UNDP Project on Environment and Development, 1978.

[10] Kabagambe, D.M. Aspects of Resource Conservation: The Role of the Charcoal Industry in Kenya. Institute for Development Studies. Working Paper No. 271, University of Nairobi, 1976.

[11] Marguand, C.J. and Githinji, P.M. Energy Resources in Kenya and Their Environmental Impacts. Department of Engineering, University of Nairobi, 1979.

(c) Land demand for agricultural production. Since the extent of depletion in each province will depend largely on the patterns of wood exploitation in relation to the urban as well as the rural centers, one can already predict that the Central Province reserves will be depleted at a very rapid rate due to the rising population in Nairobi. The per capita consumption of wood by urban populations is estimated as high as $2m^3$ per capita per annum, and with the present estimated figure of 2 million people in towns and cities, their contribution to the national use of wood may be as high as 24%. Since about 42% of the urban population lives in Nairobi it can be concluded that about 10% of the country's wood reserves is consumed in Nairobi alone.

Further, Earl[12] has noted that the transport costs incurred in collecting fuels from natural forests in East Africa is so high that at a distance greater than 80 kilometers from markets it is only profitable to carry charcoal. As local sources of fuel wood are used up around Nairobi and in the agricultural areas, it is inevitable that there will be a progressive switch to charcoal, and consequently, to a higher absolute consumption of wood per capita. Moreover, with a sharp rise in the price of oil fuels the distance within which it

[12] Earl, D.E. Forest Energy and Economic Development. Claredon Press, Oxford, 1975.

is profitable to transport wood will be reduced, thus further escalating the per capita consumption of wood through a switch to charcoal. This indicates that the areas surrounding the city will be deforested rapidly to supply Nairobi with charcoal. This situation is further exasperated by the possible oil price increases which would force more Nairobi residents to use charcoal in the place of low pressure gas for fuel.

The existing forests in the city may right now appear to be safe from tree cutters in search of fuel wood but the analysis above points to an important fact that the urban planning authorities can not ignore. It seems necessary that the city draws a regional energy strategy which would include not only the protection of the existing forests, but also planting new forests in all areas in the region that are not easily usable for other activities particularly where the soil is not stable enough for building construction.

The actual consumption itself can be greatly reduced if better methods of heat generation from fuel are developed. This includes more efficient methods of charcoal making from wood, a method that first does not waste the smaller branches and twigs of the trees, and secondly one that does not waste the energy contents of wood in the charcoal making process. On the consumer side the most immediate gains could be easily achieved by increasing the efficiency of charcoal and wood burning stoves (jikos). This can be done by increasing insulation around them. More detailed proposals are presented in later parts of this thesis.

2.04 ELECTRIC FUEL

(i) Hydro-electric Power Generation

One of the major alternatives to charcoal and fuel wood is electricity which is itself becoming a major source of energy for cooking, and is also indispensable for industrial and commercial use. Lacking in oil resources, Kenya has had to generate a large percentage of its electricity needs from imported oil, but as the cost of oil soars, hydro-electric generation is becoming increasingly competitive.

Prior to 1975 the official policy was to develop thermal power stations to serve areas which were isolated as well as Mombasa, but since then it has been found that hydro-electricity is a cheaper option to develop. The end result has been the construction of a series of dams on the River Tana in quick succession starting with Kamburu, in 1975, followed by Gitaru in 1978 and the Masinga Dam now under construction as part of the Seven Forks Hydro-electric scheme on the Tana River Basin. The total installed capacity on this river by 1979 was 293 mw, and the planned potential to be developed will be 540 mw while the estimated total potential is 835 mw.[13]

There is also an estimated potential from other smaller rivers of about 330 mw. Table 2.04 shows the percentage of hydro-electric power production in the period 1958-1974 and it is evident that the maximum potential is being approached rapidly.

Electricity demand is rising at about 9% per annum and the total consumption is expected to rise from 200 mw in 1976 to 352 mw in 1983. Table 2.05 shows the estimated sales against the demand for electricity in the country. The extra demand has to be produced from other sources. Though the newer projects are hydro-electric, nearly half of the country's electricity is still generated from oil burning plants. This implies that a crisis in the oil industry would be a major crisis in the country's energy strategy and consequently ultimately the country's economy. Further up to the present Kenya still imports about 30 mw of electricity from Uganda. In 1976 the imports were equivalent to 91,000 tons of coal equivalent.

The part played by hydro-electric power may be small in the context of the total energy picture in the country, but it is important to emphasize that it assumes a much

[13] Ondingo, Richard S. The Development of Hydro-electric Power Resources in East Africa with Special Reference to Kenya . University of Nairobi, 1979.

Table 2.04

Electricity Production in Kenya 1958-1974

YEAR	TOTAL INSTALLED (MW)	HYDRO AS PERCENT OF TOTAL
1958	82.3	31.6
1959	41.1	32.1
1960	82.3	31.6
1961	82.3	31.6
1962	100.3	25.9
1963	102.2	27.4
1964	104.4	26.8
1965	100.1	28.0
1966	113.5	24.7
1967	113.6	24.6
1968	153.0	43.4
1969	153.1	43.2
1970	153.2	44.1
1971	186.1	38.3
1972	190.8	37.4
1973	202.5	34.7
1974	266.0	50.4

Source: Richard S. Ondingo. The Development of Hydro-electric Power Resources in East Africa with Special Reference to Kenya, 1979.

Table 2.05

Estimated Sales and Maximum Demand of Electricity 1972-1978

YEAR	TOTAL SALES (WITHIN KWh)	MAXIMUM DEMAND (MW)
1972	794.8	146.0
1973	867.8	168.0
1974	971.9	186.0
1975	1108.0	212.0
1976	1207.0	232.0
1977	1316.4	255.0
1978	1434.9	274.0

Source: Kenya Statistical Abstracts.

more significant position in terms of electric power generation. It is the currently most important major energy source for commercial energy for industries and for urban supplies in Kenya. However the amount of energy that can be generated from water falls in Kenya is estimated to be only 1,000 mw. Increased industralization and the increase in population would indicate that this level may soon be attained.

Another limiting problem still looms over hydro-electric power generation. The high rate of deforestation drastically reduces the water retention power and also increases siltation which reduces the effective life of the hydro-electric project. It is reported that siltation of the Seven Forks Hydro-electric Scheme (which cost about K.Sh 1.4 billion) has reduced the effective life of the project from 50 years to 25 years.[14] The same sort of siltation process is now taking place at the much bigger hydro-electric project at the Tana River.

This indicates that the estimated total potential of 1,000 mw may not continue to be drawn for a long time after the installed capacity reaches this figure. It seems that the government should counteract these limitations by engaging in an all out campaign for forestation to increase water retention in the catchment areas and reduce soil erosion. People should be encouraged to plant trees in their land to minimize the demand from forests.

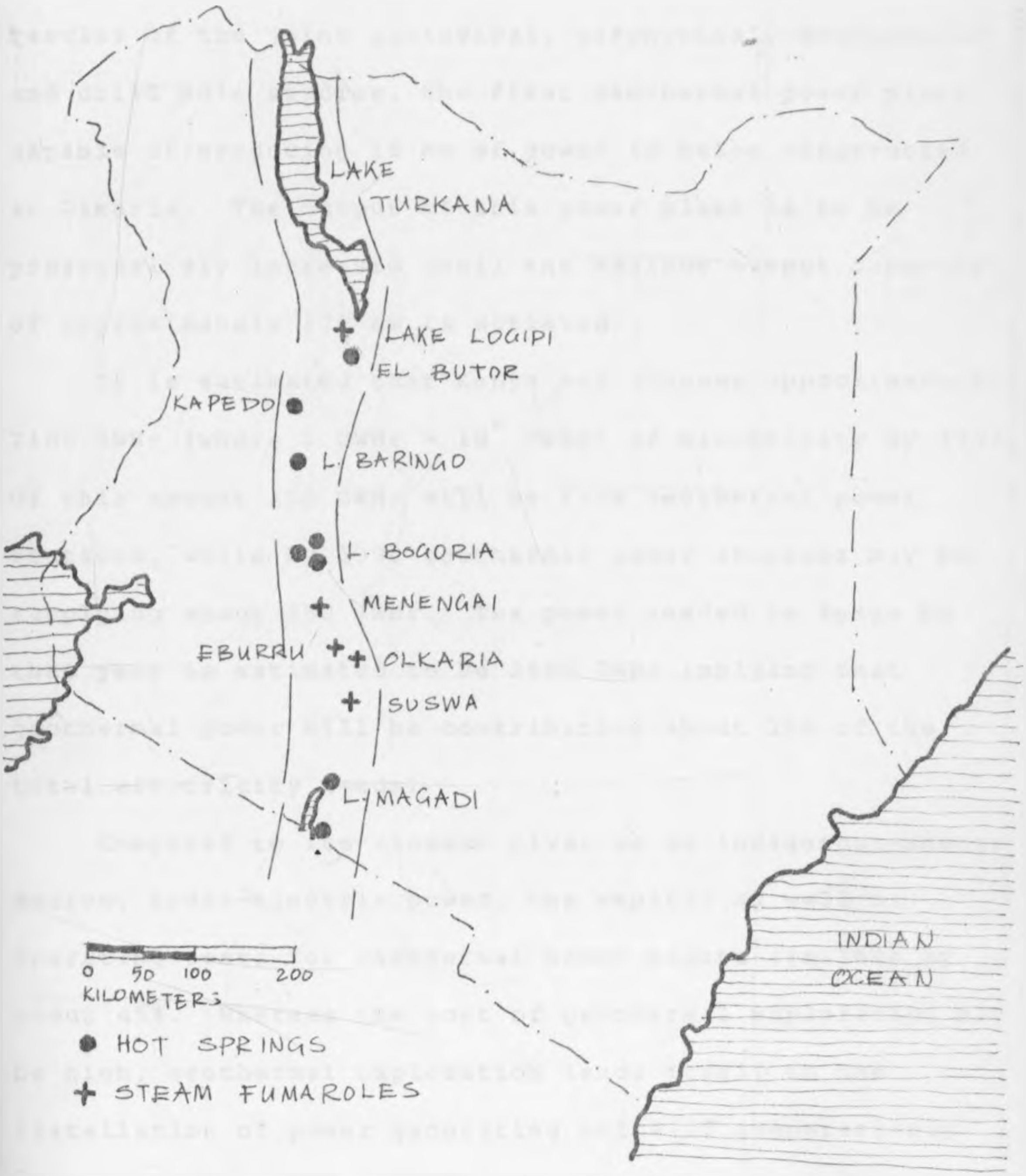
(ii) Geothermal Power

A hitherto unexploited form of energy in Kenya is that from geothermal resources. A large part of the Kenyan Rift Valley is characterized by intense geothermal activity in the form of geysers, steam fumaroles, warm and hot springs. The areas of active surface manifestation of geothermal activity are indicated in Figure 2.05.

[14] Weekly Review, Nairobi, July 27, 1979.

Figure 2.05

Location of Hot Springs and Fumaroles in Rift Valley of Kenya



Source: J.M. Ndombi et al. Prospects of Geothermal Energy in Kenya . University of Nairobi. Undated.

Increased attention has been given to the exploration and subsequent exploitation of geothermal resources since the United Nations cooperation with Kenya in the geothermal exploration, of 1970-1975. Based on the results of the joint geological, geophysical, geochemical and drill hole studies, the first geothermal power plant capable of producing 15 mw of power is being constructed at Olkaria. The output of this power plant is to be progressively increased until the maximum output capacity of approximately 170 mw is achieved.

It is estimated that Kenya may consume approximately 2100 GWHr (where 1 GWHr = 10^6 KWHr) of electricity by 1982. Of this amount 150 GWHr will be from geothermal power stations, while by 1990 geothermal power stations may be supplying about 360 GWHr. The power needed in Kenya by that year is estimated to be 3680 GWHr implying that geothermal power will be contributing about 10% of the total electricity needs.

Compared to its closest rival as an indigenous energy source, hydro-electric power, the capital as well as operating costs for geothermal power plants are less by about 45%. Whereas the cost of geothermal exploration may be high, geothermal exploration lends itself to the installation of power generating units of comparatively smaller sizes. Also geothermal power installations are technically uncomplicated and extremely simple to operate.

They do not contain the complicated high pressure plants found in thermal power stations, nor do they require fuel storage facilities. Further geothermal energy can also be used on a multi-purpose basis. In areas where drinking water is in short supply it can be provided through the medium of multistage flash distillation. Steam can also be used for drying food crops and pyrethrum.

The main handicap of geothermal power utilization involves the management of corrosive and poisonous residual fluid waste. A method of re-injection of the effluent back into the ground can however be developed. The problem of air pollution by the gaseous bi-products is not critical because the existing geothermal resources are far from major population concentrations.

(iii) Electric Power Consumption in Nairobi

Most of the electric power is used in industrial processes, street lighting and for domestic purposes. Since about 60% of the industries in the country are located in Nairobi, and the greatest street lighting demands are in Nairobi, and the highest domestic consumption is also in Nairobi, it is quite likely that more than 50% of the total electricity production in the future will be consumed in Nairobi alone. This figure would be even higher if there is a drastic reduction in the supply of other fuel forms such as oil and fuel wood. It seems important therefore that other sources of energy should be developed to minimize the dependence on electricity. The Ministry of Energy can encourage the use of solar energy and other renewable forms of energy by introducing an inverted rate structure whereby consumers charges per unit of power increase the more power is consumed. This would discourage excessive usage, and encourage conversion to solar energy.

2.06 CONCLUSIONS

Though it is estimated that the exploitable geothermal potential would be more than sufficient to supply the country with all its power needs,[15] the following factors point to a great need to conserve energy and to increasingly develop non-conventional renewable resources:

1. The rural poor, who by and large live outside the monetary economy, have very limited access to capital, education and not infrequently live within a social structure where even meagre surpluses through different mechanisms are channelled to the relatively more well-to-do.[16] Rural electrification is unlikely to be completed to a point where every dwelling has electrical power. Even if this could happen, the cost of electrical appliances added to the monthly bill would be far beyond the reach of the majority of the rural families.

[15] Ndombi, J.M. and Bhogal, P.S. Prospects of Geothermal Energy in Kenya . University of Nairobi, undated.

[16] Lonnroth, Mans. The Energy Link Between the North and the South - More Questions than Answers . The Secretariat for Future Studies, undated.

2. The urban poor are extremely insufficiently connected to the grid and where they are connected, it is solely for lighting purposes.[17] Population densities are such that energy technologies depend on grids (gas, electricity) are feasible, but lack of purchasing power means that load factors are low and energy costs high, thus perpetuating the situation.[18]
3. If electricity and commercial cooking gas are out of reach for the urban poor and the rural residents, charcoal and fuel wood become increasingly important forms of energy for these categories of people. But it has already been pointed that charcoal and fuel wood are becoming increadingly more expensive as their supply diminishes. Further, Figure 2.04 indicates that the supply will greatly lag behind the demand.
4. It seems incorrect to assume that the exploitable geothermal potential would meet all of Kenya's power needs, since this can not include transportation power needs. Oil would still have to be imported to meet transportation demands. More than 90 percent of the total energy used in transporation in Nairobi is consumed by private transport, while only less than

[17] Lonnroth, Mans. The Energy Link Between the North and the South - More Questions than Answers . The Secretarit for Futures Studies, undated.

[18] Lonnroth, Mans. Op. Cit.

5% is consumed by public transportation. This is mainly a result of urban sprawl which encourages private vehicle ownership and discourages public transportation by scattering pick up locations. An urban design strategy that greatly increases the possibilities for public transportation by increasing urban dersities, minimizing sprawl and encouraging fuel conserving models of transportation such as walking and cycling needs to be developed so as to minimize extravagant fuel usage.

5. Finally future transportation strategies should be drawn not only for urban areas but also for the rural areas, which consume as little energy as possible. Public bus transportation holds the best promise for the country in the future. Buses can easily operate on wood-alcohol instead of imported diesel. The government's Ministry of Energy could investigate the potential for wood alcohol production as well as the production of gasahol from crops that can be easily grown in the country.

3

ENERGY END USE PATTERNS IN NAIROBI

3.01 ENERGY CONSUMING ACTIVITIES FOR VARIOUS INCOME GROUPS

Energy-end use patterns in the city vary dramatically from those experienced in the rural areas. Low income migrants who previously used wood and charcoal generally purchase more oil based fuels when they move to the city. In addition, the urban populations have energy requirements that do not exist in the traditional rural areas. Food and raw materials, for example must be transported to the city. A sophisticated energy consuming distribution system is required within the city and perishable products must be refregerated and packaged. More energy-intensive products become available and necessary.

The changing characters of the urban population itself increases energy demands and alters the fuel mix. Higher per capita income encourages high levels of expenditure on energy intensive goods and services and in general a trend develops towards more sophisticated energy amenities at all income levels.

An analysis of the direct and indirect energy in the city reveals several important factors that will increasingly become causes of concern as the global energy reserves head for the decline. In their study of Nairobi energy consumption habits, McGranahan, Chubb, Nathans, and

Mbeche[1] have identified five major activities, namely

(a) Residential

(b) Transportation

(c) Food

(d) Housing Construction

(e) Services

McGranahan *et al* have also suggested five income categories in Nairobi that seem to exhibit a certain degree of variations in their energy consumption habits. Using the 1970 annual income scales they suggest the following groups.

(a) Group one - 0 to 204 Kenya pounds

(b) Group two - 205 to 600 Kenya pounds

(c) Group three - 601 to 1200 Kenya pounds

(d) Group four - 1201 to 3600 Kenya pounds

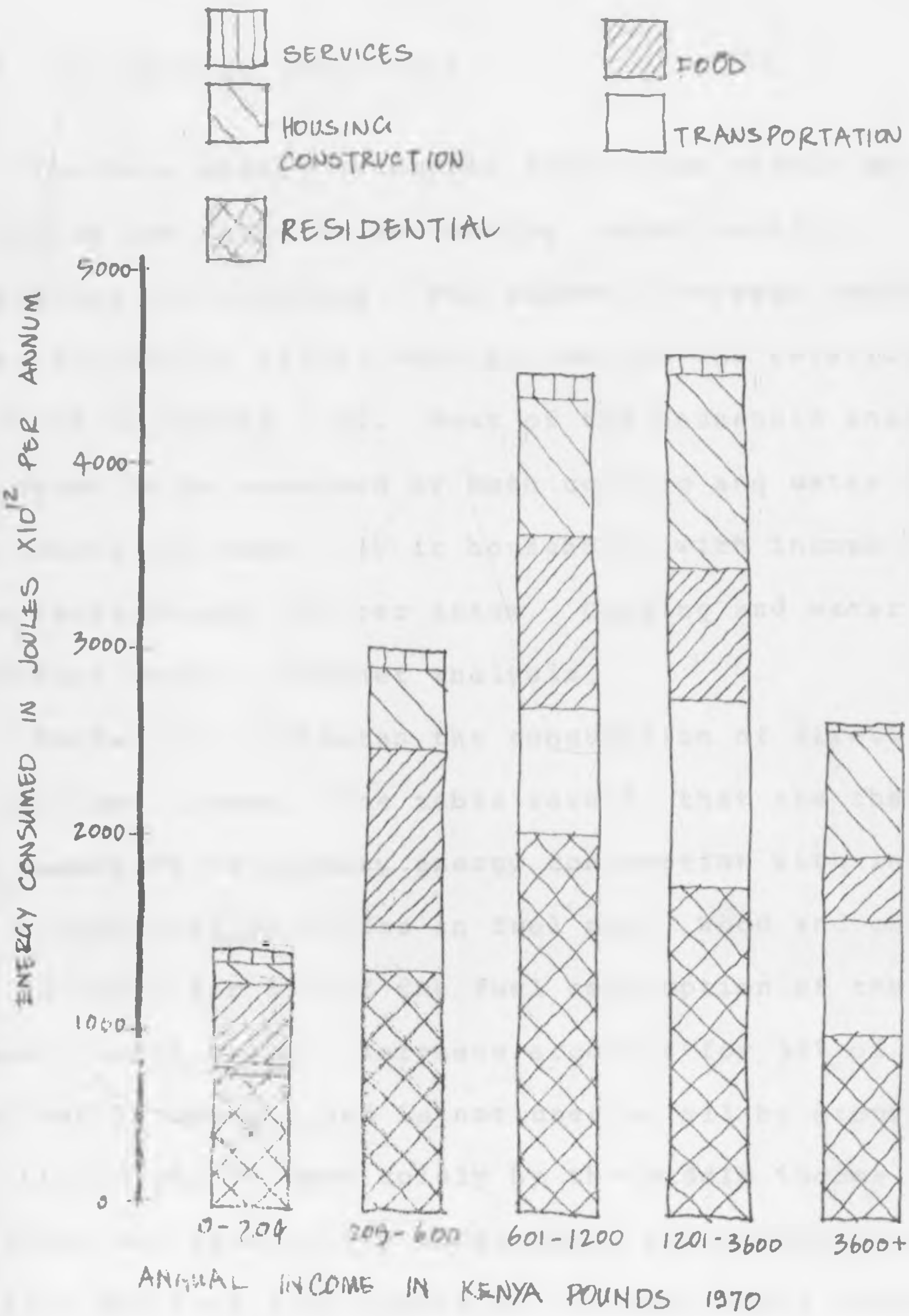
(e) Group five - over 3600 Kenya pounds

These groups will be used in the analysis below. The total energy required to support the activities of Nairobi's households is estimated at 16×10^{15} Joules. Direct energy use (that is residential and transportation) accounts for 59% of the demand, the rest being embodied in the food (21%), housing (18%) and services (2%). The energy demand by income is shown in Figure 3.01. The poorest, 59% of the

[1] McGranahan, G., Chubbs, S., and Mbeche, O. *Patterns of Urban Household Energy Use in Developing Countries: The Case of Nairobi*. The Institute for Energy Research, State University of New York at Stony Brook and the University of Nairobi, 1979.

Figure 3.01

Total Energy Use by Income Group in Nairobi



Source: McGranahan G., et al. Op. Cit.

population are indicated to account for approximately 27% of the energy consumption, while the richest, 17% account for almost 45% of the energy consumption.

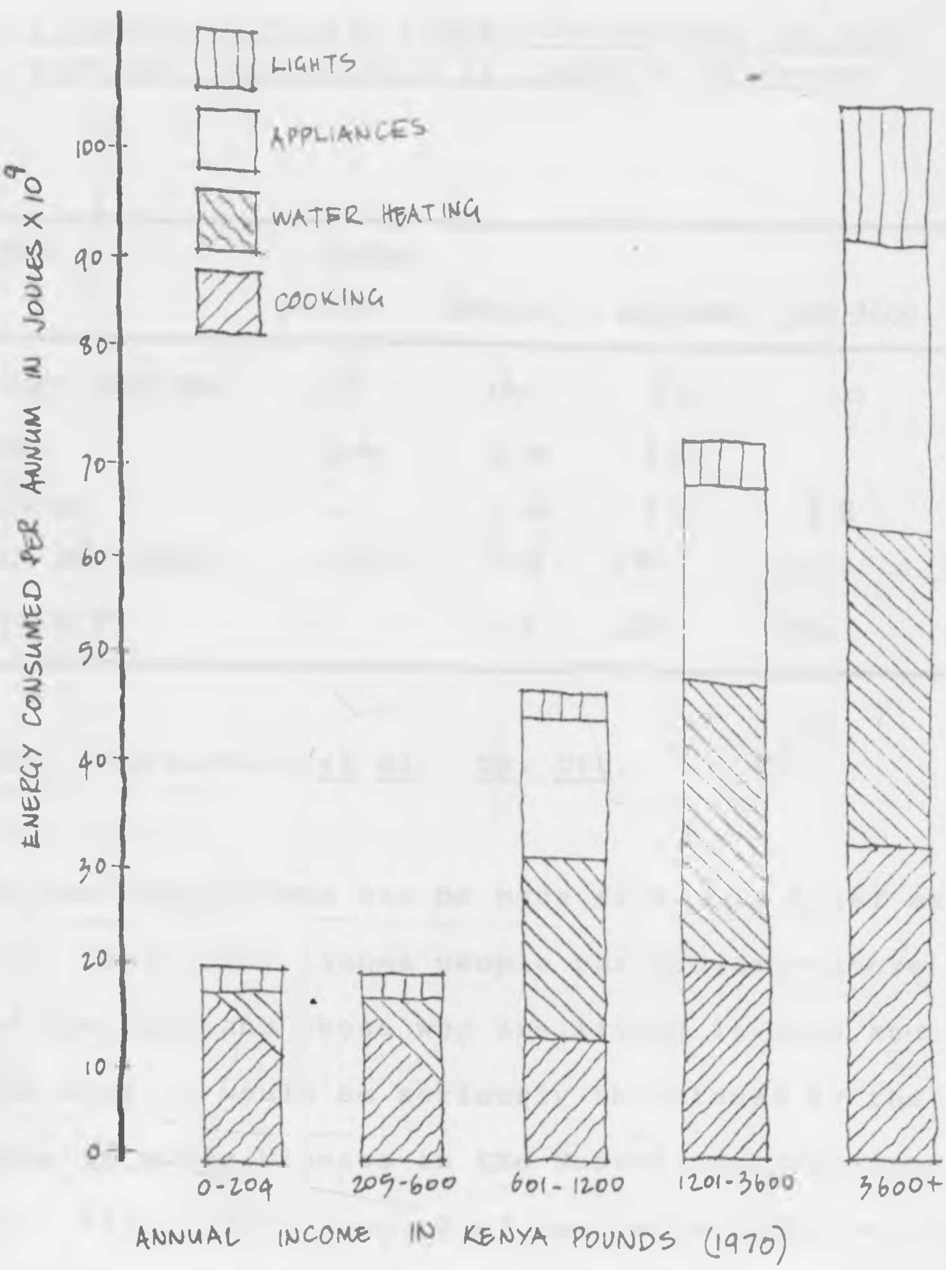
3.02 RESIDENTIAL ENERGY USE

The main energy consuming activities within an urban household are found to be cooking, water heating, appliances and lighting. The amount of energy consumed by these activities varies with income and the relationship is shown in Figure 3.02. Most of the household energy is indicated to be consumed by both cooking and water heating. Appliances are used only in households with income higher than Kenya pounds 601 per annum. Cooking and water heating therefore merit a further analysis.

Table 3.02 indicates the consumption of direct energy by fuel and income. The table reveals that the changes in the magnitude of primary energy consumption with income are accompanied by shifts in fuel mix. Wood and charcoal use accounts for 65% of the fuel consumption of the lowest income group. Kerosene accounts for 32% of the fuel use in Group 1 and is not used at all by groups 4 and 5. Liquid gas is used solely by the middle income groups. Gasolene and electricity consumption are highly income elastic and they form almost all of the direct energy needs of the highest income group.

Figure 3.02

Fuel Energy Demand per Household by Activity in Nairobi



Source: McGranahan, et al. Op. Cit.

Table 3.02

Per Household Direct Energy Consumption by Fuel Form and Income-Units in Joules X 10^9/annum

FUEL FORM	INCOME				
	0-204	205-600	601-1200	1201-3600	3600+
WOOD AND CHARCOAL	13	13	9.0	7.0	4.9
KEROSENE	6.4	3.0	2.6	-	-
LIQUID GAS	-	1.6	9.5	8.8	0.7
GASOLINE AND DIESEL	0.62	2.9	14	40	57.0
ELECTRICITY	-	1.7	25	56	98

Source: McGranahan, et al. Op. Cit.

A few conclusions can be made from this brief analysis.

(i) The lower income people particularly those living around the city and those who are living in site and service housing would be seriously threatened by the decrease in woody biomass in the Nairobi metropolitan region. Since this category of people is going to increase with rural-urban migration, provision needs to be made to minimize the decrease of this form of fuel energy.

(ii) Kerosene, liquid gas, gasoline and diesel, all forms of imported fosil fuel comprise a significant percentage of energy for all income groups which indicates that a shortage of supply would affect the entire spectrum of city residents. This high reliance should be minimized by converting to more renewable sources of energy.

3.03 TRANSPORTATION ENERGY USE

The energy consumed in transportation is shown in Table 3.03. It is found that travel among the lower income occurs primarily by foot or bicycle. These modes account for almost 80% of the total mileage travelled per household in the lowest group, 65% in the second lowest declining to 30% for the two highest groups.

Table 3.03

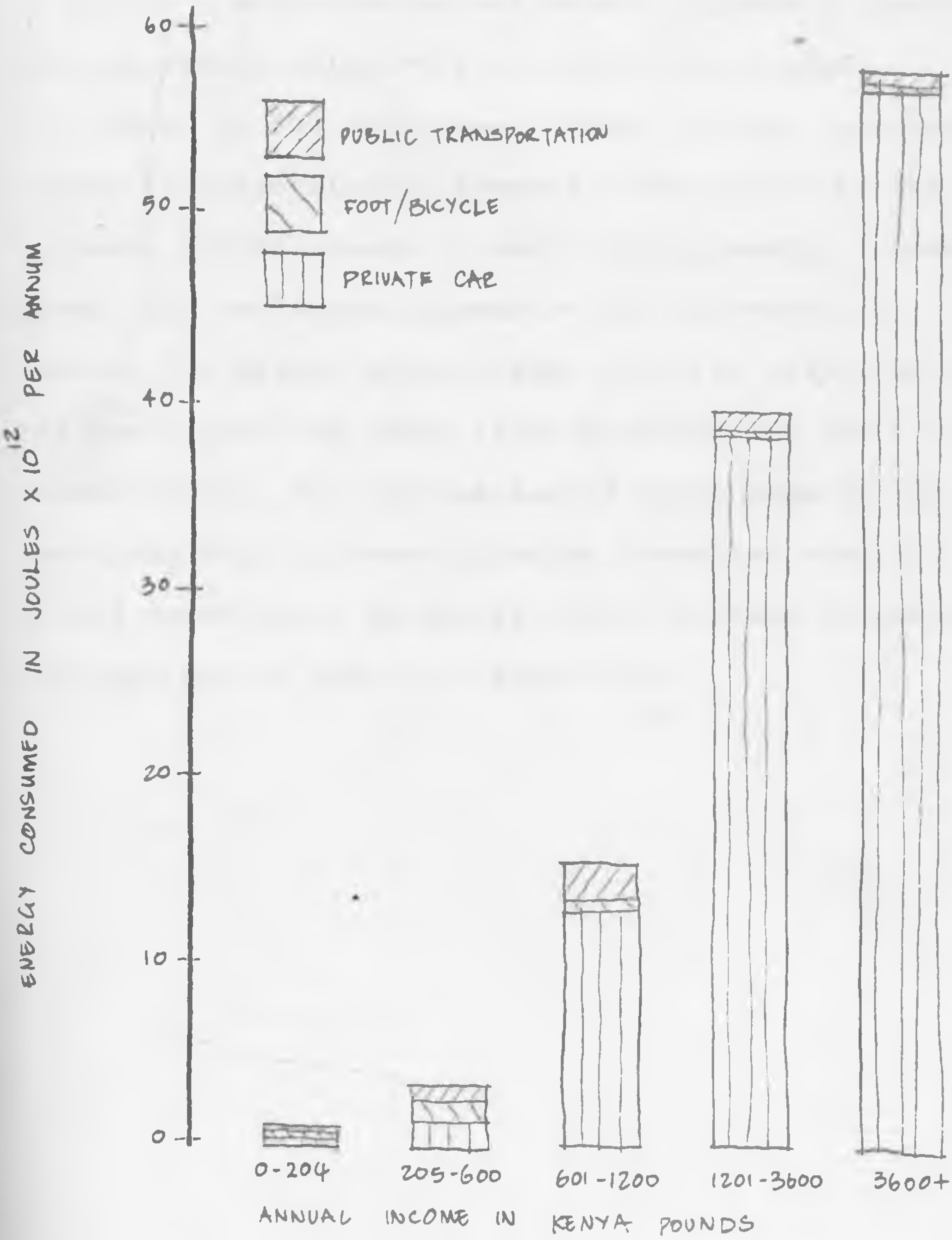
Yearly Fuel Energy Consumption by Mode in Joules X 10^9

INCOME GROUP	TOTAL FUEL ENERGY	FOOT & BICYCLE	JITNEY (MATATU)	BUS	PRIVATE CAR
GROUP 1	0.9	0.27	0.18	0.14	0.3
GROUP 2	3.3	0.48	0.45	0.68	1.7
GROUP 3	15.3	0.43	0.40	1.44	13.0
GROUP 4	39.3	0.22	0.28	0.63	38.6
GROUP 5	60.0	0.13	0.27	0.40	57.2

Source: McGranahan, et al. Op. Cit.

Figure 3.03

Fuel-Energy Consumed in Transportation per Household by Income and Mode in Nairobi



Source: McGranahan, et al. Op. Cit.

The shares of total travel-mileage by private automobile is found to be 3, 9, 40, 80 and 90 per cent for groups 1-5 respectively while the percentage shares of public transportation and matatu mileage of the total mileage remain relatively constant with income.

Thus, in the two lowest groups, travel is predominantly by metabolically powered modes; while in the two highest, travel occurs by car. Or the middle income group, the two modes automobile and foot-cycling, account for nearly equal shares of total travel distance, and their combined total is responsible for 70% of all travel-miles. The combination of these mode shifts and the eight fold increase in miles travelled over the income range leads to the 60 fold, increase in energy consumption, as shown in figure 3,03.

3.04 FOOD

The quantity and quality of food consumed in Nairobi is also found to vary with income. Energy is embodied in the food before it is purchased in three activities, namely

(i) agricultural production - the energy used on farm and in providing farm machinery thus including labor and fertilizers;

(ii) transportation - the energy used to transport food from the farms to the retail outlets;

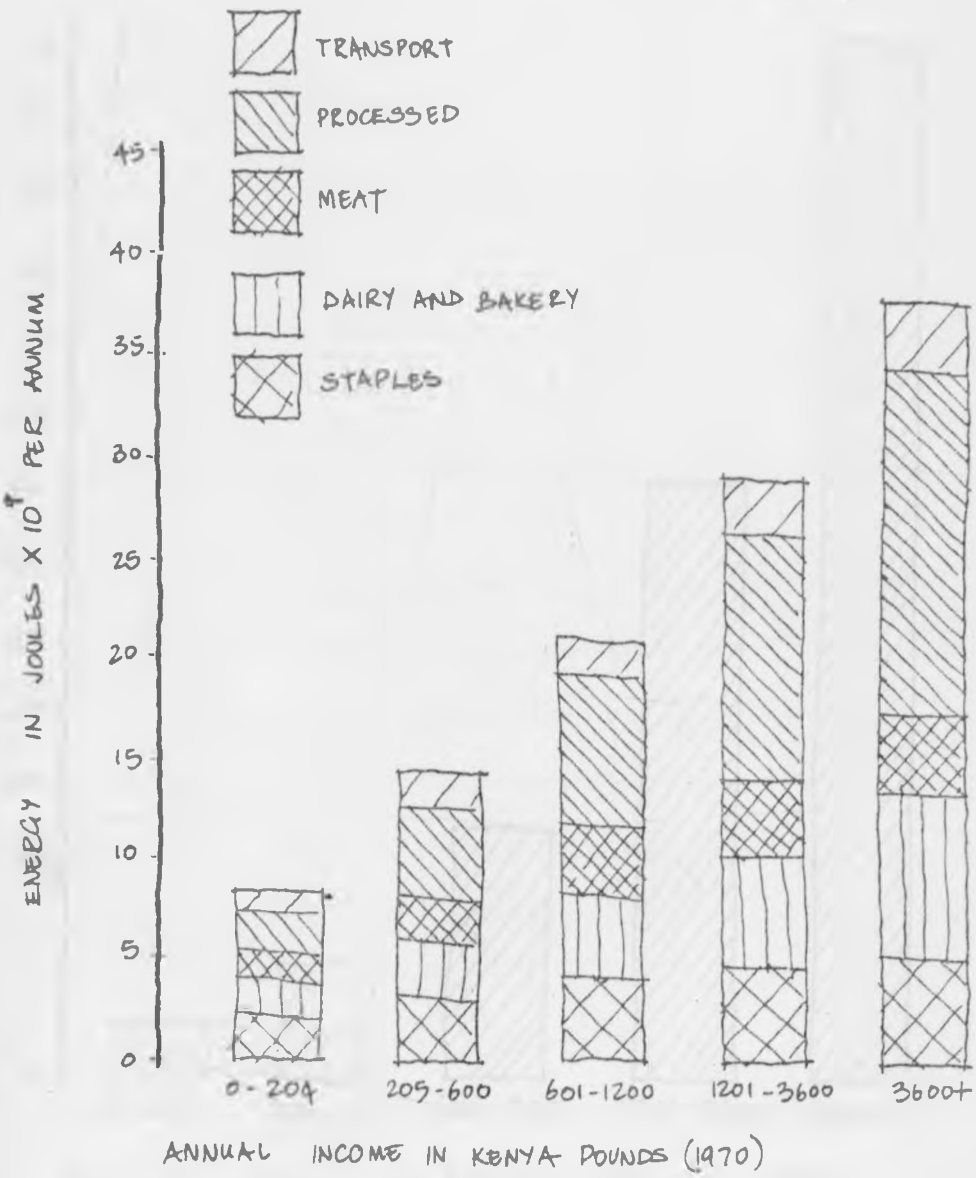
(iii) processing - the energy use associated with industrial inputs for food processing and packaging, as well as with the commercial activities of food marketing.

Figure 3.04 shows the amounts of energy consumed by the five income groups in food consumption. The food consumption is divided into four types: staple crops (grains, sugar, fruits and vegetables) dairy and bakery products, meat, and highly processed foods.

The most significant variation with income is found to be in highly processed foods and drinks. From less than one quarter of the embodied energy for the lower income level, the energy is processed food increases eight fold and accounts for half of the embodied energy of the highest income groups.

Figure 3.04

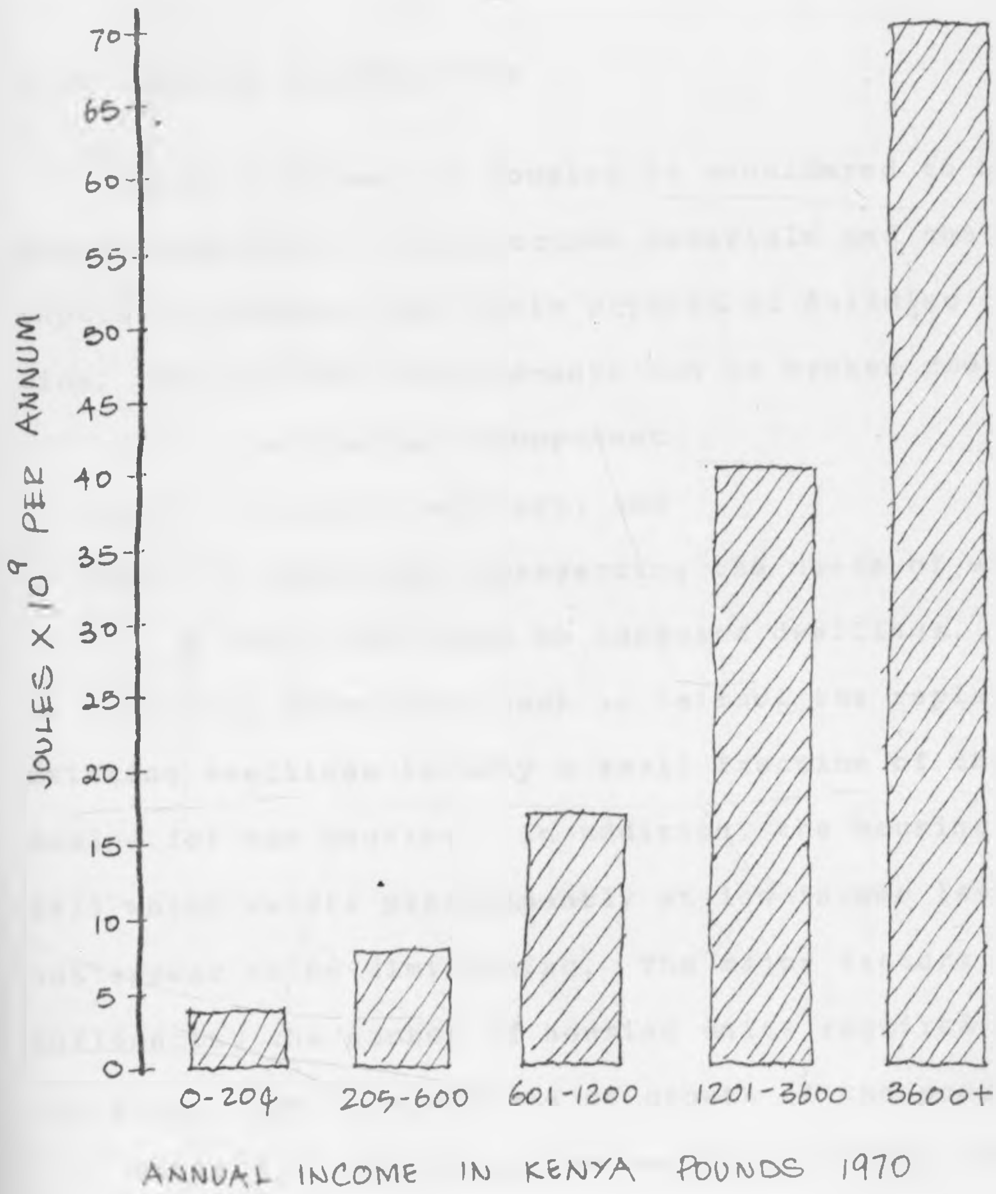
Food-Embodied Energy per Household in Nairobi



Source: McGranahan, *et al*. *Op. Cit*.

Figure 3.05

Construction - Embodied Energy Per Household



Meat, dairy and bakery products which generally require larger energy inputs to meet protein and food energy requirements also increase by a factor of four from the lowest to the highest income groups.

3.05 HOUSING CONSTRUCTION

Energy consumed in housing is considered to be that energy embodied in construction materials and the labor inputs, throughout the whole process of building construction. New housing requirements can be broken down into

(i) a replacement component,

(ii) a growth component, and

(iii) a component representing the needs of existing households with no adequate dwellings.

In a growing urban area such as Nairobi the replacement of existing dwellings is only a small fraction of the total demand for new housing. In addition, the housing short fall which exists predominantly at low income levels does not appear to be diminishing. The major factors influencing the number of housing units required are, therefore, the natural rate of growth of the population.

Table 3.05 indicates the amount of energy consumed in housing construction, for each of the income groups as well as the amount of floor space taken up by those categories of housing. Figure 3.05 shows the amount of energy consumed per household in Nairobi in housing construction.

3.06 SCENARIOUS FOR ENERGY SHORTAGE IN NAIROBI

Two scenarios are presented below, to simulate the sequence of events that would occur in case of a shortage of energy supply in Nairobi. The energy source whose supply is most perilous and the one which would have the greatest consequences in Kenya is imported oil. Nairobi, because of its high oil consumption would suffer the most.

(i) Scenario One: Constrained Oil Supplies to Kenya

Kenya has never had to ration petrol even in the worst of the oil shortages but this record is hard to hold for long. Almost 100 per cent of it comes from Iran and Saudia Arabia in exchange for about 30% of the country's foreign exchange. The precarious population situation in the Middle East made even worse by the possibility of the extension of Soviet influence, a situation which could be worsened by an American military intervention, can increasingly constrain oil supplies to Kenya. The Mobasa Nairobi oil pipe line would dry up. It would be gradually replaced by an increase in oil tankers which would deliver the last supply to the capital before they also have to stop. The last barrels would probably be consumed by public vehicles: buses, ambulances, fire engines and some would be reserved for military supply and top government administration. Meanwhile transportation would have to be increasingly done by animated methods including walking.

The lack of convenient transportation would gravely affect industries and many businesses would close both for lack of employees and consumers and of their daily stock deliveries.

Liquid gas supplied to Nairobi from Mombasa would also decline. Families would start by substituting this fuel by electricity for those who can afford the necessary equipment, and by charcoal and fuel wood for those who are too poor to afford the new equipments. Even charcoal and fuel wood would become scarce and more expensive due to the high demand. In an extreme case many people would flee to the country side where the dependency on oil and gas is less and thus bring to a halt most of the economic activities of the city.

(ii) <u>Scenario Two: Increase in Price of World Oil Supplies</u>

An even more conservative scenario could easily be conceived. Higher OPEC oil prices seem assured for the future, the only questions being how soon and how high. Any price increase has immediate, adverse effects on all oil-importing nations, causing a direct loss in national income. It is estimated that for every $1 per barrel increase in oil price, Kenya's exports earnings would have to increase by about 1¼ per cent. This expansion in exports will not be possible in the present global recession and possible depression. Yet the Kenyan economy itself depends on imported oil. This implies that increasingly more capital would be diverted from development projects to oil imports. The city's economy would thereby be threatened and would probably grind to a gruesome halt. The imagination of all the city streets being used by less than fifty per cent of the present number of vehicles and fifty per cent packed with empty tanks is not a very far fetched idea.

Buses would increasingly carry more people from home to work. Taxis would quickly run out of gasoline and business. The matatus (jitneys) could be alloted some amount of gasoline through a rationing system to continue providing their services. The shortage will mean they have to be filled even beyond their capacity. The majority of people would walk to and from work, particularly the poor who need the money for the necessities of life.

The city's woody biomass would be consumed as fuel as the shortage gets worse. Trees and bushes would be used up as charcoal gets out of reach of the very poor.

Food would be in a severe shortage as transportation becomes more difficult. The little food that gets to the city may not even get to the market. Prices would be high and many people would have to eat less. Theft would increase particularly of the foodstuffs that is grown by squatters in the river valley but this food reserve would soon be finished. If the situation gets worse food could be imported and rationed.

Many basic services would be halted and as in scenario 1 people would outmigrate to the rural areas.

4

ENERGY RESOURCE AND URBAN PLANNINIG

4.01 SETTING A CRITERIA FOR ENERGY-EFFICIENT URBAN DESIGN

The previous two chapters have revealed three significant factors that must be given a more serious consideration in the overall planning and design of the city of Nairobi in relation to its energy demands and consumption patterns.

Chapter three revealed that Nairobi

1. has a low resilency to severe energy shock
2. has insufficient local resources of both food and energy
3. has extremely high energy-inefficient consumption patterns.

Clearly, alternative sources of energy must be sought for the city. Exploration for oil in the North Eastern Province may continue, but this entails enormous sums of money for which a great competition with other development projects exists.

A criteria can then be established against which an urban design plan can be assessed for efficiency in energy consumption. An energy efficient urban plan would be one that:

(a) Minimizes the consumption of imported energy particularly in transportation.

(b) Maximizes the use of the least-energy-consuming modes of transportation namely walking and cycling.

(c) Minimizes the use of the city's natural resources namely land and the existing biomass.

(d) Promotes the increase of food and energy resources in and around the city.

(e) Promotes community and housing designs that maximize the use renewable resources as well as recycling of waste.

An energy-efficient city must be one that not only attempts to provide sufficient food and energy resources at the present time but one that promotes careful usage to minimize waste and sets up a strong strategy calculated to meet increased future demand of these resources. Methods of increasing energy resources are considered in this chapter and an example of an energy-efficient community is presented in the following chapter.

It is not to be presumed that all the issues raised so far can be solved through urban design alone, but it is the writers view that a sensitive urban planning strategy would set the basis in which most of the energy problems could be alleviated and the risk and effect of a global energy shortage minimized. The city would essentially be planned to minimize its dependency on imported sources of energy through efficient use of it and through well planned usage and replenishment of renewable resources. Some alternative sources of energy are presented below.

4.02 WOOD AND WOODY BIOMASS

The importance of woody biomass in Nairobi and the rate of its depletion in and around the city have already been considered. Two methods by which the supply of this form of energy could be maintained at a higher level are described below, namely, increasing the quantity of woody biomass and secondly increasing the efficiency of the processes used to convert the biomass into fuel energy.

Increasing the Quantity of Woody Biomass

The sun is the greatest source of energy and green plants capture the energy of sunlight and convert it via photosynthesis into food and fuel. Through this process the sun is believed to store 17 times as much energy in plant matter as is presently consumed world-wide.[1] This can be put into another way, thus, the amount of solar energy falling on the earth's surface in just 10 days is equivalent to all fossil fuel reserves on earth. Also dry plant matter has an energy content roughly equivalent to 60% of the energy content of bituninous coal. Here then lies one of the principle methods by which a city such as

[1] Dr. Norman Myers, Bio energy for Kenya: Some Technical Possibilities. Paper for Symposium of Kenya Academy of Sciences and Swedish Academy of Science. Nairobi, 1979.

Nairobi (the country is also implied) might increase its energy reserves. If efficient methods of generating bio-energy are developed this stored solar energy could be used not only for domestic purposes as fuel-wood and charcoal but also as fuel for motor vehicles.

Trees go on producing wood, which is a very dense form of biomass fuel, for years on end, and provide continuous live storage without loss. Through pyrolysis, one metric ton of tropical dry wood can yield 12½ litres of methanol, 36 litres of wood oil, a light tar 330 kilograms of charcoal, and 140 litres of acetic acid, 11½ litres of creosote oil, 7½ litres of esters and 33 kilograms of pitch.[2] It is estimated that a 12,000 hectare plantation of fast-growing trees could generate energy equivalent to one million barrels of oil per year.[3]

A large variety of plants and trees exist which have a high potential for energy generation. A tree species with apparently outstanding potential is giant ipilipil, (whose botanical name is Leucaena Leucocephala).[4] This

[2] D. Earl, Forest Energy and Economic Development Clarendon Press, Oxford U.K., 1975.

[3] D.S. Clifton and J.W. Tatom, Energy-Food Plantations for the Third World . Engineering Experiment Station, Georgia Institute of Technology, Atlanta, Georgia U.S.A., 1976.

[4] M.D. Benge and H. Curran, Bayani: A Source of Fertilizer Feed and Energy for the Philippines . Agricultural Development Seminar Series, US AI Manila, Philippines, 1976.

tree can grow 4 meters tall in 6 months, almost 10 meters in 2 years and over 15 meters in 6 years; the trees can be cut at 3 to 6 year intervals, where upon the stumps resprout coppice fashion and one hectare of ipilipil can regularly produce 35 to 50 cubic meters of wood per year.[5]

Leucaena charcoal has a heating value of about 7,000 calories per kilogram (about 12,000 BTU per pound) which is 70 percent of the heating value of fuel oil.[6] It can be made in simple retorts or pits on small or large scale and offers a potentially lucrative industry where it is located. It is believed that a 9000 hectare tree farm of ipilipil will produce enough wood to fuel a 75 megawatt power plant.

Eucalyptus has also a high potential as a bio-energy source. It grows at least 30 centimeters per month, and reaches 20 meters in height and over 25 centimeters in diameter at breast height after only an 8 year rotation, whereupon the plantation produces commercial wood at rates of 30-50 cubic meters per hectare per day.[7] Eucalyptus

[5] Dr. Norman Myers, op. cit.

[6] Leucaena, Promising Forage and Tree Crop for the Tropics. National Academy of Sciences, 1977.

[7] W.E. Hillis and A.G. Brown (editors) Eucalyptus for Wood Production. Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia.

is already being grown as fuel wood on marginal land north west of Kisumu in Kenya.[8] Research on various species of eucalyptus as well as other genera that will grow well on marginal land should be carried out so that maximum potential may be achieved.

Ipilipil and eucalyptus while producing biomass that could be used for methane generation, their main use would be as firewood, charcoal, briquettes (described later) as well as building components. Several other plants are available that could be used for "growing gasoline" whereby they would be processed to generate alcohal fuels. Any automobile will run off a mixture of 90 percent gasoline and 10 percent ethanol while a modestly modified automobile will run off ethanol alone.[9] This would be especially suited to buses which will increasingly become more important in the future. Alcohol has a higher density than gasoline and the power of a motor running off alchol is 18 percent higher than a motor running off gasoline.

The most productive of all well known plants is sugar-cane which under the best circumstances can produce as much as 100 tons of biomass per hectare per year.

[8] Trees for People. International Development Research Center, 1977.

[9] Dr. Norman Myers, *op. cit.*

Brazil already produces alcohol from sugar cane and is aiming at replacing 20 per cent of gasoline with alcohol by 1980. Cassava with 25 percent starch content almost twice as high as the sucrose content of sugar cane has also a high promise for Kenya. Another plant with high potential is sweet sorghum which can be easily fermented and turned into gasohol. According to research conducted by Dr. Steven Kresovich and Dr. William Lawton, agronomists with the Battelle Laboratories at Columbus, Ohio, U.S.A. some 40,000 square kilometers of sorghum could produce 3 quads of energy equivalent to 1.5 million barrels of petroleum per day for one year.[10]

Hydrocarbon trees which use solar energy to produce hydrocarbons like oil instead of carbohydrates like sugar are already growing in the wild in many parts of Kenya. The various species of euphorbia adopted to growing in areas which are too dry for other conventional purposes such as agriculture have a high potential for Kenya and for Nairobi in particular. They would be highly suitable for nine-tenths of Kenys's territory that does not receive enough rainfall for present day agriculture. Small scale experiments indicate that one hectare of Euphorbia trees could produce between 25 and 125 barrels of oil per year

[10]Dr. Norman Myers, Ibid.

at annual production costs of about U.S. $20 per barrel to be compared with the already much higher price of OPEC oil.[11]

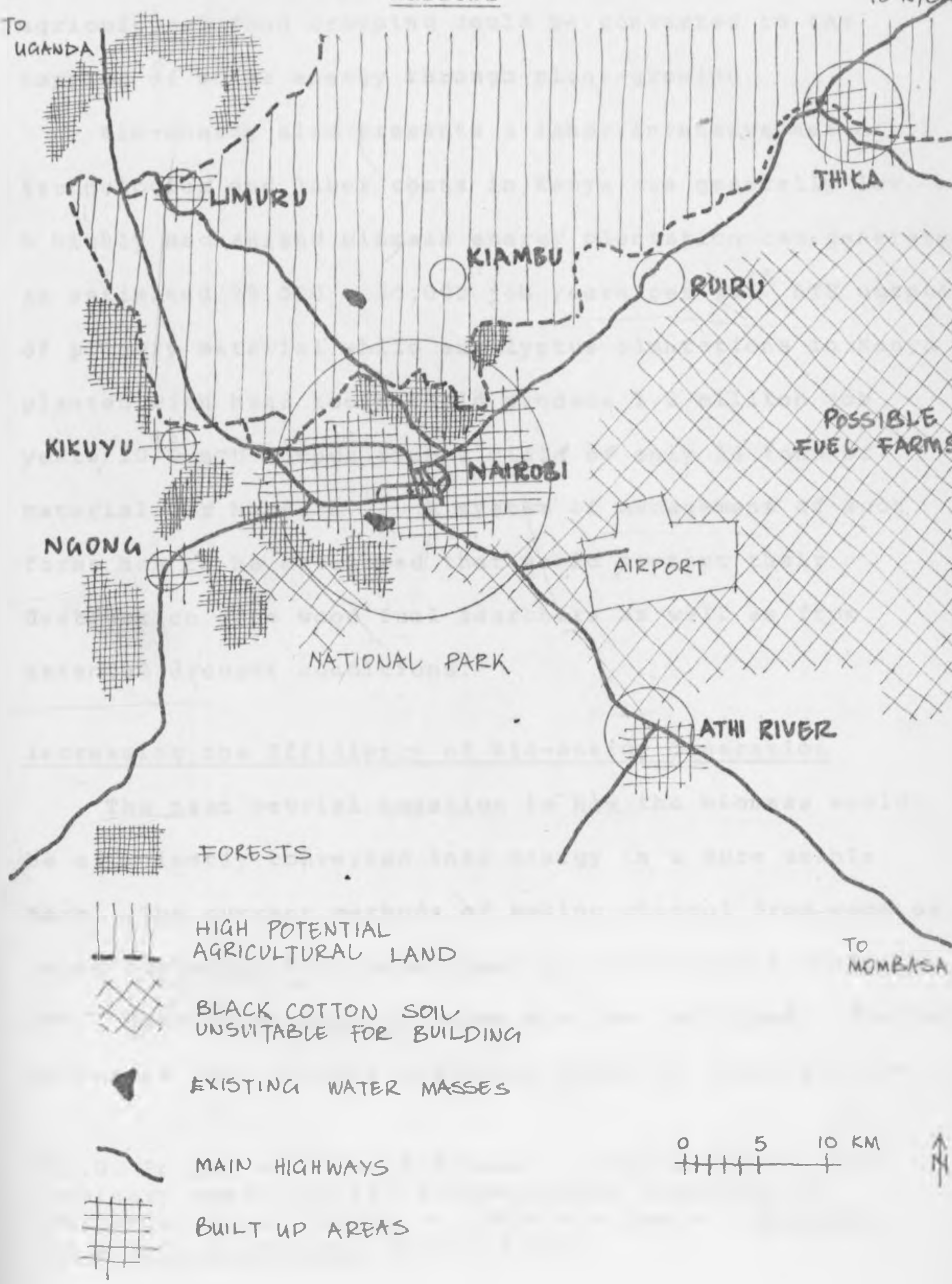
Research needs to be done to determine which trees and plants would be most suitable for the Nairobi climate and most economically viable. Methods of cross breeding could also be investigated to increase the yields per hectare. Such plants would present a renewable source of energy with several advantages. The fuels would be of good quality; the sulphur content of plant matter is generally below 0.1 per cent, compared to an average of about 2.5 per cent for coal, while the ash content of terrestrial plants is typically 2-5 per cent compared with an average of about 14 per cent for coal. Biomass-derived energy would be associated with few of the environmental drawbacks that accompany large scale use of coal oil and nuclear energy.

Figure 4.01 shows the areas around Nairobi that could be designated as bio-energy farms. Through cooperation between the Ministry of Energy, The City Council and the Department of Forestry these areas could be developed as farms to "grow" energy. Land that has already been considered as too poor for building purposes and which

[11] Dr. Norman Myers, *op. cit*.

Figure 4.01

Existing and Potential Energy and Food Resources Around Nairobi



does not have a high potential for conventional agriculture, as well as river valleys not used for agricultural food cropping could be converted to the tapping of solar energy through plant-growing.

Bio-energy also presents a labor-intensive set of technologies and labor costs in Kenya are generally low. A highly mechanized biomass energy plantation can generate an estimated 25,000 - 30,000 job years per 10^{15} BTU output of primary material while eucalyptus plantations in Kenya planted with hand tools could produce 1.2 million job years/10^{15} BTU output from a yield of only 14 tons of material per hectare.[12] A system of management of such farms has to be developed that would protect their destruction from wood fuel searchers as well as from extended drought conditions.

Increasing the Efficiency of Bio-energy Generation

The next crucial question is how the biomass would be efficiently converted into energy in a more usable form. The current methods of making charcol from wood or using fuel-wood have been shown to be extremely inefficient. More efficient processes must be developed. Further, processes that provide different forms of fuels such as

[12] A.D. Poole, and R.H. Williams. Flower Power: Preliminary Survey of the Potential and Problems of Utilizing Solar Energy via Photosynthesis. Bulletin of Atomic Scientists 32(5): 47-58.

gas and oil are also necessary if the city is to minimize its dependence on imported energy.

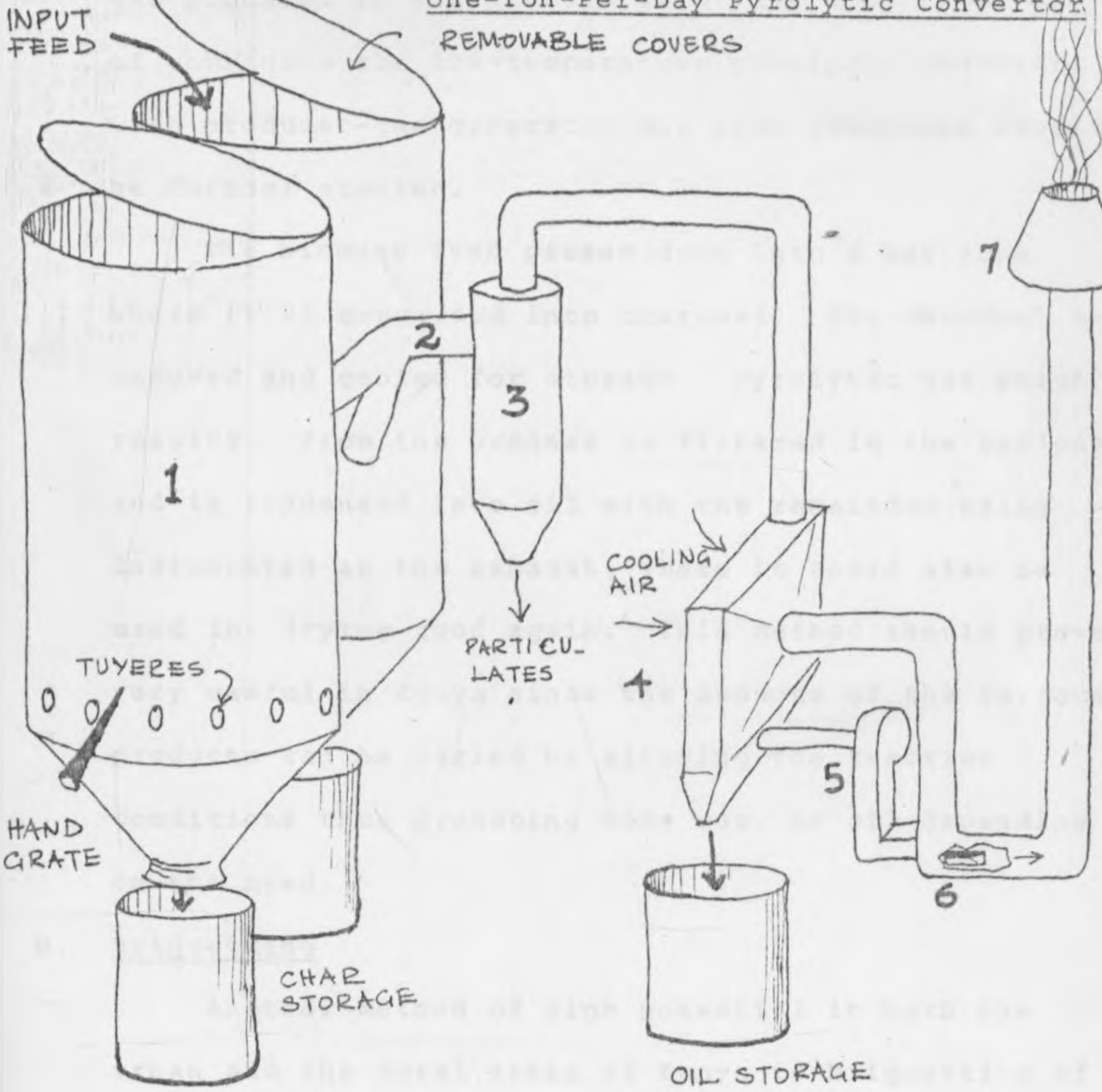
a. Low-Temperature Pyrolysis

An attractive method of converting biomass into high-energy fuels that can be stored, transported, and used much more efficiently and conveniently than its original form is low-temperature pyrolysis. Low-temperature pyrolysis produces charcoal and oil, which are the fuels that are currently used by the people and therefore this system does not require any changes in the living patterns and does not require any radical changes in any household gadgets. This method can also use a large variety of forest and agricultural waste as well as chopped wood.

Several different versions of low temperature pyrolytic convertors exist, and more research is necessary to determine the one that would be most suitable to Kenya. Figure 4.02 describes one such system which requires one ton of dry feed material per day and producing 0.25 ton of charcoal and 0.15 ton of oil per day.[13] The possibility exists of using the

[13] John W. Tatom, and Filino Harahap Pyrolytic Conversion of Agricultural and Forestry Wastes to Alternate Energy Sources in Indonesia . Agency for International Development, 1977.

Figure 4.02
One-Ton-Per-Day Pyrolytic Convertor



1	KILNS	SHEET METAL CONSTRUCTION
2	DUCTING	SHEET METAL - INSULATED
3	CYCLONE	SHEET METAL INSULATED
4	CONDENSER	3-PASS, FORCED CONECTION COOLED
5	DRAFT FAN	CENTRIFUGAL, APPROX 60 CFM
6	EJECTOR	PUMPING - SECONDARY TO PRIMARY FLOW RATION - 2
7	BURNER	DIFFUSION

Source: John W. Tatom and Filino Harahap.

gas produced in the process is drying food crops and of combining the low-temperature pyrolytic convertor with producer-gas generator and such processes should be further studied.

The biomass feed passes down into a hot zone where it it converted into charcoal. The charcoal is removed and cooled for storage. Pyrolytic gas which results from the process is filtered in the cyclone and is condensed into oil with the remainder being incinerated at the exhaust, where it could also be used for drying food again. This method should prove very useful in Kenya since the amounts of the various products can be varied by altering the reaction conditions thus producing more gas, or oil depending on the need.

b. Briquetting

Another method of high potential in both the urban and the rural areas of Kenya is briquetting of woody biomass including waste. This process converts woody biomass into high energy clean, burning, low ash residue and is suitable for a wide variety of industrial and domestic fuel applications and easily handlable.

The woody biomass after it has been dried and ground properly is blown through a conveyor pipe to the briquetting machine for compression under high pressure ranging up to about 20,000 lb per square inch.[14] One American design, the Mod-Log Machine utilizes any combustible wood waste with 10% or less moisture content and has a constant continuous extrusion rate of 3.4 ton per hour of densified briquettes.[15] The produced briquettes have a moisture content of 3.5% to 5% and a heating value of 8,350 BTU per pound and is advertised as leaving only 1.25% ash.

This method has evidently higher advantages than using raw fuel wood and its applicability to Kenya should be studied. The coffee tree prunings, coffee husks, and various other forms of agricultural waste which are currently not used at all could become major sources of energy in the rural areas while the proposed fuel crop firms for Nairobi would provide the necessary raw material for this process. Further studies need to be done to determine the cost efficiency of this process as well as its applicability in the country.

[14] S.M. Ishaq, A Study of the Fuelwood Problem in Pakistan. Pakistan Forest Research Institute Peshawar, 1964.

[15] Donald G. Campbell, Mod-Log Machine Specifications. Trans Arctic Air, San Diego, California, 1980.

c. Biogas Generation

Cooking gas will continue to be in high demand in the city. Biogas could be made in the rural areas where there are more farm animals such as cows and pigs. In Nairobi it could be produced by digesting anaerobically the biomass grown in the fuel farms and community wood lots. Table 4.01 gives the quantity of gas that can be obtained from some common fermentation materials.

Fermentation material must be properly mixed for the correct ratio of carbon to nitrogen, in order to ensure full gas production. The Chinese have, through long practice and experience found that the proportions that work best are 10% human excreta, 40% animal manure and crop residues and 50% water. The mixture must be selected according to local conditions to make efficient use of available materials.[16]

While water may be difficult to get in sufficient quantities in some rural areas, the water from sewers in the city should prove to be more than sufficient. The problem which has to be overcome is the social taboo in using human excreta. This could be solved by directing the sewer straight to the digestor and

[16] E. Ariane van Buren, The Chinese Development of Biogas and its Applicability to East Africa Kenya Academy of Sciences, Nairobi, 1979.

Table 4.01

Gas Yield of Some Common Fermentation Material

MATERIAL	AMOUNT OF GAS PRODUCED PER TONNE OF DRIED MATERIAL IN CUBIC METERS	PERCENTAGE CONTENT OF METHANE
GENERAL STABLE MANURE FROM LIVESTOCK	260-280	50-60
PIG MANURE	561	–
HORSE MANURE	200-300	–
RICE HUSKS	615	–
FRESH GRASS	630	70
FLAX STALKS OR HEMP	359	59
STRAW	342	59
LEAVES FROM TREES	210-294	58
POTATO PLANT LEAVES AND VINES ETC	260-280	–
SUNFLOWER LEAVES AND STALKS	300	58
SLUDGE	640	50
WASTE WATER FROM WINE OR SPIRIT MAKING FACTORIES	300-600	58

Source: E. Ariane van Buren. op. cit.

leading the sludge by channels straight to the farm so that there is no actual handling of the human waste.

Community organization, technical support from the government and education of the people as to how best to produce and use biogas in groups of about 15 households is necessary for the method to be effective in Nairobi.

Possibilities should also be investigated for using the city's sewage for the generation of biogas which can be used as cooking gas for a small urban community and the sludge used as fertilizer either for food crops or even for the fuel farms where the risk of transference of biological organisms to other people would be minimized. The gas could also be used to generate electricity for which there will always be a growing demand.

The municipal solid waste (MSW) from Nairobi should also be investigated as a possible source of thermal and electrical energy as well as gas. Incinerating the waste may be the only method cheaply available in the future when there will be less land available and transportation costs will be high.

4.03 CONSERVATION ENERGY

Daniel Yergin[17] has described an alternative energy source which deserves a separate treatment. It does not pollute and it is one that can provide the energy the conventional sources may not be able to furnish. To it he gives the name energy efficiency or more prosaically "Conservation Energy". It is no less an energy alternative than oil, gas, coal or nuclear. It may also well be the cheapest, safest, most productive energy alternative readily available in large amounts. All it requires is only modest adjustments in the way people live. The possible energy savings would be the equivalent of the elimination of large amounts of improrted oil. Conservation can also stimulate innovations, employment and economic growth.[18]

It has already been shown that most of the country's woody biomass will be depleted in a few more decades due to the high consumption; yet the amount of energy that is received from this energy source have also been shown to be extremely low. The amount of oil that is consumed

[17] Daniel Yergin, "Conservation: The Key Energy Source" in Energy Future. editors, Robert Stobaugh and Daniel Yergin. Random House, New York, 1979.

[18] U.S. Congress, Joint Economic Committee, Creating Jobs Through Energy Policy: Hearings, 95 Congress, 2nd Session.

in Nairobi has also been shown to be consumed mainly by private automobiles using congested city streets and most times having single occupants. Electricity gets wasted in industrial processes where heat may be generated and radiated as infra red, or put into the sewers as hot waste water.

Conservation can be thought of as a form of adjustment, entailing such things as making motor vehicles, industrial processes, and home appliances more efficient and capturing their waste heat. This can be called "productive conservation", which encourages changes in capital stock and daily behaviour that promote energy savings in a manner that is economically and socially non disruptive. Its aim is to use less energy than has been the habit to accomplish some task - be it to heat steel in a car assembly plant or to roast green maize.

In Nairobi, the most results of energy conservation action would be obtained in reorganizing transportation within the city, designing building particularly office and industrial buildings so that they do not use any artificial lighting or ventilation and in making home appliances more efficient. Educational campaigns must accompany any conservation efforts so that people are made aware and responsive to such efforts. As two prominent analysts Lee Schipper and Joel Darmstader, have expressed it, "The most impelling factor in conservation is the cost of not conserving".[19] If people can assess the benefits of conservation efforts in terms of shillings, they will be more likely to change their habits if only to reduce their monthly bills.

a. Conservation in Commercial Buildings

Commercial buildings include many kinds of enterprises; the most important for Kenya are public services (schools, hospitals); hotels and restaurants, office buildings (including government) and stores. Energy use in large structures in Kenya depends critically on the building shell design. Many of the more recent buildings in Nairobi exhibit elaborate systems of shading to keep direct sunlight off the windows.[20] However many designs have not utilized to the maximum potential the good climate that Nairobi is known for to minimize energy consumption. For example Kenyatta Conference Center with its lavish water cooling systems, consumes 2.7×10^6 KWh of electricity which is about a fifth of the total energy consumed in private office and bank buildings.[21]

[19] Lee Schipper and Darmstadter, The Logic of Energy Conservation .

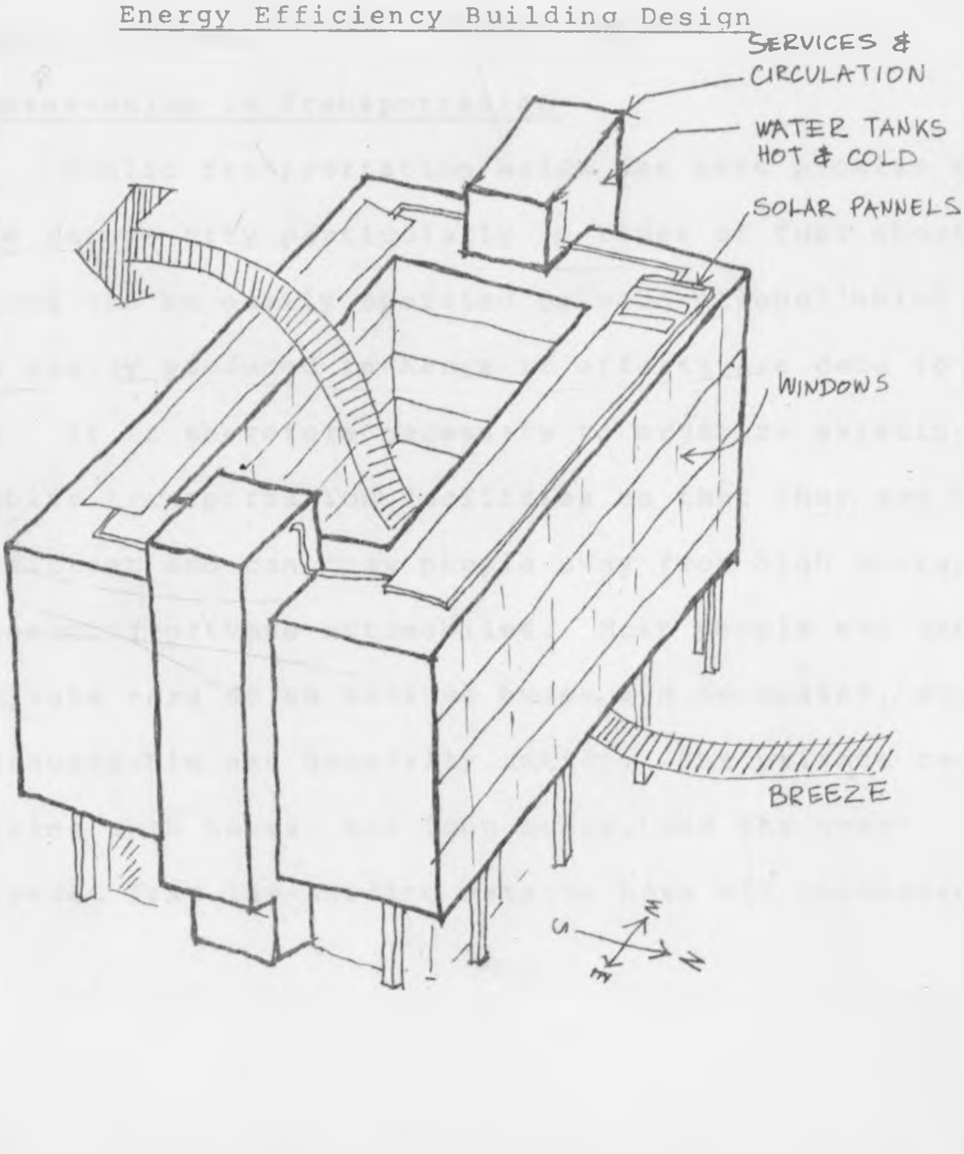
[20] Lee Schipper and Oyuko Mbeche, Energy Demand and Conservation in Kenya . Kenya Academy of Sciences. Nairobi, 1979.

[21] Lee Schipper and Oyuko Mbeche, Ibid.

Energy conserving commercial building would be those that have their axes oriented east-west, with no windows on the east-west ends and shading on the north-south sides. Such designs maximize free day light, minimizes cooling needs if any and only sometimes require use of small electric heaters in some rooms during cold months. Narrow building that can be evenly lit by natural means could be conceived in the form of "court yard" arrangements as indicated in Figure 4.03 below.

Figure 4.03

Energy Efficiency Building Design



Solar water heating should be utilized in all office and hotel buildings as well as in public buildings so as to conserve on fossil fuels and electricity. Tax disinsentives should be applied by the government on new buildings to discourage designs that use artificial means of heating and lighting. Government can make solar energy utilization mandatory as a condition for granting building permits. Office buildings could even generate their own electricity from solar energy when this technology becomes more economically competitive with other conventional energy sources.

b. Conservation in Transportation

Public transportation holds the best promise for the future city particularly in times of fuel shortage. Buses can be easily operated on wood alcohol which can be easily produced in Kenya if efforts are done to do so. It is therefore necessary to organize existing public transportation facilities so that they are more efficient and can draw people away from high energy-consuming private automobiles. Most people who use private cars do so because buses are congested, slow, undependable and generally untidy. The private cars during rush hours, the long buses, and the over-crowded less law-abiding matatus have all increased congestion in the city, making it very unsafe for pedestrians and almost completely impossible for cyclists - and so even more people buy cars and the cycle continues.

The following measures could be adopted to minimize congestion in the city and to improve public and non-motorized transportation.

1. Recognition of the matatu (jitney) service and the imposition of conditions that are aimed at improving their service. These would include mandatory periodic checks, assignments of specific routes of operation and the fixing of some standard fares.
2. Adapting a highly well-designed transport system segregating buses from trucks, taxis, matatus and private cars on principal streets and highways. This would leave the more easily manouverable vehicles to use the narrow and tortuous streets more effectively while allowing buses to run more smoothly. Buses could also be provided with an electronic devise to control street lights, thus giving them a higher right of way.
3. Quieter, cleaner, and more comfortable light transport executive minibuses serving from doorsteps to places of work in the city combined with a telephone service (dial-a-ride-system)

could be developed to minimize private driving by higher income people and business executives.

4. Car pooling and van pooling, options now opera-ing in other large cities such as San Francisco, aimed at minimizing the number of vehicles entering the city should be investigated. Incentives should be adopted that encourage people to pooling associations rather than drive half-empty cars to work. Government restrictions on car ownership should increase pooling associations.
5. Congestion pricing could also be introduced whereby restrictions are placed to discourage driving vehicles with less than capacity loading in some sections of the city during rush hours. Vehicles requiring parking or using congested streets could be charged and businesses locating in congested areas should also be taxed higher for increasing congestion. Congestion could also be minimized by staggering working hours.

The above measures would result in better flows of traffic, less fuel consumption, less threat to the environment and even allow opportunities for better planned pedestrian and cycle systems in the city. Fuel-concerving methods of transportation should be investigated and encouraged by designing the streets to accommodate them more effectively. These would include the following:

1. Light roads which allow vehicles to flow unimpeded to shops, schools, small manufacturing industries without conflicting with the heavier traffic and pedestrians.
2. Side steets and slow ways which encourage aid-to-walking vehicles such as mopeds, scooters, light three wheeled delivery and private vans, while also providing pedestrians cyclists and hand-pulled carts a safer and a more convenient circulation system within the city.

Further reduction in trips could be achieved by improving telephone services in the city and public transportation can be made more feasible by increasing urban densities and minimizing urban sprawl. Also the production of food at the consumption points would greatly minimize the energy that is required for transportation.

4.04 ANY ENERGY EFFICIENT CITY STRUCTURE?

A general survey of literature on energy and the structure of the city seems to indicate that this relationship has not been fully studied and that there is more work that still needs to be done. This is particularly so in the developing countries where relatively less study on any energy related issue has been done. There does not therefore seem to be any "off the shelf" prescription for an energy-efficient structure of a growing metropolis and it does seem that each design problem has to be dealt with on its own merit. There however seems to be a greater body of literature prefering a decentralized structure to a sprawl-like urban form for a growing Third World metropolis.

A paper for the United States Agency for International Development on the energy needs of the developing countries has indicated that

> "Although there is some question as to how much leeway planners have in changing the location of economic activities, there seems little doubt that many of the larger cities in the developing countries have reached a physical size where their spatical configuration imposes severe constraints on attempts to provide more energy-efficient services."[22]

The paper has further indicated that

> "The largest urban centers with their congestion and pollution problems are far less energy-efficient than closely spaced networks of smaller urban nuclei."

In seeking a solution to the high energy demands of the larger Third World cities, the USAID paper had suggested that,

> "Decentralization of work places, manufacturing sites and residences would not only reduce transportation energy demands,

[22] United States Agency for International Development, Energy Needs, Uses, and Resources in Developing Countries and the Implications for U.S. Assistance. Brookhaven National Laboratory, 1978.

> but would also reduce some of the large energy consumption differencials between rural and urban settlements."

Michael Thompson after analyzing various traffic management policies in major cities of the world has proposed what he refers to as Low-cost strategy appropriate for cities of the developing world where heavy expenditures on luxurious rail systems are inappropriate.[23] He states that this strategy must require little infrastracture, aim at minimizing investments in lavish new transport facilities. He suggest that buses and trains must carry the greater part of the traffic end the roads must be managed so as to make this possible.

The physical layout of this strategy consists of a high-density city with a major center served by numerous bus (or train) corridors in which non-residential activities are concentrated.

He indicates further that employment in the city center should be limited to about 500,000 to 700,000 in the cities of two million people. Other employment opportunities should be provided by

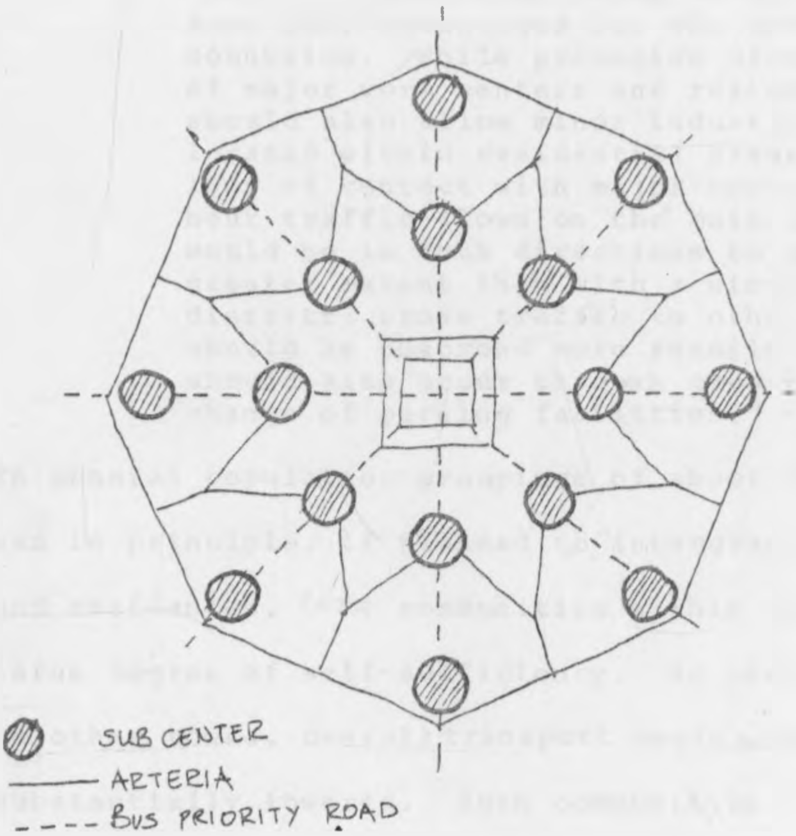
> "Creating a second line of small, pedestrian-scale sub-centers and expanding some of these sub-centers into larger stragetic sub-centers with internal transport facilities provided by bus or train."

[23] Michael Thompson, Great Cities and Their Traffic . Victor Gollancz Ltd. London, 1977.

Figure 4.04 is a graphic representation of Thompsons low-cost archetype.

Figure 4.04

Low Cost Urban Strategy



Source: Michael Thompson. op. cit.

The views expressed above are shared by the World Bank on its study of urban transportation problems in the Third World.[24] The bank suggests that transportation

[24]World Bank, Urban Transport - Sector Policy Paper . World Bank, 1975.

within a large metropolitan area could be made more effective if urban activity centers are developed around the major city and connected by a system of public transport. In seeking a solution to the transportation problems in Third World countries the bank notes that

> "Multinuclear urban forms should indeed have many advantages for the developing countries. While promoting close location of major work centers and residencies, they should also allow minor industry to be located within residential areas without loss of contact with major centers. Peak-hour traffic flows on the main arteries would be in both directions to a much greater extent than with a single business district; cross traffic to other areas should be absorbed more readily. Economies should also occur through greater interchange of parking facilities."

In general population groupings of about 75,000 or more can in principle, if planned to intergrate employment and residences, form communities within the city with a large degree of self-sufficiency. By reducing transport to other towns, overall transport needs would be substantially lowered. Such communities, or towns would be developed gradually where nuclei towns already exist. Any reduction in transportation means a substantial amount of energy would be saved.

If Third World cities can learn from the cities of the developed countries, then Peter Halls views gives further illumination to the problem caused by gigantism.

After analyzing the metropolitan structures of seven large world metropolis he has concluded that:

> "...the polycentric metropolitan regions like the Dutch Randstad or the German Rhine-Ruhr region, apparently work with no less efficiency than single-centered giant cities like Paris or London",

But he has further added that:

> "they suffer much less severe problems of traffic congestion or long commuter journeys. They achieve success by concentrating specialized types of activity, or systems of urban linkage, into partly specialized centers."

Examples where the polycentric city or the multi-nuclear urban structure have been applied are numerous in the Third World. The East Asian cities of Delhi, Jakarta, Singapore and Bangkok are four such cases. It will be sufficient here to give a brief summary of each. Delhi was studied in relation to the adjoining states and planned in an integrated manner with the region. This included several other cities which were then planned to hold a substantial number of rural-urban migrants who would otherwise have ended up in Delhi.

Jarkata with a population of 6.5 million in 1967 was planned also in a regional context with four cities within this region being designated as growth poles to be connected to the central city by a system of transportation network.

The concept plan of Singapore aims at decentralizing both populations and economic activities to several points on the island as growth centers. The central city itself is expected to retain the regional role it already plays as a financial center. The growth centers are connected with a system of mass transportation with the central city.

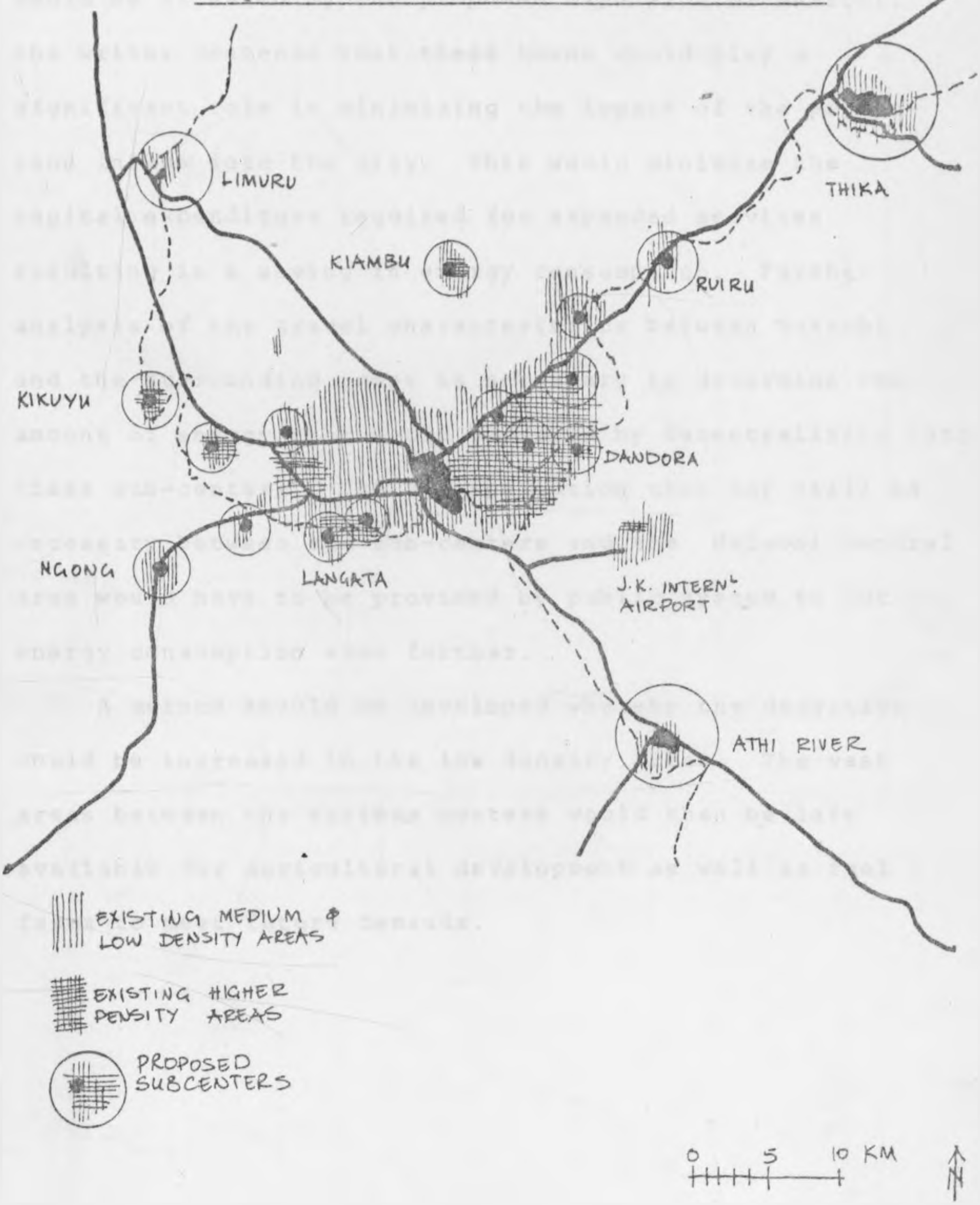
The plan for Bangkok has used an integrated regional and urban land use and transportation approach. The concept of a polycentric development with the various centers connected by radial transport routes to the central city was adopted. The central city of Bangkok still remains the main service center of the region. The population of Bangkok was over 2.5 million in 1967.

All these cities are much larger than Nairobi but provide useful approaches to the problem of "gigantism" and inefficiency that Nairobi could be confronted with if steps are not taken to control its growth. The East Asian cities given here as examples, adopted these strategies to solve their problems of congestion and overcrowding which threatened their efficiency. Nairobi therefore can easily avoid such problems by adopting some of these policies while the situation is still manageable.

There already exists a number of embryonic growth centers around the city of Nairobi that could be developed into larger towns or major secondary downtowns as indicated in Figure 4.05. While the current City Councils

Figure 4.05

Polycentric Urban Structure for Nairobi



growth strategy for Nairobi makes no definitive indication as to how any of these towns and district shopping centers could be affected by the proposed expansion of Nairobi, the writer contends that these towns could play a significant role in minimizing the impact of the population influx into the city. This would minimize the capital expenditure required for expanded services resulting in a saving in energy consumption. Further analysis of the travel characteristics between Nairobi and the surrounding towns is necessary to determine the amount of energy that would be saved by decentralizing into these sub-centers. The transportation that may still be necessary between the sub-centers and the Nairobi central area would have to be provided by public system to cut energy consumption even further.

A method should be developed whereby the densities could be increased in the low density areas. The vast areas between the various centers would then be left available for agricultural development as well as fuel farms to meet future demands.

5

DESIGNING AN ENERGY-EFFICIENT URBAN COMMUNITY

5.01 THE LAYOUT OF THE COMMUNITY

An energy efficient community can be conceived of. Such a community will have to depend as little as possible on exogenous sources of energy. The community must therefore improvise various innovations using as much of the currently available technology as possible. Provision should also be made for the possibility of upgrading or altering the technology with time and possibly the size of the community as it expands by increasing densities vertically or horizontally. The organization of the community must be such that various levels of services and technologies can be applied at the appropriate scales.

A hypothetical community of about 5000 to 7000 people, the catchment population for a primary school[1] is considered in this proposal. This number is subdivided into four groups which form neighborhoods of about 1250 to 1750. Such neighborhoods are a suitable catchment populations for a nursery school.[2] This community could be one of the site and service schemes currently being developed, or new housing projects being built on the outskirts of the central city of Nairobi.

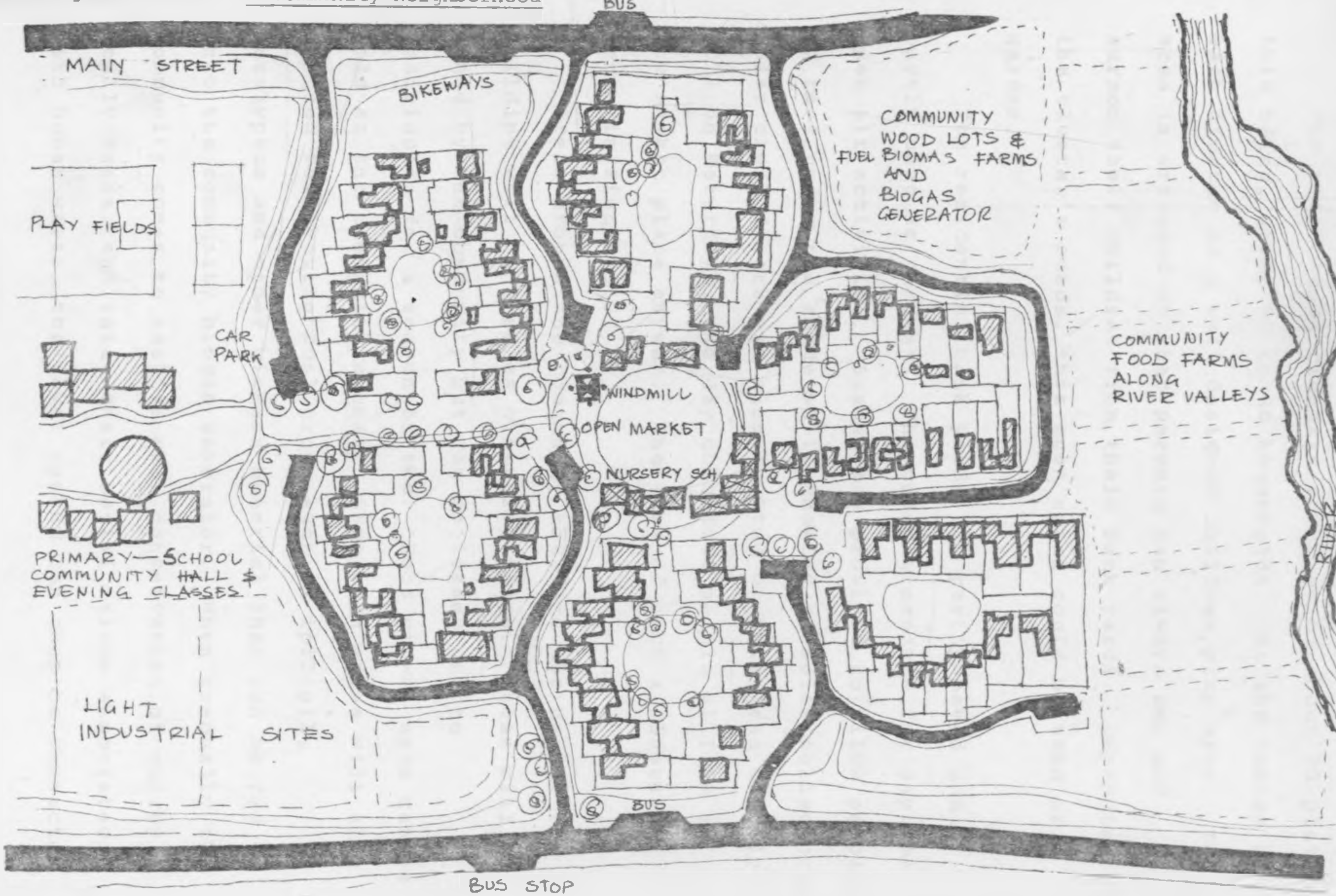
[1] Horacio Caminos and Reinhard Goethert, Urbanization Primer. MIT Press, 1978.

[2] City Council of Nairobi, Nairobi Metropolitan Growth Strategy. Appendix 3, Nairobi, 1973.

The focal point of the neighborhood is the market place - the timeless traditional activity of the Kenyan people. This could be located right in the middle of a well designed open space which is at the middle of the community. In this area also could be such facilities as nursery schools, day care centers, small multipurpose halls all of which are designed to be usable during day and night for evening adult literacy classes. A possible organization of such a neighborhood is demonstrated in Figure 5.01.

The market area will be used for such activities as open air educational meetings, and films. Here will be demonstrations of more economical and fuel efficient methods of cooking. Solar heating panels, flat plate collectors, parabolic collectors and all the future age gadgets will be demonstrated in this area. The windmill for recycling grey water back to flush the toilets will also be in this central market place. Here will also be a demonstration urban farm - the size of a back yard farm to show what the people can grow on their back yards. In the afternoons and evenings nutrition classes will be conducted in this area and in the nursery school. The community organizer can live in one of the nearby houses to plan and announce all such activities on market days.

Figure 5.01 A Community Neighborhood



The residential clusters comprise of about 20 plots, this being about 50 to 80 households. At the center of each cluster is a well designed children play area. The area is arranged so that parents can always see and surmon their children from their back yards. Depending on the cluster's needs, this open space could be used as a garden.

The residential back yards are partly paved and partly used as gardens. The paved areas are for daytime open air activities. Shades are provided to allow people to rest under the shade while cooking on solar collectors. Solar cloth dryers are also located on this area usually full on Saturdays, the day that most people will be in the market place anyway. The view of such a cluster is shown in Figure 5.02

Areas around the community that are not usable for building will be used as community farms. These will be owned by the community but can be leased out to individulas for a season or two. Food grown here can be sold at the community market. Some such areas will also be used for growing fuel crops such as ipilipil, eucalyptus and other biomass material that can be fed into the community biogas generator. When gradually the community comes to realize what conservation of energy really means, and relax their social stigma associated with human waste, the sewer system can then be connected

Figure 5.02

View of Housing Cluster

to the biogas generator. The sludge goes to the farms and the gas is piped back to the community. Depending on the quantity expected, the gas could first be used for cooking in the day care center, nursery school and for demonstrations during nutrition classes.

An energy efficient community must also be designed to have sufficient high schools and primary schools and these to be located within walking distances. Bikeways and safe pedestrian ways have to be provided to encourage students to use these modes. Where streets have to be crossed, appropriate signs are introduced and devices employed to slow all motorised traffic.

Employment for the majority of the low and middle income people will be in industries and factories as well as commercial businesses and self-employed cottage industrial activities. Sites can be left at appropriate locations within the community particularly on the main streets for the larger scale industrial and office enterprises. While the cottage industries will take place mainly in the front yards of individual dwellings, larger scale ones could be provided at larger sites. These could be managed by such organizations as the National Christian Council of Kenya or groups of entrepreneurial community members who form into companies. Such companies already exist in the Mathare Squatter

Settlement, where they have built company houses for rent and engaged in businesses dealing in building components.[3]

The market area is approachable from the residential clusters on foot without crossing even a single street. All the neighborhood streets terminate in small car parks which can be used for delivery both by trucks and vans as well as hand carts; guest parking and most importantly as matatu - (jitney) and executive bus pick up centers. Bikeways and pedestrian paths are designed to provide access to most of the facilities without interferring with motorized vehicles. Bus stops are located at appropriate points along the main streets and a bus schedule is displayed. Car-ownership is not expected to be high with good bus service but those who may own a car will use the neighborhood streets to the front of their houses where they may park them. When the need for private car driving will be eliminated by public service, (and gasoline prices) these streets will become pedestrian and bike ways and some might be converted to farms by extending individual plot boundaries to the curb.

Improved telephone services would also minimize the number of trips from the community. Since not everyone

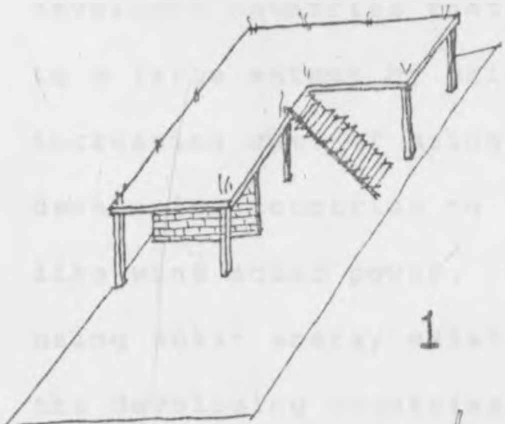
[3]Horacio Caminos and Reinhard Goethert. op. cit.

can afford a telephone, one could be provided for a group of people either in a shop within a housing cluster, in someones house who has then to allow people to use it at will or in a public open space where it must be protected from vandalism. This can be possible if small secure open spaces are provided that are not accessible to people from other housing clusters.

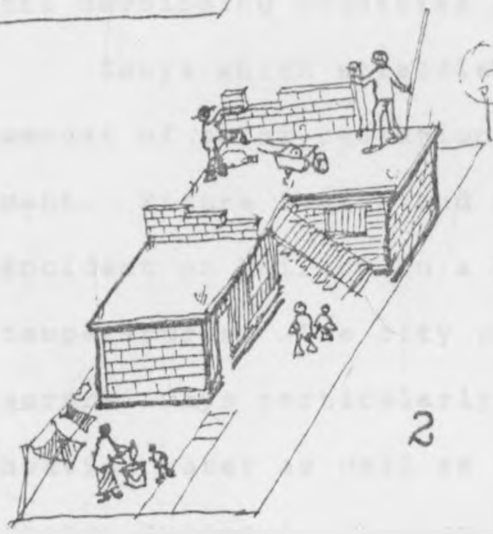
Houses should be designed to be easily constructed to be as labor-intensive as possible and applying appropriate technology that utilizes local materials. Adobe (mud) bricks could be used to replace the energy rich cement blocks while wood poles and timber pannels could be well treated to withstand weather and termites. In site and service schemes, the government can provide people with the wet core, columns and a slab. Through well organized mutual labor and self help techniques people would then build in the walls and this way build houses that could go up to even four stories. A possible building process is demonstrated in Figure 5.03.

Figure 5.03

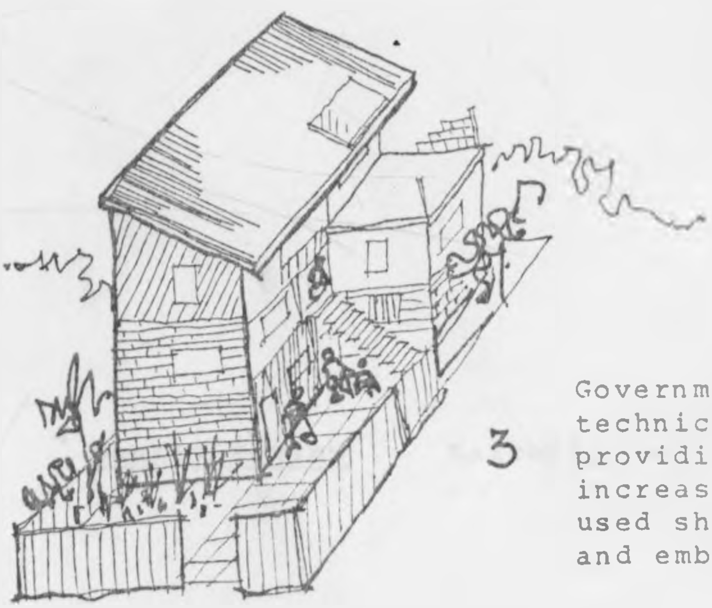
Possible Building Process



Government provides a site, wet core and a slab on columns



People construct their house adding more walls and more stories using community self help and mutual-labor, while occupying lower floor



Government can help again in technical assistance in providing more floor slabs to increase density. Materials used should be locally produced and embodying low-energy

5.02 COMMUNITY USE OF SOLAR ENERGY

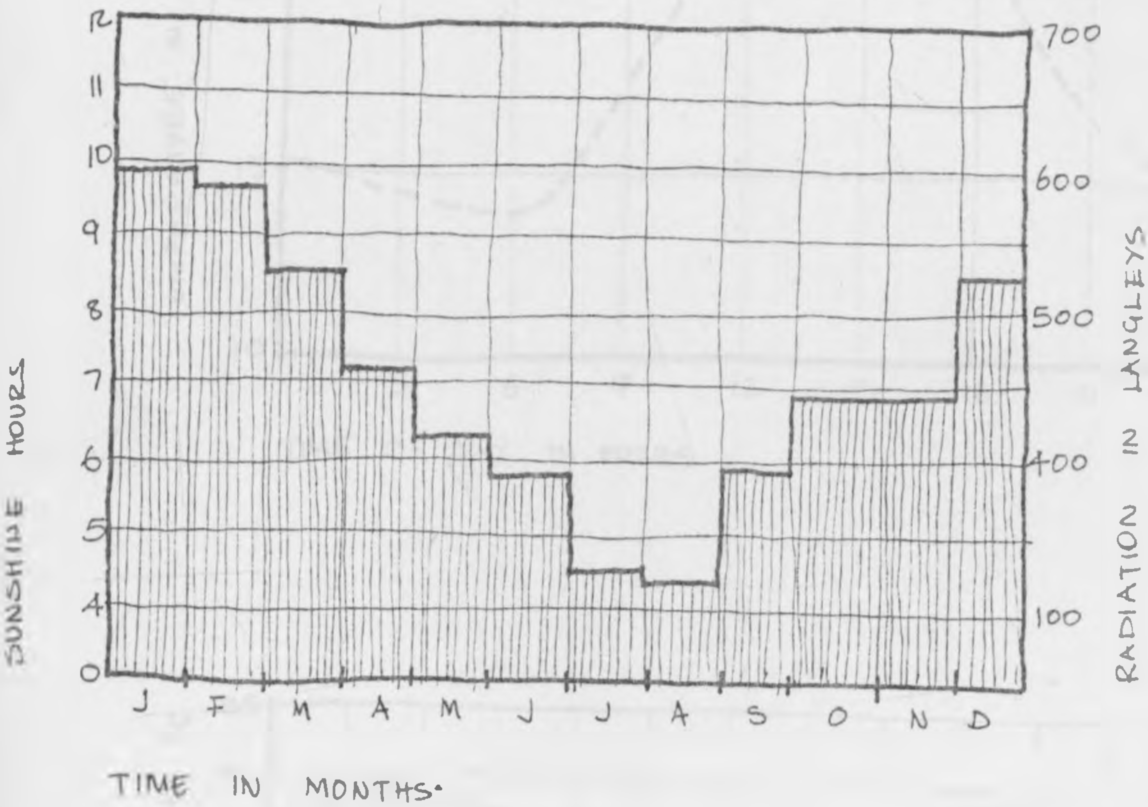
Developing countries resent the constant advocacy by developed countries that their energy needs could be met to a large extent by using solar energy.[4] However the increasing cost of using oil will gradually compel the developing countries to replace oil by other energy sources like wind (solar) power. The greatest opportunities for using solar energy exist in the tropics where also most of the developing countries are located.

Kenya which straddles the equator receives an immense amount of solar radiation which can be tapped for development. Figure 5.04 A and B show the amount of sunshine incident on Nairobi in a year and the daily average temperatures. The city can make use of this energy in several ways particularly in providing energy fuel for heating water as well as cooking. A community solar energy system is diagramatically shown in figure 5.05.

[4] Weekly Review . Nairobi, July 27, 1979.

Figure 5.04 A

Annual Sunshine in Nairobi

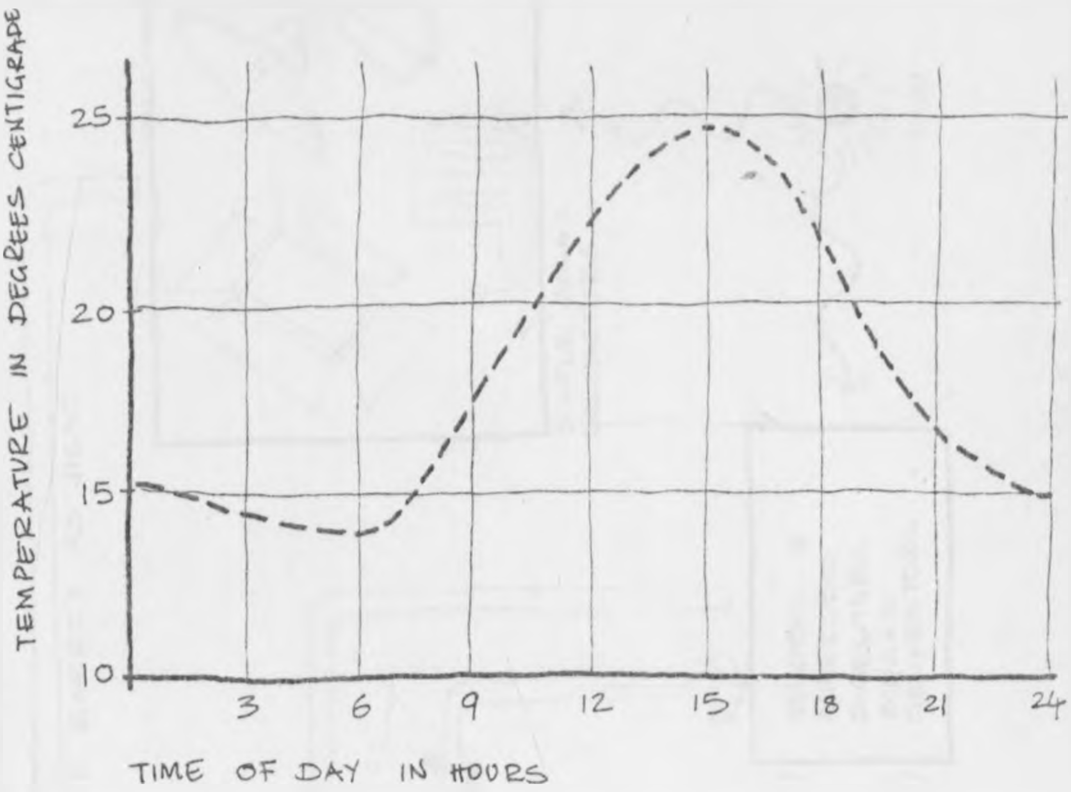


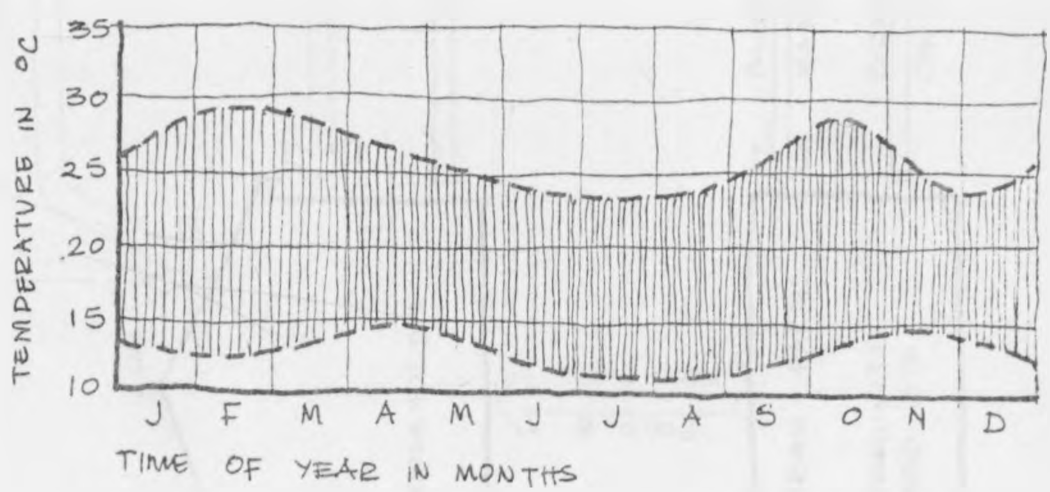
LOCATION - NAIROBI - (EASTLEIGH)
ALTITUDE - 1634 METERS
LATITUDE - 01° 17' S
LONGITUDE - 36° 50' E

Source: Design for Climate
Housing Research Development Unit
University of Nairobi, 1975

Figure 5.04 B

Air Temperature in Nairobi in One Day and in One Year

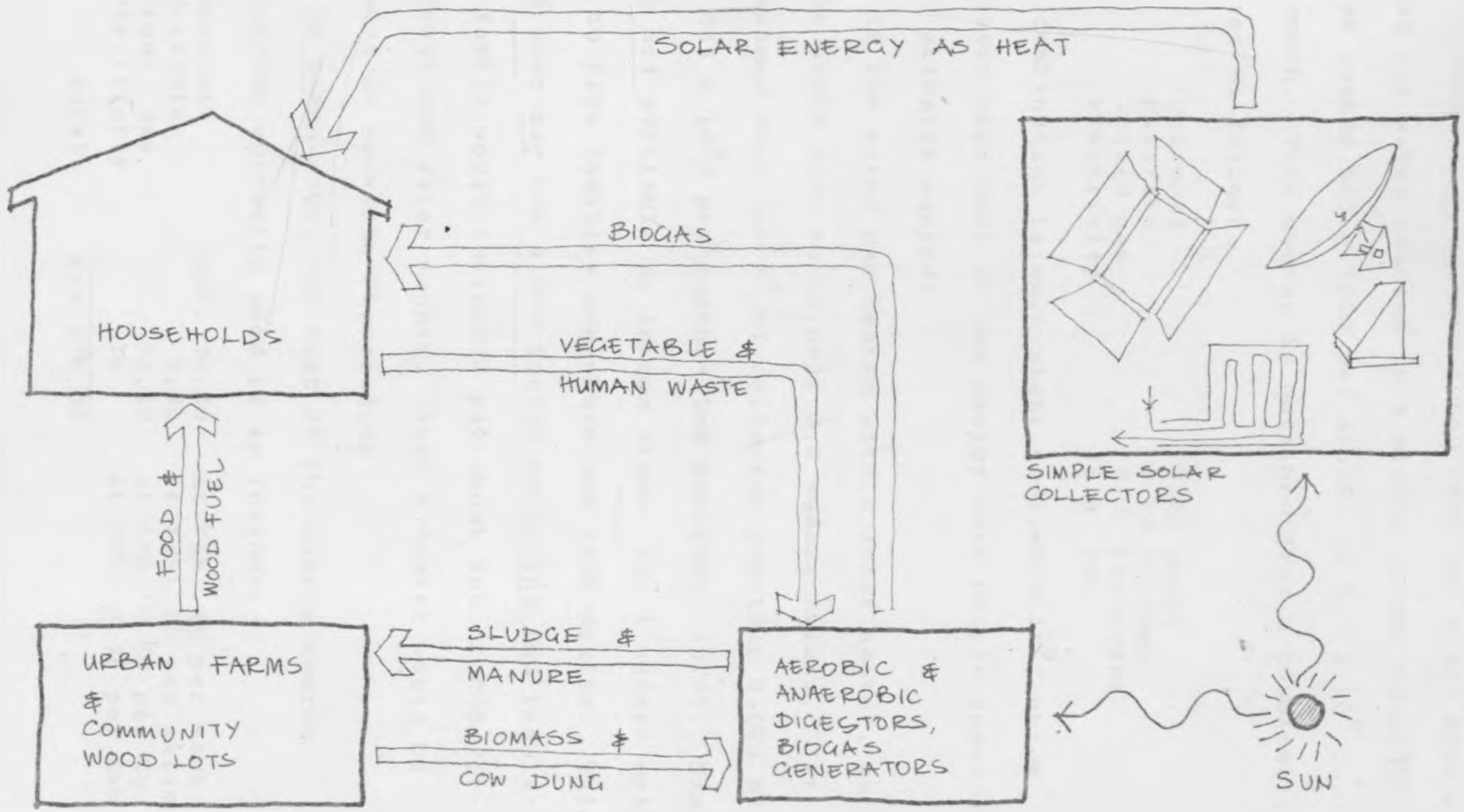




Source: Design for Climate
Housing Research and Development Unit
University of Nairobi, 1975

Figure 5.05

Community Use of Solar Energy



McGranhan *et al* have found that the basic energy demand for water heating in a middle income household (Kenya pounds 601 - 1200 per annum) is 5.7×10^8 Joules per month. This energy is obtained from a combination of sources as follows:

charcoal	0.62 sacks
paraffin	0.64 gallons
liquid gas	8.7 kilograms
electricity	45.9 Kwh.

This combination is equivalent to 1.49×10^9J which indicates that most of the energy that people spend money on is actually wasted!

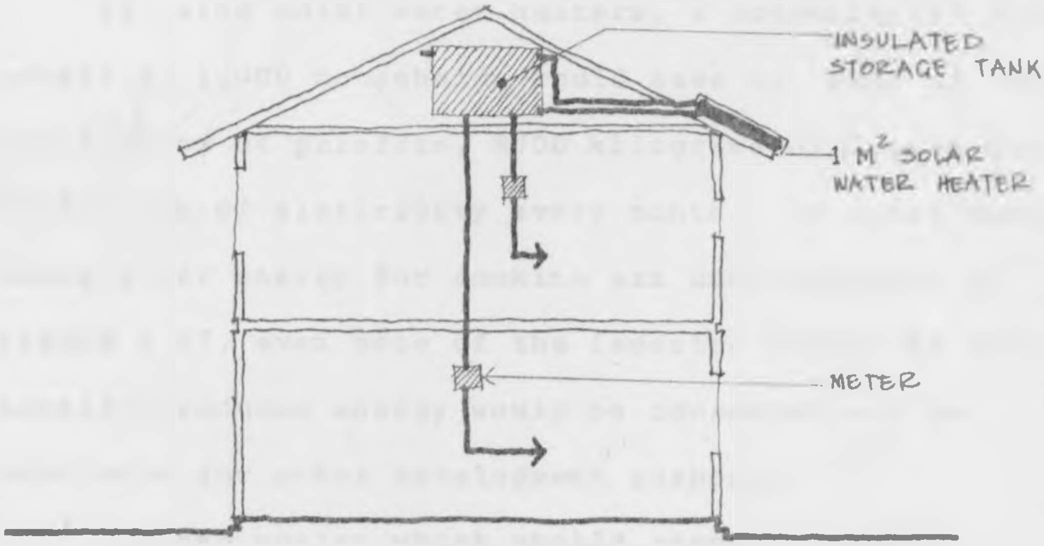
If the water was heated with a solar heater, such a heater would have to be only 0.2 square meters. (It is assumed that one M^2 of collector provides 9,000 BTU/day or 2.845×10^9J per month - Lee Schipper, 1979). Since these are available at larger sizes, say 1 square meter, four to five families can share one such devise. This would cost say Ksh 4,000 including piping and insulation. Each family would therefore pay about Ksh 1,000 for a permanent hot water supply. Such a devise would be arranged as shown in Figure 5.06

In comparison, the cost of the energy source combination currently used is as follows.

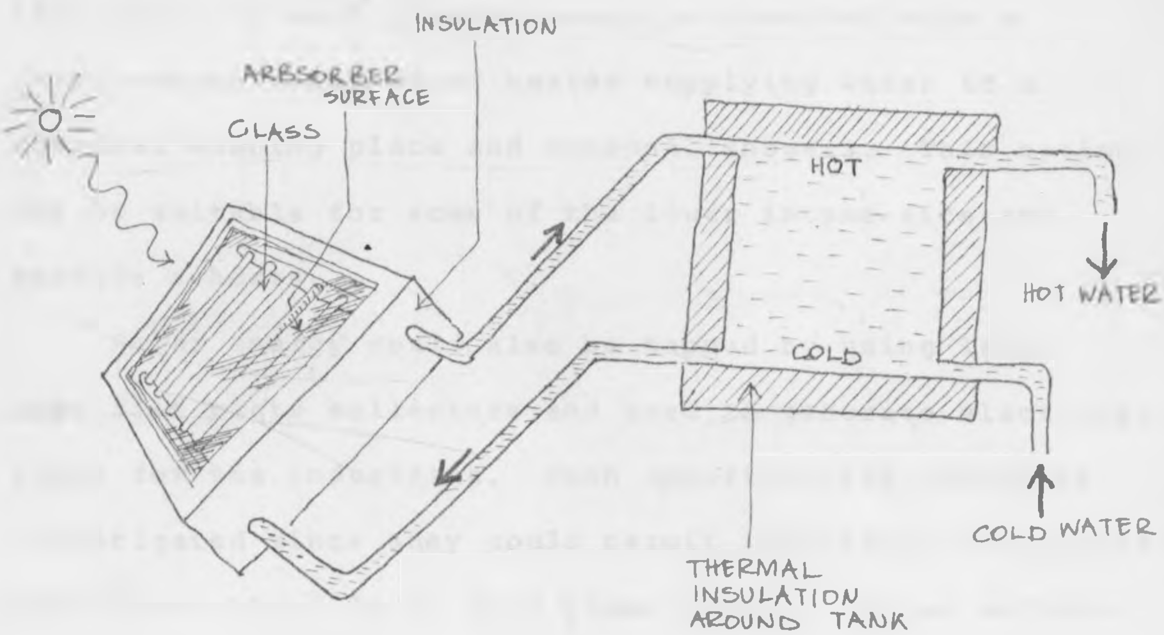
Charcoal	Ksh. 30.00	at Ksh. 48 per sack
Paraffin	5.40	at Ksh. 10 per gallon
liquid gas	56.60	at Ksh. 6.50 per Kg.
electricity	16	at Ksh. 0.36 per Kwh.
Total	Ksh. 108.00	

Figure 5.06

Solar Hot Water Systems



PIPING IN THE HOUSING UNITS



SIMPLE DESIGN OF A SOLAR WATER HEATER

Thus, a family would be able to pay for solar heater in about 9 months. In addition the combination of fuel shown above would be conserved.

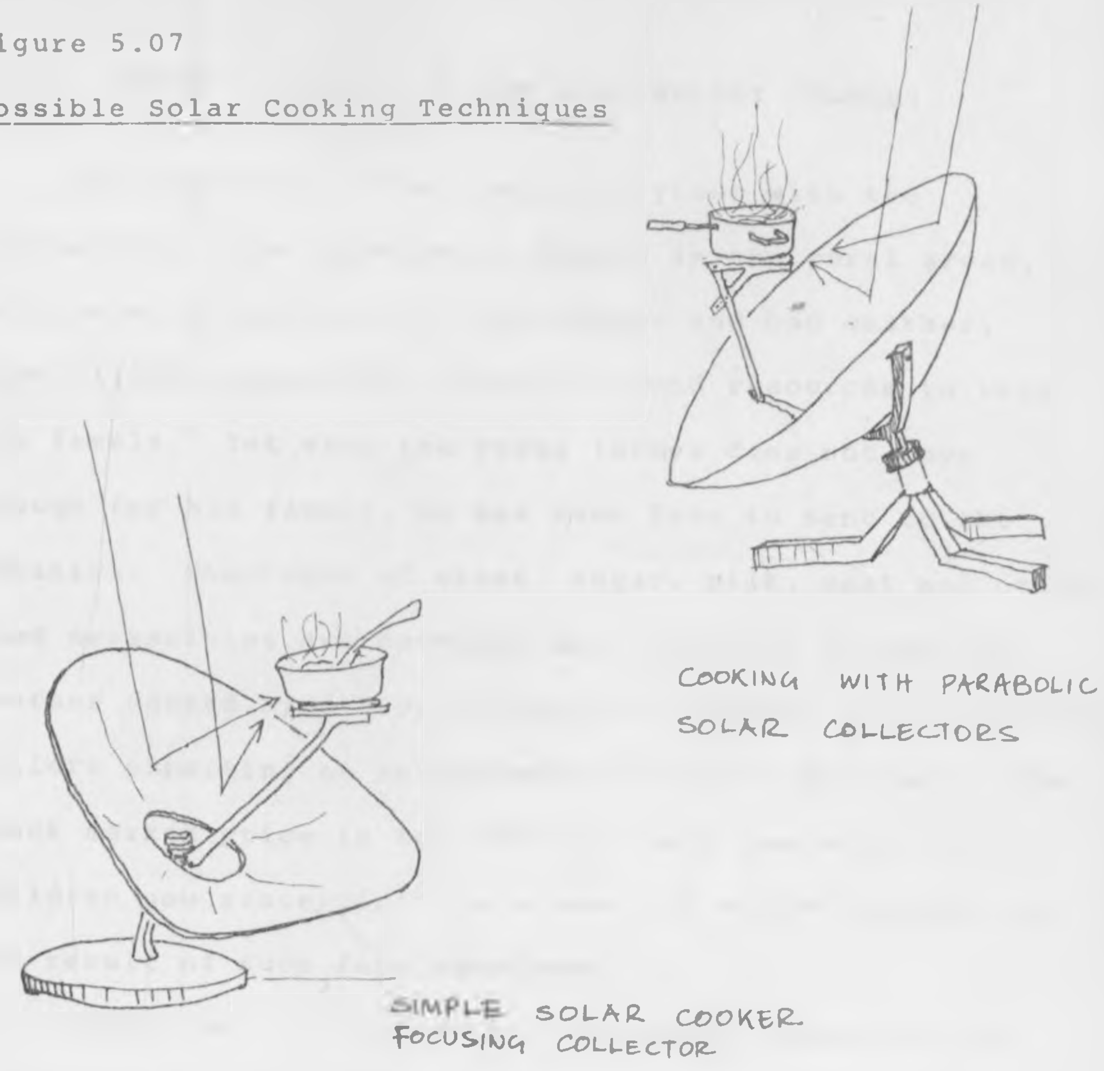
By using solar water heaters, a community of 5,000 people or 1,000 households would save 620 bags of charcoal, 640 gallons of paraffin, 8700 kilograms of liquid gas and 45,900 Kwh of electricity every month. If other devises using solar energy for cooking are used as shown in Figure 5.07, even more of the imported energy as well as locally produced energy would be conserved and be available for other development purposes.

Another option which should receive careful consideration is the use of a communal solar-water heater for clusters of households. A communal water center at the center of each cluster could be provided with a large enough solar water heater supplying water to a communal washing place and communal showers. This option may be suitable for some of the lower income site and service schemes.

Solar energy could also be tapped by using large area flat plate collectors and used to generate electrical power for the industries. Such opportunities should be investigated since they could permit industries to operate even where there is no grid power supply. Other methods of using solar energy through photosynthesis and wind energy are considered elsewhere in this thesis.

Figure 5.07

<u>Possible Solar Cooking Techniques</u>



5.03 COMMUNITY FARMS FOR NEW FOOD ENERGY SOURCES

The demand for food naturally rises with the population. The increase in demand in the rural areas, coupled with shortages of fertilizer and bad weather, have already pushed the country's food resources to very low levels. Yet when the rural farmer does not have enough for his family, he has even less to send to the urbanite. Shortages of wheat, sugar, milk, meat and other food necessities are becoming more frequent in the city whether caused by a crop failure or hoarding by prospective sellers expecting an announcement of price increase. The black market price is too high for many and malnutrated children now susceptible to a hoast of other diseases are the result of such food shortages.

These factors can not be ignored in assessing the potential for the self-sufficiency of any rapidly growing city. Urban food production methods have to be incorporated in future housing designs so as to decrease households' dependence of rural-grown daily foodstuffs.

Alternatives for the traditional sources of the nutrients necessary for proper human growth have to be sought which can be easily produced in urban areas. Other sources of proteins such as fish and eggs can be developed to substitute for the scarce and expensive beef.

Vitamins can be obtained from fruit and vegetables that can be grown in urban areas. Coupled with this substitution must be an education program on nutrition so that people can more accurately assess the type and amounts of food they need to eat for balanced diets. If the arts of cooking and eating could be rationalized to the point where people ate a nutritionally balanced combination of what was most economically produced the outcome would be equivalent to a doubling of the yield in agricultural production.[5] This would result in more balanced diets and a saving on energy required in food production.

Most of the animals consumed in Nairobi are raised at distant points, slaughtered there, and the refrigerated carcasses are transported and stored before they are cut up to meal-size portions. Every calorie of nutrition obtained from this meat consumption requires five to ten calories of vegetable feed, and the feed is produced by the same soil resources that would grow staples for a low-income human diet.[6] Thus the meat is produced at the expense of food supplies for large numbers of poor urbanites. The increase in both rural and urban population which increases the demand for food will compel

[5] Richard L. Meir, Planning for an Urban World - The Design of Resource - Conserving Cities . MIT Press, 1974.

[6] Richard L. Meier, Ibid.

farmers to convert cattle ranches to the production of more of the staple grains such as maize, rice and wheat. Meat and milk will thus become even more scarce and more expensive. Protein promises to be most cheaply produced by using nitrogen-fixing blue-green algae particularly the thermophilic varieties, which convert sunlight more efficiently and are not easily infected by bacteria. It is estimated that yields could exceed 10 tons per hectare of a product that is 50-60% protein.[7] An appropriate method could be developed where by the algae is added to other common foodstuffs thus increasing their protein content before they are sold on the market. Alternatively the algae could be fed to small crustaceans, which in turn are fed to fish raised in fish ponds which are then sold on the market. It should be realized though that as one moves up the food chain, energy is lost at each level, and so one could capture more of the sun's energy by eating the algae directly than by eating organisms that feed on organisms that feed on the algae.[8] Until an acceptable method of eating algae is developed fish would have to be used for protein. Fish production can be improved

[7] Richard L. Meier, Ibid.

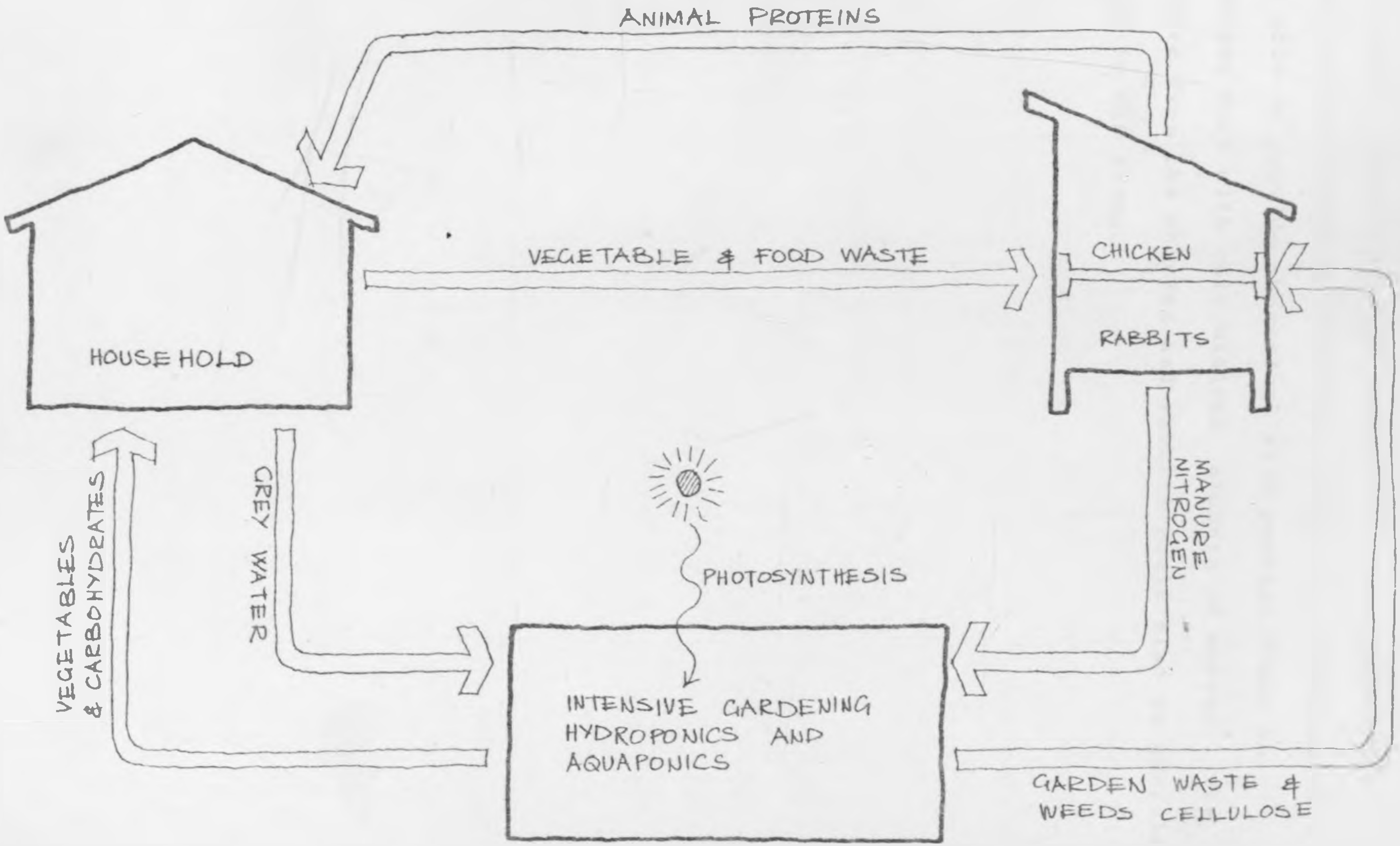
[8] Helga Olkowski, Self-Guided Tour to the Integral Urban House . Farallones Institute. Berkeley, California (undated).

even further by fertilizing the aquatic life that naturally occurs in the ponds by using manure or sludge from biogas generators. Tilapia can be grown to market size using this method.

Other methods of producing protein for direct human consumption exist such as the Japanese technology of growing chlorella from soluble fertilizers and sunlight in open shallow ponds in the city. The methanol bio-products from breweries in Nairobi, the molasses from sugar refineries and cellulose which can be easily extracted from plant matter are also suitable ways of producing "single cell" protein foodstuffs and should be investigated and exploited.

Intensive photosynthesis using intensified hydro-poninics could be developed both in community and in individual rear gardens, to provide the urban communities with fish vegetables, fruits and some grains. Recycled water will be used for irrigation while the effluent and sludge from community biogas generators could be used as fertilizer. Figure 5.08 shows the recycling possibilities of intensive gardens. More fertilizer could be produced by using well controlled methods of aerobic digestion of vegetable waste in compost manure heaps, to replace the expensive imported high energy chemical fertilizers. Families could raise chicken for eggs and meat and rabbits

Figure 5.08
Intensive Urban Gardening By Waste Recycling



for meat. These could be fed on left over foodstuffs and vegetable grown on the gardens. This way, families will be able to provide themselves with protein foods to replace beef with only minimal amounts of energy. The manure from the chicken and rabbits could also be recycled back to the farms.

5.04 WASTE WATER RECYCLING

Water is frequently in short supply in Nairobi and as the population increases, the disappearances might be more frequent. Yet much water which could be re-used is emptied into the sewers and never used again. The water that is used in washing of clothes and in showers could be used in a second cycle for flushing the toilets.

A pipe would collect this water from the individual dwellings or from a communal water center, and lead it to an underground tank located in a communal place. Overflow from such a tank could enter a public sewer, or be used to irrigate community farms. A wind-mill pump could then pump this water to a holding tank at a higher level from where another pipe would distribute this water to high level cisterns in the houses. The system is shown in Figure 5.09.

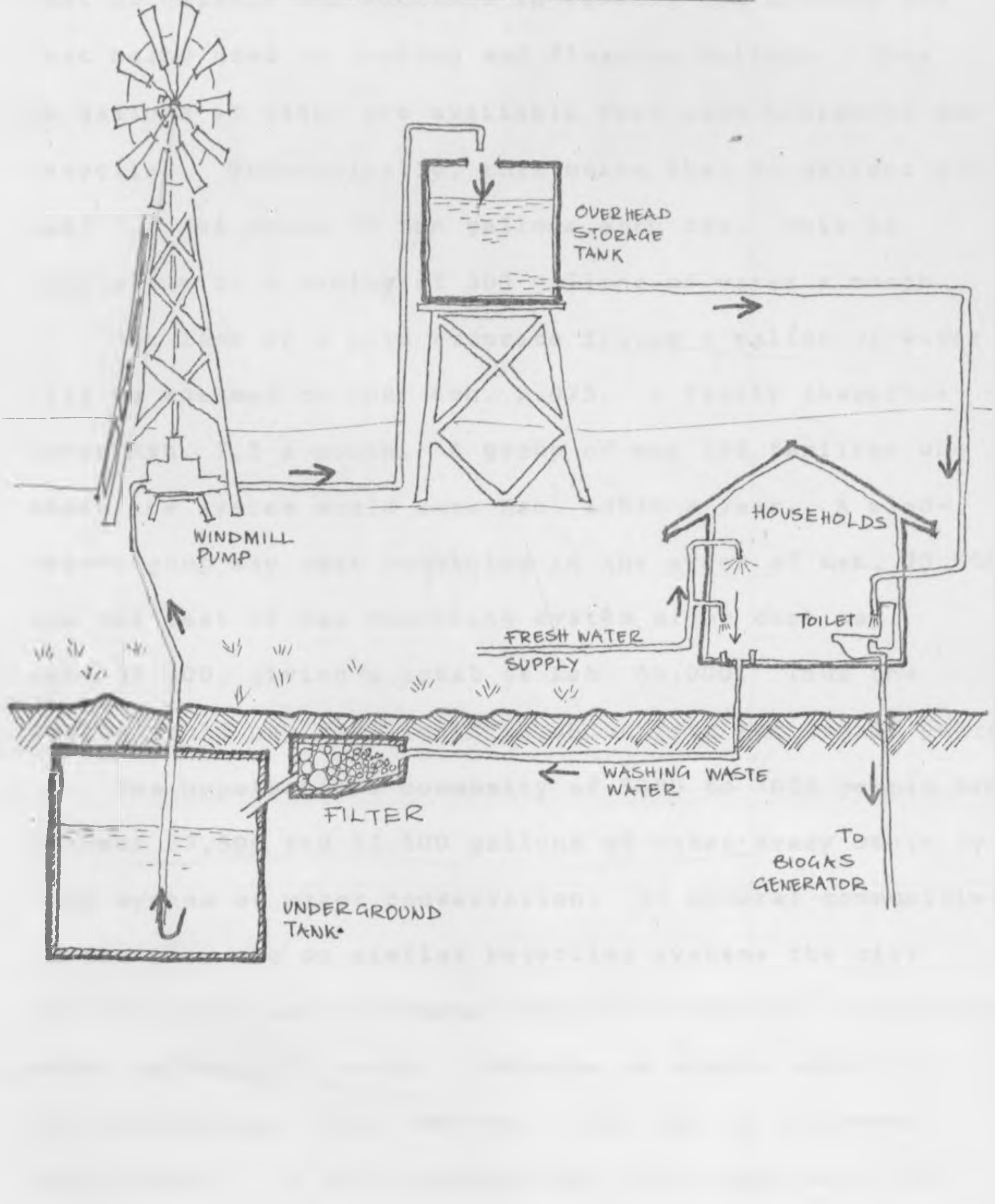
The cost of such a system would have to be compared with the cost of an equal amount of fresh water as well as with the inconveniences that occur during water shortages preventing toilets to be flushed and thereby increasing health hazards.

The two very low income groups of households consume about 40 gallons of water a day per household.[9]

[9] G. McGranahan *et al*. *Patterns of Urban Household Energy Use in Developing Countries: The Case of Nairobi* . The Institute for Energy Research, State University of New York at Stony Brook, 1979.

Figure 5.09

Recycling Waste Water to Flush Toilets



Since there are no separate meters, it can be assumed that 20 gallons are consumed in washing and bathing the rest being used in cooking and flushing toilets. Thus 20 gallons of water are available from each household for recycling. Theoretically, this means that 20 gallons are used for the price of ten gallons each day. This is equivalent to a saving of 300 gallons of water a month.

For lack of a more accurate figure a gallon of water will be assumed to cost Ksh. 0.025. A family therefore saves Ksh. 7.5 a month. A group of say 150 families who share the system would save Ksh. 13500 a year. A wind-driven pump may cost something in the order of Ksh. 30,000 and the rest of the recycling system might cost say Ksh. 30,000, giving a total of Ksh. 60,000. Thus the system would pay for itself in about four and a half years.

The hypothetical community of 5000 to 7000 people saves between 37,500 and 52,500 gallons of water every month by this system of water conservation. If several communities in the city are on similar recycling systems the city council would save enormous amounts of capital investments which is embodied energy, conserve on scarce water from the countryside, thus leaving it for use by the rural populations. If rural populations using such water can improve their life, they might opt to stay there than to come to the city which is further conservation on building materials and road construction in the city - a net saving on energy.

CONCLUSIONS

PLANNING ENERGY RESOURCES

Energy resource planning is becoming increasingly important and the creation of the Ministry of Energy in Kenya in 1979 came at a time when much work is needed in this field. Such a ministry in cooperation with other ministries and government departments is in a position to control the exploitation of the country's natural energy resources, minimize dependence on foreign oil by increasing the consumption of renewable energy resources in the country. There are several areas that ought to receive high priority in any efforts to conserve and plan energy resources in the country.

First the forests have been shown in this study to be extremely important. Fuel wood is depended upon by more than 75% of the total population and is therefore the most important source of energy. Also the hydrolectric power generation depends greatly upon reliable sources of water which can only be protected through forestation. Deforestation on the other hand increases soil erosion thereby increasing siltation of hydroelectric dams and minimizing the agricultural potential of land. Most of the deforestation is caused by charcoal burners as well as by farmers looking for new farm lands. The rate of deforestation in the country should be decreased through more forestation, decrease in wasteful charcoal burning and co-ordinated planning with other ministries such as that of agriculture so that conflicts between agricultural and forestation needs could be minimized.

Secondly the maximum potential from geothermal and hydroelectric power generation should be thoroughly sought. These are the most important sources of commercial energy in the country and once they have been fully exploited little can be done to improve their energy output. Where opportunities for cogeneration exist through cascading water and heat usage,these should be fully used. The heat from a geothermal plant in the form of steam might be used to run an agricultural industry, or a timber saw mill instead of being wasted. Congeneration in industrial processes as well as the planning of industrial machinery to minimize wastage of energy would also minimize the demand for electricity.

Thirdly renewable energy sources should be developed to replace imported oil. A National biogas generation program could be initiated which would promote the use of locally available biomass, converting it to biogas and producing fertilizer. Liquid fuels could also be developed from locally available sources such as sugar cane, cassava, sweet sorghum and a variety of other plants. Thorough study of these options should be carried out. The ministry should also promote mass transport services instead of private auto driving and develop buses that can operate on wood alcohol and a minimum of gasoline for both urban areas and rural areas.

Lastly much study and experimentation are necessary in all areas of energy resources and conservation. The ministry should seek ways of training and employing local staff including scientists, engineers and planners on all energy related issues. The most important areas will be data collection, storage and the dissemination of information to all points where energy is being consumed. Such manpower training could be jointly organized by the ministry of agriculture and the Central Bureau of Statistics. The University should also play a leading role in research. This issue is elaborated further in the last section of conclusions.

URBAN PLANNING AND ARCHITECTURE

Urban areas are the major consumers of energy both locally produced and imported and must therefore be accorded very careful consideration in future energy strategies. Urban land-use planning should be consciously done in a manner that will both conserve on the existing energy resources and make provision for the development of other alternative energy sources. Planting more trees, recycling of urban waste and increasing the use of renewable resources could all be achieved only if urban planning strategies are oriented towards energy conservation.

Urban planning through its effects on residential commercial and industrial location and transportation infrastracture could alter the average trip distances and the modal split. Priority should be given to serving long-term needs of existing urban and suburban areas through maintaining and rehabilitating existing transport facilities. Dependence must be reduced on private auto use by curbing wasteful urban sprawl and directing new development to existing towns and suburban centers. Undeveloped and under-utilized land within existing urban areas presently served by streets, water, sewer and other public services should be used up first before any new land is urbanized. Building densities in existing built-up areas should be increased and new developments should be planned in a way that will enable densities to be increased in the future.

Particular attention has to be given to preserving the existing and all potential agricultural areas while also encouraging urban gardening instead of prohibiting it. Open green areas should also be preserved in well located areas not only for recreation but also as possible future energy reserves, and sites for biogas production. A land use pattern that stimulates necessary development while protecting the environmental quality should be developed. A planning authority coordinating all urban planning activities in Nairobi and all the towns in the surrounding area as far as Thika, Athi River and Limuru seems a necessity so as to delineate agricultural areas and fuel farms and areas that could be urbanized without adversely affecting the future food and energy needs of the whole region.

Energy efficient building designs that can cut the use of artificial lighting and ventilation devices, cement, steel glass, metals, plastics, synthetic fibres and other energy intensive materials while still providing comfortable and suitable working and living spaces should be developed. Such materials as wood, natural fibers such as bomboo and other low energy locally available materials can be substituted. Labor-intensive methods of construction should be used where possible to minimize on energy consuming capital intensive techniques.

Methods of solar heating and cooling more efficiently for office buildings and groups of residences should be developed so as to cut down on the energy-intensive methods currently being used. Conventional sewer construction with its energy intensive material inputs such as cement and steel can be replaced by modern dry composting methods for sanitary waste which not only save these costs, but by recirculating nutrients to agriculture, conserve the high energy inputs of synthetic fertilizer.

For the above suggestions to be possible, several adjustments have to be made to the city councils building code and zoning regulations. The code and regulations should be critically reviewed with the aim of making them more responsive to the current energy needs. The code's insistence on high energy-intensive materials would prevent the use of less-energy-intensive ones proposed above while the current zoning regulations would prevent the increase in densities and the mix of uses proposed in this study. Review and updating of these regulations should be embarked on as soon as possible and as new discoveries and inventions bring new materials and technology into the market, and since the needs of the society are not static, these regulations should also be modified continuously to keep pace with changing world conditions and societal needs. Mechanical and electrical building codes should be thoroughly examined for energy conservation.

RESEARCH

A thorough study is necessary to determine more accurately the energy resources available in the country, the energy consumption patterns both in the urban and the rural areas and to study the various methods that can be used to conserve it. In particular a study and design of more energy efficient household gadgets such as the jiko for cooking and more efficient designs for charcoal making kilns must be carried out and the designs introduced to the public.

Research is also necessary to determine the species of trees that have the highest yields and are most adaptable to Kenya. Cross-breeeing may also produce species that may prove to be more efficient in wood production. Studies should accompany tree-planting efforts to determine the most efficient methods and cheapest methods of producing energy from the woody biomass. Methods of using solar energy, through simple solar collectors, and wind mills should be developed for use both in the rural and urban areas. Emphasis must be placed on renewable energy.

Such research and the dissemination of information can be accomplished through the existing institutions such as the University of Nairobi particularly the departments of Architecture, Housing Research and Development Unit, Engineering, Agriculture and the Institute of Developmental Studies. Village Polytechnics, Kenya Industrial Estates, and other bodies which are engaged in training local manpower could be very effectively used to disseminate new technology and information. The Ministry of Energy together with the National Council for Science and Technology and the University of Nairobi should find ways of coordinating all energy research and technology.

EDUCATION

The solutions proposed in this study pose no insurmountable technical problems but they are likely to meet many resistances rooted in cultural conditions and the established economic interests. Widespread and serious resistance must therefore be anticipated in the introduction of many of the proposed energy-efficient technical solutions that may go against the grain of the prevailing attitudes and standards. Only much increased energy prices and/or fuel shortages are likely to change social values sufficiently to allow their usage.

Educational campaigns are therefore necessary at all levels of the society to make people aware of the need to conserve energy and to teach them new ways of energy utilization. It is essential also to integrate the operation of the new technologies such as biogas generation into traditional patterns of life. Unless new technologies and existing patterns are well integrated, no matter how perfectly the technicalities are worked out, they may never be accepted. Social organizations and community development programs should be used to introduce any new technologies, never imposing them on people and expecting people to accept them.

With the education on energy efficiency and conservation, must also be education on the need for parents to plan to have smaller families. As long as population growth rate remains high, the demand for energy can not be expected to slow down. The demand for food will also rise with population. More effective ways of teaching people about family planning and better nutrition should be given very high priority in the country. It is only in this way that the demand for energy both in the rural areas and in the high-energy consuming urban areas, can be maintained at more manageable levels.

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