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CO2 Emissions from Developing Countries: Better Understanding the Role of Energy in the Long Term; Volume IV: Ghana, Sierra Leone, Nigeria and the Gulf Cooperation council (GCC) Countries

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PREFACE

Recent years have witnessed a growing recognition of the link between emissions of carbon dioxide (CO_2) and changes in the global climate. Of all anthropogenic activities, energy production and use generate the single largest portion of these greenhouse gases. Although developing countries currently account for a small share of global carbon emissions, their contribution is increasing rapidly. Due to the rapid expansion of energy demand in these nations, the developing world's share in global modern energy use rose from 16 to 27 percent between 1970 and 1990.[1] If the growth rates observed over the past 20 years persist, energy demand in developing nations will surpass that in the countries of the Organization for Economic Cooperation and Development (OECD) early in the 21st century.

Restraining the future growth of carbon dioxide emissions in the developing world entails a thorough understanding of present and future patterns of energy use in these regions. To address this need, the International Energy Studies Group at the Lawrence Berkeley Laboratory (LBL) initiated this study in collaboration with research groups in the developing world. The study seeks to examine the forces that galvanize the growth of energy use and carbon emissions, to assess the likely future levels of energy and CO_2 in selected developing nations and to identify opportunities for restraining this growth. The purpose of this report is to provide the quantitative information needed to develop effective policy options, not to identify the options themselves. The results are being used by the Intergovernmental Panel on Climate Change to determine the impact of changes in energy use and supply on carbon emissions and, ultimately, on the Earth's climate. The U.S. Environmental Protection Agency supported this work.

Individual studies were conducted for Argentina, Brazil, Mexico and Venezuela in Latin America; China, India, Indonesia and South Korea in Asia; and Nigeria, Sierra Leone and Ghana in Africa. A combined study was carried out for the countries of the Gulf Cooperation Council (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates). For each nation, the participating regional experts derived a set of reasonable assumptions about future activity levels from a thorough analysis of energy use patterns in 1985.[2] Based on this information, the experts then developed high and low scenarios of energy use and carbon emissions for the year 2025. Although the same spread-sheet model was used for all of the country studies, the socio-economic and energy-related assumptions made in each case differ according to the unique conditions of each nation (See appendix A for a description of the methodology of the study).

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[1] These figures include the Middle East. British Petroleum Company, *BP Statistical Review of World Energy* (London: Corporate Communications Services, June 1991).

[2] Alternate base years were chosen in three cases due to the availability of better data (1987 for Mexico and Ghana and 1984 for Venezuela).

The studies of the African and GCC countries are being published in this volume (Volume IV). The summary paper, the studies of the Latin American and of the Asian countries are being published separately (Volumes I, II and III respectively). Each paper begins with a discussion of the socio-economic assumptions made, followed by a sectoral analysis of current and future patterns of energy use and an examination of the impact of these patterns on future emissions of carbon dioxide.

The scenarios and the initial report for each country presented in this volume were prepared by the following experts:

Ghana/Sierra Leone	---	Ogunlade R. Davidson, University of Sierra Leone
GCC	---	Abdul Majeed Al Shatti, Kuwait Institute for Scientific Research
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In each case, the opinions expressed are those of the authors and do not necessarily reflect those of the affiliated institutions.

Jayant Sathaye, LBL, worked closely with each analyst to develop the scenarios and to prepare each report. Nina Goldman revised and edited the drafts and the final report for each country.

Two workshops were held in conjunction with this project. We would like to thank the workshop participants, the individuals who contributed to the development of the scenarios and numerous colleagues in the United States and abroad who supported this project. We would specifically like to acknowledge the support of Hoe Sung Lee, Korea; A. Arismunandar, Indonesia; Zhou, Fengqi and Zhou, Dadi, China; Aaron Dychter and Marcelle Serrato, Mexico; Jose Goldemberg, Brazil; Alberto Larralde, Venezuela; Ibrahim Ibrahim, Qatar; and Irving Mintzer, United States.

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GHANA AND SIERRA LEONE

1 INTRODUCTION

Typical of many African countries, Ghana and Sierra Leone have among the lowest levels of delivered energy[1] demand per capita across the globe. Primary energy demand per capita in these two West African nations equals about one quarter of the world's average and about one twentieth of the United States' average. In addition to this similarity, Ghana and Sierra Leone share many other energy-related characteristics: both have experienced similar economic trends over the past few decades; both rely heavily on biomass fuels; and both possess a wealth of unexploited energy resources.

This paper presents two scenarios of energy use and carbon emissions[2] in Ghana and Sierra Leone for the year 2025. In the high emissions (HE) scenarios, policy changes focused on galvanizing economic growth lead to significant increases in energy use and carbon emissions in Ghana and Sierra Leone between the present and 2025. In the low emissions (LE) scenario, the implementation of policies aimed specifically at curtailing carbon emissions limits the increase in carbon in both nations by 2025.[3]

2 GDP AND POPULATION GROWTH

African nations typically experience among the fastest population growth rates in the world. Between the early 1970s and the mid-1980s, while Africa's population expanded at an average annual rate of 3 percent,[4] the populations of West African nations tended to grow more slowly -- at an average rate of 2.8 percent annually. In more recent years, due to the activities of family planning organizations, improved educational systems and increased access to birth control devices, growth rates in most of West Africa have declined even further. In urban areas, the impact of the current economic crises afflicting most West African nations has led many couples to choose to have fewer children.

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1 Delivered and primary energy include biomass unless otherwise specified.

2 The term "carbon emissions" refers to those emissions generated from commercial fuel use. Unless otherwise specified, carbon emissions from biomass are excluded.

3 Published reports and unpublished, locally-generated information provided the base year data for this study (1985 for Sierra Leone and 1987 for Ghana). In most cases, local energy experts wrote the reports. These experts, in conjunction with representatives from the two countries' different economic sectors, developed the 2025 data for this study.

4 World Bank, *World Development Report 1989* (New York: Oxford University Press, 1989).

With the availability of better training facilities[5] in West African regions, demographers have attained more accurate records of past growth rates and have improved their estimates of future growth. Based on the latest information, between 1987 and 2025, Ghana's numbers increase three-fold. Sierra Leone's population expands slightly more slowly (Table 1).

Table 1
Population Size (Millions)

	Base Year	2025	AAGR
Ghana	13.4	42.7	2.9%
Sierra Leone	3.5	8.8	2.3%

AAGR = annual average growth rate

While population growth rates soared throughout Africa between 1970 and the early 1980s, economic growth rates receded. Sierra Leone and Ghana both suffered from these recent economic hardships. However, both nations, and particularly Ghana, have made comebacks over the past few years. Projections by local government planners provided the basis for the estimates of GDP in Ghana and Sierra Leone for the year 2025.[6]

Starting in 1970, economic activities across all of Ghana's sectors declined.[7] Among its hardships, Ghana suffered from growing budget deficits, poor production figures, a dwindling tax base, rampant smuggling and unprecedented inflation rates. These factors led to political instability and deterred foreign investors. During the late 1970s, a prolonged drought exacerbated these problems, not only by crippling agricultural production, but also by preventing the Volta hydro plant, which supplies over 90 percent of Ghana's electricity, from maintaining its required water level. In 1982, the government's National Review Committee implemented the Economic Recovery Program of 1984-86 to combat these negative trends. The success of this program led to the formation of two other programs from 1986-88 and 1988-90. As a result, Ghana's economy grew by 6 percent annually during the latter half of the decade.

Observers believe that growth rates will decline after 2000.[8] According to both scenarios, Ghana's GDP increases five-fold between 1987 and 2025 (Table 2). Due to population growth, GDP per capita, which was quite low in 1987, increases at a slower rate.

Sierra Leone's economic crisis began in the mid-1970s and has endured ever since. The nation's problems stem from a host of factors including: the closure of the country's iron ore

[5] Ghana now has a United Nations Training Center and most Universities in the region have also improved their facilities.

[6] National Energy Board, interviews of Energy Board staff members by author, Ghana, 1989.

[7] Due to Ghana's acute economic problems in 1985, 1987 serves as the base year for this country study.

[8] National Energy Board, interviews of Energy Board staff members by author, Ghana, 1989.

mines, which served as a major foreign exchange earner in the past; the rising price of crude oil; the dwindling production of diamonds; and the implementation of agricultural policies that fail to provide incentives to the farming community. Excessive public spending between 1979 and 1981 resulted in weak internal monetary policies, which in turn spurred intense smuggling and an unprecedented scarcity of foreign exchange in the mid-1980s. In response to these hardships, Sierra Leone's new government launched a recovery program in 1985. While the government has instituted various measures, Sierra Leone's economic problems remain daunting.

Sierra Leone's potential lies in its wealth of mineral resources -- which include kimberite, gold, rutile and bauxite -- and its wide expanse of arable land. Recently the government embarked on a program to privatize government activities that have proved unprofitable in the past. The government has lifted its control over the private sector and the central bank has made moves to narrow the gap between exchange rates. Such measures, which helped Ghana's economy, are expected to bring about a turnaround in Sierra Leone as well.

Thus, although Sierra Leone witnesses slower economic growth than Ghana in forth-coming decades, the economy continues to grow at a fairly rapid pace between 1985 and 2025 (Table 2). GDP per capita increases more slowly. Sierra Leone's GDP per capita in 2025 remains 5 percent lower than Ghana's in 1987.

Table 2
GDP and GDP/Capita

	GDP (US$ Billion)			GDP/capita (US$)		
	Base Year	2025	AAGR	Base Year	2025	AAGR
Ghana	4.59	22.76	4.0%	342.8	532.9	1.2%
Sierra Leone	0.87	2.88	3.0%	246.7	326.5	0.7%

3 SECTORAL ANALYSIS AND CARBON EMISSIONS

While Sierra Leone and Ghana's residential sectors consume the largest share of the nations' energy supplies, their transport sectors produce the greatest portion of commercial energy-related carbon. The heavy consumption of biomass for domestic purposes limits the extent of the residential sector's carbon emissions. In contrast, the carbon-intensive nature of transport leads to significant carbon emissions from this sector in both nations (Tables 3 and 10).

3.1 RESIDENTIAL SECTOR

In most African nations the residential sector dominates energy use.[9] Currently, households consume 68 percent of the delivered energy demand in Ghana and 77 percent in Sierra Leone (Table 3). In general, the primacy of this sector in total energy demand stems

[9] World Bank, *Household Energy Demand in Sub-Saharan Africa* (Washington, D.C.: World Bank, 1988).

from the widespread use of traditional fuels (firewood and charcoal) and low-efficiency cooking devices. In both nations, the residential sector's share in total energy demand declines significantly by 2025 (Table 3).

Table 3[10]
Delivered Energy Use

	Ghana			Sierra Leone		
	1987	2025		1985	2025	
		High	Low		High	Low
Delivered Energy (PJ)	192	616	474	53	118	100
Residential	68%	58%	57%	77%	64%	61%
Industrial	13%	22%	23%	3%	9%	10%
Transportation	10%	8%	8%	19%	27%	29%
Services	9%	11%	12%	*	*	*
Agriculture	*	*	*	*	*	*

* Less than 1 percent

Reliance on modern fuels generally accompanies the urbanization process. Thus, the low urbanization levels in these two nations explains the heavy dependence on traditional fuels. Only 32 percent of Ghana's population and 28 percent of Sierra Leone's inhabit cities.[11] In both nations, however, rising income levels have increased the rates of urban migration in recent years. By 2025, approximately 60 percent of Ghana's population and 50 percent of Sierra Leone's will reside in urban areas.

While in both nations the number of rural households currently exceeds the number of rural households, by 2025, this ratio reverses. Ghana has twice the number of households located in cities as in the country by 2025 and Sierra Leone witnesses a seven-fold increase in the number of urban households, but only a doubling in the number of rural households. This declining urban-to-rural household ratio shifts the emphasis of energy use in the residential sectors away from traditional fuel types and towards more modern fuels.

Rising incomes lead to decreases in household sizes in both nations by 2025. Urban and rural households still remain relatively large in 2025, however, because African families tend to house older parents and extended family members. Longer life expectancy rates, due largely to improved medical facilities, also contribute to the limited decline of household size in these two nations. By 2025, urban households consist of over 6 members in Sierra Leone and of over 5 members in Ghana in 2025 and rural households average 7 members in Ghana and 8 members in Sierra Leone.

Only a small portion of the homes in Ghana and Sierra Leone have access to electricity. In the mid-1980s, only 30 percent of each nation's urban homes and a mere 4 to 5 percent of

[10] The shares presented in the tables do not always add up to 100 percent due to rounding.

[11] C.Y. Charles Wreko-Bobby and J.O. Nkum, *Population and Energy Resources in Ghana* (Ghana, 1988).

their rural homes were electrified. Ghana's Ministry of Fuel and Power has declared that by 2025 electricity will reach 90 percent of the nation's urban households and 35 percent of its rural households. In Sierra Leone, only 60 percent of urban homes and 20 percent of rural homes have access to electricity in 2025.

Cooking consumes 97 percent of Ghana's residential energy and 82 percent of Sierra Leone's household energy. This study initially planned to disaggregate energy use for **water and space heating**, but the former cannot easily be differentiated from cooking and the latter is rarely required in Africa. While in a few instances, people in Ghana rely on immersion electric heaters, these heaters consume negligible amounts of electricity.

In most urban West African countries, consumers must use more than one fuel for each end-use in order to combat shortages and high fuel costs. In the case of cooking, a single African household sometimes employs as many as five fuels (firewood, charcoal, kerosene, LPG and electricity) to meet the family's needs. Due to electricity's high cost and the high costs of electricity-using devices, this energy source rarely serves as the dominant cooking fuel in these households. In rural areas, most households do not have access to other fuels and, therefore, use firewood for cooking.

Though biomass continues to serve as the dominant fuel for cooking in 2025, LPG and kerosene replace a large portion of the biomass supply, particularly in urban areas. A program recently implemented by Ghana's government aims to have LPG provide 60 percent of all cooking energy in urban households by 2025. Under this program, local refineries will produce the LPG. The government has already established several industries to produce gas stoves and has embarked on a massive campaign to popularize LPG use.

While Sierra Leone has not undertaken any organized measures, higher incomes should lead to increased LPG use in this nation as well and, in addition, shifts in Ghana's residential energy use will likely influence the composition of Sierra Leone's fuel mix. In both Ghana and Sierra Leone, the intensity of biomass use for cooking improves as programs promoting better stoves and charcoal kilns continue to make headway (Table 4).

Lighting consumes the bulk of the household electricity supply in both of these nations. At present, however, only a small percentage of households are electrified, which has created a great deal of suppressed demand.

Ownership of **appliances** generally depends on household income levels. Most homes have radio sets. Affluence levels and household sizes largely determine both who owns refrigerators, freezers and electric fans, and the size of the appliances owned. Currently, 20 percent of all urban homes in Ghana and Sierra Leone have refrigerators, but by 2025, this share increases to 60 percent as income levels rise. Rural refrigerator saturation remains low in both nations by 2025 -- at 10 percent in Sierra Leone and 5 percent in Ghana.

An increasing number of secondhand sales of refrigerators from high-income groups to middle- and low-income groups helps disseminate refrigerators throughout the population by 2025. Market restrictions and high costs limit the purchase of bigger refrigerators, however, and thereby control the growth of unit energy consumption. More stringent international standards lead to higher efficiencies in the newer, imported refrigerators. By 2025, the unit energy consumption of refrigerators decreases by 20 percent in the HE emissions scenario. The low emissions scenario achieves even further declines (Table 4).

Table 4
Residential Energy Intensities[a]

	Ghana			Sierra Leone		
	1987	2025		1985	2025	
		High	Low		High	Low
COOKING						
Urban household (HH)						
LPG/Kerosene (GJ/HH)	20	22	18	25	27.5	22.5
Biomass (GJ/HH)	60	54	30	70	46.2	38.5
Electricity (kWh/electrified HH)	245	245	196	735	558.6	441
Rural household						
LPG/Kerosene (GJ/HH)	13	13	11.7	22	24.2	19.8
Biomass (GJ/HH)	97	97	77.6	90	59.4	49.5
Electricity (kWh/electrified HH)	0	0	0	735	558.6	441
LIGHTING						
Urban (kWh/electrified HH)	1000	1200	800	789	2224.8	1727.2
Rural (kWh/electrified HH)	500	600	450	300	360	240
REFRIGERATORS (kWh/electrified HH)	900	720	630	600	480	360

[a] In the case of fuel use, the intensities refer only to the amount of fuel consumed by each household that uses that fuel type and, in the case of electricity use, the numbers only refer to electricity use per electrified household. These numbers are not averages for all households.

Very few homes use **air conditioning** at present. And, due to electricity's continuing high costs, only a small share of homes use air conditioning in the future. By 2025, 15 percent of urban homes and 1 percent of rural homes in Ghana and Sierra Leone have air conditioners. Air conditioning efficiency improves by 10 percent in the HE scenario. The LE scenario improves the efficiency air conditioners by 20 percent of the 1985 level.

While the saturation of other appliances also increases with higher incomes by 2025, in general, saturation levels remain low and these appliances continue to demand a small share of both nations' total residential electricity supplies.

In Ghana, residential delivered energy demand increases just under three-fold between 1987 and 2025 in the high emissions scenario. The low emissions scenario limits total demand in 2025 by one quarter of the HE figure. Household energy demand increases more slowly in both scenarios for Sierra Leone (Table 5). The LE scenario reduces the total energy requirements in the residential sector by 19 percent of the HE level. In both nations, increases in cooking activities account for about 80 percent of the expansion in residential energy use between the base year and 2025 and higher demand for lighting accounts for most of the remaining growth in household energy consumption.

Table 5
Residential Energy Use and Carbon Emissions

	Ghana			Sierra Leone		
	1987	2025		1985	2025	
		High	Low		High	Low
Delivered Energy (PJ)	130	358	270	41	75	61
Oil	4%	24%	26%	4%	15%	15%
Biomass	95%	63%	61%	95%	80%	81%
Electricity	1%	13%	13%	1%	5%	5%
Carbon Emissions (MT)	0.09	2.08	1.4	0.06	0.34	0.21

In both Ghana and Sierra Leone the composition of the residential fuel mix shifts significantly (Table 5). In Sierra Leone, the role of biomass in fueling household activities decreases. In Ghana, the share of biomass in the fuel mix declines even further, particularly in the LE scenario. In both nations, the share of electricity and oil in the fuel mix increase to compensate for biomass' decline.

The widespread substitution of carbon-intensive fuels for biomass resources in both Ghana and Sierra Leone's residential sectors significantly heightens residential carbon emissions (Table 5). In Ghana, carbon emissions increase by a factor of 21 between 1987 and 2025 in the HE scenario.[12] The LE scenario limits Ghana's residential emissions in 2025 to 14 times the 1987 level due to the widespread use of LPG in urban areas.

In Sierra Leone, where biomass continues to provide a larger portion of residential energy demand, commercial energy-related carbon emissions grow more slowly. Sierra Leone's residential carbon emissions increase five-fold in the HE scenario. The LE scenario restricts the level of carbon emissions in 2025 to just over three times the 1985 level.

3.2 TRANSPORT SECTOR

The transport sector accounts for the largest share of both nations' carbon emissions by far due to the completely oil-based nature of the fuel mix.

Passenger transport absorbs the largest portion of this sector's energy. By 2025, the number of cars increases in both Ghana and Sierra Leone (Table 6). Public transportation often proves unreliable in these two nations and this inconvenience often spurs car purchases. Additionally, as more and more middle-income households come to have two income-earners, they often purchase second cars.

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[12] In 1985, only 5 percent of residential energy in Ghana was derived from commercial sources. Therefore, the residential carbon emissions figure for 1987, which excludes emissions from biomass use, only reflects this 5 percent share of total household energy use. By 2025, however, almost 40 percent of the energy used in Ghana's households is from commercial energy sources, leading to an almost eight-fold increase in the level of commercial energy-related carbon emissions counted from this sector. Taking into account the three-fold increase in population over the 1987-2025 time period, carbon emissions from household energy use increase over twenty-fold in the HE scenario, despite a far slower rate of growth in household energy consumption (including biomass).

While many high-income people buy new, high efficiency vehicles, many middle- and low-income people purchase the secondhand, less efficient vehicles being replaced. Since most of the older cars remain within the nation, overall fuel intensity improvements in the car fleet are limited (Table 6). In both nations, the distance traveled per car falls by between 10 and 15 percent over the observed time period.

Table 6
Car Saturations and Fuel Intensities

	Cars (Per 1,000 persons)			Fuel intensity (Liters per kilometer)		
	Base Year	2025		Base Year	2025	
		High	Low		High	Low
Ghana	3.8	5	5	0.24	0.17	0.12
Sierra Leone	7.1	10	10	0.20	0.16	0.14

While the number of motorcycles increases in both nations, the distances these vehicles travel decline. The number of buses also increases. In Ghana, the distance traveled per bus drops by over 30 percent in the HE scenario and almost 40 percent in the LE scenario. In Sierra Leone, however, the distance traveled per bus increases by over 25 percent according to both scenarios, because Sierra Leone has no rail system to relieve the pressure on the bus system.

Freight transport in Ghana is divided between truck and rail. In the early 1960s, Ghana's rail system switched its fuel base from coal to diesel. This transition placed increased pressure on the nation's already limited petroleum resources. Ghana has made little investment in its rail system and the system has grown increasingly unreliable. As a result, the nation has witnessed a shift away from rail to road, which consequently has increased overall diesel consumption. The number of trucks in Ghana increases almost six-fold between 1987 and 2025, but the distance traveled drops by 20 percent in the HE scenario and by almost 30 percent in the LE scenario. Ghana's truck fleet continues to consume a considerably larger share of the transport energy demand than rail in 2025.

Diesel-powered trucks carry the bulk of all freight in Sierra Leone. Although this nation once had a rail system, its use was discontinued during the 1970s when the World Bank and German advisers told Sierra Leone's government that the system was likely to remain unprofitable in the future. The German government then provided the necessary funds to build improved roads for truck passage. Sierra Leone's sole reliance on trucks has had a severe impact on the agriculture sector, which has a hard time meeting its transport needs with the limited cargo capacity of trucks. The number of trucks in Sierra Leone increases from 3 to 8 million between 1985 and 2025 and the distance traveled per truck increases from 30,000 to 50,000 kilometers. Fuel intensity declines by 20 percent in the HE scenario and by 30 percent in the LE scenario.

In the past, the low level of development in Ghana and Sierra Leone has limited the growth of transport. Transport expands considerably over the next four decades, however, leading to substantial increases in transport fuel consumption in both nations (Table 7). This growth will be some what limited by the increasing pressure from oil import bills. In Ghana, the growing fuel demands of trucks and buses combined account for over 80 percent of the increase in transport energy use between 1987 and 2025 in the HE scenario. In Sierra Leone, buses spearhead the increase in transport fuel demands between 1985 and 2025 followed closely by cars. Together, these two transport modes account for over 70 percent of the increase in transport energy use in the HE scenario.

The fuel mix remains 100 percent oil-based in the HE scenarios for both nations (Table 7). In the LE scenarios, ethanol makes a small contribution to the transport fuel mix. Sierra Leone, which already has a sugar refinery, has carried out several ethanol experiments to date.[13] These experiments have examined the potential for using different blends of ethanol and gasoline and pure ethanol in petrol vehicles.

Table 7
Transport Energy Use and Carbon Emissions

	Ghana			Sierra Leone		
	1987	2025		1985	2025	
		High	Low		High	Low
Delivered Energy (PJ)	19	52	38	10	32	29
Oil	100%	100%	98%	100%	100%	97%
Biomass	0%	0%	2%	0%	0%	3%
Carbon Emissions (MT)	0.38	1.04	0.74	0.21	0.63	0.55

The transport sector remains the largest carbon producer in both nations in 2025. Transport's emissions triple in Sierra Leone by 2025 according to the HE scenario and more than double according to the LE scenario. In Ghana, carbon emissions increase almost three-fold between 1987 and 2025. The LE scenario limits this growth to a factor of two.

3.3 INDUSTRIAL SECTOR

Compared to other nations, industry plays a minor role in the economies of both Ghana and Sierra Leone. The bulk of the industrial activities carried out in both these nations involve the mining or manufacturing of very light goods. In Ghana, industry consumes 13 percent of the delivered energy demand and in Sierra Leone industry absorbs only 3 percent of the nation's energy demand.

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13 O.R. Davidson, *Petrol-Ethanol Mixtures as Transport Fuel in Sierra Leone* (Freetown: University of Sierra Leone, 1986).

No disaggregated information on Ghana and Sierra Leone's industrial activities are available. The scenarios assume that VALCO, a transnational aluminum production company, is Ghana's main energy-intensive industry. VALCO consumes 70 percent of the industrial electricity supply in Ghana (Appendix B). In both nations, industry only accounts for a small share of value added -- 16 percent in Ghana and 14 percent in Sierra Leone.

Both nations have **mining** industries. Ghana has at least one intermediate processing industry, aluminum. Sierra Leone mines a more varied array of ores (gold, diamond, bauxite and rutile), but its activities are limited to extracting the ore and cleaning it for export. Both nations have cement industries, but they import the cement materials after the most energy-intensive processes have already been carried out. The processes that take place within Ghana and Sierra Leone mainly involve the crushing and packaging of cement. Both nations also have crude oil refineries. On the whole, however, **energy-intensive manufacturing** constitutes a small share of total operations.

Because the electricity grid does not reach the mining areas in Sierra Leone, diesel supplies the bulk of the electricity used for its most energy-intensive processes. In Ghana, the national grid powered by the Volta Dam supplies electricity to the nation's more energy-intensive industries.

Both nations recently have embarked on industrial energy conservation initiatives.[14] In addition, because Ghana and Sierra Leone rely on international suppliers for machinery, they are likely to only import equipment that meets the efficiency standards of the country of origin (assuming that exporters do not attempt to dump low-efficiency equipment in these two countries). In Ghana's high emissions scenario, these factors lead to declines of 5 percent in fuel intensity (GJ/US$), 23 percent in biomass intensity and 17 percent in electricity intensity between 1987 and 2025. The low emissions scenario makes much more significant strides in improving efficiencies.

In Sierra Leone's HE scenario, electricity intensity (kWh/US$) declines by 12 percent, but fuel intensity increases by 55 percent. Sierra Leone's mining activities, which account for almost all of the nation's industrial energy use, generate their own petroleum-based electricity from captive plants. The substantial growth of mining over the four decade period leads to a dramatic increase in fuel intensity, although much of the fuel use is eventually channeled towards electricity production for mining. In the LE scenario, electricity intensity further declines by 21 percent of the 1985 level. The intensity of fuel use increases, although less dramatically, by 42 percent of the 1985 figure.

Both nations expand their industrial sectors by 2025. Included among the new industrial activities are: pre-processing of some mining products, the development of petro-chemical manufacturing and steel production. As a result, energy demand from the industrial sectors of

[14] In Ghana, the National Energy Board and the World Bank are seeking ways to improve industrial energy conservation. The University of Sierra Leone and the Ministry of Energy are working on improving industrial energy conservation in Sierra Leone.

both Ghana and Sierra Leone increase significantly (Table 8). In Ghana's HE scenario, energy demand increases by a factor of 3.3. This expansion stems mainly from the growth of both energy-intensive and non-energy intensive industries. The LE scenario limits this increase to 2.5 times the 1987 demand. Sierra Leone witnesses a much more dramatic rise in energy inputs; industrial energy demand increases over seven-fold in the HE scenario. The growth of mining-related activities accounts for 96 percent of the increase in industrial energy demand between 1985 and 2025. The LE scenario limits this growth to six times the 1985 level.

Table 8
Industrial Energy Use and Carbon Emissions

	Ghana			Sierra Leone		
	1987	2025		1985	2025	
		High	Low		High	Low
Delivered Energy (PJ)	24	135	109	1.51	10.9	9.96
Oil	11%	13%	13%	84%	91%	91%
Biomass	47%	45%	41%	0%	0%	0%
Electricity	41%	42%	46%	15%	9%	9%
Carbon Emissions (MT)	0.054	0.815	0.274	0.046	0.227	0.19

By 2025, Ghana's industry relies increasingly on electricity and oil, although biomass continues to provide a substantial portion of the industry's energy demand. Sierra Leone increases its dependence on oil use in industry; oil comprises a 91 percent share of the industrial fuel mix by 2025 and electricity satisfies the remaining demand (Table 8).

The growth of Ghana's industrial sector and the increasing share of oil in the industrial fuel mix lead to a sixteen-fold increase in industry's carbon emissions between 1987 and 2025 in the HE scenario. In the LE scenario, these emissions are substantially reduced; emissions levels increase only five-fold from the 1987 level.

Sierra Leone also experiences a substantial, though less startling, increase in industrial carbon emissions over the observed time frame. Between 1985 and 2025, carbon emissions from Sierra Leone's industrial sector increase five-fold in the HE scenario and over four-fold in the LE scenario.

3.4 SERVICE SECTOR

Ghana's service sector derives 82 percent of its energy from biomass, 14 percent from oil and 4 percent from electricity. The fuel mix remains almost identical in 2025. While Sierra Leone's service sector also draws the largest share of energy from biomass (47 percent), electricity supplied 42 percent of this sector's energy and oil 11 percent in 1985. In general, these nations use most of the biomass to fuel cooking in schools, prisons and hospitals. Electricity powers most of the operations and, particularly in Ghana, electricity satisfies the air conditioning needs of some large buildings.

Energy intensity declines by 10 percent in the service sector between 1987 and 2025 in Ghana's high emissions scenario. The low emissions scenario achieves greater gains. Electricity intensity declines by 20 percent of the 1987 level and biomass and fuel intensity decline by 30 percent. In Sierra Leone, fuel intensity drops by 40 percent in the HE scenario and 60 percent in the LE scenario. Biomass and electricity efficiency improvements are minimal in the HE scenario; in the LE scenario, however, biomass and electricity intensity decline by 20 percent.

The energy demand of Ghana's service sector increases from 17 PJ in 1987 to 70 PJ in 2025 in the HE scenario. The LE scenario constrains this demand to under 80 percent of the HE figure. Sierra Leone's service sector consumes 0.23 PJ of energy in 2025, up from 0.09 PJ in 1985, in the HE scenario. In the LE scenario, services' energy demand decreases by 13 percent of the HE figure. In both scenarios in both countries, services' energy demands remain low.

Carbon emissions from Ghana's service sector increase from 48 thousand tons to 218 thousand tons in the HE scenario. The LE scenario limits services' carbon emissions to 150 thousand tons. In Sierra Leone, the service sector witnesses very little growth between 1985 and 2025 and as a result carbon emissions only increase from 3.4 to 3.6 thousand tons over the 40 year time frame. The LE scenario, however, indicates that efficiency improvements can actually lower the amount of carbon generated by Sierra Leone's service sector to 1.2 thousand tons by 2025.

3.5 AGRICULTURE SECTOR

Over 60 percent of the total work force in Ghana and Sierra Leone work directly or indirectly for the agricultural sector. Peasantry and manual labor satisfy most of this sector's needs, however, and mechanization levels remain quite low. Traditional tools meet most of the farming requirements. Tractors generally consume the small amount of diesel used by this sector. In both Ghana and Sierra Leone, agriculture requires less than one half of one percent of the nations' total energy demand.

In Ghana, agriculture currently demands 1 PJ of energy. This energy requirement remains flat in 2025 according to both scenarios. Agricultural energy inputs in Sierra Leone were one-tenth the amount of Ghana's in 1985. Although the energy demand increases by 2025, agriculture in Sierra Leone continues to demand less than 1 PJ of energy.

In Ghana, carbon emissions from agriculture actually decrease from 23.2 thousand tons in 1987 to 18 thousand tons in the HE scenario and to 16 thousand tons in the LE scenario. In Sierra Leone, carbon emissions increase, but continue to comprise a negligible share of total emissions in 2025.

3.6 AGGREGATE DELIVERED ENERGY DEMAND

Ghana's aggregate delivered energy demand increases almost four-fold to 616 PJ between 1987 and 2025 in the HE scenario. The LE scenario reduces Ghana's total energy demand by 23 percent of the HE figure. Already much smaller to start with, Sierra Leone's energy demand increases less dramatically. Between 1985 and 2025, total energy demand more than doubles to 118 PJ in the HE scenario. The LE scenario's total demand lies 15 percent lower (Table 9).

Table 9
Aggregate Energy Use (PJ)

	Ghana			Sierra Leone		
	1987	2025		1985	2025	
		High	Low		High	Low
Total	192	616	474	53	118	100
Oil	16%	27%	27%	25%	45%	46%
Biomass	78%	56%	54%	74%	51%	50%
Electricity	7%	17%	19%	1%	4%	4%

In 1987, energy demand per capita in Ghana equalled 14.3 GJ. While in the HE scenario, Ghana's demand per capita remains level in 2025, in the LE scenario, energy demand drops to 11.1 GJ per capita in 2025. Energy demand per capita in Sierra Leone falls from 15 GJ in 1985 to 13.4 GJ in 2025 in the HE scenario. In the LE scenario, energy demand per capita drops further to 11.3 GJ. The stabilization and/or decline of energy demand per capita in both nations reflects the impact of fuel substitutions (primarily the replacement of inefficient biomass sources with commercial fuels) and improved end-use technologies on the efficiency of energy use. As a result, each person uses lower energy inputs to receive the same, if not improved, levels of energy service.

4 ELECTRIC POWER GENERATION

Electricity comprises a small but growing share of the energy demand in Ghana and Sierra Leone. In both nations, electricity demand far surpasses the available supplies.

At present, Ghana and particularly Sierra Leone derive only a small share of their delivered energy demand from electricity. By 2025, electricity comes to play a more important role in both nation's fuel mixes (Table 9).

Transmission and distribution losses are extremely high in both nations. Ghana currently loses 26 percent and Sierra Leone 29 percent. While these nations reduce their losses by 2025, losses still remain relatively high at 15 percent in Ghana and 20 percent in Sierra Leone (Appendix B).

In real terms, Ghana's electricity demand increases eight-fold in the HE scenario between 1987 and 2025. The LE scenario reduces the electricity demand to seven times the 1987 level.

In Sierra Leone, electricity demand increases five-fold. The LE scenario limits this increase to a factor of four.

Ghana derives all of its electricity from the hydro sources of the Volta Dam at present. In the HE scenario, the composition of Ghana's electricity fuel mix shifts. Hydro's share drops to 80 percent; natural gas gains a 15 percent share and oil a 5 percent share. In the LE scenario for Ghana, hydro retains its monopoly on electricity generation in 2025.

Sierra Leone has yet to reap the benefits of available hydro resources to generate its power supply. In 1985, oil provided 97 percent of the fuel for electricity generation and hydro constituted a mere 3 percent. In the HE scenario, hydro's share grows to 50 percent and oil provides the remaining half in 2025. Carbon emissions are reduced in the LE scenario by restricting oil's share to 20 percent in 2025 and using biomass to fuel 30 percent of the power supply.

In Ghana, the capital costs of the power supply increase more rapidly than GDP between 1987 and 2025. While GDP increases by a factor of five over the observed period, electric power capital costs increases by a factor of 8.4 in HE scenario and 7.7 in the LE scenario. The discrepancies in the growth rates indicates that in 2025 a larger share of Ghana's GDP will be channeled towards funding power plant construction.

In Sierra Leone, while GDP increases just over three-fold between 1985 and 2025, capital costs for power plants increase ten-fold in the HE scenario and eight-fold in the LE scenario. Thus, in both scenarios, the power supply requires an increasing share of Sierra Leone's GDP as well.

5 ENERGY INTENSITIES AND PRIMARY ENERGY SUPPLY

Energy consumption grows more slowly than GDP in both Ghana and Sierra Leone. In Ghana the energy/GDP ratio drops by 24 percent between 1987 and 2025. Sierra Leone experiences an even greater decline of 30 percent.

Between 1987 and 2025, Ghana's primary energy supply increases almost four-fold in the HE scenario (Table 10). The LE scenario limits the level of the supply to 80 percent of the HE level. The share of biomass in the primary energy supply drops substantially in both scenarios and hydro and oil's shares increase. In the HE scenario, biomass continues to be the mainstay of Ghana's energy demand. In the LE scenario, however, hydro's share surpasses that of biomass.

In Sierra Leone, the primary energy supply increases to 130 TJ between 1985 and 2025 in the HE scenario (Table 10). The LE scenario moderately reduces the total primary energy supply by 17 percent of the HE figure. Sierra Leone's fuel mix grows increasingly oil based by 2025. In 1985, biomass comprised a 70 percent share of the primary energy mix and oil held a 30 percent share. The Sierra Leone of 2025 has a much more oil-based primary fuel mix. In the HE scenario, oil use surpasses biomass consumption in 2025. The LE scenario slightly reduces oil's share and relies more heavily on biomass. The expanding share of oil increases the amount of carbon produced for each unit of energy. The ability to afford the increase in oil imports will depend both on the price of oil and on the state of Sierra Leone's economy.

Table 10
Primary Energy Supply (PJ)

	Ghana			Sierra Leone		
	1987	2025		1985	2025	
		High	Low		High	Low
Total	232	884	707	56	130	108
Oil	14%	22%	20%	30%	48%	46%
Natural Gas	0%	5%	0%	0%	0%	0%
Biomass	64%	39%	36%	70%	46%	49%
Hydro, Solar, Other	22%	34%	44%	0%	6%	5%

An important feature characterizes the energy outlooks for both Ghana and Sierra Leone: each nation has a considerable wealth of currently unexploited renewable energy resources. These alternatives may make a major contribution to reducing the carbon intensity of the fuel mix in the future.

Ghana's greatest renewable energy potential lies in biomass, hydropower and solar resources. Trees presently cover about 75 percent, or 8.8 million hectares, of Ghana's land. According to observers, Ghana's growing stock of biomass equals 322 million MT. The annual incremental growth of biomass in this nation amounts to 12.3 million tons (Appendix C). Two large hydro plants in Ghana -- at Akosombo and Kpong -- supply 1072 MW or 92 percent of Ghana's installed capacity. Planned sites promise to provide an additional 100 MW. Ghana has developed about one half of its potential hydro sites thus far. Despite the fact that significant portions of Ghana lack electricity, the nation trades some of its electricity to neighboring nations (Togo and Benin). Average annual sunshine ranges from 1945 to 2724 hours with a mean daily solar intensity of between 16 and 20 MJ/square meter. Ghana has yet to exploit its vast solar energy potential. Currently crop and dish drying and certain industrial processes rely on solar resources.

As for Sierra Leone, the nation receives about 2000 hours of sunshine annually with a mean daily solar energy intensity of about 16.6 MJ/square mile. Aside from its use for agricultural crop drying, solar power has yet to be harnessed in Sierra Leone. Sierra Leone's biomass potential lies in its 6.3 million hectares of forest resources. While Sierra Leone possesses hydro resources of over 1000 MW, this nation only uses 5 MW of hydropower. Petroleum products provide over 95 percent of the nation's electricity at present. Sierra Leone recently initiated the construction of a 300 MW hydro plant with a first stage of 79 MW which is expected to be completed by the mid-1990s.

For both these nations, moving towards the greater use of indigenous energy sources would reduce their vulnerability to the problems associated with oil imports. Increasing the reliance on local *renewable* resources, in particular, would hold the benefit of substantially reducing the high emissions of carbon dioxide that accompany the use of fossil fuels.

6 CARBON EMISSIONS

In both Ghana and Sierra Leone, carbon emissions increase more rapidly than energy consumption between 1985 and 2025. In Ghana's HE scenario, energy demand grows by 220 percent, while carbon emissions grow by 595 percent. In the LE scenario, energy demand increases by 150 percent and carbon emissions by 330 percent. In Sierra Leone, delivered energy demand increases by 123 percent between 1985 and 2025 in the HE scenario and by 89 percent in the LE scenario. Carbon emissions, however, increase by 278 percent in the HE scenario and by 200 percent in the LE scenario (Table 11).

Table 11
Carbon Emissions (Million Tons)

	Ghana			Sierra Leone		
	1987	2025		1985	2025	
		High	Low		High	Low
Carbon Emissions	0.64	4.42	2.74	0.32	1.20	0.95
Residential	15%	47%	51%	19%	28%	22%
Industrial	8%	18%	10%	15%	19%	20%
Transportation	59%	23%	27%	65%	52%	58%
Services	7%	5%	5%	1%	*	*
Agriculture	4%	*	*	*	*	*
Losses	6%	6%	6%	--	--	--

* = Less than 1 percent

Currently, Ghana and Sierra Leone's transport sectors generate the largest amounts of carbon (Table 11). By 2025, the share of Ghana's transport sector in total carbon emissions drops substantially and the residential sector becomes the premiere carbon emitting sector. Industry's share of carbon emissions increases from 8 to 18 percent between 1987 and 2025 in the HE scenario; the LE scenario reduces industry's share to 10 percent. Service's and agriculture's contributions to carbon emissions fall in both scenarios.

In Sierra Leone, transport continues to produce the nation's largest share of carbon in 2025. Residential activities, which currently account for about one quarter of the nation's carbon, comprise an increasing share in both scenarios. Like in Ghana, in Sierra Leone industry's share in carbon emissions expands over time. The agriculture and service sectors' shares of total carbon emissions remain negligible in both scenarios.

In Ghana's high emissions scenario, CO_2 emissions per capita increase from 48 kg in 1987 to 104 kg in 2025. The low emissions scenario limits emissions per capita to 64 kg in 2025.

As Ghana's fuel mix grows increasingly oil-based, the carbon emissions generated for each unit of commercial energy produced increase as well. In 1985, each unit of commercial energy emitted 2.8 kg of CO_2. By 2025, the CO_2/commercial energy ratio increases to 5 kg/GJ in the HE scenario and to 3.9 kg/GJ in the LE scenario.

In Sierra Leone, carbon emissions per capita increase from 93 to 140 kg between 1985 and 2025 in the HE scenario. In the LE scenario, CO_2 emissions per capita are limited to 111 kg by 2025. In 1985, each unit of energy produced 6 kg of CO_2 in Sierra Leone; by 2025 this figure increases to 10 kg/GJ in the HE scenario and to 9 kg/GJ in the LE scenario.

7 CONCLUSIONS

Policy measures to reduce carbon emissions should focus on the residential, transport and industrial sectors, the largest carbon emitters and energy consumers in these two nations.

In the urban residential sector, improving the efficiency of energy use will entail strong policies that encourage the use of more energy-efficient stoves for cooking. Because urban households prefer LPG and kerosene to biomass, the government should promote the dissemination of improved LPG and kerosene stoves in cities. In rural areas, efforts should emphasize preserving biomass's share in the fuel mix through centralized actions aimed at increasing the available supply of biomass (e.g., tree planting).

In the transport sector, Ghana can achieve the greatest energy savings by focusing efforts on improving truck and bus modes. The greatest potential impacts in Sierra Leone lie in reducing the energy demands of private cars and fostering the use of public transport, such as buses. In both countries, the transport sector can attain improved efficiencies and control emissions by setting stricter standards for the imported vehicle fleet. On the domestic front, the government needs to investigate the potential for setting pollution standards, regulating the composition of the future vehicle fleet and improving the nations' road and communication systems.

The industrial sector contributes a smaller amount of carbon than the residential and transport sectors in 2025, but its contribution is still substantial. By switching from modern fuels to biomass, this sector's emissions can be reduced even further. Agricultural wastes can be used at little or no cost and can create potential opportunities for cogeneration. The palm products and forestry industries in these nations recently have begun using biomass residues to produce electricity. The government should continue to encourage this transition in new industries.

The scenarios indicate that the focus of energy policies in Ghana and Sierra Leone also should shift to raising adequate capital for the construction of power plants and related facilities in the electricity sector. Ghana's electricity development requires a 67 percent larger share of GDP in 2025 than at present and Sierra Leone's requires a 25 percent larger share. The current fragility of both countries' economies calls for innovative approaches in attracting the foreign capital needed to build new plants. Also, if efforts to reduce losses and improve generation efficiency are intensified, a larger supply of electricity can be made available for utilization. These savings will reduce the capital requirements that would otherwise be required for new power facilities.

NIGERIA

1 INTRODUCTION

At 95.7 million, the size of Nigeria's population surpasses that of every other African nation. Approximately one out of every five Africans is Nigerian.[1] Over the next four decades, as the nation's population continues to grow rapidly and its economy continues to expand, Nigeria's energy demand increases considerably. Economic growth and increased urbanization simultaneously result in shifts in the composition of Nigeria's energy mix over this time period; fossil fuels increasingly replace biomass resources, which currently constitute the nation's primary energy resource. The combination of these factors leads to a substantial growth in Nigeria's carbon emissions between 1985 and 2025.[2]

This paper presents a high emissions (HE) and a low emissions (LE) scenario for energy use and carbon emissions in Nigeria for the year 2025. In the HE scenario, changes in both the type and quantity of energy consumed in Nigeria between 1985 and 2025 cause carbon emissions to more than double. With the implementation of policies promoting the substitution of natural gas for more carbon-intensive fossil fuels and with the employment of more stringent energy-efficiency measures, the LE scenario limits total carbon emissions to three quarters of the HE level.

2 GDP AND POPULATION GROWTH

Nigeria's population growth rate, one of the highest in Africa, averaged 3.4 percent annually during the early 1980s. The fear of a population explosion -- and, more specifically, of the socio-economic problems that often accompany population booms -- prompted the Nigerian government to initiate a population control policy limiting the birth rate to four children per woman. This policy, coupled with higher literacy rates, is expected to moderate population growth rates in the long term. The World Bank estimated that Nigeria's population would grow at an average rate of 3.0 percent annually between 1987 and 2000.[3] This study assumes that this growth rate remains steady until 2025, when Nigeria's population reaches 318 million.

Nigeria's GDP equalled US$ 81.8 billion in 1985. Between 1970 and 1985, Nigeria's economic growth rates fluctuated. When world oil prices increased during the 1970s, Nigeria's

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[1] The size of Nigeria's population is a highly politicized issue. The results of the last census, carried out in 1973, were annulled after numerous allegations about corruption and miscounting. This study relies on estimates by the United Nations Development Programme, *Human Development Report 1988* (New York: Oxford University Press, 1988).

[2] The term "carbon emissions" refers to carbon emissions from commercial energy sources (biomass fuel emissions are excluded) unless otherwise specified.

[3] World Bank, *World Development Report 1990* (New York: Oxford University Press, 1990).

economy grew rapidly. At the height of the oil boom (1974-78), Nigeria's real GDP increased by 29 percent. With the decline in oil prices during the early 1980s, however, Nigeria's economy floundered.

In 1984, the government instituted a series of reforms aimed at broadening the oil-based economic structure and revamping the economy. These measures fueled an average growth rate of 4.0 percent per annum between 1985 and 1989. Both scenarios assume that Nigeria maintains this 4 percent annual growth rate until 2025. According to this growth rate, Nigeria's GDP expands to US$ 405 billion by 2025.

Although Nigeria's economy increases five-fold between 1985 and 2025, rapid population growth limits the growth of GDP per capita. Between 1985 and 1988, GDP per capita increased at an average annual rate of only 1.05 percent. By 2025, GDP per capita in Nigeria increases by only 50 percent of the 1985 level, rising from US$ 788 to US$ 1,176.

The sectoral shares of GDP in Nigeria have shifted considerably over the past 20 years. Agriculture's share -- though still dominant in 1985 -- fell dramatically (Table 1).

Table 1
Sectoral Shares in GDP (US$ Billion)

	1965	1985	2025
Total	81.8	405.1	405.1
Agriculture	53%	38%	25%
Industry	19%	28%	35%
(Manufacturing	7%	10%	25%)
(Mining, Construction, Utilities	12%	18%	10%)
Transport	0%	4%	7%
Services	28%	30%	33%

Industry's portion of GDP simultaneously grew. These trends continue between 1985 and 2025. Within the industrial sector, manufacturing's share expands considerably over the observed time period as several heavy industries, which currently are being planned or developed in Nigeria, become fully operational (Table 1).

3 SECTORAL ANALYSIS AND CARBON EMISSIONS

Nigeria's residential sector, the largest sectoral energy user, absorbs almost three quarters of the nation's energy (Table 2). Because Nigerian homes derive most of their energy from biomass fuels, however, carbon emissions from this sector remain relatively low. In contrast, Nigeria's transport sector, which draws all of its energy from fossil fuels, generates over twice the amount of carbon as do households. Nigerian industry, which uses less than one tenth the amount of energy as does the residential sector, generates almost an equivalent amount of carbon. Energy use and carbon emissions in the service and agriculture sectors remain minimal.

Table 2[4]
1985 Energy Use and Carbon Emissions

	Energy Use (PJ)	Carbon Emissions (MT)
Total	1345	.9
Residential	73%	21%
Industrial	7%	18%
Transport	19%	53%
Services	*	2%
Agriculture	*	1%
Losses	--	5%

* Less than 0.5 percent

3.1 RESIDENTIAL SECTOR

While household activities consumed 90 percent of Nigeria's traditional fuel supply in 1985, they accounted for less than 20 percent of the commercial energy consumption.

The Nigerian Population Commission calculated that 16 percent of Nigeria's population lived in cities in 1985. The Commission also estimated that the nation's largest city, Lagos, was growing at an annual rate of 10 percent. The World Bank calculates that Nigeria has experienced less dramatic urban growth rates of 6 percent per annum.[5] The onset of economic recession in the late 1970s and early 1980s initiated a trend of reverse migration back to rural areas; as a result, urban growth rates have declined considerably in recent years. Based on these trends, urban population continues to grow at a rate of 5 percent annually over the four decade time frame. By 2025, 35 percent of Nigeria's population inhabits cities.

According to a 1985 Household Survey conducted in Nigeria[6], on average 4.5 members make up each urban Nigerian home and 5.5 members comprise each rural home. As income levels increase, household sizes diminish. By 2025, urban households average 3.5 members and rural households average 4.0.

With household sizes condensing but the overall size of the population still growing, the number of households in Nigeria increases manifold. In 1985, Nigeria counted 3.4 million urban households and 15 million rural households. By 2025, the number of urban households climbs to 32 million and the number of rural households rises to 52 million.

[4] The shares presented in the tables throughout this paper do not always add up to 100% due to rounding.

[5] World Bank, *World Development Report 1988* (New York: Oxford University Press, 1988).

[6] Federal Office of Statistics (FOS), *National Integrated Household Survey (1985)* (Lagos: FOS, 1987).

About 80 percent of Nigeria's urban homes and 10 percent of its rural homes had access to electricity in 1985. In spite of the economic problems that afflicted the nation during this time period, the 1980s witnessed a doubling in the number of residential connections to the national grid. By 2025, a much larger share of Nigerian homes have electricity. About 95 percent of all urban households are electrified by that time and, with the help of the government's ambitious rural electrification program, electricity serves about 60 percent of all rural homes.

At present, **cooking** absorbs 93 percent and **water heating** 6 percent of household energy in Nigeria. Nigerians tend to rely on the same devices both to cook and to heat water. The majority of all urban households have access to LPG and kerosene and prefer to use these fuels for cooking and water heating. However, due to occasional supply shortages, most urban homes also have firewood stoves. Almost every rural home in Nigeria uses a three-stone stove for cooking and water heating. Less than one third of all rural households rely on LPG and kerosene for these purposes due to the limited supply of these fuels and their typically high costs. Due to the high cost of transporting coal in Nigeria, coal use for cooking and water heating remains limited to a small number of households located near coal mines.

By 2025, cooking and water heating account for a smaller share of residential energy consumption. In 2025, almost all urban households rely on LPG and kerosene as their main fuel source for cooking and water heating when these fuels are available (Table 3). The Nigerian government currently plans to provide a distribution network for gas in major urban centers; as a result, natural gas saturation increases in the HE scenario. The LE scenario further increases the availability of natural gas to Nigeria's urban homes. In rural regions, LPG and kerosene penetrate a much larger share of all homes by 2025 than at present. While LPG and kerosene use surpasses biomass use for cooking in the HE scenario, more rural homes rely on biomass than LPG and kerosene in the LE scenario.

Table 3
Urban and Rural Residential Energy Use
(Percent of households using each fuel for cooking)

	1985	2025 High	2025 Low
Urban Households			
Natural Gas	1%	10%	25%
LPG/Kerosene	80%	95%	95%
Coal	5%	5%	5%
Biomass	95%	25%	40%
Electricity	5%	10%	15%
Rural Households			
LPG/Kerosene	30%	60%	50%
Coal	3%	5%	5%
Biomass	100%	50%	60%
Electricity	0%	2%	3%

Fuel intensities (GJ/Household) for cooking and water heating drop for every fuel type. Electricity intensity declines by only 10 percent by 2025, because currently Nigeria's end-use electricity efficiency remains relatively high. Biomass intensities decline substantially. In the HE scenario, urban households use 25 percent less biomass and rural areas households use 50 percent less because of efficiency improvements and fuel switching. Biomass consumption diminishes more rapidly in the LE scenario, declining by 50 and 75 percent in urban and rural households respectively by 2025 (Table 4).

Table 4
Residential Energy Efficiencies

	1985	2025 High	2025 Low
COOKING			
Urban households (HH)			
LPG/Kerosene (GJ/HH)	11.2	8.9	8.4
Natural Gas (GJ/HH)	2.7	2.2	1.6
Biomass (GJ/HH)	28.7	21.5	14.4
Electricity (kWh/electrified HH)	394.9	355.4	355.4
Rural Households			
LPG/Kerosene (GJ/HH)	7.6	6.1	5.7
Biomass (GJ/HH)	51.7	25.9	12.9
LIGHTING			
Urban Households (kWh/electrified HH)	265	238.5	212
Rural Households (kWh/electrified HH)	142	213	170.4
REFRIGERATORS (kWh/HH with refrig.)	620	496	372

[a] The amount of fuel and/or electricity used per household are not averages for all Nigerian households. Fuel use per activity refers only to the amount of each fuel used by those households that rely on that fuel type to carry out a particular activity. Electricity use per household refers only to the amount of electricity used for each given activity in electrified households.

Together **lighting** and **refrigeration** currently consume about half of the residential electricity supply in Nigeria. All of Nigeria's electrified homes have lighting. In urban areas, the average electrified home has three 40-watt incandescent light bulbs and one 25-watt fluorescent bulb. In rural regions, the average home has 1.3 40-watt incandescent light bulbs and one 25-watt bulb. Assuming that in both areas households use each bulb for an average of 5 hours a day, lighting consumes 265 watts per electrified urban home each year and 142 watts per electrified rural home.

By 2025, lighting efficiency improves in all Nigerian households. These efficiency gains stem from substituting fluorescent for incandescent bulbs as well as from other technological improvements in the lighting systems. As a result, urban lighting intensity drops by 10 percent of the 1985 level in the high emissions scenario. The low emissions scenario achieves reductions of 30 percent of the 1985 level.

In rural regions, increased lighting offsets these efficiency improvements. Thus, lighting intensity in rural households actually increases to 150 percent of the 1985 level in the HE scenario. The LE scenario limits this increase to 120 percent of the 1985 level. By 2025, the lighting intensity of the average urban home still surpasses that of the average rural home.

Nigerian homes possess relatively few **appliances**. Sales figures indicate that Nigeria has a total of 1.25 million refrigerators. Only about 40 percent of all electrified urban households and less than 9 percent of all electrified rural households possess refrigerators. Assuming that Nigerian refrigerators average about 120 watts of power and that they operate about 65 percent of the time, unit energy consumption per refrigerator averages about 620 kWh/year.

About 4 percent of all electrified urban households have **air conditioners**. A negligible share of all rural households -- about one in every one hundred homes with refrigerators -- use air conditioning. Air conditioning units average about 1500 watts of power in Nigeria and operate for about 3 hours per day. Thus, each air conditioner absorbs about 1,700 kWh of electricity per year.

Very few Nigerian households have **electric washers** -- only about 0.5 percent of all electrified urban homes and very few rural homes. Unit energy consumption per washer averages about 200 kWh annually.

As appliance prices decline and income levels rise, ownership of electric appliances in Nigeria increases substantially. By 2025, refrigerators penetrate about 60 percent of all electrified urban homes and 25 percent of all electrified rural homes. Saturation of air conditioners rises to 20 and 5 percent of all urban and rural electrified households respectively. About 10 percent of all electrified urban households possess washers by 2025.

Residential energy demand increases by 61 percent between 1985 and 2025 in the HE scenario (Table 5). Larger energy inputs for cooking account for two thirds of the expansion in residential energy use over this time period and increases in the saturation of all types of appliances account for another 30 percent of this growth. The LE scenario limits this increase to 25 percent of the 1985 level.

Table 5
Residential Energy Use (PJ)

	1985	2025	
		High	Low
Total	983	1584	1231
Oil	7%	31%	35%
Natural Gas	0%	0%	1%
Biomass	92%	56%	50%
Electricity	1%	12%	14%

The types of energy consumed shift significantly over this time period. While biomass continues to fuel the majority of all household activities, its share in the fuel mix drops dramatically. In the LE scenario, biomass' portion declines further than in the HE scenario and oil and electricity comprise slightly larger shares.

These shifts in the composition of Nigeria's residential fuel mix translate into a substantial jump in the absolute amounts of petroleum consumed. Electricity use rises steadily as the number of electrified households grows and the penetration of electrical appliances increases.

Nigeria's residential sector emitted 2 million tons of carbon in 1985. While residential energy demand less than doubles according to both scenarios, carbon emissions increase nine-fold in the HE scenario. This dramatic rise in carbon emissions results from the transformation of Nigeria's once biomass-based residential fuel mix to a more fossil fuel-dependent fuel mix. The low emissions scenario, which slightly mitigates the use of more carbon-intensive fuels, manages to modestly reduce the amount of carbon generated to seven times the 1985 level.

3.2 TRANSPORT SECTOR

While Nigeria's transport sector uses less than one fifth of the nation's total delivered energy demand, it consumes the largest share of the nation's commercial energy supply by far. In 1985, transportation requirements absorbed over 60 percent of Nigeria's commercial energy. Gasoline, used mainly by passenger cars, and diesel, used mainly by trucks, buses and trailers, comprise most of the transport fuel mix.

Between 1970 and 1985, as economic growth led to increased demand for transportation and as rising incomes allowed for more private vehicle ownership, the amount of fuel consumed by Nigeria's transport sector each year increased from 35 PJ to 250 PJ. Since 1985, transport energy demand has decreased, dropping to about 220 PJ in 1988, due to higher fuel and car prices and the simultaneous devaluation of Nigerian currency.

In 1985, Nigeria had about 1.1 million cars in total and about 2.4 million motorcycles. By 2025, the total number of both cars and motorcycles increases over four-fold.[7] In 1985, about 11.4 cars existed for every 1,000 members of the Nigerian population; by 2025, this figure increases to 14.4. For motorcycles, the per capita figures rise from 25 per 1,000 persons in 1985 to 32 in 2025. The distance traveled drops by 10 percent per car and by 20 percent per motorcycle between 1985 and 2025.

Cars absorb over half of Nigeria's transportation energy. Nigerian cars require about twice the fuel inputs as in other countries mainly due to the heavy congestion in urban areas. Cars consumed about 0.19 liters of gasoline per kilometer (lt/km) in 1985 and **motorcycles** consumed about 0.05 lt/km. By 2025, technological improvements lead to significant increases

[7] The number of automobiles and motorcycles was estimated by taking figures for a base year and then adding the new vehicle registrations and subtracting vehicles retired due to old age and accidents. In 1978, a study conducted for the Nigerian National Petroleum Corporation indicated that there were 450,000 cars and 1.2 million motorcycles in Nigeria. Between 1978 and 1985, an average of about 70,000 car and 150,000 motorcycle registrations were added to the stock annually, thus, leading to the 1985 figures. (Federal Office of Statistics, *Annual Abstract of Statistics* (Lagos: FOS, 1987).

in efficiency. The fuel intensities (liters per kilometer) of cars and motorcycles drop by 50 percent in the HE scenario. In the LE scenario, the fuel intensities of both these vehicles drop by 65 percent between 1985 and 2025.

Limited information exists on **trucks** and **buses** in Nigeria. Based on data from Lagos,[8] the scenarios assume that Nigeria had 50,000 trucks and 39,600 buses in 1985. Their fuel intensities ranged from between 0.4 lt/km for trucks to 0.3 lt/km for buses. While the sizes of the truck and bus fleets expand by 2025, the distances traveled per vehicle decline.

Nigeria's poorly developed **railway** system covers only 3500 kilometers of track. Rail has made only minor contributions to GDP in the past. In 1985, rail's share of GDP reached a historical high of 0.15 percent; since that time, rail's share has dropped to about 0.08 percent. Trains have played a diminishing role largely because very little investment has been made in the nation's rail system in recent years. Additionally, rising freight and passenger fares and growing competition from road carriers have discouraged many potential rail users.

At present, rail consumes less than 2 percent of Nigeria's diesel supply. The government has recently shown renewed interest in the railway subsector. As a result, the growth of mass transit in Nigeria should lead to an increase in the share of rail in Nigeria's GDP. By 2025, the rail system accounts for 0.5 percent of Nigeria's GDP. By this time, the energy intensity of the rail system declines by 30 percent in the HE scenario. In the LE scenario, because of electrification, the energy intensity drops to 50 percent of the 1985 level.[9]

Nigeria's government runs 15 airports at present and plans to increase this number to 22 by 2025. **Air**, like rail, accounts for a small portion of GDP (0.2 percent in 1988). In Nigeria, the level of cargo traffic by air correlates strongly with the total GDP and the magnitude of passenger traffic reflects the amount of income earned per capita and the prices of air travel. Because the economic outlook appears brighter for 2025, air transport's share in GDP increases to 0.5 percent. While air consumed only 7 percent of the nation's transport energy in 1985, by 2025 air absorbs almost 20 percent of Nigeria's transport energy.

In 1985, **freight transport** comprised only 14 percent of total energy consumption in this sector -- the lowest share in all the countries studied. By 2025, the share of freight in total transport increases to 35 percent in the HE scenario and 25 percent in the LE scenario. Notably, by 2025, air transport's energy demand increases by 650 percent of its 1985 level and rail transport's energy demand rises by 1,400 percent.

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[8] Federal Office of Statistics, *Annual Abstract of Statistics*, Ref. 7.

[9] These figures refer to the delivered energy intensity of rail, not the primary energy intensity. The transition from diesel- to electric-powered trains leads to large declines in the delivered energy requirements of Nigeria's rail system. In terms of primary energy use, however, the disparity between the requirements of the diesel and electric rail systems is not nearly as great.

Transport's total energy demand increases from 259 PJ to 691 PJ between 1985 and 2025 in the HE scenario. The increased energy requirements of air and car travel each account for about 28 percent of the growth. The LE scenario reduces this 2025 figure by 30 percent. In the former scenario, the transport fuel mix remains completely oil based. The low emissions scenario limits carbon emissions by allocating a 14 percent share of the fuel mix to natural gas. In accordance with current government promotions of natural gas in the transportation sector, in the LE scenario, natural gas contributes 25 percent of all fuel used in cars in 2025.

In 1985, Nigeria's transport sector emitted 5 million tons of carbon -- more carbon than all of the other sectors combined. By 2025, the transport sector emits 13 million tons of carbon. The low emissions scenario improves conservation measures and integrates natural gas into the fuel mix; thus, transport produces 25 percent less carbon than in the HE scenario.

3.3 INDUSTRIAL SECTOR

Nigeria's industrial sector has grown more rapidly than any other sector of the economy over the past two decades. Industrial output (as measured by the index of industrial production) more than doubled between 1972 and 1988. Beginning with a small base, manufacturing -- the most dynamic portion of this sector -- witnessed an almost 500 percent increase in output. Despite this growth, manufacturing still only accounted for 10 percent of the nation's GDP in 1985.

In contrast, **mining and quarrying** comprised an 18 percent share, due largely to the importance of oil and gas exports to the Nigerian economy. Gas, used to produce oil and natural gas, provides most of the energy used in the mining, utilities and construction subsector.

Non-energy-intensive manufacturing (which includes the production of textiles, beverages, cigarettes, soaps, detergents, shoes, paper and packaging) accounts for about 95 percent of Nigeria's manufacturing output. These activities accounted for 29 percent of industrial fuel use, 76 percent of industrial electricity use and all of the nation's industrial biomass use. Small-scale manufacturing accounted for most of the estimated 20 PJ of biomass consumed by this sector. As the availability of commercial fuels increases, industrial biomass use declines. As a result the energy intensity of biomass use drops by 75 percent in both scenarios.

As of 1985, Nigeria had only two **energy-intensive industries**: cement production and petroleum refining. The Nigerian government has recently begun to promote some more heavy industries, including steel, petrochemical and fertilizer production. The government's ambitious steel development program aims to produce 5.3 million tons per year in the long term. Nigeria's newly established petrochemical industry should produce 35,000 tonnes of polypropylene and 330,000 tonnes of linear alkyl benzene annually for the next few years. In the longer term, Nigeria hopes to produce about 300,000 tonnes of ethylene, 100,000 tonnes of caustic soda and 110,000 tonnes of low density polyethylene annually. Nigeria's first nitrogenous fertilizer plant, currently being built, aims to produce 400,000 tonnes of urea each year and 300,000 tonnes of compound fertilizer.

Based on these changes, energy-intensive manufacturing's share of GDP increases from 0.5 percent in 1985 to 3 percent in 2025. Manufacturing's share in value added increases from 10 to 25 percent over this time period.

The growing emphasis on energy-intensive industries in Nigeria's economy leads to a major increase in total industrial energy demand by 2025 despite an improvement in energy intensity. While in 1985 energy-intensive industries accounted for 37 percent of Nigeria's industrial fuel use, by 2025, these industries account for 72 percent.

Table 6
Industrial Energy Use (PJ)

	1985	2025	
		High	Low
Total	92	939	832
Coal	2%	12%	12%
Oil	40%	45%	29%
Natural Gas	25%	23%	39%
Biomass	22%	6%	7%
Electricity	11%	13%	13%

Total energy demand in the industrial sector increases ten-fold according to the HE scenario (Table 6). Increased energy inputs for energy-intensive manufacturing account for two thirds of this growth. The LE scenario reduces the HE figure by 11 percent; this scenario achieves 70 percent of these savings through improvements in energy-intensive manufacturing. Even in the LE scenario, however, industrial energy demand increases by over 800 percent between 1985 and 2025.

The industrial fuel mix shifts according to both scenarios. In the HE scenario, oil continues to provide the bulk of all industrial energy demand and biomass use is reduced substantially. In the LE scenario, natural gas supplants oil as the major industrial fuel. Coal powers a much greater share of industrial activities in both scenarios (Table 6).

Carbon emissions from Nigeria's industrial sector increase more rapidly than those from any other sector. At 2 million tons in 1985, industrial carbon emissions increase to 19 million tons in the HE scenario. The LE scenario limits the level of industrial carbon emissions in 2025 to 15 million tons.

3.4 SERVICE SECTOR

Nigeria's service sector consumes less than 0.5 percent of the nation's delivered energy demand. In recent years, Nigeria's service sector has expanded to support the growing activities of its economy. Between 1965 and 1985, the service sector's share of GDP increased from 28 percent to just over 29 percent. According to this trend, service's share of GDP grows to 33 percent by 2025.

Although the intensity of fuel use decreases between 1985 and 2025, energy demand in the service sector increases four-fold over the observed time period. Service's energy demand grows to 22.7 PJ in the HE scenario and to 21.2 PJ in the LE scenario. Electricity comprised a 52 percent share of the service sector's fuel mix in 1985 and oil made up the remainder. By 2025, electricity's share only increases marginally to 53 percent.

A major fuel mix transition does occur in the service sector, however: natural gas increasingly replaces oil. In the HE scenario, natural gas holds a 9 percent share of the fuel mix and, as a result, oil's share drops to 37 percent. In the LE scenario, natural gas's share increases to 14 percent and oil's share decreases further.

Nigeria's service sector accounted for a minimal share of the nation's total carbon emissions in 1985. Between 1985 and 2025, as growth of the service sector mirrors economic growth, services' carbon emissions increase to 1 million tons.

3.5 AGRICULTURE SECTOR

Nigeria's broad range of soil and climatic conditions allows for the production of a wide variety of different crops. The nation's northern dry savannah region produces grains such as millet, maize, sorghum and groundnuts; the middle belt and southern areas, which have up to five rainy months a year, grow tubers, including cassava, yams and plantains; and some of the swampy river basin areas produce rice. Despite its great agricultural potential, since 1960, Nigeria has shifted from being a major exporter of agricultural products to being a substantial importer of these goods.

The agriculture sector consumes 5.7 PJ, or about 0.4 percent, of Nigeria's delivered energy demand. Small-scale farmers, who mostly rely on traditional farming methods, carry out the majority of Nigeria's agricultural activities. Thus, mechanization levels remain quite low.

The nature of Nigerian agriculture, however, has recently begun to shift. Land holdings, which average about 1 hectare at present, are increasing in size. Large-scale methods which utilize 50 to 20,000 hectares of land and rely on modern production methods are gaining acceptance. This transition should boost the currently low levels of Nigerian agricultural production. However, it will also increase the energy intensity of Nigerian agriculture. Between 1985 and 2025, the energy intensity of agriculture doubles in the HE scenario. The LE scenario reduces this increase to 150 percent of the 1985 level.

By 2025, agricultural energy demand increases just under ten-fold in the HE scenario. The LE scenario manages to limit this increase to just over eight times the 1985 level. Agriculture continues to draw 99 percent of its energy from oil and the remaining 1 percent from electricity in 2025.

In both the HE and LE scenario, agriculture generates 1 million tons of carbon in 2025.

3.6 AGGREGATE DELIVERED ENERGY DEMAND

Nigeria's delivered energy demand more than doubles between 1985 and 2025 in the HE scenario.. The LE scenario limits the total to about 80 percent of the HE figure (Table 7).

Biomass plays a far more minor role in Nigeria's fuel mix by 2025 as petroleum products replace biomass fuels in the residential sector. As a result, oil's share in delivered energy demand increases. Coal use, which comprised less than 0.5 percent of all energy use in 1985, is revived by Nigeria's budding steel industry. The share of natural gas in Nigeria's energy mix also grows, particularly in the LE scenario. In the latter scenario, the bulk of this increase stems from the introduction of natural gas into transport activities. The expanding number of electrified households, the widening ownership of appliances and the increasing demand of heavy industries all contribute to the growing electricity consumption in both scenarios (Table 7).

Table 7
Aggregate Energy Use (PJ)

	1985	2025 High	2025 Low
Total	1345	3292	2617
Coal	1%	4%	4%
Oil	28%	50%	44%
Natural Gas	2%	7%	15%
Biomass	69%	29%	26%
Electricity	2%	10%	11%

4 ELECTRICITY GENERATION

The National Electric Power Authority (NEPA), a government parastatal, manages most of Nigeria's electricity generation, transmission and distribution. Between 1970 and 1989, the nation's installed generating capacity increased tremendously from about 700 MW to 4559 MW. Aside from those plants tied to the national grid, private individuals and industrial establishments possess about 900 MW of installed electrical capacity.

In 1988, hydropower provided 28.5 percent of the installed capacity, gas turbines 26 percent and gas-fired steam plants 44 percent. Coal- and diesel-fired plants accounted for about 1 percent of total installed capacity.

Nigeria generates, transmits and distributes power inefficiently. Particularly in light of the fact that modern gas-fired plants in other nations typically have efficiency levels of 40 percent, Nigeria's 27 percent average remains quite low. Slow repairs, usually due to the unavailability of spare parts, and drought, which has affected the water level at Nigeria's largest hydroelectric plant, Kainji Dam, contribute to these low efficiencies.

High transmission and distribution losses in Nigeria reflect the inefficiency of the nation's power system. Transmission and distribution losses averaged 32 percent in 1985. Aside from technical problems, power theft and ineffective bill collection procedures augmented these losses.

By 2025, the efficiency of electricity production and distribution improves significantly. The government has shown interest in breaking down NEPA into smaller, more stream-lined and efficient units and in allowing private sector participation in the power sector. The coming decades also witness the introduction of more efficient power plants. Additionally, a trend toward manufacturing spare parts locally allows for better plant maintenance. Thus, generation efficiency increases to 39 percent in the HE scenario. The LE scenario shows efficiency rates increasing to 41 percent of the 1985 figure by 2025. Transmission and distribution losses simultaneously decrease to 16 percent in the HE scenario. The LE scenario further reduces losses to 10 percent.

Of all the different types of electric power plants, building hydro-electric plants in Nigeria currently requires the highest capital costs (about 2380 US$/KWe) and constructing gas-fired plants entails the lowest capital costs (about 595 US$/KWe). By 2025, Nigeria produces many of the necessary electric power equipment components locally, and capital costs drop by 25 percent for every type of power plant.

Natural gas continues to dominate the generation of electricity in 2025 (Table 8).

Table 8
Electricity Generation (PJ)

	1985	2025 High	2025 Low
Total	38	399	324
Coal	0%	10%	5%
Oil	6%	8%	5%
Natural Gas	66%	67%	68%
Hydro, Solar & Other	29%	15%	22%

In the HE scenario, Nigeria develops about 75 percent of its total hydroelectric potential. In the LE scenario, Nigeria exploits about 95 percent of its hydro potential. Coal provides 10 percent of the nation's electricity in 2025 according to the HE scenario. The LE scenario tapers down coal's share to 5 percent by relying more heavily on hydro and natural gas.

5 ENERGY INTENSITIES AND PRIMARY ENERGY SUPPLY

Between 1985 and 2025, Nigeria's primary energy supply expands to 4117 PJ in the HE scenario (Table 9). The LE scenario reduces this total by over 20 percent.

Table 9
Primary Energy Supply (PJ)

	1985	2025	
		High	Low
Total	1482	4117	3205
Coal	0%	6%	5%
Oil	27%	45%	39%
Natural Gas	8%	22%	30%
Biomass	62%	23%	21%
Hydro, Solar & Other	3%	4%	5%

A major shift in the composition of the primary energy supply mix accompanies its overall growth (Table 9). Oil usurps biomass's role as the primary energy resource in Nigeria. Additionally, the share of natural gas rises sharply between 1985 and 2025. In the LE scenario, Nigeria limits the growth of its carbon emissions between 1985 and 2025 by maintaining a higher reliance on natural gas and a lower dependence on oil and coal than in the HE scenario.

Despite the increase in the total primary energy supply, the primary energy supply per capita decreases from 15.5 GJ in 1985 to 12.9 GJ in the HE scenario. The LE scenario further reduces the energy supply per capita to 10.1 GJ by 2025. Per capita levels drop because the substitution of efficient fossil fuels for inefficient biomass in the residential sector lowers the amount of primary energy required to satisfy equivalent energy requirements.

The primary energy supply also grows more slowly than Nigeria's GDP. As a result, the amount of energy required to produce each unit of GDP declines from its 1985 level of 18.12 MJ/US$ by 44 percent in the HE scenario and by 56 percent in the LE scenario. Excluding biomass, the ratio of primary energy to GDP increases from 6.8 to 7.8 MJ/US$ between 1985 and 2025 in the HE scenario. In the LE scenario, the intensity of primary energy use declines to 6.2 MJ/US$.

Nigeria possesses over 16 billion barrels of proven oil reserves.[10] Currently, the domestic crude oil requirement of 303 million barrels per annum lies well below the present production level of about 500 million barrels. If production levels remain constant between 1985 and 2025, less crude oil will be available for export.

[10] This estimate is based on exploration activities in the Delta region. If present prospecting activities prove successful, this estimate will surely increase. United States Department of Energy/United States Geological Survey, *Report of the Petroleum Resources of the Federal Republic of Nigeria* (Washington, D.C., 1987).

Most of Nigeria's proven natural gas reserves were discovered coincidentally during oil exploration. Thus, the extent of Nigeria's proven gas reserves remains somewhat uncertain. Medium estimates indicate that about 4.25 billion m3, or 25 billion barrels of oil equivalent, of both associated and non-associated gas reserves exist in Nigeria.[11] In terms of natural gas production, the LE scenario indicates that Nigeria needs to produce 30 percent more natural gas in 2025 (or 2.75 x 1010 m^3 per annum) than at present. Nigeria currently flares over 80 percent of its natural gas; by halting this practice, a larger share of Nigeria's gas demand can be satisfied in the future (See appendix E).

Conservative estimates, based on very limited exploration, indicate that Nigeria possesses about 700 million tons (approximately 3 billion barrels of oil equivalent) of sub-bituminous coal and 900 million tons (approximately 4 billion barrels of oil equivalent) of lignite.[12] Increased supply requirements place the greatest pressure on the coal industry. The increased amount of energy derived from coal in the HE scenario places production requirements at 8.3 million tons per annum in 2025, up from the current coal production rate of less than 150,000 tons annually. Coal mining operations and production methods will require substantial investments to bring about a much needed modernization process.

Nigeria's total hydro-electric potential amounts to about 8000 MWe, which at 0.5 plant capacity factor can generate 35,000 GWh of electricity or twice Nigeria's current level of electricity production.[13] Of Nigeria's total 91 million hectares of land, about 15 million hectares are forested and offer potential biomass resources.

6 CARBON EMISSIONS

Nigeria's commercial energy-related carbon emissions increase six-fold between 1985 and 2025 in the HE scenario. The LE scenario limits the level of carbon emissions in 2025 by 24 percent of the HE figure (Table 10).

Between 1985 and 2025, Nigeria's industrial sector shifts from being a relatively low carbon producer to being the nation's largest carbon-emitting sector. While the residential sector's share in total energy demand drops, as the residential fuel mix grows more reliant on commercial fuels, Nigeria's households account for an increasing portion of the nation's carbon emissions. Between 1985 and 2025, energy demand in the transport sector grows much less rapidly than in both the residential and industrial sectors. As a result, transport's share in total carbon emissions drops dramatically (Table 10).

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[11] The British Petroleum Company p.l.c., *BP Statistical Review of World Energy* (London: Dix Motive Press Ltd., 1985).

[12] Motor-Columbus Consulting Engineers, Inc., *Energy Study for the Fourth National Development Plan, 1980-85* (Report submitted to Federal Ministry of National Planning, Federal Republic of Nigeria, Lagos, 1980).

[13] Motor-Columbus Consulting Engineers, Inc., *Energy Study for the Fourth National Development Plan, 1980-85*, Ref. 12.

Table 10
CO_2[a] Indicators for Nigeria

	1985	2025 High	2025 Low
CO_2 Emissions (Million Tons)	9	54	41
Residential	21%	34%	34%
Industrial	18%	36%	37%
Transportation	53%	22%	22%
Services	2%	1%	1%
Agriculture	1%	2%	2%
Losses	5%	5%	4%
CO_2 per capita (kg)	98.7	171.4	129.4
CO_2 per Unit GDP (kg/US$ 1985)	0.12	0.13	0.10
CO_2 per Unit Primary Energy (kg/GJ)	6.4	13.2	12.8

[a] Excluding biomass

Due to the combination of population growth and increased reliance commercial fuels, the amount of carbon generated per capita increases by 74 percent of the 1985 level in the HE scenario. The LE scenario reduces CO_2 emissions per capita to three quarters of the HE level.

GDP rises more rapidly than energy use, and as a result, CO_2 emissions (including biomass emissions) per unit of GDP decline. Two forces push the CO_2/primary energy indicator in opposite directions. While increased coal use raises the amount of carbon produced per unit of primary energy, the increased substitution of natural gas for oil and biomass drive the carbon/primary energy ratio lower. The latter force proves stronger, and hence, the level of CO_2 emissions per unit of primary energy supply decreases.

7 CONCLUSIONS

This analysis indicates that increased economic activities and high rates of population growth will cause Nigeria's energy demand to expand between 1985 and 2025. By improving energy efficiency and increasing the use of natural gas and renewable energy sources, Nigeria can minimize its future energy demands and restrain the growth of carbon emissions associated with energy production and use.[14]

On the demand side, efforts should focus on the industrial, residential and transport sectors, which together account for 97 percent of the growth in Nigeria's energy use between 1985 and 2025 according to the HE scenario. The greatest opportunities for reducing the energy requirements of Nigeria's various industrial activities lie in integrating more energy-efficient technologies into Nigeria's heavy industries and modifying some of the wasteful practices and conditions which have added to industrial fuel use (e.g., plugging steam leaks, operating

[14] A.O. Adegbulugbe, "Energy Demand and CO_2 Emissions Reduction Options in Nigeria," *Energy Policy*, to be published, November 1991.

boilers/kilns more efficiently). In the residential sector, efforts primarily should focus on disseminating more efficient cookstoves and promoting the use of modern fuels (e.g., LPG and kerosene) over biomass to lower the energy requirements of cooking. Additional energy savings can be achieved in the household sector through the use of more efficient appliances and lighting devices. Restraining the growth of energy use for transport will require the implementation of a range of traffic management schemes, the enforcement of compulsory vehicle inspections and the development of driver education programs. In the longer term, Nigeria must develop an effective mass transit system to reduce the heavy fuel demands associated with high levels of private vehicle use and severe traffic congestion.

On the supply side, Nigeria can improve the efficiency of its energy use through three major avenues: (1) the improved generation, transmission and distribution of electric power; (2) the substitution of low-carbon fuels for high-carbon fuels; and (3) the increased reliance on non-carbon energy carriers. Access to new technologies, the rehabilitation of old technologies and the implemenation of effective training programs can contribute to the more efficient production and distribution of power. The increased reliance on non-carbon primary fuel options, primarily hydro and solar resources, can have a major impact on lowering the levels of carbon emissions generated by an energy system based on fossil fuels.

The adoption of the above options will entail overcoming a number of obstacles, including a poor energy-pricing system, major financial constraints (particularly foreign exchange requirements), the absence of a comprehensive policy for managing energy demand and the lack of awareness and information about the opportunities for improving energy efficiency. However, by developing Nigeria's legislative and institutional capabilities, establishing a more balanced approach to the nation's energy policy and educating the people of Nigeria about the many opportunities for improving energy efficiency, Nigeria can surmount many of these barriers and begin moving towards a more energy-efficient future.

THE GCC COUNTRIES

1 INTRODUCTION

The wealth of indigenous oil resources has largely determined the economic and energy use patterns in the member countries of the Gulf Cooperation Council (GCC). During the 1970s, sizable profits accrued from the inflation of world oil prices spurred tremendous economic growth across the Gulf. The GCC nations channeled this oil wealth into the development of infrastructure and the creation of super-welfare states. Today, these highly affluent societies enjoy benefits ranging from free medical care, schooling and housing to subsidized electricity and gasoline supplies.

The GCC was established in 1981 following the outbreak of war between Iraq and Iran, and is made up of six neighboring Arab states -- Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates (UAE). These nations banded together with the stated purpose of enhancing political and economic cooperation in the Gulf region.[1]

The combination of great personal prosperity, abundant petroleum resources and highly subsidized energy prices has led to excessive energy use among the Gulf nations. These countries have among the highest levels of energy consumption per capita in the world. Correspondingly, these countries generate among the highest levels of energy-related carbon per capita.

This paper presents two scenarios of aggregate energy use and carbon emissions[2] in the GCC nations for the year 2025. In the high emissions (HE) scenario, the GCC governments promulgate policies between 1985 and 2025 focused primarily on promoting greater economic growth, irrespective of the potential environmental hazards. Improvements occur in the efficiency of energy use as better technologies disseminate throughout the region, but the energy savings remain limited and energy-related carbon emissions rise sharply. In the low emissions (LE) scenario, the GCC governments take direct measures to reduce emissions of energy-related carbon. With the implementation of fuel switching efforts and energy efficiency measures, the LE scenario reduces the level of carbon emissions in 2025 to about 80 percent of the HE figure.

2 GDP AND POPULATION GROWTH

In recent years, the GCC countries have experienced some of the fastest population growth rates in the world. Between 1975 and 1985, the total GCC population almost doubled.[3]

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[1] A. M. Al Shatti, "The Gulf Cooperation Council and the World Oil Market," in *Government and Energy Policy*, ed. R.L. Itteilag (Alexandria: International Association of Energy Economists, October 1983).

[2] The term "carbon emissions" refers to carbon emissions from commercial energy sources -- and not from biomass sources -- unless otherwise specified.

[3] Economics Department, *GCC Economic Bulletin* (Riyadh: GCC Secretariat, 1988), No. 3.

While in most developing nations, high population growth results from high birth rates, in the GCC countries, immigration has galvanized the bulk of the population growth. The combination of improved living standards and increased demand for foreign labor due to massive development programs in infrastructure has drawn a multitude of immigrants to the GCC countries. In total, only about one half of the GCC population are indigenous to the region. In Kuwait, the UAE and Qatar, foreigners make up about 70 percent of the total population.

Population sizes vary among the six nations (Table 1). Qatar and Saudi Arabia bracket the two extremes with 300,000 and 11 million inhabitants respectively. The most accurate estimates of population growth rates exist for Kuwait. Because of the clear similarities between the nations, this study accepts Kuwait's annual growth rate as representative for the other five nations as well.[4,5] Based on Kuwait's past trends, this study assumes that between 1985 and 2025 the GCC population increases by 3.5 percent annually, a rate that far surpasses population increases in most of the other study countries. Assuming population growth rates remain stable, the total population of the GCC region expands from 16.3 to 66.1 million between 1985 and 2025.

Table 1
Population & GDP in the GCC Countries, 1985

Country	Population (Mn)	GDP (US$ Bn)	GDP/capita (US$)
Total	16.3	163.4	--
Bahrain	0.4	4.9	11270
Kuwait	1.8	19.7	11060
Oman	1.2	9.9	8060
Qatar	0.3	6.3	20840
Saudi Arabia	11.2	94.9	8440
UAE	1.3	27.8	21170

In every GCC nation, the national government plays a critical role in the well-being of the economy. The governments serve as the primary economic investors, developers and employers. Thus, government expenditures largely determine the economic growth rates. The extent of government spending depends on the level of oil revenues, which account for over 70 percent of the government's total revenues.

Following a decade of high oil prices, the aggregate GDP for the six GCC countries reached $236 billion in 1981. However, during the early 1980s, oil prices dropped dramatically (Arabian Light, for example, fell from $32/barrel in 1981 to $16/barrel in 1986). As a result, the total GDP for the Gulf region sank to $163 billion in 1985 (Table 1). Between 1981 and 1986, government revenues dropped from $160 billion to $56 billion.

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[4] Kuwait Ministry of Planning, *Annual Statistical Abstract* (Kuwait City: Ministry of Planning, 1988).

[5] World Bank, *World Development Report 1990* (New York: Oxford University Press, 1990).

As a result of these extreme economic fluctuations, the GCC states have had to come to terms with some of the obvious weaknesses of their economies. The far-reaching welfare measures implemented during the 1970s improved the quality of life across the GCC region, yet eliminated the countries' incentive systems and, thus, lowered productivity levels. The subsidization of energy prices led to over-consumption and waste. And, most important, the heavily oil-based economic structure proved shaky and unreliable. In response, the GCC nations have recently embarked on an ambitious drive to diversify their economies. They have invested heavily in the development and improvement of the non-oil sectors of the economy, including industry, transportation, construction services and, to a lesser extent, agriculture.

The development of the oil market and the success of efforts to diversify these oil-dependent economies will largely determine the economic future of the GCC nations. The scenarios assume that the GCC nations' economies grow at an average annual rate of 4.7 percent between 1985 and 2025. Simultaneously, the price of oil increases by 2 percent per annum reaching $40 a barrel by 2025. The aggregate GDP for the six GCC countries equals $1084 billion in 2025.

3 SECTORAL ANALYSIS AND CARBON EMISSIONS

Because oil production forms the basis of the GCC economy, mining activities comprise the largest share of the GDP in each nation (Table 2).

Table 2[6]
GDP and Delivered Energy Use

	GDP (US$ Billion) 1985	GDP 2025 High	GDP 2025 Low	Energy (PJ) 1985	Energy 2025 High	Energy 2025 Low
Total	163	1084	1084	2219	15416	12983
Residential	--	--	--	11%	11%	11%
Industry	56%	56%	56%	38%	39%	43%
(Manufacturing	8%	8%	8%	--	--	--)
(Mining/Util.	48%	48%	48%	--	--	--)
Transport	6%	6%	6%	38%	31%	28%
Agriculture	2%	2%	2%	4%	11%	11%
Services	35%	35%	35%	9%	8%	7%

During the 1970s, the GCC governments promoted industrialization by providing a number of incentives ranging from low interest industrial loans to price subsidies. These efforts led to a doubling of manufacturing's share of value added between 1981 and 1986 and caused mining's share of GDP to drop. Simultaneously, the scope of government services grew substantially and trade and banking activities increased, which led to the rapid expansion of the service sector. Only recently, with the development of manufacturing and trade, has the transport sector come

6 The shares presented in the tables do not always add up to 100 percent due to rounding.

to comprise a significant share of GDP. Despite GCC efforts to ensure food stability, agriculture's share of value added remains minimal.

3.1 RESIDENTIAL SECTOR

Increased urbanization levels and the spread of electrification commonly correspond with the growth of household energy and electricity consumption. Oil revenues have allowed the GCC countries to develop many urban centers. In 1985, the urban population share averaged 71 percent across the GCC region. Over 90 percent of the population in Kuwait, the UAE, Bahrain and Qatar inhabited urban areas while only 50 percent of Oman's population lived in cities.[7] By 2025, the urban population share in the GCC rises to 85 percent.

Currently about 6 members comprise each urban GCC household and 10 members make up each rural GCC home.[8] With the expected improvements in education and health care between 1985 and 2025, household sizes drop to 4 and 6 members per household in urban and rural households respectively.

This decline in household size coupled with the dramatic increase in the overall size of the population leads the number of urban households to increase from 1.9 million in 1985 to 14 million in 2025. The number of rural homes also rises, although less dramatically. At 0.5 million in 1985, the number of rural households expands to 1.7 million by 2025.

Electricity currently reaches a large share of all households in the GCC region -- 95 percent of all urban and 74 percent of all rural homes. By 2025, virtually all urban homes and 95 percent of all rural homes have access to electricity.

In 1985, cooking accounted for 11 percent of residential energy use in the GCC nations, water heating for 7 percent and space heating for just over 1 percent. In urban households, LPG and kerosene provide most of the fuel used for cooking and electricity satisfies most water- and space-heating needs. While modern fuels also meet the majority of all cooking and water heating in rural households, biomass makes up 40 percent of the cooking fuel mix and a small portion of the water-heating fuel mix. Between 1985 and 2025, the fuels used to satisfy each end use change very little in urban areas. Rural households, however, draw more of their fuel from modern energy sources in 2025.

Fuel and biomass intensities (GJ/HH) for cooking and water heating drop in both scenarios, although the LE scenario achieves greater reductions. In both scenarios, electricity intensity drops by only 10 percent for cooking. In urban regions, the intensity of electricity use

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[7] World Bank, *World Development Report 1988* (New York: Oxford University Press, 1988).

[8] The number of persons per household in Kuwait is assumed to be representative of household sizes across the GCC region.

for water heating rises by 20 percent between 1985 and 2025 in the HE scenario. The LE scenario maintains the 1985 electricity intensity levels.

Due to the high living standards in the gulf nations, GCC households own far more appliances than do households located in the other study countries. The majority of all urban homes have television sets, VCRs, refrigerators, stoves, air conditioners and washing machines (Table 3). Appliances absorbed 80 percent of the GCC's residential energy demand in 1985. Air conditioners account for over half of household energy use in the GCC and refrigeration and lighting account for 12 and 11 percent respectively. By 2025, rural regions in particular witness a major influx of household appliances.

Table 3
Appliance Saturation and Unit Electricity Demand (kWh/year)

	1985	2025	
		High	Low
Electricity Use/Electrified HH			
Urban Household	26950	24215	21080
Rural Household	16325	24163	20700
Lighting			
Urban energy consumption/HH	3500	3150	2800
Rural energy consumption/HH	2500	3750	3000
Refrigerator			
Ref. energy consumption/HH	4000	3200	2400
Urban saturation	95%	100%	100%
Rural saturation	95%	100%	100%
Washers			
Wash. energy consumption/HH	500	450	400
Urban saturation	30%	70%	70%
Rural saturation	5%	25%	25%
Air Conditioning			
AC energy consumption/HH	18000	16200	14400
Urban saturation	100%	100%	100%
Rural saturation	50%	100%	100%
Other			
Urban Household	1500	1350	1200
Rural Household	1000	900	800

As the number of appliances indicates, household electricity consumption in GCC nations far surpasses that of other developing nations. The GCC governments highly subsidize electricity prices. In Kuwait, electricity costs $ 0.01/kWh and in Qatar, native residents receive electricity for free. These low prices promote excessive electricity consumption. Still, at 208 GJ, primary energy consumption per capita in the GCC countries still falls short of the 240 GJ per capita average in the OECD countries.[9]

In 1985, urban GCC households consumed 82 percent more electricity per household than rural households. Between 1985 and 2025, electricity use per household drops in urban areas

[9] World Bank, *World Development Report 1990*, Ref. 5.

as efficiency gains surpass increases in appliance ownership. The growing influx of appliances to rural regions, however, offsets efficiency improvements; as a result, electricity use per rural household rises to just under the urban household level by 2025.

Continued high living standards, the growth in the number of households and the increased role of electricity in rural households lead the aggregate energy demand in the residential sector to increase almost seven-fold by 2025 to 1656 PJ in the HE scenario (Table 4). Increased energy use for air conditioning accounts for 60 percent of the growth in household energy demand between 1985 and 2025 according to the HE scenario. Together, the further dissemination of lighting and refrigeration account for 36 percent of the increase in residential energy demand over the 40 year period. The LE scenario limits the increase in household energy use by 13 percent.

Table 4
Residential Energy Use (PJ)

	1985	2025	
		High	Low
Total	247	1656	1443
Oil (LPG & Kerosene)	7%	6%	6%
Natural Gas	0%	*	*
Biomass	3%	*	*
Electricity	89%	94%	93%

* Less than 1 percent

The majority of all GCC households already have access to electricity and modern fuels. Biomass only comprised a 3 percent share of the fuel mix in 1985 (Table 4). By 2025, electricity's share in the residential fuel mix increases slightly and biomass use is phased out. In the HE scenario, residential electricity consumption increases by 5 percent per annum between 1985 and 2025, while fuel consumption increases by 3.6 percent each year. In the LE scenario, household electricity use increases at 4.6 percent per year over the 40 year period, whereas fuel use increases by 3.3 percent.

Residential carbon emissions increase from 13 million tons in 1985 to 74 million tons in 2025 according to the HE scenario. The LE scenario reduces the HE figure by 18 percent.

3.2 TRANSPORT SECTOR

The fuel demands of the transport sector absorb 38 percent of the energy use in the GCC. Between 1985 and 2025, the fleet size increases for every vehicle type. The distance traveled per vehicle falls for private transport modes (cars and motorcycles), but increases for public transport and freight vehicles. By 2025, fuel efficiencies improve across the board (Table 5).

Passenger transport absorbs the majority of the GCC's transport fuel supply. Averaging 145 cars per 1,000 persons, the GCC nations have a far higher level of private vehicle ownership at present than any of the other study countries. Even Latin American nations, where private transport has historically played a major role, have fewer cars relative to the total size of the population than do these six Arab countries.

Table 5
Transport Indicators

	1985	2025 High	2025 Low
Transport Fuel Demand (PJ)	837	4772	3625
Vehicles (Per '000 persons)			
Cars	144.7	231.5	231.5
Motorcycles	15.3	24.5	24.5
Buses	38	62	62
Trucks	88	144	144
Fuel efficiency (liter/km)			
Cars	0.10	0.06	0.03
Motorcycles	0.05	0.02	0.02
Buses	0.30	0.24	0.18
Trucks	0.15	0.11	0.09
Distance Traveled/Vehicle (Km)			
Cars	15000	13000	13000
Motorcycles	10000	8000	8000
Buses	50000	65000	65000
Trucks	30000	40000	40000

The GCC nations imported about 20 percent of their cars from the United States, 68 percent from Japan and 11 percent from Europe in 1989. The typical GCC consumer prefers the large engine automobiles produced in Europe and the United States. These large motors require high fuel inputs. Gasoline, which is highly subsidized, costs less in the GCC regions than almost anywhere else in the world. Typical of the prices in all the GCC countries, gasoline in Kuwait costs about $US 0.50 per gallon.

Cars presently consume 14 percent of the nation's transport energy demand. Motorcycles, which are far less common in the GCC than in other developing nations, account for less than one percent. By 2025, the share of cars in transport energy falls to 8 percent in the HE scenario and 6 percent in the LE scenario.[10] Motorcycles continue to account for a negligible share of transport energy use in both scenarios.

Buses currently absorb 40 percent of all transport fuel. By 2025, the role of public transport widens. The number of buses per capita only increases slightly, but each bus travels 15,000 miles further. Thus, buses consume a growing share of transport's energy demands.

[10] A. M. Al Shatti, "Government Subsidy Policy in the Agriculture and Fisheries Sector" (Paper delivered at the Conference for Agriculture Development, Oman, November 1989).

Between 1985 and 2025, with increased economic cooperation within the GCC region, the energy demands of **freight transport** rise. Trucks currently account for over one quarter of the energy consumed in the transport sector. With more inter-regional commerce, both the number of trucks per capita and the distance each truck travels expand.

Increased trade and higher living standards have spurred the development of air transport in the GCC countries. In addition to the four state-owned airlines operating in the GCC, Bahrain and Dubai, two UAE cities, serve as the refueling bases for many major international airlines operating between Europe and the Far East. Between 1985 and 2025, air transport's value added increases from 2 to 3 percent. As air travel takes on a more significant role in the GCC economy, it encompasses a growing share of transport's energy demand.

According to both scenarios, the same number of vehicles saturate the GCC regions in 2025, vehicles travel equivalent distances and the fuel mix remains completely oil-based. The critical difference between the two scenarios is that the LE scenario manages to make greater efficiency strides than the HE scenario for every vehicle type aside from motorcycles (Table 5).

The efficiency improvements made in the LE scenario manage to lower the needed fuel inputs in 2025. In the HE scenario, transport energy demand in the GCC countries rises from 837 PJ to 4772 PJ between 1985 and 2025. Bus modes account for 45 percent of the increase in transport fuel demands and trucks and air travel account for 27 and 20 percent of this growth respectively. The LE scenario reduces the amount of fuel needed for transport activities to three quarters of the HE level.

Carbon emissions increase more substantially in the transport sector than in any other sector. In the HE scenario, transport activities generate 116 million tons of carbon in 2025 -- up from 18 million tons in 1985. The LE scenario limits transport carbon emissions to 103 million tons in 2025.

3.3 INDUSTRIAL SECTOR

While all of the GCC nations have recently embarked on industrialization programs in order to diversify their economies away from oil, the paths and goals of the various programs differ. Saudi Arabia has made a full-fledged effort to develop its heavy industries. In contrast, Kuwait has chosen to promote less energy-intensive industries, except in the cases of petrochemical production and oil refining. The UAE has focused on encouraging investments from international companies; the establishment of the Jebal Ali Free Zone Authority has attracted about $500 million in foreign funds from companies including Union Carbide, 3M and Xerox.

Energy-intensive manufacturing absorbs almost half of the GCC industrial energy demand. In 1985, the GCC nations produced 6.9 million tons of fertilizers, 16 million tons of cement, 2.4 million tons of steel and 150 thousand tons of aluminum.[11] In addition, these six Arab nations produced about 775 million tons of refined products. Three GCC nations -- Saudi Arabia, Kuwait and Bahrain -- account for 55 percent of the Middle East's refining capacity and about 4 percent of the non-communist world's capacity.[12]

Over the next four decades, the demand for these energy-intensive products remains high. The GCC nations constructed most of their basic infrastructure within the last 15 years. Many needs have yet to be satisfied. Kuwait, for example, has a backlog of 33,000 applicants waiting for government housing. In addition, the majority of the GCC population is quite young; fifty percent of Kuwait's population members are under the age of 25. As this young population ages, the demand for housing and other infrastructural needs increases.[13] Thus, between 1985 and 2025, the level of cement and steel production increase significantly.

The Gulf countries also produce a variety of non-energy intensive products, such as food and beverages, air conditioning equipment and wood and paper products. These manufacturing activities account for a small share of the GCC industrial energy use.

Oil and gas mining provide the foundation of the GCC economies. The mining and utilities subsector, therefore, consumes a much more substantial share of the industrial energy demand in this region than in the other study countries.

Industrial energy consumption increases over seven-fold by 2025 according to the HE scenario. The LE scenario reduces industrial energy demand by 9 percent (Table 6). Due to the ample resources, oil and natural gas continue to fuel the bulk of all industrial activities by 2025. In both scenarios, however, the industrial sector grows increasingly less oil-based and natural gas comes to comprise a more substantial share of the fuel mix. The LE scenario reduces industrial carbon emissions below the HE level by further integrating natural gas into the fuel mix.

Table 6
Industrial Energy Use (PJ)

	1985	2025	
		High	Low
Total	849	6061	5538
Oil	71%	58%	52%
Natural Gas	22%	36%	42%
Electricity	7%	6%	6%

[11] Economics Department, *GCC Economic Bulletin* (Riyadh: GCC Secretariat, 1988), No. 3.

[12] The British Petroleum Company p.l.c., *BP Statistical Review of World Energy* (London: Dix Motive Press Ltd., July 1989).

[13] A. M. Al Shatti, *Dynamic Sustainability of the Housing Market* (Kuwait City: Kuwait Institute for Scientific Research, 1990).

Industrial carbon emissions expand from 16 million tons to 93 million tons between 1985 and 2025. While carbon emissions increase more substantially in the transport sector than in the industrial sector, the LE scenario indicates that, in absolute terms, the greatest opportunities for reducing emissions lie in the industrial sector. The LE scenario reduces industrial carbon emissions by 25 percent of the HE figure.

3.4 SERVICE SECTOR

Between 1981 and 1985 the share of the service sector in GDP increased from 19 to 35 percent. This scenario assumes that services' share of value added remains stable over the next 40 years.

Electricity powers 58 percent and oil 42 percent of the activities in this sector. In both scenarios, electricity's share of the service energy mix grows between 1985 and 2025 (Table 7).

Table 7
Services Energy Use (PJ)

	1985	2025	
		High	Low
Total	200	1216	951
Oil	42%	36%	35%
Electricity	58%	64%	65%

In the HE scenario, although the intensity of fuel use (GJ/US$) drops by 20 percent between 1985 and 2025, the intensity of electricity use remains stable at 47 GJ/US$. In the LE scenario, electricity intensity drops by about 20 percent of the 1985 figure and fuel intensity drops by 40 percent.

The service sector absorbs 9 percent of GCC energy at present. By 2025, although the service sector accounts for a slightly smaller share of total energy demand, services' energy use increases over six-fold in the HE scenario and almost five-fold in the LE scenario.

In 1985, the GCC service sector released 8 million tons of carbon. By 2025, services' emissions rise to 45 million tons in the HE scenario and to 34 million tons in the LE scenario.

3.5 AGRICULTURE SECTOR

The harsh environment and scarcity of water in the Gulf region prohibit major agricultural development. However, some of the GCC states have resorted to modern agricultural techniques, such as the use of air conditioned greenhouses and drip irrigation, to combat the problems presented by this arid climate. In a number of cases, the governments have encouraged the agriculture sector to boost its output by offering low interest loans and providing a wide range of subsidies. A recent study examines the dramatic rise in wheat production in Saudi Arabia between 1981 and 1986.[14] The Saudi Arabian government's successful attempt to boost agriculture and, thereby, diversify its economy has actually led to a surplus of wheat.

Despite this interest and some recent successes, agriculture will continue to make a minor contribution to GDP in the future. The further development of this sector would require large investments in capital-intensive technologies. Even if these funds were readily available, the lack of water and shortage of labor would continue to hinder this sector's development.

Due to the low level of energy inputs at present, energy demand increases more rapidly in the agriculture sector than in any of the other sectors. In the HE scenario, agricultural energy consumption expands twenty-fold between 1985 and 2025, reaching 1711 PJ. The LE scenario limits agricultural energy demand in 2025 to 1426 PJ. The composition of the industrial fuel mix remains unchanged over time. Oil continues to satisfy 58 percent of agricultural needs and electricity 42 percent.

Commensurate to the growth of agricultural energy use, carbon emissions from the agricultural sector expand more rapidly than in the other sectors. In 1985, the agriculture sector -- the lowest sectoral carbon emitter -- accounted for only 3 million tons of carbon. By 2025, increased mechanization leads this sector's carbon emissions to increase to 53 million tons in the HE scenario. The LE scenario limits agricultural carbon emissions to 42 million tons. In both scenarios, agriculture's contribution to CO_2 emissions surpasses that of the service sector.

3.6 AGGREGATE ENERGY DEMAND

In the HE scenario, the aggregate energy demand expands seven-fold between 1985 and 2025 reaching 15.4 exajoules (EJ). The LE scenario reduces the total energy demand to less than 85 percent of the HE figure (Table 8).

The GCC nations draw all but a negligible share of their energy demand from three sources: oil, gas and electricity (Table 8). By 2025, these nations continue to concentrate on oil, natural gas and electricity as the mainstays of their energy supply. In both scenarios, however, the fuel mix does grow less oil-based and the shares of natural gas and electricity increase to compensate. In the LE scenario, the absolute amount of natural gas consumed surpasses the amount in the HE figure.[15]

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[14] H. Al-Sheikh, "Wheat Policy in Saudi Arabia" (Paper written at the Department of Civil Engineering, Stanford University, Palo Alto, 1989).

[15] The scenarios assume that the GCC countries continue making use of only those natural gas resources found in association with oil production. The extent to which the GCC nations further incorporate natural gas into their fuel mix will depend largely on their willingness to pursue non-associated natural gas resources.

Table 8
Aggregate Energy Use (PJ)

	1985	2025 High	2025 Low
Total	2219	15416	12983
Oil	72%	64%	60%
Natural Gas	9%	14%	18%
Biomass	*	*	*
Electricity	20%	22%	22%

* Less than 1 percent

4 ELECTRICITY GENERATION

Electricity accounts for one fifth of all energy use, a higher share than in any of the other study countries. Oil and gas serve as the primary fuels for electricity generation (Table 10). The ample supply of these fossil fuels and the dearth of any feasible energy alternative suggest that oil and gas will maintain their dominance in electricity generation in the future.

The GCC's total installed electricity generating capacity equalled 26,820 MW in 1986 and its peak load capacity amounted to 18,652 MW. Saudi Arabia has the highest installed capacity, at 14,761 MW, and Oman has the lowest, at 953 MW.

Electricity consumption per capita in the GCC countries is among the highest in the world. Each Kuwaiti citizen, for example, used an average of 9,563 kWh. The peak capacity in summer is twice that in winter, because the blistering summer weather leads to a heavy reliance on air conditioning. Although the utilization factor appears to be quite low, the possibility of power failure -- especially during the summer months -- has serious implications because the government operates the entire power supply.

Electricity production in the Gulf states continues to prove unreliable. Due mostly to poor maintenance, blackouts are common. As a result, most of the GCC nations over-produce electricity to safeguard against possible system failures. Thus, a major problem with electricity generation in the GCC continues to be the underutilization of the power supply.

The residential sector consumes over half of the GCC region's electricity supply. The service and industrial sectors account for 27 and 14 percent respectively.[16] Transmission and distribution losses absorb 10 percent of GCC electricity consumption. Auxiliary consumption is very high at 14 percent.

Electricity prices are subsidized both in the residential and industrial sectors (Table 9). Data on the cost of generating electricity in the GCC is unavailable except in the case of Kuwait.

[16] Kuwait Ministry of Electricity, *Statistical Yearbook 1988* (Kuwait City: Ministry of Electricity, 1988).

In 1984, electricity in Kuwait cost an estimated \$ 0.09/kWh. Capital costs accounted for 42 percent of this total and fuel costs comprised the remainder. Distribution accounted for 25 percent of the total cost.[17]

Table 9[18]
Industrial Electricity Costs
(U.S. Cents/kWh)

Country	Cost
Bahrain	4.24
Kuwait	0.54
Oman	5.20
Qatar	1.65
Saudi Arabia	1.33
UAE	2.04

The GCC nations have looked into one potential area of cooperation: the possibility of connecting their national electricity grids. Studies reveal that this endeavor would cost US\$ 1 billion.[19] One of the barriers hindering this joint venture is that while Saudi Arabia uses the standard 60 Hz AC, the rest of the GCC uses 50 Hz AC. A more major problem is the coincidence of daily peak load across the region, particularly in the summer time.

Electricity continues to satisfy a major share of the GCC nation's energy needs by 2025. Alongside this growth, the composition of the fuels used for electricity generation shift slightly (Table 10). Natural gas comes to play a more major role in electricity generation, as more becomes available in association with the production of oil. Renewable energy resources, which currently account for 1 percent of the electricity generated in the GCC, no longer provide electricity to this region in 2025.

Table 10
Electricity Generation (PJ)

	1985	2025	
		High	Low
Total	483	3757	3144
Oil	69%	65%	65%
Natural Gas	30%	35%	35%
Hydro, Solar, Other	1%	0%	0%

17 S. Al Oudsi and A. Al Shatti, "Is the Life Line a Viable Alternative to Kuwait Fixed Electricity Tariff?" in *World Energy Markets: Coping with Instability*, ed. J. Rowse (Proceedings of the Ninth Annual Meeting of the International Association of Energy Economists, Calgary, Canada, 1987).

18 M. Grigis and R. Shaban, *Industrial Incentives in the GCC Countries* (Kuwait City: Kuwait Institute for Scientific Research, 1990).

19 Kuwait Institute for Scientific Research/King Fahad University, Saudi Arabia, *Joint Study on Inter-Connection of Power Networks in the Gulf States* (Kuwait City: Kuwait Institute for Scientific Research, 1986).

Electricity use led to the emission of 62 million tons of carbon in 1985 -- or 40 percent of the GCC total. While electricity's share in emissions remains stable between 1985 and 2025, in absolute terms, carbon emissions from electricity use rise substantially in both scenarios.

5 ENERGY INTENSITY AND PRIMARY ENERGY SUPPLY

Between 1985 and 2025, the GCC's primary energy supply expands over six-fold to 22.3 EJ (Table 11). The LE scenario reduces the supply by 18 percent.

Table 11
Primary Energy Supply (EJ)

	1985	2025	
		High	Low
Total	3.4	22.3	18.2
Oil	80%	76%	74%
Natural Gas	19%	24%	26%
Biomass	*	*	*
Hydro, Solar, Other	1%	0%	0%

* Less than 1 percent

Although its share declines slightly, oil continues to dominate the primary fuel mix. Oil accounts for about three quarters of the primary energy supply in both scenarios. Natural gas comes to play a slightly larger role in the mix by 2025, particularly in the LE scenario.

At 208 GJ, primary energy per capita in the GCC in 1985 far surpassed the world's average of 64.7 GJ per capita, but remained well below the United States' average of 279.5 GJ per capita. As energy use grows more rapidly than the size of the population, primary energy per capita in the GCC region increases to 337 GJ in 2025 in the HE scenario. The LE scenario limits primary energy per capita to 276 GJ in 2025.

The GDP's economy grows at about the same rate as its energy use in the HE scenario. For this reason, while the primary energy intensity (MJ/US$) remains virtually stable at about 20.7 MJ/US$ in the HE scenario. In the LE scenario, however, this ratio drops to about 16.8 MJ/US$.

6 CARBON EMISSIONS

Carbon emissions rise to 402 million tons by 2025 according to the HE scenario. The LE scenario limits carbon emissions by 18 percent of the HE figure (Table 12).

The industrial sector continues to contribute the greatest share of GCC carbon in 2025. While the shares of the transport, residential and service sectors in carbon emissions fall slightly, agriculture's share rises from 5 to 13 percent over the 40 year period due largely to the widespread mechanization of this sector.

Increasing at an average annual rate of 4.8 percent in the HE scenario and 4.3 percent in the LE scenario, CO_2 emissions in the GCC grow more rapidly than the size of the population. As a result, CO_2 emissions per capita increase from 3.8 tons in 1985 to 6.1 tons in the HE scenario. The LE scenario reduces CO_2 emissions per capita to 5 tons.

The annual rate of economic growth surpasses the annual increase in carbon emissions. Thus, the amount of CO_2 released for each unit of GDP, which stood at 379 tons per US$ million in 1985, falls slightly to 371 tons/US$ million in the HE scenario. The LE scenario reduces this figure to 302 tons/US$ million.

Table 12
Carbon Emissions (Million Tons)

	1985	2025	
		High	Low
Total	62	402	328
Residential	21%	18%	19%
Industrial	29%	29%	31%
Transport	26%	23%	22%
Services	13%	11%	10%
Agriculture	5%	13%	13%
Losses	6%	6%	6%

7 CONCLUSION

According to the HE scenario, the largest increases in energy use between 1985 and 2025 stem from the industrial and transport sectors, which account for 39 and 30 percent of the total growth respectively. The over consumption of energy, a problem which has now racked the GCC economies for decades, continues to characterize the region's growth patterns in this vision of the future.

Historically, several factors have led to the over consumption of energy across the GCC region:

1) The absence of emissions standards and the failure to enforce existing standards. The GCC countries import appliances, cars and building materials from every corner of the world with no consideration for energy efficiency. Building codes in the GCC are obsolete; until recently none of the GCC nations required thermal insulation in their buildings. While most of the nations take city planning into account, few pay attention to energy efficiency.

2) The under-utilization of power plants. By improving maintenance, the efficiency of power generation could be increased.

3) The lack of incentives. The GCC nations over-subsidize energy prices, thereby promoting over-consumption. The governments of both Saudi Arabia and Kuwait tried to increase electricity prices in the past, but these efforts failed due to public pressure. In both of these cases, the governments approached the pricing issue poorly. The motivation for increased energy prices in the past stemmed from the need for greater revenues. In the future, these measures should represent efforts to reduce waste.

4) The lack of public awareness. The members of the GCC population lack an awareness of energy and environmental issues. The dearth of incentives to save energy and the absence of standards contribute to this ignorance.[20]

The LE scenario illustrates that by tackling the above issues the GCC countries can lower future energy demands and restrain their CO_2 emissions without sacrificing access to the many services that energy provides.

A decade ago, the Iran-Iraq war posed a major threat to the GCC nations. At present, the Iraqi invasion of Kuwait represents the GCC's greatest challenge. This crisis certainly will leave a firm imprint on the regional economies and will alter the paths of development in the GCC. While the GCC states are likely to sustain their welfare measures and their present levels of affluence, the Iraqi invasion of Kuwait may result in more emphasis on productivity and incentives to achieve such productivity across the Gulf region. Such a change would have a positive impact on reducing both energy consumption and CO_2 emissions in the GCC. Only upon the resolution of this conflict, however, will the full impact on energy demand and carbon emissions be understood.

[20] A. Reddy, "Barriers to Energy Efficiency Improvements" (Paper delivered at the Second International Workshop on Reducing Carbon Dioxide Emissions from the Developing World: Assessment of Benefits, Costs and Barriers, Lawrence Berkeley Laboratory, Berkeley, California, October 4-6, 1990).

APPENDIX A

Description of Methodology

For each nation, the researchers developed a high emissions (HE) and a low emissions (LE) scenario to examine levels of energy use and carbon emissions in 2025. In the HE scenario, the governments of developing countries promote policies between the base year and 2025 that do not explicitly derive from efforts to limit potential environmental damage. As a result, every nation witnesses a substantial increase in both energy demand and associated emissions of carbon dioxide. The LE scenario examines how far carbon emissions can be reasonably lowered in a world where the consequences of the increased atmospheric concentration of carbon dioxide are accepted as a major environmental concern.

The HE and LE scenarios incorporate the same economic and population growth rates, but different economic structures, energy intensities and fuel mixes. The reductions in carbon emissions achieved in the LE scenario reflect the various barriers to implementing carbon-reducing measures and are achieved largely through efficiency improvements, fuel switching efforts and small changes in economic structure.

The methodology used to construct the long-term energy scenarios combines elements of a detailed end-use analysis with judicious international comparisons to provide a guide to the likely level of activities in the future. The scenarios provide a self-consistent picture of the future from which energy demand and supply can be derived. The primary focus is on this picture of 2025; we do not explicitly analyze the path to the year 2025 quantitatively.

Each country study examines the residential, transport, industrial, commercial and agricultural sectors and estimates the demand for delivered energy in these sectors according to three major forms: fossil fuels, electricity and biomass.[1] The studies further disaggregate fossil fuel demand into coal, oil and natural gas use. Based on the above analysis, the scenarios calculate the size of the fuel supply required to meet the energy demand. The scenarios rely on gross domestic product (GDP), in real terms, as the indicator of overall economic activity. The energy demand estimates for freight transport and the industrial, agriculture and service sectors take into account changes in the composition of GDP.

The approach used consists of two basic elements. First, the analysis disaggregates energy demand according to its major end-uses. Primary energy supply is estimated on the basis of the demand for individual fuels and electricity for each major end-use in each economic sector. Each sectoral discussion begins with a discussion of the particular end-use approach used. Each research group used the same spread sheet model (STAIR) to estimate the end-use and sectoral energy demand and the total primary energy supply (Figure 1). For each sector, the STAIR framework provides alternative ways of estimating energy demand. Different alternatives are chosen based on the availability of end-use data.

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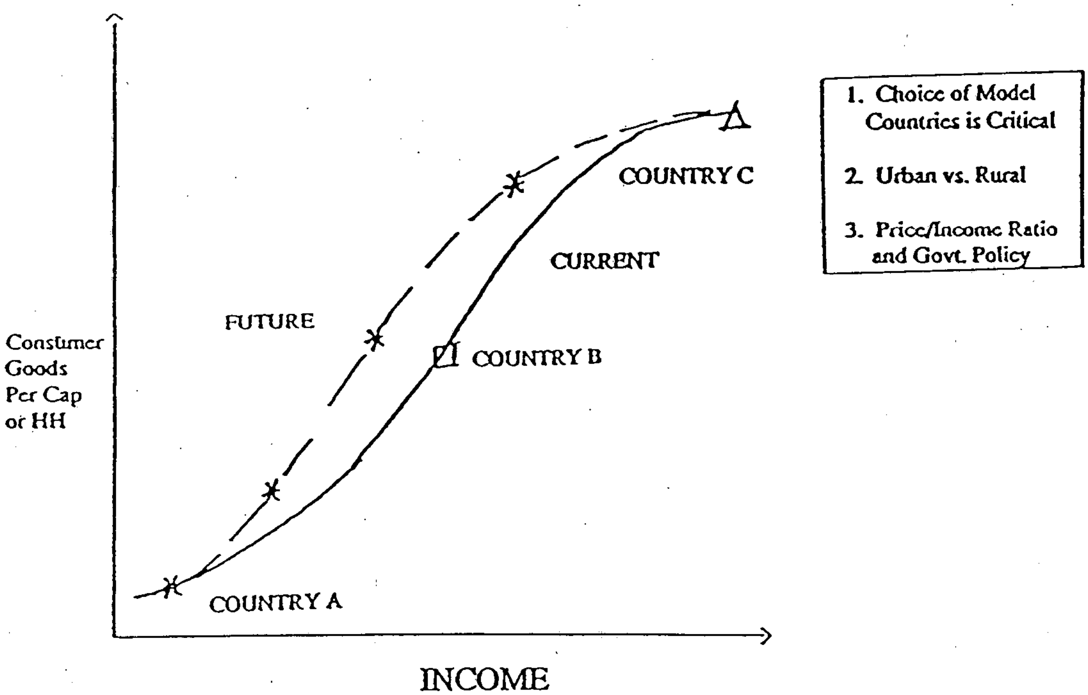
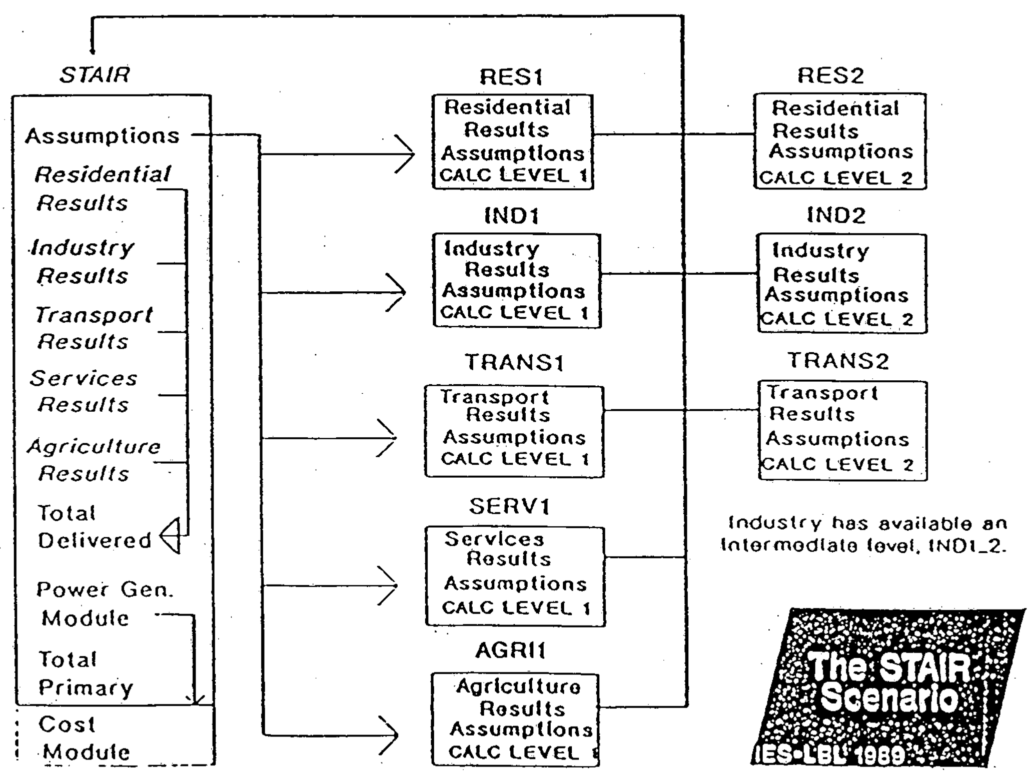
[1] The terms "biomass" and "traditional energy sources" refer to agricultural residues, dung and fuelwood unless otherwise specified.

Figure 1

INTERNATIONAL COMPARISONS





For each end-use, the estimate of energy demand depends on a series of driving forces. Factors such as the distance traveled per car, the fuel use per kilometer (fuel intensity) and the levels of car ownership, for example, determine the energy demand for automobiles. The perceived availability of fuels and the relative prices as influenced by government policies determine the choice of fuels. Table 1 provides examples of the types of indicators used to estimate energy demand for 2025 for various end-uses.

Table 1
Structure and Indicators, Examples

Sector & End-Use	Indicators
General	Population (Urban and Rural), GDP and Structure, Fuel Price, Income Distribution
Residential	Urban and rural population and no. of households Level of Electrification
Heating	Fuel Use/hh./degree-day
Cooking	Fuel Use/capita per meal
Refrigerators	Unit Electricity Use per month
Transportation	Ton-km. by mode, Distance traveled, Number of vehicles/capita
Cars and Motorcycles	Fuel Use/Km
Trucks and Buses	Fuel Use/Km
Air and Water	Fuel Use/Value Added
Industry	Physical Output and Value Added
Energy-Intensive (Steel, Cement, etc.)	Fuel, Electricity Use/Ton of Output
Non-Energy Intensive	Fuel, Electricity Use/Value Added
Mining	Fuel, Electricity Use/Value Added
Commercial	Fuel and Electricity Use and Value Added
Agriculture	Fuel and Electricity Use and Value Added

Second, the study uses international comparisons to estimate future activity levels -- i.e., the production of materials per capita and the saturation of consumer goods, such as appliances and cars. This method assumes that in the future developing countries will reach income levels similar to those enjoyed by more developed economies today and that their purchases of consumer goods will increase accordingly. In some countries, changes in income distribution are analyzed explicitly for their impact on the saturation of consumer goods.

The use of international comparisons helps to determine the saturation of various energy-consuming goods in the residential and transportation sectors and to estimate the production levels of energy-intensive materials in the industrial sector. Basic elements of today's energy use patterns (automobile and truck use, household appliance ownership, etc.) at different income levels are used to select future activity levels consistent with the income levels each developing country is projected to reach by 2025. Future activity levels are then modified to take into account the fact that changes in the ownership of energy-consuming goods depend not only on changes in income but also on changes in the prices of goods. In choosing comparison countries, researchers look for similarities in saturation levels across countries and/or regions. For example, automobile saturations in Latin America are several times those in Asia at relatively similar average income levels. Hence, Latin American countries may not serve as good guides to future car saturation levels in Asia.

Figure 1 shows the concept used to project the 2025 activity levels for materials production and saturation of consumer goods. Future activity levels are based on activity levels for countries at that income today. This assumption implies that the saturation of cars per household in country A will reach the same level in 2025 as that of country B today. Because the comparisons take into account the fact that the ownership of energy-consuming goods depends both on income and prices and that the prices of goods relative to income levels are likely to decline in the future, the future growth curve for saturation of consumer goods will then be steeper as shown in Figure 2. Government policies can either delay or speed up the acquisition of consumer goods depending on the tariffs and licensing schemes that these policies promulgate.

In most countries, 1985 served as the base year for the scenarios. Different years were selected for Venezuela and Mexico, 1984 and 1987 respectively, due to the availability of better data for those years. Estimates of changes in end-use efficiency and energy and fuel intensity are based on historical analyses of energy consumption patterns. Researchers in individual countries relied primarily on literature available from sources within the countries. Comparative historical analyses have also been reported by Sathaye and Meyers (1985), Sathaye, Ghirardi and Schipper (1987), Goldemberg, et.al. (1988), among others.[2,3,4]

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[2] Goldemberg, J., Johansson, T., Reddy, A. and Williams, R. 1988. Energy for a Sustainable World. New Delhi: Wiley Eastern Limited

[3] Sathaye, J. and Meyers, S. 1985. "Energy Use in the Cities of the Developing Countries." Annual Review of Energy. Vol. 10, pp.109-33

[4] Sathaye, J., Ghirardi, A. and Schipper, L. 1987. "Energy Demand in Developing Countries: A Sectoral Analysis of Recent Trends." Annual Review of Energy. Vol. 12, pp.253-81

APPENDIX B

Electricity Use in Ghana's Aluminum Industry

In the late 1950s and early 1960s, Ghana's government constructed the Volta Dam project at Akosombo. At the time of the dam's construction, sufficient electricity demand did not exist in Ghana to make use of the dam's 600-700 MW of power. Thus, the government sold this excess electricity to VALCO to use for its aluminum production activities. Ghana's government and VALCO embarked on a mutually beneficial arrangement: Ghana profited from the revenues of electricity sales and the creation of jobs in the aluminum industry and VALCO gained access to low-priced electricity.

By the 1970s, Ghana's residential and industrial electricity demand had increased significantly. But, due to its commitment to VALCO, the government could not meet the growing electricity demand with existing supplies. To combat these shortages, the Volta project's capacity was expanded to 1072 MW. To date, however, VALCO continues to consume between 70 and 75 percent of the nation's electricity, which it purchases at a highly discounted rate. Although the government recently raised these rates, the company still pays far less for its electricity than Ghana's households pay for their electricity supplies.

Over 95 percent of Ghana's electricity supply currently comes from hydropower. Thus, electricity generation in Ghana accounts for a minimal generation of carbon. In an attempt to expand Ghana's electrical capacity, the nation has undertaken a series of exploration efforts geared at uncovering natural gas resources to be used for electricity generation purposes. If electricity demands in Ghana continue to grow, power generation may become increasingly dependent on more carbon-intensive fuels and may grow to account for a more significant share of the nation's carbon emissions.

APPENDIX C

Improving Power Generation in Sierra Leone

Power generation in Sierra Leone is extremely carbon intensive and highly inefficient. Because the nation derives almost all of its electricity from diesel and fuel oils, the power sector makes a significant contribution to total carbon emissions. In addition, for a variety of reasons, Sierra Leone's national grid has grown increasingly unreliable in recent years: the electricity-generating machinery has aged and performs badly; the national power system suffers from poor management; and the distribution network is quite limited. As a result, the government must ration the available power and power users frequently experience blackouts.

Sierra Leone's mining industries often draw their power from private generation. Other industries have standby plants which run more regularly. But the nation's households, the majority of which rely on the national grid, continue to suffer from the unpredictability of the system and the limits set on the supplies. Increasingly, more and more of Sierra Leone's domestic consumers are relying on private generation to satisfy their electricity needs. Because maintaining many small generators proves significantly more expensive than producing electricity from a national grid, power generation in Sierra Leone has rapidly become a growing economic burden.

Several opportunities may exist to improve the delivery of power to the nation's electricity consumers:

o Improved management skills. Better planning in the power sector may lead to greater savings. Not only can waste be eliminated on the supply-side, but greater conservation efforts on the demand-side can help to relieve the pressure on the power supply.

o Increased hydro capacity. Drawing more power from hydro resources would both reduce carbon emissions and relieve excess pressure on the national grid. Currently, Sierra Leone has a hydro capacity of about 1000 MW. The nation is in the process of completing the first phase (70 MW) of the Bambuna Project. Eventually this plant will be capable of generating up to 300 MW of power.

Two major barriers continue to hinder hydro development projects: (1) high capital costs and (2) extended implementation times. Currently, the nation plans to develop more diesel plants in the short-term to satisfy the nation's immediate power needs with the expectation of eventually replacing this fossil-fuel generation with hydro-generation. This development would mean a substantial increase in carbon emissions from electricity generation in the short term, but a significant reduction in carbon emissions from electricity generation in the long term.

o Expanded use of agricultural residues in industry. Agricultural activities generate a substantial amount of residues in Sierra Leone. The nation already has several agri-based industries. The forest product industries produce about 1.5 MW of power from agricultural wastes and the palm products industries just under 1 MW of power. Thus, the scope already exists in Sierra Leone to utilize these surplus agricultural products. Not only could more industries generate biomass-fueled power for themselves, but additionally they could sell power to local households. The widespread implementation of a biomass-based generation scheme would both help to ameliorate some of the difficulties of providing homes and industries with power and, additionally, would reduce electricity's contribution to Sierra Leone's carbon emissions.

APPENDIX D

Generating Power from Agricultural and Wood Residues

In 1986, Ghana's wood production equalled about 8.6 million tons (MT). Its timber industry produced another 2.3 million MT. Presently, logging and sawmill activities in Ghana produce an estimated 1 million MT of residues, most of which are discarded. Agriculture yields a significant share of residues as well. With proper management, these residues could be used to produce electricity.

The greatest opportunity for making use of these biomass wastes lies in the industrial sector. Disseminating new energy sources to the household sector often proves difficult due to the large number of units which comprise this sector and their dispersion. In contrast, the industrial sector is highly centralized and, therefore, easier to access. In addition, industries are driven by profit and efficiency motives and might find the use of these already existing wastes to be a cheap and effective means for providing power.

The increased use of these surplus biomass resources could offer a cheap and more environmentally-acceptable solution to industrial fuel shortages and carbon emissions.

APPENDIX E

Natural Gas Potential in Nigeria

The amount of ultimately recoverable natural gas available in Nigeria may be as high as 95 trillion cubic feet.[5] Despite the enormity of this resource base, Nigeria has yet to significantly exploit its natural gas supply. In 1980, Nigeria produced almost 770 billion cubic feet natural gas; 91.4 percent of this gas was flared.[6]

Currently, Nigeria makes use of about 20 percent of the natural gas it produces. Although the nation uses a larger share of the natural gas it produces today than it did ten years ago, Nigeria still flares the vast majority of its supply. Two factors have continued to provide barriers to increased natural gas consumption in Nigeria:[7]

o Natural gas supply systems require large capital investments. Particularly when the markets requiring the fuels are located far away from the supplies, the transport and distribution of natural gas proves costly and difficult.

o The Nigerian government subsidizes the prices of competing fuels. By lowering the cost of alternative fuels, especially petroleum products, the government has squelched buyers' incentives to consume natural gas products.

Natural gas could potentially serve as a major domestic energy source cross-sectorally in Nigeria. To successfully exploit natural gas supplies in Nigeria, however, the Nigerian government must consider various policy measures, including: 1) subsidizing the cost of natural gas or removing the subsidies that lower the costs of various competing fuels in order to promote greater domestic natural gas consumption; 2) prioritizing the development of natural gas transportation and distribution networks; 3) implementing schemes for financing these gas networks; and 4) restructuring current agreements with oil production companies to facilitate the production of natural gas.[8]

Perhaps the most effective route for Nigeria to optimize its available energy resources and simultaneously to combat the environmental damage posed by continued oil consumption entails taking greater advantage of its natural gas reserves in coming years.

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[5] F.B. Dayo and A.O. Adegbulugbe, "Utilization of Nigerian Natural Gas Resources," *Energy Policy*, vol. 16, no. 2 (April 1988): 122.

[6] F.B. Dayo and A.O. Adegbulugbe, *The Nigerian Energy System: Perspectives and Strategies for Action*, Technical Report No. IKE-DC-85/7 (Stuttgart: Institut fur Kerneneergetik und Energisysteme, Universitat Stuttgart, November 1985): 40.

[7] Dayo and Adegbulugbe, "Utilization of Nigerian Natural Gas Resources," Ref. 14.

[8] F.B. Dayo and A O. Adegbulugbe, "Utilization of Nigerian Natural Gas Resources," Ref. 14.

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