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AN END-USE APPROACH TO DEVELOPMENT OF LONG-TERM ENERGY DEMAND SCENARIOS FOR DEVELOPING COUNTRIES1

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1 Introduction

In recent years, several studies have linked global emissions of carbon dioxide and other gases to possible climate change. Over the last century, the global atmospheric concentration of carbon dioxide has increased substantially, and the resulting "greenhouse effect" may have serious consequences for human well-being.[1] Emissions from energy consumption activities are the single largest contributor to this effect. An examination of possible trends in energy consumption, and the potential for its reduction is therefore crucial to any attempt to prevent or delay this effect.

In this paper, we explore the contribution of developing countries to the demand side of the problem. We present long-term energy demand scenarios* for these countries, spanning a wide range of possible rates of global and regional economic growth. The scenarios are called the Rapidly Changing World (RCW) and the Slowly Changing World (SCW). We also examine the impact on each scenario of policies aimed at improving energy efficiency and reducing energy consuming activities for each scenario. These policy scenarios are called the Slow Policy Case (S/Policy) and the Rapid Policy Case (R/Policy).** With these scenarios, other researchers can estimate the extent of climate change that may occur due to the emissions resulting from the energy demands we obtain, and determine whether significant reductions in energy demand will mitigate or at least defer the climatic effects, allowing more time to develop alternative energy sources whose climate effects are benign.

We use information about energy and economic activity in the developing and developed countries to construct these scenarios for the year 2025 in five regions: Asia, China, Africa, Latin America and the Middle East.† In analyzing energy demand, we examine five sectors in each region: industry, transportation, residential, commercial and agriculture. We establish measures of energy intensity (energy consumption per unit of activity) for each sector, and seek to understand the changes in structure of that sector that influence its energy intensity. We also examine the changes in the mix of fossil fuels (taken as a group), biomass, and electricity in each sector.

We present delivered and primary energy demand for 2025. In order to compute primary demand, we make assumptions about the likely improvements in efficiency of electricity generation and transmission and distribution by the year 2025. Since the focus of this paper is on energy demand, we do not dwell on the availability of capital and other resources, which pose important constraints to the development of new energy supplies.

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* Since we estimate energy consumption which contributes to net CO2 emissions, we do not account for human and animal energy use.

** Our analysis does not consider the energy impacts of changes in regional climate caused by the "greenhouse effect".

† China includes smaller centrally planned economies of Asia. Egypt is included in Africa and Iran in the Middle East.

Energy supply and the integration of energy demand and supply are treated elsewhere in the larger EPA study.

The International Energy Studies Group at Lawrence Berkeley Laboratory has been one of the pioneering centers for sectoral- and end-use-oriented study of energy consumption, particularly that in developing countries (LDCs). In recent years, the group has relied on sector-specific data and information to understand and explain the evolution of energy demand and economic activity in 20 or more developing countries.[2-6] It must be noted, however, that data on LDC energy consumption are less complete and accurate than those for the developed countries. Thus, estimates for several parameters are based on qualitative information and understanding of LDC energy-economy linkages which we have developed over the last decade.

2 Evolution of Energy Demand in Developing Countries

The developing countries' share of world modern energy* consumption increased from 16% in 1970 to 24% in 1986. At the same time, that of the the OECD countries declined to about 53% (Figure 1). The inclusion of traditional fuels would increase the LDC share of total energy use, since much of the these fuels are consumed in the LDCs. The rapid growth in LDC energy demand, 4.7% annually since 1973, and sluggish growth in the OECD countries means that the LDCs are becoming an important segment of world energy consumption. If this trend persists, energy demand in the developing countries will approach that in the OECD countries by the year 2010.

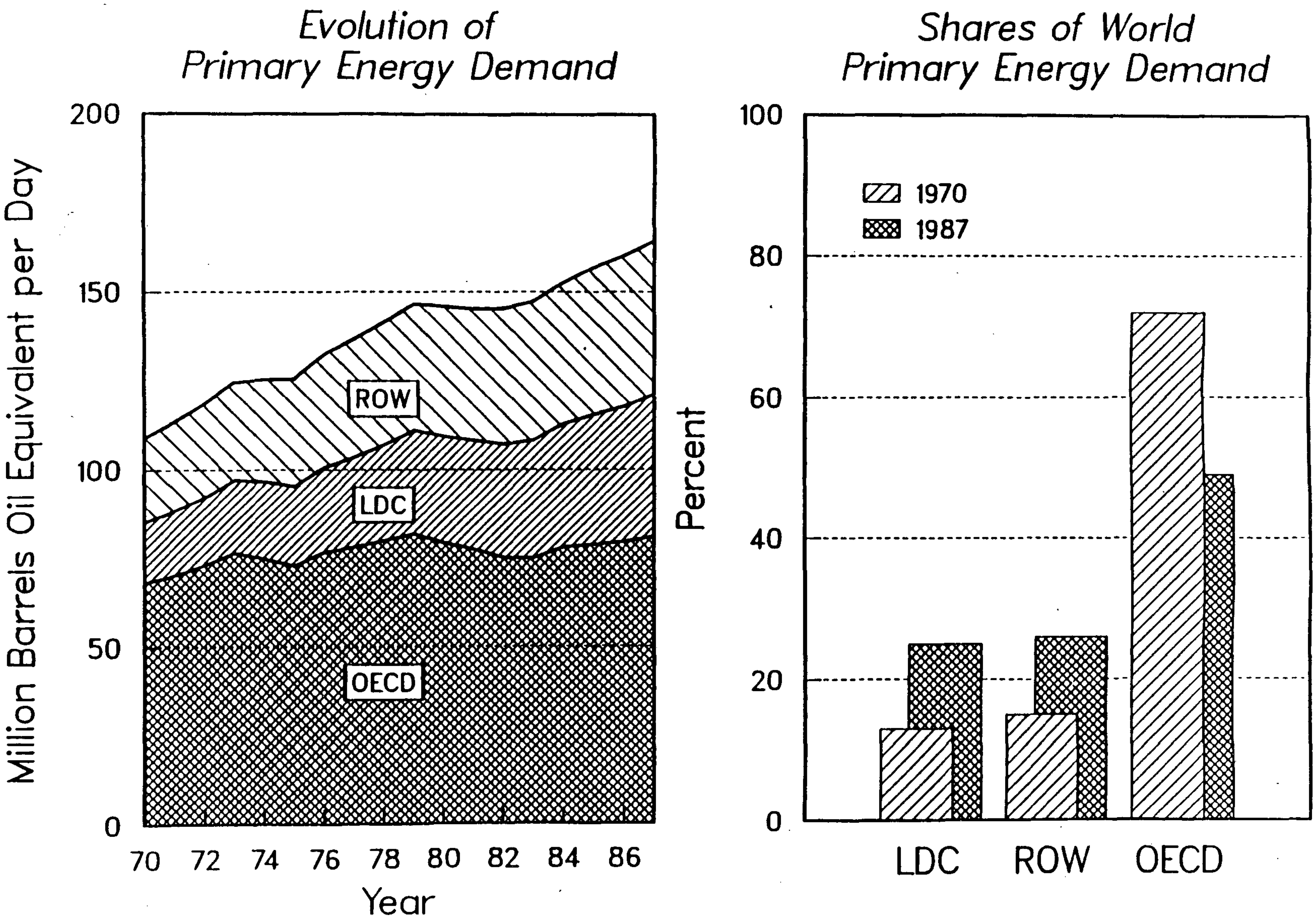
The LDCs are a much more diverse group of countries than the member countries of the OECD. They range from some of the poorest countries, such as Bangladesh and Ethiopia, to some of the richest ones, such as Saudi Arabia and Kuwait. The group includes oil exporters and importers at different levels of per capita income.

This diversity contributed to the steady growth in LDC energy demand after 1973. Rapid growth in energy and oil demand in the oil-exporting countries balanced the slow growth in oil-importing countries during periods of high oil prices. During the subsequent decline of oil prices, the reverse occurred. But even within the oil importing countries, energy demand grew at very different rates. The larger oil importers, e.g. China and Brazil, were in a position to borrow capital to invest in oil substitutes and/or to invest in more efficient plant and equipment, something which the small oil importers could not do.

Within each country, urbanization and industrialization, two phenomena that characterize modern economic development, led to this growth in energy demand. Urbanization rates have differed depending on whether the country is poor or rich, an oil exporter or importer, centrally planned or market oriented. But the phenomenon is common to all

* Refers to coal, oil, natural gas, nuclear, hydro and geothermal sources.

Figure 1



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developing countries. For example, 72% of the population in Saudi Arabia lived in urban centers in 1985, compared with 39% in 1965. Beginning with a low urbanization rate, urban population in Ivory Coast increased at rates higher than 8% annually between 1973 and 1984, while the overall population there grew at 4.5%.

Urbanization permits the adoption of modern lifestyles by an increasing section of the population. This change means higher ownership of appliances and vehicles, which results in greater consumption of electricity, gasoline and middle distillates. Urbanization also draws consumers away from using traditional fuels to these modern fuels. The access to modern fuels leads to increased use of these fuels even during periods of economic adversity.

Industrial development has been pursued more or less successfully by each developing country. Smaller countries in East Asia have been extremely successful in pursuing industrial development led by exports of manufactured products. Some of the larger ones in Asia have had slower industrial growth, for a variety of reasons. Several economies in Latin America and Africa have accumulated massive debts which have threatened to bankrupt these countries.

The patterns of energy use differ among the various developing countries (Table 1) and their relative importance changes over time. The industrial sector's share of energy consumption declines while that of the transport sector increases as one moves from Asia to Latin America to West Africa. The share of electric power generation sector is highest in Asia and Latin America. (When China is included in Asia, the industrial sector dominates (43% in 1983) because of the high industrial energy intensity in China.) The share of the sectors have changed somewhat over time. Since 1978, the share of the industrial sector has declined or stayed the same, while its share of oil use has declined, in all three regions. This decline is not surprising considering industries' concerted efforts to move away from fuel oil. There has been growth in the share of electric power in each region.

Table 1 Sectoral shares of energy and oil demand (%)

	ENERGY 1978	ENERGY 1983	OIL 1978	OIL 1983
Asia-9[b]				
Industry	28	28	23	18
Transportation	22	21	29	30
Res/Service	14	12	13	13
Power	36	38	35	39
Latin America-4				
Industry	31	25	31	23
Transportation	30	28	49	54
Res/Service	7	7	8	10
Power	33	40	12	14
West Africa-4				
Industry	22	19	25	20
Transportation	45	47	56	59
Res/Service	8	9	10	11
Power	25	25	9	10

Source: Sathaye, Ghirardi and Schipper (1987).

Historical evidence suggests that industrial energy demand increased in the larger Asian countries but stagnated in Argentina and Brazil (although electricity demand continued to grow in all of them). Energy prices influenced the location of a few very energy-intensive industries, such as aluminum, but the pattern of final demand and each country's resource endowments influenced industrial structure far more than higher energy prices.

The importance of biomass and other renewables in the LDCs must not be ignored, even if the use of these fuels cannot be estimated very accurately. Biomass accounted for a very large share of energy use in many of the poorer LDCs (e.g., 41% in India and 68% in Bangladesh), but for a smaller share in the richer LDCs (e.g., 25% in Brazil and only 3% in S. Korea). Fuelwood forms a major portion of biomass used in this manner, and current rates of fuelwood use exceed the annual biomass increment in many areas, resulting in a net addition to atmospheric CO_2. Biomass use is also very inefficient compared to that of modern fuels. Thus, at the margin, net emissions may be reduced by substituting biomass fuels with modern petroleum fuels.*

* Net emissions would be reduced if the fuel wood used at the margin were derived from standing biomass. The extend of reduction would depend on the difference between the carbon content and efficiency of fuel wood and modern fuels.

The diversity of countries among the LDC group means that each country has different patterns of fuel consumption shaped by a myriad of human activities, and its government pursues policies perceived to be appropriate to the development of its indigenous resources. Grouping the LDCs together as a single entity, for the purpose of projecting or forecasting energy demand or for developing global energy policies, can lead to gross misrepresentation of the implications of human activity and government policy on energy consumption. Country or region-specific sectoral analysis of human activities and their linkages to energy consumption is important for proper interpretation of historical linkages and for the development of self-consistent scenarios for future long-term growth of demand. We have disaggregated the LDCs into five regions for analyzing the energy implications of future scenarios described below.

3 Scenarios

We develop two basic scenarios of the world in 2025 based on assumptions about economic growth rates, energy price trends, and population growth derived from those made available by the World Bank, the U.S. Department of Energy and the U.S. Bureau of the Census. On the basis of these exogenous driving variables, we estimate the rate of technological progress and of human (economic & other) activity and productive assets, which in turn determine changes in energy intensity or efficiency as well as levels of activity and consequent demand for energy. We examine the impact of implementing policies aimed at reducing energy consumption on the rapidly changing world and the slowly changing world scenarios.

These scenarios are not forecasts. They simply provide the framework for plausible and self-consistent scenarios of the future from which energy demand can be derived for 2025. Our primary focus is on a picture of 2025; we keep the *path* to the year 2025 in mind only in a qualitative sense.

RCW: The Rapidly Changing World

In this scenario, world economic growth proceeds at a rate between 3 and 4% annually, with somewhat higher rates in many developing regions (Figure 2). Figure 3 indicates our assumptions about population growth in each region. In this case, technological progress leads to higher economic growth, which drives energy demand upward. The same thrust of progress also provides a host of new ways of using energy more efficiently.

However, a rapidly growing world also provides its citizens with means for using energy for mobility and comfort. These end uses tend to grow rapidly once they become important (e.g., Germany in the 1960s,[7] Korea in the mid-80s) and their impact may drive total energy use up more rapidly than the rate of economic growth for a considerable length of time. Parts of all regions in the developing world that have not entered

Figure 2.

AVERAGE GDP PER CAPITA

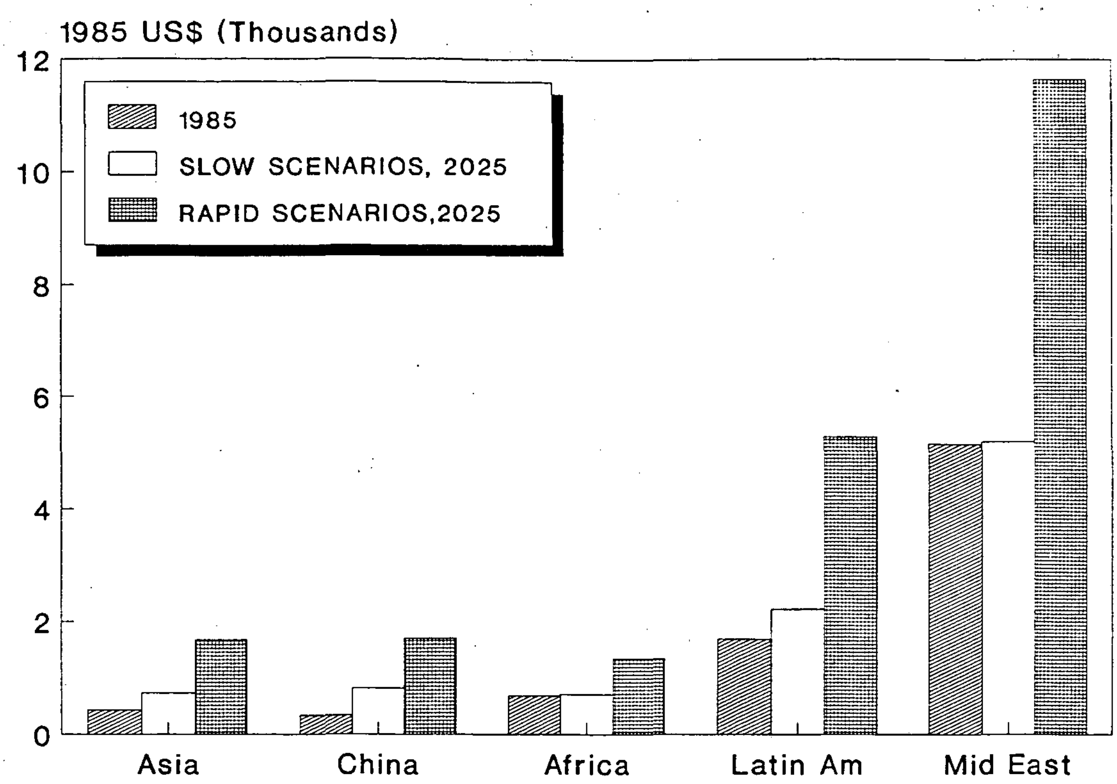
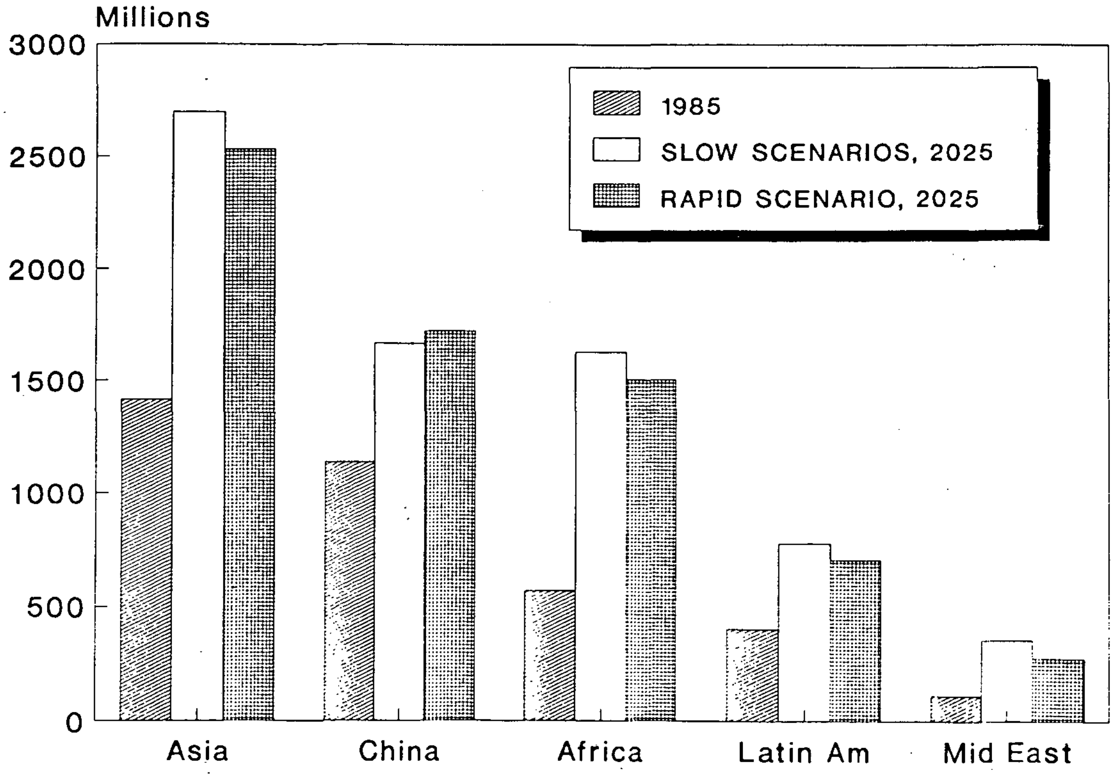


Figure 3.

POPULATION



this phase of energy demand development already will likely pass into such a development by the year 2025. Thus the Rapid case shows significant increases in motorization and comfort and service levels in homes and buildings. In some countries in the past, this expansion caused these energy uses to grow at several times the rate of economic growth for more than a decade. Since the efficiency of providing these services is higher in 2025 than today, only the detailed calculations can show whether energy use or total output (measured by GDP) grows more rapidly.

SCW: The Slowly Changing World

In the *Slowly Changing World,* world economic growth is so slow that energy demand growth is sluggish. As a result, energy prices do not rise significantly over present day levels. Technological progress, although slower than in the RCW case, does tend to reduce energy intensities, but the low price of energy retards any serious efforts to increase efficiency. Slower economic growth restrains the opportunities for people in developing countries to improve their comfort and mobility, and even the rate of increase in urbanization and electrification is restrained. Population growth is somewhat higher in this case than in the RCW case due to slow economic growth, and household formation is slower, so that household sizes are larger than in the Rapid case.

Policy Cases

These cases are intended to examine the extent of reduction that may be achieved in CO2-emitting energy use in LDCs in the two scenarios. These would lead to reductions in energy intensities and (in some cases) a reduction in activity levels over the values in the RCW and SCW scenarios. These policy variations are referred to as the *R/Policy Case* and the *S/Policy Case.*

4 Structure of Energy Demand in Developing Countries

The LDCs are a very diverse set of countries, yet it is possible to develop a logical framework with which one can describe the structure of energy demand in any of them. Table 2 illustrates such a framework. Energy demand is broken down by sectors, and each sector into a series of subsectors listed from the least to the most energy-intensive. The table illustrates a process of economic development in LDCs characterized by transition within each sector as low-energy activities are replaced by those demanding more energy and producing (or consuming) more output. For each economic activity, the energy consumption depends on the activity, the technology used to perform the activity and the behavior of energy users. With this framework in mind, we examine energy demand and assess potential for energy conservation by sector, and where possible by sub-sector, for each of the ones listed in the table except fisheries.

Table 2
Classification of Energy Demand in LDCs

Sub-Sector	Examples	Main Form of Energy
Agriculture		
Traditional	Plowing and irrigation	Animals
Mechanized	Pumps and tractors	Electricity, Diesel
Fisheries		
Non-motorized	Nets. Canoes	
Motorized	Fleets	Diesel
Industry		Electricity, Fuel oil, Coal, Natural Gas
Handicraft	Weaving baskets	
Light	Shoes, Textiles	
Heavy	Metal processing	
Energy Intensive	Cement, Aluminum	
Feedstocks	Fertilizers, Chemicals	
Transportation		
Personal	Cars, Motorcycles	Gasoline
Informal Public	Jitneys	Mostly Diesel
Formal Public	Buses, Rail Transit	Mostly Diesel
Light Truck		Gasoline, Diesel
Heavy Truck		Mostly Diesel
Rail		Coal, Diesel, Electric
Air		Mostly Jet Fuel
Residential		
Rural	Cooking, Lighting	Biomass, Kerosene, Electricity
Urban	Cooking, Lighting	LPG, Natural Gas, Kerosene, Electricity, Biomass
	Appliances	Electricity
Commercial		
Buildings	Offices, Hotels, Restaurants	Mostly Electricity

In the agricultural sector, the transition from traditional agriculture using human and animal motive power to using modern fast growing varieties of crops which require regular and copious amounts of fertilizer and water has led to significant increases in intensity of modern energy use. The rapidly expanding acreage under irrigation adds to the overall use of energy in this sector. Fishing is unique to nations with coastal belts, but here again the transformation to mechanized fleets, necessary to compete with fleets of the more developed nations, adds to the energy consumption.

Industrial development has led to the gradual replacement of handicraft and cottage industries to those using more sophisticated forms of machinery and labor skills. This transition has been demonstrated in Korea over a period of three decades. Energy intensity during the transition increases initially, but it may decline with rapid growth as newer and usually more energy efficient plant and equipment stock replaces older ones more rapidly, and production shifts towards more technology-intensive light industry.

One pattern that stands out among all countries is the early emergence of the transport sector, for which few economic substitutes for oil are available. The acquisition of private cars is part of the shift led by a desire for greater mobility. Air travel, which used to be rare, is now spreading as feeder airlines make rural areas more accessible. The future of transport energy use in lower- and middle- income countries is very dependent on choices made today about the road and rail infrastructure, settlement patterns and location of industry.

Residential energy use patterns differ sharply between rural and urban households. In low-income countries, cooking may be the largest energy use in most households. As incomes rise, and where electricity is available, appliance ownership increases radically. The commercial sector comprises a host of activities which use primarily electricity for lighting, air-conditioning, etc., and constitutes bulk of electricity consumption in cities, e.g. Singapore and Kuwait.

5 End-Use Methodology: An Overview

The end-use approach requires a detailed examination of energy-consuming activities in the LDCs, in order to identify the structural and social factors that affect energy consumption and the technological factors that affect the energy intensities of these activities. Ideally, this would mean constructing energy demand scenarios for each country for each of the end-use in each sub sector. Since we were constrained by the time available for this analysis, we have grouped the countries into five regions labeled Africa, Asia, China, Latin America and the Middle East. In each region, we examine the residential, transportation, industrial, commercial and agricultural sectors. We estimate the demand for delivered energy in the three major forms that occur today--fossil fuels, electricity, and biomass.

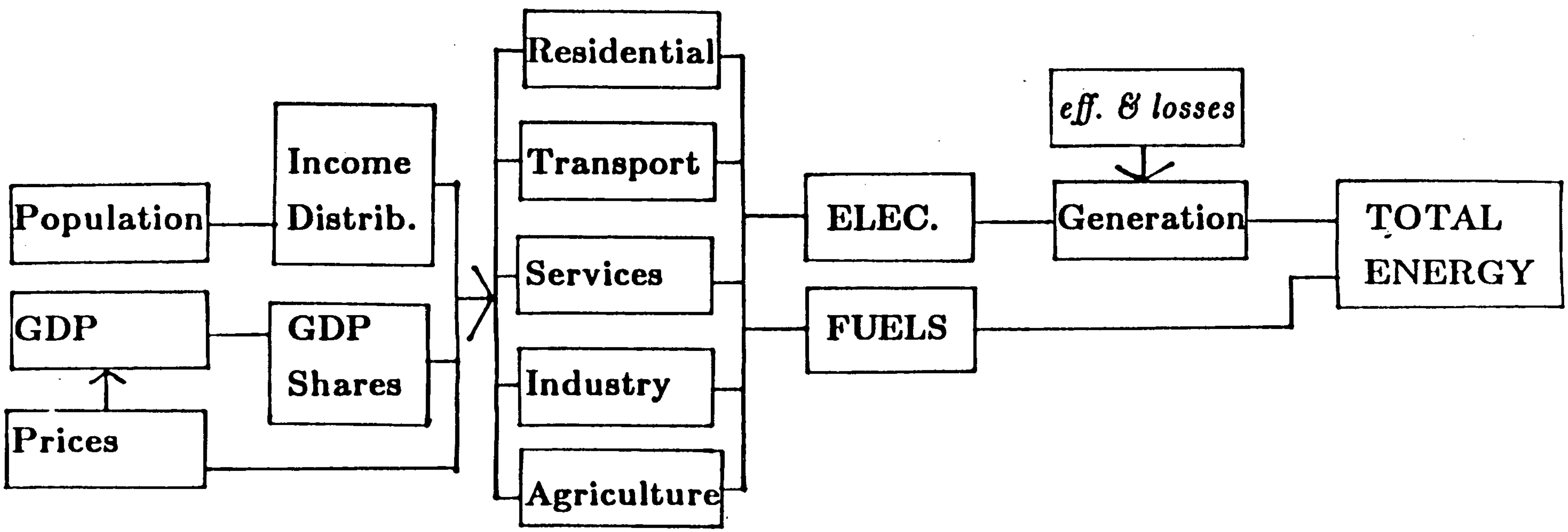
The calculations we employ differ somewhat from region to region, but they contain the following common elements:

1. Gross Domestic Product (GDP), in real terms, is taken as the indicator of economic activity. The composition of GDP changes as manufacturing and service industries assume a greater role, reducing the share of agriculture in GDP. Where "industry" today has a large contribution from mining or energy processing, we expect that manufacturing will assume a larger share.
2. The magnitude and composition of present day* regional demand is estimated by either extrapolating data from groups of countries that cover a large portion of total

* The most recent year for which reasonably complete data were available was 1985; hence we use that as the *base year*.

Figure 4.

LDC ENERGY SCENARIOS: REGIONAL FRAMEWORK



demand in the region (ie., Latin America, Asia w/o China), or by an approximation to country data (China), or by dividing up approximately known supply data taken from the U.N. and similar sources according to energy use patterns of a few countries in the region (Africa, Middle East). Figure 4 shows the framework for analyzing demand by sectors for each region.

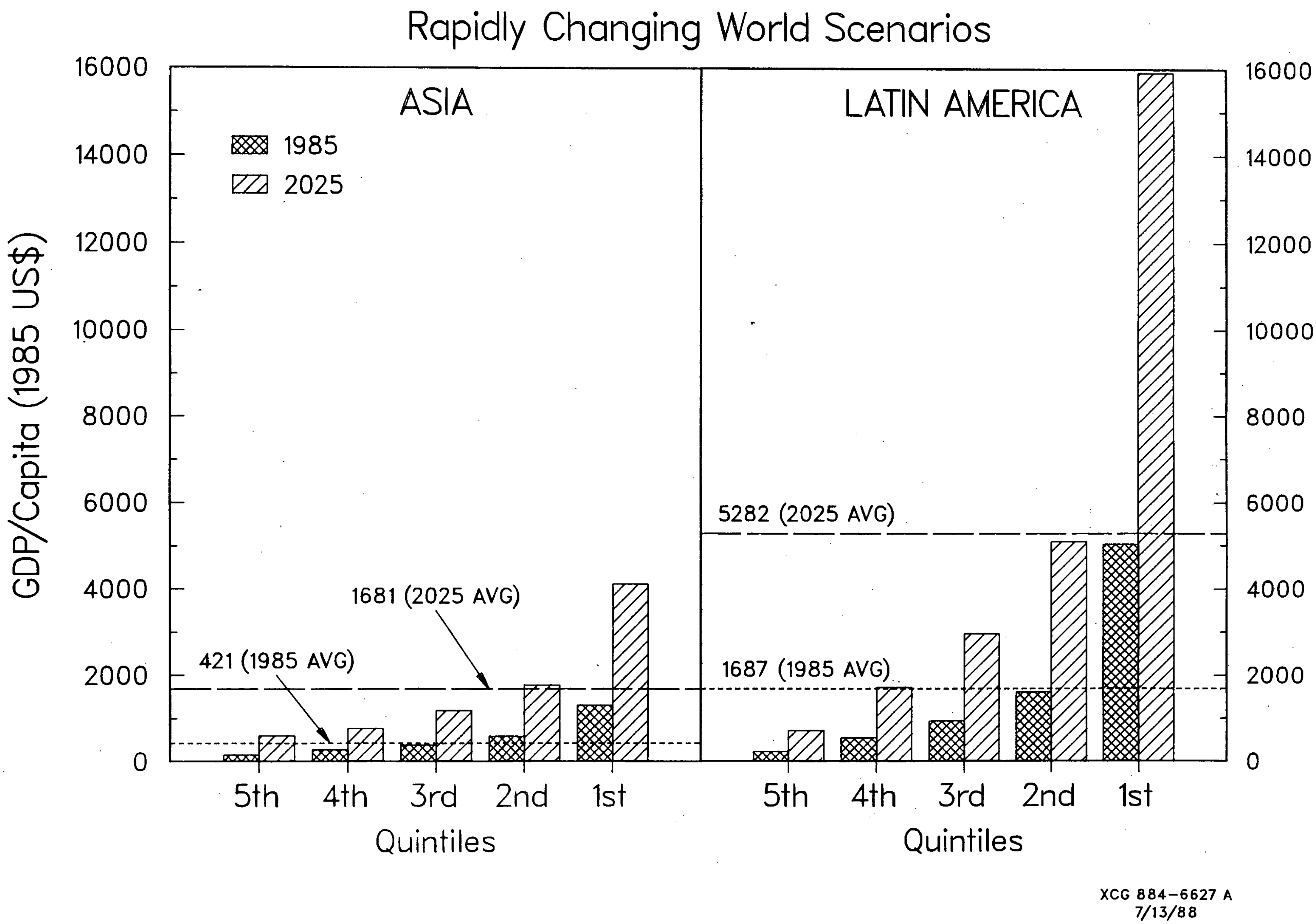
3. Sectoral activity levels are chosen to be consistent with the levels of income obtained from the exogenous economic growth rates. We examined basic elements of today's patterns of energy use (output of raw materials, automobile and truck use, household appliance ownership) at different levels of present income/value-added to select (for each region) future activity levels that are consistent with the income levels these regions are projected to reach. In doing so, we have tried to take into account the fact that the ownership of energy-consuming goods (cars, appliances, air conditioners) depends not only on income but also on the prices of the goods, and that these (relative) prices are likely to decline in the future.

Our approach disaggregates energy consumption in the LDCs by five geographic regions, each of which is composed of a very diverse group of countries. For example, the Asian region consists of Bangladesh with an average income per capita of $150 and Singapore at $7000. In order to capture this diversity within a region, we construct an income profile by population quintile for that region.

The income per capita for each income quintile (20%) of the regional population is estimated from the regional average income per capita using the regional average income distribution. This regional distribution is based on a population weighted income distribution of several countries from that region, e.g. 9 in Asia. Figure 5 shows the income for each quintile in 1985 for Latin America and Asia for the RCW scenario. This income distribution is held constant for 2025. For each quintile, we construct consumption patterns for 2025 which are similar to groups of countries at similar income levels today. For example, the highest quintile in Latin America, which consists of 150 million people in 2025 displays an average income of $16,000 in 1985 US dollars. Consumers in this quintile are likely to adopt a way of life and energy consumption patterns similar to those of European countries at that income level today.

The RCW scenario assumes substantial increase in per capita GDP; in Latin America GDP levels would reach about $16,000 per capita for the highest quintile. This should stimulate better income distribution. Yet, there is no compelling long-term evidence to suggest substantial improvement in income distribution in the developing countries, particularly those in Latin America. We have therefore assumed that income distribution does not change between 1985 and 2025.

Figure 5


Rapidly Changing World Scenarios
ASIA
LATIN AMERICA
1985
2025
GDP/Capita (1985 US$)
16000
14000
12000
10000
8000
6000
4000
2000
0
1681 (2025 AVG)
421 (1985 AVG)
5282 (2025 AVG)
1687 (1985 AVG)
5th
4th
3rd
2nd
1st
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4. The composition of delivered energy is different for each sector.

• Residential energy use is divided into various end-uses: cooking, water heating, space heating, lighting, and appliance use. Transportation is divided into modes (land and air) and land transport is further subdivided into vehicle types (cars, trucks, etc). We estimate activity/ownership levels and energy use per unit of activity (or per unit of ownership), multiplying these parameters to obtain total energy use for each end use.

• For industry, we divide energy use into electricity and non-electricity components. We then calculate the current ratio of each component to industrial value-added, estimate the value of this ratio in 2025, and calculate the demand for each energy type from the (estimated) level of industrial value-added for that region. (For the appropriate regions, the consumption of fossil fuels in refining, chemical feedstocks and fertilizers, and other energy processing industries is accounted for separately and included in the final accounting of primary energy.)

• For the commercial/services sector, we estimated fuel and electricity intensities from data for those countries that treat the sector separately from the residential sector. Future energy demand is calculated using similar ratios and estimates of the future value-added in these sectors.

• For agriculture, we made rough estimates of fuel and electricity use and formed intensities and estimates of future value added similar to those made for the commercial sector.

6. We then sum energy demands (electricity, fossil fuels, biomass) in each sector. Electricity use is converted to primary energy use. Projecting future thermal efficiency and system losses from present-day values, we obtain primary energy requirements for electricity. The type and quantity of fuels for generating electricity are estimated elsewhere in the main report.

We have used 1985 as the base year for developing scenarios for 2025. However, our estimates of changes in efficiency of end-uses and intensity of energy and fuel use are based on the historical analysis of energy consumption patterns done at LBL and elsewhere. Historical analysis has been reported in Sathaye and Meyers (1985), Schipper and Meyers (1983), Sathaye, Ghirardi and Schipper (1987), Goldemberg, Johansson, Reddy and Williams (1988), among others.[8]

6 Sectoral Assumptions and Results

6.1 Residential

Historically, growth in urban population and in the service sector has caused an increase in residential and service sector modern energy demand. The urban population has increased with rural-urban migration, which is very high in West Africa and is also significant in Asia and Latin America. As people move to cities, the main cooking fuel tends to shift from biomass to kerosene. Liquified petroleum gas or electricity may replace kerosene at higher incomes. In lighting, electricity replaces kerosene as electrification advances. The spread of electricity in rural areas has also increased energy demand in most countries.

The main end-uses in this sector are cooking, water heating, space heating (in some regions), lighting, and electric appliances. The first two uses can be satisfied by electricity, fossil fuels or biomass, while lighting is provided by either kerosene or electricity. Electric appliances include refrigerators, air-conditioners, washing appliances, other home appliances (such as irons), and electronic equipment.

Methodology

In order to project the regional end-use patterns in 2025 from the pattern in 1985, we need to examine the *structure* of the residential sector, i.e., the key factors/parameters that determine these patterns. Figure 6 shows our general schematic for the residential sector. Extent of urbanization, extent of electrification, and household size are the three structural factors that we use. Urbanization is reasonably well correlated with access to modern energy sources, while electrification determines the exact population that has access to electricity. Household size is needed for the variables/uses that are better correlated with number of households than with total population (like appliance ownership).*

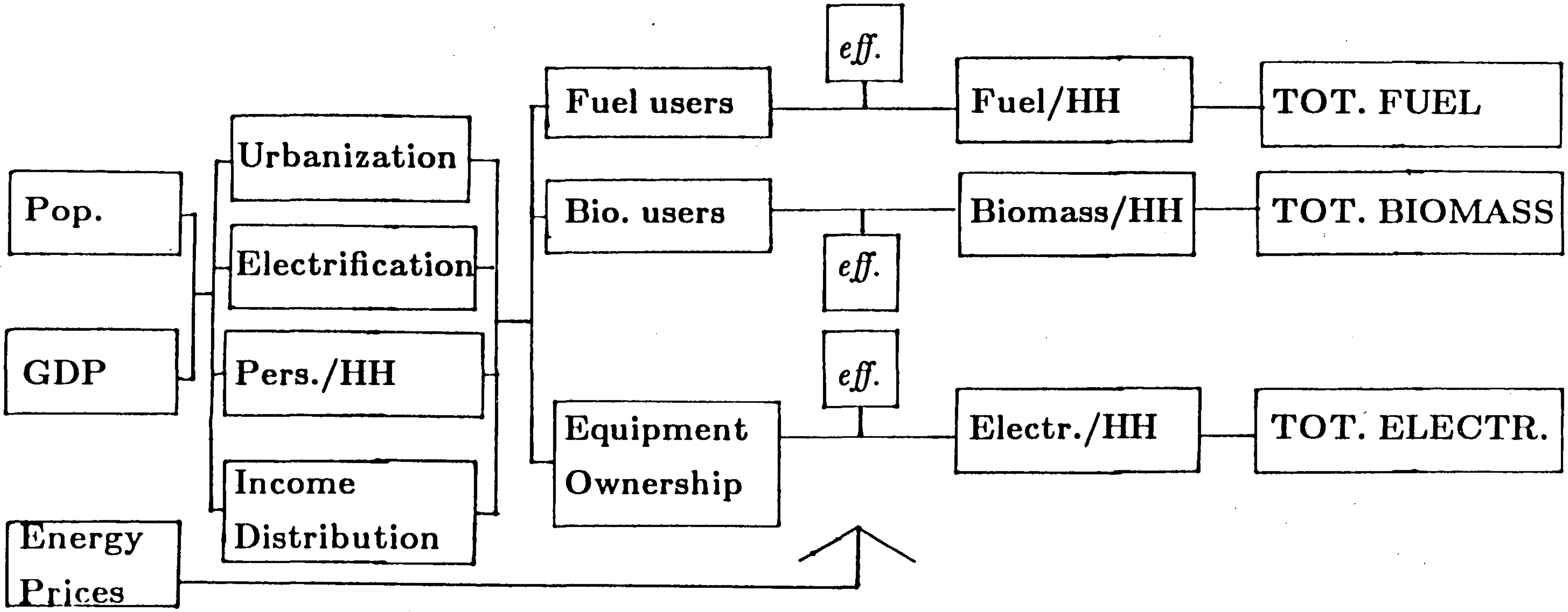
Historically, urbanization has been an integral part of the process of economic development (Figure 7). The development of urban centers is due to the migration of rural population to economically attractive urban areas and due to the gradual increase in size of smaller towns which eventually become large enough to be denoted as urban areas.

Higher levels of urbanization are associated with higher average incomes. For example, the urbanization rate in Japan in 1960 was 62%, and in Korea at a similar income level in 1985 it reached 64%. The way continents were settled and consequent economic development took place also has a strong influence on urbanization levels. In Latin

* Other things being equal, energy use in large households, though greater than that in smaller ones in absolute terms, is lower per capita, because of economies of scale. We keep this in mind in projecting future uses.

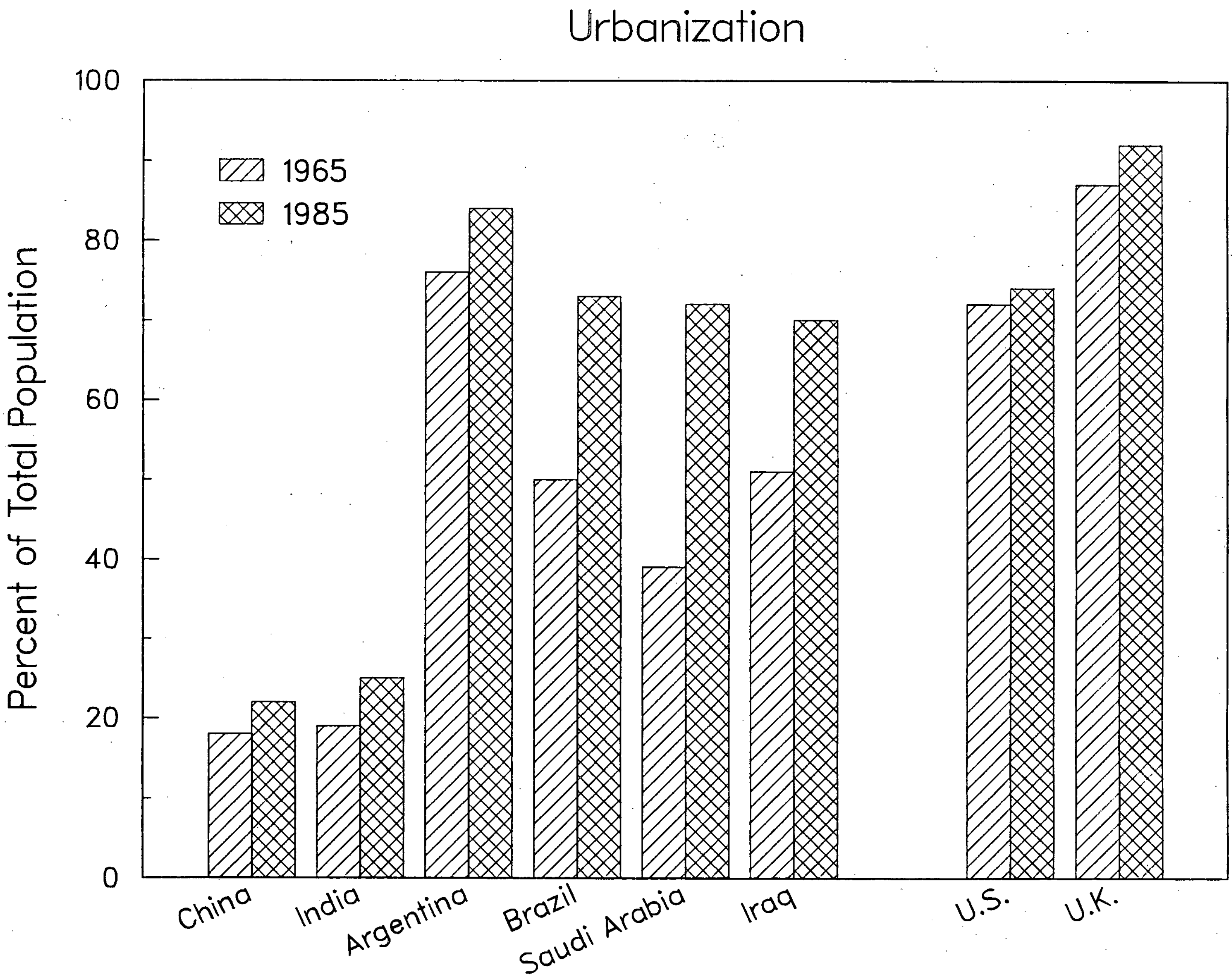
Figure 6.

LDC ENERGY SCENARIOS: RESIDENTIAL MODULE



[HH = household; *eff.* = efficiency assumptions]

Figure 7



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America, where much of the settlement took place due to migration from abroad, urban centers developed quickly. Development of the hinterland and farms occurred as settlers moved towards less hospitable terrain, often lured by valuable mineral deposits.

In our scenarios, we assume that *urbanization* rates increase with higher incomes. For Asia and Latin America, we compare the urbanization in countries today whose *average* incomes correspond to the income levels in each quintile (20% of the population) of income projected for 2025 (Figure 5). This procedure yields an estimate of urbanization in 2025 for each quintile, and thereby for the entire population in those regions. By 2025, we have estimated urban population to reach 85-87% in average for Latin America. (Around 70% of Latin American population is already urbanized, with Argentina and Venezuela exceeding 80%.) By contrast, the levels are significantly lower in Africa, such that the rural share of the population is more than twice as large in Africa as in Latin America.

We assume that *electrification levels* will continue to increase, assisted by government policy, in both RCW and SCW scenarios (Table 3). The level of electrification estimated for Asia is a composite picture of the levels projected for those households we believe could be electrified by 2025 in each income quintile, again by noting how electrified countries at these quintile levels are today. Electrification is already high in both Latin America and the Middle East, and is expected to cover almost all households in the RCW scenario. For Africa, electrification proceeds slowly in the SCW, since income per capita does not increase much. (Given the poor debt situation, government policy alone will not be able to push electrification very far.) In all countries, electric appliances spread rapidly through electrified households, but heavy appliances are much more common in RCW than in SCW.

Household size is projected to decline with rising incomes as has happened in the more economically advanced developing countries. For example, households in South Asia had about 5.8 members in 1985 and those in Koreas had about 4.5. Within countries, urban areas at higher income levels also tend to have lower household sizes. This change occurs as younger people leave the family sooner, and as older people remain longer on their own, i.e., as the nuclear family declines. In addition, slower population growth also causes household size to decline. Our assumptions for population growth indicate slower growth in population in the case of RCW. Since this will be reflected in a lower number of persons per household, we have assumed household size will decline more in the RCW case. We make similar assumptions for each region, although household size is considerably higher in the Middle East, Africa and Asia than in China or in Latin America both today and in the future. Our assumptions about household size and electrification levels are summarized in Table 3.

We assume that structural factors, along with income, determine activity levels and hence energy demand per end-use per capita. For a given end use and fuel type, the amount of energy used is shown by the equation below:

$$[\textit{Demand for energy type } f]_{activity\, j} =$$

$$\frac{[\textit{Energy demand for } j \textit{ per capita}]}{[\textit{End-use efficiency of } f \textit{ in } j]}\ [\textit{Fraction using } f \textit{ for } j]\ [\textit{Total population}],$$

and

$$[\textit{Fraction Using } f \textit{ for } j] \propto [\textit{Level of Urbanization, Electrification}]$$

(with capita and population being replaced by household and number of households, respectively, wherever necessary).

Cooking and Water Heating

The main fossil fuels used for cooking and water heating (C&WH) are kerosene and LPG. (Natural gas use is increasing in countries endowed with it and is included in the final estimates of fuel demand*). Electricity use for cooking is significant in some regions and is increasing for water heating.** [9] Biomass is used for C&WH mostly (though not exclusively) in rural areas. We estimate the amount of energy likely to be used for C&WH in each region and the share of fossil fuels (kerosene & LPG), biomass and electricity. The assumptions for the important parameters are given in Table 3.

We begin by assuming that the basic requirement of *useful* energy for C&WH is 1.2 GJ/cap. This is equivalent to using one 15 kg cylinder of LPG for a household with 4 members. This is then modified by region and income level and kept consistent with current levels of use and expected trends derived from various surveys (see footnote to Table 3).

The type of energy used or the share of different energy types varies significantly by region as well as by income level. It will also change over time. For instance, fuel use per capita for cooking will increase in low income regions as family size declines and as poor families are able to afford several cooked meals a day. At the same time, use per capita declines among urban families, as they spend less time cooking and as the penetration of electricity use for cooking and water heating increases.

For Asia and China, we assume that fuel use per capita will increase slightly from 1985. For Africa, it increases slightly in the SCW case but is about the same in the RCW case. For Latin America, it increases, as electric water heating share is captured by natural gas, despite being partially offset by an increase in the efficiency of hot water devices. In the Middle East, fuel use per capita and penetration is constant in SCW, while fuel use penetration in the RCW and R/Policy scenarios is boosted by the development of

* Natural gas is used in Argentina, Bangladesh and Pakistan as household fuel, but also increasingly in cities (e.g. Cairo) where local grids are being developed. Continued expansion in countries with natural gas (L. America, S- and SE Asia, M. East) is likely.

** In Costa Rica, electricity is used for cooking at all income levels; in Nairobi, Kenya, it is used mainly by high income households. A survey for Hyderabad, India showed that a negligible fraction of households used electricity for cooking. In China, a virtual ban on electric cooking means that its use is not significant at any income level.

TABLE 3

ASSUMPTIONS AND INDICATORS FOR 2025 RESIDENTIAL SECTOR FOR 5 LDC REGIONS:

PARAMETER or INDICATOR	REGION	1985	<------------ 2025 A.D. ------------> SLOW	aagr	S/POLIC	aagr	RAPID	aagr	POLICY	aagr
HH SIZE (persons/hh)	ASIA	5.9	5.4		5.4		4.9		4.9	
	CHINA									
	AFRICA	6.0	5.0		5.0		4.3		4.3	
	LAT.AM.	4.5	3.8		3.8		3.4		3.4	
	MID.EAST	6.0	5.0		5.0		4.5		4.5	
ELECTRIFICATION (% hh electrified)	ASIA	35%	70%		70%		82%		82%	
	CHINA	35%	70%		70%		82%		82%	
	AFRICA	25%	40%		40%		55%		55%	
	LAT.AM.	78%	92%		92%		98%		98%	
	MID.EAST	65%	85%		85%		95%		95%	
BIOMASS ENERGY USE* (GJ/capita that use biomass for C&WH)	ASIA	8	7	-0.3%	6	-0.7%	8	0.3%	6	-0.5%
	CHINA	9	6	-1.1%	5	-1.4%	7	-0.8%	6	-1.1%
	AFRICA	10	6	-1.3%	5	-1.6%	7	-1.0%	6	-1.4%
	LAT.AM.	13	8	-1.3%	7	-1.4%	6	-1.7%	6	-1.8%
	MID.EAST	8	6	-0.9%	4	-1.7%	6	-0.9%	4	-1.9%
EFFICIENCY OF BIO-MASS USE (%)	ASIA	8%	12%		16%		12%		16%	
	CHINA	9%	15%		17%		15%		17%	
	AFRICA	6%	10%		15%		12%		16%	
	LAT.AM.	6%	10%		12%		12%		14%	
	MID.EAST	7%	10%		14%		10%		15%	
RES.ELECTRICITY USE (kWh/elec. capita).	ASIA	136	153	0.3%	134	0.0%	245	1.5%	184	0.7%
	CHINA	69	190	2.6%	166	2.2%	227	3.0%	170	2.3%
	AFRICA	298	396	0.7%	286	-0.1%	481	1.2%	298	0.0%
	LAT.AM.	308	413	0.7%	359	0.4%	684	2.0%	469	1.1%
	MID.EAST	297	412	0.8%	365	0.5%	632	1.9%	474	1.2%
RES.FUEL USE (GJ/capita using fuel for C&WH)	ASIA	3.0	3.0	0.0%	3.0	0.0%	2.5	-0.5%	2.5	-0.5%
	CHINA	3.0	3.0	0.0%	3.0	0.0%	2.5	-0.5%	2.5	-0.5%
	AFRICA	3.8	4.4	0.3%	3.6	-0.2%	4.3	0.3%	3.3	-0.4%
	LAT.AM.	4.4	3.9	-0.3%	3.9	-0.3%	5.0	0.3%	4.4	0.0%
	MID.EAST	3.1	3.0	-0.1%	3.0	-0.1%	5.6	1.4%	4.2	0.7%
SPACE HEATING (GJ/heated cap)	ASIA	12.8	12.2	-0.1%	11.2	-0.3%	9.5	-0.8%	8.0	-1.2%
	CHINA	7.8	6.3	-0.5%	5.6	-0.8%	5.1	-1.1%	3.9	-1.7%
	AFRICA									
	LAT.AM.									
	MID.EAST									

* Derived from assumptions about end-use efficiencies for fossil fuel and biomass.

NOTES: RESIDENTIAL

[A major data source for the estimation of these parameters was the information and data on 9 major Asian and 4 major Latin American countries that has been put together by IES from country sources, such as national energy statistics, statistical yearbooks, annual reports of utility companies, etc. We refer below to data from this collection as "IES data".]

1. **Household Size**: *1985 values*: Asian value is based on Ref.2,3. In the absence of data, values for China are assumed to be the same as those for Asia. Latin America value is from Ref.4. Numbers for Africa and Middle East are estimates based on values observed for other LDCs. *Scenarios:* These are estimates based on historical data for decreases in household size with economic development.

2. **Electrification**: *1985 values*: Population-weighted average of IES data on India, Pakistan, Korea, Taiwan, Thailand was used for Asia and China. Population weighted average for Argentina, Brazil, Mexico and Venezuela was used for Latin America. Middle East estimate were derived similarly. Values for Africa are estimated. *Scenarios*: Based on historical correlation between income growth and electrification levels for each region. It is expected that governmental policy in LDCs will push electrification faster than overall economic situation, but the latter will impose some capital constraints.

3. **Biomass energy**: *1985 values*: End-use efficiency of biomass use and actual consumption per person were estimated simultaneously as follows: Various surveys have indicated end-use efficiencies of anywhere between 5% and 15%; we use a range of 6% to 8% for current average efficiencies. Leach (1987) contains a comprehensive analysis of data on biomass energy consumption in South Asia, and his figures indicate a useful energy of 0.55-0.75 GJ per capita for C&WH in that region. We use this as the minimum useful energy requirement. This, when divided by efficiency, gives the actual energy consumption per capita. Finally, we estimate the fraction of the population using biomass for C&WH from Leach and other sources, and cross-check our estimate of energy consumption and efficiency with the total biomass energy consumption for that region (IES data for Asia, China, South America; Trocki et al. (1985) for Central America; UN data for Middle East).

   Scenarios: Reductions in biomass energy use per capita that still use biomass in the future are expected due to plain necessity arising out of biomass scarcity, governmental programs for the dissemination of improved woodstoves--particularly in Asia, and, in the policy cases, perceived contribution of biomass use for C&WH to atmospheric CO_2. Data on field trials of improved cookstoves indicate that field efficiencies may not be more than 20%; we therefore assume that average efficiencies in the policy scenarios will approach 17%. Calculations for commercial fuels in Asia indicate useful energy consumption significantly higher than 0.75 GJ, which indicates the presence of latent demand that is suppressed because of scarcity of biomass. We therefore assume an increase in the useful energy consumed if end-use efficiency improves. Hence, the biomass energy use does not drop automatically as efficiency increases.

4. **Residential Electricity Use**: *1985*: Values for Asia, China and Latin America are based on data from country sources on residential electricity consumption. Middle East and Africa values are estimated from these and data on total consumption. *Scenarios:* Projections for Asia, China, Middle East and Latin America were derived from data on 9 Asian countries (used for Asia and China), 4 Latin American countries, and 11 Middle East countries, that allow correlation between income/capita and residential electricity use. Policy case assumptions are given in the text. African residential electricity use was estimated from our understanding of the relationship between income levels, appliance ownership and residential electricity use in LDCs and OECD countries.

6. **Residential Fuel Use**: *1985 values*: Calculated from IES data on total fuel consumption in the residential sectors, using estimates of fraction of population using fuel for C&WH from various reports. *Scenarios*: Combination of efficiency improvements from 50% to at most 70%, and estimates of useful energy consumption from correlations between income/capita and fuel-use/cap in higher income countries. In the policy cases, a switch away from electricity use for C&WH towards using fuel is expected since such direct fuel use is less emissive. Some use of solar water-heating is also assumed in the policy scenarios.

7. **Space heating**: Energy use for space heating in Latin America, Middle East and Africa is negligible. Asian use is dominated by Korea and China. (See text.)

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local natural gas networks.*

Electric or fuel-based water heating was estimated to be present in 30% of African households in 1984 and used about 25% of fuel and electricity. LPG or natural gas is important for water heating in other LDCs, except where electricity use is encouraged by a low price (e.g., Brazil, Venezuela, Kenya) or permitted by higher incomes.* By 2025, we expect use of electricity for hot water to expand to larger number of households in Africa too. At the highest income levels in Asia electricity use for water heating is common. At lower income levels, water heating is done using the same fossil fuel used for cooking. However, evidence in Latin America shows that it is not uncommon among low income users of LPG for cooking to keep using fuel wood for hot water. Some policy measures could decrease the share of households using biomass, as we assume in the case of Latin America where the share is taken to drop to 5% for R/Policy case.

There is substantial scope for improvement of the efficiency of biomass use. Laboratory experiments in Asia with improved cookstoves suggest that it is possible to achieve efficiencies of up to 33% (as against current averages of 8%). However, experience from the last decade of improved cookstove dissemination projects suggests that efficiencies are unlikely to exceed 20% in the field. We assume the dissemination of efficient cookstoves to almost all users of biomass only in the Policy Cases. Thus, the average efficiency of biomass use is assumed to improve to 15-17% in each region in the Policy Cases. Minor improvements are also expected in the efficiency of use of fossil fuels.

*Space Heating***

Space heating is common and significant in S. Korea and China,† where the populations using it are 40 million and 350-400 million respectively.‡ The energy used for space-heating per capita is about 4 times that used for cooking (Table 3). Assuming that the coal, light heating oil, and heavy fuel oil used in the residential sector in Korea are for space heating only, we get an estimate of fuel use per capita using space heating of 13 GJ for 1985./c 10 In China, this figure is somewhat lower.

For the RCW scenario, we assume that because of higher incomes, heating will spread to the transition zone in China, and to the northern parts of South Asia, but with milder winters the heating demand there will only be 2/3rds of that of South Korean households. This would add another 100 million people to the number of persons that use

* E.g., Brazil survey: 40% of 2.4 MWh per household goes to water heating.

** Note that we have not considered the impacts of climate change on space heating or air conditioning.

† Space heating is also common in Argentina and other South American countries, but given the limited size of the population living in these areas and the short heating season, we have included this demand in water heating. Data on energy use for space heating in Middle East are almost non-existent; however, it is unlikely that the amount is significant.

‡ Authorities in China divide the country into 3 heating zones. The central heating zone, where the average daily temperature is less than 5° C for more than 90 days, the transition zone, where the average daily temperature is less than 5° C for 60 to 89 days or is less than 8° C between 60 to 75 days, and the non-heating zone. For our purposes, the central heating zone has 50% of the floor area and the average consumption is about 30 kg. coal/ m^2-year.

space heating. By contrast, little increased space heating penetration is assumed to occur in SCW. In the Policy Cases, reductions in space heating intensity occur because of better design of buildings, better use of passive solar gain and the spread of more efficient heating systems. Combined, these elements reduce heating use per household by as much as 24% in the R/Policy case compared to the RCW case.

Lighting and Appliance Electricity Use

The relative importance of lighting as an end-use of electricity rises with increased electrification and urbanization, but then declines as large appliances become common. However, having access to electricity does not necessarily lead to high use, because low income restricts the number of appliances, and supply shortages and high prices of electricity make extensive use unaffordable. In China, for example, households are virtually forbidden from using electricity for air conditioning, and must pay a price several times higher for usage above 80-100kWh/month, while in Kenya a large share of electrified households can afford only a few lights, a radio, and a single cook-plate. But households in higher income countries (Korea, Taiwan, Singapore, Venezuela) own a set of appliances comparable to those in households in Europe in the late 1960s, and in addition have much more electronic equipment. Recent evidence from China* also supports our belief that, government policy permitting, ownership of appliances can rise more rapidly than income (Figure 8), and high income households in low income countries use electricity today in the same way as in Europe.[11,12] Thus, incomes and appliance prices are more important determinants of ownership level than electricity prices, but electricity prices will affect size and efficiency of appliances. Given falling appliance prices (relative to real incomes), it is in fact likely that appliance ownership will reach high levels at much lower income levels in the developing world than the income levels in Europe at which these appliances appeared. However, electricity consumption may not be as high, since many of the new appliances are smaller in size than those in Europe and will be of more modern and efficient design. On the whole then, we expect that at a given income level in 2025, homes will obtain and use at least as many electric appliances as homes at the same income levels have today.

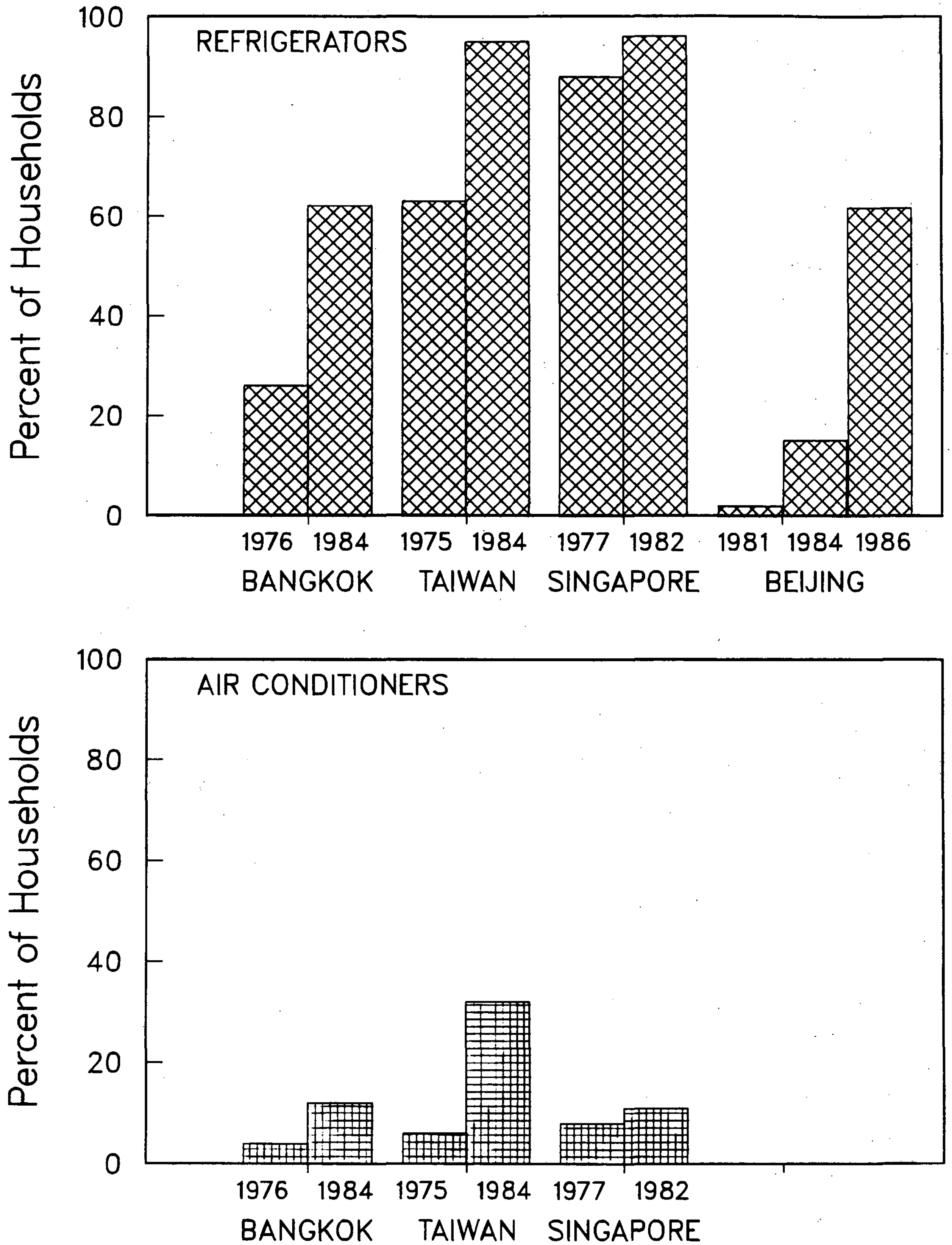
In the Middle East, where electricity use is already high on a per household basis, demand is expected to grow with increased electrification and further spread of air conditioning, already important at middle and high incomes. In Latin America, the level of electricity use per electrified dwelling was already high in 1985, around 1.4 MWh/yr. This high average reflects the use of energy-intensive appliances in some of the households, although many still use electricity only for lights.** On the other hand, room air

* Refrigerator saturations in Beijing, for instance, increased from 1.5% in 1981 to 15% in 1984 to 62% in 1986.

** Surveys in urban households in Brazil indicate that the average apartment dwelling use more than 2.4 MWh per year, 40% for refrigeration, 40% for electric hot water, and the rest for lights and building services.

Figure 8

Saturation of Refrigerators and Air Conditioners



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conditioning is not expected to increase dramatically in Latin America, except in limited areas (e.g. Northern Mexico), or at highest income levels.

Our assumptions about electricity use per household, including that for C&WH, are shown in Table 3. Electricity use per capita in households with electricity is quite low in Asia, China, and Africa, but much higher in the other two regions. Since saturations of appliances are expected to be higher with higher incomes, they would be higher in the RCW case than in the SCW case. On the other hand, efficiency is somewhat greater in RCW than in SCW. The average electricity use per household for Latin America reaches 2.3 MWh/yr in the RCW but only 1.6 MWh/yr. in the SCW case. (These figures are comparable to 2.2 MWh/yr. of electricity use for hot water and appliances in Italy in 1985.) In comparison, African households arrive at a lower level, 1.7 MWH/yr in RCW and 1.04 MWh/yr in SCW, reflecting fewer and smaller appliances in either case.

In the Policy cases, we expect substantial improvements in energy efficiency of household appliances, room air conditioners, and hot water systems, as well as active discouragement of electricity use for C&WH. In Latin America, we also foresee accelerated fuel switching of hot water systems to natural gas. These changes should provide almost 30% electricity savings on a per household basis, lowering demand to 1.6 MWh/yr in Latin America. and to 1.08 MWH/hh in Africa (for appliances). Solar water heating is expected to penetrate to 15% of all households in R/Policy in Africa, accelerating a trend that began in the 1970s. This acceleration would reduce electricity demand further.

Results

Totals for fuel and biomass energy use for cooking and water heating, and electricity use for C&WH as well as for lighting and appliances are shown in Table 4. In each region, the growth rate of modern fuel use is higher in the RCW than in the SCW scenario. This occurs as a larger fraction of the population moves to urban areas in the RCW scenario. As a consequence, less biomass are used. Despite, end-use efficiency for biomass being lower than that for modern fuels (in spite of improvements in the former between 1985 to 2025), total biomass consumption declines in the RCW scenario. However, this is not enough to offset the increase in the use of fuels and electricity. Total residential energy use is therefore highest in the RCW scenario.

The growth rates for electricity consumption are high for each region except Latin America, where the electricity use per household is already high and much of the region is electrified. By contrast, Asia, China and Africa have low levels of electrification in 1985, and the anticipated increase in electrification levels adds to the total electricity use.

TABLE 4
2025 SCENARIOS, RESIDENTIAL SECTOR

	1985		SLOW GROWTH 2025			SLOW GROWTH + POLICY 2025			RAPID GROWTH (Price) 2025			RAPID GROWTH +POLICY 2025		
	Use	%	Use	%	AAGR %	Use	%	AAGR %	Use	%	AAGR %	Use	%	AAGR
RESIDENTIAL, MTOE (a)	705		977		0.8%	873		0.5%	1082		1.0%	885		0.6%
Electricity, TWH	249		1194		3.9%	1005		3.5%	1875		5.0%	1324		4.2%
Asia	66	19%	289	25%	3.7%	253	24%	3.3%	509	18%	5.1%	381	16%	4.4%
China	27	7%	222	15%	5.2%	195	14%	4.9%	322	9%	6.2%	241	8%	5.5%
Africa	38	19%	258	38%	4.8%	187	33%	4.0%	399	31%	5.9%	248	25%	4.7%
Latin Am	96	25%	299	27%	2.8%	260	27%	2.4%	479	20%	4.0%	329	18%	3.0%
Mid East	21	10%	126	16%	4.4%	111	15%	4.1%	166	11%	5.1%	125	9%	4.4%
Fuels, MTOE	172		360		1.8%	351		1.7%	449		2.4%	397		2.1%
Asia	46	20%	105	20%	2.1%	104	20%	2.0%	116	13%	2.3%	111	15%	2.2%
China	82	25%	128	17%	1.1%	119	17%	0.9%	180	15%	1.9%	151	15%	1.5%
Africa	10	9%	47	16%	3.9%	43	17%	3.7%	49	9%	4.0%	43	11%	3.7%
Latin Am	30	11%	63	10%	1.8%	67	13%	2.0%	77	7%	2.3%	72	8%	2.2%
Mid East	5	3%	17	5%	3.3%	19	6%	3.4%	26	5%	4.3%	21	4%	3.7%
Biomass, MTOE	512		514		0.0%	436		-0.4%	472		-0.2%	374		-0.8%
Asia	170	100%	244	100%	0.9%	206	100%	0.5%	242	100%	0.9%	182	100%	0.2%
China	250	100%	136	100%	-1.5%	120	100%	-1.8%	132	100%	-1.5%	117	100%	-1.8%
Africa	50	75%	105	67%	1.8%	94	64%	1.5%	83	79%	1.2%	69	70%	0.8%
Latin Am	36	100%	21	100%	-1.3%	13	100%	-2.4%	11	100%	-2.9%	5	100%	-4.6%
Mid EAst	6	100%	7	100%	0.3%	3	100%	-1.5%	4	100%	-1.3%	1	100%	-3.9%

In the Policy Cases, electricity consumption in each region declines sharply from the RCW but much less than in the SCW. The decline is caused by the spread of improved appliances and more efficient lighting because of stronger government policy. Despite policies promoting efficiency, electricity consumption in the R/Policy case remains higher than in the SCW case.

6.2 Transportation

Energy use in transportation is determined by the demand for movement of people and goods. Many modes are available in developing countries to meet this demand. These modes provide different types of service, measured in terms of speed and comfort of movement. The traditional human and animal-powered forms of transportation predominate in rural areas of developing countries, so the transition to motorized transport will have an important impact on modern energy use. Government policy often dictates the availability of modes, particularly where large capital investment in transport infrastructure are called for, or a choice between import and indigenous manufacture of vehicles has to be made. Thus our scenarios depend critically on assumptions about motorization (access to motorized vehicles, vs. animals or walking), mobility (total movement), mode (collective vs. private, passenger vs. freight, rail vs. air vs. road, etc.) and efficiency, which is measured in vehicle kilometers (alternatively passenger-km or tonne-km) per unit of energy. Figure 9 shows our model of the transportation sector. A general equation for the representation of energy use would be

$$[\textit{Energy Use}]_{mode\,j} = [\textit{Vehicles per Cap.}]_j[\textit{Annual Travel per Vehicle}]_j[\textit{Average Fleet Efficiency}]_j[\textit{Total Pop.}].$$

We divide the transport sector into land and air transport. Land transport is further divided into personal transport (cars and motorcycles), mass and freight transport (trucks and busses), and rail transport. (Water transport is a small component of the total and is not modeled separately for most regions.) Ideally, we would like to estimate each of the parameters in the above equation for each of the modes. But data limitations allow us to do this only for cars and motorcycles and trucks and buses in most regions. For air transport, we extrapolate from current consumption figures using projections of travel and changes in intensity. Bunker fuel is estimated as a fixed percentage of total fuel use in the transport sector. The details of the calculations for each mode are given below.

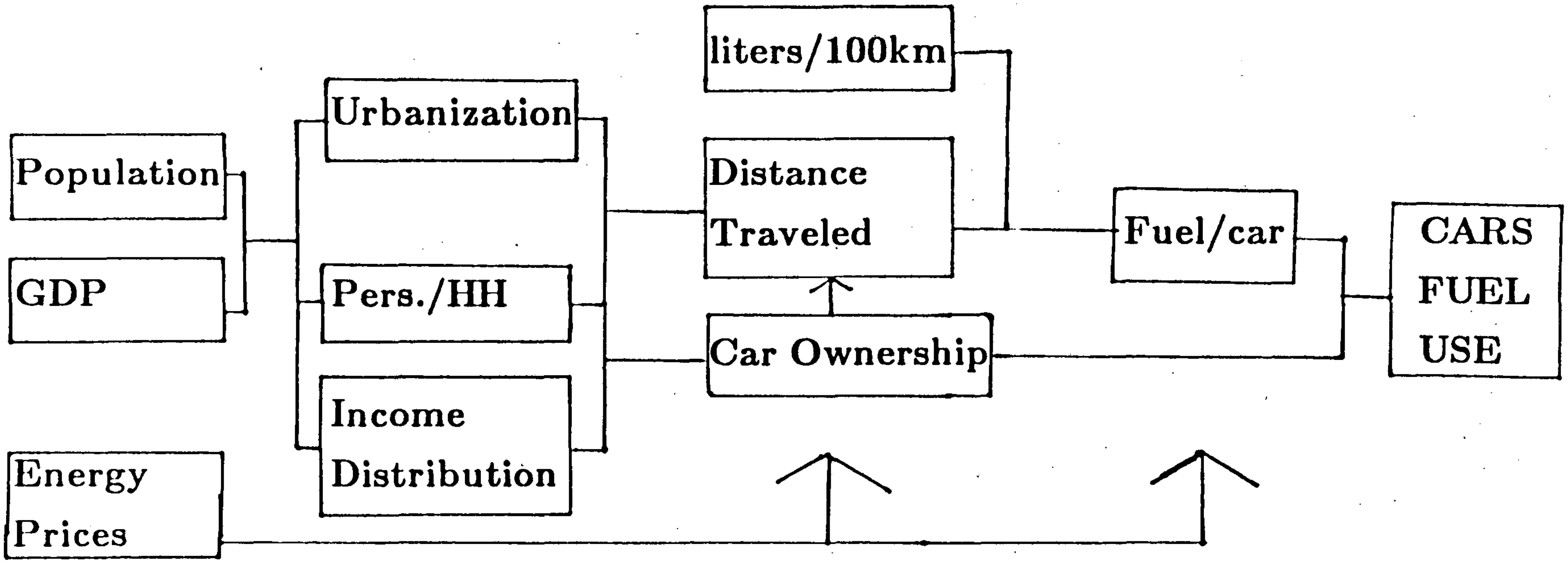
Cars and Motorcycles

There is wide disparity in car and motorcycle ownership levels among the developing countries.* Even at similar income levels, households in Latin America are more likely to

* For instance, while average motorcycle saturation in Asia in 1985 was 16 per thousand, it varied from 375 per 1000 persons in Taiwan to about 7 in India.

Figure 9

LDC ENERGY SCENARIOS: CAR TRANSPORT MODULE



own a car than those in Asia, while households in Asia are more likely to own a motorcycle than a car. Table 5 shows the car saturations in each of the five regions.

Rapid growth in ownership of cars and motorcycles can occur if economic conditions and government policy permit. Ownership of cars per capita in Taiwan increased far more rapidly once incomes reached a level where cars were readily affordable. Conversely, growth (and size of new cars) slowed in Venezuela and Mexico when the economy stagnated in the early 1980s. Government policy is also important: the ownership of motorcycles in India increased rapidly after the government liberalized the manufacture of motorcycles in 1984, permitting joint ventures with foreign manufacturers, granting licenses for setting up new plants, etc. We cannot consider all possible influences explicitly, but in our scenarios, ownership levels are significantly higher in RCW than in SCW.* In the Policy case we have assumed that car ownership will be reduced by 5-25% in various regions, as a consequence of higher taxes on sales of private vehicles and the offering of alternative modes of transport.

There are important differences among regions. In Latin America, we have also considered that (i) cities are, and will most likely remain, built predominantly for private cars and high mobility; (ii) car ownership is likely to remain a status symbol in these countries; and (iii) congestion and local pollution might place an indirect limitation on the use of cars, but not on ownership. Ownership in China, Asia, and Africa, which is very low today, will not grow as much in the Policy Case as in RCW, although in both these cases ownership will be higher than in SCW.

The average distance traveled by a car was derived for each region from gasoline consumption data and our assumptions about efficiency (see below).
There is much historical evidence that the average distance cars are driven drops dramatically as ownership passes from very low levels (ie., under 25 cars/1000) through 80-100/1000. Beyond that level, the drop in distance traveled is much slower.† [13,14] Thus we expect distance traveled to drop, particularly in Asia and Africa, where saturation levels increase dramatically (even if they remain low compared with the OECD today, or Latin America in 2025). In all regions, however, vehicle-miles/capita increase, i.e., the increase in car ownership is greater than the decrease in distance/car. Equally as important for energy use, total vehicle-miles per capita is higher in RCW or the R/Policy case than in SCW (Table 5).

* Car ownership is a function of income level. In the case of Latin America and the Middle East, as in the case of Asia, we have projected the present income distribution to 2025. We then compare the income level of each quintile in 2025 with those in countries today at the same level, to estimate future automobile saturations at the same income level. For example, we assumed that car ownership will remain prohibitively expensive for households with an income level of less than $2000/yr which constitute the two lower quintiles in the SCW case in Latin America. It is only from an yearly income of $10,000 or more per household that saturation is expected to increase dramatically. In both Latin America and Middle East, the top 20% of households are estimated to reach more than $50,000 per year in the RCW case. At those income levels, we have assumed a ceiling saturation of close to 2 cars per household.

† From 1978 to 1986, the average distance traveled annually in Asian countries has declined from 20,000 km. to about 10,000 km per car. In W. Germany, distance traveled declined from 16,500 km. in 1959 to about 12,500 km. in 1986 as the car ownership level increased from about 50 to 350 during this period.

TABLE 5
ASSUMPTIONS AND INDICATORS FOR 2025 TRANSPPORTATION SECTOR FOR 5 LDC REGIONS

PARAMETER or INDICATOR	REGION	1985	2025 A.D. SLOW	aagr	S/POLICY	aagr	RAPID	aagr	R/POLICY	aagr
VEHICLE OWNERSHIP (cars/'000 people)	ASIA	5.7	9.5	1.3%	8.1	0.9%	19.8	3.1%	14.0	2.3%
	CHINA									
	AFRICA	12	20	1.2%	18	1.0%	40	3.0%	38	2.9%
	LAT.AM.	56	132	2.2%	120	1.9%	214	3.4%	171	2.8%
	MID.EAST	43	75	1.4%	70	1.2%	137	3.0%	110	2.4%
MPG (km/lit/car)	ASIA	10	13.2	0.7%	14.0	0.8%	15.7	1.1%	21.0	1.9%
	CHINA									
	AFRICA	8	10	0.6%	12	0.9%	11	0.7%	17	1.7%
	LAT.AM.	7	11	1.3%	13	1.7%	13	1.7%	19	2.7%
	MID.EAST	7	11	1.3%	13	1.7%	13	1.7%	17	2.3%
TRAVEL (km/yr/car)	ASIA	12000	10000	-0.5%	10000	-0.5%	8000	-1.0%	9000	-0.7%
	CHINA									
	AFRICA	18000	15542	-0.4%	14628	-0.5%	13714	-0.7%	11885	-1.0%
	LAT.AM.	15000	13200	-0.3%	13200	-0.3%	12000	-0.6%	12600	-0.4%
	MID.EAST	18000	15500	-0.4%	14000	-0.6%	13000	-0.8%	13500	-0.7%

NOTES: TRANSPORTATION

[A major data source for the estimation of these parameters was the information and data on 9 major Asian and 4 major Latin American countries that has been put together by IES from country sources, such as national energy statistics, statistical yearbooks, annual reports of utility companies, etc. We refer below to data from this collection as "IES data".]

1. **Vehicle ownership**: *1985 values* are calculated from Meyers et al. (1987) and World Automotive Market (56th edition). Scenario projections are based on correlations of income level and car ownership derived from IES data, adjusting for geographic and policy factors (see text).

2. **Car Fleet Efficiency**: Gasoline consumption data for transport from IES data, and derived from UN data on gasoline, were divided by car stock to get consumption per car in 1985. Estimates of car fleet efficiency and travel were simultaneously determined from this and crosscheked with survey data (See Meyers et al., 1987 and Sathaye and Meyers, 1987).

Fuel efficiency, expressed in km./liter, is expected to improve as a consequence of technological improvements (Table 5). Survey results for Taiwan provide evidence that newer cars actually do get better gasoline mileage.[15] The improvements in efficiency will be driven both by slowly rising fuel prices as well as by generally improving technologies, particularly in the RCW. In this case, higher income permits more trade in better (i.e., more modern) vehicles, whether assembled locally or imported. Our studies suggest that the enhanced turnover leads to more efficient vehicles as well.*[16]

Energy efficiency depends on many factors besides the characteristics of the car and engine. For example, congestion has become severe in many developing country cities where much of the car travel takes place, leading to slower and less efficient operation of vehicles.**[17]

By 2025, we expect the car fleet to perform at much higher efficiency, although the aforementioned traffic conditions will limit the increases somewhat. In Latin America, the stock of private vehicles would run at 11 and 13 km/liter in the SCW and RCW respectively, compared with less than 6-7km/l today. Africa achieves 10.4 in SCW and 11 km/l in RCW, the slightly higher value in RCW reflecting the rapid increase in small cars in middle-class families. This evolution does not take place in SCW. In the R/Policy case, efficiency improvements could lead to an average of 19 km/liter (40 mpg) for the fleet in Latin America, and 17 km/l for Africa. Asian fleet achieves even higher levels of efficiency (Table 5).

In the Policy Cases, we assume that car ownership will be restrained by various taxation and import restriction policies. This could lead to an increase in the distance traveled per car as a smaller number of cars might be used more than otherwise in the RCW scenario. We assume that car ownership would be limited to low levels without impeding economic development, as was demonstrated in Korea and Taiwan through the 1970s.

Trucks and Buses

The saturation level of trucks and buses, the distance traveled per year, and the efficiency levels were estimated using a method similar to that for cars.***[18,19] For some regions, however, we collapsed truck freight energy use into a single indicator, the ratio of freight energy use to industrial GDP.

* A typical car manufactured in India had an efficiency of 8km/l, while that in Taiwan had 11.5km/l. The cars in India were 1950s vintage Ambassadors, while those in Taiwan corresponded to more modern Japanese models. Comparable cars in Japan and Germany achieve 16km/l.

** Congestion in Bangkok, Lagos, or Mexico City has worsened considerably in the last 10 years. An average vehicle in these cities moves at only half the speed of the average vehicle in London and Frankfurt.

*** Truck and bus efficiency, measured in km./liter is far less than that for cars. Buses are estimated to be five to ten times more efficient than cars on a passenger-km./liter basis. Data for Thailand suggest that efficiency of trucks and buses averages to about 3.5 km./liter. We use this figure as the basis for estimating distance traveled in 1985. As with automobiles, the efficiency of trucks is influenced strongly by road conditions, maintenance of vehicles and traffic congestion. A study in Pakistan found that several poorly maintained trucks had fuel economy levels 25-40% below that of well maintained trucks of the same model and vintage.

The efficiency of trucks and buses is expected to improve considerably from the 1985 levels as a result of technological improvements already on their way in most advanced industrialized countries, more rapidly in RCW than in SCW. This efficiency depends equally on the nature of the motors as on the utilization of the vehicles, particularly load factors. The Policy Cases also assume that more transit systems would be built, and more buses would be used as well. We have adjusted consumption for these modes upward to take this important shift into account.

Rail Transport

Rail transport is important in China and India and in some parts of Africa. Diesel and electric traction dominate rail transport, although the use of steam coal still prevails. However, rail oil and electricity consumption is usually only a minor part of total consumption of these sources. Measured by energy consumed per mile, electrified rail transport is almost 13 times more efficient than steam coal and about 3.5 more times more efficient than diesel traction.[20] We assume that the use of coal for rail transport will disappear in the RCW case in India by 2025 and will remain unchanged in the SCW case. (The already small use of coal in Africa disappears by 2025.) The R/Policy case assumes that about 20% efficiency improvements will occur in rail transport by 2025. We assume that the shares of electric and diesel traction will remain at their 1985 levels.

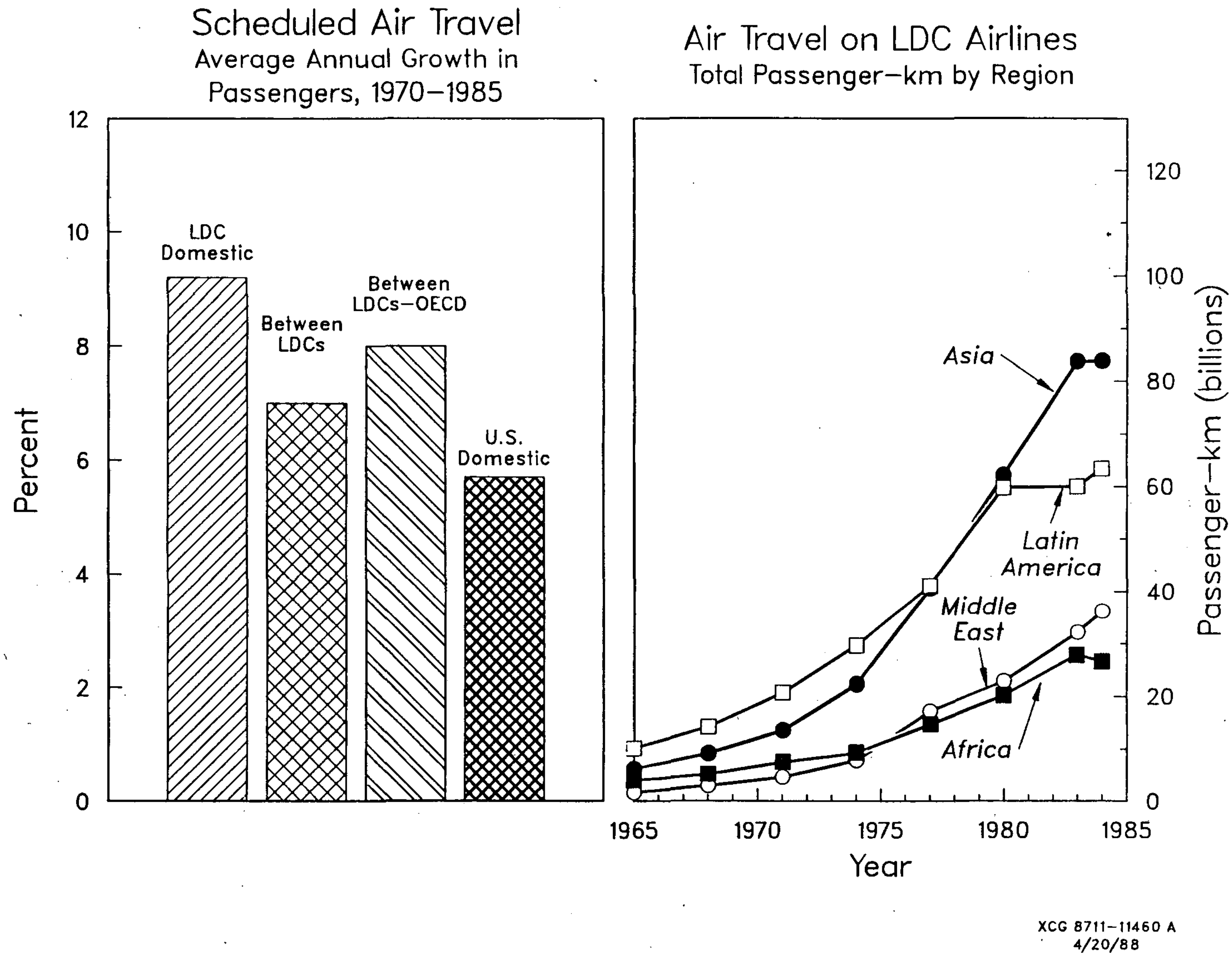
In the other regions, rail transport is mostly limited to urban subway and trolley systems that use electricity. We expect these systems to expand in the RCW, and foresee a significant increase in the Policy Cases as car ownership is restricted and riders switch to using transit systems, although their impact on overall electricity demand is small.

Air Transport

Air travel to and from and within LDCs has increased dramatically over the past 15 years. Between 1970 and 1985, the total number of air passenger-trips to and from and within LDCs increased over three-fold (Figure 9a). Domestic travel within LDCs registered the highest growth, averaging 9.2% per year.[21] Growth in domestic and international air travel are strongly related to national economic growth, but the relationship varies among the countries, and it is different for domestic and international travel. For most LDCs, the ratio of average annual growth in passenger-trips to growth in GDP for the 1970-84 period ranges between 1 and 5. The higher values tend to be for countries where GDP stagnated, or where air travel grew from a relatively small base (such as Nigeria, China and India).[22]

For Asia, we assume that air traffic would increase at least twice as rapidly as GDP in each scenario, for Africa 1.5x. The dispersed nature of the Latin American countries, and the proximity to the United States, has led to rapid development of air traffic in the

Figure 9a



Scheduled Air Travel
Average Annual Growth in
Passengers, 1970–1985
12
10
8
6
4
2
0
Percent
LDC
Domestic
Between
LDCs
Between
LDCs–OECD
U.S.
Domestic
Air Travel on LDC Airlines
Total Passenger–km by Region
120
100
80
60
40
20
0
Passenger–km (billions)
Asia
Latin
America
Middle
East
Africa
1965
1970
1975
1980
1985
Year
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TABLE 6
2025 SCENARIOS, TRANSPORT SECTOR

	1985		SLOW GROWTH 2025			SLOW GROWTH + POLICY 2025			RAPID GROWTH (Price) 2025			RAPID GROWTH +POLICY 2025		
	Use	%	Use	%	AAGR %	Use	%	AAGR %	Use	%	AAGR %	Use	%	AAGR
TRANSPORTATION, MTOE	262		605		2.1%	514		1.7%	937		3.2%	660		2.3%
Electricity, TWH	14		42		2.6%	43		2.7%	82		4.4%	93		4.7%
Asia	4	1%	13	1%	2.6%	13	1%	2.8%	25	1%	4.3%	30	1%	4.8%
China	7	2%	21	1%	2.7%	22	2%	2.9%	42	1%	4.5%	35	1%	4.1%
Africa	0	0%	1	0%	5.8%	1	0%	5.8%	3	0%	8.2%	12	1%	11.9%
Latin Am	2	1%	5	0%	1.7%	4	0%	1.4%	9	0%	3.4%	12	1%	4.0%
Mid East	1	0%	2	0%	3.4%	2	0%	3.4%	3	0%	4.5%	5	0%	5.2%
Fuels, MTOE	261		602		2.1%	511		1.7%	930		3.1%	652		2.3%
Asia	61	27%	117	22%	1.6%	115	23%	1.6%	171	19%	2.5%	119	16%	1.6%
China	23	7%	71	9%	2.7%	60	9%	2.3%	115	9%	4.0%	81	8%	3.1%
Africa	49	46%	134	45%	2.5%	109	42%	2.0%	232	45%	3.8%	152	40%	2.8%
Latin Am	102	37%	210	34%	1.8%	170	32%	1.2%	321	31%	2.8%	229	27%	2.0%
Mid East	25	18%	70	19%	2.6%	56	17%	2.0%	91	16%	3.2%	71	15%	2.6%

past. We have projected demand for air transport, in passenger-km, to grow at a higher rate than GDP (1.2x), although more slowly than in Asia or Africa, where the starting point is much lower.

In the RCW case the efficiency of air travel increases more rapidly than in SCW, so that the fleet is 20-40% more efficient than in the SCW case. In the Policy Case, we assume that the introduction of more efficient engines and air frames will be rapidly accelerated, leading to almost 100% more efficient aircraft than today (ie., a reduction of 50% in energy/passenger mile). This change is achievable through both improved engine and airframe design, as well as improved handling and load factors, factors that are already receiving attention today because of their importance for safety, costs, and scheduling.

Results

The results of our analysis are shown in Table 6. Fuel use in the transport sectors of the five regions increases at 2.1% annually in the SCW scenario and at 3.2% annually in the RCW case.* Transport fuel use increases the most rapidly in China in the RCW case. This is partly because car saturations are extremely low in China even by LDC standards. (Most of the vehicles are owned by institutions.) In the RCW scenario, economic growth in China is sufficiently fast to permit private ownership of vehicles, which will add to the growth of the fleet owned by institutions.

For Africa and the Middle East, the share of fuel used in the transport sector remains about the same (46% and 18% respectively) as in 1985. In Asia, motorcycle transport grows more rapidly than does that provided by autos. This shift restrains growth in total transportation energy demand (in contrast with other regions), and the share of transportation actually declines. These comparisons illustrate the key role played by *personal automobile traffic.*

In the policy cases, fuel use declines substantially compared to the RCW and the SCW cases. In the R/Policy case, it grows only slightly faster than in the SCW case in each region, although the assumed levels of motorization are considerably higher than in the SCW case. Electricity demand increases in this sector (Table 6), because we assume that lower ownership and use of vehicles will lead to increased use of rail transit. For China, we assume that such switching will be limited. Instead, transportation electricity consumption will decline, through improved system efficiency.

* Alcohol use in Latin America is accounted as modern fuel.

6.3 Industry

Industry accounts for the largest share of delivered energy in each LDC region. In the Middle East, 69% is used in industry, partly because of the oil-based energy intensive structure of industry in that region. The lowest percentage (43%) is used in African industry. The amount of fuel and electricity used in industry, 75% of total delivered energy, is the highest in China.* Thus, the industrial sector is clearly the most important one in terms of future consumption trends. As in other sectors, we believe that the level of energy demand will be determined mainly by the level and structure of industrial activity rather than by energy prices.

Industry includes mining, manufacturing and construction sectors. Industrial structure depends on the type of final demand (including exports) that industries satisfy and the type of domestic resources that industry can readily exploit. Projecting changes in this structure over a 40 year period is difficult for even OECD countries; in the case of LDCs, paucity of data makes this task virtually impossible in the given time span. We are therefore forced to use a simple model which can be described by the equation

$$[\textit{Industrial Energy Use}] = [\textit{Energy Use per \$ IVA}][\textit{Share of IVA in GDP}][\textit{Total GDP}],$$

where IVA stands for Industrial Value Added. We extrapolate each of these parameters--share of IVA and average energy intensity--from their current values on the basis of a qualitative understanding of structural trends in the LDCs as well as the OECD countries.

Since 1973, the share of mining and manufacturing in overall Asian GDP has increased from 27% to 31% in 1978 and 33% in 1986 (Figure 10). In a few successful export-oriented countries, like Taiwan and Korea, it has even passed 50%. We expect that the share will continue to increase in the other countries, and it will reach about 35 percent of the overall GDP in the SCW scenario and 40 percent in the RCW scenario in Asia (Table 7). Manufacturing, as a share of industry, will increase *its* share, and non-manufacturing (which dominates Africa) will only remain important in countries with large mining or energy industries, like Nigeria, Indonesia, Saudi Arabia, or Venezuela. We expect the industrial share of GDP to increase more in the RCW than in the SCW.

Our historical analysis of industrial energy intensities shows that fuel intensity (fuel use per unit of value added) declined rapidly between 1970 and 1986 in most Asian countries (Figure 11). We project that Asian industrial fuel intensity will continue to decline in the long run (Table 7). This decline represents both the impact of increased efficiency and the impact of shifts in the mix of products. We believe that the latter factor will in fact lead to an increase in the intensity in Africa, due to a combination of the first appearance of domestic production of materials like steel or paper and the acceleration of growth in sectors that are very dependent on low-cost energy, such as aluminum (as in Venezuela in

* This effect arises mainly because data limitations force us to broaden the definition of what constitutes industrial energy use in China. Much of the fuel used in inter-urban transport sector, for instance, is allocated to industry. Agricultural and commercial sector energy uses are also included in industry in China.

TABLE 7

ASSUMPTIONS AND INDICATORS FOR 2025 INDUSTRIAL SECTOR FOR 5 LDC REGIONS:

PARAMETER or INDICATOR	REGION	1985	<------------ 2025 A.D.							------------------------>
			SLOW	aagr	S/POLICY	aagr	RAPID	aagr	R/POLICY	aagr
INDUSTRIAL VA/GDP (% share)	ASIA	32%	35%		35%		40%		40%	
	CHINA	42%	40%		40%		40%		40%	
	AFRICA	38%	33%		33%		39%		39%	
	LAT.AM.	29%	32%		32%		38%		38%	
	MID.EAST	49%	45%		45%		50%		50%	
FUEL INTENSITY (TOE/10E6$)	ASIA	581	476	-0.5%	428	-0.8%	331	-1.4%	281	-1.8%
	CHINA	1380	1130	-0.5%	1017	-0.8%	786	-1.4%	668	-1.8%
	AFRICA	266	243	-0.2%	219	-0.5%	248	-0.2%	186	-0.9%
	LAT.AM.	600	528	-0.3%	450	-0.7%	378	-1.1%	318	-1.6%
	MID.EAST	300	255	-0.4%	225	-0.7%	210	-0.9%	195	-1.1%
ELEC INTENSITY (MWh/10E6$)	ASIA	955	955	0.0%	860	-0.3%	991	0.1%	843	-0.3%
	CHINA	2160	2160	0.0%	1944	-0.3%	2242	0.1%	1906	-0.3%
	AFRICA	790	883	0.3%	818	0.1%	916	0.4%	798	0.0%
	LAT.AM.	1163	1163	0.0%	1047	-0.3%	1163	0.0%	930	-0.6%
	MID.EAST	582	611	0.1%	611	0.1%	640	0.2%	611	0.1%

NOTES: INDUSTRY

[A major data source for the estimation of these parameters was the information and data on 9 major Asian and 4 major Latin American countries that has been put together by IES from country sources, such as national energy statistics, statistical yearbooks, annual reports of utility companies, etc. We refer below to data from this collection as "IES data".]

1. **Industrial Value Added Share**: *1985*: Industry value added includes mining, manufacturing and construction, but excludes value added in utilities because most countries do not report energy consumed in utilities as a part of industrial energy consumption. Industrial value added share for Asia and Latin America are calculated from IES Data. Data for Africa and Middle East are from the World Development Report 1987. China data are from Asian Development Bank's Key Indicators 1987. Note that Middle East value is high because petroleum mining contributes to a large fraction of the GDP. Also note that the values will decrease if the aggregation within each region is done on the basis of PPP-adjusted GDP values instead of 1985 US$ values. *Scenario projections* are based on historical trends in the regions, e.g., industrial value added share in Asia increased from 23% to 31.5% between 1970 and 1985. Across countries those with higher GDP per capita also appear to have higher share of industrial value added (World Development Report, 1987). In slow case, oil prices are expected to remain low, and hence industrial value added share in Middle East drops.

2. **Fuel Intensity**: *1985 values* are derived from IES data. Industrial fuel use for Asia and China includes feedstocks. China value is very high because of the manner in which value-added is calculated for China, and also perhaps because of space heating in factory buildings--a need that does not exist elsewhere in the LDCs. African value is low because of the relative absence of energy-intensive industries, while there has been a trend towards such energy intensive industries in Latin America. *Scenario projections* are based on estimates about the relative impacts of structural changes and efficiency improvements. (Fuel intensity in Asia has dropped at 2.2% per annum between 1970 and 1985, while it has remained approximately constant for Latin America.)

3. **Electricity Intensity**: *1985 values* are derived from IES data. China value is very high for the same reason as above. Between 1970-85, Asian intensity remained approximately constant, while that in Latin America increased rapidly. Governmental policies to promote use of electricity in Brazil and Argentina are responsible for the high intensity in Latin America. Scenario-wise variations are the result of efficiency improvements and structural changes (see text). Energy use in feedstocks for chemical industries and fertilizers are estimated separately for Africa, Latin America and the Middle East.

the 1970s) or chemicals and fertilizer (as in Thailand and Bangladesh in the early 1980s).[23]

In some oil exporting countries, such as Indonesia, there is a move away from oil and chemicals to other kinds of materials' processing and manufacturing. A similar pattern is observable in Mexico in recent years, although industrial production in all Latin American countries is traditionally linked to the availability of local energy resources, and as a consequence it is more energy-(and electricity-) intensive than in other regions.

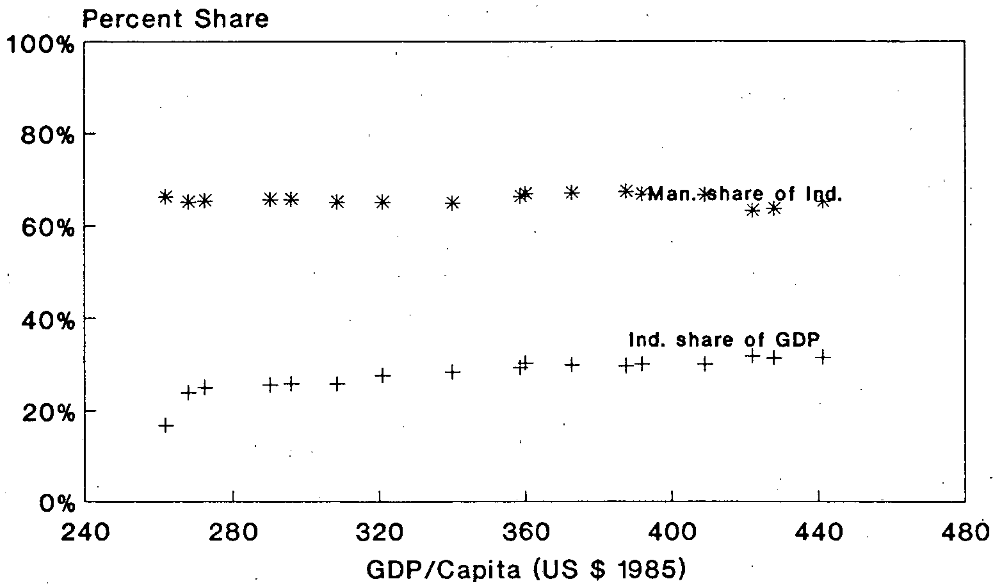
Historically, economic growth has been accompanied by increases in fuel efficiency. These increases are both a result of growth (larger, more modern facilities, more sophisticated management) and an input to growth (better management being a requirement for higher economic growth). As a result, efficiency improves more rapidly in RCW than in SCW. Technological change in RCW accelerates this move. In some countries of the Middle East and Latin America, present-day efficiencies are low by international standards. This is particularly true of Mexico and Venezuela. The extent to which energy efficiency will increase in these countries will depend on the degree to which efficiency becomes a prevailing management rationale.

Electricity intensity does not decline as much as fuel intensity, and in some of our regions electricity intensity may be higher in 2025 than today. In Asian countries, for example, electricity per unit of value added has not declined (Figure 11), and in virtually all OECD countries, electricity intensity increased through most of the post-war period. We assume that electricity intensity will not decline significantly over the long run, unless strong Policy initiatives are introduced to control electricity use (Table 7). We have not considered industrial cogeneration in these scenarios, but it could result in a slight increase in apparent fuel intensity and a significant decrease in (purchased) electricity intensity.

In the policy cases, additional efficiency improvements in this sector would occur due to policies promoting increased cogeneration, R&D in areas like new materials and processes, and to a certain extent a slight decrease in the role of energy-intensive materials. But most of this potential for improvement in energy efficiency will already have been realized in the RCW scenario; industries in the LDCs will reach or surpass the current efficiency standards of the OECD countries. Thus the incremental effect of the policies is not likely to be as substantial as in the other sectors. Further, taxation and low-interest loan policies designed to induce improvements in energy efficiency will be implemented more slowly in the S/Policy case than in the R/Policy case. We assume that the implementation will take place at the same rate that plant turnover or retrofitting occurs. The improvement in efficiency will be in proportion to the growth rate in value added in each scenario.

Figure 10.

ASIA
INDUSTRY AND MANF. SHARES

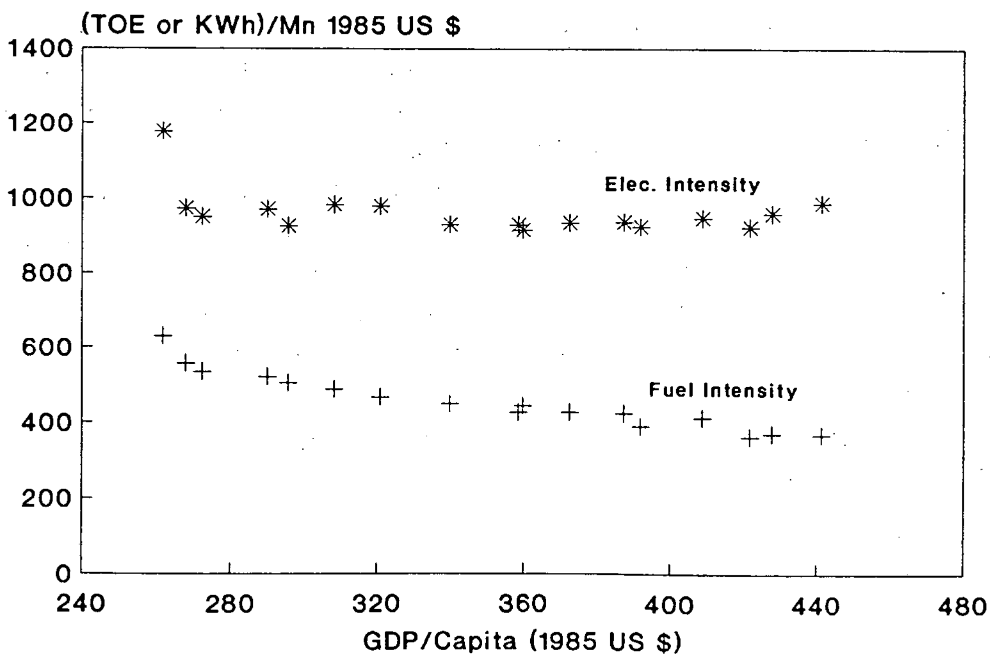


avasind

Nine country average, 1970-86

Figure 11.

ELEC. AND FUEL INTENSITIES



avasfuel

Nine country average, 1970-86

TABLE 8
2025 SCENARIOS, INDUSTRIAL SECTOR

	1985		SLOW GROWTH 2025			SLOW GROWTH + POLICY 2025			RAPID GROWTH (Price) 2025			RAPID GROWTH +POLICY 2025		
	Use	%	Use	%	AAGR %	Use	%	AAGR %	Use	%	AAGR %	Use	%	AAGR
INDUSTRY, MTOE (b)	691		1800		2.4%	1640		2.1%	3356		3.9%	2878		3.5%
Electricity, TWH	1008		3152		2.8%	2938		2.6%	7749		5.1%	6626		4.7%
Asia	183	54%	594	52%	2.9%	549	52%	2.7%	1689	59%	5.6%	1436	61%	5.2%
China	314	75%	1061	70%	3.0%	982	70%	2.8%	2638	78%	5.3%	2242	79%	4.9%
Africa	119	58%	337	50%	2.6%	312	55%	2.4%	721	56%	4.5%	627	64%	4.1%
Latin Am	229	59%	648	59%	2.6%	583	61%	2.3%	1669	69%	5.0%	1335	72%	4.4%
Mid East	164	76%	512	64%	2.8%	512	67%	2.8%	1032	69%	4.6%	985	75%	4.5%
Fuels, MTOE	605		1529		2.3%	1387		2.0%	2690		3.7%	2308		3.3%
Asia	111	49%	296	55%	2.4%	274	53%	2.2%	564	63%	4.0%	480	65%	3.6%
China	223	68%	555	74%	2.3%	514	74%	2.1%	925	76%	3.5%	786	77%	3.1%
Africa	46	43%	106	36%	2.1%	97	38%	1.8%	220	43%	3.9%	172	45%	3.2%
Latin Am	130	47%	325	53%	2.3%	282	53%	1.9%	609	59%	3.8%	523	62%	3.5%
Mid East	94	69%	246	66%	2.4%	221	67%	2.1%	371	67%	3.4%	347	71%	3.2%

For Africa, Latin America and the Middle East, energy use for refining was treated separately. We estimated the amount of fuel lost in refineries. Purchased electricity represents about 5% of the use of fossil fuel, a typical figure for a refinery. We assumed that total refining would increase 4 times in the base scenario and 3.5 times in the higher price scenario. The increases in efficiency were those used in the industrial sector. Feed stocks, which include inputs to petrochemicals, asphalts and lubricants, and other non-energy uses, are expected to increase by 6 fold and 5.5 fold in Africa in the two scenarios, reflecting a greater degree of production of these in Africa. In other regions where refining and chemicals industries are more well developed, increases in the output of these industries will be considerably less.

Results

The use of fuels and electricity for industry in each region for the three scenarios is shown in Table 8. In all regions, total use is higher in RCW than in SCW, but the differences are smaller than the differences in output levels. For the SCW case, the growth rates for fuel use range between 2.1 and 2.3%. The increase in value added in each region is partially offset by the decline in fuel intensity. For the RCW scenario, the growth rate is between 3.4% for Latin America and 4.0% for Asia. Energy use for industry assumes a more dominant role particularly in Asia and Latin America in the RCW scenario as rapid economic growth pushes energy use higher relative to other sectors.

In the Policy Cases, our assumptions regarding the reduced intensity of fuel use increase the share of industrial energy consumption. Policies have less of an impact on reducing fuel intensity in the industrial sector than in the other sectors leading to an increase in industry's share of energy use.

6.4 Agriculture

Agriculture is a key component of most regions' economies, but its share in GDP is decreasing. The main use of energy for agriculture is for irrigation pumping and for on-farm equipment. Irrigation pumping accounts for most of the electricity use*, while fossil fuel use is divided somewhat evenly between pumping and other machine operation, on-farm transportation, and crop drying.** The amount of diesel used for agriculture is difficult to document. This diesel is bought at the same retail outlets that sell diesel for transport and small-scale electric power generation. Furthermore, in every country diesel

* Electricity use for pumping has the fastest growth rate among end-use sectors in India. Electricity is also an important component for poultry and cattle raising, but this electricity is often produced locally by small generators and is therefore difficult to account for.

** Petroleum is also used as feedstock in the manufacture of fertilizers, a very rapidly increasing input to LDC agriculture. This use is accounted for in the industrial sector along with other feedstock uses.

TABLE 9

ASSUMPTIONS AND INDICATORS FOR 2025 ENERGY SCENARIOS FOR 5 LDC REGIONS

PARAMETER or INDICATOR	REGION	1985	2025 A.D. SLOW	aagr	S/POLICY	aagr	RAPID	aagr	R/POLICY	aagr
AGRICULTURE										
ELECTRIC INTENSITY (kWh/$1000 VA)	ASIA	202	234		222		271		244	
	CHINA									
	AFRICA	23	57	2.3%	52	2.1%	85	3.4%	68	2.8%
	LAT.AM.	170	204	0.5%	187	0.2%	238	0.8%	204	0.5%
	MID.EAST	58	116	1.7%	113	1.7%	157	2.5%	110	1.6%
FUEL INTENSITY (TOE/10E6$)	ASIA	50	59		56		68		61	
	CHINA									
	AFRICA	18	35	1.7%	30	1.3%	45	2.4%	35	1.7%
	LAT.AM.	80	64	-0.6%	56	-0.9%	56	-0.9%	48	-1.3%
	MID.EAST	90	135	1.0%	126	0.8%	180	1.7%	126	0.8%
COMMERCIAL										
ELECTRIC INTENSITY (kWh/1000$VA)	ASIA	205	191		178		226		181	
	CHINA									
	AFRICA	244	118	-1.8%	108	-2.0%	135	-1.5%	80	-2.7%
	LAT.AM.	126	114	-0.3%	95	-0.7%	101	-0.6%	76	-1.3%
	MID.EAST	110	165	1.0%	143	0.7%	187	1.3%	131	0.4%
Power Generation: ELEC. LOSSES (%)	ASIA	21%	21%		15%		15%		10%	
	CHINA	7%	7%		7%		7%		7%	
	AFRICA	18%	16%		14%		14%		12%	
	LAT.AM.	16.7%	14.5%		11.5%		11.5%		9.1%	
	MID.EAST	15%	13%		11%		11%		9%	
GENERATION EFF. (%); thermal only	ASIA	28%	28%		32%		32%		35%	
	CHINA	28%	28%		28%		32%		35%	
	AFRICA	28%	31%		33%		33%		35%	
	LAT.AM.	30%	30%		32%		35%		37%	
	MID.EAST	24%	28%		32%		32%		33%	

NOTES: COMMERCIAL AND AGRICULTURAL SECTORS

[A major data source for the estimation of these parameters was the information and data on 9 major Asian and 4 major Latin American countries that has been put together by IES from country sources, such as national energy statistics, statistical yearbooks, annual reports of utility companies, etc. We refer below to data from this collection as "IES data".]

1. **Commercial Electricity Intensity**: *1985*: Value-added in commercial sector consists of value-added in the 'trade','transport' and 'others' categories in the Inter American Development Bank economic statistics. Asia, China and Latin America values are based on IES data. Africa and Middle East values are based on our estimate of the possible sectoral breakdowns of total electricity consumption. *Scenario values*: Value for Africa is high to begin with probably because of the presence of a narrow-based highly energy intensive tourist industry (hotels, etc.) dominating the commercial sector. With economic growth, this sector is expected to diversify and thus rapidly become less energy-intensive. The commercial sector in Latin America is already broad-based, so less structural change-led intensity reduction is expected there.

2. **Agriculture**: *1985*: Values for Asia, China and Latin America are calculated from IES data; those for Middle East and Africa are estimated from UN data. Fuel and electricity intensities in Latin America are very high due to the higly modernised agricultural sector there, which includes mechanization in farming, cattle ranching. Intensities are expected to rise rapidly in Africa because of the substantial scope for modernization of agriculture. (We do not consider the adoption of alternative/sustainable agriculture techniques.)

3. **Power generation**: T&D losses include unauthorised use of electricity.

tractors are routinely used for transporting produce in addition to on-farm use. Thus our estimates of current fuel use in agriculture are uncertain.

Our method for estimating agricultural energy use is similar to that for the industrial sector, i.e.,

$$[\textit{Agri. Energy Use}] = [\textit{Energy Use per \$Agri. VA}][\textit{Share of Agri. VA in GDP}][\textit{Total GDP}].$$

We use data on fuel and electricity use in agriculture for 1985 to estimate their intensity. We then use our understanding of how conservation (and change in farming methods) will increase or decrease these intensities to estimate the values for 2025 in the scenarios. (Table 9 gives our estimates for fuel intensity. No data were available for China.) Electricity intensities are the highest in Asia and Latin America where electricity use for ground water pumping dominates irrigated agriculture. In Africa, these intensities are an order of magnitude lower as irrigated agriculture is still in its infancy. Our general assumption of greater technological progress in RCW than in SCW implies more mechanization and electrification in farming. As a result, energy intensities increase.†

There are, however, many opportunities for more efficient energy use. The use of energy in this sector is sensitive to cropping patterns, the types of crops that are planted, the type of irrigation systems in use and the anticipated improvement in efficiency of diesel engines, electric motors and pumps. For the Policy Case, we estimate that small reductions in energy intensity may be achieved through resorting to one or more of these aforementioned strategies. Improvements in transportation systems and motors will be reflected in greater efficiencies in farm equipment, and that solar energy will be used to a significant degree for crop drying. The drop in energy intensity for Latin America is mainly due to less use, or more efficient use, of biomass fuels. In the Policy cases, we expect a 5-15% improvement in the energy intensity.

Results

Results for fuel and electricity consumption in agriculture are given in Tables 10. Fuel consumption in Asia, Africa and the Middle East increases the fastest in both SCW and RCW. For Asia, much of the consumption occurs in South Asia, where the level of irrigation is growing rapidly and energy-intensive agriculture is replacing labor-intensive one. In Latin America, with its agriculturally mature economies, the transition to modern fuel use in agriculture has already taken place to a great extent, and energy use will therefore not increase as much in the future.

† We have not considered the possibility of a radical shift in agricultural practices from mechanized and fertilizer intensive farming techniques to a pattern that is broadly termed "sustainable agriculture". Such a shift would significantly reduce fossil fuel consumption for agriculture; however, it is not clear at this stage what constitutes sustainable agriculture, and whether farmers in LDCs can be persuaded to adopt it as a viable alternative.

TABLE 10

2025 SCENARIOS, COMMERCIAL AND AGRICULTURAL SECTORS

	1985		SLOW GROWTH 2025			SLOW GROWTH + POLICY 2025			RAPID GROWTH (Price) 2025			RAPID GROWTH +POLICY 2025		
	Use	%	Use	%	AAGR %	Use	%	AAGR %	Use	%	AAGR %	Use	%	AAGR
COMMERCIAL, MTOE	32		84		2.4%	73		2.0%	155		3.9%	116		3.2%
Electricity, TWH	196		579		2.7%	518		2.4%	1209		4.5%	877		3.7%
Asia	54	16%	173	15%	2.9%	161	15%	2.7%	471	17%	5.4%	377	16%	4.9%
China	25	6%	76	5%	2.7%	72	5%	2.6%	127	4%	4.0%	76	3%	2.7%
Africa	42	21%	67	10%	1.2%	61	11%	0.9%	134	10%	2.9%	79	8%	1.6%
Latin Am	51	13%	121	11%	2.1%	101	10%	1.7%	218	9%	3.6%	163	9%	2.9%
Mid East	24	11%	141	18%	4.4%	123	16%	4.1%	260	17%	6.0%	182	14%	5.1%
Fuels, MTOE	15		34		2.0%	29		1.6%	51		3.0%	40		2.4%
Asia	0	0%	0	0%		0	0%		0	0%		0	0%	
China	0	0%	0	0%		0	0%		0	0%		0	0%	
Africa	1	1%	3	1%	2.5%	3	1%	2.0%	4	1%	3.2%	3	1%	2.1%
Latin Am	8	3%	13	2%	1.1%	11	2%	0.7%	22	2%	2.4%	18	2%	1.8%
Mid East	5	4%	17	5%	2.8%	15	5%	2.5%	24	4%	3.7%	19	4%	3.1%
AGRICULTURE, MTOE	28		79		2.6%	74		2.4%	139		4.0%	116		3.5%
Electricity, TWH	95		270		2.6%	256		2.4%	506		4.2%	458		3.9%
Asia	31	9%	83	7%	2.5%	79	7%	2.3%	150	5%	3.9%	135	6%	3.7%
China	45	11%	137	9%	2.7%	130	9%	2.6%	273	8%	4.5%	259	9%	4.3%
Africa	6	3%	12	2%	1.7%	11	2%	1.5%	21	2%	3.1%	16	2%	2.6%
Latin Am	9	2%	18	2%	1.6%	16	2%	1.4%	27	1%	2.7%	23	1%	2.3%
Mid East	4	2%	19	2%	3.7%	19	2%	3.7%	35	2%	5.3%	25	2%	4.3%
Fuels, MTOE	20		56		2.6%	52		2.4%	95		3.9%	76		3.3%
Asia	8	3%	21	4%		20	4%		38	4%		34	5%	
China	0	0%	0	0%		0	0%		0	0%		0	0%	
Africa	1	1%	7	2%	4.6%	6	2%	4.2%	11	2%	5.6%	8	2%	5.0%
Latin Am	4	2%	6	1%	0.6%	5	1%	0.3%	6	1%	0.9%	5	1%	0.6%
Mid East	7	5%	23	6%	3.0%	21	6%	2.8%	41	7%	4.5%	28	6%	3.6%

The share of fuel and electricity consumed in this sector is small, less than 10% in each region. Despite its small share, agricultural consumers carry much political clout. Because of this clout and the dispersed nature of the activity, it is difficult to impose government policies in this sector to improve efficiency of energy use. The share of fuel and electricity consumed in this sector relative to other sectors therefore increases noticeably in the R/Policy case.

6.5 Commercial or Services

Little is known about the detailed structure of this sector in the developing countries, which is made up of office buildings, schools, hospitals, restaurants, hotels, etc. Space and water heating in such places being rather limited in the LDCs,* fuel use plays a limited role, and is concentrated in hotels, restaurants, schools, and laundries. For example, in Kenya approximately 10% of fuel use went to this sector (vs. nearly 20% in OECD countries).

Electricity is the major energy source in the commercial sector. This sector accounts for 44% of the electricity used in Singapore (in 1984), which is dominated by office buildings, and 25% of that used in Kenya (in 1979), where the mix of buildings is more typical of early stages of development. In Singapore, air conditioning is a very important end use, as is the case in the wealthy countries in the Middle East. In other countries, the share is smaller, though increasing, as lighting and cooling levels increase and more stores, offices, and other electricity-intensive buildings are erected.

We project the use of electricity in this sector to grow in proportion to the value added in this sector. Thus,

$$[\textit{Comml. Elec. Use}] = [\textit{Elec. Use per \$Comml. VA}][\textit{Share of Comml. VA in GDP}][\textit{Total GDP}].$$

Table 9 gives our projections for electricity intensity. Significant improvements in end-use efficiencies, especially in lighting and air conditioning, will occur even in the SCW case, as present technologies are substituted over the next forty years by devices which are just emerging from R&D labs. (Note that most of the building stock which will be in place in 2025 has yet to appear.) But we believe that increase in sectoral activity and the resulting increases in use of air conditioning and lighting will still push up electricity demand per unit of value added in the SCW and RCW scenarios. In the policy cases, however, we believe that policies will be able to drive electricity (and fuel) intensity downward to as much as 70% of the RCW and SCW cases. Solar water heating and cooling will play an important role in this, particularly in Africa where the intensity in the R/Policy declines to 60% of the RCW case.

* In China there is a significant space-heating demand, but available data account for this energy use in the industrial sector.

Results

The projections for electricity and fuel use in this sector are shown in Table 10. The share of electricity consumed in this sector is highest in Africa, about the same in Asia and Latin America, and slightly smaller in the Middle East. The share in the RCW scenario is higher than in the SCW case. Consumption increases rapidly in both scenarios. Fuel use rises, but is less significant than electricity use, particularly as air conditioning increases its importance. Efficiency of fuel use improves in all cases. In the R/Policy case, significant improvements in efficient use of electricity and fuel in this sector take place. Despite these improvements, the levels of consumption for the R/Policy case are higher than those in the SCW case.

7 Electricity Generation

Here we estimate the amount of electricity generation in order to estimate the primary energy demand for each scenario. We have not attempted to describe the various technologies used to generate electricity and their capital requirements. These are treated elsewhere in a companion report on this topic.

The *production* and *distribution* of electricity is inefficient in the LDCs compared to that in the developed countries. The thermal efficiency of electricity generation in Asia was about 28% in 1985, and about the same in other regions (Table 9). This efficiency will increase in the future, with use of more efficient power plants and with improved institutional structure and better management of these plants. Efficiency reaches about 35% in the R/Policy case in each region.*

Transmission and distribution losses, which reflect true losses as well as theft, are highest among the regions in Asia, about 21% (Table 9).** With improved management of electric utility systems and better technical control, losses may be reduced substantially in all three cases. In R/Policy case, for example, losses are reduced to 10% of generation.

8 Overall Results

Table 11 gives the overall results by region and scenario. Total delivered energy is comprised of electricity, modern fuels and biomass. Primary energy includes electricity calculated in terms of its fossil fuel equivalent, as explained immediately above.

* To account for potential changes in generation efficiency, we count all primary inputs to electricity (whether electricity is supplied by fossil fuel, nuclear power, hydro, or some other form) at the same thermal efficiency (the inverse of the heat rate). Improvements will be reflected in changes in the amount of actual fuel consumed, which means that in hydro- or nuclear-intensive regions, these differences could be small.

** These are measured as the difference between generation and sales as a fraction of generation. The very low line losses for China are somewhat fictitious, because, Chinese statistics show only transmission losses in lines above 110 KV.

TABLE 11

IES-LBL 2025 SCENARIOS: OVERALL SUMMARY

	1985		SLOW GROWTH 2025			SLOW GROWTH + POLICY 2025			RAPID GROWTH (Price) 2025			RAPID GROWTH +POLICY 2025		
	Use	%	Use	%	AAGR %	Use	%	AAGR %	Use	%	AAGR %	Use	%	AAGR
TOTAL DELIVERED, MTOE	1736		3598		1.8%	3227		1.5%	5691		2.9%	4684		2.5%
Electricity, TWH	1563		5237		3.0%	4760		2.8%	11422		5.0%	9379		4.5%
Asia	337	100%	1152	100%	3.0%	1055	100%	2.8%	2844	100%	5.3%	2359	100%	4.9%
China	419	100%	1518	100%	3.2%	1401	100%	3.0%	3401	100%	5.2%	2854	100%	4.8%
Africa	204	100%	676	100%	3.0%	572	100%	2.5%	1277	100%	4.6%	982	100%	3.9%
Latin Am	388	100%	1090	100%	2.6%	964	100%	2.2%	2402	100%	4.5%	1862	100%	3.9%
Mid East	214	100%	801	100%	3.3%	767	100%	3.2%	1497	100%	4.9%	1321	100%	4.5%
Fuels, MTOE	1073		2581		2.2%	2329		1.9%	4215		3.4%	3474		2.9%
Asia	226	100%	539	100%	2.1%	512	100%	2.0%	889	100%	3.4%	742	100%	2.9%
China	328	100%	754	100%	2.0%	693	100%	1.8%	1221	100%	3.3%	1018	100%	2.8%
Africa	108	100%	298	100%	2.5%	258	100%	2.2%	516	100%	3.9%	378	100%	3.1%
Latin Am	275	100%	617	100%	2.0%	534	100%	1.6%	1036	100%	3.3%	848	100%	2.8%
Mid East	136	100%	374	100%	2.5%	332	100%	2.2%	553	100%	3.5%	488	100%	3.2%
Biomass, MTOE	529		566		0.2%	489		-0.2%	495		-0.2%	404		-0.7%
Asia	170	100%	244	100%	0.9%	206	100%	0.5%	242	100%	0.9%	182	100%	0.2%
China	250	100%	136	100%	-1.5%	120	100%	-1.8%	132	100%	-1.5%	117	100%	-1.8%
Africa	67	100%	158	100%	2.1%	146	100%	1.9%	105	100%	1.1%	99	100%	1.0%
Latin Am	36	100%	21	100%	-1.3%	13	100%	-2.4%	11	100%	-2.9%	5	100%	-4.6%
Mid East	6	100%	7	100%	0.3%	3	100%	-1.5%	4	100%	-1.3%	1	100%	-3.9%
TOTAL PRIMARY, MTOE	2157		4926		2.0%	4262		1.7%	8063		3.3%	6368		2.7%
Asia	526		1228		2.1%	1052		1.7%	2031		3.3%	1568		2.7%
China	700		1342		1.6%	1226		1.4%	2287		2.9%	1839		2.4%
Africa	255		688		2.4%	577		2.0%	1024		3.4%	764		2.7%
Latin Am	446		1004		2.0%	840		1.6%	1713		3.3%	1329		2.7%
Mid East	230		664		2.6%	566		2.2%	1008		3.7%	868		3.3%
Delivered/capita, KTOE	477		503		0.1%	452		-0.1%	841		1.4%	693		0.9%
Primary/capita, KTOE	708		742		0.1%	642		-0.2%	1248		1.4%	986		0.8%
Delvrd/GDP (KTOE/bn$)	658		444		-1.0%	398		-1.2%	351		-1.5%	289		-2.0%
Primary/GDP (KTOE/bn$	976		655		-1.0%	566		-1.3%	520		-1.5%	411		-2.1%

Note: % column gives the share of each sector in that region's total consumption of that energy form.

Total delivered energy for all LDCs increases from 1.74 billion TOE* in 1985, to 3.6 billion TOE in the SCW case, and 5.7 billion TOE in the RCW case by 2025. Policies designed to improve the efficiency of energy use in the each case reduce energy consumption to 3.2 billion TOE in the S/Policy case and to 4.7 billion TOE in the R/Policy case, which is still 31% higher than in the SCW case. (Delivered energy increases at 1.8%, 2.9% and 1.5% and 2.5% annually in the four scenarios.)

The use of electricity and modern fuels increases in each scenario, but that of biomass declines in RCW and the two Police cases. Total primary energy use, which was at 2.6 billion TOE in 1985, reaches 5.3 and 8.4 in the two scenarios, and 4.6 and 6.7 billion TOEs in the two Policy cases.

Total modern fuel use grows at 2.2%/yr in SCW and at 3.4%/yr in the RCW case. Driving this growth is both the substitution for biomass and the overall increases in activities in all sectors, even in the SCW case. Modern fuel use growth rates are lowest in Latin America, both because biomass has the lowest relative importance and because the potential for energy conservation, which is very high in this region, is realized substantially. Similar growth rate is achieved in China which because of its fast economic growth manages to achieve substantial improvement in energy efficiency.

The growth rate of electricity use is much faster than that for modern fuels. As a result, electricity use assumes a larger share of delivered energy use in 2025. Electricity use increases from 1560 TWh in 1985 to about 5240 TWh in the SCW scenario (at a rate of 3.0%/yr.), and to about 11420 TWh in the RCW scenario (5.0%/yr.). Policies reduce these growth rates to 2.8%/yr and 4.5%/yr., resulting in a demand close to 4800 and 9400 TWh in the Policy Cases This may be compared with 2300 TWh of electricity consumption in the U.S. in 1985. Across regions, electricity-use growth rates range from 2.2% in Latin America to 3.2% in China in the SCW case, and from 4.5% in Latin America to 5.3% in Asia in the RCW case.

Overall, policy has about the same impact on electricity and modern fuel use growth, consumption of electricity being reduced by 10% and that of modern fuels by 18% of the levels in the SCW and the RCW case.

Biomass use varies significantly across scenarios. In the SCW scenario, more people use biomass in 2025 than today: the slow increase in electrification and penetration of modern fuels does not compensate for population growth. In the RCW scenario, biomass consumption declines at -0.2% /yr, because of increased end-use efficiency and substitution by modern fuels. Improvements in the efficiency of biomass use drive its volume for all LDCs down by -0.7% /yr. in the R/Policy case.

* 1 billion TOE = 41.87 exajoules = 44.38 quad; 53 MTOE = 1 million barrels per day of oil equivalent (mb/doe).

9 Uncertainties

The above discussion highlights scenarios of population and economic growth and illuminates a picture of their energy consequences for five geographic regions spanning the LDC world. In drawing these scenarios, we have used the best information available to us about the economic and structural linkages to energy demand in both the developing and developed countries. Below, we outline several aspects which merit further research.

Economic and Structural Aspects

We noted at the outset that some of our assumptions are extrapolations of present-day trends, or based on today's distributions. For example, in our use of income levels to estimate residential energy use and vehicle ownership levels, we have assumed that the relative income distribution in 2025 is the same as that prevailing today. We also use US dollar values for income and economic activity, whereas values in purchasing-power-parity-adjusted dollars (PPP$) would provide better estimates. PPP-adjustment is particularly important in LDCs, where exchange rates may distort the domestic purchasing power of LDC currencies by factors of up to 3 and 4.

We have been unable to be very detailed about industrial structure, although we made some assumptions about changes in the make-up of industry and in the energy intensity of the output of manufacturing. Industrial structure tends to be very country specific and an improved understanding of structural change in at least the larger LDCs is needed to improve the characterization of energy use in the industrial sector. For example, the manufacturing sector forms a much larger share of industrial value added in Korea and Taiwan while mining activities constitute a significant share in Indonesia. Future growth of the industrial sector and changes in its structure will be different for the former two countries compared with the latter. climate change. More investigation is needed to determine the type of regional or country-specific industrial development that might occur by 2025 in a manner consistent with global industrial growth.

Our judgemental estimates of the potential for increased efficiency, do not call on any unproven or even uncertain technologies; the most important hidden assumption is that we believe only some of this potential will be realized in a world characterized by rapid growth but without rapid growth in energy prices. The real difference in the levels of efficiency in these worlds is uncertain, but our calculations give a good sense for how much farther we believe we can be taken by present or expected technologies. If anything, we have been conservative in our judgements about increased efficiency, but we have probably been equally conservative in our assumptions about the penetration of home and automobile energy uses.

We have only represented "urbanization" with two extrapolated quantities, the share of the population living in urban areas, and the share of homes (urban and rural) that have access to electricity. Since energy use is a complex function of the shape of urban areas, we may have seriously over- or under- estimated the impact on energy use of potential changes in the size and role of urbanization. We need to better understand the development of urban infrastructure and its role in determining the level of urban activity and the implications on urban energy use.

A number of smaller issues remain. For one thing, we have not treated agriculture, services, or the energy industries in great detail, because so little is known about consumption in these sectors today. Further, the treatment of agriculture needs to be consistent with the assumptions made elsewhere in the larger EPA report.

Population and Resource Considerations

The basic forces driving energy demand in this study are population growth and economic growth. We have not, however, considered the effects of population control policies of the type implemented in China in recent years. We also have not considered surprises, such as the potential reduction in population as a consequence of the AIDS epidemic, or changes in population growth brought about by the early effects of climate change on food production and its distribution.

Similarly, we have not considered the implications of the energy demand scenarios for capital requirements for expanding energy production, and whether these requirements could have an important effect on economic growth. Capital issue is particularly important in dealing with the development and use of energy in the developing countries. More than 30% of government budgets go to development of energy in these countries. Improved efficiency of use, although less costly than developing equivalent new supplies, will still require more capital. These need to be estimated in order to ensure that the level of economic growth postulated in the Policy Cases is not adversely affected by drawing capital away from other users.

10 Sensitivity Analysis

Our analysis develops two scenarios with extreme, yet reasonable, population and GDP levels. These may be considered a test of the sensitivity of the results to different rates of population and GDP growth.

Below, we report on sensitivity of the results to variations in the values of other parameters that influence energy consumption in our methodology. Estimates of the values of these parameters for 2025 are based upon their values in the base year, 1985, and our perception of the changes by 2025 based on historical evidence and our qualitative understanding of linkages between energy and human activity. Both, the 1985 values and our estimate of their trend in the context of a particular scenario are uncertain. The effect of these uncertainties on overall results are examined here.

Ideally, one would like to test the sensitivity of the results to all the parameters accounting for possible correlations among parameters.* However, given the time constraint as well as our limited understanding of the potential variability in parameter correlations, we have carried out a simplified sensitivity analysis which treats all parameters as independent**. We test the sensitivity of the results to changes in a select set of parameters (Table 12) for the Rapid Scenario. This set was chosen taking into consideration the energy share of the sector in total energy consumption and, more importantly, our perception of the uncertainty in the estimate of the parameter.† The results of this sensitivity analysis are shown in Table 12 and are discussed below.

Industrial Sector: The overall results show that the industrial sector is the largest consumer of energy. And, the representation of this sector is simpler than desired because the analysis is conducted at a regional rather than at a country-specific level. Thus, variations in industrial energy intensities of 25% above or below our assumed values are possible. The sensitivity analysis shows that such, rather large, changes in the most important sector have a small effect, 6 to 7 percent, on total primary energy consumption.

Also interesting is the difference between the effect of change in electricity intensity on delivered energy (1.9% for a 25% change in intensity) versus primary energy consumption (7.1% for the same change). This is caused by the inclusion of conversion efficiency and electricity losses when estimating primary energy. To the extent that additional electricity generation may be provided by hydro or nuclear sources, this effect may be somewhat misleading. But it does highlight the fact that small changes in the values estimated for electricity intensity may have a disproportionately larger impact on CO2 emissions.

Residential Biomass Use: The choice of a 30% variation in future biomass use reflects the large uncertainties that accompany estimates of current biomass use and that of suppressed demand. However, the net result of such a variation is only a 0.5% change in primary energy use, suggesting that biomass use is not a significant factor.*** A similar variation in biomass use in the Slow scenario would lead to larger, but still small, variation in the overall results, since biomass use is a larger fraction of total energy use in this scenario.

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* For instance, a 25% rise in residential fuel consumption could lead to a drop in biomass and/or electricity consumption. Similarly, if the industrial sector is less fuel-intensive, it may be more electricity-intensive.

** This is equivalent to taking the uncertainty in the future value of the parameter to be a result of not the uncertainty in the structure of scenario but of the uncertainty about the current value of the parameter or (in cases like the energy/value-added ratios) an uncertainty about the coupling of that parameter with the exogenous variable.

† Note also that the percentage variations in the parameter values are not necessarily indicative of the extent of uncertainty in the value.

*** Moreover, since only a fraction of the biomass use leads to deforestation and therefore to net contribution of CO2 to the atmosphere, the effect of biomass use on climate change is even smaller.

Table 12

SENSITIVITY ANALYSIS , RAPID SCENARIO

Parameter	Parameter Value	Percentage Change in Sectoral F/E/B Cons.*	Tot. Delivered F/E/B Cons.**	Tot.Delivered Energy Use	Tot. Primary Energy Use
Ind.Fuel Intensity	25.0%	25.0%	16.0%	12.0%	6.5%
Ind.Elec.Intensity	25.0%	25.0%	18.4%	1.9%	7.1%
Res-Bio. Delivered	30.0%	30.0%	20.6%	1.8%	0.5%
Comm. Elec.Intensity	25.0%	25.0%	2.9%	0.3%	1.1%
Car Ownership	20.0%	6.3%	1.4%	1.0%	0.6%
Car Efficiency	10.0%	2.8%	0.7%	0.5%	0.3%
	-30.0%	-8.5%	-2.1%	-1.6%	-0.9%

* Change in sectoral consumption of the particular fuel affected by the change in the parameter.

** Change in delivered consumption of the particular fuel affected by the change in the parameter.

Commercial Electricity Use: We allow for 25% uncertainty in the electricity intensity parameter for this sector, since little is known about the current structure and energy use trend in this sector in LDCs. The small share of this sector in total delivered energy use results in only a 0.3% change in the latter; however, the change is magnified when considered in primary energy terms for reasons explained above.

Car Ownership & Efficiency: A 20% change in car ownership leads to a smaller change in fuel consumption at the trasnportation sector level, since car fuel consumption is only about a third of the fuel consumption for transport. Its importance declines when considered as a fraction of total delivered fuel and total delivered energy. Finally, a 20% change in car ownership leads to only a 0.6% change in primary energy.

We believe that our estimates about improvements in the car fleet efficiency may be optimistic. We therefore vary the car efficiency by +10% and -30%. Such changes get attenuated to a smaller, 3.2 to -9.5%, change at the sectoral level and to only 0.3 to -0.9% change at the primary energy level for the same reasons that primary energy use is little changed by changes in car ownership.

Overall, larger changes in individual parameters have a smaller effect on delivered and primary energy use. The methodology thus dampens the errors in estimates of individual parameters.

11 Conclusion

The two scenarios and the two policy cases we have developed illustrate several important facets of the growing use of energy in the developing world:

• The impact of population growth and an increased level of basic energy services in homes and energy use in production will lead to a more than doubling in energy demand, even if economic growth is slow. If, however, economic growth in LDCs approaches the rates experienced between 1960 and 1973 developing country energy demand would increase to three to four times over its 1985 level.

• The increases in efficiency we expect to occur under a scenario of rapid technological progress reduce the growth in energy use. But if active policies to encourage energy efficiency while maintaining the same economic growth are implemented, energy use could be further reduced in the Rapidly Changing World by more than 20%.

We noted at the outset that the goal of our work was to illustrate different worlds that would allow us to identify plausible levels of energy use, as well as important opportunities where increased efficiency might reduce energy use without hurting economic growth. The end-uses that are most receptive to policy driven strategies for greater efficiency were household appliances, automobiles, and the uses of electricity in commercial buildings. Solar energy could contribute a significant portion of the water heating (and even space cooling) we foresee to be important in 2025. In other sectors, particularly the industrial sector, policies that directly affect energy use may be less important than policies that promote new approaches to materials use.

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Appendix 1

Adjusting for Purchasing Power Parity

In comparing economic quantities across countries, the choice of an appropriate common unit is critical. The traditional method converts local currencies in real terms into US dollars at a fixed market exchange rate. This is not appropriate, especially for LDCs, because the exchange rate does not correctly reflect the relative domestic purchasing power of the local currency. The International Comparison Project of the World Bank has published a new series of country GDPs measured in what are called Purchasing Power Parity-adjusted dollars (PPP$) [1]. By comparing GDP values using this series with those obtained from a series in US$, one can estimate how much the market exchange rate underestimates the purchasing power of an LDC currency, thus coming up with an exchange-rate deviation index (ERDI). This appendix explains how the use of PPP$ in place of US dollars improves our analysis of income distribution, has no effect on the analysis of the industrial sector and, if we had the time, would have been useful in improving the analysis of the residential and transportation sectors.

1. First, in estimating the average income distribution in a region, we take a GDP-weighted average of the distributions of countries within that region. The average regional income distribution changes when PPP$ are used in place of US$. For example, the share of the poorest quintile in total income in Asia drops from 7.1% to 5.4% while that of the richest quintile increases from 49% to 53% when the income profile is measured in PPP$. We adjust the average regional income distribution using PPP$ in our analysis.

2. Second, PPP$ adjustment can change the sectoral share of regional GDP (used to calculate the energy intensities for industry, commerce and agriculture), which is estimated as a GDP-weighted average of shares across nations within that region. For example, the share of industrial value-added (IVA) in GDP is 23% for India and 51% for Taiwan. The average for Asia using US$ is 33%. But since the ERDI is higher for the less-industrialized countries (e.g., 3.6 for India) than for the industrialized ones within that region (e.g., 1.7 for Taiwan), the IVA share becomes 28% when calculated using PPP$. In the case of Latin America, there is little difference in the ERDIs for the four major countries, and hence there is no significant change in the sectoral shares.

   However, we did not use PPP$ for this part of the analysis. Its use does not affect our calculations and results, because we do not use absolute values for energy intensities, nor make inter-regional comparisons. PPP$ would change the results if our estimates of energy intensity were to approach some absolute technological barriers to improvements that were common to all regions, and if we were to compare intensities across regions to ascertain their appropriateness.

3. Finally, we make aggregations and comparisons across countries when trying to correlate residential energy use, car ownership, etc. with per capita income (section 5). The use of PPP-adjusted income levels here would have helped improve the correlation in the analysis. Moreover, since the relative incomes in LDCs rise with respect to those in developed countries when PPP-adjustment is carried out but car ownership levels and energy consumption levels remain the same, the use of PPP$ will lower the ownership/activity level projections where the projections draw upon experiences in the developed countries.

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