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CO{sub 2} Emissions from Developing Countries: Better Understanding the Role of Energy in the Long Term; Volume III: China, India, Indonesia, and South Korea

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PREFACE

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

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

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

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

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

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

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

China	---	Wu Zongxin and Wei Zhihong, Tsing Hua University
India	---	R.K Pachauri, Vivek Suri and Sujata Gupta, Tata Energy Research Institute
Indonesia	---	Saswinadi Sasmojo, Institut Teknologi Bandung
Korea	---	Ji-Chul Ryu and Seung-Jin Kang, Korea Energy Economics Institute

In each case, the opinions expressed are those of the authors and do not necessarily reflect those of the affiliated institutions.

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

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

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INDIA

1 INTRODUCTION

India consumed 7.1 exajoules (EJ) of energy in 1985. Commercial energy sources alone generated 115 million tons of carbon that year. Over the next four decades, as the size of India's population grows to exceed that of any other nation, India's delivered energy demand and energy-related carbon emissions will increase substantially.

This paper examines 1985 energy use and carbon emissions[1] in India and presents two scenarios for the year 2025.[2] Environmental policies do not find a place on India's political agenda in the high emissions (HE) scenario. As a result, as economic and population growth lead to the increased availability of goods and services between 1985 and 2025, India's carbon emissions rise over six-fold. In the low emissions (LE) scenario, the Indian government implements policy measures aimed at restraining carbon emissions and promoting energy efficiency. As a result of these efforts, the low emissions scenario limits the growth in carbon emissions between 1985 and 2025 to a factor of five.

2 GDP AND POPULATION GROWTH RATES

India had 766 million inhabitants in 1985. Between 1965 and 1980, the Indian population grew at an average annual rate of 2.3 percent. This growth rate declined slightly over the next six years.[3] Between 1985 and 2025, growth rates continue to diminish; the population increases at an average annual rate of 2 percent. Due to the enormous size of the population base, however, even with the receding growth rates, India's population approaches 1.7 billion by 2025. While in 1985, the size of China's population surpassed India's by almost 300 million, by 2025, India's population eclipses China's.

In 1985, India's GDP amounted to US $191 billion. Between 1965 and 1980, India's GDP grew by 3.7 percent annually. Economic growth rates then picked up averaging 4.9 percent each year through 1986.[4] These high growth rates continue over the next four decades; between 1985 and 2025, the economy grows at an average annual rate of 5 percent. By 2025, India's GDP amounts to US$ 1,347 billion.

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[1] In this paper the term "carbon emissions" refers to CO_2 generated from the use of commercial energy sources (not biomass).

[2] The study entailed the preparation of six scenarios. Each which incorporated different rates of economic and population growth and varying saturations of goods and services. The following section outlines two of these scenarios.

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

[4] World Bank, *World Development Report 1988, op cit*, Ref. 3.

Because economic growth surpasses population growth, GDP per capita more than triples. By 2025, India's GDP per capita rises to US $796. While this pace represents relatively rapid economic growth, GDP per capita in India still lags behind that of many other developing nations. In 2025, China's GDP per capita is over twice that of India.

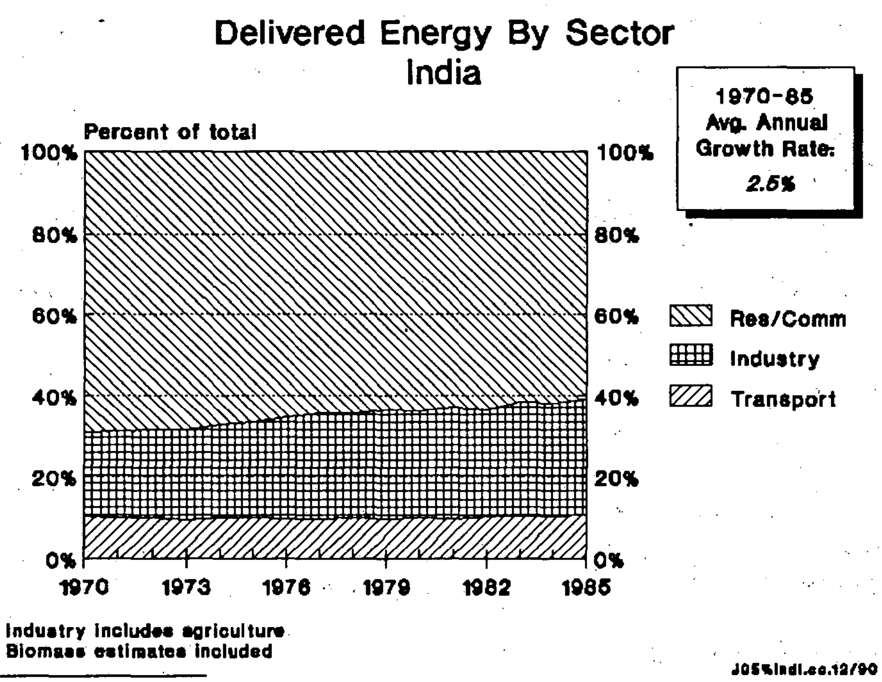
3 SECTORAL ANALYSIS AND CARBON EMISSIONS

While the residential, industrial and transport sectors consume about 95 percent of India's energy, agriculture and services account for over two thirds of India's value added (Table 1).

Table 1[5]
Delivered Energy Use and GDP, 1985

	Energy Use (PJ)			GDP (US$ Billions)		
	1985	2025		1985	2025	
		High	Low		High	Low
Total	7081	29849	25312	191.3	1346.8	1346.8
Residential	49%	23%	20%	--	---	---
Transport	12%	24%	23%	5%	10%	10%
Industry	34%	47%	50%	29%	37%	37%
(Manufacturing	--	--	--	19%	25%	25%)
(Mining	--	--	--	11%	12%	12%)
Services	2%	3%	3%	33%	36%	36%
Agriculture	4%	3%	3%	33%	17%	17%

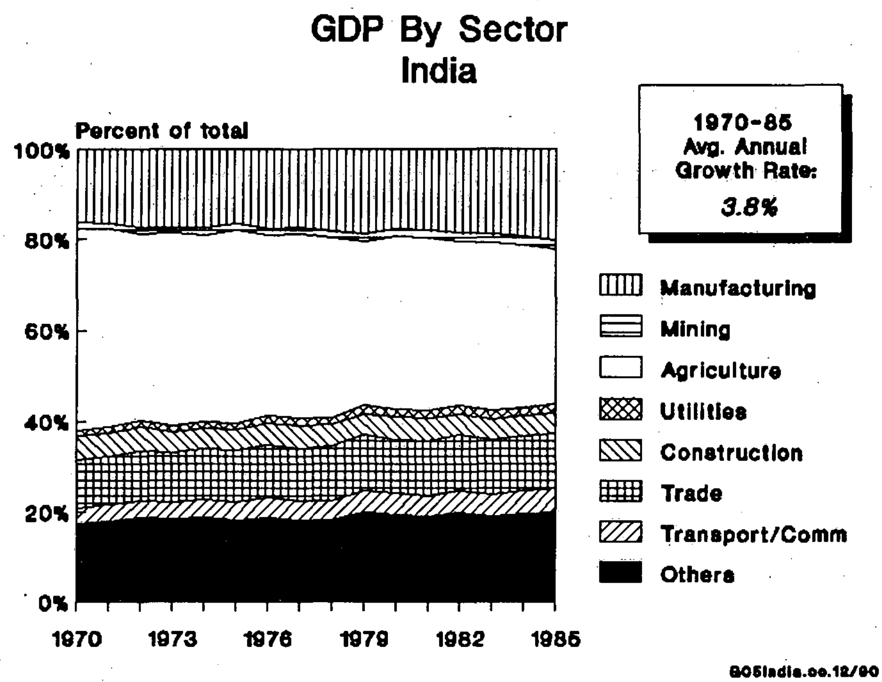
Figure 1



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

Historically, households have dominated Indian energy use. Between 1970 and 1985, however, the residential sector's share of energy demand dropped and industry's share rose (Figure 1). Over this same period, agriculture's share of value added fell sharply, while the shares of services, manufacturing and transport increased (Figure 2). These trends continue over the next four decades.

Figure 2



Biomass fuels embody the largest share of India's delivered energy demand. In 1985, fuelwood, dung and agricultural residues provided 43 percent of the nation's delivered energy demand (Table 12). The bulk of this consumption occurred in India's residential sector, which absorbed over 99 percent of the total biomass supply. Commercial fuels -- mostly coal -- satisfy most other sectoral energy needs. Among the other study countries, only China used more coal than the 1.7 EJ consumed by India in 1985.

3.1 RESIDENTIAL SECTOR

The current dominance of the residential sector in India's overall energy consumption reflects the importance of biomass as a household energy source in India. Relatively inefficient, biomass fuels require higher energy inputs than most other energy sources. Thus, household activities in India account for about half of the nation's total energy use.

High levels of urbanization accompany India's dramatic overall population increase over the next four decades. In 1985, 25 percent of India's population lived in cities. This share increases to 50 percent by 2025. These burgeoning urban populations place greater demands on modern fuel and electricity supplies. Still, urbanization levels in India remain relatively low in 2025 compared to urbanization levels in many other developing nations. In many Latin American countries, for example, the urban share of the population surpasses 80 percent by 2025.

The average size of Indian households decreases between 1985 and 2025. Urban households drop from an average of 4.9 members per household to 4.0 members. Rural households witness a more gradual decline; while in 1985, they average 5.2 persons, by 2025, about 4.8 persons fill each rural home.

The ratio of urban households to rural households increases substantially between 1985 and 2025. The number of rural households grows from 110 million to 178 million; simultaneously, the number of urban households soars from 40 million to 211 million. Concurrently, a mounting share of both rural and urban households gain access to electricity.

The growing dissemination of electricity appears most striking in rural regions. Only 6 percent of all rural households in India had electricity in 1985. By 2025, 90 percent of rural homes obtain electricity. The share of urban homes with electricity increases from 74 percent in 1985 to 100 percent by 2025.

Cooking and water heating consume 80 percent of India's urban residential energy use and 90 percent of India's rural residential energy demand. In the past, as income levels have risen in India, a growing share of India's residential energy supply has been dedicated to lighting and electrical appliance use, and a diminishing share has been devoted to cooking. This trend continues into the future.

By 2025, the shares of LPG, kerosene, natural gas and electricity used to fuel cooking and water heating in urban regions increase. Biomass and coal's shares both decline. Rural households do not use any natural gas for cooking and water-heating purposes. In contrast to the urban dwellers, rural homes increase their coal consumption over time.

The growth in the number of households in India, increasing GDP per capita and increased electrification all lead to higher levels of **appliance** saturation by 2025. The number of refrigerators per 1,000 persons in India increases thirty-fold between 1985 and 2025, the number of TVs multiplies twenty-five-fold and the number of fans over five-fold (Table 2).

The amounts of electricity needed for an average refrigerator and air conditioner decrease by 2025. According to the HE scenario, the unit electricity consumption for televisions sets rises as their sizes increase and as more color sets penetrate the market. Efficiency improvements in the low emissions scenario reduce the amount of electricity required by each television set in 2025 (Table 2).

Total delivered energy demand in the residential sector doubles between 1985 and 2025 in the HE scenario. Growing fuel needs for cooking and water heating activities account for 74 percent of this growth, while the greater saturation of lighting and fans account for 12 and 9 percent of the increase respectively. The LE scenario reduces the residential energy demand by 26 percent of the HE level.

Table 2
Appliance Saturation and Unit Electricity Use

	1985	2025 High	2025 Low
Refrigerators			
Unit Energy Consumption (kWh)	360	240	180
No. per 1,000 persons	5	152	152
Air Conditioners			
Unit Energy Consumption (kWh)	1500	1275	1125
No. per 1,000 persons	0.4	3	3
Television Sets			
Unit Energy Consumption (kWh)	90	160	100
No. per 1,000 persons	5	130	130

Alongside these increases, the composition of the fuel mix shifts. By 2025, biomass makes up a smaller, but still substantial, share of residential energy use. The expanding shares of oil and electricity compensate for the declining consumption of biomass (Table 3).

Table 3
Residential Energy Use (PJ)

	1985	2025 High	2025 Low
Total	3469	6904	5099
Coal	1%	2%	1%
Oil	9%	15%	17%
Biomass	87%	67%	61%
Electricity	2%	17%	20%

Rising incomes usually lead to transitions in the types of fuel consumed in urban India. Typically, first coke and kerosene replace biomass and later LPG and electricity replace those two fuels. Throughout India, however, three factors aside from rising income levels determine the extent to which modern fuels replace biomass resources: the availability of modern fuels; the relative prices of modern and traditional fuels; and the first cost of the equipment needed to use modern fuels. Even when incomes rise, biomass consumption continues to be high in India's rural regions due to both resource and financial constraints.

Despite its large share in total energy demand, India's residential sector generated only 10 percent of the nation's commercial energy-related carbon emissions in 1985. This share may be compared to an 18 percent average in the other study countries. Between 1985 and 2025, however, carbon emissions increase more rapidly in India's residential sector than in any other sector. According to the high emissions scenario, carbon emissions increase more than eight-fold, reaching 91 million tons in 2025. The low emissions scenario reduces residential carbon emissions by 11 percent of the HE level due to improved efficiency in the use of electricity to power appliances and lighting and a lower reliance on fossil fuels.

Indian households currently use many commercial and non-commercial energy sources inefficiently, although most of these usage patterns are backed by justifiable reasons, such as high availability and low prices. Various practices contribute to these low efficiency levels. Despite kerosene's relatively low efficiency levels, this petroleum-based fuel presently provides much of the lighting in India's rural regions. In terms of traditional fuels, the wood-and dung-burning chulhas, typically used in Indian homes, have an average efficiency of 8 percent.

3.1.1 OPTIONS TO REDUCE CO_2 EMISSIONS FROM THE RESIDENTIAL SECTOR

A number of opportunities exist to improve household energy efficiency. First, rural households can replace kerosene lighting with electric lighting. Second, LPG stoves, which operate at 50 to 60 percent efficiency levels, can replace the currently widespread biomass chulhas. Third, by using the dung presently used in these inefficient chulhas to produce biogas, a cleaner fuel with a higher utilization efficiency can be produced, and an excellent fertilizer material can be derived from the slurry produced by biogas plants.

3.2 TRANSPORT SECTOR

Rail and road travel currently dominate India's transport sector. In recent years, however, transport in India has witnessed a distinct shift away from rail and towards road modes. While railways carried 80 percent of all freight traffic in 1951, rail's share had dropped to 40 percent by 1985. The share of rail in passenger transport similarly has declined from 62 percent in 1951 to 20 percent today.

Trucks currently consume 33 percent of India's transport energy, **buses** 31 percent and **rail** 19 percent. **Cars** and **motorcycles** together account for only 11 percent of the energy consumed in this sector. Typical of most nations experiencing rapid growth in GDP, India witnesses a significant shift in the structure of transport between 1985 and 2025 (Table 4). Although the share of trucks in transport fuel demand expands, the shares of other public transport modes fall as private vehicle ownership increases.

The energy intensity of India's transport sector has declined considerably in recent years. While overall energy consumption in India's transport sector grew from 14.9 mtoe to 23.7 mtoe between 1971 and 1987, the energy intensity of this sector fell from 0.47 kilograms of oil equivalent (kgoe)/rupee (value added in 1980-81 prices) to 0.25 kgoe/rupee.

In the case of rail transport, the substitution of more efficient diesel and electric trains for energy-intensive steam locomotives contributed to the decline. However, the energy efficiencies of the more modern diesel and electric trains have not improved. Structural shifts have led to similar declines in the energy intensity of India's road transport.

Table 4
Transport Indicators

	1985	2025 High	2025 Low
Cars			
Number ('000)	1627	27065	27065
Per 1,000 persons	2.12	16	16
Fuel intensity (liters/km)	0.09	0.06	0.05
Distance traveled per car (km/yr)	12600	12000	12000
Motorcycles			
Number ('000)	5798	67663	67663
Per 1,000 persons	7.57	40	40
Fuel intensity (liters/km)	0.03	0.02	0.02
Distance traveled per m-cycle (km/yr)	6000	6000	6000
Trucks			
Number ('000)	848	11481	11481
Per 1,000 persons	1.11	6.79	6.79
Fuel intensity (liters/km)	0.25	0.20	0.17
Distance traveled per truck (km/yr)	40130	46150	46150
Buses			
Number ('000)	230	3114	3114
Per 1,000 persons	0.30	1.84	1.84
Fuel intensity (liters/km)	0.25	0.20	0.16
Distance traveled per bus (km/yr)	80100	82500	82500

According to the high emissions scenario, fuel intensity (liters/kilometer) declines by 38 percent and electricity intensity by 11 percent between 1985 and 2025. In the low emissions scenario, fuel and electricity intensities drop further (by 48 and 21 percent of the 1985 level respectively). Fuel intensities fall more dramatically in the low emissions scenario both because of shifts in the fuel mix and the introduction of better technologies.

Transport's share of value added doubles between 1985 and 2025. In 1985, rail transport amounted to a 1 percent share of India's GDP and air's share was negligible. In both scenarios, rail's share increases to 2 percent and air's share to 1 percent by 2025.

By 2025, energy use in India's transport increases more than eight-fold in the HE scenario (Table 5). Trucks account for one half and buses for one quarter of this growth in fuel demand. The LE scenario diminishes energy use by 17 percent of the HE level.

Accompanying this increase in transportation's energy demand, India's transport fuel mix changes. By 2025, coal use ceases. Oil satisfies 98 percent of the transport sector's delivered energy demand and electricity the remainder. In the LE scenario, oil comprises a slightly less significant share of the fuel mix. A higher integration of natural gas into India's transport fuel mix compensates for this diminished consumption of oil.

Commensurate with the increase in energy demand, the amount of carbon generated increases eight-fold. In 1985, India's transport sector generated 18 million tons of carbon. By 2025, transportation activities emit 143 million tons of carbon in the HE scenario. In the LE scenario, despite the 17 percent reduction in transport energy demand, carbon emissions only drop by 11 percent of the HE level.

Table 5
Transport Energy Use (PJ)

	1985	2025 High	2025 Low
Total	837	7112	5901
Coal	20%	0%	0%
Oil	78%	98%	93%
Natural Gas	0%	0%	5%
Electricity	1%	2%	2%

3.2.1 OPTIONS TO REDUCE CO_2 EMISSIONS FROM THE TRANSPORT SECTOR

India's plans to phase out all steam locomotives by the year 2000 should provide a first step towards improving transport efficiency. In addition, a number of other routes to improving the efficiency of the transport sector exist, including: reducing wheel-rail friction; limiting rolling resistance of wagons, coaches and locomotives; improving the aerodynamic profile and conversion efficiency of locomotives; implementing better operation and maintenance practices; and modifying vehicle designs.

A number of other improvements can be attained by working through other channels:

o Improvements in the condition of Indian roads and adherence to optimum speed limits can greatly improve fuel economy. Tables 6 and 7 reveal the effect of speed and surface quality of roads on fuel consumption;

o By reducing the weight of vehicles and making them more aerodynamic, significant fuel savings can be attained. The Maruti car, for example, gets 20 km/liter;

o In many cases, buses house engines designed for trucks. Carefully matching horse power ratings of engines with the weight of vehicles will reduce the waste of fuel for pulling relatively light vehicles.

o Multi-axled vehicles can carry heavier loads than traditional two-axled vehicles for the same amount of fuel.

o The quality of the diesel currently marketed for transport purposes should be upgraded. Currently specifications permit the inclusion of a greater normal percentage of heavier distillates in diesel which do not have time to burn completely in high speed engines.

Thus, more fuel is consumed. Alternative fuels, such as compressed natural gas and mixtures of petrol and alcohol are being investigated and their use will help reduce consumption of imported oil.

Table 6[6]
Effect of Speed on Fuel Consumption and Vehicle Efficiencies
(Fuel consumption expressed as a percentage of fuel consumption at optimum speed)

Speed (km/hr)	Ambassador (Car)	Premier (Padmini)	Mahindra (Jeep)	Tata (Truck)	Ashok Leyland (Heavy duty Truck)
10	239	126	187	298	145
15	--	--	--	203	120
20	134	105	139	156	108
25	--	--	--	131	102
30	106	100	104	115	100
35	--	--	--	--	--
40	100	100	102	102	102
50	105	102	119	102	108
60	117	106	148	108	118
70	134	111	188	122	132
80	156	118	--	140	132
90	183	126	--	162	--
100	214	135	--	--	--

Table 7[7]
Effect of Road Surfaces on Vehicle Efficiency
(Fuel consumption expressed as percentage of fuel consumption on the best surface)

Roughness (mm/km)	Surface Type	Ambassador	Premier	Mahindra	Tata	Ashok Leyland
3000	Asphaltic Concrete	100	100	100	100	100
5000	Premix Carpet	102	106	104	102	104
6000	Surface Dressing	102	108	105	103	106
8000	Good Waterbound Macadam	104	114	110	105	111
12000	Poor Waterbound Macadam	107	125	116	108	119
15000	Gravel/Earth	110	133	122	111	126

6 Government of India, *Recommendations of the Advisory Board on Energy* (Delhi, 1984).

7 Government of India, *Recommendations of the Advisory Board on Energy*, Ref. 6.

3.3 INDUSTRIAL SECTOR

All of India's **energy-intensive manufacturing** industries are growing rapidly. The production of aluminum, iron, steel, cement, fertilizers and textiles consume about 53 percent of the energy absorbed by this sector and comprise 19 percent of industrial value added. To date, however, these industries have used energy inefficiently. Thus, while the overall demand for energy in manufacturing will definitely increase in the future, great potential for energy efficiency improvements also exists.

Material output per capita almost doubles between 1985 and 2025 in most of the energy-intensive manufacturing processes (Table 8). Aluminum production per capita, the sole exception, increases four-fold. Even with these increases, the material produced per capita remains quite small compared to the per capita averages of other developing nations (Appendix B).

Table 8
Output & Intensity in India's Energy-Intensive Industries

	1985	2025 High	2025 Low
Steel			
Output ('000 tons)	12030	42000	42000
Decline in Fuel Intensity (%)		20%	30%
Decline in Elec. Intensity (%)		13%	22%
Cement			
Output ('000 tons)	32000	120000	120000
Decline in Fuel Intensity (%)		10%	20%
Decline in Elec. Intensity (%)		10%	15%
Paper			
Output ('000 tons)	1517	10000	10000
Decline in Fuel Intensity (%)		10%	20%
Decline in Elec. Intensity (%)		10%	15%
Fertilizer			
Output ('000 tons)	5756	30150	30150
Decline in Fuel Intensity (%)		15%	22%
Decline in Elec. Intensity (%)		10%	25%
Aluminum			
Output ('000 tons)	273	2878	2878
Decline in Fuel Intensity (%)		12%	20%
Decline in Elec. Intensity (%)		19%	33%
Textiles			
Output (million meters)	12498	60000	60000
Decline in Fuel Intensity (%)		15%	30%
Decline in Elec. Intensity (%)		19%	35%

According to the HE scenario, industrial energy demand increases almost seven-fold between 1985 and 2025 (Table 9). The expansion of **non-energy-intensive manufacturing** accounts for 68 percent of this growth and the rise of energy-intensive manufacturing accounts for another 28 percent. The LE scenario reduces industrial energy demand by 9 percent of the HE level. In both scenarios, the composition of the fuel mix shifts. Coal fuels a smaller portion of industrial activities and natural gas and electricity take on greater roles.

Table 9
Industrial Energy Use (PJ)

	1985	2025 High	2025 Low
Total	2404	14109	12778
Coal	63%	54%	53%
Oil	21%	23%	20%
Natural Gas	5%	10%	15%
Biomass	1%	1%	1%
Electricity	10%	13%	12%

Indian industry emitted 63 million tons of carbon in 1985. In the HE scenario, emissions rise to 369 million tons. The LE scenario reduces emissions by 41 percent of the HE level.

3.3.1 OPTIONS TO REDUCE CO_2 EMISSIONS FROM THE INDUSTRIAL SECTOR

While the reasons for the current low level of energy efficiency vary from industry to industry, three factors consistently contribute to the inefficiency of all of India's manufacturing processes: poor utilization of capacity; erratic power supplies from state grids; and lack of proper instrumentation and control systems.

Enhancing capacity utilization can serve as a powerful method for conserving energy. For example, when steel plants increase their capacity utilization by 10 percent, producing each ton of output requires an estimated 12.3 percent less energy for blast furnaces and 10.5 percent less energy for open hearth furnaces. The same increase in capacity utilization in the aluminum industry saves 4.2 and 2.3 percent of thermal and electrical energy respectively.

Quantitative restrictions on the supply of electric power and the poor quality of the supply impose severe infrastructural constraints throughout the industrial sector. Abrupt load shedding and voltage and frequency dips not only cause production losses but also increase the overall power requirements of industry. Specific examples for improving industrial efficiency in include:

1) The energy inputs for India's remaining wet cement production processes often are as much as 62 percent higher than similar processes carried out in industrialized nations (Table 10). Even India's more efficient dry processes still require between 38 and 41 percent more kWh of electricity to produce each ton of cement than in industrialized nations. By incorporating various technological innovations, such as pre-calcination systems and suspension preheaters, into the dry processes, not only can electricity and coal be used more efficiently, but lower qualities of coal and limestone can be used.

2) Throughout the textile industry, the use of antiquated machinery continues to inhibit improvements in manufacturing processes. As of 1985, almost all of India's composite mills were over 35 years old. Over half of the steam-generating systems relied on Lancashire boilers, with efficiencies of about 50 percent. With the introduction of forced

draft systems, operational improvement, the installation of new boilers and changes in grates, these systems can achieve an overall efficiency of 65 percent. Additionally, by installing high efficiency motors and by modernizing variable speed drives, these processes can conserve between 15 and 35 percent of the energy they currently expend.

3) A relatively modern paper mill in India consumes about 70 percent more heat energy and 7 percent more electrical energy to produce one tonne of paper than does a typical Scandinavian mill. Not only do Indian mills have lower efficiency levels, but additionally, they tend to rely more heavily on purchased fuel and power than do their counterparts in industrialized nations. Exploitation of the cogeneration potential and improvement of the boilers which recover black liquor, a by-product fuel obtained during the manufacture of paper, could reduce the dependence on purchased energy.

Table 10[8]
Comparison of Indian and International Energy Consumption in the Cement Industry (1983-84)

	Electrical (kWh/tonne of OPC)		Thermal (Gcal/tonne of OPC)	
	Indian*	International	Indian	International
Wet	114	70-104	1.7	1.2-1.3
Semi-dry	123	90-95	0.1	0.8-0.81
Dry	155	110-112	0.1	0.7-0.8

* Weighted average, where weights used are actual production.

3.4 AGRICULTURE SECTOR

In the 1960s, India launched a new agricultural strategy designed to meet the needs of its burgeoning population. Instead of trying to bring more land under cultivation, the strategy attempted to enhance the yield per acre. This scheme required substantially greater fertilizer inputs and relied on increased irrigation. As a result, Indian agriculture grew much more energy intensive. The regions that successfully implemented these improved measures (Punjab, Harayana and Western Uttar Pradesh) witnessed a remarkable growth in productivity.

The use of pumpsets for lifting water for irrigation requires more commercial energy than any other process within the agricultural sector. In 1985-86, India's irrigation required about 2 million electric and 3.5 million diesel pumpsets. As attempts to exploit untapped groundwater and to increase agricultural productivity continue in the future, irrigation will consume the bulk of the energy supply in the agriculture sector.

Providing exact estimates of the energy intensity of India's agriculture is difficult due to the heterogeneity of India's geography and climate and the diversity of agricultural methods used from region to region. An Inter-ministerial Working Group on Utilization and Conservation of

8 Bureau of Costs and Prices, *Energy Audit of the Cement Industry* (Delhi: Ministry of Industry, Government of India, 1986).

Energy recently indicated the potential to increase energy savings by 30 percent in diesel and electric pumpsets.[9] Included among the problems that continue to hinder efficiency improvements are that proper-sized pumpsets are seldom installed; that the water lift head range in which a pump operates efficiently often differs from actual operating conditions; and that pumps are not properly maintained.

In the HE scenario, agriculture's delivered energy demand increases from 250 PJ in 1985 to 870 PJ in 2025. The fuel mix shifts minimally in this scenario. Oil continues to satisfy 63 percent of agriculture's energy demand. The LE scenario reduces agricultural energy consumption to 750 PJ. The nature of the fuel mix changes as well. Oil's share drops to 58 percent and the shares of natural gas and electricity rise.

In 1985, agricultural activities led to the generation of 9 million tons of carbon. Carbon emissions increase in the HE scenario to 28 million tons. The LE scenario reduces that increase by about 9 percent of the HE level.

3.5 SERVICE SECTOR

India's service sector consumed less than 2 percent of the nation's delivered energy demand in 1985, but accounted for one third of India's GDP. The service sector's share of value added increases to 36 percent by 2025.

Fuel intensity declines by 10 percent and electricity intensity by 5 percent in the HE scenario. The LE scenario achieves further declines of 20 and 8 percent respectively.

Energy demand in the service sector increases seven-fold between 1985 and 2025 in the HE scenario. The LE scenario reduces this consumption level by 8 percent of the HE figure. The fuel mix shifts slightly by 2025. Coal use declines and the consumption of oil, natural gas and electricity increase (Table 11).

Table 11
Services Energy Use (PJ)

	1985	2025 High	2025 Low
Total	121	855	787
Coal	12%	3%	1%
Oil	51%	54%	52%
Natural Gas	1%	5%	7%
Electricity	36%	38%	40%

[9] Inter-Ministerial Working Group, *Report on Utilization and Conservation of Energy* (Delhi: Government of India, 1983).

Concurrent with the level of energy increases, carbon emissions from the service sector increase about seven-fold in both the high and low emissions scenarios. In the high instance, emissions increase from 4 million tons in 1985 to 29 million tons in 2025. The LE scenario reduces carbon emissions by about 6 percent of the HE figure, due to a lower overall energy consumption and a diminished reliance on carbon-intensive energy sources.

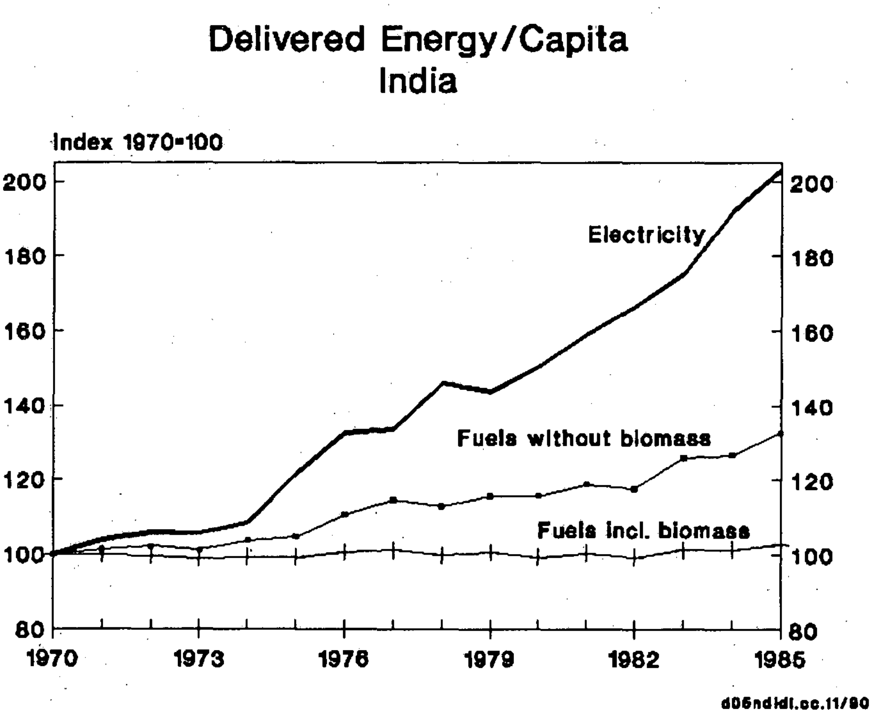
3.6 AGGREGATE DELIVERED ENERGY DEMAND

India's total delivered energy demand increases substantially between 1985 and 2025 (Table 12). In the HE scenario, delivered demand increases four-fold. The LE scenario reduces this figure by about 15 percent.

Table 12
Aggregate Energy Use (PJ)

	1985	2025	
		High	Low
Total	7080	29850	25310
Coal	25%	26%	27%
Oil	24%	41%	38%
Natural Gas	2%	5%	9%
Biomass	43%	16%	13%
Electricity	6%	12%	13%

Figure 3



Consistent with past trends, energy demand per capita (including biomass) grows from 9.2 gigajoule (GJ) in 1985 to 17.6 GJ in 2025 in the high emissions scenario (Figure 3). In the low emissions scenario, demand per capita remains slightly lower, at 15 GJ. Although energy consumption per capita more than doubles, Indian energy consumption per capita in the year 2025 still equals less than 40 percent of the world's 1985 average per capita.

Electricity consumption per capita increases at a far more rapid rate. Between 1985 and 2025, the electricity consumed per capita rises from 161 kWh to 606 kWh in the high emissions scenario. The low emissions scenario reduces consumption by 10 percent of the HE level.

4 ELECTRIC POWER GENERATION

India's overall electricity generation efficiency equalled 29 percent in 1985. Electricity generation and distribution remain significantly less efficient in India than in industrialized countries and slightly less efficient than in other developing countries. By 2025, the efficiency with which India generates electricity increases to 32 percent. The greatest efficiency improvements occur in the generation of electricity from natural gas. While in 1985 the generation efficiency for natural gas equalled 13 percent, by 2025, the efficiency increases to 40 percent with the construction of more combined-cycle plants.

In 1985, transmission and distribution losses in India, which averaged 22 percent, surpassed those of most other larger developing nations. While virtually all the other study countries witness substantial reductions in these losses over the next few decades, India's losses remain unchanged. The losses mostly stem from poor accounting and electricity theft. These problems are unlikely to disappear in the near future.

The fuel mix for electricity generation shifts similarly according to both scenarios; coal remains the dominant electricity source and natural gas and nuclear sources take on greater roles (Table 13).

Table 13
Electricity Generation (PJ)

	1985	2025 High	2025 Low
Total	565	4647	4176
Coal	62%	62%	62%
Natural Gas	1%	3%	3%
Nuclear & Geothermal	3%	4%	4%
Solar, Hydro, Other	34%	30%	30%

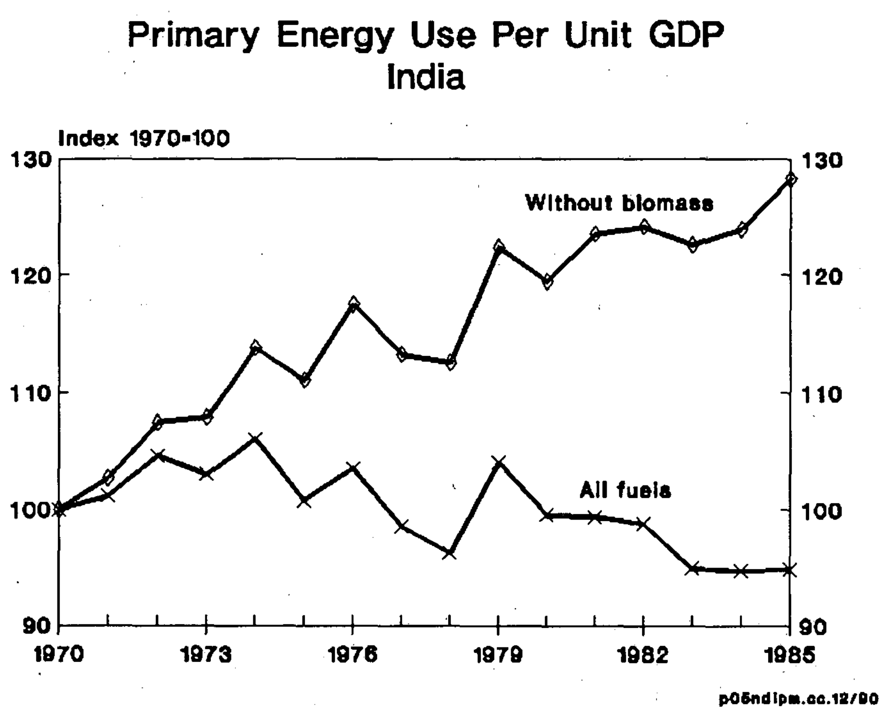
Total capital costs for producing electricity increase seven-fold according to the HE scenario. Because GDP also increases by a factor of seven over the observed time period, an equal share of India's financial resources will be required for electricity generation by 2025 according to the HE scenario. In the LE scenario, however, the capital costs increase six-fold from the 1985 level and, thus, a smaller portion of India's GDP is devoted to financing power plants.

India drew only about 6 percent of its delivered energy from electricity in 1985. However, the fuels used to produce electricity accounted for 28 million tons, or almost 25 percent, of India's carbon emissions that year. By 2025, carbon emissions from electricity production and generation grow substantially. In the HE scenario, electricity-related carbon emissions increase to 219 million tons. The LE scenario diminishes the amount of carbon produced by electricity use by 10 percent, to 197 million tons.

5 ENERGY INTENSITIES AND PRIMARY ENERGY SUPPLY

Between 1970 and 1985, the intensity of India's primary commercial energy use (MJ/US$) increased (Figure 4). In various sectors of the Indian economy, the intensity of energy use per unit of value added exceeds the intensity levels in most industrialized nations and many developing nations.

Figure 4



Three factors indicate that this rapid increase in energy intensity cannot be sustained. First, India is quickly depleting its reserves of non-renewable energy sources. Second, India increasingly lacks the funds for investing in the energy supply. Finally, India's environment cannot sustain a continued dependence on fossil fuels.

In 1985, India's primary energy intensity equalled 47 MJ/US$. According to the HE scenario, India's energy intensity decreases by 1 percent annually between 1985 and 2025. As a result, the intensity of energy use, including biomass, drops to 32 MJ/US$ by 2025. The LE scenario decreases the intensity of energy use by 1.4 percent annually between 1985 and 2025. In this scenario, the energy intensity is reduced to 27 MJ/US$ -- 42 percent below the 1985 level.

In the HE scenario, primary energy per capita increases by 1.9 percent annually, rising from 11.8 GJ in 1985 to 25.1 GJ in 2025. The LE scenario foresees a slower annual growth rate of 1.5 percent. Thus, the primary energy supply per capita is reduced to 21.7 GJ in 2025.

India's primary energy supply increases from 9.1 EJ in 1985 to 42.5 EJ in 2025, according to the HE scenario. The LE scenario reduces the primary energy supply by 14 percent of the HE level.

By 2025, the primary fuel mix shifts substantially (Table 14). In both scenarios, the share of every energy source increases except for the share of biomass, which declines considerably. In the low emissions scenario, oil comprises a smaller share of the fuel mix and natural gas and hydro maintain greater shares. In both scenarios, nuclear's share remains at 1 percent, but the absolute amount of nuclear energy consumed increases more than eleven-fold.

Table 14
Primary Energy Supply (PJ)

	1985	2025	
		High	Low
Total	9055	42505	36642
Coal	35%	42%	43%
Oil	21%	31%	28%
Natural Gas	2%	5%	7%
Biomass	34%	11%	9%
Nuclear & Geothermal	1%	1%	1%
Hydro, Solar, Other	7%	10%	11%

6 CARBON DIOXIDE EMISSIONS

In the HE scenario, while India's delivered energy demand increases just over four-fold between 1985 and 2025, carbon emissions increase over six-fold. By 2025, carbon emissions (excluding biomass) equal 703 million tons. While the low emissions scenario reduces these emissions by 13 percent of the HE figure, carbon emissions still increase more rapidly than energy demand.

In 1985, about 12.7 kilograms (kg) of carbon were emitted for each GJ of energy produced. In the HE scenario, the amount of CO_2 emitted for each GJ of energy produced increases to 16.5 kilograms by 2025. In the LE scenario, each unit of energy leads to the generation of 16.8 kilograms of CO_2.

Table 15
Carbon Emissions (Million Tons)

	1985	2025 High	2025 Low
Total	115	703	615
Residential	10%	13%	13%
Industry	55%	52%	53%
Transport	15%	20%	19%
Services	4%	4%	5%
Agriculture	7%	4%	4%
Losses	9%	6%	6%

CO_2 emissions per capita increase, but remain relatively low. In the HE scenario, emissions per capita rise from 150 kg/capita in 1985 to 416 kg/capita in 2025. The LE scenario reduces carbon emissions to 364 kg/capita.

The intensity of carbon emissions (tons/million US$) declines. In 1985, the production of every million dollars of GDP entailed the generation of 0.6 tons of carbon. In the HE scenario, the carbon/GDP ratio declines to 0.52 tons/million US$ by 2025. The LE scenario further reduces the C02/GDP ration to 0.46 tons/million US$.

While the share of residential energy demand in India's total energy demand drops in the HE scenario, due to the substitution of fossil fuels for biomass, the residential sector emits a growing share of India's carbon -- about 13 percent. In both scenarios the share of transport in India's overall generation of carbon increases by 2025, although the elimination of coal from the transport fuel mix partially tempers the growth of carbon emissions in this sector. Agriculture's share in total carbon emissions drops in both scenarios. While in 1985, the agriculture sector generated 7.4 percent of India's anthropogenic carbon emissions, by 2025, this share diminishes to 4 percent.

7 CONCLUSIONS

The greatest opportunities for reducing India's energy use lie in modifying household, industrial and transport practices. According to the HE scenario, India's industrial sector accounts for half of the growth in the nation's delivered energy demand between 1985 and 2025; transportation activities account for another 28 percent of the increase. The LE scenario achieves about 40 percent of its total energy savings in the residential sector, 29 percent in the industrial sector and 27 percent in the transport sector.

Greater conservation efforts and newer technologies can contribute to achieving the goals laid out by the low emissions scenario. The development of government policies that reward efficiency and penalize waste could help facilitate the implementation of these improvements as well.

In order to better its management of energy demand, India must review and modify its present energy-intensive strategies. In the residential sector, efforts should focus on encouraging the use of less carbon-intensive fuels and disseminating more efficient devices for cooking and other household end uses. Trade and industrial policies that encourage the domestic manufacture of highly energy-intensive products (e.g., aluminum, fertilizers, petro-chemicals and cement) need to be revamped. In particular, India must reduce tariffs/barriers, decontrol output prices and set tariffs at levels that reflect the real economic costs (opportunity costs) of energy supplies. Measures in the transport sector should emphasize promoting the electrification of India's railways and substituting rail modes for road, coastal shipping and inland waterway options.

As the LE scenario illustrates, improved energy efficiency in India can make a notable contribution to restraining emissions of of carbon dioxide. However, the proposed solutions will incur substantially high costs. Hence, on the domestic level, efficiency improvements need to be coupled with changes in the nation's economic structure that will allow India to earn some of the foreign exchange and capital necessary to cover the expense of these transitions. In addition, external assistance can help ensure the success of India's efforts. Since the entire global community would reap the rewards associated with India's efforts to abate the growth of carbon emissions, the Indian government would be justified in seeking international funds to help support such endeavors.[10]

[10] N. Mongia, J. Sathaye, R. Bhatia and P. Mongia, "Cost of Reducing CO_2 Emissions from India: Imperatives for International Transfer of Resources and Technologies," *Energy Policy*, to be published, November 1991.

INDONESIA

1 INTRODUCTION

The fifth most populous nation in the world, Indonesia consumed 1.7 exajoules (EJ) of energy in 1985 and generated 27 million tons of energy-related carbon dioxide. In coming decades, a range of factors -- population and economic growth, technological improvements and lifestyle changes -- will spur substantial increases in Indonesia's energy demand. As a result, Indonesia's carbon emissions[1] will expand manifold.

This paper examines current energy use and carbon emissions patterns in Indonesia and presents two long-term scenarios for the year 2025. In the high emissions (HE) scenario, Indonesia's government does not incorporate any explicit environmental policy measures into the nation's strategy for economic growth. Hence, energy use rises dramatically between 1985 and 2025 and, correspondingly, carbon emissions expand five-fold. In the low emissions (LE) scenario, Indonesia's government recognizes the atmospheric concentration of carbon dioxide to be a serious environmental concern and implements policy measures aimed at limiting carbon-intensive energy use. As a result, the LE scenario restrains the level of Indonesia's carbon emissions in 2025 to about 80 percent of the HE level.

2 GDP AND POPULATION GROWTH

Indonesia had 172 million inhabitants in 1985. Between 1970 and 1987, Indonesia's population increased at an average rate of 2.2 percent annually. Over this time period, the number of people living in Indonesia expanded by almost 50 percent.

Taking into account the strong family planning programs recently implemented in Indonesia, the World Bank has estimated that the Indonesian population will increase at an average rate of 1.8 percent per year between 1987 and 2000.[2] Assuming that these family planning programs continue to meet with success, this rate of growth declines even further at the beginning of the next century (Table 1).

Prior to the 1980s, Indonesia's major export was oil. The two oil price increases of the early 1970s led to substantial revenue increases in Indonesia and, thus, contributed to rapid economic growth in the decade that followed. Indonesia reinvested a large share of its oil revenues into the capital- and energy-intensive basic metals and chemical industries; as a result,

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[1] The term "carbon emissions" refers to carbon emissions generated by the production and consumption of commercial energy. CO_2 from biomass consumption and production is excluded unless otherwise specified.

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

industrial energy use increased by 13.5 percent annually between the early 1970s and the early 1980s.

The 1980s were a more turbulent time for the Indonesian economy. In 1983, oil prices suddenly dropped and Indonesia's economic growth rates fell to 2 percent per annum. In response, the nation diversified its economy. Indonesia shifted away from its almost exclusive reliance on oil export revenues and began to export other commodities, such as natural gas and agricultural products. With this transition, Indonesia created a more secure and balanced economic base, which was less vulnerable to the external price changes of individual commodities. By 1989, growth rates picked up once again, averaging 6 percent per year.

Taking these recent changes into account, Indonesia's economy grows at a moderate rate over the next 40 years (Table 1). Between 1985 and 2025, Indonesia's GDP expands more than three-fold. At US$ 510 in 1985, Indonesia's GDP per capita is one of the lowest among all South East Asian countries. By 2025, GDP per capita in Indonesia almost doubles.

The mix of activities that comprise GDP shifts by 2025. Over the past two decades, activities in Indonesia's industrial, transport and service sectors have increased and agricultural operations have declined (Figure 1). Both the high and low emissions scenarios assume that these past trends continue over the next four decades.

Figure 1

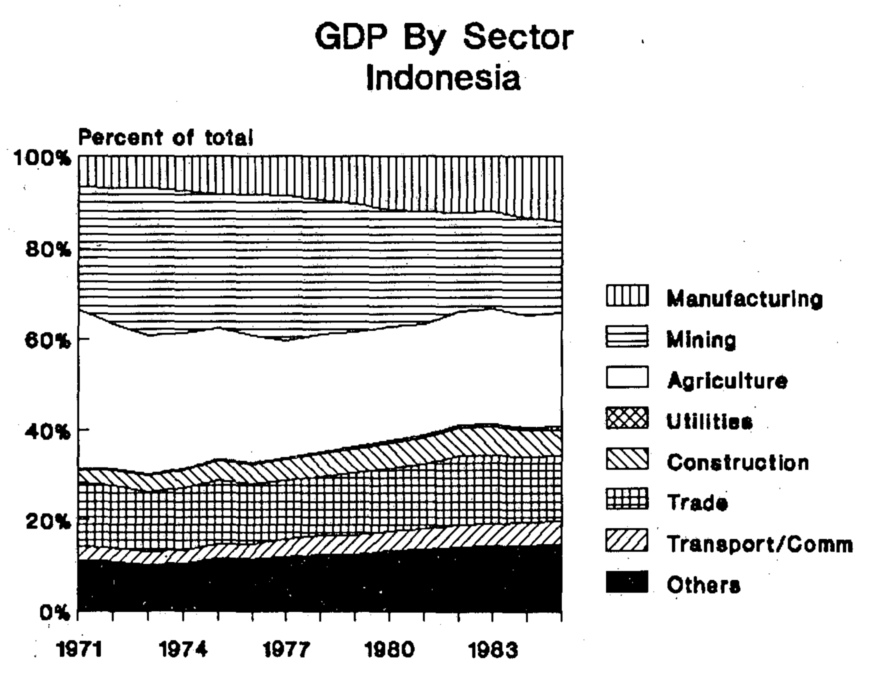

Table 1
GDP and Population Growth

	1985	2025	AAGR
Population (Mn)	165	267	1.2%
GDP (Bn US$)	84	280	3.0%
Industry	37%	40%	
(Manufacturing	13%	25%)	
Transport	6%	10%	
Agriculture	24%	15%	
Services	33%	35%	
GDP per capita (US$)	510	1050	1.8%

AAGR = Average annual growth rate

3 SECTORAL ANALYSIS AND CARBON EMISSIONS

At present, Indonesia's residential sector relies heavily on biomass, a fuel resource which is comparatively non-carbon-intensive, but highly inefficient. As a result, Indonesia's households consume the largest share of the nation's energy supply, but emit relatively low levels of commercial energy-related carbon. While Indonesia's fossil fuel-based industrial sector consumes 44 percent less total energy than households, it generates 29 percent more commercial energy-related carbon. By 2025, the share of the residential sector in total energy use and carbon emissions declines substantially as Indonesian households come to substitute modern fuels for biomass. Simultaneously, the growth of Indonesia's transportation activities leads to a dramatic rise in this sector's share of energy and carbon emissions (Tables 2 and 10).

Table 2[3]
Delivered Energy Use (PJ)

	1985	2025	
		High	Low
Total	1670	7134	6131
Residential	45%	21%	21%
Industrial	25%	24%	25%
Transport	20%	45%	44%
Services	1%	1%	1%
Agriculture	8%	9%	9%

3.1 RESIDENTIAL SECTOR

At present, about one quarter of Indonesia's urban residents live in Jakarta. Between 1965 and 1985, the share of the Indonesian population living in cities rose from 16 to 26 percent. Before 1980, the size of Indonesia's urban population increased at an average annual

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

rate of 4.7 percent. During the last decade, however, slower rates of economic growth have stemmed the flow of rural to urban migration and the rate has fallen to about 2.3 percent annually. According to both scenarios, the pace of urban population growth in Indonesia continues to exceed the pace of overall population growth. As a result, 40 percent of the Indonesian population lives in cities by 2025.

In 1985, urban households in Indonesia had 4.6 members on average and rural homes had approximately 5 members. By 2025, both urban and rural households average 4 members. Because the population continues to grow while household sizes gradually shrink, the number of urban households in Indonesia increases between 1985 and 2025 from 9.4 to 26.7 million and the number of rural households increases from 24.4 to 40 million. This substantial growth in the number of households implies an increased demand for appliances and residential energy use by 2025.

Indonesia lacks a national electricity grid. The nation consists of a string of islands -- a geographical set up which interferes with efforts to centralize electricity generation. In the past, industries sprouting up in smaller areas have provided energy to the towns that support their operations. Since the early 1980s, however, the government has made extensive efforts to extend electrical capacity to both urban and rural areas. As a result, a rapidly growing portion of Indonesia's population has gained access to electricity. Between 1981 and 1985, the share of electrified urban households in Indonesia increased from 41 to 72 percent. In contrast, only 8 percent of Indonesia's rural households had access to electricity in 1985. Both scenarios assume that current trends continue and that an increasing share of Indonesian households gain access to electricity. By 2025, virtually all of Indonesia's urban households (98 percent) and 45 percent of Indonesia's rural households have electricity.

Urban and **rural households** consume significantly different types and quantities of fuel. The average urban household in Indonesia consumes four times more modern fuels and 15 times more electricity than the average rural household. Rural homes, however, consume nine times more biomass. Because biomass fuels are much less efficient than modern fuels, most rural households require larger fuel inputs than urban households.

The average urban household consumes 19.4 GJ of fuel and 1.8 GJ of biomass.[4] In terms of modern fuel use, urban residents derive most of their household energy supply from kerosene. However, kerosene prices have risen sharply since 1981 and, as a result, kerosene consumption has declined. Electricity and LPG have increasingly replaced kerosene in recent years. Low-income households in cities still draw most of their energy from biomass.

Rural homes consumed about 5.3 GJ of fuel and 16.5 GJ of biomass in 1985. While biomass provides the bulk of the rural energy supply, kerosene has comprised a growing share of the rural fuel mix in recent years.

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[4] World Bank, *Indonesia: Urban Household Energy Survey* (Washington, D.C.: Energy Sector Management Assistance Program, February 1990).

Rising income levels and increased electrification resulted in a wider saturation of **appliances** in Indonesia during the 1980s. About 60 percent of all high-income households have color televisions, about 47 percent have refrigerators and about 35 percent have water pumps. Of Indonesia's low-income households, about 5 percent have color TVs and about 2 percent have refrigerators and water pumps.

At present, urban households account for most of the nation's electricity demand. While the average electrified urban home consumed 782 kWh of electricity in 1985, the average electrified rural home consumed only 50 kWh of electricity that year. Throughout Indonesia, households have increasingly substituted electricity for kerosene to power lighting and for charcoal to fuel irons. According to the HE scenario, by 2025, the amount of electricity consumed by each electrified urban household increases to 1095 kWh, which is equivalent to the amount currently consumed by Indonesia's high-income households. The LE scenario reduces electricity demand in electrified urban households by 14 percent. According to both scenarios, the amount of electricity consumed by each electrified rural household doubles between 1985 and 2025.

While fuel and electricity intensities (expressed in GJ/household and kWh/household respectively) increase in both urban and rural regions between 1985 and 2025, biomass intensity (GJ/household) declines. In urban households, fuel intensity increases by 10 percent by 2025 and electricity intensity increases by 40 percent. In the LE scenario, more efficient appliances penetrate the urban markets and, thus, the intensity of electricity use only increases by 20 percent of the 1985 level. Biomass intensity drops by 50 percent in both scenarios as traditional fuels take on a less essential role in the fuel mix.

In rural homes, fuel intensity increases by 20 percent in the HE scenario. In the LE scenario, fuel intensity remains flat. A surge in the use of rural electricity use leads to an 100 percent increase in electricity intensity. In rural areas, biomass intensity diminishes by 20 percent in the HE scenario. In the LE scenario, the intensity of biomass use declines further, by 40 percent of the 1985 level, as more efficient stoves penetrate the market.

Residential energy demand doubles between 1985 and 2025 according to the HE scenario (Table 3). The greater availability of appliances and electricity contribute to this rise. The low emissions scenario achieves greater efficiency measures and, as a result, limits the 2025 residential energy demand by 13 percent of the HE level.

The composition of Indonesia's residential fuel mix shifts between 1985 and 2025 (Table 3). Biomass still satisfies the bulk of the residential energy demand in the HE scenario, but its share drops dramatically. Oil also plays a lesser role. The amounts of electricity, gas and coal consumed increase in both relative and absolute terms.

In trying to reduce residential carbon emissions, the LE scenario's fuel mix appears quite different. Natural gas, not biomass, provides the largest share of energy to households in 2025 and the shares of biomass, oil and coal in the residential fuel mix drop below their HE levels.

Table 3
Residential Energy Use (PJ)

	1985	2025 High	2025 Low
Total	752	1489	1299
Coal	0%	14%	6%
Oil	41%	28%	15%
Natural Gas	1%	14%	39%
Biomass	56%	37%	32%
Electricity	3%	7%	7%

Between 1985 and 2025, carbon emissions from Indonesia's residential sector increase from 7 to 20 million tons in the HE scenario. As commercial fuels play an increasing role in household energy use, residential carbon emissions almost triple even though energy demand less than doubles. In the low emissions scenario, carbon emissions also increase more rapidly than energy demand. Total emissions are reduced, however, by 20 percent of the HE total to 16 million tons. A lower reliance on oil and coal, the most carbon-intensive fuels, and greater efficiency gains serve to decrease carbon emissions.

3.2 TRANSPORT SECTOR

Over the past two decades, the growth rate of energy use in Indonesia's transport sector increased rapidly. This growth shows no signs of slowing down.

Between 1975 and 1980, the annual growth rate of Indonesia's vehicle fleet averaged a soaring 15.3 percent. Between 1980 and 1985, the growth rate declined somewhat to 11.4 percent. Despite its rapid expansion, Indonesia's vehicle fleet is quite small relative to the tremendous size of the nation's population; only 41 vehicles exist for every 1,000 members of the Indonesian population.

The numbers of motorcycles, trucks and buses in Indonesia have increased more rapidly than the number of cars. In 1975, motorcycles comprised 66 percent of the fleet, cars 21 percent, trucks 11 percent and buses 2 percent. By 1985, cars comprised only 15 percent of the total vehicle population, while the relative number of all other vehicle types increased.

Indonesia had a fleet of 989 thousand **cars** and 4.8 million **motorcycles** in 1985. As income levels increase, people tend to buy more cars and fewer motorcycles. Both South Korea and Taiwan exemplify this pattern; these two countries presently have a slightly higher proportion of cars to motorcycles than Indonesia is predicted to have in 2025.

Based on the higher income projections for 2025, Indonesia's car fleet increases more rapidly than its motorcycle fleet. In the high emissions scenario, the number of cars increases over twelve-fold, to almost 12 million in 2025, and the number of motorcycles increases under six-fold, to about 26 million. Thus, the number of cars per capita rises from 6 to 45 per 1,000 persons between 1985 and 2025 and the number of motorcycles increases from 29 to 100 per 1,000 persons. In the LE scenario, the car fleet grows less rapidly. The size of the car fleet is reduced by 22 percent of the HE level. The number of motorcycles, however, increases by 25 percent of the HE figure to compensate.

Currently, the size of Indonesia's **truck** fleet almost equals the size of its car fleet. Trucks account for 46 percent of transport fuel use. By 2025, the truck population increases over five-fold. The number of trucks per 1,000 persons increases from 5.3 in 1985 to 18.2 in 2025. Due to the more rapid growth of other vehicle modes, however, the share of trucks in transport energy falls to 19 percent by 2025 according to the HE scenario and to 16 percent according to the LE scenario.

Buses tend to saturate the Indonesian transport sector at a much slower pace than trucks, cars and motorcycles. In 1985, Indonesia had a bus fleet of 231,000 or 1.4 buses per 1,000 persons. About 43 percent of these buses were located in Jakarta. While buses constituted only 25 percent of Jakarta's vehicle fleet and absorbed only 18 percent of Indonesia's transport energy use, they carried 67 percent of the city's passenger traffic. In the high emissions scenario, the proportion of passenger traffic carried by buses decreases by 2025 as the car and motorcycle populations grow. The number of buses per capita increases by 2025, however, to 4.8 buses per 1,000 people.

While each truck travels slightly further in 2025, for all other vehicles, travel distances decline. Due to increased population densities, changes in vehicle uses and less frequent use of each vehicle, travel distances drop by 7 percent for buses, by 20 percent for cars and by 17 percent for motorcycles. In the LE scenario, travel distances decline less for each vehicle type because the size of the overall vehicle fleet expands more slowly, therefore, requiring greater use of each available vehicle.

Currently, fuel intensity (liters/kilometer) in Indonesia is quite high (Table 4). Fuel efficiency improves considerably by 2025. In the HE scenario, the fuel intensity of cars declines by 50 percent between 1985 and 2025 and the fuel intensity of motorcycles drops by 40 percent. Fuel intensities for trucks and buses diminish by 30 percent. The LE scenario achieves further intensity declines of 60 percent of the 1985 level for both cars and motorcycles and of 50 percent of the 1985 level for both trucks and buses.

Railroads and **ships** each carry about 10 percent of Indonesian passenger and freight traffic. Ships account for about 1.5 percent of value added, **planes** for 0.8 percent and railroads for 0.2 percent. By 2025, Indonesia relies more heavily on all three of these transport modes. Both water and domestic air transports' shares of GDP increase to 2.5 percent and rail's share increases to 1.5 percent.

In 1985, Indonesia's transport sector consumed 333 PJ of energy. Between 1985 and 2025, transport's energy demand increases almost ten-fold in the HE scenario. The growth of water, air and truck travel modes account for 42, 29 and 16 percent of this increase respectively.

The fuel mix shifts from an exclusive reliance on oil in 1985 to a growing dependence on natural gas (9 percent) and biomass-based alcohol (3 percent) in 2025. The low emissions scenario reduces total fuel demand by 16 percent of the HE figure in 2025. Despite the tremendous growth in energy consumption for air travel between 1985 and 2025, the LE scenario shows that the opportunities for the most substantial energy savings in this sector lie in improving water and truck efficiencies. The LE scenario integrates a larger share of natural gas into the fuel mix (10 percent) and decreases transport's reliance on oil.

Table 4
Transport Fuel Intensity
(Liters/100 Kilometers)

	1985[5]
Motorcycles	2.2
Cars	10.0
Bemo/Bajaj	5.0
City Buses	45.0
Intercity Buses	30.0
Van, Microbus	28.5
Van, Minibus	10.0
Pickup Trucks	12.5
Medium Trucks	28.5
Large Trucks	40.0

As fuel demands ascend, transport's carbon emissions skyrocket. In 1985, Indonesia's transport sector generated 6 million tons of carbon. By 2025, this figures expands to 58 million tons. Transport's ten-fold increase in carbon emissions far surpasses emissions increases in any of Indonesia's other sectors. The low emissions scenario, with its diminished energy consumption, reduces the level of carbon emissions in 2025 by 16 percent. Even in the low emissions scenario, however, the 49 million tons of carbon emitted in 2025 represents a substantial increase above the 1985 level.

3.3 INDUSTRIAL SECTOR

Industry consumed one quarter of Indonesia's energy demand in 1985. Indonesia has extensive deposits of several major minerals -- including tin, bauxite, nickel and copper -- which it has exported in varying amounts for the past two decades. The country also produces fertilizers, petrochemicals, cement and paper products. Just recently, Indonesia began to manufacture aluminum.

[5] Limited data exists on the amount of fuel consumed by certain types of vehicles in Indonesia. These estimates assume an average value of 25 liters/km for trucks and 30 liters/km for buses.

The industrial sector, which includes mining, manufacturing, construction and utilities, comprised 37 percent of the nation's GDP in 1985. **Mining** has gradually come to dominate the other sub-sectors. Between 1970 and 1985, mining's share of GDP rose from 10 to 17.4 percent. Manufacturing's share of value added also increased over this period, although less rapidly, rising from 8.6 percent in 1970 to 13.2 percent in 1985.

Between 1985 and 2025, the structure of the industrial sector continues to shift. Manufacturing activities increase -- particularly those that make use of the nation's wealth of mineral resources. By 2025, manufacturing's share of GDP expands to 25 percent. In the high emissions scenario, Indonesia continues to rely more heavily on energy-intensive industries and, as a result, the share of energy-intensive manufacturing in GDP increases from 5.8 percent in 1985 to 10 percent in 2025. The low emissions scenario limits the share of energy-intensive manufacturing to 8 percent of the GDP in 2025.

Indonesia's industry sector has only made limited efficiency gains in recent years.[6] In 1985, industrial fuel intensity in Indonesia equalled 10.78 GJ/US$ and electricity intensity totaled 507 kWh/US$. Based on historical patterns and the assumed future growth of energy-intensive industries, the high emissions scenario indicates that the intensities of fuel and electricity use (GJ/US$ and kWh/US$) rise by 10 and 15 percent respectively by 2025. The low emissions scenario, however, manages to reduce the intensity of fuel use to slightly below the 1985 figure and to moderate the increase in electricity intensity.

Rising at a rate of 3.4 percent annually, industrial energy demand increases four-fold between 1985 and 2025 in the HE scenario. The growth of **energy-intensive** and **non-energy-intensive** manufacturing account for 51 and 36 percent of this increase respectively. The LE scenario moderately reduces industrial energy demand by 11 percent of the HE level (Table 5). About 97 percent of the savings achieved in the LE scenario result from modifications in energy-intensive manufacturing.

Table 5
Industrial Energy Use (PJ)

	1985	2025 High	2025 Low
Total	424	1732	1541
Coal	3%	20%	9%
Oil	37%	27%	26%
Natural Gas	39%	30%	41%
Biomass	7%	10%	9%
Electricity	13%	14%	15%

6 Since data on fuel use and corresponding physical output of various products could not be reconciled, this study analyzes industrial energy use based on the intensity of fuel use per unit of value added in industry's three major sub-sectors: energy-intensive manufacturing; non-energy-intensive manufacturing; and mining, construction and utilities.

The Indonesian government has begun to encourage its cement and steel industries to derive their energy from coal so that the limited supplies of oil and natural gas can be channeled to the household and transport sectors. As a result, the composition of the industrial fuel mix changes between 1985 and 2025 (Table 5). In the high emissions scenario, coal's share increases and the shares of oil and natural gas in the industrial energy mix decline. The low emissions scenario maintains a much less carbon-intensive industrial fuel mix. This scenario reduces the absolute amount of coal consumed by 60 percent, further suppresses oil demand and compensates by increasing the absolute amount of natural gas consumed.

The rapid expansion of industrial energy use and coal's growing role in industry has major implications for carbon emissions. In the HE scenario, industry's carbon emissions jump from 9 million tons in 1985 to 33 million tons in 2025. The low emissions scenario reduces carbon emissions by 15 percent to 27 million tons in 2025.

3.4 SERVICE SECTOR

Indonesia's service sector, which encompasses a range of activities including trade, finance and government operations, consumed 24 PJ of energy in 1985. The service sector comprises about 33 percent of Indonesia's GDP, but consumes only 1 percent of the nation's delivered energy demand. By 2025, services' share of GDP increases to 35 percent.

The service sector derived 60 percent of its delivered energy demand from electricity in 1985 and 32 percent from natural gas. Oil satisfied the rest of the demand in this sector. The proportions of various fuels in the energy mix remain relatively steady between 1985 and 2025. In both scenarios, however, oil's and electricity's shares decline slightly and natural gas's share grows.

Between 1985 and 2025, fuel intensity (GJ/US$) declines by 5 percent and electricity intensity (kWh/US$) drops by 15 percent in the HE scenario. The low emissions scenario achieves greater efficiency gains; in this scenario, fuel and electricity intensities drop by 10 and 25 percent respectively between 1985 and 2025.

By 2025, services' energy requirements increase to 91 PJ in the HE scenario. The LE scenario reduces this demand by 9 percent. The service sector emitted 1 million tons of carbon in 1985. According to both scenarios, services' emissions increase to 2 million tons by 2025.

3.5 AGRICULTURE SECTOR

While today agriculture still plays a significant role in Indonesia's economy and energy use, with the expansion of industrial- and service-related activities in recent years, agriculture's importance has steadily declined. Between 1985 and 2025, agriculture's share of GDP falls from 24 to 15 percent.

As mechanization proceeds and more farmers rely on irrigation and on-farm machinery, the intensity of agricultural fuel use (GJ/US$) increases by 200 percent. The low emissions scenario reduces the increase in fuel intensity to 150 percent of the HE level. In both scenarios, the intensity of biomass use drops by 50 percent.

Agricultural energy demand increases four-fold in the HE scenario. The LE scenario limits the amount of fuel used for agriculture in 2025 by 15 percent of the HE level. Diesel, which is used for pumping water and powering farm machinery, dominates the agricultural fuel mix at present. In the high emissions scenario, oil continues to satisfy the bulk of the energy demand in 2025. However, natural gas is introduced into the fuel mix after 1985 and, by 2025, natural gas satisfies over one quarter of agricultural energy demand. In the LE scenario, agriculture relies even more heavily on natural gas (Table 6).

Table 6
Agricultural Energy Use (PJ)

	1985	2025	
		High	Low
Total	138	620	525
Oil	67%	65%	45%
Natural Gas	0%	28%	45%
Biomass	33%	8%	9%

While agricultural energy demand increases four-fold between 1985 and 2025, carbon emissions increase five-fold. In the HE scenario, agricultural carbon emissions rise from 2 to 10 million tons. The low emissions scenario reduces the amount of carbon generated by agricultural activities by 20 percent of the HE level.

3.6 AGGREGATE DELIVERED ENERGY DEMAND

Between 1985 and 2025, Indonesia's total delivered energy demand rises almost four-fold according to the HE scenario. The low emissions scenario reduces total demand by 14 percent (Table 7).

Table 7
Aggregate Delivered Energy Use (PJ)

	1985	2025	
		High	Low
Total	1670	7134	6131
Coal	1%	8%	4%
Oil	53%	57%	51%
Natural Gas	11%	17%	28%
Biomass	30%	12%	11%
Electricity	5%	6%	6%

The share of biomass in the aggregate fuel mix declines substantially over the observed time period (Table 7). In the HE scenario, the share of every other type of fuel in the mix increases. In absolute terms, these small relative increases translate into substantial growth in the HE scenario. Most notably, the absolute amount of coal consumed expands by a factor of 37. The low emissions scenario mitigates the amounts of coal and oil consumed by Indonesia by satisfying more of the energy demand with natural gas.

4 ELECTRICITY GENERATION

Electricity accounted for only 5 percent of Indonesia's delivered energy demand in 1985. A state-owned company, PLN, manages all of Indonesia's centralized power generation. Only during the last decade has Indonesia's government made extensive efforts to make electricity widely available. To date, urban households have benefitted the most from these efforts. The government is in the process of implementing measures to increase the rural electricity supply.

Because Indonesia built most of its power plants recently, electricity is generated fairly efficiently. In 1985, generation efficiency surpassed 30 percent. By 2025, the efficiency of electricity generation improves to 39 percent in the HE scenario and further to 41 percent in the LE scenario. The greatest efficiency gains stem from the construction of more combined-cycle plants to generate electricity from natural gas.

Transmission and distribution (T&D) losses, however, remain quite high. Between 1975 and 1985, T&D losses averaged between 21 and 25 percent. By 2025, these losses fall to 15 percent.

Electricity generation increases four-fold in the high emissions scenario (Table 8). Between 1985 and 2025, electricity generation increases at a rate of 3.5 percent annually while fuel use for electricity generation increases at a rate of only 2.9 percent annually. Improvements in the generation, transmission and distribution of electricity account for the lower level of inputs required to produce each unit of delivered electricity demand. The low emissions scenario limits the amount of electricity generated in 2025 by 7 percent. This reduction stems largely from further improvements in generating efficiencies, which result from a switch to natural gas-based combined-cycle units.

In 1985, oil and hydro served as the nation's primary electricity sources. The Indonesian government has recently expressed its desire to reduce the amount of oil used for electricity generation. In response, PLN plans to increase its use of coal. In Java, for example, PLN plans to increase the share of coal in the island's installed electrical capacity from 26 percent today to 77 percent by 2004.[7]

[7] Embassy of the United States of America, *The Petroleum Report: Indonesia* (Jakarta, October 1989).

Taking these intentions into account, the composition of fuels used to generate electricity changes considerably between 1985 and 2025. According to the HE scenario, oil's share falls dramatically. To compensate, the shares of coal, natural gas and hydro all expand. In the LE scenario, oil's share falls even further, coal's share increases less dramatically and natural gas's share rises further (Table 8).

Table 8
Electricity Generation (PJ)

	1985	2025 High	2025 Low
Total	116	472	439
Coal	8%	20%	15%
Oil	52%	19%	14%
Natural Gas	10%	20%	30%
Biomass	0%	1%	1%
Nuclear & Geothermal	1%	5%	5%
Hydro, Solar, Other	29%	35%	35%

Plants that generate power from coal have higher capital costs than those that generate power from either oil or natural gas. Thus, in the HE scenario, which emphasizes coal electricity generation, the total capital costs loom at $21 billion in 2025. The LE scenario saves 2.2 US$ billion in capital costs by relying less heavily on coal. However, the higher costs of procuring the additional natural gas and/or oil supplies in the LE scenario might offset the lower capital costs.

5 ENERGY INTENSITY AND PRIMARY ENERGY SUPPLY

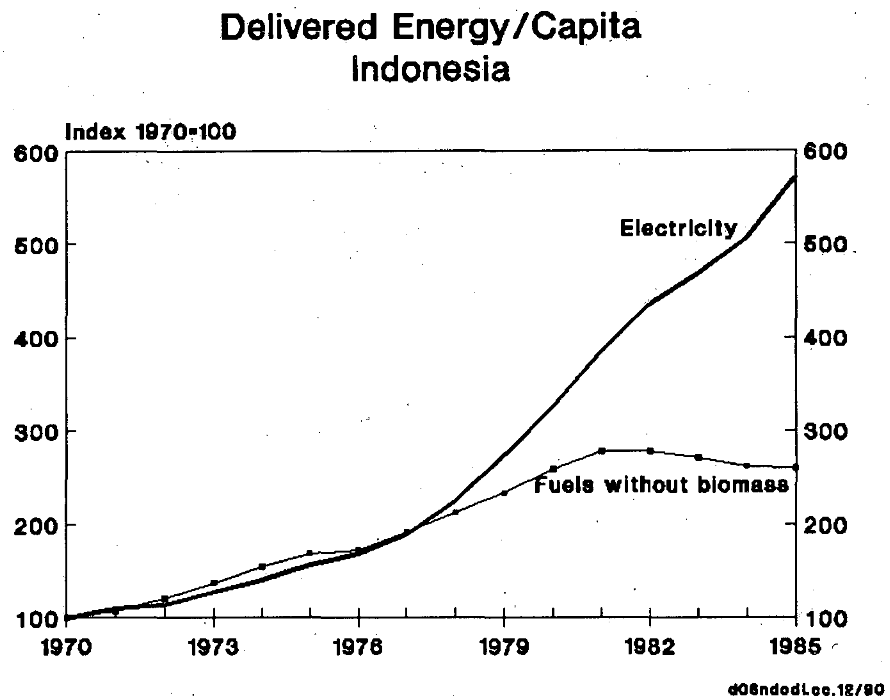
Indonesia's primary energy supply increases from 2035 PJ in 1985 to 8343 PJ in 2025 according to the HE scenario. This increase in primary energy supply is almost directly proportional to increases in delivered energy demand. The LE scenario reduces the primary energy supply by 15 percent of the HE level (Table 9).

Table 9
Primary Energy Supply (PJ)

	1985	2025 High	2025 Low
Total	2035	8343	7105
Coal	2%	11%	6%
Oil	57%	55%	49%
Natural Gas	11%	18%	29%
Biomass	24%	11%	10%
Nuclear & Geothermal	0%	1%	1%
Hydro, Solar & Other	5%	5%	5%

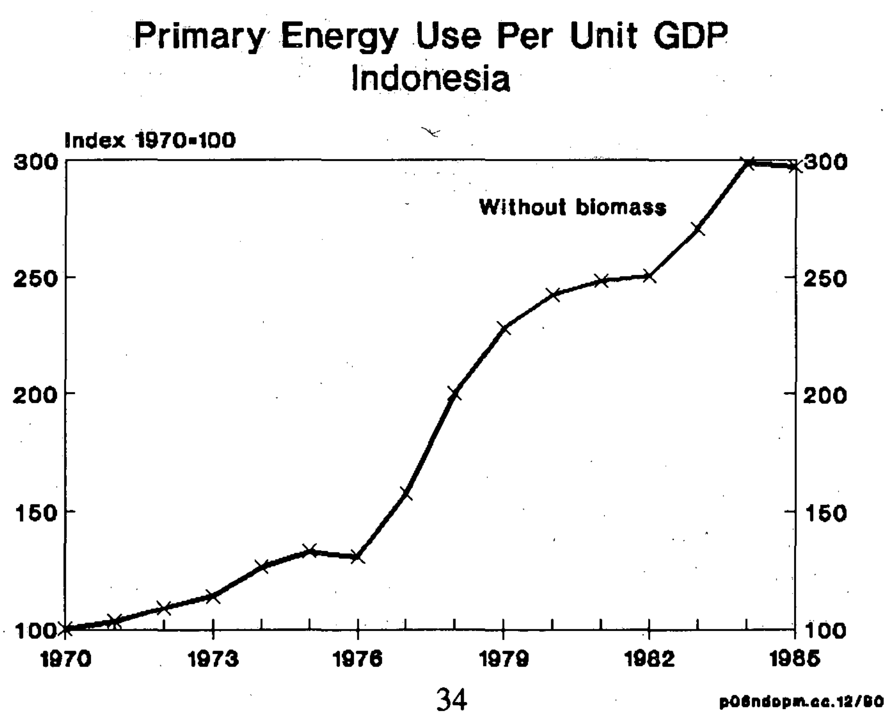
Between 1970 and 1985, delivered energy demand per capita more than tripled (Figure 2). In accordance with this historical trend, primary energy per capita rises substantially in coming years. In the HE scenario, primary energy per capita increases from 8 GJ in 1985 to 32 GJ in 2025. In the LE scenario, primary energy per capita falls by 16 percent of the HE level to 27 GJ.

Figure 2



Between 1970 and 1985, the energy/GDP ratio increased by 3.7 percent annually, largely because of Indonesia's continued investments in energy-intensive industries (Figure 3). As a result, by 1985, producing each dollar of GDP required 73 percent more energy than in 1970.

Figure 3



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In the eyes of the Indonesian government, the nation's energy resources endow it with a comparative advantage. In accordance with this view, both scenarios assume that Indonesia continues to exploit its energy resources over the next few decades. Although the energy/GDP ratio continues to grow in coming years, the rate of growth diminishes. In the HE scenario, more efficient modern fuel types increasingly replace biomass fuels and efficiency improves. Thus, the energy/GDP ratio increases by only 1 percent annually between 1985 and 2025. In the LE scenario, the growth rate slows down further to 0.6 percent annually. According to the LE scenario figures, the amount of energy required to produce each dollar of GDP increases by 34 percent over the entire time frame.

6 CARBON EMISSIONS

Between 1985 and 2025, Indonesia's total fuel consumption increases, particularly to meet the substantially higher energy needs of industry and transport. Simultaneously, Indonesia's fuel mix grows more carbon intensive. Thus, carbon emissions increase five-fold in the HE scenario. The LE scenario reduces total carbon emissions by 18 percent of the HE level. Notably, as carbon emissions from the transport sector increase by a factor of 10 in the HE scenario, transport's share in total carbon emissions jumps from 24 percent in 1985 to 45 percent in 2025 (Table 10).

Table 10
Carbon Emissions (Million Tons)

	1985	2025	
		High	Low
Total	27	131	107
Residential	27%	15%	15%
Industrial	33%	25%	25%
Transport	24%	45%	46%
Services	4%	2%	2%
Agriculture	7%	8%	7%
Losses	6%	6%	6%

The amount of carbon generated for each unit of energy produced rises from 13.1 kilograms per gigajoule (kg/GJ) in 1985 to 15.7 kg/GJ in 2025 in the HE scenario. In the LE scenario, the increased role of natural gas and renewable resources in the fuel mix leads to lower carbon emissions per unit of energy of 15.0 kg/GJ.

Carbon emissions per capita more than triple in the high emissions scenario, reaching 491 kg in 2025. The low emissions scenario reduces emissions per capita to 400 kg per capita.

In the high emissions scenario, the amount of carbon generated for each dollar of GDP increases after 1985. The CO_2/GDP ratio rises from 0.44 to 0.54 kg/US$ between 1985 and 2025. In the LE scenario, CO_2/GDP ratio does not increase beyond the 1985 level by 2025.

7 CONCLUSIONS

Indonesia's unique development pattern, based largely on the nation's energy-rich resource base, has been characterized by far more rapid increases in energy use than in GDP in the past. Unlike most of the other study countries, Indonesia continues to experience this high energy use/GDP ratio in coming years.

According to the scenarios, the expansion of energy-intensive manufacturing and rising levels of transport activities (particularly among air, water and truck modes) account for the bulk of the increase in fuel demand and carbon emissions between 1985 and 2025. In the residential sector, the substitution of modern fuels for biomass restrains the growth of fuel demand, but leads to higher levels of commercial energy-related carbon emissions.

The greatest potential for reducing carbon emissions appears to lie in shifting the current patterns of energy use in Indonesia's industrial and transport sectors. These two sectors combined account for three quarters of the carbon savings achieved in the LE scenario. In order to reduce emissions to this degree, Indonesia would have to implement measures aimed primarily at promoting the use of natural gas and disseminating more energy-efficient technologies throughout the industrial and transport sectors.

Further analysis suggests that Indonesia also could minimize its CO_2 growth by adopting a different macro-economic strategy. This approach would require that Indonesia shift away from its reliance on export-based earnings and focus on enhancing its domestic technological capacity and developing its agriculture sector. Such an approach, coupled with the deregulation of energy prices, would reduce energy intensity and help to restrain the growth of carbon emissions without stifling the growth of the national economy.[8]

[8] S. Sasmojo and M. Tasrif, "Measures for CO_2 Emission Reduction Through Energy Price Deregulation and Fossil Fuel Taxation: A Case Study for Indonesia," *Energy Policy*, to be published, November 1991.

KOREA

1 INTRODUCTION

The Korean economy has witnessed tremendous growth over the past 20 years. Alongside this rapid industrialization, Korea's energy demands have soared. Between 1970 and 1988, primary energy consumption increased four-fold. Due to the scarcity of indigenous energy resources, Korea has had to rely increasingly on imported energy sources to fuel its growth. In 1988, Korea imported almost 83 percent of its energy supply, including all of its oil, bituminous coal, natural gas and nuclear energy.

Because of the lack of native energy sources, the nature of the economy and the characteristics of the climate, energy security remains a primary concern for the Korean government. Korea's recent economic expansion hinged on the development of energy-intensive, heavy industries, such as steel and petrochemical production. Thus, the Korean economy is highly energy intensive relative to the other study countries. In addition, Korea's long, harsh winters place a much higher emphasis on space heating than in the other study countries, requiring particularly high energy inputs in the residential and service sectors.

Following the second oil shock in 1979, the Korean government attempted to diversify the nation's energy reliance by introducing nuclear, natural gas and bituminous coal sources into the national energy mix. Primarily as a result of the extensive dependence on nuclear for power generation, the share of fossil fuels in Korea's primary energy mix fell from 91 to 84 percent between 1980 and 1988. This fuel transition contributed to a 12 percent drop in the amount of CO_2 emitted per unit of energy consumption (kg/GJ) between 1980 and 1988.

Simultaneously, Korean energy policy has emphasized energy conservation. Although conservation has been implemented actively, energy intensity declined only 15 percent between 1970 and 1988. This relatively slight reduction indicates that Korea has had little room for energy conservation during its period of development.

Recently, as public concerns have turned to environmental problems -- both on the domestic and international fronts -- Korea's energy policy has entered a new phase. The Korean government has decided to revise its long-term energy strategy in order to better address environmental issues.

This paper presents two long-term scenarios for Korean energy use and carbon emissions in the year 2025.[1] While the rates of economic and population growth remain constant in both the high emissions (HE) and low emissions (LE) scenario, the LE scenario presents far greater opportunities for promoting fuel substitutions and improving energy efficiency. In the HE

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[1] Much of the data used in this study was drawn from the following two sources: Korea Energy Economic Institute, *Sectoral Energy Demand in the Republic of Korea: Analysis and Outlook* (Seoul, August 1989) and Korea Energy Economic Institute, *Yearbook of Energy Statistics* (Seoul, 1990).

scenario, with the implementation of policies primarily focused on galvanizing Korea's economic growth, energy-related carbon emissions rise by 273 percent between 1985 and 2025. With a policy environment focused on minimizing the emissions of CO_2, the LE scenario reduces the level of carbon emissions in the LE scenario by about one third of the HE figure.

2 GDP AND POPULATION GROWTH

Korea's population totaled 40.8 million in 1985. Because of the nation's small size, Korea has a relatively high population density (over 420 persons per square kilometer). In the 1960s, the Korean government's policies aimed at controlling population growth helped to reduce the population growth rate dramatically from 2.5 percent per annum in the 1960s to 1.2 percent per annum in the 1980s.

According to a recent projection by the Economic Planning Board (EPB), Korea's population should grow at a rate of 0.75 percent per annum between 1985 and 2010 and at a rate of 0.15 percent per annum thereafter.[2] Thus, the size of the Korean population stabilizes at 50.3 million after the year 2020 (Table 1).

Table 1[3]
Demographic Trends

	1961	1970	1980	1985	2025	AAGR (%) '60s	'70s	'80s	to 2010	to 2025
Population (mn)	25.8	32.2	38.1	40.8	50.3	2.5	1.7	1.2	0.75	0.15
No. of HH (mn)	4.2	5.9	7.5	8.8	15.7	3.2	3.0	3.2	--	--
Persons per HH	6.1	5.8	5.1	4.7	3.2	-0.7	-1.2	-1.9	-0.82	-1.14

AAGR = Average Annual Growth Rate

A small open economy, Korea has oriented the bulk of its activities to exports over the past several decades. Between 1962 and 1988, Korea's Gross Domestic Product (GDP) increased at an average annual rate of 9.2 percent -- a far more rapid rate than experienced in most of the other study countries. Both scenarios assume that Korea's economy grows at a slower, but still healthy rate between 1985 and 2025. By 2025, GDP increases ten-fold. GDP per capita increased slightly more slowly over that same period. By 2025, GDP per capita in Korea reaches US$ 18,416, which is a equivalent to current GDP per capita in today's industrialized countries (Table 2).

Korea's industrial development has led to major shifts in its economic structure in the past. During the 1960s, in the early stages of its development, Korea's manufacturing sector

[2] Bureau of Statistics, *Report on Population Movement and Projection of Its Future Trend in Korea* (Seoul: Economic Planning Board, October 1989).

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

emphasized labor-intensive, light industries, such as textile and food production. Korea substantially expanded its heavy industries during the 1970s in an effort to establish the foundation for sustainable economic growth. Starting in the late 1970s, Korea's machinery and equipment industries, such as the ship building, automobile manufacturers and electronics industries, began to expand.

The share of agricultural production in GDP decreased from 28 percent in 1970 to 9.6 percent in 1988, while that of the manufacturing sector increased from 13.8 to 34.4 percent. Simultaneously, service's share of GDP declined from 45.2 to 40 percent (Table 2).

Table 2
GDP and GDP Per Capita

	1970	1980	1985	2025	AAGR (%) '60s	'70s	'80s to 2010	to 2025
GDP (Bn US$)	28.5	62.0	92.9	926.3	9.6	8.1	9.7	6.8	4.0
Industry	22.4%	37.7%	41.8%	53.0%				
(Manufacturing	13.8%	26.7%	30.3%	42.0%				
(Mining, etc.	8.6%	11.0%	11.5%	11.0%				
Transportation	4.4%	6.0%	5.7%	6.0%				
Agriculture	28.8%	14.2%	12.8%	4.0%				
Services	45.2%	42.1%	39.7%	37.0%				
GDP/capita (US$)	885	1627	2276	18416	6.9	6.3	8.4	6.1	3.9

AAGR = Annual Average Growth Rate

Between 1985 and 2025, Korea's manufacturing sector -- particularly its less energy-intensive industries -- continue to propel the nation's economic growth. Although the expansion of Korea's energy-intensive industries slackens as they approach maturation level, both scenarios assume that Korea's manufacturing sector grows more rapidly than any other sector between 1985 and 2025. As a result, manufacturing's share of GDP increases substantially and, those of the agriculture and service sectors decline (Table 2).

3 SECTORAL ANALYSIS AND CARBON EMISSIONS

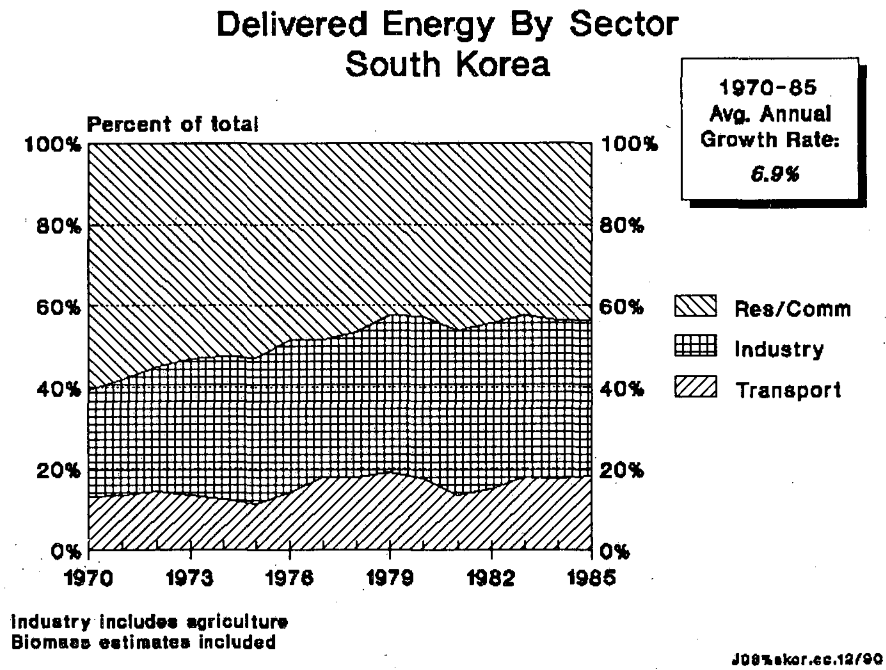
Korea's industrial sector currently absorbs the largest share of the nation's energy demand followed closely by the residential sector (Table 3). Between 1970 and 1985, the residential sector's share of delivered energy demand dropped, while those of industry and transport increased (Figure 1).

Consistent with past trends, over the next 40 years, as Korea phases inefficient coal sources out of its residential fuel mix, the share of household energy in total energy drops substantially. Simultaneously, the shares of both the industrial and transport sectors expand. The service, agriculture and public sectors continue to account for small shares of the nation's total energy demand (Table 3).

Table 3
Aggregate Energy Use (PJ)

	1985	2025 High	2025 Low
Total	1963	7636	6024
Residential	32%	11%	12%
Transport	14%	25%	23%
Industrial	41%	50%	51%
Services	6%	7%	7%
Agriculture	2%	1%	1%
Public & Others	5%	5%	5%

Figure 1



3.1 RESIDENTIAL SECTOR

Korea's climate largely determines the nation's residential energy consumption patterns. Unlike most of the other study countries, Korea has four distinct seasons: a mild spring and autumn, a hot summer and a cold winter. The average monthly temperature in Korea ranges from -3° C in January to 26° C in August. Thus, during the winter, space heating absorbs a significant portion of the residential energy demand and, in the summer, electricity use for cooling accounts for a notable portion of household energy use.

In addition to climate, socio-economic factors -- such as the number of households, household size, urbanization levels and appliance ownership -- largely influence the energy consumption patterns in the residential sector.

Between 1985 and 2025, the urban population share in Korea increases from 66 to 85 percent. However, because Korea is a small country with a high population density, few differences in lifestyles exist between urban and rural areas. The average household size decreases from 4.7 persons per household to 3.2 in both urban and rural regions. The number of urban households surges from 5.8 to 13.4 million, while the number of rural households drops from 2.9 to 2.4 million. As is currently the case, virtually every household in Korea -- urban and rural -- has access to electricity in 2025.

Space heating presently absorbs almost 80 percent of Korea's residential energy demand. While space heating consumes a decreasing portion of household energy demand in the future -- under 65 percent in 2025 -- the expansion of this end-use accounts for about 45 percent of the increase in residential energy demand over the observed time period. Heating energy demand per household decreases significantly -- by 38 percent of the current level according to the HE scenario and further in the LE scenario. These reductions stem mainly from the introduction of more efficient heating systems, such as district heating, the improvement of insulation and fuel substitutions. The district heating system offers a particularly favorable option in light of Korea's specific needs; the nation has substantial requirements for space heating, high urban concentrations and population densities and a rapid rate of housing construction. District heating from combined heat and power plants also offers opportunities to improve the efficiency of energy use, to utilize cheaper and lower quality fuels and to lower space heating costs.

Koreans rely on higher quality fuels to satisfy their space heating needs by 2025. Coal's share, which is currently quite high (85 percent in urban areas and 65 percent in rural), declines to less than 5 percent in 2025, while oil and natural gas come to play leading roles in space heating. The replacement of less efficient with more efficient fuels eventually contributes to the improvement of average heating efficiency and the reduction of heating energy input per household.

While the efficiency of space heating has increased continuously in Korea, the improvements have been offset by increased energy consumption resulting from the demand for higher indoor temperatures. In the future, the improvement of heating appliance efficiencies and house insulation offer significant potential for energy savings.

Cooking accounts for a substantial share of household energy use in the other study countries, but plays a minor role in Korea. The scenarios assume that cooking energy intensities decline, for every fuel type in both rural and urban areas, with decreases in household size. Similar to the case of space heating, the average intensity declines even more rapidly due to an increasing reliance on more efficient fuels to satisfy cooking end-uses. Cooking's share of household energy use drops from 14 percent in 1985 to 11 percent in the HE scenario and 10 percent in the LE scenario in 2025.

While a growing number of Korean households have water heaters, the diffusion of these heaters is quite low at present. Only 23 percent of urban and 12 percent of rural households had water heaters in 1985. In total, water heating accounts for only 2 percent of residential energy use. By 2025, the ownership of water heating devices reaches 90 percent in urban areas and 65 percent in rural areas, and water heating's share of residential energy use expands to 9 percent. In the HE scenario, fuel intensities for water heating decrease by about 30 percent in urban areas by 2025, due to the improved efficiency of equipment and fuel substitutions. In contrast, the intensity of electricity use increases by 10 percent in the HE scenario.

Between 1985 and 2025, the growth of appliance energy use accounts for 56 percent of the increase in Korea's residential energy consumption. The level of appliance ownership in Korea varies according to appliance type. About 97 percent of urban and 56 percent of rural households had refrigerators in 1985. By 2025, not only do refrigerators saturate virtually every Korean household, but many households possess more than one. While the saturation of electric washers remains low at present -- 39 and 7 percent in urban and rural regions respectively -- saturation rates increase to 90 percent in urban and 75 percent in rural households by 2025. Relatively few households owned room air conditioners in 1985, but by 2025, as income levels rise, so does the saturation of cooling devices.

Appliance electricity intensities rise significantly between 1985 and 2025 because consumers increasingly prefer larger-sized, multi-functioning appliances and tend to use each appliance more as they aspire to higher comfort levels and more convenient lifestyles.

Accordingly, electricity demand per urban household increases from 1244 kWh in 1985 to 2912 kWh in 2025 in the HE scenario. While electricity demand grows more rapidly in rural than in urban regions, urban household electricity use continues to surpass that of rural households in 2025. The LE scenario reduces household electricity demand to about three quarters of the HE level.

Residential energy demand increases from 619 PJ in 1985 to 856 PJ in 2025 in the HE scenario (Table 4). The LE scenario limits residential energy demand by 15 percent of the HE figure. This sector's energy demand grows at a relatively slow pace, largely because of the adoption of the district heating system, thermal insulation in new housing, more efficient heating devices and fuel substitutions. Thus, the share of the residential sector in total energy demand drops from 32 percent in 1985 to 12 percent in the HE and 11 percent in the LE scenario.

While household energy use has grown more slowly than energy use in Korea's other burgeoning sectors, residential energy demand in Korea has experienced a more significant structural change in fuel mix. As economic development has raised income levels and living standards, Korean households have increasingly substituted more convenient and expensive fuels -- such as oil, electricity and gas -- for cheaper, less efficient fuels -- such as anthracite and wood. The structure of the residential fuel mix continues to shift over the observed time period. Coal (anthracite), which monopolizes household energy use at present, rapidly loses its competitiveness; oil and gas penetrate more Korean households. The LE scenario relies more heavily on natural gas than oil in an effort to reduce carbon emissions.

In absolute terms, household electricity demand increases six-fold in the HE scenario and five-fold in the LE scenario between 1985 to 2025. According to both scenarios, electricity's share in the fuel mix rises from 6 percent in 1985 to 25 percent in 2025.

Despite the waning share of residential energy demand in total energy, household carbon emissions increase from 13 to 17 million tons in the HE scenario. The LE scenario manages to reduce carbon levels to below those in 1985.

Table 4
Residential Energy Use (PJ)

	1985	2025 High	2025 Low
Total (PJ)	619	856	723
Fuel Shares			
Coal	69%	2%	0%
Oil	12%	43%	36%
Natural Gas	0%	23%	30%
Biomass	13%	7%	10%
Electricity	6%	25%	25%
Urban/Rural Shares			
Urban	69%	88%	87%
Rural	31%	12%	13%
End-Use Shares			
Cooking	14%	10%	11%
Water Heating	2%	9%	9%
Space Heating	78%	63%	64%
Appliances, etc.	5%	19%	16%

3.2 TRANSPORT SECTOR

Energy use in Korea's transport sector has increased more rapidly than in any of the nation's other sectors. Between 1975 and 1988, transport's share in total energy demand increased from under 10 percent to almost 18 percent (Figure 1). Simultaneously, the share of transport oil in total oil consumption expanded from 14 to 31 percent.

In particular, road transport energy use has grown more rapidly than other transport modes due mainly to a rapid increase in the size of the vehicle stock. In recent years, car ownership has increased rapidly in Korea as incomes have reached levels where cars were readily affordable. Compared to other countries with similar income levels, however, the current level of vehicle ownership in Korea remains relatively low.

The size of the vehicle fleet grows steadily between 1985 and 2025 according to both scenarios (Table 5). The level of car ownership, for example, increases from 11.2 per 1,000 persons in 1985 to 210 per 1,000 persons in 2025 in the HE scenario. The LE scenario limits the growth of private transport modes; the saturation of cars only increases to 170 per 1,000 persons. The total stock of passenger cars increases from less than 0.5 million in 1985 to more than 10 million in 2025 for the HE scenario. In contrast, the stock of other vehicle types, such as taxis, buses and trucks, increases at a more moderate rate -- particularly in the LE scenario. Despite the large increases in both scenarios, Korea remains under-motorized in 2025 relative to today's industrialized countries.

Table 5
Transport Indicators

	1985	2025	
		High	Low
Cars			
Per 1,000 persons	11.2	210	170
Distance traveled per car ('000 km/yr)	20	13	14
Fuel intensity (liter/km)	0.10	0.09	0.06
Taxis			
Per 1,000 persons	2.4	11	9
Distance traveled per taxi ('000 km/yr)	100	70	70
Fuel intensity (liter/km)	0.10	0.8	0.7
Buses			
Per 1,000 persons	10.5	60	50
Distance traveled per bus (1,000 km/yr)	36	27	25
Fuel intensity (liter/km)	0.25	0.19	0.16
Trucks			
Per 1,000 persons	3.1	25	20
Distance traveled per truck ('000 km/yr)	30	24	22
Fuel Intensity (liter/km)	0.22	0.16	0.14

Consistent with the past experiences of today's industrialized countries, the average distance traveled per vehicle declines gradually in Korea along with the expansion of the vehicle fleet. In the LE scenario, the distances traveled per bus and car decline beyond the HE level. Each car travels slightly further in the LE scenario, however, to compensate for the smaller size of the vehicle fleet (Table 5).

Fuel efficiency improves for every vehicle type as a consequence of technological improvements. As incomes increase, however, consumers tend to prefer larger, more comfortable cars, a trend that offsets the fuel efficiency gains.

The analysis of energy use for non-road transport relies on the value-added share of each transport sub-sector. Between 1985 and 2025, increases occur in the shares of air and ship transportation at the expense of those of road and rail (Table 6).

The fuel intensity of air transportation, expressed in GJ/US$, declines by 17 percent in the HE scenario and 33 percent in the LE scenario between 1985 and 2025. The fuel intensity of ship transport declines by a third in both scenarios.

The share of non-road modes in total transport energy use increases from 23 to 38 percent in the HE scenario, resulting mainly from the expansion of air transport. In the LE scenario, the share of non-road transport increases to 44 percent by 2025.

Table 6
Transport Value Added

	1985	2025 High	2025 Low
Transport	5.7	6.0	6.0
Road	4.08	3.7	3.7
Rail	0.36	0.2	0.2
Air	0.34	1.0	1.0
Ship	0.92	1.1	1.1

Total delivered energy demand for transport in Korea increases almost seven-fold in the HE scenario. The LE scenario limits this increase by 28 percent. The types of fuel used for transport, which currently are confined to oil and electricity, do not change dramatically. The LE scenario does integrate small shares of natural gas and biomass into the transport fuel mix, however, thereby limiting the use of more carbon-intensive fuels (Table 7).

Table 7
Transport Energy Use (PJ)

	1985	2025 High	2025 Low
Total	279	1917	1388
Oil	99%	98%	93%
Natural Gas	0%	0%	1%
Biomass	0%	2%	5%
Electricity	1%	1%	1%
By Vehicle Type			
Cars	11%	20%	18%
Taxis	12%	6%	6%
Buses	16%	13%	11%
Trucks	38%	23%	21%
Rail	5%	3%	4%
Air	7%	22%	24%
Ship	11%	13%	15%

Commensurate with the increase in transport energy use, transport carbon emissions increase over seven-fold in the HE scenario. The LE scenario restricts the growth of carbon to a factor of five.

3.3 INDUSTRIAL SECTOR

Korea's industrial sector dominates its economic activity, energy use and carbon emissions. Between 1975 and 1988, industrial energy consumption increased over three-fold alongside the industrialization of the economy. Industry accounted for 42 percent of GDP, 47 percent of delivered energy demand and 43 percent of carbon emissions in Korea in 1985.

Of the three industrial sub-sectors -- mining, manufacturing and construction -- manufacturing has been at the vanguard of this increase; in 1985, manufacturing absorbed 92 percent of total industrial energy use. Energy-intensive industries consume 53 percent of Korea's industrial energy, but account for only 4.7 percent of 1985 value added.

The growth of industrial energy use in Korea, however, has corresponded not only with the development of the manufacturing sector but also with restructuring of the industrial structure. During the 1970s, when Korea expanded its energy-intensive industries, industrial energy use grew remarkably quickly (13 percent per annum). This rate fell to 3.8 percent per annum in the first half of 1980s, with the growth of the less energy-intensive industries. This change eventually influenced the changes in overall energy intensity.

Consistent with recent trends, the scenarios assume that Korea's less energy-intensive industries continue to grow more rapidly than the nation's energy-intensive industries between 1985 and 2025. Thus, the value-added share of non-energy-intensive industries increases from 26 percent today to 39 percent in 2025, while that of the energy-intensive industries decreases from 4.7 to 3.1 percent. Among the energy-intensive industries, the share of the steel and cement industries in GDP decreases significantly from 1.7 and 1.1 percent respectively in 1985 to 1 percent and 0.3 percent respectively in 2025. The value-added share of basic chemicals remains level, at about 1.9 percent, over the observed time period.

While their shares in GDP decline, steel and cement production increase significantly; steel output per capita increases from 0.22 tons today to 0.70 tons in the HE scenario and 0.65 tons in the LE scenario and cement output per capita expands from 0.57 to 0.85 tons in the HE scenario and to 1 ton in the LE scenario.

Industrial energy intensities decline due to technological improvements, changes in the industrial structure, the transition to higher value-added products, the introduction of energy-efficient manufacturing processes and other energy conservation efforts. The greatest improvements in energy efficiency result from structural changes in the economy, which place a greater emphasis on less energy-intensive industries.

Aggregate industrial energy intensity, expressed in GJ/US$, declines to 37 percent of the 1985 value in the HE scenario and to 30 percent of the 1985 value in the LE scenario. The energy-intensive industries achieve slightly higher energy-efficiency improvement than the non-energy-intensive ones.

Industrial energy demands expand from 808 PJ in 1985 to 3804 PJ in 2025 in the HE scenario. The expansion of Korea's less energy-intensive industries account for three quarters of this growth. The LE scenario restrains this growth by almost 20 percent. Over this time period, the share of non-energy-intensive industries in industrial energy demand increases from 41 percent in 1985 to 62 percent in 2025 in the HE scenario and 60 percent in the LE scenario. The industrial fuel mix shifts between 1985 and 2025. Industry comes to rely less on coal and oil and more on natural gas and electricity, particularly in the LE scenario (Table 8).

Table 8
Industrial Energy Use (PJ)

	1985	2025 High	2025 Low
Total	808	3804	3067
Coal	33%	20%	16%
Oil	52%	50%	46%
Natural Gas	0%	5%	11%
Biomass	0%	0%	1%
Electricity	14%	24%	26%

Industrial carbon emissions rise from 20 million tons in 1985 to 88 million tons in 2025 in the HE scenario and 63 million tons in the LE scenario.

3.4 SERVICE SECTOR

As in Korea's residential sector, in the service sector four end-uses dominate: space heating, cooking, electric appliance use and lighting. Space heating absorbs 74 percent of all energy used in Korea's service sector. Energy use for cooking and for appliances and lighting combined account for 15 percent and 12 percent of service's energy use respectively.

The scenarios assume that value added in the service sector increases by a factor of nine between 1985 and 2025, rising from US$ 36.8 billion to US$ 342.7 billion. Its share of GDP declines, however, from 40 percent in 1985 to 37 percent in 2025.

By 2025, the thermal efficiency of commercial buildings improves as a result of better thermal insulation, the increase in new, more energy-efficient buildings and the expansion of the district heating system. Thus, the fuel intensity of the service sector declines by 60 percent between 1985 and 2025 in the HE scenario and by 70 percent in the LE scenario. Electricity intensity remains stable in the HE scenario, however, because improved appliance efficiencies are offset by increases in electricity demand. In the LE scenario, the intensity of electricity use declines by 10 percent.

Energy demand in the service sector increases over four-fold in the HE scenario and by a factor of about 3.5 in the LE scenario. The composition of the service's fuel mix shifts. The shares of coal and oil drop significantly and those of natural gas and electricity rise. In the LE scenario, Korea completely phases coal out of the services fuel mix (Table 9).

Table 9
Service Energy Use (PJ)

	1985	2025 High	2025 Low
Total	127	555	447
Coal	29%	4%	0%
Oil	58%	49%	35%
Natural Gas	0%	22%	35%
Biomass	2%	2%	5%
Electricity	11%	23%	26%

Carbon emissions from the service sector rise from 3 million tons in 1985 to 12 million tons in 2025 in the HE scenario. The LE scenario maintains the level of service's carbon emissions to 8 million tons.

3.5 AGRICULTURE SECTOR

Korea's agriculture sector consumes only about 2 percent of the nation's energy. By 2025, its share drops further to about 1.5 percent. Oil accounts for the bulk of all fuel used in agricultural activities today. In 2025, oil dependence remains high. However, the LE scenario reduces the reliance on oil by increasing the share of natural gas in agricultural activities. This fuel transition relies on the assumption that a gas pipeline network is constructed which allows for distribution even to rural areas (Table 10).

Table 10
Agricultural Energy Use (PJ)

	1985	2025 High	2025 Low
Total	40	109	90
Coal	7%	5%	0%
Oil	86%	83%	73%
Natural Gas	0%	5%	18%
Biomass	1%	1%	1%
Electricity	5%	7%	7%

Due to the increasing mechanization of farming and to the growing popularity of greenhouse planting in winter, agricultural energy demand increases from 40 PJ in 1985 to 109 PJ in 2025. The LE scenario limits this growth by 17 percent of the HE figure.

Agricultural carbon emissions remain low in 2025. In both scenarios, emissions rise from 1 to 2 million tons.

3.6 AGGREGATE ENERGY DEMAND

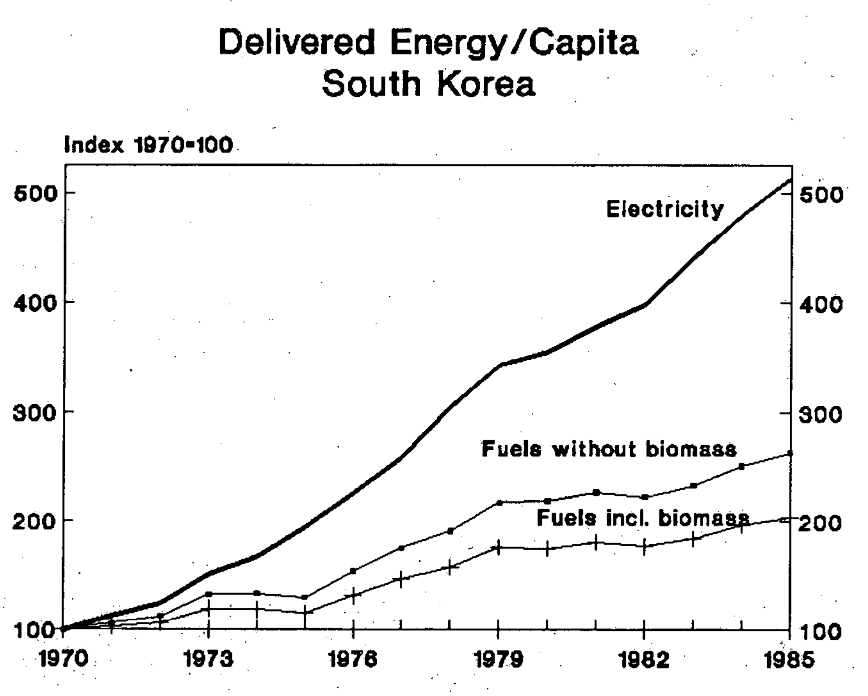
Spearheaded by the expansion of the industrial and transport sectors, Korea's aggregate energy demand increases substantially between 1985 and 2025 (Table 11).

Table 11
Aggregate Energy Use (PJ)

	1985	2025 High	2025 Low
Total	1963	7636	6024
Coal	38%	11%	8%
Oil	49%	62%	56%
Natural Gas	0%	7%	13%
Biomass	4%	2%	3%
Electricity	9%	18%	20%

Consistent with past trends, delivered energy demand per capita increases almost four-fold in the HE scenario and three-fold in the LE scenario (Figure 2).

Figure 2



The shares of industry and transport in total energy use increase from 41 and 11 percent respectively in 1985 to 50 and 25 percent respectively in 2025. Simultaneously, the share of the residential sector in Korea's energy use drops (Table 3).

The structure of the fuel mix shifts. The shares of oil, natural gas and electricity expand at the expense of coal. Oil plays a much lesser role in the LE scenario and natural gas and electricity power a larger share of Korea's activities.

4 ELECTRIC POWER GENERATION

Korea's electricity demand has increased far more rapidly than fuel demand in the recent past. Nonetheless, Korea's electricity consumption per capita still lies far below those of industrialized countries with similar income levels. Thus, significant potential exists for the further growth of electricity demand in Korea over the next 40 years.

Between 1985 and 2025, Korea's electricity demand increases more than seven-fold in the HE scenario while total energy demand increases less than five-fold. This increase represents the introduction of automation into industrial processes, the expansion of appliance ownership and consumers' pursuit of clean and convenient energy sources.

Accordingly, total power generation rises from 53,906 GWh in 1985 to 397,706 GWh in 2025 in the HE scenario. The LE scenario limits total generation to 348,843 GWh, which represents a 13 percent reduction of the HE figure.

The fuels used to generate electricity differ in the HE and LE scenarios. Coal's share in electricity generation rises in the HE scenario, but falls in the LE scenario. The share of nuclear power remains flat over time according to both scenarios. In the LE scenario, oil and natural gas constitute larger shares of the electricity mix to compensate for the lesser reliance on coal. Biomass contributes to power generation only in the LE scenario (Table 12).

Table 12
Fuel Use for Electricity Generation (PJ)

	1985	2025	
		High	Low
Total	576	3817	3094
Coal	30%	40%	21%
Oil	33%	5%	10%
Natural Gas	0%	10%	15%
Biomass	0%	0%	5%
Nuclear	30%	40%	40%
Hydro, Other	7%	5%	8%

Transmission and distribution losses in Korea currently equal about 6 percent. This average is relatively low compared to the other study countries because of Korea's small size. By 2025, losses fall to about 5 percent as further technical improvements occur. The efficiency of electricity generation rises from 34 percent in 1985 to 38 percent in 2025 with the introduction of more efficient power plants.

Carbon emissions from the power sector rise substantially over the four decades. In 1985, electricity accounted for 8 million tons of carbon. By 2025, CO_2 emissions from electricity generation expand to 45 million tons in the HE scenario. The LE scenario reduces emissions to 28 million tons.

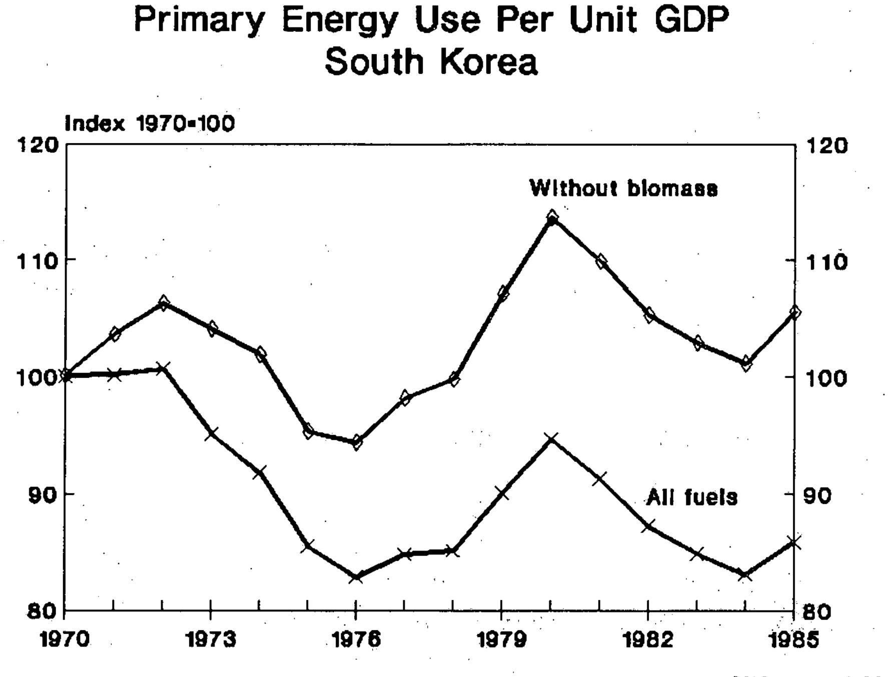
5 PRIMARY ENERGY SUPPLY

Korea's primary energy demand increases from 2,410 PJ in 1985 to 10,244 PJ in 2025 in the HE scenario. The LE scenario reduces the HE figure by 22 percent.

Primary energy use per capita rises from 59.1 GJ in 1985 to 203.5 GJ in 2025 according to the HE scenario. In the LE scenario, energy demand per capita rises less dramatically to 159.4 GJ.

Primary energy intensity, expressed in GJ/US$ 1,000, fluctuated between 1970 and 1985 (Figure 3). Over the next four decades, this ratio steadily declines from 26 in 1985 to 11.1 in the HE scenario and 8.7 in the LE scenario.

Figure 3



Despite the drop in demand for anthracite coal -- currently the mainstay of the residential sector -- as household incomes rise, the absolute amount of coal consumed in Korea increases from 930 PJ in 1985 to 2383 PJ in 2025 in the HE scenario as demand for bituminous coal expands in the industrial and power sectors. In the LE scenario, however, coal demand only increases slightly to 1179 PJ. Oil demand increases much more rapidly than coal, although the share of oil in the primary fuel mix remains flat in the HE scenario and decreases slightly in the LE scenario. Natural gas, which will serve as the major substitute for anthracite coal in the residential and service sectors, comes to play a significant role, particularly in the LE scenario. Nuclear continues to contribute significantly to power generation. Due to geographical limitations and technological problems, Korea has little room for new and renewable energy sources to penetrate the market. Assuming, however, that technologies improve, renewable energy comes to play a minor role in the HE scenario and a slightly greater role in the LE scenario (Table 13).

Table 13
Primary Energy Supply (PJ)

	1985	2025	
		High	Low
Total	2410	10244	8025
Coal	39%	23%	15%
Oil	49%	49%	47%
Natural Gas	0%	9%	16%
Biomass	4%	1%	4%
Nuclear	7%	15%	15%
Hydro, Other	2%	2%	3%

Coal and oil, the two highest emitters of carbon dioxide, account for 72 percent of the primary energy supply combined in the HE scenario. In the LE scenario, the combined share of these two carbon-intensive fuels drops to 62 percent.

6 CARBON EMISSIONS

Korea's carbon emissions increase over three-fold in the HE scenario, rising from 45 million tons in 1985 to 168 million tons in 2025. The LE scenario reduces total carbon emissions to 118 million tons (Table 14).

Correspondingly, CO_2 emissions per capita rise from 1150 kg/capita in 1985 to 3394 kg/capita in 2025 in the HE scenario and 2501 kg/capita in the LE scenario.

The amount of carbon emitted for each GJ of energy declines, however, from 19.5 kg/GJ in 1985 to 16.7 kg/GJ in the HE scenario. The LE scenario further reduces this ratio to 15.7 kg/GJ. This decline reflects the increasing substitution of less carbon-intensive energy sources, such as natural gas and nuclear energy, for oil and coal.

Table 14
Carbon Emissions and Indicators

	1985	2025 High	2025 Low
Total (Million tons)	45	168	118
Residential	29%	10%	10%
Transport	12%	22%	22%
Industrial	43%	53%	53%
Services	7%	7%	7%
Agriculture	2%	1%	1%
Public & Others	4%	5%	5%
Losses	3%	2%	2%
CO_2/Capita (kg)	1150	3394	2501
CO_2/GDP (kg/US $100)	51	18	14
CO_2/Energy (kg/GJ)	19.5	16.7	15.7

The amount of carbon dioxide per unit of GDP, expressed in kg/US$ 100, drops from 51 in 1985 to 18 in the HE scenario. The LE scenario achieves further reductions of 23 percent of the HE figure. The LE declines can be attributed to the expansion of the less energy-intensive industries.

Korea's industrial sector continues to dominate carbon emissions. By 2025, over one half of Korea's $C0_2$ originates from industrial activities. The growth of the transport sector, coupled with fuel substitutions in the residential sector, leads transport to surpass households as the second largest carbon producing sector in Korea in 2025. The residential sector's share of carbon emissions plummets between 1985 and 2025, while the shares of all other sectors remain stable over time.

7 CONCLUSION

Korea's economy is still in the process of developing. For this reason, the nation's energy needs have not yet reached the point of saturation. According to the scenarios, the next 40 years see Korea increasing its energy consumption to fuel further economic development and, correspondingly, generating far higher levels of carbon dioxide.

While coal currently produces the bulk of Korea's carbon emissions, oil becomes the largest $C0_2$ contributor in Korea by 2025, primarily due to the growth of the industrial and transport sectors. Coal demand does increase significantly in Korea's industrial and power sectors. Overall, however, the scarcity of domestic reserves, the inconvenience of coal use and local air pollution problems constrain Korea's use of coal.

In terms of fuel substitutions, the opportunities for reducing $C0_2$ emissions in Korea lie in three areas. First, a growing reliance on natural gas can contribute to the reduction in carbon emissions. Second, once the economic feasibility of biomass use has been proven, Korea's various end-use sectors can incorporate biomass into their energy mixes. Finally, the expansion of nuclear generation can offer a tangible solution to the CO_2 problem (but only if the controversies associated with the choice of plant and waste disposal sites can be resolved). To successfully minimize emissions of carbon dioxide through any of these avenues will entail satisfying substantial capital cost requirements.

In light of its heavy reliance on expensive fuel imports and its highly energy-intensive industrial structure, Korea should regard improvements in energy efficiency as a top priority. Although the Korean government has displayed a growing interest in energy conservation in recent years, this attention has not resulted in substantial energy savings to date, due largely to the proliferation of highly inefficient appliances and energy-related facilities across Korea's energy-producing and -consuming sectors. Korea will have to gain access to a new technological stock in order to raise the efficiency of its energy use in the future. The transfer of more efficient technologies from industrialized countries can make a major contribution to this effort.

The success of Korea's quest to follow a more sustainable development path in the future will rely heavily on the extent to which the nation is able reduce its energy waste. Perhaps Korea's greatest challenge will lie in restraining the growth of energy use and carbon emissions while simultaneously satisfying the ever-increasing demands for higher levels of service and comfort that will accompany rising incomes. Overcoming this obstacle will require that the Korean government and consumers make a strong commitment to changing current energy use patterns and strategies. This commitment only will be made when global climate change is percieved as a severe and imminent threat.

CHINA

1 INTRODUCTION

In 1985, China consumed 24.5 exajoules (EJ) of energy, about the amount consumed by all the other study countries combined. Despite its tremendous delivered energy demand, China's average primary energy consumption per capita (27.5 GJ) equals less than one tenth of the United States' average per capita (279.5 GJ) and less than one half of the world's average per capita (64.7 GJ).

Commercial energy use in China generated 480 million tons of carbon in 1985. The extent of these emissions is disproportionately high relative to China's share in global energy consumption; while China consumes 8 percent of the world's commercial energy, it generates almost 12 percent of the world's commercial-energy related carbon emissions.[1] The predominance of coal in China's fuel mix partially explains this imbalance. China derives about 75 percent of its commercial energy from coal, which generates about 85 percent of China's CO_2 emissions each year.

This paper explores two scenarios for energy use and carbon emissions[2] in China for the year 2025. In the HE scenario, China continues to develop economically between 1985 and 2025 without making any concerted efforts to stem its emissions of greenhouse gases. As a result, CO_2 emissions expand over three-fold. In the low emissions (LE) scenario, the Chinese government implements policy initiatives targeted explicitly at improving energy efficiency and lowering carbon emissions. Through these efforts, the scenario restrains the total amount of carbon generated in China in 2025 to 80 percent of the HE scenario figure.

2 GDP AND POPULATION GROWTH

China's 1.1 billion inhabitants comprise over one fifth of the world population (Table 1). Mandates by the Chinese government restrict family size to one child per couple. Despite restrictions, however, many families in rural areas -- and outside of the direct eye of the government -- are likely to have more than one offspring. Thus, both the high and low emissions scenarios assume that China will average two children per couple in 2025.

China's population increased by 1.2 percent annually on average between 1976 and 1986 and is projected to grow at this rate until 2000. At the beginning of the next century the growth rate declines as the size of the population begins to reflect the family size restrictions which were

[1] U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries*, OTA-E-486 (Washington, D.C.: U.S. Government Printing Office, January 1991); World Bank, *World Development Report 1990* (New York: Oxford University Press, 1990).

[2] The term "carbon emissions" only refers to CO_2 generated by commercial energy sources unless otherwise specified.

first implemented in 1975. Between 2010 and 2025, the average rate of growth falls to 0.3 percent annually.

Table 1
Population and GDP

	1985	2025 High	2025 Low	AAGR[a] 1985-2025
Population (Mns)	1045	1420	1420	0.78%
GDP/capita (US$)	310	2000	2000	4.66%
GDP (US$ Bn)	324	2840	2840	5.58%

[a]Average annual growth rate

China's population reaches 1.4 billion by 2025. Due to the relatively slow rate of population increases, China's population will comprise a smaller share of the world's population in 2025 than it does today.

Assumptions about China's future economic growth rate are based largely on the economic plans and aspirations of the Chinese government. With an average GDP per capita of only 310 US$ in 1985, China falls in the United Nations' low-income country category. In the early 1980s, the Chinese government established a new goal for economic development: to quadruple the gross output value of industry and agriculture by the year 2000. In 1987, the government revised this goal, aiming to raise GDP per capita to 1,000 US$ over this time period. As designed in 1987, this plan required that economic growth rates in China average 6.5 percent annually between 1987 and 2000. During the 1980s, because of the government's policy of economic liberalization, economic growth exceeded this rate.

According to both scenarios, economic growth continues to proceed at an annual rate of 6.7 percent until the year 2000. Because this high growth rate cannot be sustained, the economic growth rate declines to 4.2 percent between 2000 and 2010 and to 2.8 percent between 2010 and 2025. Correspondingly, GDP per capita reaches 2,000 US$ by 2025.

3 SECTORAL ANALYSIS

The value-added shares of China's agriculture, service and manufacturing sectors have fluctuated considerably since the 1970s. Due two decades of heavy industrialization and rapid industrial growth rates, China's industry sector currently dominates its economy. The share of the nation's service sector in value added lies well below the average of the other study countries. Based on the assumption that China's manufacturing and agricultural activities have peaked, the scenarios envision a decline in the value-added shares of these two sectors (particularly agriculture) over the next 40 years. In contrast, China's service sector comes to account for a far larger share of the nation's GDP (Table 2).

Table 2[3]
GDP (US$ Billions)

	1985	2025 High	2025 Low
Total	324	2840	2840
Industrial	47%	43%	43%
(Manufacturing	37%	33%	33%)
(Mining, Construction, Utilities	10%	10%	10%)
Transportation	5%	6%	6%
Services	15%	34%	34%
Agriculture	33%	17%	17%

3.1 RESIDENTIAL SECTOR

Relative to most other developing nations, the amount of energy consumed per household in China (40 GJ) is quite high. Two factors contribute to this comparatively steep demand. First, as a result of China's location in the northern temperate zone, two thirds of China's population live in areas which require space heating in the winter (although the government only permits one third of the population to heat their homes). Second, contrary to situation in most other developing countries, a considerably large share of the nation's rural homes are electrified. As a result, Chinese households consume substantial quantities of electricity (about 110 kWh per household). Nonetheless, household energy use in industrialized countries still dwarfs the Chinese levels. In Europe, for example, the average home consumes about 60 GJ of energy.

Demographic shifts strongly influence transitions in China's residential energy use and CO_2 emissions between 1985 and 2025. Due to the limits on family sizes imposed by the government, household sizes in China already are relatively small. The scenarios assume that household sizes decline even further by 2025 (Table 3).

The total number of households in China increases significantly over the observed time period, propelled mainly by the growing number of urban homes. According to the HE scenario, the number of urban households expands over three-fold between 1985 and 2025 while the number of rural households remains flat. The LE scenario moderates the growth of urban households and accelerates that of rural households relative to the HE scenario (Table 3).

Currently, 20 percent of China's population lives in cities. By 2025, the share of China's population living in urban areas grows to 45 percent in the HE scenario. In the LE scenario, 42 percent of China's population inhabits cities in 2025. These growing urban populations increasingly demand more modern fuels.

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

Table 3
China's Rural and Urban Indicators

	1985	2025 High	2025 Low
Persons per Household			
Urban	3.8	3.7	3.7
Rural	4.4	4.1	4.1
Percentage of Population			
Urban	20%	45%	42%
Rural	80%	55%	58%
Number of Households (Mn)			
Urban	55	173	161
Rural	190	190	201
Electricity Use per household (kWh)			
Urban	235	1105	1040
Rural	70	320	295

In 1985, 95 percent of China's urban households and 75 percent of China's rural homes had electricity. These shares reach 98 percent in urban and 83 percent in rural regions by 2025.

Cooking currently absorbs about three quarters of the energy consumed by Chinese households. **Space heating** accounts for 19 percent of China's residential energy use and **water heating** for only 7 percent.

Coal fuels 85 percent of the cooking and water heating and virtually all of the space heating in urban China. Coal-based gas currently is being promoted in the major cities. LPG and natural gas make up most of the remaining fuel supply for cooking and water heating. In rural households, biomass provides 69 percent of the fuel supply for cooking and water heating and most of the fuel used for space heating. Coal serves as the major secondary fuel source throughout rural China. Due to the predominance of rural households in China, biomass resources account for 64 percent of the energy delivered to China's residential sector (Table 4).

Table 4
Residential Energy Use (PJ)

	1985	2025 High	2025 Low
Total	10270	14410	13220
Coal	34%	62%	61%
Oil	1%	1%	1%
Natural Gas	*	5%	5%
Biomass	64%	24%	24%
Electricity	1%	8%	8%

* Less than 0.5 percent

Between 1985 and 2025, as the quality of cookstoves improves and Chinese households make the transition to more efficient cooking fuels (from coal to natural gas in urban homes and from biomass to coal in rural homes), cooking comes to account for an increasingly smaller share of the energy consumed in China's residential sector. Over the same period, China witnesses an upsurge in both water- and space-heating activities. At present, only a fraction of households in China have adequate bathing facilities. By 2025, improved access to bathing facilities leads to a two- to three-fold increase in the amount of energy each household consumes for bathing purposes. With the subsidence of the chronic fuel shortages that have deprived many residents of China's central zone of heating in the past, indoor space heating becomes a more common feature in Chinese households. Simultaneously, the overall improvement in living standards leads those consumers who are already living in heated homes to demand higher levels of comfort.

In comparison to most other developing nations in Asia, levels of appliance ownership in Chinese households are strikingly low. An average of 10 percent of urban households and very few rural households in China possess **appliances** at present. In recent years, however, appliance ownership has increased. Between 1981 and 1988, the number of television sets per urban household in China doubled, the number of washing machines increased twelve-fold and the number of refrigerators increased over fifty-fold.

Based on an examination of recent trends, the scenarios assume that certain appliances proliferate across the residential sector by 2025. For example, both washing machines and refrigerators permeate over 90 percent of urban households according to both scenarios. In contrast, no more than 10 percent of urban households have air conditioning in 2025. The share of appliances in residential energy use rises from 1 percent in 1985 to 6 percent in 2025.

The unit electricity consumption of appliances improves by 2025; an average refrigerator uses 13 percent less electricity in 2025 than in 1985. This improvement is offset by more intensive lighting and a higher saturation of refrigerators and other appliances. The use of electricity for lighting, electronics and other home appliances increases by 2025. Electricity consumption per household expands four-fold in both rural and urban China, although the average urban household uses almost four times more electricity than the average rural home (Table 3). By 2025, electricity plays a growing role in cooking and water heating and a modest role in space heating.

The results of the HE scenario illustrate a substantial increase in residential energy demand between 1985 and 2025. Water- and space-heating activities combined account for over 90 percent of this growth. The LE scenario limits the amount of energy consumed in this sector by 8 percent of the HE figure (Table 4).

Both urban and rural households witness major shifts in their fuel mixes between 1985 and 2025. The consumption of coal in urban households drops by half as the urban Chinese increasingly replace it with more convenient and energy-efficient fuel types. LPG, natural gas and coal gas provided 20 percent of the energy used for cooking and water heating in urban Chinese households in 1985. These shares rise to between 70 and 75 percent by 2025. As biomass resources grow more scarce, rural regions increasingly substitute commercial energy sources for traditional biomass energy. Rural households double the amount of coal they use for cooking and heating. The share of commercial energy in China's residential fuel mix rises from 36 percent in 1985 to 76 percent in 2025 and the share of biomass drops dramatically.

This higher modern fuel consumption implies an increase in residential carbon emissions. In 1985, China's residential sector emitted 90 million tons of carbon. This figure increases over three-fold in the high emissions scenario. The LE scenario reduces residential carbon emissions to just under three times the 1985 level.

3.2 TRANSPORTATION SECTOR

Transportation absorbed 5 percent of China's delivered energy demand in 1985. Between 1985 and 2025, transportation activities in China increase significantly mainly due to the expansion of truck and air transport modes. By 2025, transport accounts for 14 percent of China's energy consumption in the HE scenario and 12 percent in the LE scenario (Table 7).

While rail systems play a limited role in most developing countries' transport sectors, China's rail system provides most of the nation's freight transport (even across short distances) and over 50 percent of its passenger transport. Public buses and bicycles provide the vast majority of local passenger transport. China has only 0.6 cars for every 1000 members of the population.

Freight currently accounts for 81 percent of transport energy demand in China. By 2025, freight's share grows to 85 percent. The tonne-kilometer/GNP ratio of China's freight transport remains steady through 2025. Although railroads continue to transport the largest share of freight in 2025, road, water and air transport all take on greater roles in freight activities.

In absolute terms, trains carry significantly more tonne-kilometers by 2025 than they do today. Trains transported 780 billion tonne-kilometers in 1985. By 2025, this figure increases by a factor of six in the HE scenario. In order to reduce the level of emissions associated with other freight modes, the LE scenario further increases freight movement by trains to almost eight times the 1985 level. Trucks and boats account for a growing share of freight activities by 2025, particularly in the HE scenario.

In recent years, road and air modes have played a growing role in **passenger transport**. In 1985, railways accounted for 56 percent of all passenger-kilometers in China and road transport accounted for only 37 percent. By 2025, the road share of passenger volume exceeds the rail share. The number of cars in China increases to 20 per 1000 persons in the HE scenario. The LE scenario limits this growth to 15 cars per 1000 persons. The number of motorcycles rises more slowly, from 0.9 per 1,000 persons in 1985 to between 7 and 10 per 1,000 persons in 2025. Despite these increases, car and motorcycle saturations remain quite low in China. Together, these two vehicle types still consume only about 7 percent of the energy used by the transport sector.

As China continues to develop economically, the distance traveled by both cars and motorcycles decreases as the number of personal vehicles expands. The total distance traveled by rail, air and buses rises in proportion to the increase in transport value added. According to both scenarios, the number of passenger-kilometers increases more than three-fold for trains, five-fold for buses and thirty-fold for planes.

China's enormous size, the long distances between those regions with well-developed economies and those with rich natural resources and the heavy use of coal all contribute to the high unit energy consumption in China's transport sector. The electrification of China's railroads, the development of a highway system and improvements in fuel efficiency cause unit energy consumption for both freight (MJ/tonne-km) and passenger (MJ/pass-km) modes to decline significantly by 2025. Efficiency improvements also stem from the growing reliance on heavy-duty trucks and the increasing substitution of diesel-fueled vehicles for vehicles powered by gasoline. Fuel intensity declines from 0.08 GJ/US$ in 1985 to 0.05 GJ/US$ in the HE scenario. The LE scenario further reduces the intensity of fuel use to 0.03 GJ/US$. The intensity of electricity rises from 0.25 kWh/US$ in 1985 to 1.09 kWh/US$ by 2025 in the HE scenario and to 1.07 kWh/US$ in the LE scenario.

In the HE scenario, delivered energy demand in the transport sector increases almost seven-fold between 1985 and 2025 (Table 5). Truck and air transport account for 54 and 25 percent of the increase in China's transportation energy respectively. Relative to the HE figure, the LE scenario lowers the amount of energy required by China's transport sector by almost 25 percent.

The composition of China's transportation fuel mix changes between 1985 and 2025 (Table 5). Most notably, China completely phases out the use of coal for transport. The greatest changes result from the electrification of China's railroads. In 1985, coal fueled 91 percent of the railways. By 2025, electricity comprises 70 percent and oil 30 percent of the energy used to power China's trains. Both oil and electricity make up significantly larger shares of the transport fuel mix in 2025.

Table 5
Transport Energy Use (PJ)

	1985	2025	
		High	Low
Total	1260	8450	6490
Coal	38%	0%	0%
Oil	61%	91%	90%
Natural Gas	0%	1%	0%
Biomass	0%	0%	0%
Electricity	1%	8%	10%

Carbon emissions from energy use in China's transport sector increase almost seven-fold between 1985 and 2025 in the HE scenario. Carbon emissions rise less rapidly in the LE scenario as a result of greater improvements in fuel efficiency and a higher reliance on public transport.

3.3 INDUSTRIAL SECTOR

Industrial activities generate 47 percent of China's GDP and consume 44 percent of China's delivered energy (Table 1).. Energy-intensive manufacturing uses 41 percent of the sector's energy, but comprises only 6 percent of the nation's GDP.

China produces almost every type of **energy-intensive** product. Steel manufacturing consumes about 45 percent of the fuel used by energy-intensive industries in China. China's other energy-intensive manufacturing activities include the production of: ammonia, cement, pulp and paper, aluminum, caustic soda, motor vehicles and ethylene.

The physical production of energy-intensive commodities increases several-fold by 2025. Steel output per capita increases from 45 kilograms in 1985 to 165 kilograms in 2025 according to the HE scenario. The LE scenario reduces per capita output to 150 kilograms. These figures may be compared with those for Korea, which produced 225 kilograms per capita in 1985, and India, which produced only 15 kilograms per capita that same year.

China's energy-intensive manufacturing processes are much less efficient than similar processes carried out in more industrialized nations. In the early 1980s, 45 types of energy-intensive manufacturing processes in China consumed about twice the amount of fuel per unit of production as did similar processes in industrialized countries. The six-fold expansion of China's GDP between 1985 and 2025 results in the replacement of as much as 80 percent of the current production capacity with more modern and more energy-efficient technologies. By implementing various conservation measures, such as by adopting the more energy-efficient machinery currently used in industrialized countries, China reduces the amount of energy used per product to industrialized nations' levels.

At 63 MJ/US$ in 1985, industrial fuel intensity drops by 69 percent in the HE scenario as China adopts improved technologies. In the LE scenario, industrial fuel intensity drops by 74 percent of the 1985 level by 2025. Industrial electricity intensity, at 2.02 kWh/US$ in 1985, declines by 33 percent and 38 percent of the 1985 level in the HE and LE scenarios respectively.

China's industrial energy demand rises to 30 EJ in the HE scenario (Table 6). The low emissions scenario reduces industrial energy demand by 14 percent relative to the HE figure. The composition of the industrial fuel mix changes between 1985 and 2025. Coal and oil consumption drop and natural gas and electricity demand surges.

Carbon emissions from industry increase from 293 million tons in 1985 to 843 million tons in 2025 according to the HE scenario. The LE scenario reduces industry's carbon emissions by 17 percent. In 1985, China's industrial sector consumed 44 percent of the nation's commercial energy supply and produced 61 percent of China's carbon emissions. By 2025, this gap closes. Industry accounts for about half of both China's energy demand and carbon emissions.

Table 6
Industrial Energy Use (PJ)

	1985	2025 High	2025 Low
Total	10700	30000	25800
Coal	70%	61%	59%
Oil	16%	10%	10%
Natural Gas	4%	9%	9%
Biomass	0%	0%	0%
Electricity	10%	20%	21%

3.4 SERVICE SECTOR

Between 1985 and 2025, as the service sector's share of value added increases, services absorb a greater share of China's delivered energy demand (Table 7).

Fuel intensity in the service sector declines considerably between 1985 and 2025. Currently, fuel intensity is about 32.7 MJ/US$; by 2025, the intensity of fuel use drops to just over 5.3 MJ/US$ as the service sector's reliance on coal diminishes. The intensity of electricity use also declines, although less dramatically. Between 1985 and 2025, electricity intensity diminishes from 0.32 kWh/US$ to about 0.23 kWh/US$.

China's service sector absorbed 1650 PJ of energy in 1985. While in most developing nations this sector draws the majority of its energy from electricity, coal serves as the predominant energy source in China's service sector. In 1985, coal embodied 83 percent of the energy delivered to the service sector, while electricity accounted for under 4 percent. By 2025, China mitigates its use of coal in the service sector. Although coal still serves as the leading energy source, its share of delivered energy demand drops to 74 percent in the HE scenario and to 71 percent in the LE scenario. Expanding shares of both natural gas and electricity in the service sector compensate for coal's decline.

In 1985, China's service sector generated 41 million tons of carbon. By 2025, this figure increases to 166 million tons according to the HE scenario. The LE scenario moderately reduces carbon emissions (by 5 percent) relative to the HE level. As coal and oil prove less crucial to China's service sector, the amount of carbon emitted per unit of energy consumed diminishes. In the high emissions scenario, energy use almost quadruples in the service sector between 1985 and 2025, but carbon emissions only triple. In the low emissions scenario, energy consumption also increases more rapidly than carbon emissions.

3.5 AGRICULTURE SECTOR

Irrigation and farm work account for over half of the energy consumed in China's agricultural sector. Only 30 percent of all farming activities in China are mechanized at present; by 2025, the level of mechanization increases to 68 percent in the HE scenario and to 63 percent in the LE scenario.

In 1985, the agriculture sector consumed 620 PJ of energy. Oil comprised 52 percent of the delivered energy demand, coal 30 percent and electricity the remaining 18 percent. These fuels were used for irrigation, on-farm machinery and crop drying. In the HE scenario, energy demand for agriculture rises to 1220 PJ. Oil comprises a less substantial, although still dominant, share of energy use at 41 percent. Coal use increases to 38 percent and electricity use to 21 percent. The low emissions scenario reduces agriculture's energy demand to 1050 PJ. In this scenario, coal's share (40 percent) surpasses oil's share (39 percent) in 2025 and electricity, once again, comprises about one fifth of total agricultural energy consumption.

In 1985, carbon emissions from agricultural energy use totaled 19 million tons. In the HE scenario, carbon emissions increase to 34 million tons by 2025. The LE scenario limits the amount of carbon generated to 28 million tons.

3.6 AGGREGATE DELIVERED ENERGY DEMAND

China's total delivered energy demand increases to 60.3 exajoules in 2025 in the HE scenario (Table 7). The LE scenario reduces total energy demand by 13 percent relative to the HE figure.

Table 7
Aggregate Energy Use (PJ)

	1985	2025	
		High	Low
Total	24515	60260	52560
Sectoral shares			
Residential	42%	24%	25%
Industrial	44%	50%	49%
Transport	5%	14%	12%
Services	7%	10%	11%
Agriculture	3%	2%	2%
Fuel shares			
Coal	54%	53%	53%
Oil	12%	20%	19%
Natural gas	2%	6%	6%
Biomass	27%	6%	6%
Electricity Use	6%	15%	16%

In the HE scenario, the absolute amount of all carbon-intensive fuels increase significantly. The LE scenario reduces coal demand by 27 percent, oil demand by 19 percent, natural gas demand by 8 percent and electricity demand by 7 percent compared to their HE levels. In both scenarios, electricity demand witnesses the greatest surge and the absolute amount of biomass consumed declines by almost 50 percent between 1985 and 2025.

The share of the residential sector in delivered energy demand drops considerably between 1985 and 2025 as inefficient biomass fuels are replaced (Table 7). Consistent with past trends, the shares of industry, transport and services in China's energy use all simultaneously expand.

4 ELECTRIC POWER GENERATION

Electricity generation in China increases seven-fold between 1985 and 2025 in the HE scenario (Table 8). The LE scenario reduces the HE figure by about 7 percent by making cross-sectoral cuts in electricity demand.

Table 8
Electricity Generation (PJ)

	1985	2025	
		High	Low
Total	1546	10206	9408
Coal	65%	67%	58%
Oil	15%	1%	1%
Natural Gas	0%	1%	2%
Nuclear & Geothermal	0%	7%	9%
Hydro	20%	25%	30%

In 1985, the efficiency of China's electricity generation was 28 percent. This figure improves considerably by 2025 due to technological innovations and the use of more efficient combined-cycle plants; average efficiency reaches 34 percent.[4] Transmission and distribution losses (measured down to 100 KV), which currently equal about 8.2 percent, decrease slightly to 7.9 percent.

Coal comprises about two thirds of the fuel supply used to power the generation of electricity. Hydro and oil account for most of the remaining generation. Recently, China has begun to use nuclear power to produce electricity. By the year 2000, total nuclear power capacity will reach about 6000 MW. By 2025, this capacity will have increased to between 30

[4] The choice of electricity-generating plants in China has a large bearing on levels of efficiency, fuel use and CO_2 emissions. In recent years, the combination of unrelenting power shortages and the growing decentralization of the Chinese government has led to the proliferation of highly inefficient, small coal-fired plants in certain regions of China (See R. M. Wirtshafter and E. Shih, "Decentralization of China's Electricity Sector: Is Small Beautiful?" *World Development*, Vol. 18, No. 4, pp.505-512, 1990). If China continues to construct these inefficient plants, achieving the efficiency goals set out in the scenarios will prove a major challenge.

and 40 GW. Both scenarios increase the share of hydro in the electricity mix and introduce the use of nuclear power. The LE scenario reduces coal's share by relying more heavily on both nuclear and hydro power (Table 8).

If China uses up its other non-renewable resource options, electricity generation in China may have to rely almost completely on coal after 2025. China has 380 GW of potential hydropower, a higher capacity than any other nation in the world. Of this capacity, about 225 GW is close to the population centers and can be readily exploited. However, only 8.6 percent of this capacity has been exploited to date. By the year 2025, China develops almost all of these resources, aside from the more difficult to develop waterways located in the nation's remote Western plateau. Although China currently does not draw any of its electricity from nuclear sources, nuclear power plays an increasingly important role in the future, particularly in those highly developed regions in China that experience chronic energy shortages.

5 ENERGY INTENSITY AND PRIMARY ENERGY SUPPLY

China's currently high energy intensity implies opportunities for large energy savings. In most other developing nations, energy consumption has increased more rapidly than economic growth over the last decade. In China, however, energy consumption grew at 5.3 percent annually between 1980 and 1987 while GNP grew at almost twice that rate (10 percent). Thus, the elasticity of energy consumption was 0.53.

China's energy conservation plan, put into effect in 1980, led to a 4.2 percent average annual decline in energy intensity during the first eight years of the plan's implementation. The energy/GDP ratio continues to decline in the future, mirroring the trends of the 1980s.

In 1985, China required 89 MJ of energy to produce every dollar of GDP. The replacement of modern fuels for biomass partially explains the decline in energy intensity; biomass is an inefficient fuel, which requires high energy inputs for each unit of energy produced. Even excluding biomass use, however, the ratio decreases by about 64 percent in the HE scenario. The LE scenario reduces energy intensity by 69 percent between 1985 and 2025. China's overall energy intensity totals 32 MJ/US$ in the HE scenario and 26.1 MJ/US$ in the LE scenario.

Even with substantial improvements in energy efficiency, the primary energy demand grows quite large (Table 9). Primary energy supply per capita increases from 28 GJ in 1985 to 64 GJ in 2025 in the HE scenario. The LE scenario limits this total to 53 GJ. These figures still equal only a fraction of the primary energy per capita consumed in industrialized nations today.

Coal, China's major energy resource, continues to make the most significant contribution to China's primary energy supply in the future (Table 9). The LE scenario manages to limit coal's share slightly. The absolute amount of coal consumed is 25 percent lower in the LE scenario than in the HE scenario.

Table 9
Primary Energy Demand (PJ)

	1985	2025 High	2025 Low
Total	28720	91200	75470
Coal	57%	65%	59%
Oil	14%	16%	17%
Natural Gas	2%	4%	5%
Biomass	23%	4%	4%
Nuclear & Geothermal	0%	2%	3%
Hydro	4%	8%	11%

Despite diminishing supplies, the first two and a half decades of the 21st century witness the continual growth of petroleum production in China. By 2025, the share of petroleum in the fuel mix increases slightly from 14 percent in 1985 to 16 percent in the HE scenario and 17 percent in the LE scenario. At the turn of the century, as the demand for oil comes to surpass indigenous oil supplies, China is forced to increase its imports of crude oil and oil products and to produce synthetic fuels from coal.

Natural gas production faces far brighter prospects than petroleum production. Natural gas production increases about seven-fold according to the HE scenario. In the LE scenario, natural gas production increases more than four-fold. The share of natural gas in the primary energy supply remains quite small.

China has only recently begun to integrate nuclear power into its fuel mix. In late 1990, the first nuclear power station, with a capacity of 300 MW, will commence operation. By 2025, nuclear plants generate 185 GWh of electricity and account for almost 2 percent of the primary energy supply in the HE scenario. In the LE scenario, with the emphasis on reducing carbon emissions, the share of nuclear energy increases to 245 GWh or 3 percent of the primary energy supply.

6 CARBON DIOXIDE EMISSIONS

As China's energy production soars, carbon emissions rise dramatically. In 1985, China emitted 478 million tons of carbon. By 2025, carbon emissions from commercial energy sources rise to 1.7 billion tons in the HE scenario (Table 10). The low emissions scenario reduces total carbon emissions by 20 percent relative to the HE figure. The LE figure represents a smaller, but still substantial, increase above the base year.

As a result of the increasing substitution of fossil fuels for biomass, commercial energy-related carbon emissions in China expand more rapidly than total energy demand. In the HE scenario, primary energy demand rises to 320 percent of the 1985 level, but CO_2 emissions expand to 350 percent of the 1985 level. In the LE scenario, energy demand grows by 260 percent and carbon emissions by 290 percent. China's industrial sector continues to produce the largest share of the nation's carbon, although its share drops (Table 10).

Table 10
CO_2 Emissions (Mn Tons)

	1985	2025 High	2025 Low
Total	478	1701	1365
Residential	19%	17%	19%
Industrial	61%	50%	51%
Transport	6%	11%	11%
Services	9%	10%	11%
Agriculture	4%	2%	2%
Losses	2%	11%	7%

Declines in CO_2 intensity (CO_2 emissions per unit of GNP) over the past two decades imply that the potential exists to decrease China's CO_2 emissions significantly. Between 1970 and 1986, the intensity of the world's CO_2 emissions declined at an average rate of 1.4 percent annually. Major improvements in energy efficiency accounted for the bulk of this overall reduction. Reflecting past trends, the intensity of China's CO_2 production drops from 1.9 kg/US$ in 1985 to 0.6 kg/US$ in the HE scenario and to 0.5 kg/US$ in the LE scenario.

As a result of efficiency improvements, the amount of carbon generated per unit of primary energy drops from 21.6 kg/GJ in the base year to 19.5 kg/GJ in the HE scenario and to 19 kg/GJ in the LE scenario.

Due to China's relatively slow population growth and rapid energy growth, carbon emissions per capita rise. In 1985, carbon emissions per capita equalled 594 kg. By 2025, emissions per capita increase to 1250 kg in the HE scenario. The LE scenario reduces emissions per capita to 1010 kg/capita.

7 CONCLUSIONS

The growth of industrial energy use, particularly of energy-intensive manufacturing, spurs 54 percent of the increase in China's energy demand between 1985 and 2025 in the HE scenario. Increased transport activities, particularly for truck and air modes, account for another 20 percent of this growth. The lower levels of energy consumption achieved in the LE scenario suggest that China can reduce its CO_2 emissions in the future through greater energy conservation, improved conversion efficiencies and the increased substitution of non-carbon energy sources for fossil fuels:

1) Energy conservation. More than half of China's energy is consumed by its industrial sector. China's energy-intensive industries are twice as energy intensive as those in the major industrialized economies. Thus, efficiency improvements in China's industrial sector could help curtail China's high level of CO_2 emissions.

2) Improvements in conversion efficiency. Fossil fuel-based electricity constituted only 16 percent of the energy consumed in China in 1985. In order for China to translate its aspirations for high economic growth into economic development, power generation must increase greatly.

Four measures could greatly increase China's generating efficiency: replacing out-dated and inefficient equipment; expanding generation capacity; importing advanced technologies from industrialized countries; and strengthening management. Switching to new technologies may prove to be one of the best options. The further research and development of generation technologies such as fluidized bed combustion, gas-steam combined-cycle generation and magnetic fluid generation could lead to net efficiency levels as high as 35 to 45 percent -- even higher than the efficiency levels achieved in the two long-term scenarios.

3) Substitution of nuclear energy for coal. Due to China's abundance of coal and its dearth of other non-renewable energy resources, coal will continue to provide the largest share of China's energy supply for many years to come. However, China has increasingly relied on non-carbon energy sources to produce energy and generate electricity in recent years. Of all the non-carbon options, nuclear power offers the most promise for generating electricity and minimizing CO_2 emissions in China.

Aside from problems of gaining public support for nuclear plants, the development of nuclear power will be restricted by shortages of investment funds in the short term and and by the limited availability of domestic uranium resources in the long term. With the availability of sufficient investment funds, China could achieve substantially greater nuclear power capacity by 2025. If China developed a total nuclear power capacity of 60 GW, CO_2 emissions would decline at a rate of 2.5 percent annually, far more quickly than in either of the scenarios.

4) Promotion of energy-saving wood stoves in rural areas. Biomass resources (including firewood, agricultural residues and animal dung) currently provide about three quarters of the energy used for space heating and cooking in rural Chinese households. China consumes about 0.18 billion tons of firewood and 0.4 billion tons of straw and stalk each year.

According to both the high and low emissions scenarios, between 1985 and 2025, rural Chinese households will increasingly substitute coal for biomass as the mainstay of their household energy supply in an effort to improve energy efficiencies and to raise their living standards. Thus, according to these scenarios, Chinese households will consume only 0.12 billion tons of straw and stalk despite increasing total agriculture crop yields.

To reduce CO_2 emissions and to alleviate the pressure placed on commercial energy sources, rural areas should limit their substitution of coal for biomass. Simultaneously, efforts must be made to rectify some of biomass's drawbacks. For example, the stoves typically used in rural households should be replaced by various types of wood-saving stoves. These improved technologies can raise thermal efficiencies from the current average of about 10-15 percent to 20-30 percent. Furthermore, if medium- or large-scale digesters were built to provide methane gas in peasants' houses, the inconvenience of using straw and stalk would be avoided.

APPENDIX A

Description of Methodology

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

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

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

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

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

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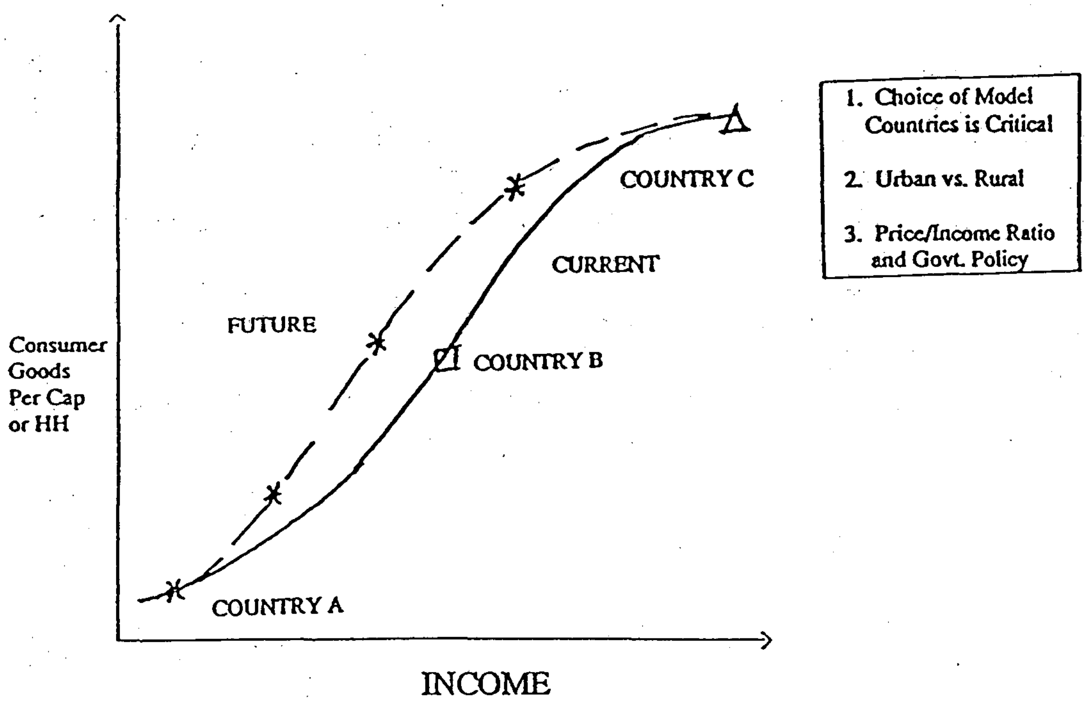
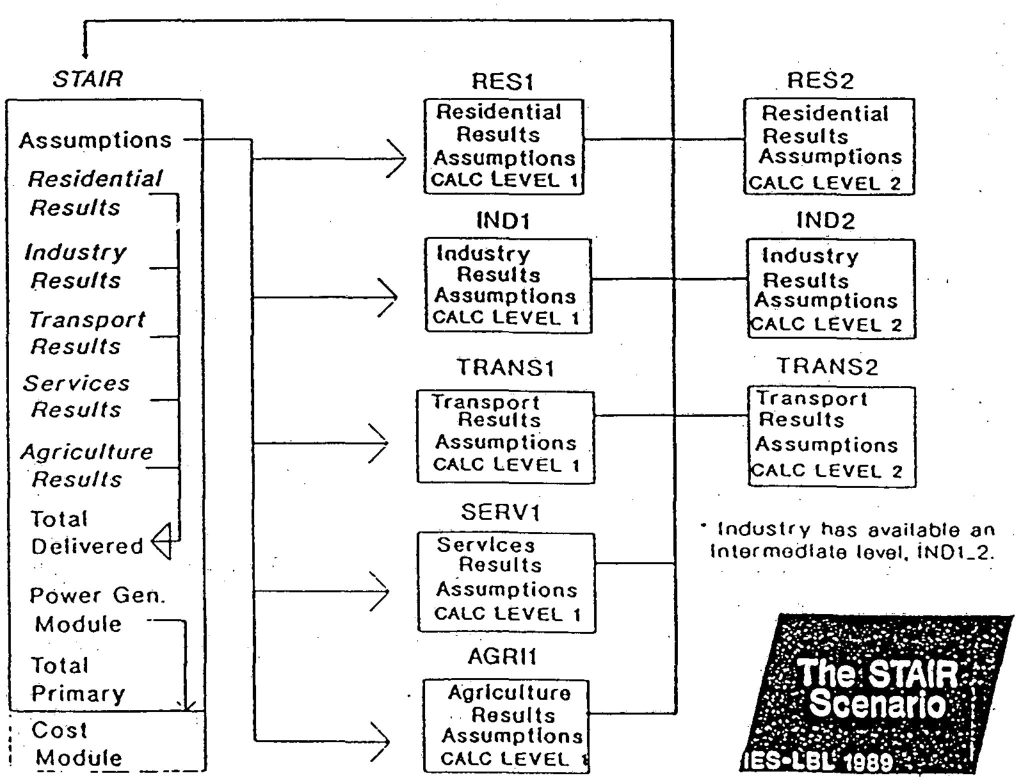
[1] The terms "biomass" and "traditional energy sources" refer to agricultural residues, dung and fuelwood unless otherwise specified.

Figure 1

INTERNATIONAL COMPARISONS





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

Table 1
Structure and Indicators, Examples

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

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

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

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

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

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

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

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

APPENDIX B

A Detailed Look at India's Industrial Sector

In 1985, India's industrial sector generated 50 percent more carbon than all of India's other sectors combined. By 2025, industrial carbon emissions in India increase significantly. The following section provides a more detailed description of India's five major industries:

Steel -- Steel manufacturing consumed more energy than any other Indian industry in 1985. The production capacity of India's steel industry increased from just under a million tonnes in 1951 to a targeted figure of 14.6 million tonnes in 1989-90. Despite this growth, steel production per capita in India remains quite low, at 16 kilograms per capita. In order to support the infrastructural requirements of a growing economy, India's steel industry grows in coming years. The emergence of better quality steel and of cheaper steel substitutes, however, may mitigate this growth to a certain extent.

A typical Indian steel plant draws between 75 and 85 percent of its energy from coking coal, between 10 and 13 percent of its energy from non-coking coal and between 3.5 and 8 percent of its energy from petroleum. On average, the total energy requirement to produce one tonne of steel is 39 GJ in India, which is between two and three times the required energy for similar processes in industrialized countries.

Indian steel production relies on three processes -- the open hearth furnace (OHF), the basic oxygen furnace (LD converter) (BOF) or the electric furnace -- which produce 37, 33 and 30 percent of the steel output respectively. While across the industrialized world, producers have eliminated the OHF process due to its inefficiency, this process is used to produce most Indian steel. Even when Indian steel production uses the BOF process, a far more efficient method, the energy efficiency achieved lies far below the potential. In the scenarios, between 1985 and 2025, the BOF process replaces the OHF process in many instances, and the energy intensity of the current BOF process is reduced.

Fertilizer -- Only steel production consumes more of India's industrial energy each year than does the production of chemical fertilizers. Currently, India's fertilizer industry consumes 330 PJ of the nation's fuel and 4160 GWh of its electricity. In 1985, this industry produced 5.8 million tons of fertilizer, which satisfied about 85 percent of India's domestic fertilizer demand.

By 2025, demand for fertilizers increases as population growth spurs greater agricultural production. The efficiency of fertilizer use also improves over this period, such as in the case of Kharif paddy cultivation, where efficiencies presently remain quite low at around 50 percent. Additionally, farmers increasingly supplement chemical fertilizers with the application of bio-fertilizers, such as Azolla, Blue Green Algae and Rhizobium. These substitutions further improve efficiencies.

The transition from oil to natural gas feedstock in the production of nitrogenous fertilizers decreases the industry's overall energy demand. With the recent discovery of natural gas in Bombay High and the installation of the HBJ pipeline, gas makes a growing contribution to the fertilizer industry by 2025.

Aluminum -- In 1985, India's aluminum industry produced 270 thousand tons of aluminum. As India further develops the use of electricity and as the Indian transport grows, the demand for this versatile metal increases. By 2025, India produces 2.9 million tons of aluminum.

Currently, India's aluminum industry demands 27 percent more energy than industrialized nations to produce the same output. Because no proven technological alternatives currently exist for the basic Bayer-Hall process, reductions in the energy intensity of India's aluminum manufacturing will stem from energy conservation efforts rather than from the introduction of more efficient technologies.

Cement -- Of the three processes used to produce cement in India -- the wet, the semi-dry and dry processes -- the dry process is the most energy efficient. Between 1960 and 1985, the emphasis shifted in India's cement production to much more efficient methods (Table 1).

Cement output increases almost four-fold between 1985 and 2025. Coal's share in the fuel mix increases from 96 percent in 1985 to 99 percent according to the HE scenario. Cement production in the HE scenario consumes 580 PJ of fuel and 10,640 GWh of electricity in 2025. To produce the same amount of output, the low emissions scenario achieves an 11 percent reduction in fuel input and a 6 percent reduction in electricity input.

Table 1[5]
Share of Different Processes in Cement Manufacture

Process	1960	1985
Wet	90%	33%
Semi-Dry	8%	3%
Dry	1%	64%

Textiles -- India's production of textiles consumed 9 percent of the nation's commercial energy in 1985 and accounted for 1.2 percent of its GDP.

In 1985, textile manufacturing consumed 90 PJ of fuel and 7220 GWh of electricity. According to the high emissions scenario, fuel input less than doubles to 140 PJ by 2025, but electricity consumption increases almost four-fold to 28000 GWh. In the low emissions case,

[5] Bureau of Costs and Prices, *Studies on the Structure of the Industrial Economy, Volume III, Cement Industry* (Delhi: Ministry of Industry, Government of India, 1983).

textile manufacturing consumes 18 percent less fuel and 20 percent less electricity than in the high emissions scenario to produce the same amount of textiles.

Changes in the fuel mix partially account for the efficiency differences. Steam and power comprise the prime energy inputs of the textile manufacturing process, although inputs vary according to the quality of the product produced. Oil currently provides 46 percent of the fuel used in India's textile process. The non-availability of coal and the pollution regulation act have curtailed the use of coal for this process in the recent past. Due to its low cost, however, coal constitutes a growing share of the fuel mix in the future. According to the high emissions scenario, coal's share grows from 54 percent of textile fuel use in 1985 to 85 percent in 2025. Oil's share simultaneously drops to 14 percent. In the low efficiency scenario, coal's share is limited to 80 percent. Other more efficient energy sources -- natural gas and electricity -- make up the remainder of the fuel mix in this scenario.

Pulp and Paper -- By the turn of the next century, the installed capacity for paper production in India is expected to grow from the present level of 2.7 million tonnes to 4.25 million tons.

The existing production capacity currently lies half in large mills (with an annual production capacity of over 20,000 tons) and half in small mills. Capacity utilization currently hovers at around 60 percent, due mostly to the lack of necessary raw materials.

Paper and pulp output increases to 10 million tons in 2025 and output per capita almost triples. While coal accounts for 100 percent of the fuel used in the paper industry according to the HE scenario, in the LE scenario, paper draws 2 percent of its fuel from natural gas. Fuel use grows just under six-fold between 1985 and 2025 in the HE scenario, but paper output increases over six-fold. The LE scenario reveals the potential to reduce fuel inputs by 11 percent and electrical inputs by 6 percent to produce the same tonnage of paper.

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