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DIVISION

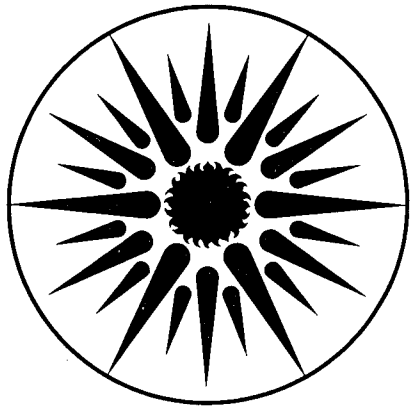
CO_2 Emissions from Developing Countries: Better Understanding the Role of Energy in the Long Term

Volume II: Argentina, Brazil, Mexico, and Venezuela

Editors: A. Ketoff, J. Sathaye, and N. Goldman

Contributors: A. Behrens, G. Graca, Y. Mendoza, G. Dutt, N. Pereira and A.M. Segnini

July 1991



APPLIED SCIENCE DIVISION

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CO_2 EMISSIONS FROM DEVELOPING COUNTRIES: BETTER UNDERSTANDING THE ROLE OF ENERGY IN THE LONG TERM

Volume II: Argentina, Brazil, Mexico and Venezuela

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July 1991

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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 four Latin American countries are being published in this volume (Volume II). The summary paper, the studies of the Asian and of the African and GCC countries are being published separately (Volumes I, III 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:

Argentina	---	Alfredo Behrens, Panama
Brazil	---	Gilena Graca, University of São Paulo
Mexico	---	Yolanda Mendoza, Ministry of Mines and Energy
		Gautam Dutt, National University of Mexico
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In each case, the opinions expressed are those of the authors and do not necessarily reflect those of the affiliated institutions.

Andrea Ketoff, 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. Omar Masera reviewed the reports and revised the data.

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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ARGENTINA

1 INTRODUCTION

Aided by its fertile land and wealth of natural resources, Argentina attained a high level of development early in the twentieth century. Yet, in more recent years, Argentina's economic growth has faltered. Continuing troubles suggest that over the next four decades the Argentine economy will experience minimal growth. As a result, Argentina's energy demand and associated carbon emissions expand slowly between 1985 and 2025 relative to the other Latin American nations studied.

This paper presents two scenarios of energy use and carbon emissions[1] in Argentina for the year 2025. In 1985, the consumption and production of commerical energy in Argentina led to the generation of 21 million tons of carbon. According to the high emissions (HE) scenario, the amount of carbon emitted by Argentina rises to 43 million tons in 2025. The low emissions (LE) scenario implements specific policies aimed at reducing carbon emissions and, thus, restrains the level of carbon emissions in 2025 to 32 million tons.

2 GDP AND POPULATION GROWTH RATES

Between 1970 and 1985, Argentina's population grew at a rate of 1.6 percent annually. The National Institute for Statistics in Argentina anticipates that these growth rates will recede, averaging about 1.1 percent annually from the present until 2025.[2] In accordance with these projections, Argentina's population expands from 30.6 million in 1985 to 47.4 million in 2025.

Obstacles will continue to hinder the growth of Argentina's once burgeoning economy. While high economic growth rates facilitated Argentina's rapid development at the beginning of this century, the Great Depression and World War II disrupted Argentina's early economic successes. Having just launched a full-fledged industrialization effort, Argentina found itself entrenched in indebtedness and deprived of its main market, Britain. Increasingly isolated, Argentina tried to substitute local products for imports to support its industrialization process. However, this strategy reached its limits by the end of the 1950s.

Over the past three decades, living standards in Argentina have deteriorated, industry has aged with little retooling and infrastructure has worn without significant upgrading. Famine has even reached the nation's once productive agricultural regions. Due to ongoing conflicts between industrial workers and owners, Argentina's productive base has never witnessed significant reform.

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[1] The term "carbon emissions" excludes those produced by biomass fuels unless otherwise specified.

[2] National Institute for Statistics (INDEC), *Proyeccion de Poblacion, 1970-2025, Estudios 4* (Buenos Aires: INDEC, 1986).

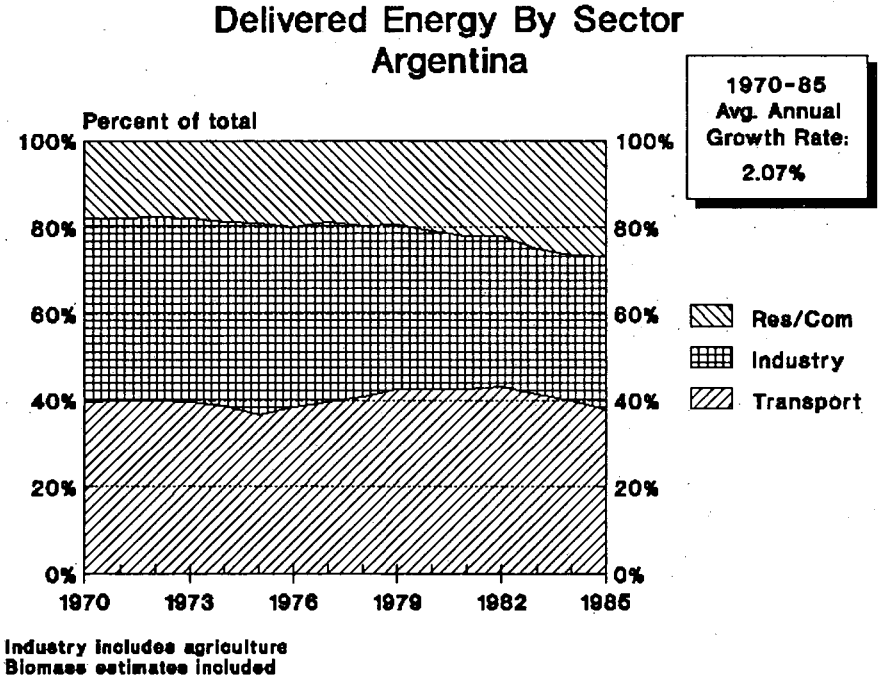
Argentina has consistently relied on its trove of rich natural resources to protect it from economic collapse. The country is endowed with large reserves of natural gas, enough oil to avoid having to import and substantial potential for hydro-generation. Yet energy and food self-sufficiency have effectively insulated the country from external pressure to restructure its economy along more competitive lines. This excessive confidence may undermine the impetus to make much needed improvements in the Argentine economic structure in coming decades.

Argentina's economic growth rates are expected to remain quite low between 1985 and 2025. The latest World Bank estimates for Argentina's economic growth equal half the rates projected in previous official reports.[3] Accordingly, both the high and low emissions scenarios assume that the economy grows by 2 percent annually. The nation's GDP, which amounted to US$ 70.2 billion in 1985, increases to US$ 156.2 billion by 2025. Expanding at an even slower rate of 0.9 percent annually, GDP per capita rises from US$ 2296 to US$ 3294.

3 SECTORAL ANALYSIS AND CARBON EMISSIONS

Transportation activities currently use the largest portion of Argentina's energy. Over the past 15 years, however, transport's share of delivered energy demand has fallen slightly as has the share of the nation's second largest energy user, the industrial sector. The residential and service sectors have used an increasingly larger portion of energy since 1970 (Figure 1).

Figure 1



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

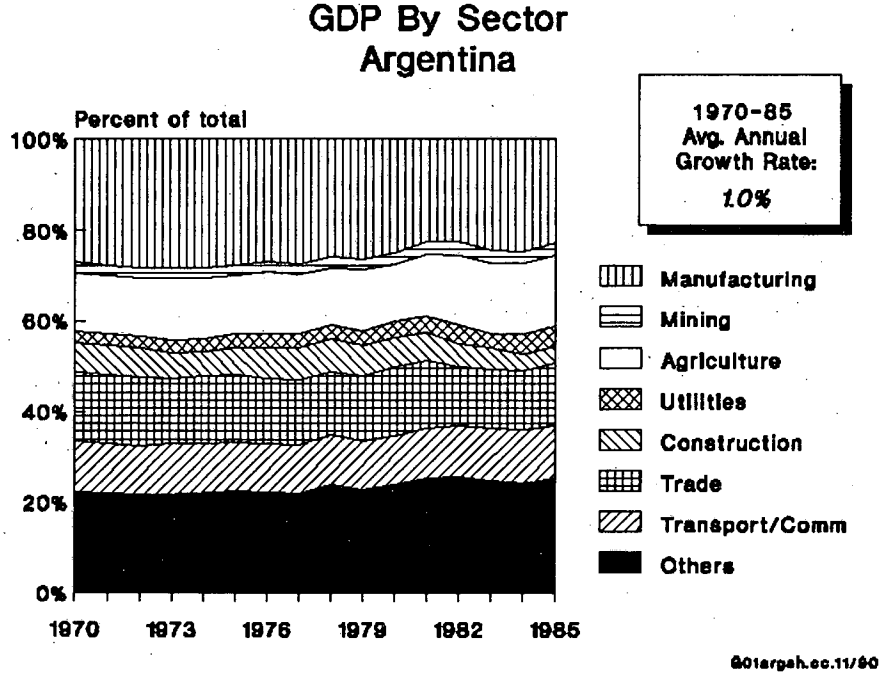
Consistent with past trends, both transport and industry consume smaller shares of the nation's energy by 2025, while the residential and service sectors absorb growing shares (Table 1).

Table 1[4]
Delivered Energy Use and GDP

	GDP (US$ Bn.)			Energy (PJ)		
	1985	2025		1985	2025	
		High	Low		High	Low
Total	70.2	156.2	156.2	1122	2219	1848
Residential	--	--	--	17%	24%	28%
Transport	11%	11%	11%	35%	29%	26%
Industry	47%	45%	45%	31%	29%	27%
(Manufacturing	24%	22%	22%	--	--	--)
(Mining	23%	23%	23%	--	--	--)
Services	29%	29%	29%	11%	12%	12%
Agriculture	13%	15%	15%	6%	7%	8%

Industry accounts for the greatest share of Argentina's GDP (Table 1). For the past two decades, however, the industrial sector has experienced historically low investment rates. Aside from several key agricultural exports (mostly beef), mining and gas-based chemical production, the Argentine economy has lost competitiveness. Between 1970 and 1985, manufacturing's share of GDP fell while agriculture's increased (Figure 2). Over the next four decades, past trends in these two sectors continue. Transport and services' shares of GNP remain steady.

Figure 2



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

3.1 RESIDENTIAL SECTOR

Shifts in demography commonly denote changes in residential energy use. Increasing urbanization signals a transition to modern fuel sources. Shrinking household sizes lead to a greater number of appliances and expanding electrification propels higher household electricity consumption. Because Argentina achieved a high level of development years ago, many of these transitions already have occurred. Thus, from 1985 to 2025, these indicators change little and residential energy use rises less rapidly in Argentina than in most of the other study countries.

Between 1985 and 2025, the bulk of Argentina's modest population growth occurs in urban regions. In 1985, just under 85 percent of Argentina's population inhabited cities. By 2025, 43 million Argentines, or 90 percent of the total population, reside in cities. The size of the rural population remains virtually flat at 4.5 million.[5]

Argentine household size, which already lies well below the Latin American average, further decreases from 4.0 persons in 1985 to 3.4 in 2025. The largest drops occur in urban households, which average 3.3 persons in 2025 as opposed to 3.9 today. Rural households also grow smaller, shrinking from 4.4 members in 1985 to 4.0 members in 2025. The number of urban households doubles, rising from 6.6 million in 1985 to 13 million in 2025, while the number of rural households remains constant at 1.1 million.

At 79 percent, a very high percentage of Argentina's households currently have access to electricity. The Argentine government's recent National Energy Plan[6] aims to electrify 85 percent of all homes by the end of this decade. Slower than anticipated growth rates, however, and increasingly scarce resources have crippled Argentina's economy since the implementation of this plan. Thus, the government may concentrate on serving urban households with electricity and delay improving services to rural homes. By 2025, today's 36 percent share of rural electrified homes grows only to 50 percent, but virtually all urban homes have electricity. Due to the predominance of urban residents in Argentina, however, by serving 99 percent of all urban households, 95 percent of all Argentine households -- rural and urban -- have electricity by 2025.

Space heating and cooking consume the largest share of the residential energy supply in Argentina. In urban regions, where the natural gas distribution network serves 41 percent of all households, gas fuels a significant share of space heating. Natural gas is used for water heating and cooking as well. The majority of houses not served by natural gas use LPG instead.

Argentina's rural households have no access to natural gas at present and must rely on other sources. In its Energy Plan, the government has made the expansion of the natural gas

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[5] INDEC, *Proyeccion de Poblacion, 1970-2025*, Ref. 2.

[6] Secretario de Energía, *Plan Energetico Nacional 1986-2000* (Buenos Aires: Ministro de Obras y Servicios Pùblicos, 1986).

distribution system a top priority. In light of Argentina's recent sluggish economic growth, this costly endeavor may present a major challenge. The scenarios assume, however, that Argentina improves the availability of natural gas and that by 2025 a growing share of all urban homes draw their energy from gas (Table 2).

Table 2
Urban and Rural Residential Fuel Mix
(Percent of households using each fuel for cooking and heating)

	1985	2025	
		High	Low
Urban Households			
Natural Gas Users	41%	54%	65%
LPG/Kerosene Users	50%	40%	29%
Biomass Users	10%	5%	5%
Rural Households			
LPG/Kerosene Users	29%	50%	50%
Biomass Users	71%	50%	50%

As families acquire more **appliances**, electricity intensity (kWh/electrified household) increases by 50 percent of the 1985 level in the HE scenario.[7] The LE scenario limits this increase to 30 percent of the 1985 level. In both scenarios, Argentina's poor economic prospects limit the fulfillment of potential energy savings.

This surge in household electricity demand typifies the development process in most developing nations. An interesting facet of Argentina's development is that households simultaneously increase the intensity of their fuel use (GJ/household) between 1985 and 2025, due primarily to the substantial space-heating demands. As space- and water-heating penetrate more homes, natural gas consumption rises from 36 to 43 GJ/household and oil consumption increases from 13 to 17 GJ/household in the HE scenario. While fuel intensities also rise in the LE scenario, household fuel consumption is reduced by 8 percent of the HE level through improvements in end-use efficiency.

Delivered energy demand in Argentina's residential sector increases just under three-fold between 1985 and 2025 in the HE scenario (Table 3). The LE scenario only reduces the HE figure by 3 percent. The composition of the fuel mix changes in both scenarios as natural gas supplants oil.

Carbon emissions from the use of modern fuels and electricity in the residential sector rise from 3 to 10 million tons between 1985 and 2025 in the HE scenario. The LE scenario reduces emissions to 8 million tons. Carbon emissions increase more rapidly in Argentina's residential sector than in any other sector, largely due to a substantial increase in the use of natural gas, in addition to that of electricity.

[7] Scant information exists on fuel use and appliance saturation in Argentina's households.

Table 3
Residential Delivered Energy Use (PJ)

	1985	2025	
		High	Low
Total	188	529	515
Oil	24%	18%	13%
Natural Gas	52%	58%	66%
Biomass	5%	2%	2%
Electricity	19%	22%	20%

3.2 TRANSPORT SECTOR

Argentina's transport sector, which includes an underground subway system, is far more motorized than in the other study countries. As a result, transportation in Argentina consumes a relatively large share of energy.

Because Argentina's population is strewn across a wide territory and because the nation's agricultural activities require an extensive feeder system to distribute the land's produce, Argentina has especially large transportation requirements. Agricultural production occurs at the nation's far reaches, thus entailing the gathering of heavy loads in dispersed areas and the transportation of these loads to more central regions. On-farm gathering and transportation to central channels rely mainly on oil-fired trucks, trains and ships.

Passenger transport modes absorb a major share of this sector's energy demand. Argentina has one of the highest ownership of vehicles in the developing world. With one vehicle for every 5.6 inhabitants, Argentina has a vehicle saturation level comparable to those of several low-income European countries. In contrast, South America averages one vehicle per 12 inhabitants, Mexico has approximately one per 11 persons and Peru one per 34 persons. Cars absorbed one half of the Argentina's transport energy in 1985.

Vehicle sales in Argentina have remained sluggish for the past decade. The number of cars sold in 1988 equalled the number sold annually in Argentina during the 1960s. We assume that passenger vehicles increase gradually by 2025. As vehicle saturations increase, cars are used less intensively. More Argentineans rely on public passenger transport in the LE scenario than in the HE scenario. As a result, the passenger-distances traveled per bus are higher in the LE scenario than in the HE scenario (Table 4).

Freight transport absorbed 36 percent of this sector's energy demand in 1985. Trucks dominate this sub-sector, consuming about 90 percent of the fuel used for freight. By 2025, freight's share in transport energy declines slightly. The increase in the number of trucks corresponds with the growth of GDP over the 40-year time period.

In 1985, Argentine cars traveled 8 km/liter and motorcycles 25 km/liter. Because car sales have been low in recent years, Argentina's vehicle fleet has aged. Even new cars produced

in Argentina often reflect the designs of 20 years ago. Once the replacement of the fleet begins, vehicle efficiencies improve, particularly as Argentina imports an increasing number of cars from Brazil. By 2025, fuel intensity drops to 0.08 liters/kilometer for cars and 0.024 liters/kilometer for motorcycles in the HE scenario. In the LE scenario, cars and motorcycles both consume half the amount of fuel per kilometer as they did in 1985.

Table 4
Transportation Indicators

	1985	2025	
		High	Low
Cars			
Number ('000)	3863	9484	9484
Per 1,000 persons	126	200	200
Fuel intensity (liters/km)	0.13	0.08	0.06
Distance traveled per car (km/yr)	12200	11500	11000
Motorcycles			
Number ('000)	728	7113	7113
Per 1,000 persons	24	150	150
Fuel intensity (liters/km)	0.04	0.02	0.02
Distance traveled motorcycle (km/yr)	4400	3600	4000
Trucks			
Number ('000)	1374	2606	2606
Per 1,000 persons	45	55	55
Fuel intensity (liters/km)	0.18	0.15	0.11
Distance traveled per truck (km/yr)	15700	15000	14000
Buses			
Number ('000)	58	110	110
Per 1,000 persons	1.9	2.3	2.3
Fuel intensity (liters/km)	0.25	0.20	0.15
Distance traveled per bus (km/yr)	90000	65000	75000

Delivered energy demand in the transport sector increases from 395 PJ in 1985 to 634 PJ in 2025 in the HE scenario. The growth of Argentina's car and truck fleets account for over three quarters of this increase. The LE scenario reduces this demand by 24 percent of the HE level. Oil continues to provide the majority of transportation energy in 2025, although its share drops from 98 percent in 1985 to about 93 percent in 2025 in the HE scenario. In the LE scenario, oil's share decreases further to under 91 percent.

In recent years, Argentina has widened its transport fuel base to encompass natural gas and alcohol. Biomass alcohol provides just under 4 percent of car fuel use at present. Alcohol, however, may not constitute a lasting fuel resource for transportation in Argentina. During Argentina's protracted sugar crisis, northern sugar producers lobbied for the switch to alcohol to support their endeavors. Over time, the lobbyists have not gained substantial support. Thus, alcohol continues to comprise a minor share of the fuel mix in 2025.

Argentina has large natural gas resources and has experience in the transport and distribution of this fuel. The expansion of the distribution networks allows natural gas to play an increasingly important role in transportation in coming years. While natural gas comprised a negligible share of the transport fuel mix in 1985, by 2025, this fuel constitutes a 5 percent

share in the high emissions scenario. In the LE scenario, the share of natural gas increases to 7 percent.

Carbon emissions from Argentina's transport sector increase from 8 to 12 million tons between 1985 and 2025 in the high emissions scenario. The low emissions scenario reduces transport carbon emissions to 9 million tons in 2025 by relying on less carbon-intensive fuels and by using vehicles more efficiently.

3.3 INDUSTRIAL SECTOR

The industrial sector consumed 31 percent of Argentina's delivered energy demand in 1985. Manufacturing's share in GDP declined from 27 percent in 1970 to under 24 percent at present (Figure 2). Over the past two decades, value-added in Argentina's manufacturing sector increased at a rate of only 0.6 percent annually.

At present, high unemployment rates afflict the manufacturing sector and prospects for future growth appear grim.[8] Historically slow growth and current political tensions coupled with low expectations indicate that growth rates likely will not exceed 1 percent annually for the next decade and will not exceed 1.5 percent each year between 2000 and 2025.

Argentina's energy data publications do not disaggregrate fuel consumption by various sub-sectors of industry. Thus, it is difficult to assess the energy implications of a change in the structure of Argentina's industrial output. Various analysts have suggested that Argentina's poor industrial performance for the last few decades necessitates major shifts in this sector -- including greater integration of natural gas into the industrial fuel mix and the implementation of more beneficial alternative institutional trade agreements.[9] In these agreements, Argentina adheres more forcefully to regional markets in which it would have to compete with Brazil's more modern industry.

In the two scenarios, Argentina's industrial focus shifts away from heavier industries and car production by 2025 and moves towards lighter industries -- such as food and beverage production and the textile and leather industries -- in which it has a comparative advantage. These structural changes help to substantially reduce the intensity of industrial fuel and biomass use between 1985 and 2025. In the high emissions scenario, both intensities drop by 20 percent. In the low emissions scenario, fuel and biomass intensities are reduced further. Despite low growth rates, more efficient electrical machinery enters the industrial sector. In the HE scenario, higher reliance on electricity-intensive industries accompany these improvements. Thus, the electricity intensity of industrial output increases by 10 percent. In the low emissions scenario,

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[8] B. Kosacoff and D. Azpiazu, *La Industrial Argentina: Desarrollo y Combios Estructurales* (Buenos Aires: Centro Editor de America Latina, 1989): 26.

[9] Kosacoff and Azpiazu, *La Industrial Argentina: Desarrollo y Combios Estructurales*, Ref. 8.

electricity intensity decreases by 20 percent of the 1985 level.

In the high emissions scenario, delivered energy demand in the industrial sector almost doubles between 1985 and 2025. The low emissions scenario limits this increase by 23 percent of the HE level. The fuel mix witnesses few changes between 1985 and 2025, although oil's share drops and electricity's increases. In the LE scenario, increased natural gas and biomass shares lead to further reductions in oil demand (Table 5).

Table 5
Industrial Energy Use (PJ)

	1985	2025	
		High	Low
Total	353	647	492
Coal	5%	6%	4%
Oil	19%	14%	11%
Natural Gas	42%	42%	45%
Biomass	14%	13%	15%
Electricity	20%	25%	24%

Industrial carbon emissions increase from 6 to 11 million tons between 1985 and 2025 in the HE scenario, due to increases in virtually every type of energy production. The low emissions scenario reduces emissions by 37 percent of the HE level.

3.4 SERVICE SECTOR

Argentina's service sector consumed 11 percent of the nation's delivered energy demand in 1985. Only limited data exist on energy use in Argentina's service sector. The estimates provided for fuel consumption are based on the scant data available on electricity demand and on estimates of natural gas and LPG use for space-heating purposes.

Fuel intensity decreases in the service sector as Argentinean's increasingly substitute gas for oil. In the HE scenario, electricity intensity increases with the growing use of air conditioning. Imports of higher efficiency air conditioners manage to reduce this electrical intensity by 30 percent in the LE scenario.

Energy consumption in the service sector increases correspondingly with GNP (Tables 2 and 6). By 2025, the service sector consumes 260 PJ of energy in the high emissions scenario. The LE scenario reduces services' energy demand by 15 percent of the HE level. In both scenarios, natural gas increasingly dominates the service fuel mix. Between 1985 and 2025, oil consumption declines and electricity's share in service activities surpasses that of oil.

The 2 million tons of carbon currently generated by Argentina's service sector increase to 5 million tons in 2025 according to the HE scenario. Due to a higher proportion of natural gas and hydro-generated electricity in the LE scenario, carbon emissions drop to 3 million tons.

Table 6
Services Energy Use (PJ)

	1985	2025	
		High	Low
Total	122	260	222
Oil	25%	15%	11%
Natural Gas	53%	59%	65%
Biomass	1%	1%	1%
Electricity	21%	26%	23%

By placing greater emphasis on its high-value added service sector, Argentina could make better use of its highly-educated population. The quality of Argentine training could place its professionals at the forefront of the consulting business. Software houses could be developed to provide services throughout the region. Agricultural research could easily find markets abroad. All of these developments, however, would also increase the service sector's electricity demand.

3.5 AGRICULTURE SECTOR

The backbone of Argentina's economic development during the early part of the century, the agriculture sector may represent Argentina's greatest hope. Argentina's agriculture sector absorbed less than 6 percent of the nation's total energy demand in 1985.

Since the 1930s, Argentina promoted industry with proceeds accrued from agriculture. Yet high taxes on agriculture precluded greater development of this sector. As this process of industrialization comes to a close, Argentina places greater emphasis on its agriculture sector. During the four coming decades, the agriculture sector grows at a more rapid rate than does the nation's economy. Basic research and improved efforts to disseminate modern technologies continue to benefit Argentine agriculture, particularly in the areas of cattle ranching and cereal production.

Argentina's agriculture sector is highly fuel and electricity intensive. Oil, the mainstay of agriculture in Argentina, witnesses some efficiency improvements by 2025. More fuel-efficient machinery penetrates the sector, although the rate of penetration remains slow. Thus, the oil intensity of agriculture declines modestly over the observed period. Argentina's sparsely inhabited rural regions deter extensive gasification of the nation's agricultural production. Argentina's abundant supply of natural gas, therefore, continues to constitute a negligible role in the agricultural fuel mix, although gas does serve to benefit the agricultural sector by way of cheap fertilizers.

By 2025, agriculture becomes increasingly electrified, although shortages of capital and low rural population densities limit the extent of the electrification. Improvements in the efficiency of electric machinery serve to temper the increase in the electricity intensity of agricultural output in Argentina.

Agriculture currently derives 98 percent of its delivered energy demand from oil and the remainder from electricity. Official estimates indicate no biomass use in the agricultural sector at present, although these estimates may be flawed. By 2025, agricultural energy demand increases from 64 PJ in 1985 to 148 PJ in the HE scenario. The LE scenario, which indicates limited potential for decreasing this demand, only reduces the amount of energy consumed by agriculture by 5 percent. Oil retains its 98 percent share of the agricultural fuel mix and electricity continues to provide the remainder.

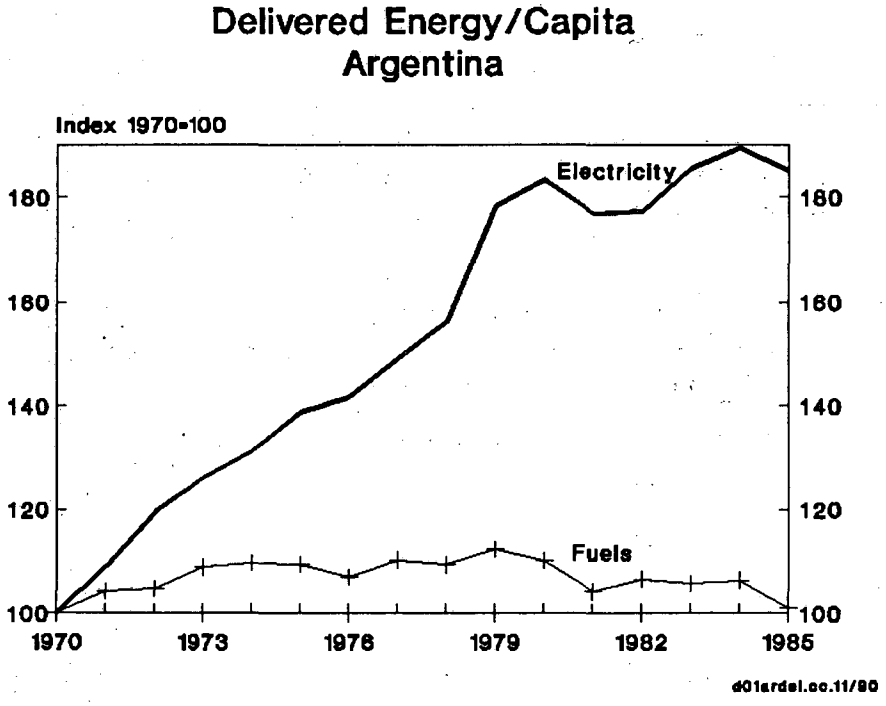
Carbon emissions from Argentina's agriculture sector triple between 1985 and 2025. According to both scenarios, Argentine agriculture generates 3 million tons of carbon in 2025.

3.6 AGGREGATE DELIVERED ENERGY DEMAND

The aggregate delivered energy demand doubles between 1985 and 2025 in the HE scenario. The LE scenario limits this demand by 17 percent of the HE level.

Delivered energy demand per capita in Argentina rose gradually after 1970 and declined slightly as Argentina experienced economic hardship in the late 1970s and early 1980s (Figure 3).

Figure 3



In the HE scenario, delivered energy demand per capita rises once again between 1985 and 2025, from 36.7 GJ to 42.5 GJ. In the LE scenario, Argentina manages to maintain the current level and reduces energy demand per capita to 35.5 GJ by 2025.

The increased shares of natural gas and electricity in the fuel mix by 2025 allow Argentina to reduce its dependence on oil and biomass fuels. While this shift is notable in the HE scenario, oil continues to serve as the major fuel source. In the LE scenario, however, the share of natural gas in the fuel mix actually supersedes that of oil by 2025 (Table 7).

Table 7
Aggregate Energy Use (PJ)

	1985	2025 High	2025 Low
Total	1122	2219	1848
Coal	2%	2%	1%
Oil	53%	43%	39%
Natural Gas	28%	35%	40%
Biomass	6%	5%	5%
Electricity	12%	16%	15%

4 ELECTRIC POWER GENERATION

Electricity accounted for 12 percent of Argentina's energy demand in 1985. Electricity generation in Argentina relies on a broad range of sources (Table 8). Hydropower fuels the bulk of Argentina's electricity generation. Thermal generation draws 64 percent of its energy from natural gas resources.

Electricity generation increases by a factor of about 2.5 between 1985 and 2025 in the HE scenario (Table 8). The share of natural gas in generating electricity increases, surpassing the role of hydro as the major electricity generator. The LE scenario, reduces electricity generation by 25 percent with respect to the HE figure. In this scenario, not only does hydro continue to fuel the bulk of all electricity generation, but hydro's share actually increases.

Table 8
Electricity Generation (PJ)

	1985	2025 High	2025 Low
Electricity Generation	163	417	314
Coal	3%	3%	1%
Oil	12%	10%	6%
Natural Gas	27%	45%	38%
Nuclear	12%	7%	8%
Hydro	45%	35%	47%

Argentina has an excess of power capacity. Due to poor maintenance, however, many of the existing plants function poorly and electricity demand continues to exceed supply. The existence of these potentially useful plants in Argentina serves to delay the expansion and renovation of the nation's power system. In the past, when its own plants required maintenance, Argentina has imported electricity from Uruguay instead of revamping its own power network.

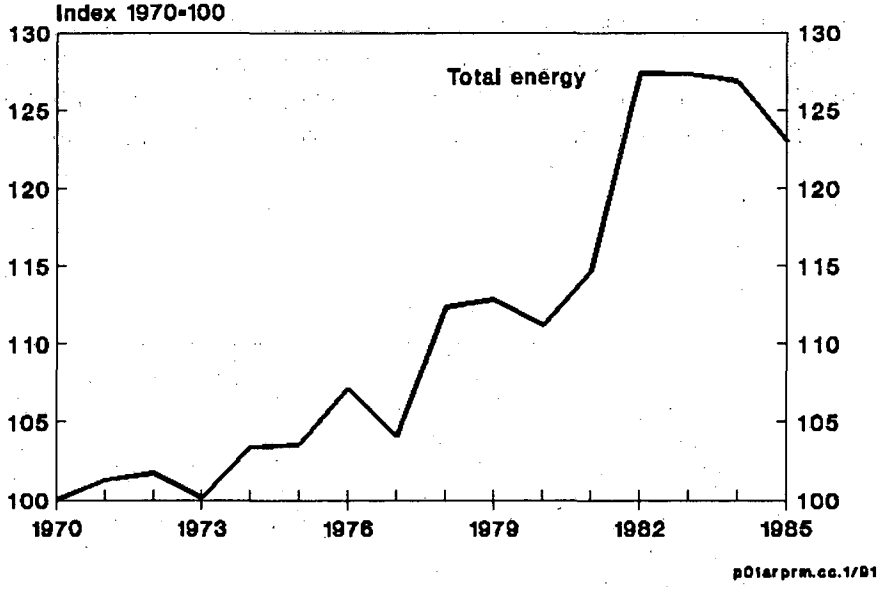
Between 1985 and 2025, local utilities are expected to increase their power generation efficiency. The scenarios assume that between 1985 and 2025, transmission and distribution losses fall to comparable levels of current transmission and distribution losses in Brazil and Mexico. Thus, Argentina's currently high transmission and distribution losses for electricity generation drop from 19 percent in 1985 to 15 percent in the HE scenario and to 12 percent in the LE scenario.

5 PRIMARY ENERGY SUPPLY

Primary energy consumption per capita increases by 0.6 percent annually in the HE scenario, rising from 52 GJ in 1985 to 67 GJ in 2025. In the low emissions scenario, primary energy consumption per capita drops to 52 GJ in 2025, the same level as in 1985.

Figure 4

Primary Energy Use Per Unit GDP
Argentina



The amount of primary energy required for each unit of economic output increased after 1970, peaking between 1982 and 1984. The energy/GDP ratio (MJ/US$) then2 began to fall (Figure 4). According to both scenarios, primary energy/GDP continues to drop between 1985 and 2025. In the HE scenario, the energy/GDP ratio declines at a rate of 0.3 percent annually. At this rate, each dollar of output requires 20.4 MJ of energy input in 2025 (as opposed to 22.6 MJ in 1985). The energy/GDP ratio declines more rapidly in the LE scenario; shrinking at a rate of 0.9 percent annually, each dollar of output demands only 15.7 MJ of energy input.

Both the high and low emissions scenarios foresee decreasing shares of the most carbon-intensive fossil fuels -- coal and oil -- accompanied by increasing shares of natural gas (Table 9). In the LE scenario, increasing the share of natural gas in the fuel mix and maintaining stable shares of biomass and hydro compensates for the diminished reliance on fossil fuels.

Table 9
Primary Energy Supply (PJ)

	1985	2025	
		High	Low
Total	1589	3184	2451
Coal	2%	3%	1%
Oil	44%	36%	33%
Natural Gas	30%	43%	44%
Biomass	4%	3%	4%
Nuclear	4%	3%	3%
Hydro	15%	13%	15%

6 CARBON EMISSIONS

By 2025, Argentina's carbon emissions rise to 43 million tons in the HE scenario. The LE scenario reduces the level of carbon emissions by 26 percent. In 1985, the transport sector accounted for the bulk of all carbon emissions, followed by the industrial sector and the residential sector. In both scenarios, this pattern prevails in 2025, although in the LE scenario the industrial sector's share of carbon falls slightly and the residential sector's share increases (Table 10).

Table 10
Carbon Emissions (Million Tons)

	1985	2025	
		High	Low
Total	21	43	32
Residential	15%	22%	25%
Industrial	27%	26%	22%
Transport	36%	28%	28%
Service	10%	11%	11%
Agriculture	6%	7%	9%
Losses[a]	6%	5%	5%

[a] Excluding electricity generation from total

Due to population growth and particularly slow economic growth, carbon emissions per capita grow much more slowly than total carbon emissions between 1985 and 2025. Currently, each member of Argentina's population accounts for 738 kg of carbon emissions. This figure increases by 29 percent in the HE scenario and actually decreases by 4 percent in the LE scenario.

The amount of carbon generated for each unit of GDP drops from 0.32 to 0.29 tons/million US$ between 1985 and 2025 according to the HE scenario. The LE scenario further reduces the amount of carbon produced per every million dollars of GDP to 0.22 tons. Similarly, the HE scenario foresees a constant ratio of CO_2/primary energy (KG/GJ) between 1985 and 2025, while the LE scenario reduces this ratio by 3 percent.

7 CONCLUSIONS

In both scenarios, improvements in energy efficiency and shifts in the fuel mix lead to a less energy-intensive Argentina in 2025. Across almost every sector, natural gas comprises an increasing share of the energy mix, and oil's share decreases. Power generation also comes to rely more heavily on natural gas in 2025, lessening the reliance on capital-intensive hydro and nuclear power.

According to the low emissions scenario, the greatest opportunities for energy savings lie in the transport and industrial sectors. Together, these two sectors account for 84 percent of the reduction in energy use and 64 percent of the carbon savings achieved in the LE scenario. Within the transport sector, the car and truck sub-sectors appear most conducive to change.

While the low emissions scenario incorporates some basic measures that would reduce both energy use and carbon emissions in Argentina, the country could reduce carbon emissions further by implementing more stringent actions. One example of this effort would be to increase the use of natural gas beyond the level proposed in the LE scenario. Over the past few years, many of the nation's taxi cabs switched from gasoline to natural gas. Drivers who travel more than 18,000-20,000 km per year find natural gas to be competitively priced. Measures to lower the price of natural gas further, particularly in relation to diesel fuel costs, would promote its more widespread use. In addition, only some of Argentina's urban centers can provide natural gas to cars at present. Efforts to improve the natural gas distribution network would also facilitate an easier transition away from oil.

The levels of energy use and carbon emissions in both the high and low emissions scenarios are largely influenced by the economic assumptions made for Argentina between 1985 and 2025. If Argentina experiences more rapid rates of economic growth over the next four decades, CO_2 emissions and energy demand are likely to surpass the levels presented in the scenarios. However, the greater financial resources also would provide Argentina with greater opportunities to renovate its infrastructure and improve the energy efficiency of its economy.

BRAZIL

1 INTRODUCTION

One of the largest countries in the world, Brazil makes a commensurate contribution to global carbon emissions. Brazilian deforestation, which according to recent estimates[1] produced 250 million tons of carbon each year during the 1980s, accounts for the majority of these emissions. In comparison, energy production and consumption in Brazil generate a small share of the nation's carbon. Coal, oil and natural gas use in Brazil emitted 45 million tons of carbon in 1985. While the nation also relies heavily on biomass and hydropower, these two energy sources release no net emissions.[2] Due to the emphasis on biomass and hydro, oil's share in Brazil's delivered energy demand remains relatively low compared to the other Latin American nations analyzed in this study. The lesser role of oil, coal and natural gas in the nation's energy mix helps temper Brazil's emissions of energy-related carbon.

This paper presents two scenarios of Brazil's energy use and carbon emissions for the year 2025.[3] As described in these scenarios, the Brazil of 2025 has a higher level of comfort, increased mobility, improved environmental quality and slightly better income distribution than the Brazil of today.[4]

In the high emissions (HE) scenario, current energy use trends continue between 1985 and 2025: fuelwood use declines; natural gas demand blossoms further; electricity consumption increases; oil's share in the fuel mix drops; and certain industrial processes rely more heavily on coal and charcoal. By 2025, processes are carried out using the best technology available on the Brazilian market today.

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[1] See G.M. Graca et al., *Tropical Forestry and Global Climate Change: An International Research Network*, Report No. LBL-35326 (Berkeley: Lawrence Berkeley Laboratory, April 1990); M.E. Marcondes Helene and M. Ferreira Bueno, "Tropical Deforestation and CO_2 Emissions: A Review," *Energy and Environment*, vol. 3, 1991; P.M. Fearnside, "Deforestation Rate in Brazilian Amazonia," in G.M. Woodwell (ed.), *The Earth in Transition: Biotic Impoverishment* (New York: Cambridge University Press, in press).

[2] Carbon emissions' figures do not include those emissions generated from the use of biomass fuels. In most cases, we assume that much of the biomass fuel consumed is drawn from agricultural residues, already fallen trees and/or trees that are felled on a sustainable basis. In these instances, the net amount of carbon released into the atmosphere from biomass fuel consumption is negligible. Emissions would have been about 85 million tons if the biomass were derived from perennial sources. On the other hand, we know that part of the deforestation process is due to the use of fuelwood in some branches of industry. It is difficult to separate the deforestation caused by energy use and that caused by changes in soil use. Because we know that the latter activity makes the largest contributions, we leave the issue of carbon emissions from fuelwood to discussions on deforestation.

[3] These scenarios use the disaggregated information available on energy demand in each major sector of the Brazilian economy in 1985 to draw a detailed picture of the nation's end-use energy consumption. In recent years, researchers have developed several energy scenarios for Brazil to forecast power generation capacity requirements and to understand the "energy-related" implications for Brazil of implementing different economic strategies. See Centrais Elétricas Brasileiras S.A. – Eletrobras, *Plano 2010: Relatório Geral* (Rio de Janeiro: Ministério das Minas e Energia, December 1987) and J. Goldemberg, R. Hukai, et al., *Country Study – Brazil, A Study on End-Use Energy Strategy* (São Paulo: Companhia Energética de São Paulo, 1984).

[4] Due to Brazil's current economic hardships, some of the changes assumed in both the high and low emissions scenarios may be disputable. However, the purpose of this exercise is to describe one possible path that the Brazilian economy might take. Given the general context of a plausible economic future, this study attempts to maintain consistency between the assumptions about and the implications for Brazil's economy, energy use and environment.

The low emissions (LE) scenario assumes that between 1985 and 2025 Brazil incorporates the most energy-efficient technology presently available on the world market. The most significant change in the fuel mix is that natural gas becomes a major fuel source in industry while its contribution to power generation decreases as the presently installed hydropower satisfies the bulk of the electricity demand.

The analysis in this paper shows that despite improvements in energy efficiency brought about mainly by faster economic growth, Brazil's carbon emissions increase over three-fold by 2025 in the HE scenario. In the LE scenario, additional changes in lifestyle, technology and government policy aimed specifically at limiting the growth of carbon emissions reduce 2025 carbon emissions to less than half of the HE level.

2 GDP AND POPULATION GROWTH

Population growth rates in Brazil have declined rapidly in recent years; Brazil's population grew by 2.2 percent in 1987, by 2.1 percent in 1988 and by 1.7 percent in 1989. By 2050, the size of Brazil's population is expected to stabilize at 240-250 million.[5] Based on this information, both scenarios assume that Brazil's annual population growth rate averages 1.2 percent between 1985 and 2025. By 2025, Brazil has 214 million inhabitants (Table 1).

Future GDP levels were estimated based on the expected Brazilian lifestyle in 2025 (as defined by the quantity and quality of production and services in place), a comparison with the actual GDP per household in European countries of today and the observation that over time similar levels of comfort can be attained with lower incomes. Between 1985 and 2025, Brazil's GDP increases at an annual rate of 3.2 percent. GDP per capita more than doubles over this time period (Table 1).[6]

Table 1
Economic and Demographic Indicators

	1985	2025
Total Population (Mns)	132	214
Urban Population Share (%)	76%	80%
Number of Households (Mns)	31	55
Total GDP (Bn US$)	250	890
GDP/Household (US$)	8100	16200
GDP/Capita (US$)	1880	4165

[5] G. Martine, "O Mito da Explosão Demografica," *Ciencia Hoje*, vol. 9, no. 51, March 1989.

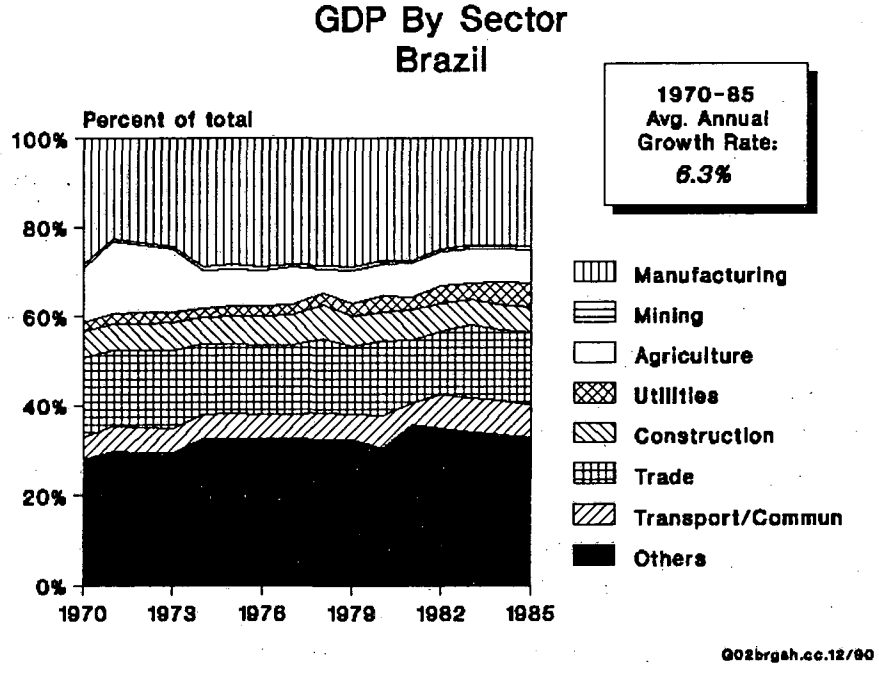
[6] The GDP growth rate for the 1985-2025 period was derived based on the assumption that GDP per household doubles over this time frame. While Brazil's GDP per capita in 2025 still remains far below today's European levels, the comfort levels are similar in Brazil as those currently found in Europe.

3 SECTORAL ANALYSIS AND CARBON EMISSIONS

During the 1970s and 1980s, Brazil showed a considerable capacity to undergo rapid changes in its fuel mix, particularly in the industrial and transport sectors. This flexibility reflects the nation's ability to adapt its energy use to changing economic, social and political conditions. The specific assumptions made for each sub-sector take this characteristic of the Brazilian economy into account.

Between 1970 and 1985, while industry's share of value added remained flat, manufacturing's share fell and mining's share increased (Figure 1). Agriculture's share also declined. Over the next four decades, sectoral shares of GDP witness little change. Value added in the industrial sector falls from 38 percent in 1985 to 35 percent in 2025 and that of the service sector increases from 47 percent in 1985 to 50 percent in 2025.

Figure 1



Brazilian industry has the largest sectoral energy requirements (Table 2). However, because biomass fuels meet 44 percent of industry's demands, commercial energy-related carbon emissions from industry remain low relative to the other nations studied (Table 10). Brazil's transport sector -- which consumes lesser amounts of energy than industry but relies heavily on fossil fuels -- generated the most sizable portion of commercial energy-related carbon. Brazil's residential, agriculture and service sectors all emit relatively small shares of carbon (Table 10).

Table 2[7]
Sectoral Shares in Energy Use (PJ)

	1985	2025	
		High	Low
Total	4256	10511	6288
Residential	20%	12%	14%
Industrial	41%	44%	43%
Transport	30%	32%	31%
Services	4%	6%	4%
Agriculture	6%	6%	8%

3.1 RESIDENTIAL SECTOR

Cooking currently absorbs 83 percent of Brazil's residential energy. Due largely to a decline in biomass use, cooking accounts for less than 60 percent of the nation's household energy use by 2025. Between 1985 and 2025, the rapid dissemination of household appliances and increased demand for water heating spur a rapid growth in energy use by households. As a result, the combined share of appliances and water-heating activities in residential energy use increases from 17 percent in 1985 to over 40 percent in 2025.

A number of factors contribute to shifts in Brazil's residential fuel demand. The size of Brazil's overall population continues to grow, placing increasing pressure on Brazil's energy supplies. However, because a large share of Brazil's population already resides in cities, the percentage of the population living in urban areas expands only minimally between 1985 and 2025 (Table 1). Consequently, urbanization has a far more limited impact on household energy use in Brazil than in many of the other study countries.

The size of urban households shrinks from 4.2 to 3.8 persons between 1985 and 2025. The average number of members in Brazil's rural households diminishes from 4.9 to 4.3 persons over the observed time period. As total population growth continues and household sizes decline, the number of households expands. In 2025, Brazil has 45 million households located in urban regions and 10 million located in rural regions.[8]

In 1985, 95 percent of Brazil's urban households and 39 percent of its rural households were electrified. By 2025, the electricity grid extends to 100 percent of the urban population. About 5 million rural households inhabiting the Amazon and Pantanal regions continue to lack electricity in 2025. Instead, they rely on small gas or fuelwood generators, photovoltaics or solar heaters to fulfill their electricity requirements. Due to the high level of urbanization in Brazil, however, by 2025, 91 percent of all households have electricity.

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

[8] Note that in Brazil rural areas are defined by their level of economic activity, not by their population size.

LPG served as a primary **cooking** fuel in 90 percent of Brazil's urban households in 1985. As certain Brazilian cities develop their natural gas grids -- particularly larger metropolitan areas, such as São Paulo and Rio de Janeiro, and Southern cities, where space heating is desired -- LPG's role in urban cooking declines slightly, but still remains dominant. In the HE scenario, 20 percent of all urban households use natural gas for cooking, up from 1 percent in 1985. In the low emissions scenario, 30 percent of all urban households use natural gas for cooking in Brazil by 2025.

Fuelwood, which constitutes the sole cooking fuel source in 70 percent of today's rural Brazilian households and a supplementary source in at least 20 percent more, continues to supply all of the cooking energy to about 50 percent of Brazil's rural homes by 2025. In 2025, the other half of all rural Brazilian households relies on LPG as the primary cooking fuel. In the HE scenario, 20 percent of these primarily LPG-reliant rural homes continue to use fuelwood as a secondary cooking fuel. In the low emissions scenario, however, more stringent local environmental policies put an end to this use of wood.[9]

The amount of fuel used for cooking per household declines as Brazilians change their eating habits and as new technologies penetrate the market. Between 1985 and 2025, rural and urban households in Brazil continue to substitute pasta (which has a quicker cooking time) for rice and beans and also eat out more often. In the LE scenario, the efficiency of gas ranges increases from 40 percent to 60 percent, leading to even lower levels of fuel use for cooking.

A high share of Brazil's households have **water-heating** devices at present (80 percent of urban homes and 20 percent of rural homes). By 2025, all households have water heating. In urban areas most of the water heaters require electricity, although natural gas serves as the major supplementary fuel source. In rural households, where electricity is less accessible, electricity serves only half of all homes and LPG provides the remainder.[10]

By 2025, Brazil's water-heating activities place greater pressure on the nation's electricity supply than they do today. Most water heaters currently used in Brazil -- cheap instant electric flow-through heaters ("chuveiros") -- consume large quantities of electricity during peak times. Between 1985 and 2025, the use of storage heaters rises, particularly in apartment buildings and in high-income households. While these heaters provide better service, they require more electricity per household than do the "chuveiros." As more efficient vertical storage systems replace the currently available horizontal systems, the unit energy consumption of electric storage heaters declines somewhat. Even with these improvements, however, the electric heaters continue to consume four to five times more energy per household than the instant showers.

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[9] The assumption here is that environmental concerns lead to a reduction in fuelwood use as a means for curtailing local pollution levels. In terms of net CO_2 emissions, substituting fuelwood for hydrocarbons (when fuelwood does not entail deforestation) reduces the intensity of the environmental impact of energy activities.

[10] The HE scenario assumes that one third of the rural households connected to the grid will continue using electric showers. This share drops to 15 percent when more stringent policies are implemented.

Currently, very few Brazilian households rely on **space heating**, mainly because most areas have hot or temperate climates. In some regions of the south, however, cooler temperatures occasionally necessitate the use of small electric heaters. By 2025, electric space heating diffuses to 20 percent of urban and 10 percent of rural households. Unit energy consumption remains stable.

Lighting and appliances currently absorb 12 percent of Brazil's residential energy. Saturation levels increase for virtually every type of appliance between 1985 and 2025 (Table 3). The use of water pumps drops in both rural and urban households, however, as water distribution systems improve. According to the HE scenario, appliances consume one quarter of the nation's residential energy demand in 2025.

Table 3
Appliance Saturation and Unit Electricity Demand

	1985	2025	
		High	Low
Lighting			
Urban household (kWh/yr)	233	373	224
Rural household (kWh/yr)	267	427	256
Refrigeration			
Ref. energy consumption/HH (kWh/yr)	666	1000	400
Urban saturation (%)	79%	100%	100%
Rural saturation (%)	64%	100%	100%
Washers			
Wash. energy consumption/HH (kWh/yr)	60	60	48
Urban saturation (%)	30%	80%	80%
Rural saturation (%)	5%	40%	40%
Air Conditioning			
AC energy consumption/HH (kWh/yr)	500	750	300
Urban saturation (%)	3%	20%	20%
Rural saturation (%)	0%	20%	20%
Water Pump			
W.P energy consumption/HH (kWh/yr)	240	240	240
Urban saturation (%)	12%	0%	0%
Rural saturation (%)	15%	5%	5%

In the high emissions scenario, unit energy consumption increases or remains stable for all appliances by 2025 (Table 3). The increases stem largely from higher levels of comfort which entail larger refrigerators, more light bulbs per household and the increased use of air conditioners. In the LE scenario, however, unit energy consumption decreases for almost every type of appliance. In this scenario, Brazil's households gain access to the most modern and efficient appliances currently available and more compact fluorescent light bulbs disseminate across the nation (on average, two per household). As a result, in the LE scenario, the average electricity demand per household mirrors current levels, despite the higher saturation of comfort devices.

Energy demand in the residential sector increases by 63 percent between 1985 and 2025 in the HE scenario (Table 4). Appliances account for almost half of the increase in residential energy demand in this scenario and water heating accounts for another 35 percent. The LE

scenario limits this growth to 2 percent of the 1985 level. The promotion of more efficient technologies -- particularly in the areas of cooking and appliance use -- reduces electricity and LPG consumption significantly in the latter scenario.

Table 4
Residential Energy Use (PJ)

	1985	2025	
		High	Low
Total	842	1335	871
Oil (LPG)	20%	21%	20%
Natural Gas	1%	11%	19%
Biomass	64%	34%	30%
Electricity	16%	34%	31%

Electricity consumption increases far more rapidly than fuel consumption between 1985 and 2025. In the HE scenario, electricity demand increases by 3.1 percent annually over the 40-year period, while fuel demand increases by only 0.5 percent annually. In the LE scenario, electricity use expands by 1.8 percent each year, while fuel requirements actually decrease by 0.4 percent per annum as biomass is replaced by LPG.

The composition of the residential fuel mix shifts over the observed time period reflecting this uneven growth (Table 4). Biomass is increasingly replaced by petroleum fuels and the use of natural gas in urban homes increases several-fold. In both scenarios, electricity's share in the residential fuel mix rises considerably.

With the overall increase in energy consumption in the HE scenario, residential carbon emissions increase from 4 million tons to 15 million tons between 1985 and 2025. Because Brazil halves its residential biomass demand and replaces biomass sources with fossil fuels, residential carbon emissions increase at a much more rapid rate than does energy demand. Even in the low emissions scenario, where energy demand remains virtually flat between 1985 and 2025, energy-related carbon emissions rise from 4 to 7 million tons due to fuel substitutions.

3.2 TRANSPORTATION SECTOR

Typical of most Latin American countries, Brazil expends a relatively large share of its energy satisfying transportation needs. Over the next four decades, the fuel requirements of this sector continue to increase. In the high emissions scenario, the dramatic expansion of Brazil's car fleet accounts for almost half of the growth in transport's energy demand between 1985 and 2025.

Despite the potential for other modes offered by Brazil's British-built rail system and vast waterways, road transport currently satisfies most of Brazil's passenger and freight demands. While both the rail and water systems play increasingly important roles by 2025, road transport remains the dominant mode.

Higher-income families in Brazil currently have mobility levels equivalent to the average U.S. level. By 2025, personal mobility increases substantially, largely due to higher income levels and better access to secondhand cars. By 2025, households with incomes above the five lowest minimum salaries[11] (53 percent of the total Brazilian population) own on average 1.5 cars, while those with incomes between the second and fifth minimum salaries (30% of the population) possess 0.5 cars on average. Overall, Brazilian households own an average of one car and one motorcycle. However, 31 percent of all households still cannot afford cars in 2025 and 9 percent cannot afford motorcycles.

The car fleet increases over six-fold between 1985 and 2025. In the HE scenario, cars consume almost 1414 PJ of fuel in 2025 up from 477 PJ in 1985, accounting for the largest share of the increase in Brazil's transport energy use. While the number of vehicles in 2025 is the same in the two scenarios, cars travel shorter distances and are less fuel intensive in the LE scenario as a result of pricing policies, improvements in public transportation and increased use of motorcycles (Table 5).[12] These measures reduce the fuel demand of automobiles to just over half of the HE figure.

Table 5
Transportation Indicators

	1985	2025	
		High	Low
Cars			
Per 1,000 persons	63	245	245
Fuel intensity (liters/km)	0.13	0.07	0.05
Distance traveled per car (km/yr)	13000	13000	11700
Motorcycles			
Per 1,000 persons	7	263	263
Fuel intensity (liters/km)	0.02	0.014	0.013
Distance traveled per m-cycle (km/yr)	5000	7000	8000
Trucks			
Per 1,000 persons	16.7	34.1	34.1
Fuel intensity (liters/km)	0.23	0.18	0.09
Distance traveled per truck (km/yr)	25000	30000	30000
Buses			
Per 1,000 persons	1.0	2.0	2.2
Fuel intensity (liters/km)	0.4	0.28	0.16
Distance traveled per bus (km/yr)	30000	30000	30000

In the HE scenario, the number of buses per capita doubles. The LE scenario further increases the size of the bus fleet as a result of government policies geared at reducing private vehicle use. Still, due to greater efficiency improvements, in the LE scenario buses require only 63 percent of the fuel in 2025 as in the HE scenario.

[11] Brazil uses the term "minimum salary" to measure income levels. In 1990, one minimum salary was equal to about $US 2000/year using purchasing power parity.

[12] Private vehicle saturation is assumed unelastic to efficiency policies. On the other hand, distance traveled (i.e. km/year) changes in the LE case.

Alcohol, which today contributes a 39 percent share of all fuel used in cars, increases its contribution to 50 percent in the HE scenario. In the LE scenario, the share of biomass alcohol in the automobile fuel mix rises to 81 percent and the share of oil drops to 19 percent.

Despite Brazil's dependence on inefficient biomass fuels, fuel efficiency improves for all forms of passenger transport between 1985 and 2025 (Table 5). The HE scenario raises the efficiency of cars substantially, thereby limiting the extent of further improvements in the LE scenario. In the HE scenario, the intensity of fuel use in cars drops from 0.13 liters/kilometer (lit/km) to 0.07 lit/km. This figure falls slightly, to 0.05 lit/km, in the LE scenario. In the HE scenario, the intensity of fuel use diminishes by one third for buses and motorcycles as these vehicles achieve the "best" efficiency levels currently observed in Brazil. The LE scenario achieves further efficiency gains as levels equal the highest efficiencies in the world today.

At present, the poor condition of the road system and the low quality of fuels in Brazil pose barriers to achieving these efficiency targets.[13] By 2025, most of these obstacles should be surmountable. In order to reach the higher efficiencies presented in the LE scenario, Brazil will have to implement fuel quality regulations aimed at maintaining a constant quality of gasohol, a factor which currently hinders the development of high efficiency vehicles in Brazil.

Freight transport increases proportionately with the level of industrial activity. The size of the truck fleet increases more than three-fold over the observed time frame. In the HE scenario, the growth in truck traffic accounts for the second largest increase in transport energy demand between 1985 and 2025 following cars. Fuel demand for trucks rises from 489 to 1318 PJ. In the LE scenario, the efficiency of fuel use improves significantly and trucks' energy demand thereby falls to half of the HE level (Table 5).

Detailed data on air, rail and ship fleets and efficiencies are currently unavailable. Fuel consumption levels for these three transport modes were calculated on the basis of their contribution to the country's economic activity, which was assumed to remain constant over time. Both scenarios assume that fuel intensities (GJ/US$) decline. The electricity intensity (kWh/US$) of rail transport rises, however, as electricity increasingly replaces diesel fuels.

Transport energy demand increases almost three-fold over the next 40 years according to the HE scenario, reaching 3364 PJ in 2025. With the implementation of efficiency policies for all modes and uses, the low emissions scenario limits this growth in energy demand to 1.6 times the 1985 level.[14] While transport energy demand per capita increases by 65 percent in the HE scenario, demand per capita remains stable in the LE scenario.

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[13] A. Ketoff, *Overcoming Barriers to Energy Efficiency in Transportation*, Report No. LBL-30444 (Berkeley, CA: Lawrence Berkeley Laboratory, 1991).

[14] The aggregate intensity, calculated in terms of total energy per unit of economic activity of the transport sector, is reduced by 40 percent in the HE case and by more than 65 percent in the LE case. This change, however, is merely a function of the assumption made on the future importance of transport's value added, which was fixed at 5 percent of the GDP compared to the present level of 3.8 percent.

The transport fuel mix grows less carbon intensive by 2025. Oil, which comprised 85 percent of the fuel mix in 1985, constitutes a 77 percent share in 2025 in the high emissions scenario. Alcohol provides 22 percent of transport energy and electricity and coal each provide 1 percent. In the LE scenario, oil's share drops to 65 percent and alcohol's rises to 33 percent.

Carbon emissions from the transport sector increase less rapidly than energy demand in both scenarios due to a diminished reliance on carbon-intensive fuels coupled with improved efficiencies. In 1985, the transport sector generated more carbon than any of Brazil's other sectors. The 1985 figure of 21 million tons increases to 51 million tons in the HE scenario. The LE scenario reduces these emissions to just about 50 percent of the HE figure.

3.3 INDUSTRIAL SECTOR

Brazil has a highly diversified industrial sector, with activities ranging from high-tech computer manufacturing to energy-intensive steel production. Manufacturing activities accounted for 27 percent of value added in 1985; by 2025, this share drops to 25 percent. Brazil's **energy-intensive industries** include steel, non-ferrous metals, cement, chemicals and paper and pulp.

Brazil conducted most of its major construction efforts during the 1970s. The growth in production between 1985 and 2025 stems mostly from growing demands for houses and consumer goods and from a limited expansion of Brazil's infrastructure. Total output in most of the energy-intensive industries less than doubles over the next 40 years and output per capita witnesses only moderate increases (Table 6).

Considering the quality of the primary materials processed and the fuels used, Brazil's industry runs relatively efficiently at present. This efficiency stems from a major rationalization of Brazil's industrial process over the last 10-15 years, which included inter-fuel substitutions and efficiency improvements in steel, cement, chemical and paper and pulp manufacturing.

In the HE scenario, capital turnover results in a 32 percent drop in fuel intensity (GJ/US$) and a 20 percent decline in biomass intensity (GJ/US$) by 2025. The intensity of electricity use (kWh/US$) remains relatively stable overall, although for **non-energy-intensive manufacturing** intensity increases by 20 percent, as electricity powers a greater share of industrial processes.

Recent studies reveal that the potential for large efficiency improvements could be tapped if financing were available.[15] The LE scenario incorporates these measures and, as a result, fuel intensity drops by 55 percent of the 1985 level, electricity intensity falls by about 40 percent and biomass intensity witnesses the greatest decline of 60 percent.[16]

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[15] A. Bonomi et al., *Manual de Recomendacao: Conservacao de Energia na Industria de Celulose e Papel*, vol. 1, e2 (São Paulo: Instituto de Pesquisas Tecnologicas, 1985).

[16] Cogeneration potential is not accounted for here.

Table 6
Production of Energy-Intensive Materials

	1984	2025 High	2025 Low
Steel			
'000 tons	18880	39655	39655
Per capita	0.14	0.19	0.19
Fuel Intensity (GJ/T)	15.6	14.0	9.3
Biomass Intensity (GJ/T)	9.9	7.9	4.0
Electrical Intensity (kWh/T)	853.4	852.4	852.4
Non-Ferrous Metals			
'000 tons	1010	1795	1795
Per capita	7.6	8.4	8.4
Fuel Intensity	26.2	23.5	15.7
Biomass Intensity	6.1	4.9	2.4
Electrical Intensity	17405	17405	10443
Cement			
'000 tons	20610	39970	39970
Per capita	156	187	187
Fuel Intensity	2.4	2.2	1.4
Biomass Intensity	1.7	1.3	0.7
Electrical Intensity	119.1	119.1	71.5
Chemicals			
'000 tons	19590	37990	37990
Per capita	148	178	178
Fuel Intensity	5.5	5.0	3.3
Biomass Intensity	0.9	0.7	0.3
Electrical Intensity	670.8	670.8	402.5
Paper and Pulp			
'000 tons	7470	24135	24135
Per capita	56	113	113
Fuel Intensity	2.9	2.6	1.7
Biomass Intensity	12.2	9.7	4.9
Electrical Intensity	887.5	887.5	532.5

Industrial energy demand increases substantially between 1985 and 2025 in the HE scenario (Table 7). The LE scenario constrains total demand to 42 percent of the HE level. The growth of Brazil's non-energy-intensive industries accounts for almost two thirds of the increase in industrial energy demand between 1985 and 2025. The expansion of the nation's energy-intensive industries accounts for most of the remaining increase. While non-energy-intensive industries place the greatest pressure on Brazil's biomass and electricity supplies, energy-intensive industries account for the majority of the increase in fuel needs.

Biomass continues to satisfy the bulk of industrial demand in the HE scenario (Table 7). Natural gas and electricity use increase minimally and the shares of coal and oil drop. In the LE scenario, the absolute amount of oil consumed by industry drops below the 1985 level, the amount of coal only increases minimally and natural gas use increases further.

In the HE scenario, industrial carbon emissions increase by 215 percent, from 15 to 49 million tons, between 1985 and 2025 (Table 10). In the LE scenario, emissions increase by less than 50 percent. The substantial difference between the projections of industrial carbon

emissions in the high and low emissions scenarios is the result of implementing stringent policy measures to increase efficiency and the use of natural gas.

Table 7
Industrial Energy Use (PJ)

	1985	2025	
		High	Low
Total	1764	4598	2691
Coal	18%	14%	15%
Oil	16%	14%	10%
Natural Gas	2%	4%	11%
Biomass	44%	45%	38%
Electricity	20%	24%	26%

3.4 SERVICE SECTOR

Brazil's service sector witnesses rapid growth between 1985 and 2025.[17,18] In both scenarios, energy demand in the service sector grows more rapidly than in the rest of the economy.

In the HE scenario, electricity's contribution to all end uses in the service sector continues to increase. Thus, electricity intensity increases by 10 percent. Fuel intensity drops by just over 20 percent, due largely to the increased substitution of electricity for LPG.

In the LE scenario, the development of more effective natural gas distribution systems reduces the use of biomass. As a result, biomass intensity drops by 45 percent of 1985 levels and fuel intensity falls by 47 percent. Most significantly, efficiency improvements in lighting, refrigeration and air conditioning reduce the intensity of electricity use to 45 percent of the 1985 level.

The high emissions scenario shows energy use in the service sector increasing four-fold between 1985 and 2025 (Table 2). The low emissions scenario alleviates pressure on the nation's energy resources by reducing services' energy demand to about 45 percent of the HE level.

In 1985, electricity supplied 78 percent of the service sector's energy and oil provided 14 percent. In the HE scenario, electricity's share increases to 83 percent and oil's share drops.

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[17] Companhia Energética de São Paulo (CESP), *Consumo de Energia Nos Setores de Comércio e Servicos -- Relatório Final* (São Paulo: CESP, February 1988).

[18] The estimates for energy demand in 2025 are based on the 1985 energy/GDP ratios for each energy source. The calculations assume that changes occur in the intensities of fuel, biomass and electricity use and that natural gas increasingly replaces oil.

In the LE scenario, different fuel substitutions limit the use of carbon-intensive fuels. The shares of both oil and electricity in the fuel mix fall below their 1985 levels and a twelve-fold increase in natural gas demand between 1985 and 2025 compensates for their declining shares.

Carbon emissions from the service sector increase nine-fold in the HE scenario, expanding from 1 to 9 million tons. The low emissions scenario substantially restrains the growth of carbon emissions to 2 million tons in 2025.

3.5 AGRICULTURE SECTOR

In 1985, Brazilian agriculture used 100 PJ, or under 6 percent, of the nation's energy. Biomass provided 48 percent of this energy,[19] oil 45 percent and electricity the remainder.

In both scenarios, as mechanical irrigation processes increasingly penetrate the sector, electricity comes to play a growing role in satisfying agricultural energy demand. In the HE scenario, technological improvements, such as better tractors, lead to a 20 percent reduction in both fuel and biomass intensities (GJ/US$). But, due to increased rural electrification, the intensity of electricity use increases by 40 percent. The LE scenario manages to decrease fuel intensity by 40 percent of the 1985 level. In this scenario, biomass efficiency declines by 30 percent. The potential for further reducing biomass intensity appears unlikely because currently little waste occurs in the use of biomass for drying agricultural products. Electricity intensity increases in the LE scenario, as in the HE scenario, but due to further improvements in efficiency, this growth is restrained to 20 percent of the 1985 level.

Energy demand in the agriculture sector increases more slowly than economic growth. Energy demand increases to 260 PJ by 2025 in the HE scenario. Electricity's share in the fuel mix grows to 11 percent, compensating for declining shares of oil and biomass. The LE scenario reduces the increase in total energy demand by 18 percent. The shares of biomass and electricity both increase in order to achieve greater reductions in oil consumption.

Agricultural carbon emissions triple in the HE scenario and double in the LE scenario between 1985 and 2025. In both cases, however, the agriculture sector produces a small share of the nation's carbon.

4 AGGREGATE DELIVERED ENERGY DEMAND

Delivered energy demand increases by 150 percent between 1985 and 2025 in the HE scenario (Table 8).

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[19] Information on non-commercial fuel use in the agriculture sector was derived from surveys of fuelwood collection and charcoal production on farms. Instituto Brasiliero de Geografia e Estatistica, *Censo Agropecuario Brasil*, vol. 1 (Rio de Janeiro: Instituto Brasiliero de Geografia e Estatistica, 1984).

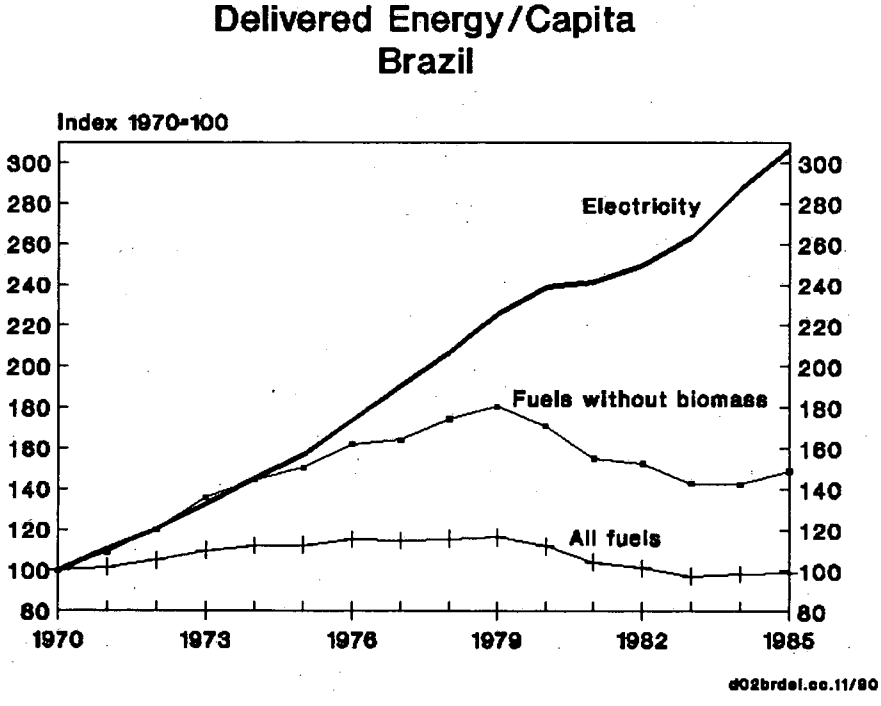
Table 8
Aggregate Energy Use (PJ)

	1985	2025	
		High	Low
Total	4256	10511	6288
Coal	8%	6%	7%
Oil	39%	36%	31%
Natural Gas	1%	3%	8%
Biomass	38%	34%	35%
Electricity	14%	20%	20%

With the implementation of more stringent policies, the low emissions scenario restricts the growth in energy demand to 48 percent of its 1985 level. The fuel mix remains similar in both scenarios. Electricity's share increases and coal and oil's shares decline. In the LE scenario, natural gas replaces more of the oil supply.

At 32 GJ/capita, Brazil's delivered energy demand per capita in 1985 stood at about one half the world's average. Rising steadily during the 1970s, demand per capita peaked in 1979 and then began to fall with the onset of Brazil's recession (Figure 2).

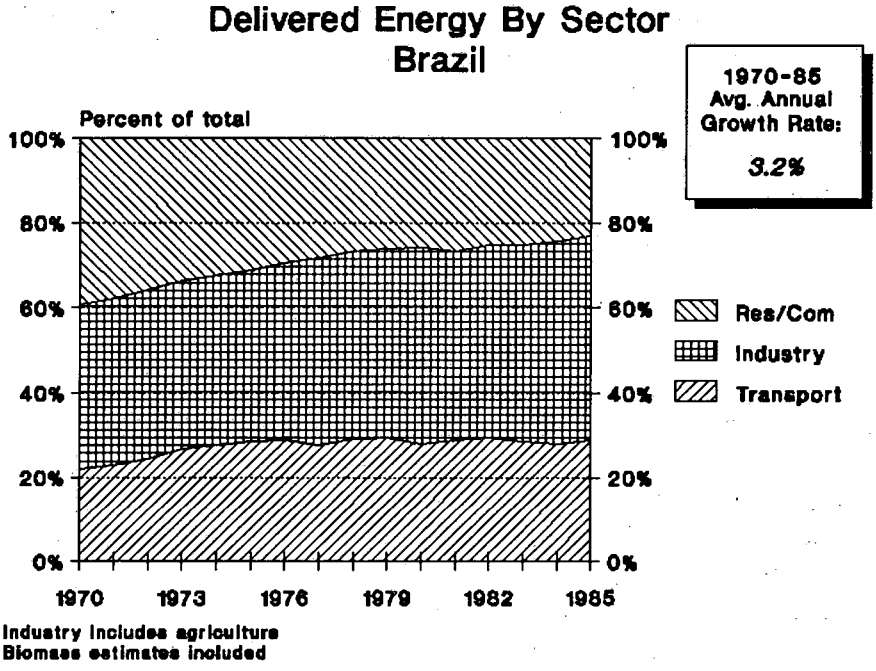
Figure 2



In the HE scenario, energy demand per capita begins to ascend once more. In 2025, it approaches the current world average reaching 49 GJ. In the low emissions scenario, energy demand per capita is reduced to 29 GJ.

Between 1970 and 1985, the share of the industrial and transport sectors in Brazil's delivered energy demand increased. On the other hand, the combined share of the residential and service sectors declined as a result of the replacement of inefficient biomass sources with more efficient modern fuels primarily for cooking (Figure 3). Over the next four decades, these trends continue as the residential sector further increases its reliance on modern fuels (Table 2).

Figure 3



4 ELECTRICITY GENERATION

Total electricity demand increases over three-fold in the HE scenario between 1985 and 2025. In the LE scenario, electricity demand doubles. This growth entails a considerable increase in capacity requirements as well as major shifts in the electricity generation fuel mix.

Historically, electricity demand per capita has been higher in Brazil than in many other developing countries. Between 1985 and 2025, electricity demand per capita increases from 5.2 to 10.9 GJ. The LE scenario reduces electricity demand per capita considerably to 6.3 GJ.

The transmission and distribution of electricity improves over the observed time period. Losses fall from 11 percent in 1985 to 8 percent in 2025. Additionally, the thermal generation efficiency improves for almost every fuel type. The overall efficiency of thermal generation

increases from 27 percent in 1985[20] to 44 percent in the HE scenario and 48 percent in the LE scenario by 2025. The use of combined cycle units leads to this high efficiency level.

In both scenarios, the key to satisfying the increased electricity demand lies in increasing Brazil's hydroelectric capacity. The Brazilian government actually has planned to increase the nation's hydroelectric capacity beyond the levels indicated in the scenarios, but environmental and social concerns appear likely to limit the construction of large dams in the Amazon Basin. Both scenarios assume that safeguarding the Amazon forest becomes a political priority in Brazil. While hydroelectric production almost doubles in both scenarios, the share of hydropower in total electricity generation falls considerably in the HE scenario (Table 9).

Table 9
Electricity Generation (PJ)

	1985	2025	
		High	Low
Total	694	2330	1335
Coal	2%	5%	1%
Oil	2%	5%	1%
Natural Gas	0%	30%	7%
Biomass	1%	8%	3%
Nuclear & Geothermal	2%	3%	1%
Hydro, Solar & Other	93%	50%	85%

Generating the amount of electricity required in the HE scenario will entail greater reliance on thermal generation. The scenarios assume that natural gas is the fuel of choice. Brazil did not derive any of its electricity from natural gas in 1985. In the high emissions scenario, natural gas accounts for 30 percent of all electricity generation. The low emissions scenario reduces natural gas's share considerably (Table 9).

In the HE scenario the fuel needed for electricity generation in 2025 absorbs about one third of Brazil's primary energy supply and electricity generates 26 percent of the nation's carbon emissions (up from 5 percent in 1985). The LE scenario diminishes electricity's share in the primary energy supply to 25 percent and its share in carbon emissions to 8 percent.

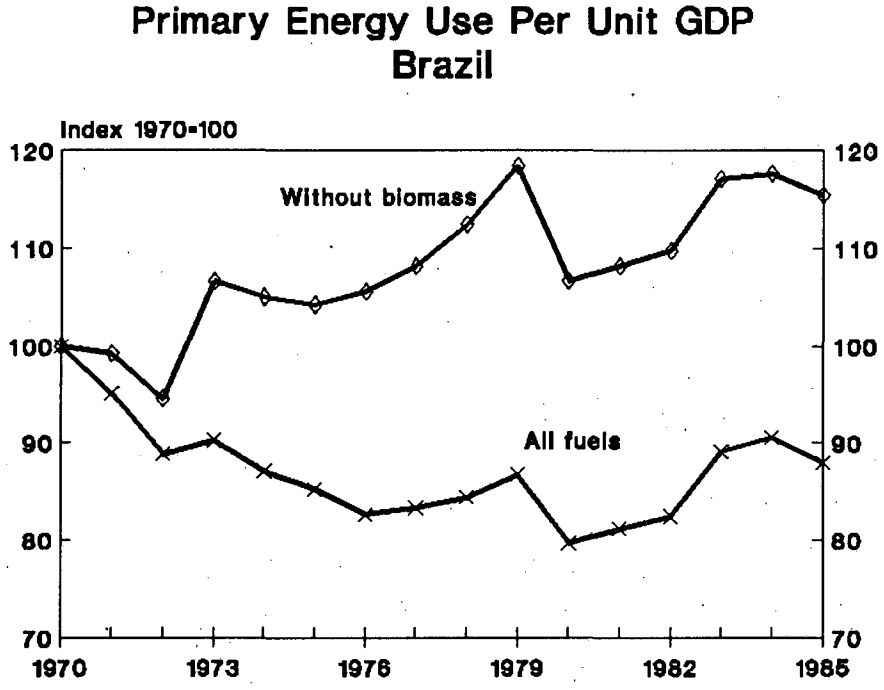
The large energy requirements of electricity generation, the high costs of increasing the nation's generation capacity and electricity's high contribution to CO_2 provide the foremost incentives to implement increased electricity-efficiency measures across Brazil's end-use sectors.

[20] Efficiency was particularly low in 1985 because it was used most often as peak capacity.

5 ENERGY INTENSITY AND PRIMARY ENERGY SUPPLY

Although the energy intensity of Brazil's economy has wavered over the past decade and a half, it was close to its peak in 1985 (Figure 4). In the high emissions scenario the amount of primary energy required to produce each unit of GDP (including biomass) drops at an average rate of 0.7 percent a year, from 18.8 MJ/US$ GDP in 1985 to 14.4 MJ/US$ GDP in 2025. In the LE scenario, a more rapid rate of decline (2.2 percent annually) leads to a substantial reduction in energy intensity to 7.8 MJ/US$ GDP by 2025.

Figure 4



In accordance with shifting sectoral demands, decreasing energy intensity and increasing power generation requirements, Brazil's primary energy supply increases at a rate of 2.5 percent annually between 1985 and 2025 in the high emissions scenario. The low emissions scenario reduces the rate of increase to 1 percent per year. By 2025, Brazil's primary energy supply increases almost three-fold in the HE scenario. In the LE scenario it increases by 50 percent.

Primary energy supply per capita, at 35 GJ in 1985, increases by about 70 percent in the high emissions scenario to 60 GJ/capita. In the low emissions scenario, primary energy per capita drops below the 1985 level in 2025 to 32 GJ/capita.

6 CARBON DIOXIDE EMISSIONS

Deforestation accounts for the largest share of carbon emissions generated in Brazil today. As emissions from deforestation decrease over time, energy-related carbon activities account for the bulk of the nation's carbon emissions.[21]

Energy-related carbon emissions increase to 138 million tons by 2025 according to the HE scenario (Table 10). The low emissions scenario curtails the amount of carbon emitted in 2025 by 55 percent of the HE level.

Table 10
Carbon Emissions (Million Tons)

	1985	2025	
		High	Low
Total	45	138	63
Residential	8%	11%	10%
Transport	46%	37%	40%
Industry	33%	35%	34%
Services	2%	7%	2%
Agriculture	5%	5%	7%
Losses	6%	6%	6%

The transport sector continues to produce most of Brazil's carbon in 2025, although its share in total emissions drops (Table 10). Industry also continues to generate a significant share of Brazil's carbon. The shares of the residential and agriculture sectors remain virtually stable, while the service sector's share increases.

The opportunity for reducing the largest percentage of carbon lies in improving electricity use. In the LE scenario, efficient use of electricity eliminates the need for additional thermal generation. Both scenarios rely on equal amounts of hydro-generation.

Carbon emissions per capita increase from 342 kg in 1985 to 645 kg in 2025 according to the HE scenario. In the low emissions scenario, emissions per capita drop below the 1985 level to 293 kg in 2025. In both scenarios, significantly less carbon is emitted for each unit of GDP produced. This figure drops by 15 percent in the HE scenario and by 61 percent in the LE scenario. Little change occurs, however, in the amount of carbon produced for each unit of primary energy.

[21] If, as most studies indicate, about 70 percent of all deforestation in Brazil was done in the last 10 years, annual emission rates in the 1970s were below 100 million tons. No immediate signs indicate that Brazil's deforestation rate will lower significantly in coming years without strong political actions. Some experts claim, in fact, that annual emissions could increase to between 600 and 700 million tons (Willy Makundi, interview with author, Lawrence Berkeley Laboratory, Berkeley, California, 1990). By 2025, however, either Brazil will have consumed most of its forest (as is the present case in the Ivory Coast) or strong action will have been taken to prevent deforestation. In both cases, annual CO_2 emissions from deforestation drop to around 100 million tons per year or less.

7 CONCLUSION

The high emissions scenario indicates that if Brazil maintains its current energy use patterns in the future, the nation's total energy requirements and carbon emissions will increase several-fold. The low emissions scenario reveals, however, that -- with the adoption of effective policy measures -- energy demand and carbon emissions can increase at a far slower rate, and emissions per capita can actually be reduced to below their 1985 levels. Both scenarios manage to maintain the same level of energy services.

The most significant opportunities for reducing Brazil's energy use lie in the transport and industrial sectors. Within the transport sector, the greatest potential lies in limiting the fuel consumption of both trucks and cars. The implementation of measures for these two modes alone account for 93 percent of the potential energy savings posed for the transport sector in the LE scenario. Within the industrial sector, the greatest opportunities for reducing biomass and electricity inputs lie in the non-energy-intensive industries, while the greatest opportunities for reducing fuel inputs lie in the energy-intensive industries. Brazil can also significantly reduce its residential energy demand; according to the LE scenario, changes in energy use for cooking and appliances alone can reduce household energy demand to two thirds of the HE figure.

Despite the great challenge posed by carbon-abatement efforts, Brazil faces this challenge holding certain advantages. First, unlike many other developing nations, Brazil already has had considerable experience using renewable energy use sources (biomass alcohol and hydro). Second, due primarily to global concern about deforestation, Brazil has developed a high level of environmental awareness. Third, Brazil has relatively well-established scientific and technical capabilities, which are reflected in the existence of the electric utility conservation program and various other institutions and initiatives. Finally, various facets of Brazil's economic and energy demand structure may work to Brazil's benefit as the nation attempts to implement improved strategies to limit energy use and carbon emissions. Examinations of energy-use patterns in the industrial sector since the 1970s suggest that Brazilian industries have the ability to adapt well to changes in fuel prices by shifting their fuel mixes and absorbing new production processes.[22] Brazil's service sector, presently at the very early stages of its development, also can incorporate substantial efficiency improvements (primarily through the construction of more energy-efficent buildings and other improved devices and structures) as it evolves in the future.

The cost of limiting the growth of energy and, therefore, carbon emissions requires a thorough evaluation. The savings implied by the avoided costs for new power generation alone could prove quite beneficial for the Brazilian economy. Concrete opportunities exist for minimizing the growth of carbon emissions in Brazil; the decision appears to be primarily a political one.

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[22] G.M. Graca, "L'évolution Harmonique de la Consommation Petrolière au Brasil," *Revue de l'Energie*, vol. 5, 1991; Ministério das Minas e Energia, *Balanco Energetico Nacional 1988. Ano Base 1987* (Rio de Janeiro, 1988).

MEXICO

1 INTRODUCTION

Mexico, the third largest producer of carbon emissions from energy production and use in the developing world, generated 74 million tons of carbon[1] in 1987. At present, oil forms the foundation of Mexico's energy supply. Between 1987 and 2025, as the nation's natural gas resources grow increasingly scarce, oil and imported coal take on a more dominant role. With the growing dependence on these two carbon-intensive fuels, Mexico emits substantially more energy-related carbon than any other Latin American nation by 2025.

The following paper describes two scenarios of energy use and carbon emissions in Mexico for the year 2025. The scenarios, which use 1987 as their base year, are based on an analysis of Mexico's past energy consumption patterns, population growth rates and economic activities. In the high emissions (HE) scenario, despite energy efficiency improvements, Mexico's carbon emissions increase three-fold by 2025. The low emissions (LE) scenario incorporates further technical improvements and deliberate government actions aimed at mitigating carbon emissions. As a result, this scenario reduces Mexico's carbon emissions in 2025 to 70 percent of the HE level.

2 GDP AND POPULATION GROWTH

Mexico has experienced particularly high rates of population growth in the past. Between 1970 and 1987, the Mexican population expanded at an average rate of 3.1 percent annually. Over the last decade, however, population growth in Mexico has slowed considerably (averaging about 2.3 percent per annum between 1980 and 1990). Between 1987 and 2025, the rate of population growth decreases to about 1.7 percent annually. This growth rate, although significantly lower than before, still remains relatively high compared to those in other Latin American nations. In accordance with this rate, the size of Mexico's population increases from 76.6 million in 1987 to 143.4 million in 2025.

While the economy has been weak in recent years, Mexico's current development and industrialization processes are expected to lead to an increase in the production of manufactured goods and the acquisition of imported consumer items. As a result, the scenarios assume that economic growth averages about 4.4 percent annually between 1987 and 2025, consistent with the 1970 to 1987 increase. Mexico's GDP of US$ 189 billion in 1987 increases over five-fold by 2025 to US$ 1 trillion.

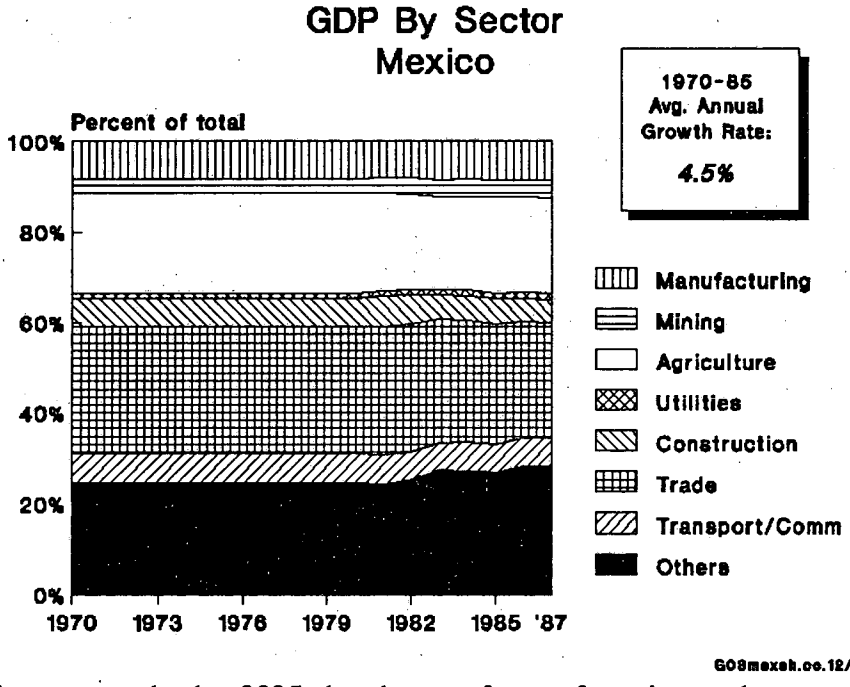
Over the observed time period GDP per capita increases more slowly than overall economic growth due to the expansion of Mexico's population. GDP per capita increases at an

[1] The term "carbon emissions" refers to CO_2 generated by commercial energy production and consumption. Carbon emissions generated by the use of all biomass fuels are excluded unless otherwise specified.

average annual rate of 2.7 percent, rising from US$ 2470 in 1987 to US$ 6980 in 2025. Of the four Latin American countries studied, only the GDP per capita in Venezuela surpasses that of Mexico in 2025.

Between 1970 and 1987, sectoral shares of GDP witnessed minimal change (Figure 1).

Figure 1



Consistent with past trends, by 2025 the shares of manufacturing and transportation in GDP slightly increase. Services and agriculture's shares of value added decline (Table 1).

Table 1[2]
Delivered Energy Use and GDP Shares

	Energy (EJ)			GDP (US$ Billion)		
	1987	2025		1987	2025	
		High	Low		High	Low
Total	3.6	9.7	7.7	189	1000	1000
Residential	14%	14%	9%	--	--	--
Industry	49%	53%	61%	35%	37%	37%
(Manufacturing	--	--	--	29%	32%	32%)
(Energy[a]	--	--	--	6%	5%	5%)
Transport	31%	26%	22%	6%	7%	7%
Services	4%	5%	5%	50%	48%	48%
Agriculture	3%	3%	3%	9%	8%	8%

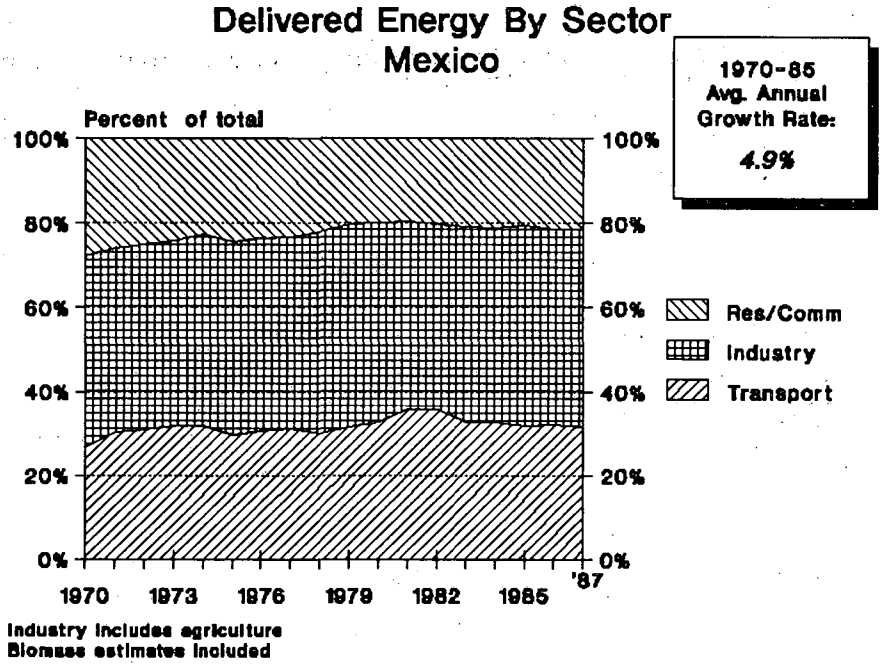
[a] Including Utilities

[2] The shares given in all the tables in this paper do not always add up to 100 percent due to rounding.

3 SECTORAL ANALYSIS AND CARBON EMISSIONS

Between 1970 and 1985, the residential and service sectors' shares in Mexico's total delivered energy use (including biomass) fell and the industrial and transport sectors' shares increased (Figure 2). By 1987, the industrial sector consumed almost half of Mexico's energy. Typical of most Latin American countries with their large vehicle fleets, Mexico's transport sector also absorbed a large portion of the energy supply. The residential, agriculture and service sectors all comprise relatively small shares of delivered energy demand (Table 1).

Figure 2



Carbon emissions in 1987 amount to 74 million tons. While in general, sectoral shares in carbon emissions correspond with those for energy, the residential sector's share is marginally smaller since emissions from biomass are excluded (Table 9).

3.1 RESIDENTIAL SECTOR[3]

Current demographic trends point to significant increases in modern fuel use, appliance

[3] Estimates of residential energy use in Mexico were culled from a variety of sources, including: the annual balances published by the Ministry of Energy, Mines and State Industries. See Secretaria de Energia, Minas e Industria Paraestatal (SEMIP), *Balances Nacionales de Energia* (Mexico City: SEMIP, 1965-1988); unpublished data on electricity sales and customers per tariff class (Mexico has four residential tariffs, depending on the climate zones) compiled by the national utility company, the Comision Federal de Electricidad (CFE); a small 1987 oil industry survey, which estimated the saturation of some basic comforts and appliances in both rural and urban households. See J.M. Willars and A. Herdia, "Caracterización Energética del Sector Doméstico Mexicano," *Cuadernos sobre Energía*, no. 1 (Mexico City: Universidad Nacional Autónoma de México (UNAM), March 1990); and a detailed survey of energy use in the rural sector carried out by SEMIP in 1987, which included estimates of unit consumption for some end-uses. See SEMIP, *Energia Rural en Mexico*, vols. 1-11 (Mexico City: SEMIP, 1988).

ownership and overall energy demand in the residential sector between 1987 and 2025. These increases lead to a marginal increase in the residential sector's share of delivered energy by 2025.

The share of Mexico's population living in urban areas, already at 69 percent in 1987, increases to 80 percent by 2025. The average sizes of both rural and urban households decrease substantially. Urban households drop from 5.1 to 3.5 members between 1987 and 2025. Rural homes average one fewer member per household by 2025 as well.

The growth of the overall population coupled with the decline in household size leads to a three-fold increase in the total number of households. Most of this expansion occurs in urban regions. By 2025, Mexico has 32.8 million urban households and 5.7 million rural households. Virtually all of Mexico's urban households had access to electricity in 1987, but only 53 percent of rural homes were electrified. By 2025, electricity becomes available to 80 percent of Mexico's rural population. As a result, the share of the total population with electricity increases from 87 percent in 1987 to 97 percent by 2025.

Between 1987 and 2025, fuel increases for water heating account for almost 55 percent of the growth in residential energy demand in the HE scenario. Cooking accounts for 22 percent of the increase in residential energy use.

In 1987, **cooking and water heating** combined absorbed 78 percent of the delivered energy used in Mexican households. In urban areas, LPG and kerosene currently provide about 90 percent of the fuel used for cooking and water heating. Natural gas satisfies the remaining demand. In the high emissions scenario, the declining availability of natural gas forces increased reliance on oil-based derivatives for these two end uses in 2025. In the low emissions scenario, while LPG and kerosene continue to provide 95 percent of all cooking energy in 2025, urban households draw 45 percent of their water-heating energy from solar energy.

In Mexico's rural households, biomass currently provides 70 percent of all energy for cooking and half of all energy for water heating.[4] LPG and kerosene supply the remainder. The share of biomass declines in the future as households shift to more convenient fuels. LPG and kerosene comprise 60 percent of the cooking fuel mix and 70 percent of the water-heating fuel mix by 2025 in the HE scenario. In the LE scenario, however, rural homes rely less on these carbon-intensive fuels for water-heating, because solar energy is integrated into the fuel mix.

Urban areas of Mexico already have a high ownership of refrigerators, TV sets and smaller **appliances**. Ownership of washers is low but spreading rapidly. Saturations of all

[4] The separation of end uses for wood used for cooking and other purposes was based on the SEMIP survey for rural areas and on O. Masera, "Sustainable Energy Scenarios for Rural Mexico: An Integrated Evaluation Framework for Cooking Stoves" (Masters of Science Thesis, University of California, Berkeley, 1990).

appliances increase in the rural and urban residential sectors of Mexico by 2025 (Table 2).[5] The unit energy consumption (kWh/household) for each type of appliance is assumed to remain unchanged between 1987 and 2025 in the high emissions scenario. Although efficiencies improve, higher levels of service and comfort (e.g. larger-sized televisions and refrigerators) require more energy per appliance. The amount of energy consumed by individual appliances decreases in the low emissions scenario by 2025, as Mexican households use the most efficient appliances available on international markets today.

Table 2
Appliance Saturation and Unit Electricity Demand

	1987	2025 High	2025 Low
Lighting			
Urban household (kWh/yr)	354	354	177
Rural household (kWh/yr)	283	283	142
Urban saturation (%)	100%	100%	100%
Rural saturation (%)	53%	80%	80%
Refrigeration			
Ref. energy consumption/HH (kWh/yr)	772	772	540
Urban saturation (%)	80%	100%	100%
Rural saturation (%)	44%	80%	80%
Washers			
Wash. energy consumption/HH (kWh/yr)	50	50	40
Urban saturation (%)	30%	80%	80%
Rural saturation (%)	3%	40%	40%
Air Conditioning			
AC energy consumption/HH (kWh/yr)	1250	1250	1000
Urban saturation (%)	20%	25%	25%
Rural saturation (%)	0%	0%	0%

In 1987, refrigeration consumed 43 percent of the electricity in the residential sector and lighting consumed 26 percent. Between 1987 and 2025, lighting's share of the residential sector's electricity demand drops to 21 percent in the HE scenario and to 15 percent in the LE scenario. The difference between the two scenarios reflects the vast savings potential offered by compact fluorescents. Between 1985 and 2025, the shares of the residential electricity supply consumed by refrigerators, washers and air conditioning increase slightly.

Delivered energy demand in Mexico's residential sector increases almost three-fold between 1987 and 2025 in the HE scenario (Table 3). The replacement of biomass by modern fuels helps restrain the growth in demand for energy. The LE scenario reduces this demand to

[5] Estimates of unit electricity consumption for refrigeration, lighting, televisions, radios and ironing were developed using a conditional analysis of energy demand based on the SEMIP rural survey (Upon regression analysis, the coefficients for refrigeration, lighting and TV turned out to be significant. The same analysis revealed that iron and radio ownership has little impact on electricity demand. Unit consumption estimates for the three significant end uses tended, however, to overestimate demand for TVs, as its coefficient probably absorbs consumption from other small appliances. Consequently, we considered the values from the regressions for refrigeration and lighting and a typical consumption -- 100 kWh/year -- for TVs.). Estimates of air conditioning electricity demand were derived taking into account the seasonal variation of electricity sales, particularly in the nation's northern regions. Using the information on electricity demand in rural households, the calculations for nation-wide air conditioning demands and additional saturation data available through partial surveys, energy demand for lighting, refrigeration and other appliances in urban households were estimated.

about half of the HE figure. The 2:1 ratio between consumption levels in the HE and LE scenarios stems from different fuel choices and the strong implementation of efficiency measures for all appliances in the LE scenario.

Household electricity use grows far more rapidly than household fuel use between 1987 and 2025. In the HE scenario, electricity consumption increases by 3.4 percent annually and fuel demand increases by 2.6 percent annually. In the LE scenario, while electricity demands increase by 2.5 percent per annum, the level of fuel consumption increases by only 0.69 percent each year. This vastly slower rate of increase for fuels in the LE scenario reflects the introduction of solar energy and the strides made in improving the efficiency of biomass use.

Oil demand still increases substantially in both scenarios (Table 3). The LE scenario limits this increase; greater shares of electricity and natural gas compensate for the lesser amount of oil. In absolute terms, the amount of oil consumed increases over four-fold in the HE scenario. The LE scenario limits the amount of oil required in 2025 to twice the amount consumed in 1987, partly because of the use of solar energy for water heating.

Table 3
Residential Energy Use (PJ)[6]

	1987	2025	
		High	Low
Total	491	1359	711
Oil (LPG and Kerosene)	45%	72%	63%
Natural Gas	5%	2%	5%
Biomass (mostly fuelwood)	38%	10%	10%
Electricity	12%	16%	21%

In the HE scenario, Mexico's residential carbon emissions expand from 8 million tons to 30 million tons between 1987 and 2025.[7] The low emissions scenario reduces the amount of carbon generated by the residential sector to less than half of the HE figure.

3.2 TRANSPORTATION SECTOR

At present, road transport accounts for 89 percent of all transport energy consumption, air transport for 6 percent, rail for 3 percent and ships for 2 percent. Mexico City's electric subways consume a mere 0.2 percent of the nation's transport energy. Cars and trucks dominate road transport fuel consumption, accounting for 54 and 24 percent of transport fuel use respec-

[6] This analysis does not separate LPG from kerosene. However, LPG comprises the bulk of the oil use in Mexico's households. Rural households tend to rely more heavily on kerosene than urban households.

[7] We assume in this analysis that one third of the fuelwood used in the residential sector is harvested in an unsustainable manner. If carbon emissions from these unsustainable biomass sources are included, the amount of carbon produced by the residential sector increases by 1 million tons in 1987 and 2 million tons in 2025.

tively. About half of Mexico's trucks and buses derive their energy from gasoline, which has a higher potential for efficiency improvements than diesel.

Because of the dominance of trucks and cars, the largest increases in Mexico's transport energy demand between 1987 and 2025 stem from the tremendous growth of these two modes. Together, the growing fuel needs of these two vehicle types account for over 90 percent of the increase in transport energy demand over the four decades.

While the oil boom years witnessed a rapid growth in motorization, the growth of **personal transport** slowed considerably during the 1980s. At 64 per 1,000 persons, the ownership of cars in Mexico remains quite low relative to that in Argentina, Venezuela and Brazil. Between 1987 and 2025, car ownership increases once more as the economy continues to diversify, reaching 250 cars per 1,000 persons in the high emissions scenario. In the low emissions scenario, a policy environment focused on lowering CO_2 emissions leads to a slower expansion of private transportation. In this scenario, only 200 cars exist per 1,000 persons by 2025 and the distance traveled per vehicle drops by 8 percent of the HE level. Car fuel efficiency, which lies well below international standards, averaged 12 miles per gallon (mpg) in 1987. By 2025, Mexican cars travel 35 mpg in the HE scenario. Mexico's small motorcycle fleet continues to consume a minimal share of transport's energy demand in 2025.

The bus fleet of 85,000 increases over four-fold between 1987 and 2025. The number of buses increases from 1 to 2.4 per 1,000 persons and the distance traveled per bus diminishes by 31 percent in both scenarios. The LE scenario improves fuel efficiency in cars to 43.4 mpg. Fuel intensity for buses declines by 50 and 60 percent in the high and low emissions scenarios respectively.

As **freight transport** also continues to grow, the share of freight in total transport energy demand increases from 32 percent to 37 and 33 percent in the HE and LE scenarios respectively. The number of trucks per capita doubles. Like trucks, the air, rail and subway modes also increase in relation to the growth of GDP and their relative contribution to GDP. While air transport's share of value added increases slightly between 1987 and 2025, rail's remains flat.

Fuel intensity for trucks drops by 30 percent in the HE scenario and by 50 percent in the LE scenario. Fuel efficiency for other freight transport modes increases on average between 10 and 15 percent in the HE scenario and by about 20 percent in the LE scenario by 2025.

The transport sector consumed 1110 PJ of Mexico's delivered energy demand in 1987. In the HE scenario, transportation absorbs 2518 PJ of energy. The LE scenario reduces this energy requirement to two thirds of the HE figure. Most of these reductions occur as a result of measures targeted at road transport modes. By implementing policies that limit the levels of car ownership, reduce the distances cars travel and improve fuel efficiencies, the LE scenario reduces the energy demands of cars by 41 percent (560 PJ) of the HE figure. Efficiency improvements reduce the fuel needs of trucks in 2025, according to the LE scenario, by almost 30 percent (220 PJ) of the HE level.

Transport's share in total energy consumption drops between 1987 and 2025 according to both scenarios, although the decrease is greater in the LE scenario (Table 1). The transport sector, which derived almost all of its energy from oil in 1987, continues the same reliance in 2025. Limited availability of natural gas precludes its use for transport in the future.

Transport carbon emissions increase at about the same pace as transport energy demand. Between 1987 and 2025, energy demand for, and carbon emissions from, transportation increase by about 125 percent. In the low emissions scenario, both increase by between 45 and 50 percent.

3.3 INDUSTRIAL SECTOR

Industry consumed 49 percent of Mexico's delivered energy demand in 1987 and accounted for 35 percent of the nation's GDP -- slightly higher than average shares than in the other Latin American study countries. Energy-intensive manufacturing, however, which accounted for 20 percent of Mexico's delivered energy, constituted only 4 percent of the GDP.

At present, Mexico has five major **energy-intensive industries**: iron and steel, cement, petrochemicals, glass and fertilizers. Total output and output per capita in all of Mexico's energy-intensive industries increase between 1987 and 2025 (Table 4).[8]

The energy intensity of Mexico's industrial production has oscillated in the past. Between 1965 and 1979, industrial energy intensity declined at an average rate of about 0.4 percent per year. Between 1980 and 1988, due primarily to Mexico's economic crisis of the early 1980s, industrial energy intensity increased annually by 1.4 percent. Since that time, the intensity of energy use has dropped once again. In general, however, the relatively high energy intensity in the Mexican industrial sector has stemmed from a combination of cheap energy prices and a low utilization of production capacity.

Between 1987 and 2025, fuel intensity decreases by 30 percent and electricity intensity increases by 6 percent in the HE scenario.[9] The LE scenario assumes that industries will reach the efficiency levels identified by the UMC-DGPE report as the best possible targets for 2025. Thus, in the latter scenario, fuel intensity is reduced to 36 percent below the 1987 level and electricity intensity is diminished to 2 percent below the 1987 level.

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[8] Estimates of per capita production levels in 2010 were derived by using the model MEDEE-S.

[9] A recent study, which compares energy use patterns in Mexico with international data on more efficient processes, provides the basis for estimates of the energy intensity for 1987 and beyond. See Unit of Quantitative Methods -- General Direction of Energy Policy (UMC-DGPE), *Consumo de Energia en el Sector Industrial Mexicano: UMC-DGPE* (Mexico City: UMC-DGPE, January 1990). This work uses the MEDEE-S model to calculate patterns of energy use in the industrial sector. This study also provides an analysis of the potential for fuel substitution and efficiency improvements within each of the major industries. The estimates of energy use patterns for 2025 rely on various assumptions drawn from this study. Estimates of energy efficiency improvements within each industrial subsector are based on a postponement of the targets obtained through the MEDEE-S modeling activity for 2010.

Table 4
Energy-Intensive Industrial Output

	1987	2025	
		High	Low
Steel			
Total ('000 Tons)	7600	25812	25812
Per capita (Tons)	0.10	0.18	0.18
Fuel Intensity (GJ/US$)	22.7	18.9	18.2
Elec. Intensity (kWh/US$)	593.9	593.9	593.9
Glass			
Total ('000 Tons)	3100	10755	10755
Per capita (Tons)	0.04	0.08	0.08
Fuel Intensity (GJ/US$)	11.2	9.5	8.9
Elec. Intensity (kWh/US$)	274.3	260.5	246.8
Paper			
Total ('000 Tons)	3400	12906	12906
Per capita (Tons)	0.40	0.90	0.90
Fuel Intensity (GJ/US$)	12.7	10.5	9.9
Elec. Intensity (kWh/US$)	461.8	461.8	461.8
Cement			
Total ('000 Tons)	21600	43020	43020
Per capita (Tons)	0.28	0.30	0.30
Fuel Intensity (GJ/US$)	4.2	3.5	3.1
Elec. Intensity (kWh/US$)	123.9	142.5	142.5
Fertilizers			
Total ('000 Tons)	3700	13623	13623
Per capita (Tons)	0.048	0.095	0.095
Fuel Intensity (GJ/US$)	3.0	2.7	2.6
Elec. Intensity (kWh/US$)	135.8	134.6	134.6

Fossil fuels dominate energy use in the industrial sector (Table 5). In 1987, natural gas provided the largest share of energy because of earlier government policy encouraging the use of gas in industry and for electricity generation. Oil and coal combined with gas satisfied 85 percent of industry's fuel demands. In the HE scenario, because of limited gas availability, oil surpasses natural gas consumption by 2025.[10] In the low emissions scenario, however, the share of natural gas in the fuel mix continues to exceed that of oil. The absolute amount of natural gas consumed by industry in the low emissions scenario is higher than the amount consumed in the high emissions scenario by 9 percent. Electricity plays an increasing role in all aspects of industrial production by 2025.

In the high emissions scenario, carbon emissions from the industrial sector increase even more rapidly than total emissions as oil and fossil fuel-based electricity play an increasingly important role in the energy mix. Industry's delivered energy demand increases by 195 percent between 1987 and 2025, while industry's CO_2 emissions increase by 225 percent. The LE scenario lowers emissions by relying less on oil. Delivered energy demand increases by 170 percent in the low emissions scenario while carbon emissions increase by only 155 percent.

[10] SEMIP, *Programa de Modernizacion Energetica 1990-1994* (Mexico City: SEMIP, 1990).

Table 5
Industrial Energy Use (PJ)

	1987	2025	
		High	Low
Total	1738	5122	4687
Coal	4%	3%	2%
Oil	37%	44%	37%
Natural Gas	44%	37%	44%
Biomass	5%	2%	1%
Electricity	10%	15%	16%

3.4 SERVICE SECTOR

Mexico's service sector comprises over 50 percent of the nation's GDP but consumes only 4 percent of the nation's delivered energy. Despite the predominance of this sector in the national economy, limited information on the details of its structural composition and energy use exists.

Mexico's service sector consumed 132 PJ of energy in 1987. By 2025, energy demand from the service sector increases over three-fold in the high emissions scenario and just under three-fold in the low emissions scenario.

The intensity of fuel use drops by 10 percent by 2025 in the high emissions scenario. The low emissions scenario further reduces fuel intensity. Electricity intensity increases in the HE scenario as more offices and homes resort to air conditioning. The LE scenario reduces the increase in electricity intensity by 30 percent of the HE level.

Oil supplies 73 percent of the service sector's energy demand at present. This share rises to 75 percent of the service fuel mix in 2025 and electricity's share drops from 27 percent in 1987 to 25 percent. Natural gas absorbs 8 percent of the energy demand in the LE scenario, allowing oil's share to drop to 70 percent and electricity's portion to decline to 23 percent.

3.5 AGRICULTURE SECTOR

Mexico's agriculture sector demands only 102 PJ, or 3 percent, of the nation's delivered energy and accounts for about 9 percent of Mexico's GDP. By 2025, agriculture's portion of delivered energy demand remains constant although its share of value added drops slightly.

Both fuel and electricity intensities decline between 1987 and 2025. In the HE scenario, the amount of fuel required to produce each dollar of GDP in the agricultural sector declines by 30 percent and the amount of electricity required drops by 10 percent between 1987 and 2025. The LE scenario achieves even greater reductions of 40 percent for fuel and 20 percent for electricity.

By 2025, agricultural energy demand increases to 281 PJ in the HE scenario. The LE scenario limits the amount of energy consumed by 14 percent of the HE figure. In 1987, oil satisfied 79 percent of the energy used in the agriculture sector and electricity provided the remainder. In both scenarios, oil's share diminishes to 74 percent in 2025 and electricity's increases to 26 percent.

3.6 AGGREGATE DELIVERED ENERGY DEMAND

Mexico's total delivered energy demand expands by a factor of 2.7 between 1987 and 2025 according to the HE scenario (Table 6). The LE scenario reduces this demand by 21 percent.

Table 6
Aggregate Energy Use (PJ)

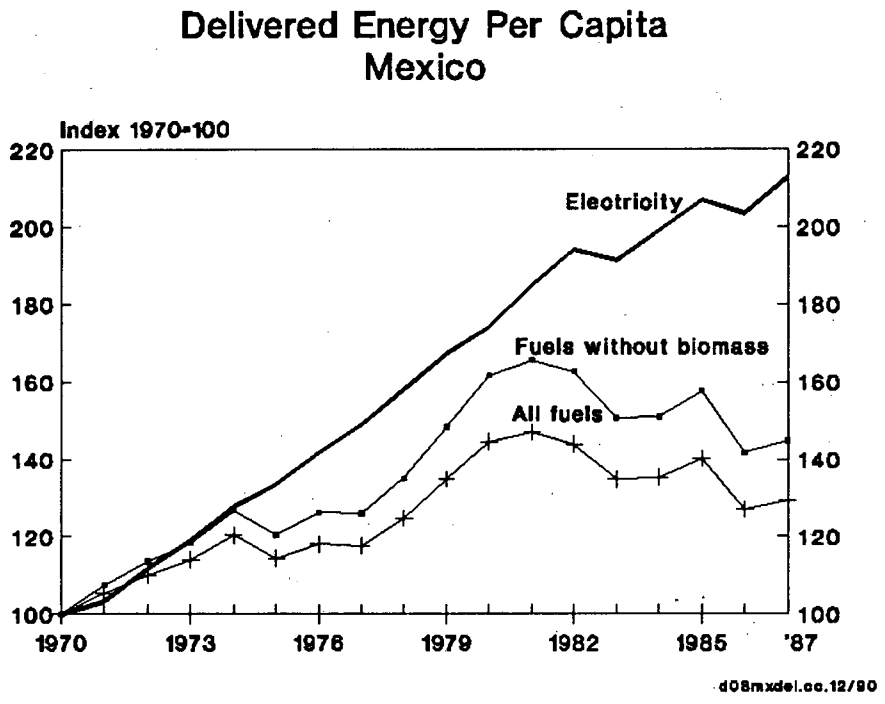
	1987	2025	
		High	Low
Total	3573	9724	7691
Coal	2%	1%	1%
Oil	60%	64%	56%
Natural Gas	22%	20%	28%
Biomass	7%	2%	2%
Electricity	8%	12%	13%

Delivered energy demand per capita rose considerably between 1970 and 1987 (Figure 3). Over the next four decades, this increase continues. Delivered energy demand per capita expands from 43 GJ to 66 GJ per capita in the HE scenario. In the LE scenario, energy consumption per capita grows more slowly, amounting to 52 GJ in 2025.

The growth in energy consumption is accompanied by a shift towards increased oil use. This shift occurs as kerosene and LPG replace biomass in the residential sector and as the use of energy (mainly oil) for transport increases more rapidly than for the other sectors. In absolute terms, the amount of oil consumed by Mexico more than triples in the HE scenario and more than doubles in the LE scenario. Thus, while in 1987 Mexican energy demand required the consumption of 1.02 million barrels of oil equivalent per day (boe/day), the increased oil demand in the HE scenario raises this figure to 2.96 million boe/day. The LE scenario reduces this figure to 2.02 million boe/day.

Electricity's share also increases in keeping with its rising share of residential energy consumption and its more intensive use in the industrial sector. Despite the extent of this growth, electricity's share in Mexico's delivered energy demand remains slightly below the average for the nations studied. Greater reliance on natural gas helps achieve reduced emissions in the LE scenario.

Figure 3



4 ELECTRICITY GENERATION

Public electricity is supplied by Commission Federal de Electricidad (CFE), a federally owned company. The installed capacity of the CFE system increased from 14.3 GW in 1979 to 23.1 GW in 1987. Most of the growth has been in dual-fuel capable oil and gas and coal-fired power plants. Mexico also added about 1000 MW of new hydro-electric capacity in 1987.

Dependence on oil for public electricity generation has increased since 1970 to 61 percent, because generation from hydro and gas has not kept up with the growth in overall generation. In recent years, the demand for Mexican oil exports has declined. Since Mexico produces much of its natural gas from wells associated with oil production, this decline has forced the utility companies to use more oil than before. Generation from coal and geothermal energy has grown since 1985.

By 2025, Mexico grows less reliant on oil-based electricity generation in both scenarios. As oil consumption for power generation declines, coal's role in electricity generation increases substantially. In the HE scenario, the absolute amount of coal consumed increases by a factor of 14 between 1987 and 2025. The LE scenario manages to temper carbon emissions from electricity demand by reducing coal's share and simultaneously increasing the share of hydro, solar, nuclear and geothermal power (Table 7). Mexico's transmission and distribution losses equalled about 14 percent in 1987. By 2025, these losses diminish to 10 percent in the HE scenario. The LE scenario further reduces transmission and distribution losses to 8 percent.

Table 7
Electricity Generation (PJ)

	1980[11]	1987	2025 High	2025 Low
Total	243	347	1334	1124
Coal	0%	8%	25%	10%
Oil	52%	61%	53%	45%
Natural Gas	14%	8%	2%	2%
Nuclear & Geothermal	1%	4%	8%	10%
Hydro, Solar & Other	33%	19%	12%	33%

In the HE scenario, carbon emissions from electricity rise from 15 to 58 million tons between 1987 and 2025. Electricity accounted for 21 percent of Mexico's carbon emissions in 1987; this share increases to 26 percent by 2025 in the HE scenario. The LE scenario reduces emissions from electricity to 32 million tons by increasing electricity generation from non-fossil sources. By halving electricity-related carbon, the low emissions scenario diminishes electricity's share in total emissions to 20 percent.

5 ENERGY INTENSITY AND PRIMARY FUEL SUPPLY

Mexico's primary energy intensity (MJ/US$) rose steadily throughout the 1980s peaking first in 1978 and then again in 1982 and 1983 during the nation's economic crises (Figure 4). Since that time, the amount of primary energy required to produce each unit of Mexico's GDP has declined. This trend continues between 1987 and 2025. In 1987, Mexico used 24.1 MJ of primary energy to produce a unit of GDP. In the HE scenario, Mexico's primary energy intensity decreases to 12.7 MJ/US$. The low emissions scenario reduces Mexico's energy intensity at an even more rapid rate to 9.9 MJ/US$ in 2025.

Primary energy demand per capita increases in both scenarios. In 1987, each Mexican consumed approximately 56 GJ of primary energy. This figure increases to 87.2 GJ by 2025 in the HE scenario. The low emissions scenario manages to limit the growth in primary energy consumption per capita to 68 GJ by 2025.

The primary energy supply increases almost three-fold in the HE scenario (Table 8). The LE scenario limits this increase to twice the 1987 level. According to the HE scenario, between 1987 and 2025, Mexico's primary coal supply increases from 156 PJ to 1179 PJ and Mexico's primary oil supply increases from 2949 PJ to 8552 PJ. In the LE scenario, an increased share of natural gas and hydro manage to mitigate the growth of oil and coal consumption.

[11] S. Meyers and C. Campbell, *Electricity Supply and Consumption in 14 Developing Countries, 1970-1988*, (Berkeley: Lawrence Berkeley Laboratory, August 1990).

Figure 4

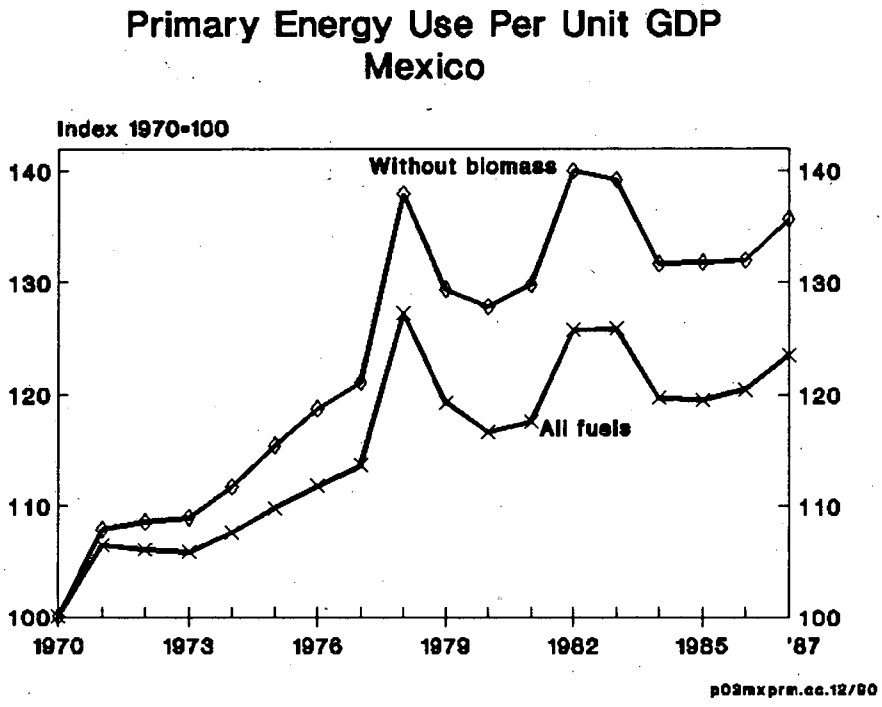


Table 8
Primary Energy Supply (PJ)

	1987	2025	
		High	Low
Total	4553	12720	9867
Coal	3%	9%	4%
Oil	65%	67%	59%
Natural Gas	21%	16%	23%
Biomass	6%	2%	1%
Nuclear & Geothermal	1%	2%	3%
Hydro, Solar, Other	4%	3%	9%

6 CARBON EMISSIONS

Despite the decline in the share of energy-intensive industries in Mexico, the industrial sector continues to make the greatest contribution to the nation's CO_2 emissions (Table 9). Transport remains the second largest sectoral carbon emitter, although the share of the transport sector in total carbon emissions declines, particularly in the LE scenario. The residential sector's share in total carbon emissions increases to over 14 percent in the HE scenario, but drops to below 10 percent in the LE scenario. The shares of the service and agriculture sectors in total carbon emissions remain relatively stable.

In 1987, the production of each GJ of primary energy generated 17.5 kg of carbon. In the HE scenario, this figure remains virtually stable in 2025. The low emissions scenario

reduces the CO_2/primary energy ratio to 16.0 kg/GJ by increasing the role of hydro and natural gas in the fuel mix.

Table 9
Aggregate Carbon Emissions (Million Tons)

	1987	2025	
		High	Low
Total	74	223	156
Residential	10%	14%	9%
Industrial	46%	50%	56%
Transport	29%	22%	21%
Services	5%	5%	5%
Agriculture	4%	3%	4%
Losses	6%	6%	6%

Carbon emissions per capita continue to increase as Mexicans consume larger amounts of primary energy per person. In 1987, CO_2 generation per capita stood at 1040 kg. By 2025, this figure increases to 1584 kg in the HE scenario. The low emissions scenario reduces emissions per capita by 30 percent of the HE figure.

Mexico's economic growth rate surpasses the rate at which the nation's carbon emissions increase. Thus, Mexico's CO_2/GDP ratio falls by 46 percent between 1987 and 2025 in the HE scenario. The LE scenario achieves further gains.

7 CONCLUSIONS

This analysis reveals that, without policy interventions, Mexico's carbon emissions will rise three-fold between 1985 and 2025. By taking actions to lower the carbon intensity of its economy, Mexico not only can minimize total emissions of CO_2 in 2025, but also can maintain carbon emissions per capita just above 1985 levels.

Measures to improve the production and use of electricity should be at the forefront of Mexican efforts to restrain carbon growth; the power sector accounts for 40% of the estimated reduction in emissions achieved in the LE scenario. Additional opportunities lie in bettering the efficiency of car and truck transport; in integrating more efficient processes and technologies into the industrial sector (with a particular focus on mining, utilities and non-energy-intensive industries) and in lowering the energy inputs required for water-heating activities in the residential sector, primarily through switching to solar heaters.

Ensuring the success of such efforts over the long term will require the adoption of a domestic energy strategy that supports the achievement of these objectives. Improvements in energy efficiency can complement Mexico's other developmental goals. By integrating effective

energy policies into its more general development plans, Mexico would reap a number of benefits, only one of which would be to contain the growth of its emissions of carbon dioxide.[12]

[12] Y. Mendoza, O. Masera and P. Macías, "Long-Term Energy Scenarios for Mexico: Policy Options for Carbon Savings and Main Barriers," *Energy Policy*, to be published, November 1991.

VENEZUELA

1 INTRODUCTION

Oil exports currently form the backbone of the Venezuelan economy. As a result, Venezuela's economic growth rates and energy consumption levels depend heavily on international oil prices and worldwide energy demand. To accommodate the wide range of possible futures posed by these uncertain external forces, this study of energy use and carbon emissions[1] in Venezuela for the year 2025 considers three possible development patterns.[2] These patterns each incorporate different economic and population growth rates for Venezuela between 1984 and 2025 and contemplate varying changes in oil export levels, production structures and income distribution.[3]

The "no change" pattern assumes that Venezuela's current economic woes continue to thwart its development; GDP only increases at a rate of 2.6 percent annually between 1984 and 2025 and income levels per capita and income distribution patterns hardly change.

The "take-off" pattern takes a more positive look at the same situation. In this case, Venezuela still maintains today's oil-dependent economic structure, but manages to boost its economy by finding a greater role for private enterprise. Over the observed time period, Venezuela's economy grows by about 4 percent per annum.

A major shift transpires in the "turnaround" case: Venezuela alters its economic path by severing its dependence on oil. By de-linking its development from oil, particularly at a time of low oil prices, Venezuela attracts greater foreign investment. As a result, more modern and energy-efficient equipment penetrates the economy. While the "turnaround" case shares the same sustained growth rate as the "take-off" case, the former scenario presents significant changes in the structure of the economy.

This paper focuses on the high emissions (HE) and low emissions (LE) scenarios of the "turnaround" case. Contrary to the other country studies developed for this project, some structural economic changes are assumed when discerning between the high and low emissions scenario for Venezuela. In the HE scenario, Venezuela pursues a program promoting high economic growth between 1984 and 2025. Despite various improvements in the efficiency of energy use, Venezuela's carbon emissions increase over four-fold. The LE scenario assumes a reduced importance of oil-related industry. In this scenario, the Venezuelan government limits carbon emissions by creating an adequate market environment and a healthy pricing system and

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[1] The term "carbon emissions" refers to carbon generated from commercial energy production and use. Unless otherwise specified, carbon emissions from biomass use are excluded.

[2] N. Pereira de Bustillos and A. Segnini, *Escenarios Energeticos a Largo Plazo* (Caracas: Ministerio de Energia y Minas, 1990).

[3] Due to the abundance of energy information made available by previous analytic efforts, 1984 serves as the base year in all three cases.

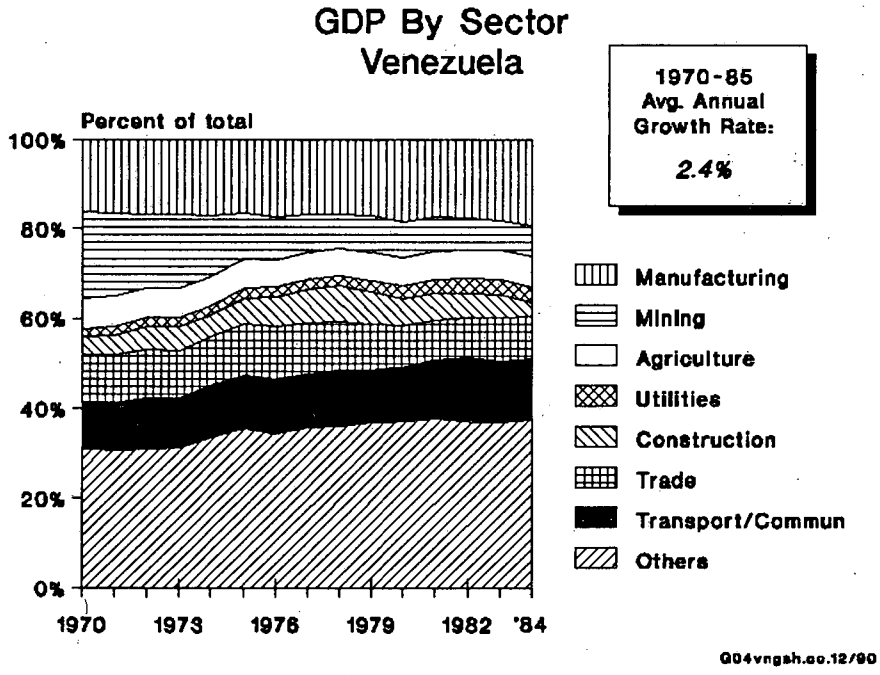
by implementing various fuel switching measures. Venezuela replaces oil with hydroelectricity and retains a constant and continually high share of natural gas in its fuel mix. As a result, carbon emissions fall to less than 80 percent of the HE level.

2 GDP AND POPULATION GROWTH

Venezuela had 17 million inhabitants in 1984. Between 1970 and 1984, population growth averaged 3.5 percent annually. As the urbanization process continues, however, population growth rates decline. Between 1984 and 2010, rates drop to 2.0 percent per year and between 2010 and 2025 these rates diminish even further to 1.2 percent annually. By 2025, Venezuela's population totals 34 million.[4]

Venezuela's economy grew steadily over the last decade peaking at about US$ 55 billion in 1979. The oil shock then caused Venezuela's GDP to fall to US$ 50 billion by 1984. Between 1970 and 1984 mining's share of GDP fell, manufacturing's share increased and agriculture's remained flat (Figure 1).

Figure 1



With the turnaround in Venezuela's economy, the annual growth rate of GDP averages 3.6 percent between 1984 and 2010 and then rises to 4.5 percent between 2010 and 2025. The nation's GDP increases almost five-fold, reaching US$ 248 billion by 2025. Future shifts in the value added shares of Venezuela's sectors correspond with past trends (Table 1).

[4] World Bank, World Development Report 1989 (New York: Oxford University Press, 1989), p. 173, table 6.

Table 1
Shares of GDP (US$ Billion)

	1984	2025 High	2025 Low
Total	50	248	248
Industry	44%	39%	39%
(Manufacturing	14%	23%	25%)
(Mining	30%	16%	14%)
Transport	11%	11%	11%
Services	7%	5%	5%
Agriculture	38%	45%	45%

Venezuela's GDP per capita of US$ 2940 more than doubles between 1984 and 2025. At US$ 7320, GDP per capita in Venezuela in 2025 equals the levels found in many industrialized countries today. As Venezuela's economy grows, the government favors an income distribution system which reinforces the consolidation of the middle class (Table 2). As a result, mobility and appliance purchases both increase by 2025 as well.

Table 2
Changes in Income Distribution

Income Level	Population Share (%) 1984	2025
Upper	1%	1%
Upper-middle	4%	7%
Middle	32%	42%
Lower-middle	25%	30%
Lower	38%	20%

3 SECTORAL ANALYSIS AND CARBON EMISSIONS

Sectoral shares of energy use shift significantly over the next four decades (Table 3).

Table 3[4]
Sectoral Energy Use (EJ)

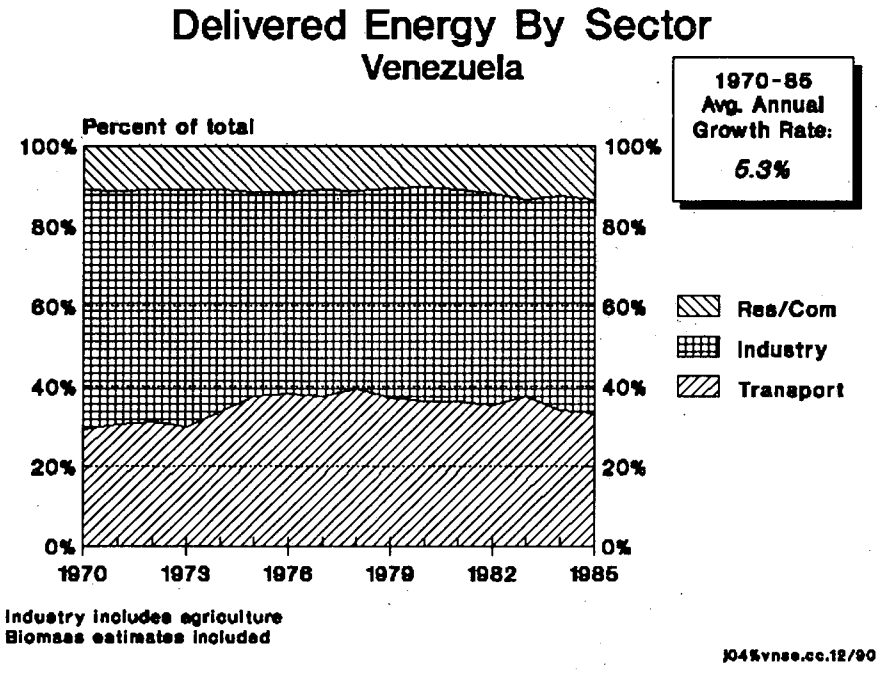
	1984	2025 High	2025 Low
Total	1.2	4.3	3.9
Residential	6%	6%	5%
Industrial	58%	70%	72%
Transport	32%	18%	16%
Services	4%	7%	7%
Agriculture	*	*	*

* negligible (between 0.1 and 0.2 percent)

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

Venezuela's delivered energy demand increased rapidly between 1970 and 1984. While industry's share of delivered energy demand fell, the share of the transport, residential and service sectors in total energy use grew (Figure 2).

Figure 2



Between 1984 and 2025, Venezuela's industrial sector accounts for a growing share of the nation's energy (Table 3). In contrast, Venezuela's transport sector absorbs a significantly smaller portion of the nation's energy demand by 2025. The residential and service sectors continue to account for only a small share of Venezuela's energy.

3.1 RESIDENTIAL SECTOR

Venezuela's residential sector currently accounts for a significantly smaller share of the nation's energy demand than in the other countries studied for a number of reasons: Venezuela's households require very little energy for heating due to climatic conditions; the saturation of water heating and air conditioning devices is relatively low at present; and industry and transportation have particularly high energy demands, thereby lowering the residential sector's relative share.

By 2025, household energy use remains comparatively low as a share of total demand. However, in absolute terms household energy consumption expands considerably. The growing electricity demands of appliances -- particularly of lighting and air conditioning -- and the expansion of water-heating activities spur the bulk of the increase in residential energy demand between 1984 and 2025.

In 1984, 81 percent of Venezuela's residents lived in cities. Between 1984 and 2025, the growing urbanization of small towns leads to a substantial increase in the size of Venezuela's urban population. By 2025, the urban population share surges to 95 percent.[5] This shift halves the size of Venezuela's rural population.

Simultaneously, household sizes shrink. Urban households, which comprised 5.5 members in 1984, average 4 members in 2025. Rural household size diminishes from 6.3 members in 1984 to 5 members in 2025. As a result of urban population growth and smaller family sizes, the number of urban households increases from 2.5 to 8.1 million between 1984 and 2025 and the number of rural homes decreases from 0.5 million in 1984 to 0.3 million in 2025. The almost three-fold increase in the number of Venezuelan households -- particularly in conjunction with per capita income growth and more equitable distribution of wealth -- implies a simultaneous enlargement in the stock of cars and appliances.

Due to Venezuela's currently high level of urbanization, a large portion of the population already has access to electricity. About 99 percent of urban households and 64 percent of rural households were electrified in 1984. By 2025, about 90 percent of Venezuela's rural homes are electrified. With this upsurge in rural electrification, about 97 percent of the total population have access to electricity.

Cooking requires more fuel in Venezuela than any other domestic activity. In 1984, cooking accounted for 62 percent of Venezuela's total residential energy demand. By 2025, cooking encompasses a much smaller share of household energy.

In urban regions, LPG continues to provide the greatest share of the cooking fuel mix in 2025. In the HE scenario, 70 percent of all households use LPG for cooking. Natural gas saturates 25 percent of all households by 2025, up from 16 percent in 1984. Only 4 percent of all urban households use electricity for cooking in the HE scenario. In the low emissions scenario, household saturation of electricity for cooking increases to 10 percent to compensate for a slightly diminished household saturation of LPG (64 percent).

In rural regions, 85 percent of all households rely on LPG for cooking in 2025 according to the HE scenario, up from 44 percent in 1984. In the low emissions scenario, LPG saturates an even larger share of rural households -- 90 percent.

The intensity of electricity use for cooking falls dramatically by 2025. In 1984 -- due to the types of food cooked, low electricity prices and the high incomes of electricity users -- cooking consumed 5000 kWh of electricity/household or five times the average European household value.[6] By 2025, unit electricity use for cooking drops to the European level.

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[5] Urban areas are defined as those regions inhabited by more than 5000 persons.

[6] A. Ketoff, O. Masera and M.J. Figueroa, *Residential Energy Use and Conservation in Venezuela: Results and Implications of a Household Survey in Caracas* (Berkeley: Lawrence Berkeley Laboratory, 1990).

Water heating currently accounts for about 8 percent of Venezuela's household energy use. In 1984, less than 14 percent of Venezuelan households had some kind of water-heating device. By 2025, saturation levels increase to about 48 percent. Electricity provides the bulk of the energy for water heating in both rural and urban regions in 2025 and the energy intensity of water heaters diminishes substantially, as smaller, more efficient devices penetrate the market. Despite these improvements in efficiency, due to increased demand, water heating accounts for over one quarter of household energy use by 2025 according to the HE scenario.

The use of electricity in Venezuelan households increases as emissions policies grow increasingly more stringent and Venezuela further develops its hydro resources. Currently, the level of appliance saturation in Venezuelan households rivals that of almost every other developing nation.[7] **Appliances and lighting** account for 30 percent of household energy use and 78 percent of residential electricity demand.

With electricity penetrating almost every Venezuelan home in 2025, household lighting consumption grows and most major appliances disseminate throughout the household market (Table 4).

Table 4
Electricity and Appliance Saturation

	1984	2025	
		High	Low
Electricity/Lighting			
Urban saturation	99%	99%	99%
Rural saturation	64%	90%	90%
Lighting/urban hh (kWh)	517	646	517
Lighting/rural hh (kWh)	381	534	515
Refrigerators			
Urban saturation	85%	100%	100%
Rural saturation	38%	80%	80%
Refrigeration/hh (kWh)	900	720	540
Washers			
Urban saturation	51%	80%	80%
Rural saturation	9%	25%	25%
Washer/hh (kWh)	85	77	51
Air Conditioners			
Urban saturation	9%	25%	25%
Rural saturation	1%	25%	25%
AC/hh (kWh)	3650	2920	2190

Refrigeration presently absorbs the largest share of the energy consumed by appliances and lighting in Venezuela. Between 1984 and 2025, better income distribution leads to a 25 percent increase in electricity demand for lighting in the HE scenario and the energy demands of lighting surpass those of refrigeration. In the LE scenario, electricity demand for lighting remains

[7] Oficina Central de Estadisticas e Informatica (OCEI), *Encuesta Sobre El Uso de Energia en Los Hogares* (Caracas: OCEI, 1988). See also Ketoff, Masera and Figueroa, *Residential Energy Use and Conservation in Venezuela: Results and Implications of a Household Survey in Caracas*, Ref. 6.

stable, because the introduction of compact fluorescents compensates for the growing demand. As ownership of electric appliances continues to increase, unit energy consumption drops from the currently high levels for almost every appliance (Table 4).

Residential energy demand multiplies over three-fold in the high emissions scenario. The low emissions scenario moderately reduces this expansion in energy demand (Table 5). Efficiency improvements in water heating, refrigerators, air conditioning and lighting account for about 90 percent of the energy savings achieved in the LE scenario. The nature of the residential fuel mix shifts in both scenarios. Households discontinue the use of both oil and biomass resources and shift to natural gas and electricity (Table 5).

Table 5
Residential Energy Use (PJ)

	1984	2025	
		High	Low
Total	73	256	205
Oil	7%	0%	0%
Natural Gas	44%	53%	47%
Biomass	10%	0%	0%
Electricity	39%	47%	53%

Due to the nature of its fuel mix, the residential sector accounts for a relatively low share of Venezuela's carbon emissions. In 1984, the residential sector produced 2 million tons of carbon. By 2025, this total increases to 3 million tons in the HE scenario. The LE scenario reduces carbon emissions to the 1984 level.

3.2 TRANSPORT SECTOR

Venezuela's transport sector absorbs a relatively large share of the nation's energy because of the enormous size of the nation's car fleet, the high energy intensity of the vehicles and the heavy reliance on highway travel.

An inefficient public transport system coupled with high incomes in Venezuela have spurred high levels of private vehicle ownership. The Venezuelan car fleet grew by 10 percent annually between 1965 and 1986. In 1984, the transport sector covered 84 billion passenger-km. Buses accounted for 52 percent of this activity and cars for 45 percent.[8]

Passenger transport witnesses a number of changes between 1984 and 2025 (Table 6). At present, car sales have diminished due to the economic recession, but sales should increase once more as economic growth picks up. The number of motorcycles expands almost four-fold

[8] Estimates of passenger transport activity for the year 2025 were derived based on past transport trends in Venezuela and on the levels of transport activity in industrialized countries in 1980. Car sales levels are based on replacement requirements and on the availability of cars per household, taking into account that as income levels increase more middle-income households are likely to purchase vehicles.

between 1984 and 2025. However, due to reductions in distance traveled and improvements in fuel efficiency, their increasing presence has a limited impact on the nation's energy use. The introduction of a new rail system in Venezuela increases rail's current 48 million pass-km to 130,180 million pass-km by 2025.

Table 6
Transportation Indicators

	1984	2025	
		High	Low
Cars			
Per 1,000 persons	87	292	292
Fuel intensity (liters/km)	0.23	0.07	0.05
Distance traveled per car (km/yr)	13500	9585	9585
Motorcycles			
Per 1,000 persons	16	60	60
Fuel intensity (liters/km)	0.08	0.04	0.04
Distance traveled per m-cycle (km/yr)	13000	7000	7000
Trucks			
Per 1,000 persons	24	39	39
Fuel intensity (liters/km)	0.50	0.25	0.20
Distance traveled per truck (km/yr)	25000	25000	25000
Buses			
Per 1,000 persons	2.6	4.1	4.1
Fuel intensity (liters/km)	0.62	0.31	0.25
Distance traveled per bus (km/yr)	48500	50000	50000

As the economy diversifies and economic activity decentralizes between 1984 and 2025, **freight transport** increases substantially. Although the level of truck activity increases four-fold, trucks -- which currently account for all of Venezuela's freight transport -- account for only one quarter of total freight transport in 2025 as Venezuela comes to rely heavily on rail modes.

Currently, the fuel intensity of Venezuela's cars and buses is quite high largely because 8 cylinder cars comprise the bulk of Venezuela's vehicle fleet. Recently, the government has placed restrictions on 8 cylinder car imports. The renewal of Venezuela's car fleet between 1984 and 2025 leads to significantly higher fuel efficiency. In the LE scenario, tighter standards promote even greater efficiency. While new airplanes prove more efficient in 2025, a nearly eight-fold increase in passenger-kilometers leads to little change in air fuel intensity.

In the HE scenario, the delivered energy demand of the transport sector increases from 378 PJ to 748 PJ between 1984 and 2025. The largest increases in transport energy demand stem from the growth of Venezuela's **truck** fleet and the increased reliance on **rail** and **air** travel. Together, these three modes account for almost three quarters (29, 26 and 18 percent respectively) of the increase in transport energy demand over the four decades. The low emissions scenario reduces transport's total demand to about 80 percent of the HE level mainly as a result of efficiency improvements in trucks and cars.

The transport fuel mix, which was completely oil-based in 1984, becomes increasingly electrified. In the high emissions scenario, oil accounts for 87 percent of transport energy and

electricity comprises the remaining 13 percent share. In the LE scenario, electricity's share increases to 16 percent and additionally natural gas comprises a minimal (1 percent) share.

Between 1984 and 2025, the amount of carbon emitted by Venezuela's transport sector increases from 7 to 19 million tons in the HE scenario. The LE scenario reduces transport carbon emissions by one third of the HE figure. The increased electrification of transport, the introduction of natural gas into the fuel mix and improved efficiencies all lead to these decreased emissions.

3.3 INDUSTRIAL SECTOR

In 1984, the industrial sector accounted for 44 percent of Venezuela's GDP. Energy-intensive manufacturing, which accounted for only 3.3 percent of GDP, absorbed one third of the industrial sector's fuel demand and just under half of its electricity in 1984. Mining and utilities, which includes the nation's oil and gas industries, accounted for 27 percent of Venezuela's GDP.

Industry grows more slowly than GDP between 1984 and 2025. As a result, industry's share of value added drops to 39 percent and energy-intensive manufacturing's share falls to 3.1 percent. **Mining and utilities'** share of GDP decreases substantially between 1984 and 2025 as a result of two factors: first, because the mining sub-sector is already highly developed at present, particularly the petroleum industry, and second, because the expansion of this sector competes for limited financial resources with industries that have a higher priority in Venezuela's diversification strategy. In the LE scenario, a third factor leads to the further reduction of mining's share in GDP: international environmental concerns hinder the growth of Venezuela's energy exports and, thus, reduce the emphasis on mining.

Venezuela has four major **energy-intensive industries**: steel, aluminum, cement and petrochemicals. The high expectations Venezuela has for the development of its energy-intensive industries indicate that production will increase in all four. The rates of change vary according to the industry (Table 7).

Inadequate pricing policies and an overabundant supply of energy have inhibited greater energy savings in Venezuela's industrial sector in the past. Thus, the current potential for energy savings remains high. Fuel intensity declines by 2 percent over the observed period in the HE scenario and further, by 9 percent, in the LE scenario. Electricity intensities, on the other hand, increase by 6 and 8 percent in the HE and LE scenarios respectively, except in the cement and aluminum industries, where electricity intensities fall by between 15 and 25 percent.

In the high emissions scenario, due largely to the implementation of higher efficiency equipment, Venezuela achieves fuel savings of between 15 and 20 percent and electricity savings of between 10 and 20 percent. The low emissions scenario makes greater strides, particularly in the area of fuel savings.

Table 7[9]
Production of Energy-Intensive Materials

	1984	2025
Steel		
'000 tons	2500	7060
Kg/capita	148	208
Aluminum		
'000 tons	377	2000
Kg/capita	22	59
Cement		
'000 tons	4783	13560
Kg/capita	283	400
Petrochemicals		
'000 tons	2115	28740
Kg/capita	125	848

Industrial energy demand increases over four-fold in both scenarios. The low emissions scenario decreases industry's delivered energy demand in 2025, but only by about 6 percent of the HE level. Oil comprises a much smaller share of the industrial fuel mix in 2025 -- particularly in the LE scenario (Table 8).

Table 8
Industrial Energy Use (PJ)

	1984	2025	
		High	Low
Total	675	2967	2799
Coal	2%	1%	1%
Oil	23%	11%	6%
Natural Gas	61%	72%	75%
Electricity	15%	16%	17%

With Venezuela's boom in production, industrial carbon emissions increase more rapidly than industrial energy demand. In the high emissions scenario, energy demand increases to 440 percent of the 1984 level while carbon emissions increase to almost 580 percent. In the LE scenario, energy demand increases to 415 percent and carbon emissions increase to 477 percent.

3.4 SERVICE SECTOR

As Venezuela's economy veers away from oil dependence, services' share of GDP increases from 38 percent to 45 percent between 1984 and 2025. The service sector's share in energy demand also increases (Table 3).

[9] Estimates for output growth are based on Venezuela's promising market conditions, a comparative analysis of production levels in industrialized countries and comparative production and location advantages -- such as the availability of natural resources (oil, natural gas, hydro-energy, bauxite and iron) and the geographic advantages of being located near the east coast of the United States' market.

Fuel intensity in the service sector (GJ/US $) declines as electricity increasingly replaces LPG. Electricity intensity (kWh/US $) simultaneously increases by about 25 percent as a result of the increased numbers of refrigerators, lighting, computers and air conditioners. In the LE scenario, electricity intensity remains slightly below the HE scenario level as improved air conditioners and more compact fluorescent light bulbs enter the Venezuelan market.

In 1984, Venezuela's service sector consumed 46 PJ of energy. In the high emissions scenario, demand increases more than six-fold. The low emissions scenario does not indicate the potential for significantly reducing future demand. Electricity supplied 61 percent of the service sector's energy demand in 1984, natural gas provided 32 percent and LPG accounted for the remainder. By 2025, electricity's share in the service fuel mix rises to just over 70 percent. Natural gas's share falls to just over 25 percent in both scenarios and LPG's share increases.

The absolute amount of carbon emitted by the service sector increases from 1 million tons in 1984 to 8 million tons in 2025, according to the HE scenario. The LE scenario limits total emissions to 5 million tons in 2025.

3.5 AGRICULTURE SECTOR

Venezuela's agriculture sector demanded less than 0.1 percent of the nation's energy in 1984. Although Venezuela cultivates wider territories in 2025 and although the nation increasingly mechanizes its agricultural processes, energy demand from this sector remains minimal. Currently oil and electricity constitute the largest fuel sources for agriculture. By 2025, electricity comprises a slightly larger share. Venezuela's agriculture sector continues to emit a negligible share of the nation's carbon.

3.6 AGGREGATE DELIVERED ENERGY DEMAND

Venezuela's total delivered energy demand increases by 360 percent between 1984 and 2025 in the high emissions scenario. The low emissions scenario limits this growth to about 325 percent (Table 9). The fuel mix changes considerably between 1984 and 2025. Oil's share drops substantially and natural gas and electricity's shares rise (Table 9).

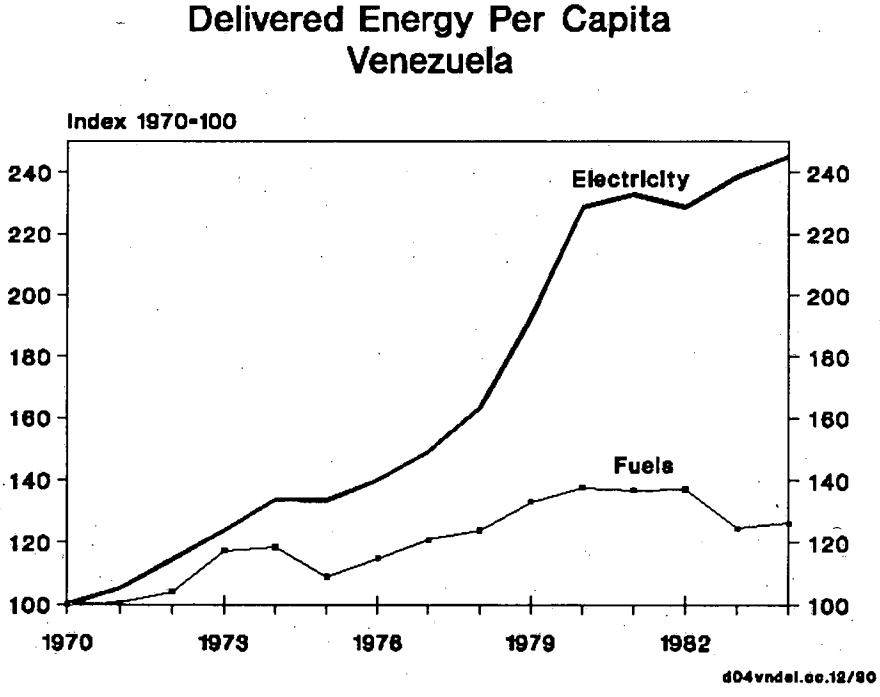
Considering that Venezuela currently has one of the lowest energy efficiency levels, the difference between the total delivered energy presented in the high and low emissions scenarios appears quite small. The scenarios, however, both assume that Venezuela majorly restructures its economy by 2025. The government completely overturns the currently inefficient economic structure, high economic growth occurs and foreign investors contribute substantial amounts of capital. Thus, although Venezuela achieves much higher energy performance in these scenarios than at present, substantial increases in production continue to require larger energy inputs.

Table 9
Aggregate Energy Use (PJ)

	1984	2025	
		High	Low
Total	1170	4270	3905
Coal	1%	1%	1%
Oil	46%	23%	18%
Natural Gas	39%	55%	59%
Biomass	1%	0%	0%
Electricity	13%	21%	23%

Delivered energy demand per capita has fluctuated over the last two decades (Figure 3). At 69 GJ per capita in 1984, delivered energy demand per capita rises to 126 GJ by 2025 in the HE scenario. The LE scenario limits energy per capita to 115 GJ.

Figure 3



The sectoral consumption of delivered energy demand also shifts (Table 3). Industry absorbs a much larger share of delivered energy demand in 2025 and transport's share in delivered energy demand drops. The transport sector's share of total electricity demand increases, however, from 0.2 percent in 1984 to 11 percent in 2025.

4 ELECTRICITY GENERATION

Electricity experiences a more substantial increase in demand between 1984 and 2025 than any other energy type. Industry continues to consume most of Venezuela's electricity supply in 2025, although its share drops from 64 to 52 percent in the HE scenario. In the LE scenario, industry consumes 54 percent of the nation's electricity. Transportation and services, which both experience rapid growth in their electricity demand, compensate for industry's declining share. By 2025, electricity demand per capita increases just under three-fold.

Transmission and distribution losses, already quite low, decrease slightly from 6 percent in 1984 to 5 percent in 2025. The increased substitution of electricity for other fuels over the observed period -- in residential cooking and industry, for example -- counteracts the effect of other reductions in electricity intensity.

Hydro generation expands dramatically in both scenarios. Over the past 6 years alone, Venezuela built a number of hydro plants and increased overall hydro-generation by a factor of three. Total capacity reached 10.6 GW in 1990. By 2025, capacity increases to between 24 and 29 GW in the HE scenario; the LE foresees an even larger hydro capacity in 2025.[10] In 1984, hydro produced 44 percent of Venezuela's electricity; by 2025, hydro accounts for 80 percent of electricity generation in the high emissions case and 90 percent in the low emissions case (Table 10). In both scenarios, natural gas mainly provides electricity used for peak demand.

Table 10
Electricity Generation (PJ)

	1984	2025	
		High	Low
Total	167	946	942
Oil	21%	5%	0%
Natural Gas	35%	15%	10%
Hydro, Solar & Other	44%	80%	90%

The formidable shift in the fuels used for electricity generation provides much of the basis for Venezuela's departure from oil-based energy production. With a vast capacity for hydro generation, the key to a less oil-reliant Venezuela lies in the exploitation of the hydro and much greater dependence on the potentially available electricity supplies.

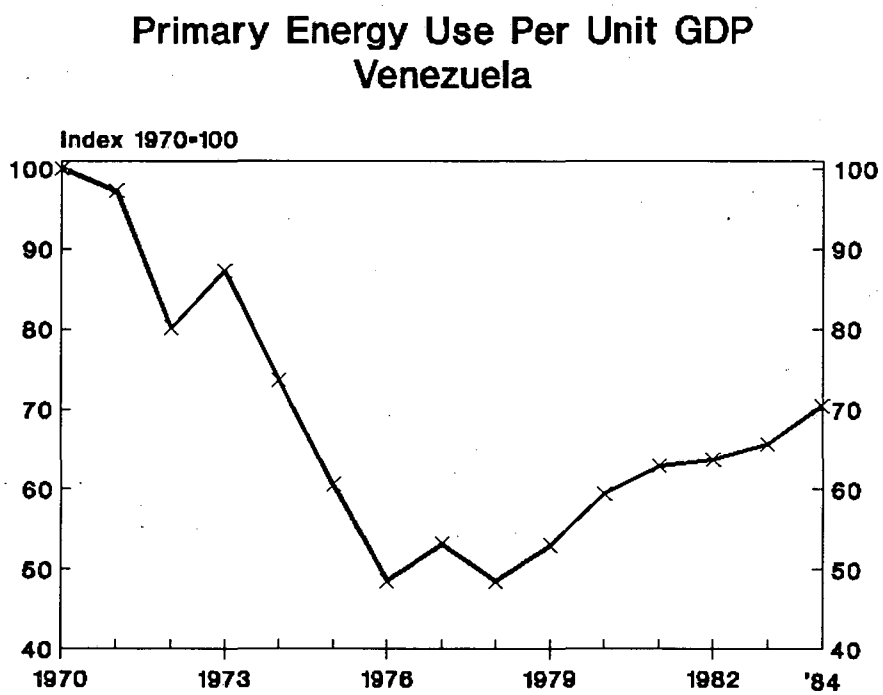
5 ENERGY INTENSITY AND PRIMARY ENERGY SUPPLY

Venezuela's energy intensity (GJ/US $1,000) dropped dramatically between 1970 and 1976. During the early 1980s, the intensity of Venezuelan energy use rose once more as GDP

[10] The potential capacity of the Caroni river is estimated around 27 GW. Additional plans are under development for other river basins.

stagnated (Figure 4). Between 1984 and 2025, energy demand grows more slowly than GDP reflecting the trends of the early 1970s. As a result, Venezuela's energy intensity (GJ/US$) drops from 36 GJ/US $1,000 in 1984 to 28 GJ/US $1,000 in the HE scenario. The LE scenario further reduces the intensity of energy use to 26 GJ/US $1,000. This decline mirrors the trend towards improved energy efficiency in other developing nations.

Figure 4



Primary energy supply per capita increases by a high of 210 percent in the service sector and a low of 41 percent in the residential sector. Only transportation witnesses a 20 percent decline in the amount of primary energy consumed per capita.

Venezuela's primary energy supply increases about four-fold in both scenarios. The composition of the primary fuel mix transforms by 2025. Most notably, oil comprises a much smaller portion of the energy supply (Table 11).[11]

In the HE scenario, natural gas and hydro dominate the primary fuel mix; oil's share decreases by half its 1984 level. In the low emissions scenario, Venezuela frees up as much of its oil production as possible for export and, thus, oil's share drops even further. The revenues for these exports finance the transformation of Venezuela's economy and its power generation. As a result, hydro generation increases substantially.

[11] Natural gas includes LPG, which constitutes about 1 percent of the total, because it is produced from natural gas refineries.

Table 11
Primary Energy Supply (PJ)

	1984	2025	
		High	Low
Total	1785	7045	6530
Coal	1%	1%	1%
Oil	41%	18%	11%
Natural Gas	42%	42%	42%
Hydro, Solar & Other	15%	40%	46%

6 CARBON EMISSIONS

Carbon emissions expand almost three-fold in the HE scenario. The low emissions scenario limits the growth in carbon emissions by 21 percent of the HE level (Table 12). Industry's share in carbon emissions rises substantially between 1984 and 2025 and transport's share falls. Because Venezuela's residential sector eliminates all use of oil fuels, its share of carbon declines as well (Table 12).

Table 12
Carbon Emissions (MT)

	1984	2025	
		High	Low
Total	25	67	53
Residential	7%	5%	4%
Industrial	52%	64%	68%
Transport	29%	21%	20%
Services	6%	5%	4%
Agriculture	*	*	*
Losses	7%	6%	5%

* Less than 1 percent

The restructuring of the Venezuelan economy and the increased reliance on hydro power inhibit the growth of total carbon emissions, particularly relative to the growth of the economy and of primary energy demand. The amount of carbon produced per GJ of primary energy falls from 14.2 kg/GJ in 1984 to 9.4 kg/GJ in the HE scenario. The LE scenario further reduces energy intensity to 8.1 kg/GJ.

The CO_2/GDP ratio declines by 47 percent in the high emissions scenario. In the LE scenario, the amount of carbon produced for each unit of GDP drops by 59 percent of the 1984 level. The amount of CO_2 produced per capita increases. In the HE scenario, carbon emissions per capita grow by 31 percent between 1984 and 2025. The low emissions scenario restrains this growth to 4 percent of the 1984 level.

7 CONCLUSIONS

The results of the scenarios highlight a crucial point: energy efficiency can be introduced as part of economic development. The economy can continue to grow and, simultaneously, efficiency improvements can reduce the energy inputs required to carry out the development process. The significant reductions in both the amount of energy required to produce each dollar of GDP and the amount of carbon generated for each unit of energy produced between 1984 and 2025 illustrate this potential.

The low emissions scenario indicates that carbon emissions can be reduced by more than 20 percent of the projected levels if effective measures are implemented. Because the HE scenario also incorporates significant efficiency improvements, however, the difference in the total carbon emissions generated in the two scenarios may appear less substantial than expected.

The greatest opportunities for achieving energy savings are in the industrial and transport sectors. About 45 percent of the energy savings potentially available within the industrial sector lie in energy-intensive manufacturing. Efficiency improvements in cars and trucks offer the bulk of the potential savings in the transport sector.

Achieving the carbon-reduction goals set by the LE scenario will entail the implementation of effective policy measures. These measures should focus on the following two areas in particular:

(1) Creating a rational energy-pricing system: Raising energy prices will help to promote the more productive use of energy resources. To enhance the impact of pricing changes, Venezuela should consider enforcing other controls and providing additional incentives aimed at encouraging energy conservation.

(2) Promoting the use of more efficient energy technologies: Technological improvements can make major contributions to raising energy efficiency. More energy-efficient technologies should be considered each time equipment turnover occurs in all of Venezuela's sectors. To ensure that these replacements take place, all users, but particularly factory managers, must be taught the benefits of energy efficiency and provided with the resources necessary to acquire these advanced, and typically more expensive, technologies.

In order to make the transition to a less carbon-intensive, more energy-efficient economy, Venezuela must mobilize participation at all levels of society -- from energy producers and suppliers to individual consumers. Above all, Venezuela's decision makers must consider how to incorporate improvements in energy efficiency as they shape the future of the nation's economy.[13]

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[13] N. Pereira de Bustillos and A. Segnini, "Energy Efficiency, Carbon Emissions and Development Paths in Venezuela," *Energy Policy*, to be published, December 1991.

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.

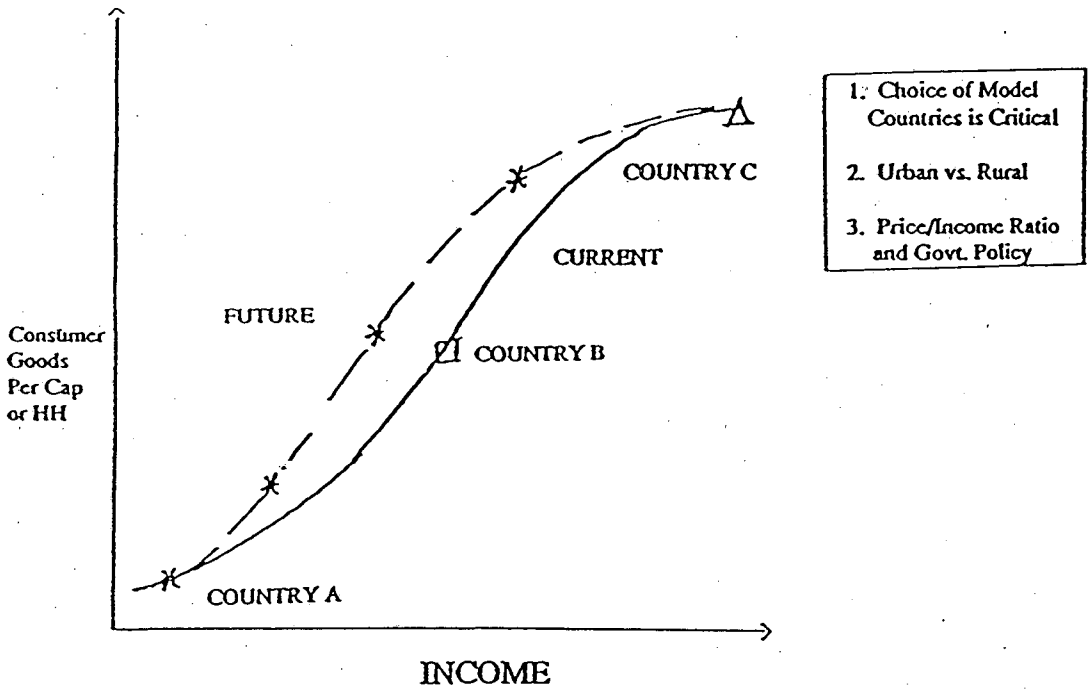
Each country study examines the residential, transport, industrial, commercial and agricultural sectors and estimates the demand for delivered energy in these sectors according to three major forms: fossil fuels, electricity and biomass.[1] The studies further disaggregate fossil fuel demand into coal, 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.

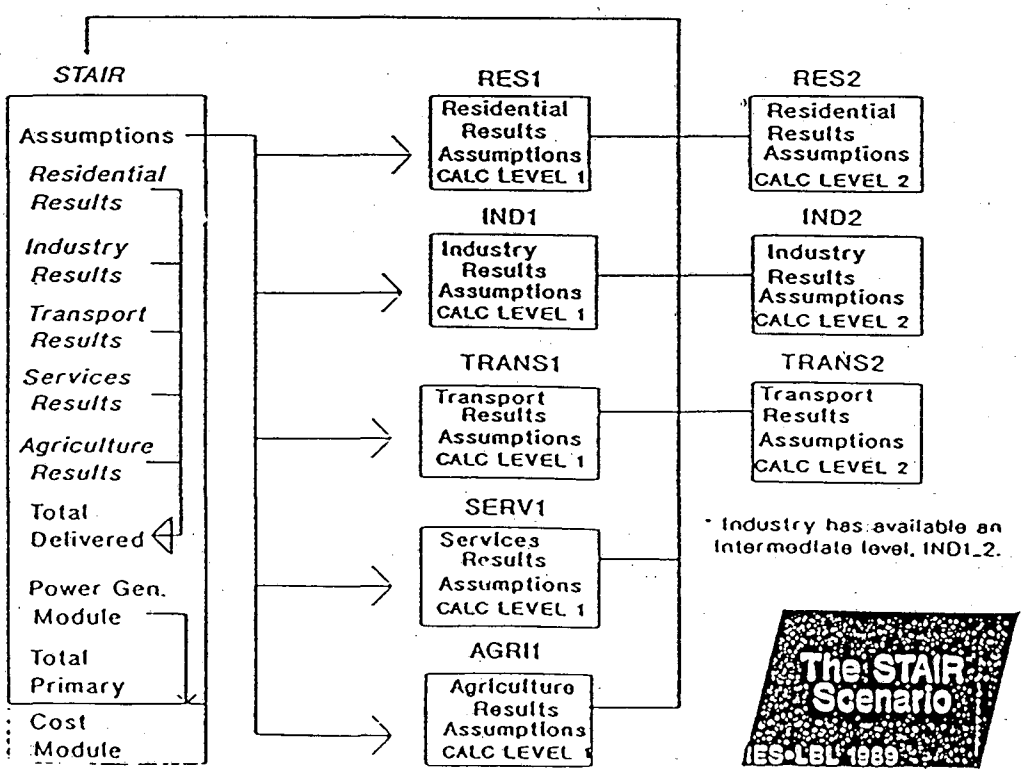
The approach used consists of two basic elements. First, the analysis disaggregates energy demand according to its major end-uses. Primary energy supply is estimated on the basis of the demand for individual fuels and electricity for each major end-use in each economic sector. Each sectoral discussion 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.

[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

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