A Sectoral Review of Energy in Brazil: Supply and Demand and Opportunities for Reducing Carbon Emissions

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GLOSSARY

ANEEL- Agência Nacional de Energia Elétrica (National Electricity Regulatory Agency)
BIG/STIG- Biomass gasifiers combined with a gas turbine suitable for producing electricity.
CDM- Clean Development Mechanism
CFL- Compact fluorescent lamp
COPPE- Graduate Studies Program of the Federal University of Rio de Janeiro
Cost of avoided carbon- annualized capital cost of the new measure plus the annual operational and maintenance costs divided by the annual carbon savings compared with the baseline case.
DNAEE- Departamento Nacional de Águas e Energia Elétrica (National Department of Water and Electricity – now extinct)
ESC- Energy-Efficient Scenario
FGV- Fundação Getúlio Vargas
Fossil fuel Energy Elasticity- α : ratio between the percentage change of fossil fuel demand and the percentage change in GDP
Fossil fuel mix factor - φ : Represents the changes in the composition of fossil fuel demand (φ <1 represents changes with greater participation of fossil fuels with less carbon content; φ =1 there is no change in the fuel mix)
Fossil Fuel Substitution Factor - β : Proportion of fossil fuel that can be substituted by renewable sources (β =1 there is no substitution)
GDP- Gross Domestic Product
HH- household
IBGE- Instituto Brasileiro de Geografia e Estatística (National Statistical Bureau)
IPCC- Intergovernmental Panel on Climate Change
IRR- Internal rate of return
MME- Ministério de Minas e Energia (Mines and Energy Ministery)
Net cost of avoided carbon- this includes any credit or additional costs incurred with the implementation of the new measure as compared to a baseline situation
NPV- Net Present Value
PROCEL- Programa de Combate ao Desperdício de Energia Elétrica (National Electricity Conservation Program)
TSC- Trend Energy Scenario
TOE- ton of oil equivalent
UFRJ- Universidade Federal do Rio de Janeiro
UNICAMP- Universidade Estadual de Campinas

1 Executive Summary

1. The purpose of this paper is to present relevant information about the energy, industrial and transportation sectors of Brazil, in order to assist those interested in pursuing the implementation of the Clean Development Mechanism. The paper identifies the main areas where initiatives could be undertaken to reduce greenhouse gas emissions from energy sources. We attempt to estimate the potential of these reductions in select sectors, accounting for the impacts in terms of tons of avoided carbon emissions as well as the cost of implementing these measures from the perspective of private investors. We have chosen the year 1994 as a reference in our estimates of carbon emissions because we base our analysis on the most recent available inventory of greenhouse gases for Brazil.

2. Brazil, with approximately 160 million inhabitants, occupies nearly half of South America. Gross domestic product (GDP) is growing at approximately 3.6 percent per year (1994-1995). Average annual per capita income is about US $4,700, with large numbers of low-income households offset by a much smaller number of wealthy households. There are major differences among regions, with the largest concentrations of industry, economy, and population occurring in the Southern and Southeastern regions of the country. The North (the Amazon region) currently has the highest population growth rates, and the Northeastern region has the lowest per capita income.

3. Total primary energy production increased from 57 Mtoe in 1970 to 165 Mtoe in 1996. Oil, hydroelectricity[1] and biomass are the main indigenous primary energy produced. Although 87 percent of total installed power capacity is from hydro sources, thermal power production is significant in some Amazonian and Southern States. Total electricity consumption has risen from 38 Terawatt-hours in 1970 to 277 Terawatt-hours in 1996, an average growth rate of 8 percent per year; electricity usage, both per unit of GDP and per capita, has also grown over the past 25 years. Fossil fuel consumption for electricity production currently represents only 5 percent of total generation, but this is expected to increase in the future to supply households which currently lack basic energy services and meet the increasing demands of a growing population and from industrial and services sectors. Hydroelectricity will remain the primary source of electricity in the future, but thermal and nuclear generation combined will account for as much as 20 percent of total generation by the year 2015.

[1] Hydroelectricity is accounted for in Primary Energy Terms following the conversion factors established in the National Energy Balance Table (MME 1996). This is the fossil fuel energy equivalent necessary to produce electricity with the country's average thermal plant efficiency. 1 MWh of electricity produced from hydro plants is equivalent to 0.29 toe of primary fossil energy.

4. Currently Brazil's greenhouse gas (GHG) emissions represent about 2 percent of global emissions. A significant share of primary energy needs is already met by renewable sources: hydroelectricity and biomass account for about 70 percent of the country's primary energy inputs. Fossil fuel carbon emissions amounted to 59 million tons of carbon (tC) in 1994, mostly from the transportation and industrial sectors. Yearly per capita carbon emissions, at 0.4 tons, are low compared to other countries such as Argentina (0.6 tC/cap), Canada (4.6 tC/cap), and the United States (6.0 tC/cap). Total net emissions from biomass energy use are 9 million tC, primarily from deforestation.

5. The energy, industry and transportation sectors account for about 86% of the country's carbon emissions, and these are the sectors which concentrate the consumption of fossil fuels. Nevertheless, it is important to notice that the use of biomass energy in the form of fuelwood, charcoal, bagasse and alcohol (biomass energy) already represent important share of the demand in some industries and the transportation sector. Biomass energy accounted for approximately 15% of the final energy demand of the industrial sector in 1995. Alcohol energy which is used blended with regular gasoline and also directly as a fuel represented 16% of the transportation sector's energy demand in 1995.

6. Some opportunities to avoid carbon emissions are already cost-effective. This is the case if private utilities invest in residential energy-efficient lighting programs and have a fossil fuel thermal generation base, we show that carbon savings can be achieved cost-effectively considering the present tariffs and prices in Brazil. The benefit-cost ratio is 1.9 in the case of utilities located in the South part of the country and 1.3 for those in the Amazon region. The ratio can raise to near 3 and 2.5 respectively if a credit of US$ 10 per ton of C avoided is considered.

7. If electricity co-generation in the alcohol-sugar industry could receive a credit of US$ 10 per ton of avoided carbon emission, the internal rate of return of its investments could raise from the present 12% value to 14% per year, or to 17% if a US$ 25 credit is considered[2].

8. Estimates of the cost of avoided carbon emissions by measures across sectors is presented in Table 1 A below. This table shows our estimates of costs for introducing energy efficiency measures or fuel substitution to avoid carbon emissions. These values *do not represent the net costs to the private investor*, and they should be compared with the present (baseline) situation of energy expenditure of the private investor. The following example illustrates the meaning of these estimates: *consider the case of the economic impacts to the consumer (private investor) by improving the performance of industrial*

[2] Considering that 1 MWh of electricity produced from biomass will replace 1 MWh produced from coal. The results considering the case of avoiding carbon emissions from electricity production from natural gas are 13% and 15%, for credits of US$ 10 and US$ 25 per ton of avoided carbon, respectively.

motors. High efficiency motors typically cost about 40% more than standard motors sold in Brazil. Nonetheless, high efficiency motors are cost effective in many applications when a new motor is needed, with a cost of saved energy of US$0.015-0.025 per kWh saved depending on the size of motor. Considering the industrial electricity tariff of US$ 0.048 per kWh (including taxes) this measure is cost-effective to the industrial consumer: the cost to save electricity is less than the tariff. In terms of avoided emissions, if 1 MWh of electricity saves 0.29 toe of fossil energy, the cost of avoiding emissions using more efficient motors is US$ 50-84 per ton of carbon. If we consider the additional savings of US$ 162 in energy expenses for each ton of avoided carbon, the benefit-cost ratio to the consumer is 3.24-1.93, depending on motor size. If a US$ 10 credit is added, this will make this measure even more attractive, raising the benefit-cost ratio to 3.44-2.04.

Table 1 A: Examples of measures and respective costs of avoiding carbon emissions

Sectors	Measures and technologies	US$/tC
Industrial sector	1. Better housekeeping (additional measures), energy audits, process improvements achieved by better information and assistance	3
	2. Retrofitting of motors	10
	3. High efficient motors	50
	4. Industrial co-generation	132
	5. Increase of use of natural gas	50
	6. Use of solar energy for pre-heating of water and industrial fluids	20
	7. Greater use of biomass	20
	Average costs for industrial-sector measures	40
Energy sector	1. Improvements in refinery processes	10
	2. Greater and more efficient use of refinery gas	20
	3. Greater use of natural gas	20
	Average costs for energy-sector measures	50
Electricity generation	1. Increase of the share of natural gas to 35% of thermal generation and substitution of 10% of fossil fuel generation by biomass sources	42
	2. Electricity conservation programs (DSM and end-use efficiency programs in other sectors) reducing 5% of total thermal production[3]	30
	3. Industrial co-generation using biomass and reducing 1% of total fossil fuel thermal electricity generation	138
	Average costs for thermal electricity generation measures	60
Transport sector	1. Use of natural gas in private and public transport	120
	2. Improved energy efficiency in vehicles	20
	3. Improvements in traffic and road conditions	120
	4. Increase of alcohol energy use	1,300
	Average costs for transportation-sector measures	1,000

Note: Author's estimates based on Moreira et al. 1996, Moreira 1997 and UNEP 1992. These costs were estimated considering the additional annualized capital investments and running costs of the measure per unit of avoided ton of carbon emission, taking the present situation as the reference case.

[3] It is important to note that electricity conservation impacts on total thermal generation is small, because we have assumed that thermal electricity is only 10% of total generation in the projected year.

If the CDM allows a credit of US$ 25/tC, several of the measures presented in Table 1 A become economically attractive, without even considering any savings from reduced energy expenditures.

9. In order to estimate the country's potential for carbon emission reductions we have projected emissions taking 1994 as a base year for a ten-year period, making assumptions for GDP growth and for two types of energy scenarios: a Trend Scenario (TSC) and an Efficient Scenario (ESC). The TSC scenario reflects the continuity of energy consumption patterns in the country, and does not consider explicit efforts to transform the energy market, by introducing more information or improving energy management practices, or by dissemination of efficient technology and fuel substitution. The ESC scenario implies extra costs and more systematic action, which would not otherwise take place, to supply consumers with information and improved technology.

10. Our aggregate analysis explored three types of changes: one related to the direct reduction of fossil fuel energy per unit of output via better technology and practices; a second type which will affect carbon emissions and is related to possibilities of fuel switching towards renewable energy; and a third type concerning possible changes in the fossil fuel mix that will affect the amount of carbon emissions. The estimates are done for the industrial sector (cement, iron and steel, chemicals and food and beverage), the transportation sector, and the energy sector (thermal electricity production).

11. The results indicated, under the assumptions made, that carbon emissions will grow even when taking into account the more aggressive measures of the ESC scenario. Even considering modest to low sectoral GDP annual growth rates (2.1% for the industrial sector and 1.2% for the transportation sector) for the projection period, the country's total carbon emissions will increase at 3.3% per year under the TSC and 1.2% under the ESC scenario assumptions. The industrial sector increased carbon emissions at the rate of 1.5% per year (TSC) and 0.5% (ESC). Improved efficiency and partial substitution for biomass in the main energy intensive industrial sectors can reduce the sector's contribution in emissions. Incentives to industrial co-generation will lead to further improvement of heat energy use within the industries. The paper and pulp, chemicals, metal and food industry present a significant potential for industrial co-generation. We have assumed that there will be a greater penetration of natural gas, both in our trend scenario (TSC) and our energy efficient scenario (ESC). However, for greater use of natural gas it is required a better technological infrastructure to supply equipment suitable for natural gas use. It is also assumed that the importation of natural gas from Bolivia and the gas pipelines for distribution in the Southeast-South regions of the country are implemented in the short future.

12. The additional costs associated with greater effort to implement the proposed measures to reduce carbon emissions totaled US$ 7 billion, and about 92% of this would be directed to the implementation of measures related to the

transportation sector (greater use of alcohol is one of the measures). This cost figure does not include any credit received from the CDM, nor the avoided expenses with conventional energy use. Taking the TSC as a reference the total carbon saved with the ESC scenario amounts to 15.4 millions tC, the amount of fossil energy saved is 14.9 millions toe. The CDM could provide a total credit of US$ 154 millions, considering the US$ 10/tC rate. Additionally there is also the credit associated with the savings in fossil energy consumption which should be counted. If the average cost of fossil energy is US$ 460/toe [4], the net cost of scenario ESC is US$ 137 millions. However, if we consider the credit due to the CDM at the rate of US$ 10 /tC the scenario ESC can be achieved at no extra cost.

13. Brazil is a country that has a good technical potential for introducing energy saving technologies and promoting further substitution in the direction of renewable sources of energy as our estimates have shown. In spite of the fact that many efficient technologies are already being produced in the country or are available in local markets, and also that some of them are very cost-effective to customers, their dissemination is still very limited. The main existing barriers are listed below:

- Immature and limited energy efficiency delivery infrastructure;
- The user's lack of knowledge of better practices and technologies;
- Lack of capital for investments in improved energy technologies and better practices;
- High interest rates in the country that inhibits new investments or borrowing to implement energy saving technologies and practices;
- Energy expenses represent a small share of total costs of most industrial customers;
- Lack of financial incentives to energy companies (electricity, oil and gas) to implement energy conservation programs;
- Unclear government definition about the future of Alcohol Program.

The CDM can be used to develop the country's potential for efficient use of energy and to expand the use of renewables. Funds are needed for financing the acquisition of better technology and helping to transform the market of energy technologies, contributing to overcome these barriers. The potential market exists, most of the technologies are available, if private entrepreneurs can develop strategies to sustain a market transformation effort most of the

[4] This is the weighted cost to the consumer of the main fossil fuels consumed: fuel oil, diesel, gasoline (1996).

measures presented in Table 1 A can be implemented and carbon savings can be achieved, as we have estimated.

14. Energy-efficient residential lighting programs such as the example presented here represent already cost-effective opportunities to electric utilities to save fossil fuel thermal generation. But residential customers still need financial incentives to substitute their lighting equipment. The CDM can help to provide for funding mechanisms in order to facilitate the implementation of large scale programs of this type that also have important societal benefits, improving load distribution in several constrained areas of the country. The government can set regulations so that privatized utilities are required to set saving targets and operate DSM programs of this type for their customers. Funds should be available to finance and operate energy efficiency programs that are in the national interest.

15. The case of co-generation in the sugar industry represents an opportunity to increase of revenues of this industry and make alcohol prices more competitive with gasoline. This industry needs to introduce more efficient technology to fully develop its potential to use biomass for steam and electricity production. More progress needs to be done in terms of harvesting the cane in order to reduce biomass losses and improvements can be introduced in combustion efficiency and new technologies, such as biomass gasification technologies. The CDM can be a very significant way to channel resources for these ends, but the government needs to set regulations and policies in order to stimulate stable production and the market for alcohol use in the country. The National Alcohol program needs a redefinition which could this time include a more regional focus, concentrating its consumption in areas close to the production centers[5] and allowing for its use in public transportation system. These measures could help reduce distribution costs and allow for partial substitution of diesel. Also the National Electricity Regulatory Agency (ANEEL) can be more forceful and create conditions for increased participation of electricity co-generated in sugar mills in the system grid.

16. In order to create better conditions for private sector initiatives towards measures to reduce carbon emissions we believe that there is the need for governmental initiatives towards the establishment of national/regional standards, regulation or agreements that enforce or stimulate the adoption of more efficient energy technology. The three regulatory agencies that have recently been created (or are in the process of creation) for the Oil & Gas sector, Electricity and Transportation should address these issues and stimulate investments in their respective areas towards alternatives that are cost effective and have less carbon emissions than the conventional practices.

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[5] Alcohol production is highly concentrated in some States of the country.

2 Introduction: a summary of geographic, socioeconomic, and energy conditions

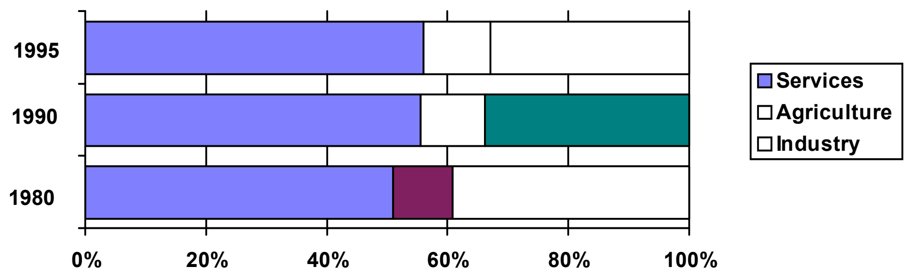
2.1 Socio-economic conditions

Brazil is the world's fifth largest country (8.5x10^6 sq. km), occupying approximately half of South America. A significant portion of the country's territory is occupied by the Amazon Basin, a region which presently is witnessing high population and economic growth rates, and at the same time has a delicate and complex ecosystem.

The population of Brazil is 160 million; more than 80 percent of the 39 million households (1995) live in urban areas, and per capita income is about US $4,700 (1995, in 1996 US $). Income distribution is strongly skewed, with 8 percent of total number of households accounting for about 40 percent of total income in 1995 (IBGE, 1997). The late 1980s and early 1990s were marked by stagnation and recession (Figure 1). Total gross domestic product (GDP) was nearly US $400 billion in 1995, and growth during 1990-95 averaged 2.8 percent per year. The service sector has accounted for an increasing share of GDP, as shown in Figure 2, and in 1995 was responsible for more than half of GDP. Industrial output has been stable and is beginning to show signs of expansion, but industrial employment has been dropping steadily. Regional differences are also significant: for instance, in the Southeastern region of the country 88 percent of households have access to treated water and 67 percent to public sewage services, while in the Northeast these figures drop to 70 percent and 5 percent, respectively.

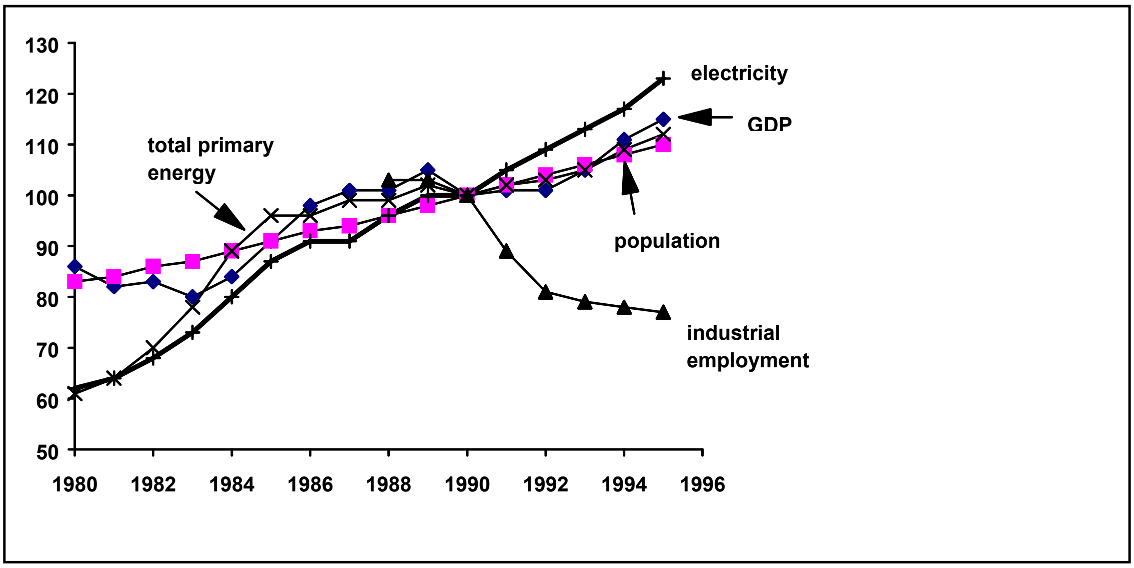
After a long period of extremely high rates, especially during 1984-93, inflation was brought under control in the beginning of 1994, as result from the economic stabilization plan "Plano Real", as can be seen from Figure 3.

Figure 1: GDP breakdown by main sectors 1980-90-95 (%)



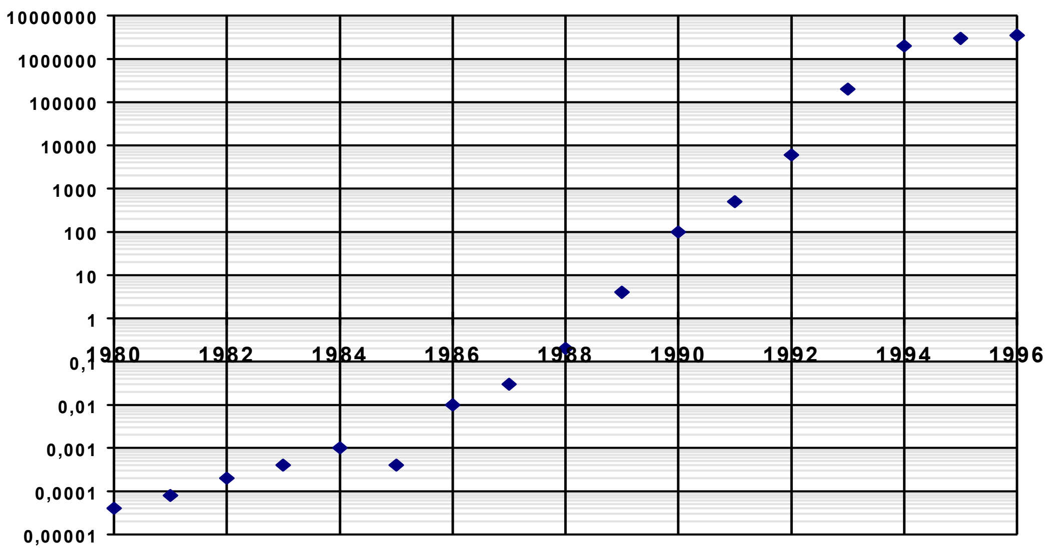
Source: FGV 1997.

Figure 2: Brazil: general indicators 1980-95 (1990=100)



Source: FGV 1996, IBGE 1997 and MME 1996.

Figure 3: Consumer Price Index 1980-95 (1990=100) (logarithm scale)



Source: FGV 1996.

2.2 The country's general energy characteristics

In this section we present the main characteristics of energy supply and demand in Brazil. The information will be presented in further detail in the following sections for the industrial, energy and transportation sectors.

2.2.1 Energy supply

Total primary energy production increased from 57 Mtoe in 1970 to 165 Mtoe in 1996. Oil, hydroelectricity and biomass are the main indigenous sources of primary energy (Figure 4).

Fossil fuels

Domestic oil production remained practically stable during 1970-79 at a level around 170 thousand barrels/day, increasing significantly over the next decade and reaching an average of 809 thousand barrels/day in 1996 (MME 1996). As result domestic oil has increased its share in total oil consumption from 32 percent in 1970 to 59 percent in 1996. Total oil and gas reserves amount to 14.1 billion barrels (proven oil reserves amount to 4.8 billion barrels). Current measured reserves would last about 17 years, at present production rates.

Coal reserves amount to 33 Gt[6], but only 16 percent of this value is considered fit for use in metallurgical processes. Most of the country's coal has high sulfur and ash content. Coal production represents only 1 percent of the country's total primary energy production.

Natural gas production has increased continuously over the past two decades, and in 1996 reached about 9 Mtoe, about 5% of the country's total primary energy production. Presently the major gas fields are located off-shore and produce about 3 millions cubic meters/day, 30 percent of which is used for electricity production. The major current development in the area is the importation of natural gas from Bolivia, which may reach 7 million cubic meters/day by year 2000.

The Power sector

The growth of the power sector, in particular, has been enormous in recent decades. Installed capacity, which was 12 GW in 1960, climbed to 59 GW by 1995 (MME 1997), 87 percent of which is from hydro sources, although some states have a higher proportion of thermal power production. As of 1996 hydroelectricity represented 44% of primary energy produced in the country. Currently it is the main primary energy source.

As of 1996, 87 percent of Brazil's installed capacity and 81 percent of total electricity production come from hydropower (MME 1997). In an international context, this places the Brazilian power sector in a favorable situation with regard to greenhouse gases. However, official projections show that thermal power production will increase to as much as 20 percent of total installed capacity by the year 2015 (Eletrobrás 1994). In addition, fossil fueled thermal electric plants dominate power production in some regions of the country,

[6] This includes measured (31%) and estimated (69%) reserves as of 1996.

particularly in the Amazon region and in the Southern part of the country[7]. The South-Southeast region has interconnections with the rest of the country, while the Amazon region has many small isolated systems, sometimes dedicated to a single city.

The current structure is a mix of federal and State government-owned companies that work with close supervision by Eletrobrás and until recently the federal regulatory agency DNAEE (Departamento Nacional de Águas e Energia Elétrica). However, this structure of the electricity sector is undergoing significant and rapid changes due to the privatization process. A new National Regulatory Commission is being installed in 1998 (Agência Nacional de Energia Elétrica - ANEEL) and new developments are expected. Eletrobrás will also undergo a major restructuring process, and parts of the company are to be privatized.

In parallel, several State and regional utilities have already been privatized or are in the process of sale.

Electricity conservation efforts in Brazil have been conducted mainly by the National Electricity Conservation Program - PROCEL, created in 1985. By 1994 PROCEL's programs resulted in an estimated 294 GWh of total electricity savings (Tavares, 1995). About 60 percent of the savings resulted from lighting efficiency improvements, 25 percent from installing meters in previously unmetered households, and 13 percent from various programs carried out through the state and local utilities. In 1995, PROCEL was given an annual budget of nearly US $27 million: US $6 million for core programs and various projects funded through grants, and US $21 million for low-interest loans from the capital investment fund for the power sector. A large portion of the 1995 budget was spent on purchasing meters for unmetered households and T&D loss-reduction projects, but a number of end-use efficiency projects were initiated or expanded as well. These projects included research and development efforts, demonstration projects, education and promotion initiatives, and implementation projects with state and local utilities. In 1995-1996, emphasis is being given to end-use efficiency and peak load reduction in regions with overloaded transmission and distribution systems.

The Biomass sector

Fuelwood and sugar cane products (bagasse and alcohol) are the main biomass fuels produced in the country. Fuelwood has had a declining share from 32% in 1981 to only 12% of the country's primary energy output in 1996, whereas the share of sugar cane products increased from 10% in 1981 to 13% in 1996.

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[7] Diesel and fuel oil supply most of the electricity generated in the Amazonian region. Coal is particularly used near the country's largest coal fields in the State of Santa Catarina, in the South region.

Fuelwood and charcoal production is done on a commercial scale to supply the needs of important industrial sectors such as the iron and steel industries. It is estimated that about 80 percent of the fuelwood primary energy produced comes from energy plantations (COPPE 1996); the remaining 20 percent comes from deforestation and is used for residential cooking, in small industries or charcoal production.

Alcohol production increased sharply during the mid-1970s as a result of the National Alcohol Program, especially when efforts were made to create a national alcohol vehicle fleet. However, during the 1990s alcohol production levels became unstable and the Program faced serious discontinuities. This was due to various factors: persistent problems with high production costs, cross-subsidies, a financial crisis amongst producers, and the increasing debt of Petrobras[8], which was responsible for the purchase and distribution of alcohol production. Alcohol productivity and costs vary among regions, and its production is highly concentrated in São Paulo State, where the highest yields and lowest costs are obtained. Alcohol costs are still above international oil prices, but declined from US $80/boe to about US $48/boe in 1996 (Moreira&Goldemberg 1997). Alcohol needs subsidies to compete with gasoline especially after the 1986 drop in world oil prices, but the government lacks the political will and the funds to maintain the required levels of support.

Major productivity gains are possible, including the use of sugar cane residues (bagasse) for electricity production. Bagasse is currently used mainly in the alcohol-sugar industry to generate process heat, mechanical power and electricity; bagasse energy use increased nearly 2.5 times during 1980-96. There is significant potential to produce additional electricity from bagasse-based systems used in co-generation, with surplus power sold to the grid. Using conventional technology, an additional 700 MW could be made available in the State of Sao Paulo. With new improved BIG STIG technology, a total of up to 2 GW could be added in the next 10 years.

This activity can also raise revenues associated with alcohol production and help reduce alcohol costs. Bagasse is also a renewable energy source and contribute to controlling the country's emissions. However, these improvements may take time to achieve significant reductions for the alcohol industry as a whole, since there has been very little investment in this sector in the recent past, and investment will likely continue to be slow in the near future.

2.2.2 Energy Demand

Energy consumption in Brazil has increased by a factor of six since 1960, reflecting the transformation of the country's economic activities,

[8] In 1995 Petrobras had an accumulated deficit of 2 billions dollars with its operation with purchases and sales of alcohol fuel.

transportation, and industrialization. Economic development has led to a continuous increase in electricity use per unit of GDP and per capita over the past 25 years; electricity use is growing more quickly than total final energy consumption (Figure 2). Total energy consumption in 1996 reached 208 million toe, from which about 40% comes from non-renewable primary energy (fossil fuels). Electricity, oil and biomass are the main types of energy consumed.

In 1996 industrial energy use represented about 38% of total final energy,[9] the transport sector 21%, the residential sector 16%, and the energy sector 7%. This structure has remained stable over the past decade (Figure 6).

Electricity demand

Total electricity consumption rose from 38 terawatt-hours in 1970 to 277 terawatt-hours in 1996, an average growth rate of 8% per year (MME, 1988, 1996). The industrial sector is responsible for 46% of the country's consumption, the residential sector for 24% and commercial and public sectors for about 20%. The country's average residential electricity consumption per household in 1997 was 175 kWh/month, reaching 202 kWh/month in the Southeast — more than twice the average residential consumption level of the poorest region, the Northeast.

Electricity used by low-income households and large industrial customers is highly subsidized. But on average electricity tariffs are not low from an international reference. As of 1997 the country's average electricity residential tariff was US $98/MWh; commercial customers paid US $92/MWh on average and industrial customers US$ 46/MWh, not including taxes. Electricity prices charged by generating utilities to distributing utilities average US$ 31/MWh.

Electricity used in the industrial sector for motors represents 51% of total industrial consumption, electrochemical processes 21%, electrothermal processes 20%, refrigeration 6%, and lighting 2% (Pinhel 1994). Growing industrial electricity intensity has been caused mainly by structural shifts in industrial production towards more electricity intensive sectors.

Fossil fuels demand

The share of oil consumption (in primary energy terms) in the country's total primary energy consumption has declined. The main oil products consumed are diesel oil, gasoline, and fuel oil (MME 1996), representing together 23 percent of total final energy consumption[10]. Industrial oil demand has been

[9] Electricity counted in primary energy terms (MME 1996).

[10] Diesel oil alone represents 12% of total final energy consumed in the country, gasoline 6% and fuel oil 5% (MME 1996).

more successfully reduced with the control of fuel oil consumption, which was substituted for electricity and biomass. Industrial fuel oil use decreased from 12.8 Mtoe in 1980 to 8.3 Mtoe in 1996. Gasoline demand also changed significantly with the introduction of alcohol fuel. Total gasoline use declined in absolute terms sharply from the mid-1970s to the mid-1980s and has risen again since then. Diesel is the main fuel used for public and freight transportation, and unlike fuel oil and gasoline, has shown continuous growth in consumption over recent decades. The transport sector accounts for about 49 percent of the country's total oil demand and the industrial sector 15 percent (1996).

About 70 percent of the country's coal demand goes to electricity production, and the remaining portion to the industrial sector. The country's cement industry uses about 10 percent of the country's coal and is the major industrial user.

The use of metallurgical-quality coal, which is imported, is used mostly for coke production in the iron and steel industry.

Biomass energy demand

The sharp drop in fuelwood consumption in the residential sector has resulted in a lower overall share of biomass — about 21 percent as of 1996 — in primary energy consumption (Figure 5). Fuelwood alone represents about 10 percent of total primary demand.

The industrial sector is also the most important biomass energy user with about 44 percent of total consumption. The food and beverage industries consume about half of the total industrial biomass energy. Other important sectors are the paper and pulp industry and the iron and steel industries.

Since 1975 alcohol has been consumed in blends with gasoline and in 1979 it started to be used as new fuel in modified Otto-cycle passenger vehicles. Several incentives were given to customers, car manufacturers, and alcohol producers in order to create a market for alcohol fuel. In 1979 consumer alcohol prices were set as 64.5 percent of the prevailing gasoline prices, taxes were reduced on manufactured alcohol vehicles and capital was made available at very attractive rates to finance the expansion of alcohol production. By 1985 alcohol vehicles sales represented 96 percent of total car sales and alcohol output had increased nearly 20 times as compared to 1975 levels. The price difference between gasoline and alcohol at the gas station has decreased to about 15-20 percent today, and alcohol-fueled vehicles production represent now a small (less than 10 percent) of annual new motor vehicle sales.

In 1996 alcohol energy represented 54% of the country's gasoline energy consumption, but in 1986 this share was 81%.

Figure 4: Primary Energy Production 1981-96 (%)

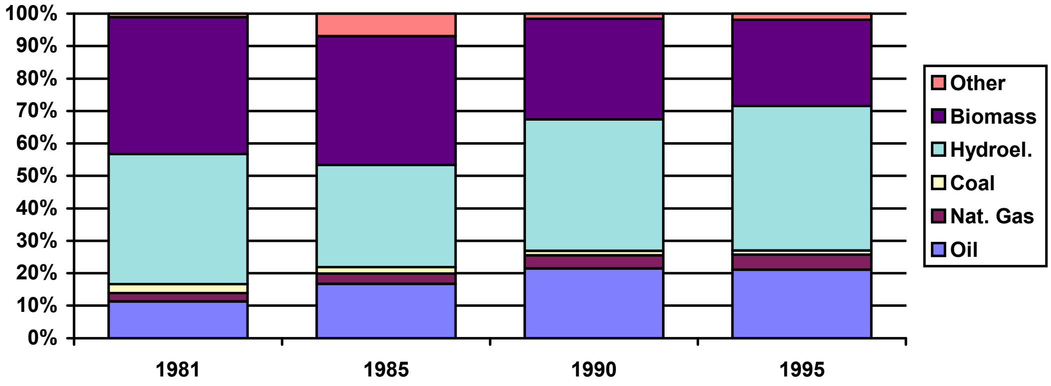


Figure 5: Primary Energy Consumption 1981-95 (%)

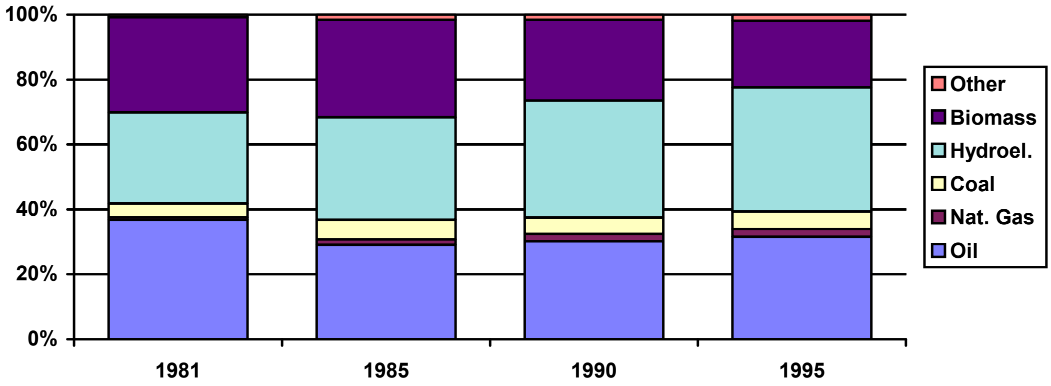
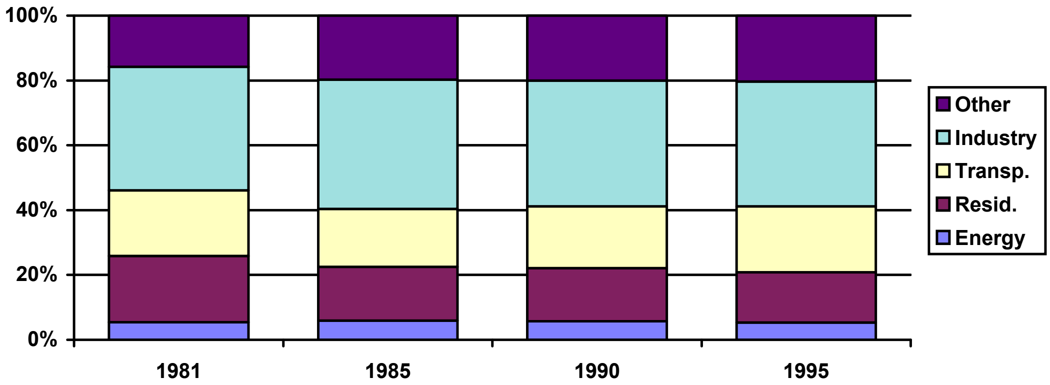


Figure 6: Structure of Energy Demand by Sector 1981-95 (%)



2.3 Carbon emissions from energy sources

National carbon emissions increased 1970-90, from 39.5 MtC in 1970 (Rosa et al. 1990) [1] to 67.6 MtC in 1994 (Tables 1 and 2). In 1970 the industrial and transport sectors contributed 30% and 28%, respectively, of the national carbon emissions. In 1970 fuelwood from deforested areas was the main source of emissions at the time with 37% of total emissions (Rosa et al. 1990). In 1994 transport sector emissions accounted for 37 percent of the country's total and industry for 27 percent.

Brazil is now responsible for about 2 percent of global greenhouse gas (GHG) emissions; per capita emissions, at 0.38 tons (Table 1), are low compared to other countries such as Argentina (0.6 tC/cap), Canada (4.6 tC/cap), and the United States (6.0 tC/cap). As pointed out earlier, a significant share of the country's primary energy needs is met by renewable sources: hydroelectricity and biomass account for about 70 percent of the country's primary energy inputs. However, energy requirements are still growing to supply households which currently lack basic energy services; this need will be partially met in the future with thermal power production and greater use of fossil energy for transportation and industry.

Fossil fuel carbon emissions amount to 59 million tC (1994), mostly from the transportation and industrial sectors.

Table 1: Brazil: Carbon emissions from fossil fuel energy use (1994)

Fossil energy sources	Total 1000 tC	tC/per capita
liquid	41,807	0.27
solid	11,904	0.08
gas	4,968	0.03
Total fossil fuels	58,673	0.38

Source: COPPE/UFRJ 1996

Total net emissions from biomass amounted to 9 million tC (1994), which represents fuelwood from deforestation. The other biomass fuels (alcohol, bagasse, charcoal) and a significant part of industrial fuelwood are used on a sustainable basis, i.e. these biomass products are regrown after they are harvested.

Table 2: Carbon emissions from biomass energy use 1994 ($10^{3\ tC}$)

Primary Energy	Total production[1] (PJ)	Stored carbon/non-energy uses	Conversion factor[2] (tC/TJ)	Total emissions (10^3 tC)	Net emissions (10^3 tC)
	A	B	C	D=(A-B)xC	E
fuelwood(a)	1,105	110(b)	29.9	29,750	8,925(c)
Sugarcane products(d)	960	48(e)	25.0(f)	22,800	-
Total	2,065	158		52,550	8,925

Sources: (1) MME 1996; (2) IPCC.
Notes: 1 toe = 45 GJ. (a) Includes charcoal energy use; (b) Assuming that 10 percent of carbon is stored in uncompleted combustion of fuelwood and charcoal, and charcoal non-energy use; (c) Assuming that 30 percent of fuelwood comes from deforestation of native forests; (d) Includes bagasse and alcohol; (e) Assuming that 5 percent is stored in uncompleted bagasse combustion and alcohol non-energy use; (f) Weighted average based on a factor of 29.9 tC/TJ and 20 tC/TJ for bagasse and alcohol output, respectively.

3 Sectoral emissions, energy patterns and the potential for changes

In this section we present information concerning the structure of energy use in the three sectors and the potential for introducing measures and technologies with the objective to reduce carbon emissions.

In order to estimate the potential for carbon emission reductions we project emissions taking 1994 as a base year for a ten-year period, making assumptions for GDP growth and for two types of energy scenarios: a Trend Scenario (TSC) and an Efficient Scenario (ESC). We follow the IPCC inventory methodology that does not include emissions from biomass energy sources when treating the energy consumption sectors. In the present work biomass will be considered as renewable sources that can substitute for fossil energy sources, thus reducing overall emissions.

The TSC scenario reflects the continuity of energy consumption patterns in the country, and does not consider explicit efforts to transform the energy market, by introducing more information or improving energy management practices, or by dissemination of efficient technology and fuel substitution. The ESC scenario implies extra costs and more systematic action, which would not otherwise take place, to supply consumers with information and improved technology.

Our analysis will explore three types of changes: one related to the direct reduction of fossil fuel energy per unit of output via better technology and practices; a second type which will affect carbon emissions and is related to possibilities of fuel switching towards renewable energy; and a third type concerning possible changes in the fossil fuel mix that will affect the amount of carbon emissions. Annex 1 explains the basic method employed and the following sections describe the calculations performed. Annex 2 shows additional tables that were used to support the present analysis.

Table 3 shows the sectors studied in this work (Energy, Industry and Transportation) for the base year 1994, which represent nearly 70% of total country's energy consumption and 86% of carbon emissions from fossil fuel sources. We have opted to treat electric generation as separate from the energy sector, which represents here internal consumption in oil refineries, coke and gas plants.

Table 3: Base Year- Carbon emissions from fossil fuels energy consumption (thous. tC)

	liquid	solid	gaseous	total	avg tC/toe
Transport	25,161	0	30	25,191	0.891
Industry	8,838	7,256	2,011	18,106	0.912
Cement	1,002	414	4	1,420	1.011
Iron & steel	495	6,019	999	7,513	0.882
Chemical	1,374	146	340	1,860	0.925
Food & beverage	844	94	119	1,057	0.938
Other	5,124	583	550	6,256	0.920
Energy (internal sectoral use)	3,423	0	942	4,366	0.878
Electric generation	1,517	1,305	174	2,995	1.016
Other sectors	2,868	3,343	1,810	8,015	
TOTAL	41,807	11,904	4,968	58,673	

source: Energy data from MME 1996. Conversion coefficients from COPPE 1997.

3.1 Definitions

The cost per unit of carbon is given by the equation:

$$\cos t = \frac{ACap + O\,\&\,M}{tC} \quad \text{Equation (1)}$$

where *Acap* is the annual capital cost (discounted over the lifetime of the measure considered), *O&M* are the annual operational and maintenance costs associated with the measure and *tC* is the annual amount of avoided carbon emissions by implementing the measure taking as reference the existing energy use system. This equation considers only the annualized expenses that the investor is making in order to avoid emissions. In the aggregate analysis developed later we use these type of figures for estimating total economic costs in introducing measures to avoid emissions.

However, if one is interested in analyzing the perspective of private investors that will be avoiding the expenditures with the conventional use of energy, it is required to include these benefits. In the following section we provide examples of this analysis. In section 3.3 we develop an aggregate analysis employing equation (1).

3.2 Examples of economically attractive carbon saving measures

Here we present three examples of measures that can be economically attractive to private investors to avoid carbon emissions in Brazil. The first example is from a private owned electricity utility perspective which invests in a lamp rebate program for the residential sector. The second example is the case of electricity co-generation in the alcohol-sugar industry.

3.2.1 Savings to the Electricity sector from Residential Lighting Programs

Here we provide an example of the opportunity to save carbon emissions from thermoelectricity production by investing in residential energy efficient lighting programs. These programs would subsidize the purchase of efficient technology compact fluorescent lamps – CFL) that would replace existing incandescent lamps. We have assumed that these programs would be developed by utilities located in two regions of the country which have significant thermal electricity production, and that tariffs and cost of electricity are the current values that Eletrobras uses in its studies. It is assumed that all the electricity savings in each region can reduce the regional electricity production.

Tables A, B and C presents the estimates from implementing utility sponsored residential programs in the two regions of the country that have a predominately thermoelectricity production. The South region[11] has nearly 50% of its installed capacity coming from thermal plants, mostly coal fired plants as shown in Table C; and the Amazon Region[12] has about 70% of its installed capacity supplied by diesel and fuel oil fired thermal plants. The estimates presented below assume that all program savings promoted in the regions can reduce the operation of the thermal plants installed in the region.

Table A presents the basic regional data and the assumptions made for the program results. Due to higher income levels in Region South, more homogenous population and higher educational levels, program results (i.e. CFL penetration level, saved wattage) are higher compared to the Amazon region. A private utility would spend US$ 0.08 per saved kWh in the South region, considering an investment horizon of 30 years (the same of a thermal plant), 12% discount rate and a lamp lifetime of 5,000 hours. Due to higher distribution costs with program implementation in the Amazon region, the cost of saved electricity is US$ 0.11. Row I in Table A show the Net Present

[11] In this example we are only considering the data from the States of Rio Grande do Sul and Santa Catarina.

[12] The States considered here are: Amazonas, Rondonia, Acre, Amapá and Roraima.

Value during the period considered of the avoided electricity production costs of peak electricity (residential lighting is an important contributor for the system evening peak). Row J estimates the revenue losses that result from promoting electricity conservation in the residential sector, which consequently affects the utility's electricity sales. Finally row K estimates the program costs to the utility during the 30 year period considered.

Table A: Energy savings and cost-benefits from a utility sponsored lamp-rebate program

		Units	Southern Region	Amazon Region
A	Number of households (HH)	10^6	3.27	0.79
B	Program participation rate	% total	20%	7%
C	Saved wattage per household	W/hh	140	96
D	# of lamps replaced per HH		3.0	2.0
E	Lamps usage	hr/day	3.5	4
F	Total electricity saved at generation point	GWh	133	10
G	Total number of CFLs	10^6	2.0	0.1
H	Cost of saved energy	US$/kWh	0.08	0.11
I	NPV saved elect. prod. Costs	10^6 US$	254	17
J	NPV lost revenues	10^6 US$	85	6
K	NPV program costs	10^6 US$	86	9

Notes: (A) Year 1995; (B)-(E) Based on section 2.3; (F)=(A)x(B)x(C)x(E)x365x$(1\text{-}\%\text{losses})^{-1}$, we include here T&D losses: assumed to be 15 percent for the whole country, 12 percent for the South, and 20 percent for the Amazon region; (G)=(A)x(B)x(D); (H) Based on equation (1), assuming a lamp lifetime period of 5,000 hours and wattage saved per household; (I) Equals the present value of providing (F) per year at 0.27 US$/kWh (the average cost of providing electricity for lighting from Jannuzzi et al 1997) over 30 years at 12 percent discount rate, (I) Excludes T&D losses because it is assumed that the 0.27 US$/kWh already accounts for these losses; (J) Calculated using an average tariff rate of 0.09 US$/kWh and excluding T&D losses from (F), over 30 years at 12 percent; (K)=(F)x(H).

Since residential lighting is an important component of the system evening peak, the projected results in terms of avoided (or deferred) peak capacity are significant. The assumptions made for the South region lamp program resulted in a cost of US$1,444 per avoided peak kilowatt. Using the estimated national average cost of supplying peak capacity to customers (including transmission and distribution investments), the net deferred capacity cost amounted to US$77 million (Table B). The benefit-cost ratio to the power sector was 1.94 for the South, and 1.27 for the Amazon region, i.e. the program is cost-effective under the assumptions made, without considering any credit for the carbon savings achieved.

Table B: Peak capacity savings, costs, and benefits from a utility sponsored lamp-rebate program

		Units	Southern Region	Amazon Region
L	Peak coincidence ratio	%	65%	70%
M	Total avoided peak	MW	60	4
N	Cost of avoided peak	US$/kW	1,444	2,310
O	Cost of supplying peak	US$/kW	2,740	2,740
P	Net deferred capacity costs	10^6 US$	77	2
Q	Benefit /Cost ratio		1.94	1.27

Notes: (l) Based on Jannuzzi et al 1997; (M)=(A)X(B)X(L), at the end-user; (N)=(K)/(M); (O) is the value used by Eletrobrás (Eletrobrás 1996, p. 85) for the average national cost of supplying peak capacity to residential customers, including T&D investments; (P)=(M)X[(O)-(N)]; (Q)= [(I)+(P)]/ [(K)+(J)]

Table C show the amount of carbon that can be saved in each region as the result from cost-effective lighting programs (Row Q, Table B), therefore utilities in this case have not incurred in any additional cost in order to avoid emissions. If a credit of US$ 10 per ton of avoided carbon is included the Benefit/Cost ratio will be improved even further for both regions: it will raise to 2.99 for the South region and to 2.46 for the Amazon region.

Table C: Regional avoided carbon emissions from a utility sponsored lamp-rebate program

			South Region	Amazon Region
R	Structure of electricity	Diesel oil	1.56%	43.34%
	Generation	Fuel oil	0.50%	17.10%
	(% of total, as of 1995)	Coal	41.93%	0.00%
S	Thermal efficiency of plants	Diesel oil	30%	25%
		Fuel oil	28%	22%
		Coal	30%	30%
T	Avoided fuel consumption	Diesel oil	24.96	60.47
	(TJ)	Fuel oil	8.57	27.11
		Coal	670.93	-
U	Emission rates	Diesel oil	20.2	20.2
	(tC/TJ)	Fuel oil	21.1	21.1
		Coal	25.8	25.8
V	Avoided carbon emissions	Diesel oil	504	1,221
	(tC)	Fuel oil	181	572
		Coal	17,310	-
W	Total carbon emissions (tC)		17,995	1,793

Notes: (r) refer to 1995 (Eletrobrás 1996b); (s) author's estimates; (t)=(f)x(r)x3.6/(s); (u) from IPCC; (v)=(t)x(u); (w)=S (v).

3.2.2 Electricity co-generation in the sugar industry

As mentioned the use of biomass for electricity production within the sugar/alcohol industry is already practiced in Brazil. This practice can be magnified significantly if more investments were directed towards technological improvement in this industry and better use of the biomass (bagasse, and sugar cane leaves[13]). If more biomass is available for co-generation and better technology also improve conversion processes, more electricity can be produced and sold to the grid, which in turn can also help reduce alcohol production costs. Today, each ton of sugar cane produces on average 20 kWh of electricity, and most of this electricity is used for local energy needs. This can be raised up to 100 kWh if existing processes are improved.

Currently the electricity sold by the national grid to the utilities averages US$ 40/MWh. We assume that this is the value of the electricity produced in a alcohol/sugar plant which is able to yield a 12% rate of return over a 10 year period. If a credit of US$ 10 per avoided ton of carbon emitted is given to the electricity producer and considering the reference case of a coal fired thermal plant, its internal rate of return will raise to 14%. If a US$ 25 credit is given, the IRR is 17%. If we consider that the electricity produced in biomass co-generation plants, such as these of the alcohol-sugar sector, will avoid carbon emissions from natural gas fired plants, the IRR are comparatively lower (Table D).

Table D: Effects of carbon credits on the IRR

Carbon credit US$/tC	Avoided carbon tC/MWh	Value of electricity produced US$/MWh	Internal rate of return
0	0	40.00	12%
10	0.35 (coal)	43.50	14%
25	0.35 (coal)	48.75	17%
10	0.22 (natural gas)	42.20	13%
25	0.22 (natural gas)	45.50	15%

3.3 Aggregate analysis: overall potential for carbon savings

3.3.1 The Industrial Sector

We have chosen to study in more detail four industrial sectors: cement, iron and steel, chemicals, and food and beverages, which amount to approximately to 52% of industrial energy use. We also deal with the industrial sector on the whole. The Brazilian industrial sector has historically reduced its use of oil, at

[13] Currently, the most sugar cane is burned in the fields to facilitate the mostly manual harvest.

the expense of more intense use of biomass and electricity. For the industrial sector we assume in the TSC that the historical trend of declining fossil energy consumption is continued, but at a lower rate, since most of the available potential considering existing practices and cost-effective measures has already been achieved. Most of the further reductions will be pursued in the ESC trying to reduce fuel oil consumption and coal.

Industrial GDP growth is assumed higher than the preceding decade, assuming higher participation of less energy intensive sectors. Table 4 presents the assumptions with regard to sectoral GDP growth and fossil fuel energy elasticities[14] for scenarios TSC and ESC. It is important to note that both scenarios assume the same GDP growth rates. The relatively lower elasticities for the ESC scenario reflect the improvements in fossil fuel energy use in each industrial sector considered (Table 4). Table 8 in the Annex shows the historical records of these energy elasticities for the industrial sector in the past.

Table 4: Scenario Assumptions for the Industrial Sector: Fossil energy-GDP elasticities (α) and GDP growth

	TSC α	ESC α	GDP 1981-94 (aapg)	GDP 1994-04 (aapg)
Industry	-1.20	-1.50	1.1%	2.1%
Cement	-1.30	-1.40	0.4%	1.0%
Iron & steel	-1.00	-1.00	2.1%	1.5%
Chemical	0.95	0.90	1.4%	1.5%
Food & beverage	0.95	0.90	1.6%	1.6%
Other	0.95	0.90	1.0%	3.5%

Note: Aapg = annual average percentage growth.

The iron and steel industry is an important user not only of fossil energy, but also of charcoal. Several improvements can be achieved in the most energy-intense phase of the industry, the process of reduction in blast furnaces, which is also the phase where most of the carbon is emitted. Better management of the process, the injection of gases, and improved processes can help reduce emissions by about 10% (Sakamoto 1997, Araujo 1997, Scherer 1993).

In the chemical industry energy improvements in ovens, distillery columns and boilers and the re-utilization of CO_2 can yield savings in fossil fuel energy and carbon emissions (Greentie 1998, Reay 1977, Dragos 1996, Ree 1995).

[14] Fossil fuel energy elasticity is ratio between the percentage change in the aggregated fossil fuel demand and the percentage change in sectoral GDP.

The food and beverage industry is an intense user of water and steam. Improvements in boilers, in both operation and maintenance and better technology, are necessary. This sector can also better utilize residues (from biomass sources) and gas (Reay 1977, IPT 1985, Greentie 1998).

Electricity conservation

For the industrial sector as a whole PROCEL estimates that savings of 8-15% are achievable based on cost-effective measures such as replacing oversized motors, improving transmission systems, replacing overloaded internal lines and transformers, correcting low power factors, and reducing excessive peak loads. Additional savings in the range of 7-15% are possible through the use of efficient motors; variable speed drives; improving electrical furnaces, boilers, and electrolytic process efficiencies; and disseminating cogeneration in industry (Geller et al. 1997).

Energy consumption in motors (and motor systems) can be reduced by correcting the operation and sizing of the existing equipment by retrofit programs and the introduction of improved technology such as variable speed drive and high efficient motors. More efficient motors are available in the national market, but they are mostly exported. The efficiency of motors can be improved significantly in the country, as many studies have pointed out (see Geller et al. 1997, Tabosa & Soares 1994). It is estimated that about 71% of all motors in use in the country operate at loads under full capacity. We estimate that the cost of retrofitting motors and motor systems is US $10/tC[15] (assuming electricity production from fossil fueled thermal electricity plants). The use of high efficiency motors is assumed to cost US $50/tC, under the same assumptions as above. An estimated amount of 10% of electricity used in electric ovens can be reduced by recycling the available heat surplus or installing more efficient equipment.

It is possible to reduce electrical consumption in metallurgical industries by 7% and in chemical industries by 10%, through improvements in electrolytic processes.

The effects of industrial electricity conservation in reducing the demand for thermal generation, and thus carbon emissions, will be considered as having a total impact of reducing total thermal electricity production by 5%, or about 2.4 TWh[16] at an average cost of US $30/tC.

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[15] Based on Moreira et al. 1996, assuming useful life of retrofits of 15 years and that all electrical savings comes from thermal generation.

[16] This assumption is based partially on Eletrobrás 1994 which gives a total estimated electricity demand of 495 TWh (High Growth Scenario). If total electricity conservation is 10% of this value and industrial conservation can account for 50% of the savings, the reduction in thermal generation will represent 2.4 TWh (thermal electricity at 10% of total generation).

The greater use of combined heat and power still needs greater incentives in Brazil, but the existing potential is significant and underexploited. In sectors such as paper and pulp, iron and steel, and the alcohol-sugar industry, the potential is great, because they produce industrial residues that can be used to generate a surplus of electricity, which then can be sold to the common grid. Legislation that establishes independent power producers is in place, but there are still problems in regulation of tariff agreements between the interested parties (industry and electrical utilities). Greater incentives for cogeneration will result in better efficiency in the burning of fuels in order to maximize the energy surpluses. We assume that industrial cogeneration will be able to reduce by 1% the amount of thermal electricity in the ESC scenario at a cost of US $138/tC using biomass sources.

With respect to the possibilities of substituting fossil energy for renewables, the TSC assumes that no additional substitution is achieved (some substitution is already included in the coefficient alpha as a reflection of the natural trend). We assume that 30% of energy use in boilers can be replaced by biomass and that 30% of the energy is used in water heating can be replaced by solar energy at a cost of US $100/tC and US $120/tC respectively. We assume that the food and beverage sector will have greater possibilities to incorporate these changes.

The average emission factor tC/toe for the industrial sector as a whole will decline as a reflection of greater natural gas penetration. For the TSC we assume that the share of natural gas will increase from 9% in the fossil fuel mix in 1994 to 20% in 2004, affecting the emission factor $\varphi=0.98$ The ESC scenario raises the share of natural gas to 30% ($\varphi=0.96$). The chemical, iron & steel and food industry are assumed to be affected more by the introduction of natural gas. Table 6 presents the emission reduction factors for various sectors assuming a greater participation of natural gas and substitutions amongst fossil fuels towards fuels with less carbon content.

3.3.2 The Energy Sector

The Brazilian energy sector is responsible for about 7 percent of the total final demand and also the same share of carbon emissions. This value only accounts for the energy used to fuel processes within the energy sector itself. If we consider also the amount of fossil energy used for electricity production, this sector has a share of 12 percent of the country's carbon emissions.

There are two areas where an increase in carbon emissions from the energy sector can be expected: the increase of oil refining production and thermal electricity.

Thermal electricity production today represents about 5% of total electricity generated. If we assume an annual growth rate of 23% of thermal electricity production, this share will rise to 10%, based on official total electricity production projections (Eletrobrás 1994). The TSC assumes that there will be an increase in the share of natural gas from 5% in the base year to 15%, which will reduce the average carbon emission factor by 4%. The ESC scenario assumes a 30% participation of natural gas in the share of fuels for thermal electricity generation, which will reduce the emission factor by 9% with respect to the base year value. The ESC also assumes that 25% of fossil based electricity generation can be replaced by biomass generation. The costs of implementing these electricity generation measures in the ESC scenario is US $240/tC.[17]

Electricity conservation potential is quite significant and cost-effective, as many studies have shown for Brazil (for example, Geller et al. 1997, Jannuzzi 1997). However, due to the characteristics of electricity production prevailing in the country, electricity conservation has a limited impact on carbon emissions reductions. Table 5 shows the impacts of energy conservation in thermal electricity generation assumed in the present work.

It was assumed that a 1% annual average increase in refining capacity will occur during the projection period. The TSC assumes that a 10% improvement will take place and therefore assumes an energy - production elasticity of 0.9 (α= 0,90, in the model). The ESC assumes that this improvement can be enhanced (α= 0,88).

3.3.3 The Transport Sector

The transport sector accounts for about 21% of total final energy consumption in Brazil (1996), a share that has remained reasonably constant over the past two decades. It is the main oil-consuming sector in the country. In 1970 it represented 63% of the total final oil demand and by 1996 its share decreased to 49%.

Diesel oil and gasoline are the main fuels consumed and have shown a continuous growth (especially diesel oil) over the past 10 years. The transport sector GDP has grown at a rate of 3.1% per year during 1981-94; we have assumed that for the projection period this sectoral growth will be 2.2% per year. Diesel and gasoline demand are assumed to increase at a faster rate than the sectoral GDP, reflecting the continuous trend in increase in car ownership and need for mobility; thus the fossil fuel elasticity for this sector was assumed to be higher than one. The TSC assumes that fossil fuel demand will increase 5% more than GDP growth and the ESC scenario assumes that it will increase at a 3% higher rate (α= 1,05 in the TSC and α= 1,03 in the ESC scenario), which also assumes that additional structural changes such as a shift

[17] Assuming that the cost of electricity produced from biomass using advanced technologies in the country is 20% greater than average cost of conventional electricity thermogeneration and a base value for fuel oil electricity generation of 60 US$/MWh (Eletrobrás 1994). Assuming also that 1 MWh requires 0.29 toe of fossil primary energy and that the average emission rate is 1.02 tC/toe.

in freight transportation towards rail and river will take place and that public transportation will increase somewhat.

We consider that an additional part of the projected fossil energy will be replaced by alcohol. The TSC scenario assumes that alcohol will continue its present trend and will not affect the future gasoline demand, but the ESC scenario considers that an additional amount of alcohol would need to be produced to replace 20% of the fossil fuel energy demand. (β= 1 for the TSC and β= 0,80 for the ESC scenario). The TSC scenario implies that present alcohol production will rise at an annual average rate of 3.1% [18]. During the period 1981-94 alcohol production increased at an annual average rate of 13.2%, but the rate of increase declined to 3.7% during 1994-96. The ESC scenario assumes that alcohol consumption will rise at an average annual rate of 4.8%. The penetration of natural gas replacing diesel will affect slightly the average emission rate in the ESC scenario.

Alcohol fuel prices to the consumer are about US $ 1,100 /toe (or US$ 154/boe, MME 1997) if we assume that 1 toe of alcohol replaces 1 toe of gasoline, the costs associated are 1,300 US$/tC.

3.3.4 Summary: Projection parameters

Table 5 presents the various measures that we have considered to the be feasible to be implemented over the next 10 years. The associated costs refer to additional effort to implement these measures that would not occur naturally. The average cost values represent an estimated weighted average for the sector considering the potential for introducing the proposed measures.

Table 6 shows the parameters used in the calculations for both scenarios TSC and ESC. As can be seen the TSC scenario assumes a continuing trend of reducing the use of fossil fuels in each sector (except for the transportation sector) as a result of improved efficiency. The ESC assumes some further substitution of fossil fuels for biomass and solar and increased change in the fossil fuel mix, allowing for greater share of natural gas in the sector's energy demand.

[18] Assuming that gasoline will represent a share of 25% of total fossil fuel demand in year 2004 and that alcohol will maintain the same proportion as in 1994 (71% of gasoline demand).

Table 5: Measures and costs of avoiding carbon emissions considered

Sectors	Measures and technologies	US$/tC
Industrial sector	8. Better housekeeping (additional measures), energy audits, process improvements achieved by better information and assistance	3
	9. Retrofitting of motors	10
	10. Industrial co-generation	132
	11. Increase of use of natural gas	50
	12. Use of solar energy for pre-heating of water and industrial fluids	20
	13. Greater use of biomass	20
	Average costs for industrial-sector measures	40
Energy sector	4. Improvements in refinery processes	10
	5. Greater and more efficient use of refinery gas	20
	6. Greater use of natural gas	20
	Average costs for energy-sector measures	50
Electricity generation	4. Increase of the share of natural gas to 35% of thermal generation and substitution of 10% of fossil fuel generation by biomass sources	42
	5. Electricity conservation programs (DSM and end-use efficiency programs in other sectors) reducing 5% of total thermal production[19]	30
	6. Industrial co-generation using biomass and reducing 1% of total fossil fuel thermal electricity generation	138
	Average costs for thermal electricity generation measures	60
Transport sector	5. Use of natural gas in private and public transport	120
	6. Improved energy efficiency in vehicles	20
	7. Improvements in traffic and road conditions	120
	8. Increase of alcohol use	1,300
	Average costs for transportation-sector measures	1,000

Note: Author's estimates based on Moreira et al. 1996, Moreira 1997 and UNEP 1992.

Table 6: Parameters used for projecting carbon emissions: summary

	Trend Scenario				Efficient Scenario				
	α	β	f	φ	α	β	f	φ	US$/t C
energy sector (a)	0.90	1.00	0.88	0.99	0.80	1.00	0.88	0.97	50
industrial sector	0.80	1.00	0.91	0.98	0.50	0.99	0.91	0.96	40
Cement	0.50	1.00	1.01	1.00	0.20	0.99	1.01	1.00	60
iron&steel	0.10	1.00	0.88	0.99	0.05	0.90	0.88	0.98	40
Chemicals	0.80	1.00	0.93	0.98	0.60	0.95	0.93	0.97	40
food and beverage	0.40	1.00	0.94	0.99	0.30	1.00	0.94	0.98	35
Other industry	0.30	1.00	0.92	0.99	0.20	1.00	0.92	0.98	102
Thermoelect. prod.	(b)	1.00	1.01	0.96	(b)	0.75	1.01	0.91	60
transport sector	1.05	1.00	0.89	1.00	1.03	0.80	0.89	0.99	1,000

Notes: (a) excluding thermal electricity production; (b) thermal electricity production was estimated as 10% of total electricity generation in year 2004 (from Eletrobras 1994, Table 19).

[19] It is important to note that electricity conservation impacts on total thermal generation is small, because we have assumed that thermal electricity is only 10% of total generation in the projected year.

3.3.5 Results

Both scenarios show that total carbon emissions will increase, even considering modest GDP growth rates assumed in the present analysis (see Table 18). According to the TSC carbon emissions will increase at 3.3 % annually during 1994-2004, with additional measures this rate can be reduced to 1.2% (ESC) scenario, but at a total estimated cost of US$ 7 billion. The transportation sector will be still the main contributor the country's emissions, and where reduction measures are most costly.

The sectoral structure of carbon emissions remain stable across both scenarios. However, the increased thermal electricity generation will affect significantly this structure and could even have a higher contribution than the industrial sector, depending on the participation of natural gas use and biomass cogeneration.

Table 7: Results: Carbon emissions by sector (tC)

	Trend Scenario		**Efficient Scenario**		**annual avg. growth 1994-2004**	
2004	10^3 tC	%	10^3 tC	%	TSC	ESC
Energy	6,128	8%	5,778	9%	3.45%	2.84%
Industry	20,928	26%	19,093	29%	1.46%	0.53%
Cement	1,490	2%	1,429	2%	0.49%	0.07%
Iron & Steel	7,556	9%	6,686	10%	0.06%	-1.16%
Chemical	1,982	2%	1,883	3%	0.64%	0.12%
Food & Bev	1,113	1%	1,085	2%	0.52%	0.26%
Other	8,787	11%	8,010	12%	3.46%	2.50%
Transport	31,570	39%	25,072	38%	2.28%	-0.05%
Electric gen.	22,892	28%	16,194	24%	22.55%	18.38%
Total	81,518	100%	66,137	100%	3.34%	1.20%

Table 8: Results: Associated carbon emission costs

	Total cost (US $ 10^3)	**US$/tC**
Energy (internal sectoral use)	17,494	50
Industry	73,409	40
Cement	3,656	60
Iron & Steel	34,781	40
Chemical	3,972	40
Food & Beverage	981	35
other	30,018	102
Transport	6,498,639	1,000
Electricity generation	401,867	60
TOTAL	6,991,411	

4 Annex 1: Method for projecting carbon emissions

The method used for estimating future contributions of each sector towards the reduction of carbon emissions is based in the elaboration of one economic scenario and two energy-emissions scenarios: a trend scenario TSC and an efficient-low emission scenario ESC. We first project aggregate fossil fuel demand based on assumed elasticities and also take into account possible reduction due to partial substitution by renewable sources.

Table 18 shows the assumptions made for GDP growth (in the case of the energy sector and thermal electricity production this is replaced by oil products production and thermal electricity generation).

$$E^{s}_{j}=[(GDP^{s}_{j} / GDP^{s}_{i})^{\alpha}.\beta^{s}].E^{s}_{i}$$

where:
s = sector, E= fossil energy, j= projected year, i= base year
GDP^{s} = sectoral GDP
α = fossil energy-GDP elasticity
β = fuel substitution factor ($\beta < 1$) or $\beta = 1$ when there is no substitution for renewable sources

Carbon emissions are calculated from fossil fuel energy projection estimated from equation 1 considering the average emission for the base year, which takes into account possible changes in fossil fuel mix towards fuels with less carbon content. Equation 2 shows the final calculation:

$$C^{s}_{j} = E^{s}_{j} \ . \ f^{s}_{i} \ . \ \varphi^{s} \qquad (5.2)$$

where:
C = carbon emissions (tC)
f = base-year emission factor (tC/toe)
φ = fuel mix factor (<1 represent changes towards fuel with less carbon content).

5 Annex 2: Additional statistical information

Table 9: Base year fossil fuel energy demand (thous. toe)

	nat. gas	coal	diesel oil	fuel oil	gasoline	LPG	gas	coke	other liq
transport	39		18,332	796	9,102				
total industry	1,735	1,098	459	7,141		314	971	6,591	1,553
cement	5	343	16	1,040					
iron&steel	433	268	39	460		29	964	6,329	
chemical	439	121	67	1,383					
food&beverage	154	78	29	840		26			
other ind.	704	288	308	3,418		259	7	262	1,553
energy setor	885		239	1,605		15	374		1,856
elect prod	154	1,082	647	812			79		175
TOTAL	4,548	3,278	20,136	17,495	9,102	643	2,395	13,182	5,137

source: MME 1996.

Table 10: Average energy prices (1995 US$ per barrel of oil equivalent)

	1990	1995
Imported oil (1)	23.2	15.9
Imported oil (2)	26.7	15.9
Diesel oil	154.4	89.2
Fuel oil	67.1	49.9
Gasoline	330.7	192.5
Alcohol	350.4	224.2
LPG	86.1	73.9
Natural gas fuel	50.2	23
Natural gas (reducing agent)	50.2	9.9
Industrial electric	193.2	116
Residential electric	255.7	208.4
Coal	29	18.6
Charcoal	50	37.4
Fuel wood (native)	21.9	13.6
Fuel wood (reforestation)	31.2	17.7

Source: MME 1996. Notes: (1) Current prices (US$); (2) Constant prices 1995

Table 11: Fossil fuel energy elasticities 1981-94

	GDP (10^6 1995 US$)		Fossil energy (thousand toe)		GDP (a)	Energy (b)	elasticity (b)/(a)
	1981	1994	1981	1994	aapg	aapg	
Energy(1)	15,281	29,691	3,218	4,366	5.2%	-15.7%	-3.0
Industry	176,899	204,993	15,198	18,106	1.1%	-18.1%	-15.9
cement(2)	8,806	8,337	2,256	1,420	-0.4%	-9.6%	22.8
iron&steel	15,659	20,393	3,948	7,513	2.1%	-11.9%	-5.8
chemical	16,888	20,173	2,786	1,860	1.4%	-14.1%	-10.3
food&beverage	18,090	22,236	1,356	1,057	1.6%	-19.4%	-12.1
other	117,456	133,854	4,852	6,256	1.0%	-22.5%	-22.3
transport	19,773	29,335	23,673	25,191	3.1%	-1.6%	-0.5

Notes: aapg = annual average percentage growth; (1)= refers to oil extraction and refining, alcohol production, electricity generation and coke production. Source: MME 1996.

Table 12: Structure of energy consumption by energy sector 1981-95 (%)

	1981	1985	1990	1995
Natural gas	2.5	6.2	6.0	6.1
Bagasse	32.7	52.5	50.	49.4
diesel oil	3.4	2.7	3.2	1.0
fuel oil	22.5	11.0	12.2	11.4
coke gas	2.0	2.8	2.5	2.5
Electricity	19.5	14.4	15.0	16.9
other oil products	17.1	10.3	10.9	12.4
other fuels	0.3	0.1	0.2	0.3
Total	100%	100%	100%	100%
Total (thous. toe)	**6,751**	**12,547**	**13,181**	**14,256**

Source: MME 1996.

Table 13: Structure of transport energy demand by fuels 1981-95 (%)

	1981	**1985**	**1990**	**1995**
diesel oil	48.4	48.6	50.5	48.1
fuel oil	5.4	6.1	2.3	1.9
gasoline	32.5	21.9	22.6	26.7
kerosene	7.3	6.5	5.8	5.7
alcohol	5.1	15.4	17.6	16.5
others	1.4	1.5	1.2	1.1
total	100%	100%	100%	100%
Total (thous. toe)	**25,217**	**26,829**	**32,311**	**40,569**

source: MME 1996.

Table 14: Fuel structure of thermal electricity production 1994 (%)

	thous. toe	%
Natural gas	154	4%
coal	1,082	25%
Diesel oil	647	15%
Fuel oil	812	19%
Fuelwood	127	3%
Bagasse	463	11%
Other residues	751	18%
gas	79	2%
other fossil fuels	175	4%
Total	4,290	100%

Source: MME 1996.

Table 15: Structure of transport energy demand by sectors 1981-95 (%)

	1981	**1985**	**1990**	**1995**
Road	81	80	81	90
Rail	3	3	3	2
Air	8	7	6	6
Water	8	10	3	3
	100%	100%	100%	100%
total (thous. toe)	25,217	26,829	32,311	40,569

source: MME 1996

Table 16: Structure of industrial energy demand by fuels 1981-95 (%)

	1981	1985	1990	1995
Natural gas	0.7	1.0	2.0	2.6
coal	1.7	2.5	1.5	1.6
fuelwood	8.0	10.5	8.1	6.4
bagasse	10.5	8.2	6.8	9.2
Other renewables	1.6	1.9	2.2	2.8
fuel oil	20.0	8.9	10.0	10.0
coke gas	0.9	1.3	1.3	1.3
coke	5.5	8.1	7.7	8.7
electricity	41.3	46.6	49.6	48.2
charcoal	6.4	8.5	8.1	5.6
others	3.3	2.6	2.7	3.5
total	100%	100%	100%	100%
Total (thous. toe)	**47,491**	**59,931**	**65,718**	**76,563**

source: MME 1996

Table 17: Structure of industrial energy demand by sectors 1981-95 (%)

	1981	1985	1990	1995
cement	7	4	4	4
Pig iron and steel	19	23	22	22
metal alloys	3	3	3	3
mining	4	4	4	4
non metals and other metals	7	10	13	13
chemicals	11	11	10	10
Food and beverage	20	18	16	18
textiles	4	4	4	3
Paper and pulp	7	7	8	9
ceramics	5	5	4	4
others	13	12	12	11
	100%	100%	100%	100%
Total (thous. toe)	**47,491**	**59,931**	**65,718**	**76,563**

source: MME 1996

Table 18: GDP average annual growth rates

sectors	1991-94	1994-04
Energy sector	5.2%	4.0%
Industrial sector	1.1%	2.1%
Cement	-0.4%	1.0%
Iron & steel	2.1%	1.5%
Chemical	1.4%	1.5%
Food & beverage	1.6%	1.6%
Other	1.0%	3.5%
Transport sector	3.1%	1.2%
Electricity generation (a)	0.6%	23.0%

Source: MME 1996.

Table 19: Power sector official estimates for electricity consumption in Brazil (TWh)

Scenario	1990	1995	2000	2005	2010	2015
I	210.3	249.2 (246.2)	302.7 (293.8)	405.1 (384.0)	510.0 (467.2)	626.9 (563.0)
II	210.3	254.5 (250.9)	344.2 (329.5)	461.9 (430.6)	574.8 (523.9)	707.1 (631.3)
III	210.3	278.3 (273.7)	378.5 (360.7)	517.4 (473.2)	660.5 (589.7)	836.7 (731.4)
IV	210.3	278.9 (273.7)	397.6 (377.6)	544.9 (495.4)	724.2 (642.6)	950.1 (826.4)

Note: Figures within parentheses include electricity conservation efforts.
Source: Eletrobras, 1994.

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