BRAZILIAN INDUSTRY'S ENERGY USE: GAINS FROM ENERGY-EFFICIENCY IMPROVEMENTS

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INTRODUCTION

Despite the two oil crises and the economic recession of the 80s, energy consumption in Brazil has been growing steadily. Since 1978, the average growth rate has been 3.1% per year (1). In view of this, there is a national consensus that a more efficient use of energy may help alleviate the need for increasing the supply of electricity and, hence, of the need for large-scale capital investments to face up to the growing demand in the near future (2). In this context, the industrial sector plays a central role with respect to the growth of energy demand. In particular, the consumption of energy of the so-called energy-intensive industries, such as iron and steel, non-ferrous metals (mainly aluminum), non-metallic minerals (cement, glass and ceramics), chemicals (petrochemicals and soda-chlorine), and pulp processing, is especially important in this connection. Taken together, these segments alone accounted for 66% of the total industrial energy consumption, and for 27% of the total energy consumption, in Brazil in 1993 (1). This paper aims at examining the evolution of industrial energy consumption in Brazil since 1950 and at identifying possible energy savings opportunities in the energy-intensive segment of industry, so as to help in the formulation of energy conservation strategies.

THE HISTORICAL EVOLUTION OF THE BRAZILIAN INDUSTRIAL SECTOR

Economic development of Brazilian industry took off very recently. It is only since the 50s that industry gained momentum, supported by a government policy of imports substitution for supplying the domestic market. Later on, the industrial growth rate became quite high, with non-durable goods registering the highest growth rate and, later, durable goods, passing through intermediary goods and finally capital goods. By 1970, Brazil had a well diversified industry already and, soon after, entered a phase of strong economic growth. At that point, the government started to support basic industries, such as iron and steel, cement and chemicals, among others, mainly those in the energy-intensive sectors of the economy.

Until 1980, the growth of Brazilian industry was very fast. Between 1949 and 1980, the annual growth rate was 8.5%, 20% more than the growth rate of the Brazilian GDP for the same period. Thus, the share of industry in the total GDP increased from 26% in 1949 to 34% in 1980 (3). Between 1965 and 1980, industrial growth in Brazil was even more extraordinary (9.5% per year), higher than the average growth rate of both developing (6.5%) and developed countries (4.8%). Only three economies performed better than Brazil's during that period: South Korea's (19.0%), Singapore's (11.4%) and Indonesia's (10.2%) (4).

During the 80s, the situation changed drastically. With the Second Oil Crisis and the beginning of a world economic crisis, Brazil's external debt reached an unprecedented level, the trade balance suffered a strong disequilibrium and the government changed the economic and industrial policies of the country (5). A strong export-oriented policy followed, with concurrent disincentives to imports. From the trade balance point of view, that policy was successful and, as a side effect, there was a further acceleration of the rate of growth in the iron and steel, aluminum and pulp and paper sectors, which directed their production more and more towards the international market. As a consequence of that process, the importance of the role of energy-intensive sectors of industry increased, and, hence, energy consumption also increased substantially, despite the period of recession and decline in economic activity within the country.

The beginning of the 90s witnessed a new period of recession, with industrial production declining in 1990, 1991 and 1992. By 1993, industrial GDP was 2.1% lower than in 1980 (1). Nevertheless, the change did not take place uniformly. In some segments, there was a substantial reduction in economic production (e.g. capital goods industry: -44% between 1980 and 1992) while in others, as a function of the maturation of earlier investments and export incentives, some growth was registered: intermediary goods +6% and non-durable goods +8%, in the perios (6). Between 1980 and 1990, the industries with the highest growth were: nonferrous metals (140%), electric machinery (123%), iron and steel (105%), and chemicals (103%) (7). Since 1993, however, the economy picked up again. But this historical trajectory has been marked by substantial structural change in Brazilian industry. There has been an increase not only in the general diversification of products, but there was also a growth in the share of energy-intensive industries in overall production. In consequence, energy demand intensified and almost all economic indicators on energy intensity registered an increase.

EVOLUTION OF ENERGY CONSUMPTION AND ENERGY INTENSITY

The fast development of Brazilian industry had an impact not only on the economy as a whole, but also has promoted significant changes in the Brazilian energy matrix. Until 1971, the largest energy consumer in the country was the residential sector, only to be superseded, one year later, by the industrial sector. In 1993, industrial consumption accounted for 39.1% of total energy consumed in the country, followed by the transportation (19.3%) and the residential (16.1%) sectors (1).

Energy consumption within the industrial sector varied as a function of the rate of economic growth of the country. Between 1975 and 1980, industrial energy consumption increased at an average rate of 9.1% per year, and between 1981 and 1993, at an average rate of 2.7% per year. During this last period, strong fluctuations were frequent, such as the sharp drop in energy consumption in the order of 6.6% in 1981 and the strong increase of 11.1% in 1984. Total industrial energy use in Brazil reached 71,497 MtOE in 1993, the main consumers being: iron and steel (25.8%), food and beverages (16.5%) and non-ferrous metals (13.3%) (1).

Table I - The Evolution of Energy Consumption in Selected Brazilian Industries

Unit: 1,000 tOE

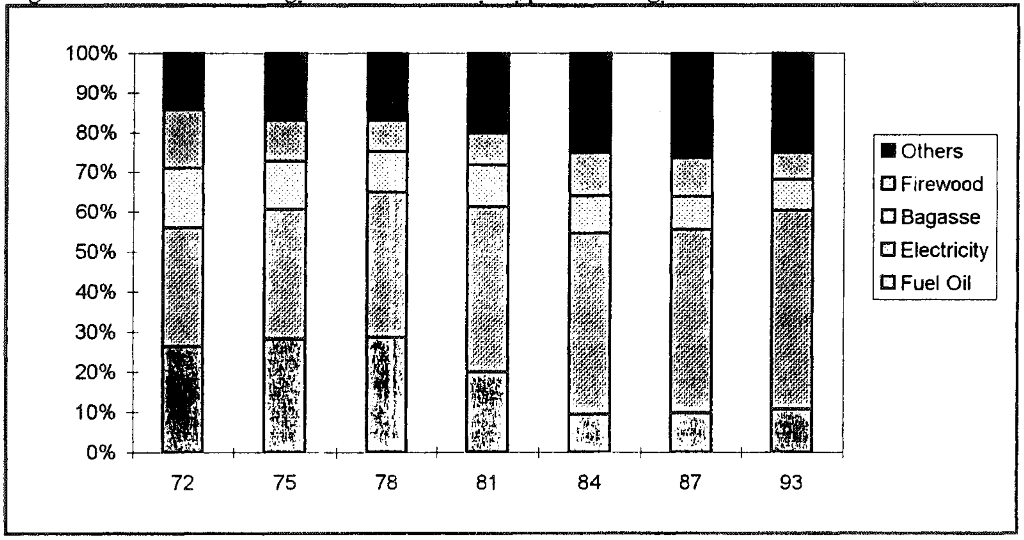
	72	75	78	81	84	87	90	93
INDUSTRY TOTAL	25,131	32,954	43,614	47,491	56,150	66,551	65,718	71,497
Iron and steel	4,944	7,214	9,172	10,157	14,167	17,433	16,777	18,421
Non-ferrous	1,347	2,210	3,228	3,416	4,959	7,300	8,515	9,,85
Chemicals	2,179	2,910	4,295	5,202	6,062	6,830	6,874	7,431
Food and beverage	6,855	7,207	8,696	9,524	10,581	11,239	10,478	11,797
Pulp and paper	1,520	1,925	2,890	3,547	4,038	4,738	5,133	6,411
Cement	1,810	2,443	3,298	3,357	2,303	2,933	2,819	2,561
Others	6,476	9,045	12,035	12,288	14,040	16,078	15,122	15,391

Assuming 1kWh = 3,132 kcal. Source: (1)

The relative importance of different power sources within the industrial sector has also changed over time. In consequence of the Second Oil Crisis, electricity increased in importance as compared to other carriers. In 1994, electricity consumption represented 49.5%[1] of the total industrial energy consumed, followed by fuel oil (10.8%), coke (8.9%), sugarcane bagasse (7.8%), firewood (6.7%) and charcoal (6.3%) (Figure 1) (1). Political and economic changes, together with changes in the profile of energy supply and demand, energy prices and technological development of the industrial processes have combined to produce significant variations in the industrial consumption of energy and in its intensity.

[1] This figure was computed considering the fossil equivalent of electricity as 3,132 kcal/kWh. If we consider instead the caloric equivalent (860 kcal/kWh), the relative participation would be eletricity 15.7%, fuel oil 16.8%, coke 13.9%, bagasse 12.1%, firewood 10.5% and charcoal 9.8%. The total energy consumption would be 9,717 MtOE.

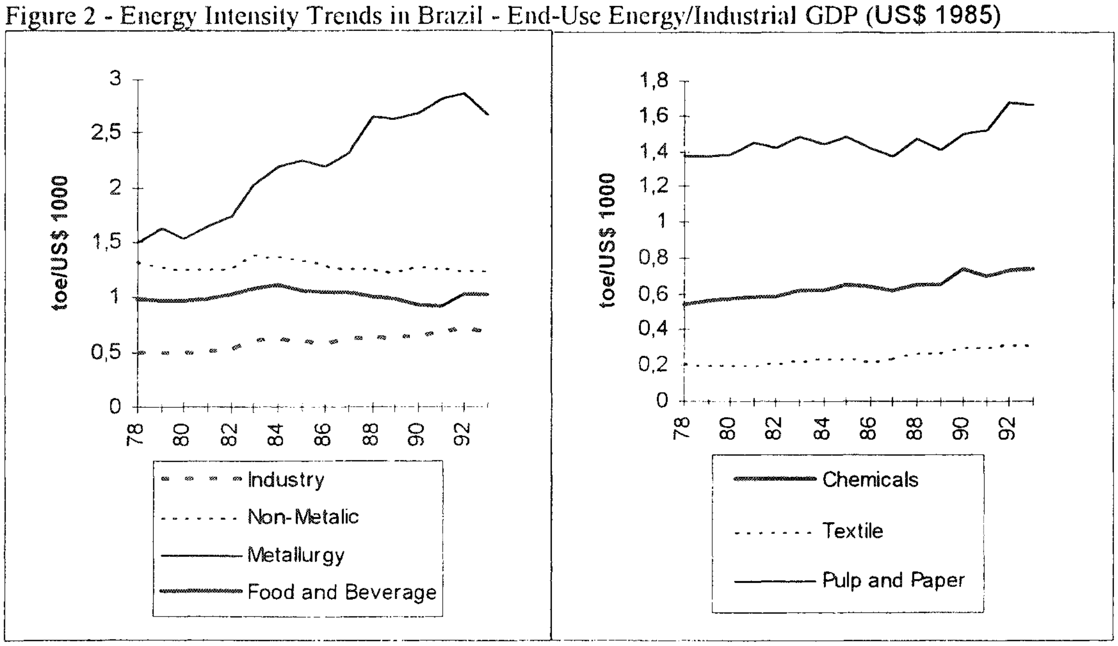
Figure 1 - Industrial Energy Use in Brazil by Type of Energy Source



Source: (1)

In contrast to the international pattern of decreasing energy intensity over the years, the indexes of energy intensity in Brazil register an increase over time. For a growth in industrial GDP of only 15% between 1978 and 1993, industrial energy consumption grew 64% during the same period in Brazil, corresponding to an increase of 42% in the country's industrial energy intensity (industrial energy consumption/industrial GDP). It is important to notice, however, that this increase in energy intensity does not necessarily mean a decrease in energy efficiency, but may indicate that structural changes have taken place in industry or simply that what has occurred is a devaluation of the market value of goods and services produced in relation to the physical productions. A trend of an upward sloping industrial energy intensity can be perceived in almost all main sectors in Brazil (Figure 2). The industrial energy consumption indicators for various countries are also shown on Table 2.

Figure 2 - Energy Intensity Trends in Brazil - End-Use Energy/Industrial GDP (US$ 1985)



Source: (1)

Table 2 - Specific Energy Intensities for Selected Countries

Country	Energy Use in Industry/Country's GDP (MJ/US$ 1985) 1970	1980	1990	Δ% 90/70
USA	6.7	5.3	4.0	-40.3
Canada	7.7	8.0	6.1	-20.8
France	5.6	4.3	3.0	-46.4
Germany	7.9	6.0	4.1	-48.1
Italy	6.2	4.5	3.7	-40.3
England	10.4	6.4	4.5	-56.7
Japan	7.7	4.9	3.5	-51.4
Spain	6.0	6.1	5.0	-16.7
BRAZIL	**7.3**	**7.1**	**7.1**	**-2.7**

Assuming 1 kWh = 860 kcal; i.e. 3.64 times lower than the other energy data shown in the Brazilian Energy Balance (1). Source: World Energy Council - Report 1992 - International Energy Data in: (1)

Even considering that "energy use/GDP" is not the most appropriate gauge to measure the country's industrial energy intensity, an assessment of trends of these coefficients over time as well as an assessment of the factors conditioning the variations in these indexes may provide a better understanding of the patterns of development of the country's industry and of specific sectors.

AN ASSESSMENT AND A BREAKDOWN OF VARIATIONS IN ENERGY INTENSITIES

A breakdown of the evolution of energy consumption and energy intensity allows for an evaluation of the extent to which various factors conditioning a specific economy contribute to overall transformations in consumption (8, 9 and 10). The factors may be grouped in three categories: real or intrinsic energy intensity, structural and activity level factors. The first one is integral to the evaluation of variations in production, sectoral product combinations and changes of energy sources. The structural factor is related to changes at a level of industrial structure affecting energy consumption patterns. The activity factor refers to the interrelation of evolving energy consumption patterns and production. In this paper, the Laspeyres Index has been used to provide a breakdown of energy intensity (9) and for comparing the evolution of different countries. An assessment of the index breakdown for USA, Japan and France was also carried out for the period 1975-1990.

Table 3 shows that the Brazilian industrial structure is different from that of the other countries considered. The different levels of energy intensity testify to this effect: Brazil uses large amounts of energy to produce a relatively low level of products, as measured by the low level of economic output generated. It is important to mention, however, that this does not necessarily indicate a low level of technical efficiency in energy use, though the technological question may play a role as well.

Table 3 - Energy Use and Value Added in Manufacturing in Selected Countries - 1990

Country	Energy use (exajoules)	Value added (billion US$ - 1985)	Energy Intensity (MJ/$)
BRAZIL	**1.9**	**76.5**	**24.8**
USA	13.0	905.5	14.4
JAPAN	4.8	551.2	8.7
FRANCE	1.5	128.8	11.6

Assuming 1kWh = 860 kcal. Source: Based on data available at: Energy Balances of OECD Countries (various years) (11), Lawrence Berkeley Laboratory data base, Industrial Statistical Yearbook (various years), MME (1) and Anuário Estatístico do FIBGE (various years)

Considering final energy use and industrial production measured in terms of value added, Brazil's index increased 16.7%, while that of USA, Japan and France decreased 43.5%, 62% and 35.9%, respectively. It is important to note that USA, Japan and France have even increased their industrial economic output while decreasing energy consumption (Table 4).

Table 4 - Changes in Energy Consumption, Value Added and Aggregate Energy Intensity in Industry - 1975/1990

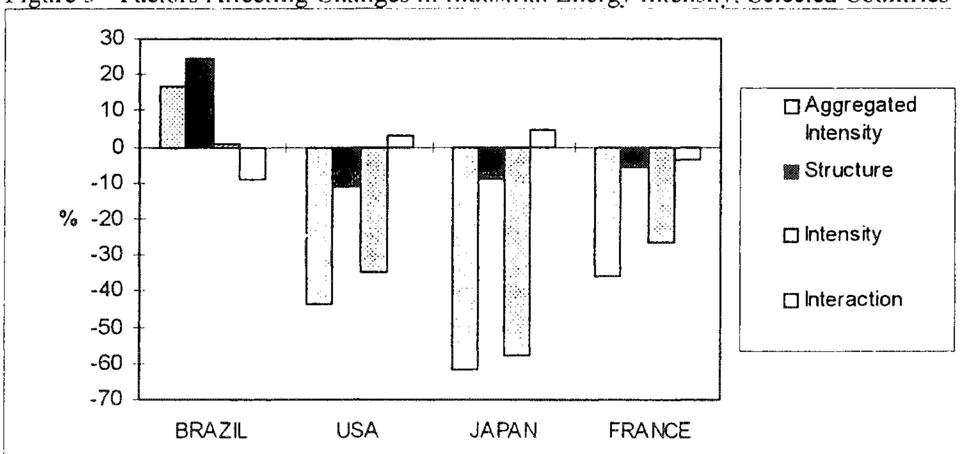
	(% variation)		
Country	Energy Consumption	Value Added	Aggregate Intensity
BRAZIL	**+65.2**	**+43**	**+16.7**
USA	-5.3	+70	-43.5
JAPAN	-6.6	+142	-62.0
FRANCE	-21.8	+18	-35.9

The breakdown of energy intensity variations also reveal a distinctively different pattern for Brazil. Looking at Table 5 and Figure 3 it can be seen that, in the three countries selected, the drop in intensity has played an important role for reducing total energy intensity, while the drop in Brazil was almost negligible and positive (+1%), indicating an increase in intrinsic energy intensity.

Table 5 - The Contribution of Different Factors on Changes in Industrial Energy Intensity for Selected Countries - 1975/1990

		(variation %)		
Country	Aggregate Intensity	Structure	Intrinsic Intensity	Interaction
BRAZIL	**+16.7**	**+24.7**	**+1.0**	**-9.0**
USA	-43.5	-11.4	-35.0	+2.9
JAPAN	-62.0	-9.0	-58.0	+5.0
FRANCE	-35.9	-5.9	-26.5	-3.5

Figure 3 - Factors Affecting Changes in Industrial Energy Intensity: Selected Countries - 1975/1990



The structural factor has proven decisive for determining total energy intensity in Brazil, that is, the structural configuration of Brazilian industry contributed decisively to aggregate energy intensity and consumption. The structural factor also conditions the indexes of USA, Japan and France, reducing the respective country's total energy intensity, although to a much lesser extent than the factors referent to intrinsic intensity. The impact of intrinsic intensities to the above described patterns has been -35.0% in the USA, -58.0% in Japan and -26.5% in France. That is, the changes within the productive subsectors were significant in reducing energy use and through the mix of products within the sectors and also through technological transformations conducive to a higher energy efficiency and productivity. Although, in this study, we have not been able to differentiate these two factors, there is some evidence that, because of the high value obtained for the intrinsic intensity effects, chances are that the technological aspects have played an important role to the global reductions achieved.

In the case of Brazil, the effect of +1% due to intrinsic intensity does not, however, necessarily mean a backward technological step or a reduction in the energy efficiency of the processes involved. It may simply indicate that a change has occurred within specific subsectors of industry conducive towards an increase in energy use per unit of economic value produced. As a matter of fact, this is probably what has happened. With the exception of the iron and steel and the "others" sectors, all remaining sectors registered growth rates in energy use higher than their value added for the period 1975-1990. There may be a trend within subsectors towards the manufacturing of goods with lower value added, but with high energy content, or an accelerated production of goods of high value but of an even higher energy content.

The importance of the intrinsic energy intensity for changing energy intensity in developed countries as compared to the situation in Brazil puts into question the impact of some factors (technology, energy mix, mix of goods within subsectors etc.) on the final coefficients of the Brazilian industry in terms of overall reduction in energy use. With respect to the continuity of the presently existent structure at a level of subsectors, it can be said that the only possibility to reduce energy intensity in Brazil entails changes in the technological base, i.e., changes leading to the adoption of technologies and processes of higher energy efficiency, techniques and procedures for a higher productivity and an energy mix of a higher overall efficiency. The impact of those changes on the final indexes would be significant. However, an assessment of the indicators of energy performance, considering the indexes of energy use per physical output of industries (specific consumption) and the technologies used, as well as a more detailed analysis of some industrial segments, may reveal new possibilities to improve energy performance and, consequently, to reduce energy intensity indexes.

INDICATORS OF ENERGY PERFORMANCE - ENERGY-INTENSIVE INDUSTRIES

The share of energy intensive industries in the industrial sector has been growing steadily. Energy use for this segment of industry increased from 55.5% of total energy use in industry in 1975 to 66.5% in 1993 (1), and is still expected to continue to increase its share in total energy use by industry (12). The energy intensive sectors in industry were exactly those with accelerated development during the phase of imports substitution promoted by the Brazilian government some twenty years ago (13). These sectors present some specific characteristics that may qualify them as relatively "efficient", at least in terms of production costs and performance, when compared to the international average. Furthermore, the sectors have benefited a great deal from the abundant source of mineral, forest and energy resources available in Brazil, at a low cost normally, a good capacity of process management, adequate technical scales and state of the art technologies (4). There are some problems in almost all subsectors, however. From the economic viewpoint, there is a productive capability concentrated only in a few products of low value added and that face a strong international competition due to excess production capacity, i.e. decreasing international prices (13). From the technological viewpoint, these segments need to be constantly updated so as to keep their competitiveness and market share. Therefore, a highly competitive market for these products makes issues related to productivity and the efficient use of inputs, such as energy, extremely important.

Even with the relatively low cost of energy in Brazil, energy-intensive industries have tried to adopt energy-efficiency production strategies. The reduction in the coefficients of energy use per physical production of goods testify to this concern. However, the reduction in specific consumption is not a generalized trend, since other factors are also present so as to make these indexes vary within the sectors. Technology may be the main factor, but other components may also play a role, such as the type of energy carrier employed, the age of the industries, the diversification of products within the industries, the diversification of products within sectors, the use of self-produced energy through cogeneration etc.

Steel

In this sector, the consumption indicators are quite varied, depending on the type of industrial process, the size and the age of the plant, the kind of coal been utilized, the degree of elaboration of the raw materials, the stage of automation and of verticalization of the industry etc. Looking at the five largest Brazilian firms in the sector - CSN, Cosipa, Usiminas, CST and Açominas - which are all coke integrated plants, there appears a specific consumption of energy pattern, showing a downward trend (Table 6).

Table 6 - Overall Specific Consumption in Coke Integrated Steel Plants

YEAR	1981	1982	1983	1984	1985	1986	1987	1988
Mcal/ton Steel	6,436	6,903	6,434	6,651	6,216	6,333	6,224	6,131

Assuming 1kWh = 2.5 Mcal. Source: ABM - Balanços Energéticos Globais in: (14)

On the other hand, based on the energy consumption pattern of a reference plant, according to the IISI - Energy and Steel Industry (14), with an estimated value of 4597 Mcal/t of steel, greater energy efficiency for Brazilian industries is still quite a long way ahead.

Aluminum

Electricity constitutes about 70% of the total energy consumed for the production of primary aluminum in Brazil (13). Given the recent establishment of plants in this segment in Brazil, the processes employed by the largest part of the industry are modern, employing pre-cooked anode technologies, with specific consumption between 14 and 15 MWh/ton, a value lower than that of the older plants, which employ electrolytic cells (Soderberg paste), with specific consumption around 17 MWh/ton (15). Considering the sector as a whole, the specific consumption of the Brazilian industry is about 16,8 MWh/ton, which is slightly better than the international pattern of 17,2 MWh/ton (15).

Steel Alloys

The Brazilian steel alloys industry is characterized by the intensive consumption both of charcoal and of electricity. The proportions vary according to the type of product. The specific consumption of this segment is quite variable by virtue of the great diversity of alloys which are produced with the most diverse energy contents. For example, for a manganese-based alloy the average specific consumption is 4,276 kWh/ton, while for a nickel-based alloy this consumption grows to 12,220 kWh/ton (13).

Soda-chlorine

The segment of soda-chlorine also has in electricity its main energy input, 80% of this energy being destined to the electrolysis process (16). When compared to more developed countries, the processes utilized in Brazilian industries are reasonably modern. About 70% of the processes employ the diaphragm cell technology, 18% mercury cell and 2% membrane cell technologies. However, when the specific consumption of electricity is compared with the international standards for the three types of technology, Brazilian firms still yield higher values.

Table 7 - Specific Consumption of Electricity in Processes of Soda-Chlorine Manufacturing (kWh/ton)

Process	BRAZIL	International Standard
Mercury Cell	3,450	3,325
Diaphragm Cell	3,360	2,850
Membrane Cell	3,070	2,700

Source: (15)

Ethylene

In the petrochemical sector, where ethylene is manufactured, the main energy sources, excluding the cases when energy sources are used as raw materials, are fuel oil and natural gas, both used as heat sources in boilers and furnaces. The consumption of electricity is also high, although restricted to the running of motors and to lighting only, which results in it having a lower share when compared to the other energy sources. Taking as a basis the production of ethylene in a typical firm of the sector, Petroquímica União, it is possible to see that the specific consumption has been reduced continuously along the years. From 1980 to 1990 the reduction was about 16,5% (14).

Pulp and paper

The major energy sources in the pulp and paper sector are fuel oil, firewood and black liquor, used for generating heat in steam boilers. This sector has being undergoing several changes due to the greater relative participation of pulp production, as well as to the substitution of energy sources during the 80s. At about the same time, the firms in this sector put forth important energy saving programs, resulting in a reduction of the overall indicators of energy consumption throughout the period. Nevertheless, given the great fluctuations in specific consumption during the last years, there is currently no clearly defined trend of evolution of the sector's total specific consumption, which average value has oscillated around 26,9 GJ/ton of output (1). At the international level, the "best practice" indicators of specific consumption vary in the range of 16 GJ/ton (17), even in the cases of a pulp/paper ratio around 50%.

Cement

The specific consumption of the cement sector is undergoing a steady decrease. From 1978 to 1993 the reduction reached 27.5% (1). However, comparison of the Brazilian specific consumption data with that of the sector in Western Europe and in some Pacific Basin countries shows that the Brazilian indicators remain about 20% higher (18). Nevertheless, this is a segment that has implemented several improvements in its processes, starting in the 70s with the gradual introduction of the dry processes, replacing the humid ones (15). Furthermore, the sector has widely substituted coal for fuel oil, previously the only fuel consumed.

Glass

The glass industry has also undergone technical improvements and has also changed its energy sources, both contributing to the reduction in energy consumption. Besides implementing measures for the optimization of the heat recovery in furnaces and for improving combustion, the introduction of electric boosters also contributed significantly to reducing specific consumption. For example, in the manufacture of plain glass specific energy consumption decrease from 14,1 to 8,6 GJ/ton between 1980 and 1990 (14).

IMPROVEMENTS IN ENERGY EFFICIENCY AND ENERGY SAVINGS POTENTIAL IN BRAZILIAN ENERGY-INTENSIVE INDUSTRIES

The Brazilian industrial sector, once analyzed through its subsectors or through indicators of energy consumption in the physical output, has been showing a steady improvement in its energy efficiency, especially in the energy-intensive segments. The iron and steel and the cement sectors seem to be those where the greatest reduction in specific consumption was achieved (14,19). A more widespread adoption of "energy conservation" concepts has been hindered by several problems, but it can be affirmed that, as a general rule, the Brazilian industries have been pursuing a more efficient use of energy, especially in those sectors where energy costs are significant in the production process. The problems range from the low public awareness of energy conservation issues to the insufficiency of incentives, given the scarcity of fiscal incentives, the low tariffs and energy prices and the lack of credit lines (16). Undoubtedly, however, the major obstacle seems to be the unstable economic scenario during the 80s, lasting up to the beginning of the current decade (2). Therefore, several opportunities for promoting the increase of energy efficiency within the industrial sector remain, including within the energy intensive segment, through the modification or adaptation of industrial processes, the replacement of less efficient equipment and the adoption of techniques that are less energy-hungry and boost up productivity. The opportunities for a more efficient use of energy can be found both in the processes that require the production of heat (using up fuel) as well as in the use of electricity. In the fuels area, aside from modifications in industrial processes and the introduction of new ones[2], there is still room for improving combustion, heat recovery and thermal insulation in boilers and furnaces.

As far as combustion is concerned, very few improvements have been effectively performed in Brazil (20). Several possibilities are open, from periodic manual monitoring to the implementation of continuous automated combustion control processes. As to heat recovery, the adoption of a few measures is slightly more complex and requires greater investments, but it remains technically feasible and economically viable. The same happens with thermal insulation, although in this case the costs are somewhat lower and the changes are simpler.

[2] The membrane processes in the chlorine soda sector and the dry process in the cement sector are examples of new processes.

To establish the savings potential of fuels, estimates were made for the average savings for each measure to be adopted in each energy-intensive industrial segment. The estimates were based on audits that were performed (19,21). Table 8 shows the data obtained and the estimated fuel savings potential.

Table 8 - Fuel Savings Potential in Selected Energy-Intensive Industries in Brazil

Industry	Consumption of Fuel(10^3 tOE)	Savings by Type of Measure (%)			Total Savings Potential	
		Combustion	Heat Recovery	Insulation.	%	10^3 tOE
Iron and Steel	2,014	5	10	5	21.3	429
Aluminum	91	5	-	-	5.0	4
Chemicals	1,802	5	10	3	11.9	214
Pulp and Paper	3,655	5	5	-	10.2	373
Cement	1,701	5	-	-	5.0	85
Glass	1.138	5	5	5	15.8	180
TOTAL	10.401				12.3	1,285

1) Fuel consumption in 1993 levels. 2) The consumption of coal in the iron and steel sector was not considered, given its use as a reducer. 3) For aluminum, the consumption data came from (15) and refers only to fuel oil in 1989. The consumption of tar and coke is excluded. 4) Given the unavailability of specific data for the ethylene and soda-chlorine sectors, the consumption of fuel oil for the chemical sector as a whole was considered. 5) For the glass sector, 50% of the ceramic sector consumption as computed in (1) was considered. Source: The authors, based upon fuel consumption in (1)

The energy savings potential identified reaches about 12.3%, equivalent to approximately 1,285,000 tOE. This figure does not include possible economies coming from the optimization of technological processes or the introduction of new ones, from automation or from the recycling of materials such as iron, aluminum, paper and glass scraps. The consideration of such factors would undoubtedly result in savings levels well above those calculated above.

In the electric energy area, several possibilities for energy savings also remain, including the use of electric motors, electrothermics, electrolytic processes and more efficient lighting systems. Electricity is used for running about 50% of the motors in the industrial sector, accounting for 30% of the country's electricity consumption (22). The possibilities for energy savings in the electric motors segment can be divided in two distinct groups. The first comprises the operations level, through the correct dimensioning of the motors and the adoption of practices leading to the correct installation, operation and maintenance of electric motors. Recent data (12) show that 71% of the electric motors operate with below nominal charges, and in 25% of the cases the charge is below 50% of the nominal capacity, which indicates a great waste of energy. The second level refers to the use of new equipment and of more advanced technologies, such as high efficiency motors and adjustable-speed drives. The potential for energy savings is significant, considering that only 15% of the motors currently installed in Brazilian industries are high efficiency ones, with power above 200 HP (16), and that the savings that can be brought up by a high efficiency motor is at least 5% of the energy consumed[3]. The energy savings potential in the motors area is even larger if we consider the savings that can arise from the adoption of adjustable-speed drives. This device brings up a savings in the order of 20% (23), and it could be employed in about one third of the existing motors, which results in an additional 6% (1/3 of 20%) savings.

Within the industrial sector, the second most important use of electricity is for heat generation in furnaces and steam-producing boilers Direct heating in several types of furnaces was responsible for about 32% of the industrial electricity consumption in 1984 and the heating process in steam generators and water heaters consumed other 10%, approximately (24). In this field there are several technical possibilities for energy savings, such as a better control of the use of energy in furnaces, better insulation and the use of timers and other simple devices (25). The specific case of the steel industry offers other possibilities - it is possible to

[3] This value is variable and depends on the power of the electric motor (16).

make substantial savings through the greater use of iron scraps in arc furnaces and through the better recovery of waste gases (carbon monoxide and hydrogen) (26). Furthermore, the new and promising "plasmamelt" technology has a potential for generating even larger savings (27). Given the numerous possibilities for energy savings in electro-thermal applications, an average savings potential of 10% (28) can be established, and it can be applied in most sectors that use electric furnaces and steam generators.

Electrolytic processes were responsible for about 7% of the industrial electricity consumption in 1984 (16). The utilization of these processes is concentrated in the aluminum and soda-chlorine industries. The specific consumption in the aluminum sector has been decreasing sharply from the 60s and 70s, when the industries used to consume between 16.5 and 18 kWh/kg of aluminum. Presently, with the introduction of several more modern plants and the incorporation of technological developments such as the use of closed cells placed side by side, the higher electric current levels, the pre-cooking of the anodes, the dry purification of gases and other improvements, the national average has been around 16.2 kWh/kg of aluminum (in 1990) (13). This level, although already acceptable by international standards, can still be improved by about 6.5% during the 90s, according to some studies (16).

In the soda-chlorine industry, it is possible to achieve energy savings through the use of improved anodes, temperature optimization and other processes. The utilization of membrane technology requires only 2.7-3.1 kWh/kg of chlorine, by contrast to the 3.5 - 4.2 kWh/kg that can be obtained through the use of mercury or diaphragm cells (13).

Lighting is responsible for 2 - 4% of the overall industrial electricity consumption. However, given that in the energy intensive sectors the relative participation of electricity is even lower, the savings that can be made in this area have not been computed. In any event, there are still reasonable savings to be made through the adoption of more efficient lamps, such as the high pressure sodium variety, for the replacement of incandescent, fluorescent and mercury vapor lamps.

Table 9 - Electricity Consumption, End Use and Energy Savings Potential - Energy-Intensive Sectors

SECTORS	Electricity Consumption (TWh)	End Use (%)			Energy Savings Potential (%)		
		Motors	Heat	Electrolysis	Motors	Heat	Electrolysis.
Iron and Steel	14.132	70	30		85	50	
Steel-alloys	7.196	8	92		85	50	
Aluminum	19.400	8		92	85		100
Ethylene	2.700	95	5		85		
Soda-chlorine	4.000	15		85	85		50
Pulp and paper	9.504	90	10		85		
Cement	2.964	95	5		85		
Glass	0.900	70	30		85	50	
TOTAL	60.796						

Source: The authors, based on data on (1) and aluminum energy consumption data from (15)

The total savings identified amount to 4,661 GWh/yr (equivalent to 343,369 tOE/yr, for a 1 kWh = 860 kcal ratio), which corresponds to 7.7% of the total energy consumption in the energy-intensive industries group, or 3.6% of the total industrial consumption. If we add to this the savings in the fuels area, the total savings potential in the energy intensive industries would reach about 1,628,369 tOE/yr, with the fuels contributing with 79% of the savings and electricity with the remaining 21%.

Table 10 - Electric Energy Savings Potential - Energy-Intensive Sectors

Sectors	Potential Energy Savings (%)			(TWh)				% of total
	Motors	Heat	Electrolysis	Motors	Heat	Electrolysis	TOTAL	consumption
Iron/Steel	11.3	10		0.950	0.212	0	1.162	8.2
Steel Alloys	11.3	10		0.055	0.331	0	0.386	5.4
Aluminum	11.3		6.5	0.149	0.000	1.160	1.309	6.7
Ethylene	11.3			0.246	0.000	0	0.246	9.1
Soda-chlorine	11.3		20	0.058	0.000	0.340	0.398	9.9
Pulp/Paper	11.3	5		0.822	0.000	0	0.822	8.6
Cement	11.3			0.270	0.000	0	0.270	9.1
Glass	11.3	5		0.061	0.007	0	0.067	7.5
TOTAL				2.611	0.549	1.500	4.661	7.7

Aside from the savings that were quantified in this study, it must be pointed out that there are quite a few other possibilities for energy savings that have not been considered so far in our research, such as, for example, cogeneration and the recycling of materials, especially aluminum, glass, paper and iron scraps. Finally, there are other technical possibilities that are hard to quantify, such as the greater automation of the processes and a more intensive utilization of certain production engineering techniques.

CONCLUSIONS

Brazilian industry has evolved in a fast pace in the last 30 years due to political, economic and other factors. In the first stage imports substitution was promoted, while in the second an exports drive was initiated in order to produce trade credits for balance of payment purposes. As a result, the industrial sectors that have been established and have been submitted to fast growth in the last years are the base industries, notably iron and steel, non-ferrous metals (especially aluminum), pulp and paper, chemicals and "others". Those are all segments that are highly intensive in the use of energy and, thus, have determined an increase in energy intensity of the industrial sector. The breakdown of energy intensity within the industrial sector confirms this structural shift. On the one hand, contrary to the international trend of declining energy intensities resulting mostly from a reduction in the intrinsic energy intensity.

The technology and energy efficiency issues have a great impact in the reduction of energy intensity in developed countries, although they are not the exclusive driving forces. The evolution of specific consumption indexes has shown the most varied patterns within the energy intensive industries. Some sectors, such as the pulp and paper sector and "others", have kept stable their specific consumption, while others, including the iron and steel and the cement sectors, have undergone a significant improvement in their specific consumption indicators. Nevertheless, the specific consumption indexes obtained fall short of those in other countries, which puts into question possible measures capable of increasing efficiency in each of the sectors.

The possibilities for energy savings are present in the areas of fuel utilization and of electricity, both through modifications and adaptations in the production process and through the incorporation of new technologies and processes. The energy savings potential that was identified reaches about 1,285,000 tOE/yr measured in terms of fuels, mostly fuel oil, and about 4,352 GWh/yr in electricity. In the latter, heavy investments in the expansion of the power generation network could be spared. Considering only the above mentioned electricity savings, it is estimated that about 725 MW in investments could be avoided, which is practically equivalent to a power plant the size of the thermonuclear plant Angra I., at a cost around US$ 1.5 billion. Furthermore, it should be considered that the energy savings should assert for the individual firms a considerable cost reduction, entailing greater productivity. And, for society as a whole, the saved energy would help the preservation of the environment, through the reduction in the emission of pollutants and through the slowdown in the construction of large hydroelectric power plants.

REFERENCES

(1) MME, Balanço energético nacional, Brasília, 1994.
(2) ELETROBRÁS, Plano estratégico do PROCEL 1995-2005, PROCEL, Rio de Janeiro, 1994.
(3) MIC, A política na nova república, Brasília. 1985.
(4) COUTINHO. L. & FERRAZ. J. Estudo da competitividade da indústria brasileira. Editora da UNICAMP, Campinas. 1994.
(5) VELLOSO, J. Idéias para a estratégia industrial e tecnológica. in: Política Industrial e Desenvolvimento Econômico - I Conferência Internacional (Passos, C. - organizador), São Paulo, 1990.
(6) FIBGE, Anuário estatístico brasileiro, 1992.
(7) UNIDO, Industry and development: global report, Viena, 1993.
(8) HOWARTH, R.; SCHIPPER, L ; DUERR, P. & STROM, S. Manufacturing energy use in eight OECD countries, Energy Economics, Vol. 13, 1991.
(9) SCHIPPER, L.; MEYERS, S.; HOWARTH, R. & STEINER, R. Energy efficiency and human activity: past trends, future prospects, Cambridge University Press, Cambridge, 1992.
(10) BOYD, G.; MCDONALD, J.; ROSS, M. & HANSON, D. Separating the changing composition of US manufacturing production from energy efficiency improvements: a divisia index approach, The Energy Journal, Vol. 8, N. 2. 1987.
(11) OECD/IEA, Energy Balances of OECD countries, Paris, various years.
(12) ELETROBRÁS, Estratégias de conservação de energia elétrica para o Brasil, Seminário Internacional, Rio de Janeiro, 1994.
(13) OLIVEIRA, A.; CASSIOLATO, J. & MARTINS, L. Indicadores e usos de energia elétrica nos setores energo-intensivos - Relatório Executivo, Instituto de Economia Industrial, Rio de Janeiro, 1994.
(14) IPT, Consumo de energia na indústria brasileira - setores industriais intensivos em energia, Seminário CEE/Brasil, São Paulo, vol. Siderurgia, papel e celulose, vidro, petroquímica e cimento, 1992.
(15) ELETROBRÁS. Indicadores de eficiência energética/análise dos grandes consumidores do setor industrial - various sectors, 1993.
(16) GELLER, H. Efficient electricity use: a development strategy for Brazil, ACEEE, Washington D.C., 1991.
(17) WORRELL, E.; CUELENAERE, R.; BLOK, K & TURKENBURG, W. Energy consumption by industrial processes in the European Union, in: Energy--The International Journal, Vol. 19, N. 11, 1994.
(18) POITRAT, R. Energy consumption in industrial processes: cement, in: 13 th Congress of the World Energy Conference, Cannes, 1986.
(19) INT. Economia de Combustíveis na indústria - diagnósticos energéticos - Relatório Final de Projeto - Convênio STI/FUNAT nº 16/83, Ajuste 002/84, Rio de Janeiro, 1988.
(20) SCHWOB, M.; AMORIM, M. & HENRIQUES JR., M. Diagnósticos energéticos realizados pelo INT na indústria fluminense - análise técnico-econômica, in: Informativo do Instituto Nacional de Tecnologia, Vol. 19, N. 39, Rio de Janeiro, 1987.
(21) IPT, Manual de conservação de energia na indústria - setores: cimento, papel e celulose, ferro e aço e vidro, São Paulo, various years.
(22) TABOSA, R. & SOARES, G. Motores e acionamentos, in: Seminário Internacional Estratégias de Conservação de Energia Elétrica para o Brasil, Procel/Eletrobrás, Rio de Janeiro, 1994.
(23) BALDWIN, S. Energy-efficient electric motor drive systems. In: Electricity - Efficient End-Use and New Generation Technologies. Johansson, T. et al., Ed. Lund University Press, Sweden, 1989.
(24) MORAES,C.; GAMBIRASIO,G. & LIMA,L. Conservação de energia elétrica - motores elétricos e sistemas de acionamento. FDTE, São Paulo, 1985.
(25) FDTE, Estudo de casos - conservação de energia em fornos elétricos, São Paulo, 1989.
(26) VASCONCELOS, E. & BECHTLUFFT, P. Conservação de energia na indústria de ferro-ligas em Minas Gerais, in: Anais do V Congresso Brasileiro de Energia, COPPE/UFRJ, Rio de Janeiro, 1990.
(27) INT, Tecnologias eletrotérmicas de aplicação industrial. Relatório do Projeto P.6.2.1 - "Estudo Tecnológico de Sistemas Mais Eficientes em Aplicações Eletrotérmicas"- PROCEL/Eletrobrás, Rio de Janeiro, 1988.
(28) ELETROBRÁS. Revisão de metas de conservação de energia elétrica, DUE, 1989.
(29) UNITED NATIONS, Industrial Statistics Yearbook, New York, various years.