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INNOVATION AND ENERGY CONSERVATION: ELECTRIC MOTORS IN BRAZIL

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SETEMBRO DE 1995

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Abstract

This paper assess the potential for energy conservation through the spread of High Efficiency Motors (HEM) in the Brazilian market. The strategy of 9 main Brazilian electric motors producers is reviewed and the market barriers to the diffusion of HEM was studied. We found out that there are technological opportunities to improve the efficiency of Brazilian electric motors. The main difficulty to improve these motors efficiency is not producers technological capability but their strategy for the domestic market. These producers have different technological strategy for foreign and domestic market. The industrial organization of motor producers suppliers represents an important barrier to the spread of HEM in domestic market. The study concludes that an innovative policy that deals with cost differential between standard and HEM motors is fundamental to induce energy conservation in the electric motors market.

1 - Introduction

After the second world war, Brazil adopted import substitution policies to induce its industrialization process (Tavares, 1979). Energy import substitution was a chief policy: a national oil and electricity companies were created to develop domestic production of primary energy resources (de Oliveira, 1977). Brazilian energy consumption and energy production both increased rapidly since. The very large hydropower potential (129 Gw-year) was intensively exploited, providing over 95% of electricity consumption. However oil production lagged largely behind: almost 80% of oil consumption was imported when the oil crisis blew up. Suddenly, Brazil had to expend over 50% of its exports to pay for oil imports.

This difficult situation led the Brazilian government to adopt a very aggressive energy policy to reduce oil imports. In order to substitute hydroelectricity for oil, special tariffs to stimulate electricity use were introduced[1]. Unsurprisingly, the electric intensity[2] of the Brazilian economy increased 30% while total energy intensity remained stable (Table 1).

In the 1980's, the collapse of oil prices and the success in the domestic search for oil have both reduced the pressure for oil substitution. Meanwhile, the debt crisis has drastically changed the financial flows to the electricity supply industry. This new situation induced a substantial change in Brazilian energy policy. The main challenge was to finance new projects for electricity supply to a still fast growing demand. At this point in time, electricity conservation became an important energy policy issue. A National Program for Electricity Conservation - PROCEL - was launched in 1985. However, the results of this program are relatively poor so far[3]. We believe that this relatively disappointing outcome from electricity conservation policies results from the lack of a clear and consistent innovation policy. Indeed, PROCEL put emphasis on R&D policy and on electric equipment users information but, so far, very little effort was made to induce the dialogue among the different actors enveloped in the innovation.

Innovation is a process that intends to achieve higher quality and/or larger quantities introducing new combination of resources or new production process (Rosenberg, 1982). It results from the continuous dialogue between users and producers of technological information (Dosi, 1988). Bell (1990) hinted that innovative firms are efficient energy users while non-innovative firms are inefficient energy users. This result indicates that energy conservation is part of a broad process where innovation is the key factor. With this particular point in mind, we have chosen electric motors as a case study to assess the role of innovation in energy conservation policy.

TABLE 1
ENERGY CONSUMPTION IN BRAZIL 1965-1991

	1965	yearly growth rate (%)	1973	yearly growth rate (%)	1979	yearly growth rate (%)	1985	yearly growth rate (%)	1991
Gasoline (Mm^3)	6.1	9.8	12.9	0.8	13.5	-9.0	7.7	5.0	10.3
Fuel Oil (Mm^3)	5.3	12.2	13.3	5.1	17.9	-10.5	9.2	0.8	9.6
Diesel Oil (Mm^3)	4.4	7.8	8.0	13.7	17.3	2.2	19.7	4.0	24.9
Alcohol (Mm^3)	0.2	6.6	0.3	38.9	2.2	24.4	8.2	6.4	11.9
Electricity (Twh)	24.3	14.7	72.8	7.3	111.0	7.7	173.6	4.5	225.4
Coal (Mton)	2.9	4.4	4.1	10.9	7.6	12.6	15.6	-2.6	13.3
Electr./GDP (Kwh/US$)	0.28	9.01	0.47	0.49	0.49	4.70	0.64	3.01	0.77
Energy/GDP (Kgoe/US$)	0.29	4.52	0.37	2.12	0.43	1.00	0.45	2.09	0.51

Source: *Araújo et. al. (1993)*

The industrial sector accounts for roughly 50% of Brazilian electricity demand and about 55% of industrial sector electricity demand is associated to motive force (72 Twh in 1994)[4]. A large share of the potential for energy conservation in this activity is related to appropriate "housekeeping measures" (such as installation, maintenance and operation) and to technological innovation of mechanical systems (compressors, fans, pumps, etc). Another substantial share is related to technological innovation of electric motors. Our paper covers this latter aspect.

The next section reviews the technological trajectory of electric motors and it assess the potential for electricity conservation due to electric motors innovation. The following section describes the Brazilian electric motors market (both supply and demand side) and it assess the role of energy conservation in the innovative strategy of Brazilian firms. We conclude with policy recommendations to stimulate the spread of energy efficient electric motors in Brazil

2 - ELECTRIC MOTORS: TECHNOLOGICAL CHANGE AND POTENTIAL FOR ENERGY CONSERVATION

Electricity was a radical innovation that allowed the development of many other innovations. Particularly important was the electric motor. It displaced other energy sources (mainly oil and coal), creating a new paradigm for driving machines. The use of electric motors spread rapidly since. For instance, in the USA, the share of electric motors among industrial engines increased from 4,8%, in 1899, to 89%, in 1939 (Rosenberg, 1982). In Brazil, there was a similar historical process (table 2).

TABLE 2
MOTIVE FORCE IN INDUSTRY[5] BY TYPE OF TECHNOLOGY - BRAZIL (1000 HPs)

	1907	1920	1940	1950	1970	1980
Steam Machines and Turbines[6]	80,0	112,2	219,9	161,2	1.116,6	2.027,4
Water wheels and turbines	23,9	32,3	28,0	34,8	116,8	98,1
Internal Combustion Motors	0,1	16,5	52,5	59,7	560,9	659,5
Electric Motors	4,6	167,2	885,9	1.823,5	11.356,7	22.978,0
Total	108,6	330,2	1.188,3	2.081,3	13.152,7	25.764,9

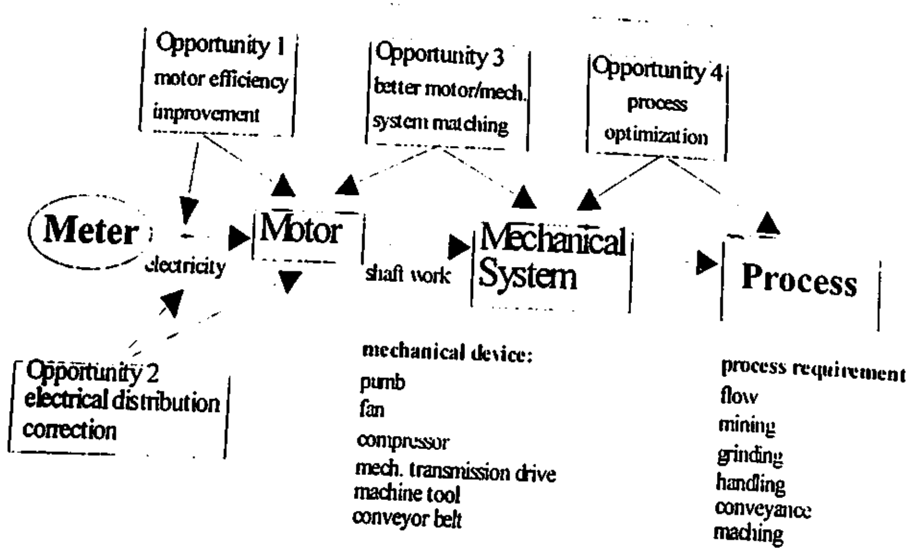
Source: Freitas Filho (1991).

Lower capital cost and higher energy efficiency, as compared to steam machine, were the main reasons for the spread of electric motors. Additional advantages were the fact that electric motors produce no pollutants and facilitate a flexible workspace layout. Product diversification and continuous reduction of capital costs were key factors for the success of the electric motor technological trajectory. This trajectory was associated to a trend for decrease of electricity tariffs that subsisted since electricity was invented to the moment of the oil crisis. However, it seems that the electric motors industry entered a new technological trajectory that is likely to increase substantially the potential for electricity conservation. This new trajectory is being pushed mainly by the continuous escalation in electricity tariffs.

2.1 - THE IMPORTANCE OF MOTORS IN ELECTRIC MOTOR SYSTEMS

To assess the potential for energy conservation one has to consider more than the motor itself. It is important to examine the *motor system* to achieve all opportunities to improve efficiency. The motor system embodies the mechanical system (fan, pump, compressor etc.) and the process (mixing, flow, grinding etc.). In the system approach, the motor efficiency improvement is only one of the opportunities. There are important opportunities in the electrical distribution network, the mechanical system and the process as well (figure1).

FIGURE 1 - THE ELECTRIC MOTOR SYSTEM



Source: Scheming & Freedman (1993).

Opportunity 1 is the result of efficiency improvement of the motor itself. This can be reached by replacing standard electric motors with more efficient models (high efficiency motors - HEM[6]). This opportunity accounts for 18% of total saving potential in motor systems in the USA (OIT) but is much higher in Brazil because HEM are seldom sold in the Brazilian market.

Opportunity 2 is linked to electric distribution correction. It is important to minimize voltage fluctuation and to correct the power factor in order to reduce electrical distribution losses. According to estimates of the Office of Industrial Technologies of USA (OIT), electrical distribution correction accounts for 8% of total savings potential in motor systems (Scheihing & Friedman, 1993).

Opportunity 3 is related to motor/mechanical systems matching. The lack of an adequate analysis of load cycle induces bad choice of electric motor usually resulting in the use of bigger motors than necessary. In Brazil, this is a very familiar problem. Industrial energy audits provided by PROCEL showed that about 40% of motors assessed are over sized[7]. The use of ASD represents a substantial opportunity in cases where the process requires motor speed variation to follow the load of the mechanical system. In this case, improvement of motor system by the use of ASD can reach 30%. According to the OIT, these are the biggest opportunities to improve the motor system efficiency, accounting to 41% of total saving potential.

Opportunity 4 is related to the use of less shaft power to do the same activity. This action includes optimization of mechanical system by replacement of over-sized mechanical devices or installing energy efficient mechanical systems. This opportunity has a high saving potential (33%) but it demands substantial investments.

We decided to analyze the process of innovation in motors technology, as an example of innovation policy's role in energy conservation (opportunity 1). Similar studies on ASD's and mechanical devices are required to assess the full potential of technological innovation to push energy conservation.

2.2 - ELECTRIC MOTOR: SHIFTING THE TECHNOLOGICAL TRAJECTORY

As pointed out earlier, innovation is the result of a complex and continuous dialogue between users and producers of technological information (Lundvall,1988). Most often, this dialogue is oriented to incremental change, intending to adjust a technological information to specific situation of different users of a technology. In the case of electric motors, there was an intense process of incremental change since the first electric motor was developed. Several types of electric motors are nowadays available, each one adapted to different needs of users in industry, homes, farms, etc. There are 4 main types of electric motors: direct current (DCs), synchronous and induction (asynchronous), using 1 or 3 phase of alternate current (ACs). The basic components of an electric motor are rotor and stator. The stator is the fixed part of the motor, where the copper wire coils are located. The rotor is the rotating part inside the stator. Other important components of any motor are: the armature; the axis, that is fixed on the rotor; the fan, that is fixed on the axis; and the axis roller bearings.

Induction (asynchronous) motors have many advantages: they are cheaper, robust, very reliable and use the current provided by the grid. Its main disadvantage is that controlling its speed and torque is difficult. Whenever speed control is needed, induction motors are badly placed to provide users needs. It is important to remark, however, that the development of power electronics is changing rapidly this situation since adjustable speed drives enable speed control of induction motors.

Synchronous motor uses the principle of magnetic induction as well. However, differently from the asynchronous motor, its rotor spins at the same speed of the rotative magnetic field. The main advantage of synchronous motor is that it offers the possibility of reactive power compensation[8]. In general, this type of motor is used when demand for power is very substantial. In these cases, the benefits of reactive power compensation are large enough to justify its additional cost.

DC motor uses direct current, usually rectified from an AC source. The basic difference between this motor and the previous ones is that the stator does not have a rotating magnetic field. A stationary magnetic field is used instead to produce power and the current is applied to the rotor. The speed of DC motors depends on the voltage applied to the rotor; therefore, it offers the advantage of varying the speed by changing the voltage applied. This type of motor is used in toys, cars, trains and a few industrial process where speed control is fundamental. The development of AC adjustable speed drive is jeopardizing the future of DC motors in the industrial market since its main advantage, speed control, can be achieved by AC motors as well, that are much less expensive, more reliable and have lower maintenance costs.

Today, induction motors accounts for the largest share of electric motors sales. In Brazil for instance, between 1980 and 1992, they represented 99,7% of total sales in terms of quantity and 92,8% in terms of power sold (table 3). It is important to remark that although the 1-phase motor represented 74,0% of electric motors sold in the Brazilian market, they sum up only 23,5% in terms of power. The 3-phase induction motors are used in industry and their average power is substantially higher than 1-phase motors. Moreover, they are intensively used, while the 1-phase motors are used a few hours in the year (in residences, service sector and rural areas). Therefore, the 3-phase induction motors are obviously much more important as far as electricity conservation policies are concerned.

TABLE 3
ELECTRIC MOTORS SELLS IN BRAZIL: QUANTITY, TYPE AND POWER (1980-1992)

Type	quantity (thousand)		Power (thousand)	
		%	HP	%
Induction 3-phase	1,532.9	25.7	66,756.8	69.3
Induction 1-phase	30,293.0	74.0	22,601.0	23.5
Direct Current	42.3	0.1	1,270.9	1.3
Synchronous	105.6	0.2	5,735,9	5.9
Total	40,973.8	100.0	96,364.6	100.0

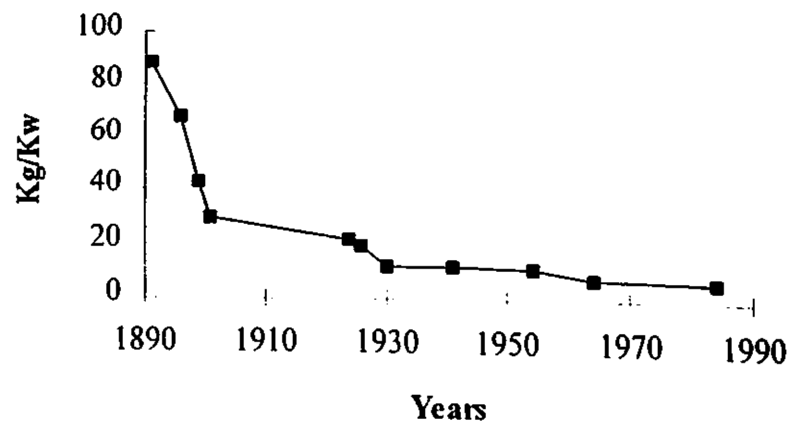
Source: ABINEE (Association of Brazilian Electro-Electronics Industry)

Since the invention of the induction motor in 1889, many incremental innovations have been incorporated into its basic technology, following a technological trajectory that was oriented to the reduction of capital costs. **Minimizing the use of materials and reducing size and weight were the main objectives of motor innovation until the oil crisis.** The use of plastics and aluminum alloys allowed the reduction of the quantity of material used in motor armatures. The use of enameled wire enabled conductors to operate under higher temperatures, making possible the reduction of the quantity of cooper used as conductors. The use of steel alloys reduced the losses, decreasing the quantity of materials needed to produce rotors and stators. The design of electric motors were substantially improved, reducing its production costs as well. Figure 2 shows that the ratio weight to

power of electric motors has been continuously falling since its invention, obviously reducing its production costs. However, this technological trajectory has been detrimental to energy efficiency.

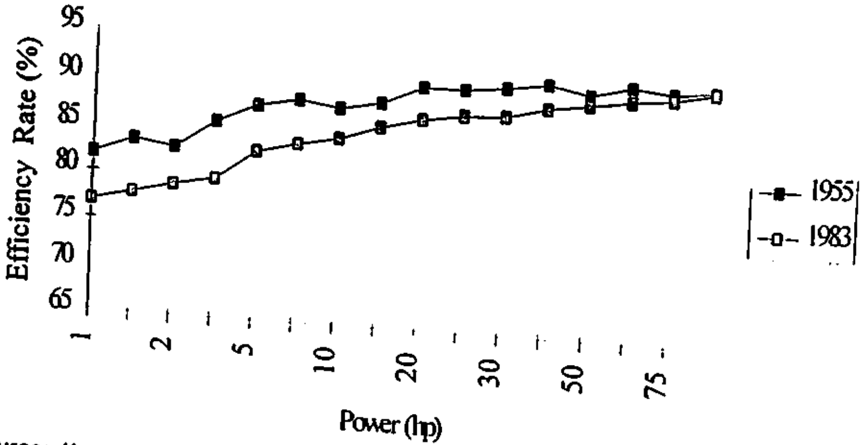
Figure 3 shows that between 1955 and 1983, there was a substantial reduction in the energy efficiency rate of American electric motors. In average, 1983 electric motors had an energy efficiency rate 3% lower than those of 1955. The deterioration in efficiency was much more important in the case of small motors. Since large motors are used more intensively and consume more electricity, there was much more care with their efficiency. In the case of small motors, it seems that the search for minimum production costs was very harmful to the efficiency rate. Availiablility of relatively cheap electricity and consumers misinformation about operational costs of electric motors are usually pointed out to explain this trajectory in the case of small motors.

FIGURA 2 - WEIGHT / POWER RATIO IN ELECTRIC MOTORS



Source: Kreutzfeld (1992)

FIGURE 3 - ENERGY EFFICIENCY IN AMERICAN ELECTRIC MOTORS IN 1995 AND 1983



Source: Kreutzfeld (1992)

Electric motor is considered a mature technology. Motor innovations are mainly incremental, intending to substitute old for new materials and to develop software that optimize designs. The actual rate of technical progress in this area is very slow, making relatively easy for producers to keep pace with technological change. Hence, industrial secrets and patents do not represent substantial obstacles to the spread of innovations in this industry. Nevertheless, the same cannot be said concerning the rate of innovation in production processes, where it seems there are large opportunities for competitiveness advantages.

After the oil crisis, increase in electricity tariffs and energy conservation programs started to move the electric motors industry to a new technological trajectory. Energy efficiency became an important characteristic of this equipment, gradually emerging the so called *High Efficiency Motors* (HEMs) in the market place. The basic technology of these motors is not different from the ones still on use.

Using more materials and better isolation, American motor producers improved their equipment efficiency but increased their weigh to power ratio from 6,8 kg/kW to 8,3 kg/kW.

2.3 - TECHNICAL POTENTIAL FOR CONSERVATION

Despite the oil crisis, Brazilian firms did not change their technological strategy for the domestic market[9]: Although a few Brazilian firms developed technological capabilities to produce HEM, their production of this sort of electric motor is mainly sold in Canada and the USA, where there are incentives for the spread of this technology; very few HEM are sold in the Brazilian market and the spread of this type of motor in the Brazilian market is insignificant as yet negligible (less then 1% of total sales).

Laboratory tests of Brazilian 3-phase "standard" motors ordered by PROCEL showed that these motors are less efficient than similar motors sold in developed countries (Cogo, 1990). Magnetic losses in both rotor and stator were pointed out as the most important explaining factor for the lower efficiency of these engines. Quality of steel used and thickness of the plate are blamed for these losses. It was identified a substantial diversity of motor design among Brazilian firms, resulting in significant differences in performance as well. A comparison of 4 main producers showed that their motors had differentials of 41% in their losses, when tested at full load. The potential to improve the efficiency of the "standard" motors sold in Brazil is substantial indeed.

Table 4 indicates the difference of efficiency between standard and HEM Brazilian motors. The main factors that explain this situation are: materials and design. The HEM use **silicon steel** plates in the rotor and stator while the standard motors use **carbon steel plates.** The silicon steel is much more efficient than carbon steel when used as magnetic material in electric motors. The design of HEM is optimized as far as efficiency is concerned when compared to *"standard"* motors design. It is interesting to remark that there are opportunities to improve the efficiency of the Brazilian HEM still as suggested by the best international technology[10].

Table 4
Electric Motors Efficiency: Brazilian versus the best International Technology[12]

Power hp	Standard Motor WEG (A)	High Efficiency Motor (WEG) (B)	Best International Technology (C)	Best International Technology Producer	A/C
1	72,6%	75,9%	86,9%	West Motors	0,83
2	74,5%	82,5%	87,5%	West Motors	0,85
5	83,0%	87,3%	90,8%	West Motors	0,91
10	87,2%	90,1%	92,6%	General Electric	0,94
20	89,8%	92,3%	94,3%	MAGNETEK	0,95
50	92,5%	93,5%	95,3%	Bardor Motors	0,97
100	92,0%	94,3%	95,8%	Siemens	0,96
200	93,1%	95,3%	96,4%	Siemens	0,96

3-phase Motor IP54 (1800 RPM).
Last catalogue revision 07/93.
Source: Weg Motores S/A e Data bank of CSA (1992).

In the 1990's, the efficiency of Brazilian motors increased remarkably thanks to PROCEL efforts to induce energy efficiency improvements. PROCEL induced a revision in the norm used to establish motor efficiency, fixing one

single methodology to measure motor efficiency. This made possible to compare the energy efficiency of different motors produced in Brazil. Recently, PROCEL created a labeling program for 3-phase motors. Nevertheless, no program to stimulate technological improvements and diffusion of HEM was created so far.

Table 5 shows that the energy efficiency of both standard and HEM produced in Brazil increased, with greater improvements for standard motors. However, it is important to note that the stock of electric motors used by Brazilian industry is far less efficient then suggested by table 4 since a large share of the installed capacity was sold before the 1990's.

Table 5
Efficiency of Brazilian Electric Motors: 1990 and 1994

Power (hp)	Standard Motor (%)			High Efficiency Motor (%)		
	1990 (A)	1994 (B)	A/B	1990 (C)	1994 (D)	C/D
1	68,0	72,6	0,94	75,9	75,9	1,0
2	72,0	74,5	0,96	82,5	82,5	1,0
5	76,0	83,0	0,91	87,3	87,3	1,0
10	84,0	87,2	0,96	88,0	90,1	0,97
20	87,0	89,8	0,97	90,3	92,3	0,97
50	90,0	92,5	0,97	92,4	93,5	0,98
100	91,0	92,0	0,98	93,6	94,3	0,99
200	91,0	93,1	0,97	94,5	95,3	0,99

Motor IP54 de 1800 RPM.
Source: Weg Motores S/A

Table 6 presents a conservative estimate of electricity conservation potential that can result from the spread of 3-phase HEM, assuming that all the stock of electric motors had the efficiency of 1994 standard motors. These savings would postpone the construction of 450 MW of installed capacity (2.0 Twh), saving roughly US$ 900 million.

TABLE 6
POTENTIAL ENERGY CONSERVATION IN ELECTRIC MOTORS : INDUSTRIAL SECTOR (1992)

Size range	Total electricity consumption	Efficiency Standard	Efficiency Energy Savers	Savings potential	Total savings
	(TWh)	(%)	(%)	(%)	(TWh)
<1	1,07	70	75	6,7	0,07
1-10	22,58	83	87,3	5,0	1,13
10 - 40	15,48	89	92,3	3,6	0,56
40 - 100	8,37	92	94	2,1	0,17
100- 250	3,70	93	95	2,2	0,08
Total	51,20	-	-	-	2,01

a) Assuming that 3-phase motors under 250 hp account for 80% of electricity used by industrial motors.
b) Performance at full load
c) Motor IP54 de 1800 RPM.
Source: Weg Motores S/A e ELETROBRÁS

3 - THE ELECTRIC MOTORS MARKET

Basically, the electric motor producers can be divided into 2 groups: tailor made and serial motors. Table 7 shows that the majority of firms (14) produce tailor made motors but this type of motor has a very small market share. The serial motors are responsible for the great majority of power installed capacity and energy consumed but a few firms are producing this sort of motor. Tailor made motors are made for specific use while the serial motors are 1-phase and 3-phase induction motors used to supply driving force in standard applications.

Import substitution of electric motors started in the 1940´s. General Electric was one of the first international companies to install a plant in the state of São Paulo. By 1959, 30 firms were producing electric motors in Brazil, selling roughly 300,000 units yearly. The economic boom of the 1970´s attracted several international firms (Siemens, Toshiba, Reliance, Sommer and Marelli) to the Brazilian market, increasing to 44 the number of producers in 1974. However, the recession of the 1980´s frustrated the growth that was foreseen for electric motors demand. The number of players in the market place was reduced to 19 firms, producing a strong industrial concentration of this market (table 7).

During the process of industrial concentration, one Brazilian company was able to control a very large share of the Brazilian induction motors market. WEG, the market leader, currently accounts for 75% of serial 3-phase induction motor market and for about 50% of serial 1-phase induction motors market (WEG Group, 1993). Competing for the market of serial motors, there are only four (4) other companies but only two (Eberle and Kohlbach) have a significant share of the Brazilian market[12].

Table 7
Electric Motor Producers in Brazil

	Serial 1-phase	Serial 3-phase (until 250 hp)	Tailor Made
1) Asea Brown Boveri Ltda			X
2) Asten & Cia Ltda			X
3) Eberle S/A	X	X	
4) Equacional Elétrica e Mecânica Ltda			X
5) Ferrum Indústria e Comércio Ltda			X
6) Gevisa S/A			X.
7) Indústria e Comércio Lavill Ltda			X
8) Indústria Brasileira de Máquinas Ltda	X	X	
9) Kohlbach S/A	X	X	
10) Maxi Control Ac. Elétricos Ltda			X
11 Motores Elétricos Brasil S/A	X		
12) Motores Kuper Eletron Ind Ltda			X
13) Nova Mot. Elétricos Especiais Ltda			X
14) Sew do Brasil Mot. Ltda			X
15) Siemens S/A			X
16) Toshiba do Brasil S/A			X
17) Varimot S/A			X
18) WEG Máquinas Ltda			X
19) WEG Motores Elétricos	X	X	

Fonte: ABINEE

Our study assessed the technological capabilities and strategies of 9 electric motor producers. The 3 main producers were visited and questionnaires were sent to 6 other producers embracing all market segments. Table 8 offers an overview of relevant economic data of the firms that have been studied.

Table 8
Researched Firms: Revenues, Exports and Number of Employees - 1993

Firm	revenues (US$ millions)	Exports (US$ millions)	number of employees
1) Weg Motores Ltda	156.2	44.4	4030
2) Eberle S/A	92.0	12.0	1590
3) Kohlbach S/A	40.0	8.0	1150
4) Motores Elétricos Brasil S/A	37.0	1.5	535
5) Weg Máquinas Ltda	24.7	3.7	500
6) Toshiba do Brasil S/A[14]	13.0	5.5	270
7) Indústria e Comércio Lavill	3.0	-	70
8) Indústria Bras. de Máquinas	2.4	-	61
9) Equacional Elétr. e Mecânica	1.7	0.04	115
10) Nova Mot. Elét. Especiais	0.7	-	30

Source: Elaborated by the authors

3.1 - Technological Capabilities

As pointed out earlier, electric motor technology is considered a mature technology. Product innovation is slow and incremental. Brazilian firms do not feel they lack technological capabilities to introduce any sort of product innovation and consider that there are few opportunities for product innovation. Indeed, two of the firms visited, got the ISO-9000 certification, and one is in process of getting it. The market leader (WEG) exports to more than 50 different countries, North American and European markets representing 47% of its exports. The Canadian Standards Association approved the commercialization of WEG high efficiency electric motors as well. Unsurprisingly, firms investigated do not expend too much on R&D (table 9). Only one firm intends to increase its expenditures on R&D while one is planning to reduce; the seven remaining firms have no change planned.

TABLE 9

SHARE OF R&D INVESTMENTS IN FIRMS TOTAL REVENUES -1993

Participation	Number of firms
0%	1
0.1-0.5%	1
0.5-2%	5
2-5%	2
+ de 5%	0

Source: Elaborated by the authors

The rate of process innovation, on the other hand, is increasing rapidly. The use of information technology provides much larger flexibility to production process. Modifications of motor project can be done in a few minutes with the help of modern software and process automation reduces the duration of the production cycle, increasing its flexibility. Information technology is modifying even the sales policy. Indeed, delivery time is reducing since production is becoming more flexible. The dynamic firms are selling directly to final consumers, reducing their stocks.

There are large differences among Brazilian firms as far as the production process is concerned. The two main motor producers have notably invested in process technology. Their production process is automated and flexible. In fact, WEG and Eberle are able to produce up to 24,000 and 30,000 different motos, respectively. Automation of production process in both companies reduced the time of production from 30 to 7 days, between 1985 and 1994.

From the point of view of energy efficiency, the main process technological difference between electric motors producers is the use of thermal treatment of steel plates. This process improves substantially energy efficiency of motors. However, only the two main producers use this technology; other firms prefer to mix carbon steel plates with silicon steel plates instead[13]. Carbon steel plates have a considerably higher rate of magnetic losses as compared to the silicon steel plates but the latter are more expensive (depending on its rate of magnetic losses it can costs 100% more). Usually, firms use carbon plates on standard motors and silicon plates on HEM.

Motor producers declare that there is no technological bottlenecks regarding their suppliers. Whenever there are some specific parts (like for instance roller bearings for high speed motors or low noise motors) that are not locally produced, they can be imported if necessary. There is, however, complaints concerning the *de facto* monopoly of the supplier of silicon steel. In Brazil there is only one producer[14] and there were obstacles to import it[15]. Nowadays, import restrictions were removed but transaction costs are considerably high[16], inducing motor producers to get their supply domestically.

Internal development is the main source of innovation of electric motor firms in Brazil (table 10). Licensing has been important to establish Brazilian firms but gradually domestic producers started to adjust licensed projects to domestic market conditions. Particularly important was the need to reduce costs, quite often to the detriment of energy efficiency, since the low quality of local raw materials give rise to extra costs to produce energy efficient motors and the market did not require this type of motor. Indeed, firms were forced to abandon their original licensee technological project in order to compete in the Brazilian market. The three firms that dominate the Brazilian market no longer use licenses. However, their process of innovation is guided by strong interchange of technological information with users of their motors and suppliers of their materials.

Table 10
Main Sources of Technology Acquisition

	"Extremely important" or "important"	"less important" or "not important"
Internal development	8	1
Technological license	2	7
universities and research centers	4	5
users and suppliers	6	3
cooperation with electric motor firms	1	8

Source: Elaborated by the authors

3.2- Competitive Strategies

The competitive strategy of Brazilian electric motor producers in the 1980's was to adapt the licensee technology to the domestic market conditions. Cost reduction instead of energy efficiency or reliability was searched for. This strategy proved correct since large multinational firms that produced higher efficiency motor eventually were pushed out of the Brazilian market. General

Electric, for instance, begun to produce energy-saver motors in 1981 but had to stop producing because there was no market for it.

The success of cost reduction strategy was due to two main factors: the low price of electricity in Brazil (figure 4) and the hyper inflation process of the 1980's. Low electricity prices were not inductive of energy efficiency while the dissociation of costs and prices produced by inflation pushed consumers to reduce as much as possible their investments costs, despite any increase in operational costs.

Brazilian electric motor producers adopted three main competitive strategies: specialization (tailor made producers); verticalisation towards the production of electric appliances and process flexibility (serial motors). As we mentioned before, most firms adopted the first strategy, one is verticalised[17] and a few (3) adopted the third strategy. Those that have adopted the process flexibility strategy have a very large range of products and they stress cooperation with suppliers and users as a key element in their strategy. Indeed, they established large networks of technical assistance through out the country.

Table 11 indicates that motor producers see price, reliability and technical assistance as their main marketing requirements. Only 2 companies suggested that energy efficiency is an important marketing requirement. Therefore, it is not surprising that there is no aggressive technology policy to improve the energy efficiency of electric motors among Brazilian firms.

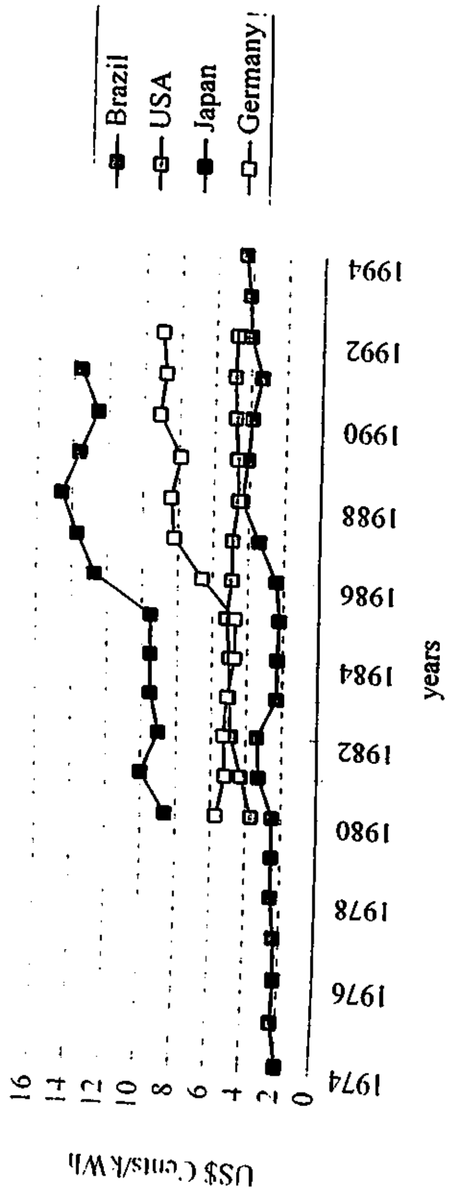


Figura 4 - Average Industrial Electricity in Selected Countries

Current US$
Source: OLADE and Eletrobras

Table 11
Principal Motor Attributes: Producers Requirements

Attributes	"Extremely important" or "important"	"less important" or "not important"
Motor price	9	0
Reliability and durability	9	0
Energy efficiency	2	7
Technical assistance	9	0

Source: Elaborated by the authors

Table 12
Obstacles to Introduction of Innovations and Energy Conservation[20]

Obstacles	"Extremely important" or "important"	"less important" or "not important"
Access to new technologies	2	7
Marketing energy efficient motors	8	1
Lack of regulation	3	3
Lack of incentives for conservation	5	1
Quality of electricity sold	2	7

Source: Elaborated by the authors

Table 12 indicates that, from the producers point of view, the main obstacle to energy efficiency improvements in electric motors is the lack of demand for this sort of product. Interesting, the lack of incentives for energy conservation comes secondly in their list of obstacles to the spread of efficient motors. Neither the quality of electricity services by the grid or technology are seen as critical factors.

It is interesting to note that the main Brazilian producers[19] hardly use any supplier of spare parts[20]. Basically electric motor firms buy their raw materials (copper, aluminum, steel plates, varnish, pigment) from a few suppliers (3 to 5), adopting the strategy of partnership in order to guarantee quality, price and delivery time. In the case of silicon steel plate, ACESITA is the only supplier, situation that strongly restrains the spread of HEM share production and sales[21]. Indeed, electric motor firms are reluctant to develop a market strategy that would depend on just one steel plate supplier.

Recently, Kolbach and ACESITA decided to establish a partnership in a new electric motor producing plant (located closed to ACESITA) to produce HEM[22]. This movement reflects recent changes in the Brazilian economy. Indeed, actual electricity tariffs were increased in the context of the Real Economic Stabilisation Plan[23], substantially improving the economic competitiveness of HEM. An important aspect of the stabilisation plan was the reduction of import tariffs that reduced the competitiveness of ACESITA's silicon steel plate as compared to international suppliers. This partnership seems to be a joint strategy that, in the case of ACESITA, intends to avoid a possible lose of market share and, in the case of Kohlbach, to increase the competitiveness by the production of HEM.

3.3 - DEMAND SIDE: REQUIREMENTS AND INCENTIVES

Electric motors buyers can be divided into three different segments: retailers, appliance manufacturers and industrial end-users. In order to assess these three segments view of energy-savers motors, a sample of 13 industrial end-users, 8 appliance producers and 10 retailers was investigated.

Table 13 shows that motor buyers are very sensitive to price and to reliability. These factors were rated as extremely important or important by 97% and 90% of our sample. Table 13 seems to confirm the view of electric motor producers that price and reliability are the key characteristics from buyers point of view. However, differently from what producers believe, buyers do value energy efficiency. Indeed, this factor was considered important by 58% of our sample.

TABLE 13
PRINCIPAL MOTORS ATTRIBUTES: BUYERS REQUIREMENTS

Attributes	"Extremely important" or "important"	"less important" or "not important"
Motor price	97%	3%
Reliability and durability	90%	10%
Energy efficiency	58%	42%
Technical assistance	48%	52%

Source: Elaborated by the authors
n = 31

Consistently with the previous analysis, most buyers consider that one of the main obstacle to the spread of HEM is price[24] (table 14). Another important obstacle pointed out by most of them is the lack of incentives for energy conservation, showing that the lack of a government strategy for rational use of energy is an important aspect of the diffusion of HEM. The Brazilian macroeconomic instability was indicated as an important obstacle by users but this obstacle was removed by the stabilization program. Nevertheless, the long period of high inflation created among managers a lack of awareness of the importance of energy efficiency since any energy cost could be passed on to consumers. The lack of special financing mechanisms and qualified human resources were considered important factors by many buyers as well. It is interesting to remark that from the point of view of 48% of our sample, the lack of methodologies for measuring the benefits of energy conservation investments is seen as an important barrier for energy-saver motors spreading.

Table 14
Main Obstacles to Energy Efficient Equipment Spreading

Factors	"Extremely important" or "important"	"less important" or "not important"
Initial cost	93%	7%
lack of incentives for energy conservation	90%	10%
Economic instability	61%	39%
lack of awareness of managers	55%	45%
lack of financing	52%	48%
Lack of qualified human resources	48%	52%
Difficulties to measure benefits	48%	52%

Source: Elaborated by the authors
n = 31

Table 15 shows that tariffs are the main factor inducing users to energy conservation. Availability of energy efficient equipment, energy conservation policies and the perspective of any sort of rationing are also very influential on buyers decision to use HEM. It is interesting to remark that environmental policy and competition although considered important are listed at the bottom of the list.

Table 15
Main Factors Inducing Conservation in Industry

Factors	"Extremely important" or "important"	"less important" or "not important"
Tariffs	100%	0%
Availability of efficient equipment	74%	26%
Energy conservation policies	74%	26%
Perspective of energy rationing	71%	29%
Environmental policy	68%	32%
Competition	55%	45%

Source: Elaborated by the authors
n=31

Market characteristics strongly differ among market segments. Industrial users of our sample are large and middle-size firms, averaging 1745 employees. The opportunities for energy conservation among these firms are large. In 10 out of 13 firms consulted, motors were responsible for more than 70% of electricity consumption. Nine firms had already done energy audit and they had their motors maintenance supervised by electrical engineers. The main obstacles pointed out by this group of buyers were the price of HEM and the lack of incentives for energy conservation.

Technical assistance was considered an irrelevant issue. Usually, motor selection, installation and maintenance have been done by the users staff or by independent specialists. This fact may have negative implications for the spread of HEM among these users[25]. Price and reliability were regarded as the most important attributes of motors but for the great majority of industrial users (11 out of 13), energy efficiency is an important attribute as well. All the 10 firms that had information to compare the Brazilians with international motors, considered the Brazilians technologically inferior.

The diffusion level of HEM among the industrial users consulted is very limited still. Only 3 firms had HEM. Nevertheless, 10 firms manifested interest to use HEM largely in the future, contradicting producers view that users have no interest in efficient motors.

Appliances manufacturers are obviously also industrial users of motors but questionnaires sent to them covered only motors they usually buy for use in their assembling line. Most firms considered energy efficiency as an increasingly important attribute in the coming years. Cooperation with motor producers is considered an important factor from their point of view. Seven (7) out of eighth (8) firms consulted considered the quality of Brazilian motors satisfactory as compared to imported ones.

Our ple of retailers consisted of 10 firms. Motor retailing has been losing importance since process automation technologies made possible main motor producers to sell directly to end-users. Nowadays, retailers

market is chiefly concentrated on small motors for small industries, and commercial and rural users. Retailers do not regard energy efficiency as an important motor attribute. Their emphasis is placed on price and reliability. It is important to remark that retailer's clients usually do not have technological capabilities to evaluate the motor technical characteristics. Unsurprisingly, retailers regard the lack of qualified human resources and the difficulty of measuring energy conservation benefits as important obstacles to the diffusion of HEM.

None of the retailers consulted has a commercial strategy for HEM. In fact, there is not a cooperative market strategy of retailers and motor producers aiming to increase the diffusion of HEM. Retailers have no incentives for selling HEM, since they are more expensive and therefore need stronger selling efforts. Therefore, retailers are to some extent reactive to energy conservation sales arguments. It is interesting to remark that eight (8) out of ten (10) retailers consulted had not even heard of the existence of PROCEL.

4 - CONCLUSIONS AND POLICY RECOMMENDATIONS

Brazilian electricity consumption is growing rapidly still and utilities are facing increasing difficulties to finance the required investments to keep supply and demand in pace. PROCEL was launched to rationalize electricity consumption, aiming to minimize investments of the electricity supply industry. Despite the very substantial potential for electricity conservation, PROCEL results are quite poor so far. From our point of view, this is so because the role of innovation in the process of electricity conservation was not fully understood by energy policy makers.

The spread HEM can save a substantial amount of electricity. Our estimate is that at least 2 Twh/year can be saved if HEM can find their way to the market place. We found out that Brazilian electric motor firms do not lack the technological capabilities to produce HEM. Indeed, they are currently exporting this type of motor to industrial countries. However, their strategy for the domestic market do not contemplate the spread of HEM although electric motor users are interested to use it. Recent increase in electricity tariffs and the success of the Real Stabilization Program improved the economic competitiveness of HEM from the demand side. It is necessary to find policies that can improve their competitiveness from the supply side as well.

ACESITA's monopoly of silicon steel plates generates additional costs for Brazilian HEM, augmenting the cost differential between standard and HEM motors. Since the Brazilian users emphasize cost, understandably the market strategy of Brazilian firms for the domestic market does not comprehend HEM spreading. From our point of view, an innovative policy that deals with that additional cost is a fundamental aspect of any electric motor conservation policy. It is clear that the ACESITA monopoly power has to be reduced either inducing a new domestic producer of silicon steel plates or improving the competitiveness of imports. The monopoly situation of ACESITA is strongly reinforced by the limited production of HEM. A policy that rapidly spread HEM would open opportunity for carbon steel plate producers to develop a silicon steel production line to compete with ACESITA.

Since the main obstacle to diffusion of HEM motors is price, efforts must emphasize the reduction of price differential between those motors and the standard ones. The price gap could be reduced using several strategies, but the easiest one is to change the tax policy. Nowadays, the electric motors are exempted of industrial products tax[26]. This policy could be changed, charging a tax on standard motors and maintaining the tax exemption only for HEM. This policy would reduce HEM price as compared to standard motors. The policy to spread HEM would enlarge the market

for silicon steel plate, creating opportunities to increase the competition in this market.

Our study pointed out that the dialogue between motor producers and users is relatively poor as yet. Although producers believe users do not value efficiency, this is not the case. The main problem is the lack of a credible methodology to assess the efficiency gains of HEM. PROCEL can play a crucial role in this aspect, providing the framework for a **fruitful dialogue** among producers, users, retailers, and research centers to produce a reliable methodology to assess the economic benefits of HEM. Organizing the market into groups of purchasers interested in specifics technologies (HEM in our case) has been an effective way to speed up the process of innovation and induce energy conservation in countries like Sweden (Nilsson,1995). The current labeling program, particularly if linked to an energy efficient procurement policy, can be a good start for that dialogue. A rebate program could be used to further improve the dialogue[27].

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NOTAS

[1] This tariff was introduced to use the surplus of electricity that existed at that time. The tariff was 6 times cheaper than standard electricity tariffs.
[2] Between 1970 and 1991, electricity consumption augmented 8.7 % while the GDP expanded 4.8 % on an annual basis.
[3] For an evaluation of Brazilian conservation programs see Araújo *et. al.* (1993).
[4] Electric motors consume a very large share of electricity in industrial societies. In Germany, for instance, they account for almost 70% of the industrial electricity consumption.
[5] The motive power used for electricity generation was not considered.
[6] The HEM are 3-phase induction motors for industrial applications.
[7] The PROCEL report (PROCEL,1990) estimated that 16,4% of electric systems losses could be reduced by the replacement of over-sized motors. These losses were estimated at 1,5% of total national electricity consumption, or 3,4 Twh in 1992.
[8] When AC is used, the apparent power demanded from the grid is larger than the actual power on use. Users are charged on the basis of the apparent power they demand. In order to reduce their electricity bill, users often introduce capacitors to bring the apparent power demand closer to actual power demand (this is known as power factor correction). The synchronous motor can produce the same results of capacitors, therefore avoiding investments.
[9] The next section will explain why Brazilian firms adopted this strategy.
[10] Project technology used by Brazilian firms does not include modern methods of project optimization as finite elements calculation.
[11] We use WEG motors, the market leader, as representative of Brazilian electric motors technology. Other Brazilian firms produce less efficient electric motors. We used the CSA assessment as representative of the best international technology (norm CSAM390-1985, comparable with the Brazilian similar NBR-5383).
[12] It is important to remark that imports of induction serial motors has an insignificant share in Brazilian market.
[13] Laboratorial studies made at CEPEL showed that the thermal treatment can reduce the rate of magnetic losses in both carbon and silicon steel plates. Nevertheless, it requires investments that can amount to US$ 2 million, and increases the production costs.
[14]This supplier is the Aços Especiais Itabira S/A - ACESITA.
[15] As soon as the this type of plate started to be to produced by ACESITA, the government prohibited its import. Nowadays, this raw material can be imported freely, and import tariffs have been strongly reduced (14%).

[16] There are obstacles to cooperate with foreign steel plates producers and garantee, prices, and delivery time. Moreover, ACESITA privileges clients that cooperate (prices, delivery time). Therefore, it is strategically very risky to change the silicon plates supplier. The competitors can get important competitive advantages.
[17] The company is Motores Elétricos do Brasil - MEB, which sell its production to electric appliances companies of its same industrial group (Springer- admiral group).
[18] 3 firms did not answered to 2 obstacles listed.
[19] Weg Motores, Eberle and Kolhbach.
[20] Even the wires are house-made.
[21] As pointed out earlier, silicon steel plate is essential for HEM.
[22] This new factory will be producing by september 1995.
[23] About the Real Stabilization Plan see Castro (1995).
[24] The economic evaluation of an 10 hp HEM demonstrated that the price differencial is recuperated in **51 months** for 3000 hours of annual use or **19 months** for an annual use of 8.000 hours, considering the high voltage industrial electricity tariff of 1994. These figures show that the price differential between standard and HEM is still very unfavorable to the diffusion of the late, in the case of the lower industrial electricity tariffs. The difference between standard and energy-saver motor's prices vary between 20 to 47%, depending on their sizes (WEG Motores S/A).
[25] The user-supply cooperation has a positive impact to the speed of innovations diffusion. Communication channels are important to augment the speed of diffusion of the information's related to the innovation (Midgley,1992).
[26] In Brazil, industrial products have to pay an industrial production tax (IPI).
[27] In Canada, for instance, some utilities offered an incentive of US$ 400 per kw saved by the replacement of standard motors by HEM (Nelson/ Ternes,1993).