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FINAL REPORT

Project: **Assessment of Energy Efficiency Performance Standards for Three-Phase Induction Motors**

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TABLE OF CONTENTS

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1 EXECUTIVE SUMMARY

The purpose of this report is to present the results of an assessment of the MEPS (minimum energy performance standards) and implementation process proposed by the Energy Efficiency Level and Indicators Management Committee (CGIEE — *Comitê Gestor de Indicadores e Níveis de Eficiência Energética*) for three-phase electric motors sold in Brazil, particularly the proposals in the New (still unnumbered) Edict issued by the Ministry of Mines and Energy (MME – *Ministério de Minas e Energia*), and scheduled to come into effect three years after publication. Specifically, this report seeks:

a. To compare the MEPS with those used internationally;

b. To estimate the operating cost savings potential from the establishment of new MEPS as well as the costs and the cost/benefit ratio from the standpoint of the user and the Brazilian Interconnected Power System;

c. To assess the potential for expansion of the range of motors covered by MEPS to 500 cv;

d. To assess the technical advances towards high efficiency in induction motors, comparing these technologies and their impacts on motor design and fabrication; and

e. To make specific recommendations as to the appropriateness, additional preparatory work and timing of standards.

1.1 Background

The process of upgrading rated motor efficiency levels has been moving steadily ahead since 1993 under the aegis of the voluntary Brazilian Labeling Program (PBE – *Programa Brasileiro de Etiquetagem*). All Brazilian manufacturers belong to the Motors Working Group (*GT Motores*), which also includes the National Metrology, Standardization and Industrial Quality Institute (INMETRO), the Electricity Savings Program (PROCEL) and the Ministry of Mines and Energy (MME). The Ministry establishes annual or bi-annual efficiency upgrade targets on a consensus basis.

Decree N° 4,508/2002 (BRAZIL, 2002) regulated the application of the Energy Efficiency Act (Law N° 10,295/2001 – BRASIL, 2001b) to three-phase induction motors, specifying both a MEPS and the efficiency levels to be achieved for motors to qualify as “high-efficiency” These ratings consolidated the best practices for motors already available in Brazil and also ushered in the conditions needed to ban less efficient motors from the Brazilian market, including less-efficient imported products.

At the same time, competition to obtain the PROCEL Energy Efficiency Seal (a concurrent efficiency program) has encouraged manufacturers to upgrade their products, as this seal is viewed as a comparative advantage on the market. Consequently, the impact of the promulgation of the 2002 Decree and its mandatory provisions was less dramatic than it would have been in the absence of other programs since, although it required a reduction in the electricity consumed by electric motors, it primarily reinforced a process that had been under way for ten years already (GARCIA, 2003).

The next step in the implementation of the Act and stepping up the required MEPS levels was the issuing of an Interministerial Edict which has not yet been approved (referred to as the “New Edict” in this Report). This New Edict establishes a single Rated Efficiency Table, making the previous high-efficiency levels the new MEPS. What follows is the evaluation of the proposal to adopt these ratings as a minimum efficiency requirement for motors sold in Brazil.

The technical analysis of these proposed standards includes: comparison with international practices, potential impacts to manufacturers, financial impacts to consumers, elaboration of test procedures, and potential to expand coverage to motor sizes currently not covered.

1.2 Comparison with International Practices

Induction motors are tested throughout the world mostly using one of two procedures. One test procedure has been established by the International Electrotechnical Commission (IEC), which assigns stray losses, and the other used by the Institute of Electrical and Electronics Engineers (IEEE), which measures them directly. The IEC method results in a higher measured efficiency, meaning that it is less stringent and the IEEE method procedure is more stringent. The Brazilian standard NBR-5383 uses the IEEE method, which is also used by Canada and the USA, while the European Union and China have adopted the IEC standard.

A comparison was carried out between the proposed Minimum Efficiency Performance Standards (MEPS), and standards (either mandatory or voluntary) in Canada, the USA, the European Union, India (which follows the EU standard) and China. Despite some differences in the test procedures and grid frequency, it is clear that the Brazilian proposed MEPS generally correspond to levels implemented elsewhere in the world. In Canada and the USA, current minimum efficiency levels are close to the proposed Brazilian MEPS. In addition the National Electrical Manufacturers Association (NEMA) defines a ‘premium’ efficiency level which exceeds the minimum. However, the NEMA frame sizes used in Canada and the USA are larger than the IEC frame sizes used in Brazil. Therefore, it is easier for motors in Canada and the USA to be designed with more copper and iron, thereby increasing efficiency. Designers of Brazilian motors have fewer options for improving motor efficiency.

1.3 Manufacturer Impacts

From the technological standpoint, improvements introduced for high-efficiency motors include: metal laminations with lower reluctance, particularly through the use of ferrosilicon alloys, better-filled slots using more copper, larger rotor conductors, and improvements in air-gaps, core heads, fans and bearings. Therefore, from the standpoint of the manufacturer, when considering minimum requirements for energy efficiency, three aspects warrant consideration:

- **Material**: the primary difference in materials used in high-efficiency motors and those manufactured for standard efficiency performance is the use of silicon steel laminations that are more expensive and less readily available on the market. In addition to costing two to three times as much as those using standard materials, these laminations have only a single supplier on the Brazilian market. Under current conditions, supply of iron has already become an issue, due to rising demand in rapidly-developing countries such as China. Iron prices have increased significantly on the international market, and today, supply is a problem for motor manufacturers. This condition will potentially become more severe after the adoption of the New Edict. Therefore, a crucial condition for the New Edict to come into effect is to ensure a steady supply of this raw material in quantities sufficient to service the market.
- **Manufacturing process**: although high-efficiency units that comply with the specifications of the New Edict are already in production, exclusive fabrication of high efficiency motors will require sweeping changes to the manufacturing process, requiring investments whose payback is still uncertain. Massive re-tooling efforts will be required by motor manufacturers to shift all production to high-efficiency motors, because the finer ferrosilicon laminations cannot be

processed by the same machinery used to produce ordinary motors. Additionally, the entire production process will require reprogramming in order to ensure minimum productivity levels. Although high-efficiency motors are currently being manufactured, their share of the manufacturing segment is small, with sales of around 10%. This means that exclusive manufacture of this type of motor would have widespread effects on the organization of the production side, requiring major investments.

- **Non-Brazilian Motors**: the presence of less efficient motors can already be observed in imported production equipment. Brazil's National Metrology, Standardization and Industrial Quality Institute (INMETRO – *Instituto Nacional de Metrologia, Normalização e Qualidade Industrial*) has only recently started to test imports, and it is important that this process is mature by the time the New Edict comes into effect, as the cost of motors made in Brazil will increase, making it tempting to import less efficient and less costly units.

1.4 Financial Impacts

Currently, high-efficiency motors are typically 40% more expensive than their standard counterparts. Due to the production reprogramming that would be required by new MEPS, economies of scale gained by widespread production of high-efficiency models may be offset by retooling costs. This report takes the ‘conservative’ approach by calculating cost-benefit ratios of assuming current incremental prices for high efficiency motors.

An analysis of the operating cost savings resulting from motor substitution should take use patterns into account – its drive load in terms of its rated capacity (loading) and operating system (hours/year). Other crucial variables include the price of consumed electricity and the discount rate that reflects the relative attractiveness of deferred savings. Discount rates related to capital use tend to be very significant in the Brazilian context. Two separate analyses were carried out to gauge cost-effectiveness: one on a motor-by-motor basis and the other examining the distribution and use of motors in Brazil, based on the available data.

A motor-by-motor analysis of the cost-benefit ratio for switching to higher efficiency motors (averaging 40% more expensive from the consumer’s initial purchase standpoint) showed that although substitution would generally be advantageous for motors working intensively at full capacity, this would not always be the case when working at partial load or at below their rated capacities, which is how motors often operate. At full loads and intensive use, the motor-by-motor analysis showed that substitution of the more widely-used two and four pole motors would almost always be advantageous for industrial consumers, but this is not always the case for their six and eight pole counterparts. When looking at partial load and partial use contexts, some substitutions may not be advantageous even for two and four pole motors, particularly for larger motors (over 100 cv). Overall, substitution would be advantageous for three-quarters of the two and four pole motors, even at low loads and functioning part-time. For the slower speed motors, these substitutions will be advantageous in some cases of intensive use, although generally disadvantageous in most other scenarios.

Table 1 shows that investment in increased efficiency is cost-effective for industrial consumers for most motor categories and use patterns. For two and four pole motors (which account for 90% of the market), the cost-benefit ratio is nearly always favorable when motors are used intensively (8000 hours per year). At 4000 hours per year, cost-effectiveness is more highly dependent on loading[1], but investment in efficiency is still cost-effective for three-fourths of cases. . The situation for slower speed (6 or 8 pole) motors is considerably less favorable.

Table 1 – Motors with Favorable Cost-Benefit Ratios (Industry)

Loading	**1**	**0.5**	**1**	**0.5**
hours / year	**8000**	**8000**	**4000**	**4000**
2 and 4 poles	100%	98%	81%	75%
6 and 8 poles	89%	70%	39%	18%

Source: Prepared in-house.

Extending these results to a characterize impacts to industrial customers on an aggregate basis shows that substitution presents a favorable cost-benefit ratio. For other consumption sectors, the situation seems similar. An analysis of the available sample of motor models showed a favorable cost-benefit ratio from the consumer standpoint for switching to high-efficiency motors, considered on an aggregate basis (application of the New Edict). A reduction in electricity consumption of 2% is estimated for these motors. This level of improvement is significant because of the large portion of national electricity consumption accounted for by these types of motors.

[1] For the loading distribution in the samples considered, see Figure 18, page 53.

In addition to the industrial sector, estimates of cost-effectiveness were also made for the commercial and residential sectors. Due to data limitations, industrial motors were used as the sample to analyze these other sectors. The situation for the commercial and residential sectors may be slightly less favorable than for the industrial segment, since motor use is less intensive in these sectors. On the other hand, commercial and residential consumers pay higher electricity tariffs, which will have a compensating effect to the low load factor and hours of operation for these sectors.

Finally, societal benefits are evaluated according to the cost of electricity delivery avoided. Using the discount rates normally considered for investments in power system expansion, it is far less expensive to invest in more efficient motors to avoid electricity use than to pay the marginal expansion cost to generate it, with additional advantages of the resulting environmental and social benefits also accruing. Investing in motor efficiency brings benefits to the electric utility as well as to the consumer. Therefore, serious thought should be given to some form of reimbursement, perhaps through financing of investments required with incentives to purchase more efficient motors. Along these lines, proposals were tabled during the implementation of the New Model for Brazil's Power Sector, suggesting that “energy efficiency bidding” might well offer an implementation alternative.

Despite their usually favorable cost effectiveness, the high-efficiency motors market still hovers around only 10% of the total number of units manufactured in Brazil, seemingly indicating that they are not spontaneously accepted by the market. One reason for this is that motors are used in production equipment purchased by manufacturing firms that are not committed to analyzing their electricity use, but rather place their emphasis largely on initial costs. This represents a market failure that standards and labeling programs can address by providing economies of scale at the fabrication level and thus lowering initial costs to consumers. As mentioned above, however, there are doubts over whether prices to consumers will drop considerably with the promulgation of the New Edict.

1.5 Extension of the MEPS to include Motors of up to 500 cv

Motors between 250 cv and 500 cv are currently not covered by the proposed MEPS. These motors have a rated efficiency of over 94%, and are much in demand by larger industries with better engineering structures. According to the manufacturers interviewed, these companies have heavier demands for high-efficiency units. Although concrete data concerning the use patterns of these motors was not available, it seems likely that the impact of adopting the high-efficiency motor ratings will be limited. Particular attention should be paid, however, to the arrival on the Brazilian market of inefficient foreign motors in this power range, once tighter controls are introduced.

1.6 Conclusions and Recommendations

- **Market Transformation from Proposed MEPS –** Adoption of MEPS at the currently proposed level represents a step forward in the development of a process which began over a decade ago and was most recently formalized in the form of mandatory standards as a result of the Energy Efficiency Act. Adoption of the MEPS stipulated by the New Edict would ban from the Brazilian market all three-phase motors at or below 250 cv which do not meet the high-efficiency designation as defined by Decree N° 4,508/2002. On average, motors carrying the high efficiency designation are two percent more efficient than their standard efficiency counterparts, which is a significant improvement, considering large portion of national electricity consumed by these motors.
- **Comparison of MEPS to International Practices –** After performing a detailed comparison with standards (both voluntary and mandatory) in several other countries, we find that the proposed Brazilian MEPS are roughly equivalent to minimum efficiency standards used internationally, particularly with MEPS in the United States and Canada. They are roughly equivalent to the EU voluntary *eff1* level, and slightly lower than voluntary high efficiency ratings in China.
- **Impacts to Manufacturers –** Currently, only 10% of the motors produced by Brazilian manufacturers meet the high-efficiency criteria. Increasing this fraction of production to 100% will necessarily involve a dramatic transformation for manufacturers, including massive retooling and reprogramming. For this reason, the economies of scale afforded by mass production of high-efficiency motors may be significantly offset by capital expenditures. Implementation of the New Edict should therefore be considered only after consultation with motors manufacturers confirms that it will not have dramatic negative financial impacts on manufacturers or end users.

- **Supply of Components –** Mass production of high-efficiency motors will require significantly increased supplies of certain materials – particularly silicon steel laminations. Currently there is only one supplier of these laminations in Brazil. Furthermore, the price of iron and its relationship to recent and projected high global demand are of significant concern. Studies of likely component availability and materials cost scenarios should be continued, and their results should be taken into account before implementation of the New Edict, in order to ensure that product availability and cost will not be severely impacted by the regulations.
- **Foreign Products –** Increase in the minimum efficiency of motors produced by Brazilian manufacturers is likely to encourage further entry to the market by less expensive, foreign made products. In order to avoid unfair competition, therefore, foreign products should require the same certification as domestic ones in order to be sold on the Brazilian market. This requires that agencies responsible for product certification possess the capability to cover all imported products by the date of implementation, and we recommend that a process be undertaken to ensure this capability.
- **Impacts to Consumers** - By analyzing the financial impacts to consumers on a motor-by-motor basis, we find that substitution of motors passing the current standard with those passing the proposed MEPS is generally cost effective in terms of incremental equipment price and operating cost savings. Cost effectiveness varies according to use patterns, motor design and capacity, however. In particular, for industrial users, we find that substitution of nearly all two and four pole motors covered by the regulations would be cost effective at high usage. For lower usage, substitution would be cost effective in 75% to 81% of the cases, depending on load. Substitution is less advantageous for six and eight pole motors. For these, substitution is still cost effective in the majority of cases at high usage, but less than half for low usage. Therefore, we recommend consideration of postponement, level adjustment, or exception for these product classes, which currently represent only a small portion of the total motors market.
- **Benefits to Society –** Cost effectiveness from a societal viewpoint was considered in terms of comparison between the incremental cost of high

efficiency motors to the cost of increasing electricity supply, using discount rates typically applied to power sector investments. This analysis finds motor efficiency to be a highly attractive investment in terms of capital outlay and avoided costs, in addition to the other environmental and social benefits it provides. The relative attractiveness of the investment to the power sector in comparison to industrial consumers suggests that financial incentives be considered as a supplementary or alternative policy to MEPS.

- **Extension of MEPS to cover large motors** – This report considered the potential benefit of extending the coverage of proposed MEPS to include motors of greater than 250 cv capacity and up to 500 cv capacity. In general, motors of this capacity currently sold in Brazil are highly efficient, and their use is highly optimized in terms of energy consumption, since they are typically used by large firms with dedicated engineering staff. Therefore, we conclude that extension of MEPS to include these levels would be less likely to have a significant impact on energy savings than the products currently covered.
- **Measures Parallel to Standards** – It should be noted that, in addition to standards, opportunities exist for energy savings in motor use that might be even more significant, such as enhancing the efficiency of the machinery driven, the use of frequency converters (see Appendix C), correct motor sizing and balanced phase power supplies Efforts made towards implementing these measures should therefore also be considered in parallel to MEPS.

2 ANALYSIS OVERVIEW

The goal of the technical analysis is to provide the Ministry of Mines and Energy and other institutions responsible for implementation of efficiency regulations under the Energy Efficiency Act with the basis for the above conclusions and recommendations. Current efficiency standards stipulate two levels of efficiency for two, four, six and eight pole motors of up to 250 cv capacity. The first of these is a minimum level (referred to as the current ‘standard’ level) and the second is a voluntary ‘high-efficiency’ rating. The MEPS currently under consideration would raise the future minimum efficiency to the current ‘high-efficiency’ level. The remainder of this report provides technical details regarding issues arising from the ratcheting MEPS in this way.

Section 3 begins with an overview of the Brazilian electric motors market. The sub-sections that follow describe the process and institutional roles for regulation of efficiency for these products, and describe in detail the evolution of minimum efficiency performance standards (MEPS) to date, setting the context for the update of MEPS currently being considered.

Section 4 presents two particular aspects of the impact that efficiency regulations have had on motors manufacturers and purchasers, both of which also have relevance for the update of MEPS. First, it describes particular efficiency improvement design options available to motors manufacturers to meet efficiency requirements, and second it presents an analysis of the impacts on retail prices as a result of advanced design. Since the proposed MEPS correspond to voluntary high-efficiency measures already implemented for some products by manufactures, the technology options and price increment are directly relevant to the cost-benefit analysis of currently proposed MEPS. Because of the mandatory and voluntary programs developed since 1993, manufacturers have had both incentive and responsibility to assess and improve the efficiency of their products. As a result, data are available on the efficiency levels of all models in all capacity categories. In general, at least one model is already marketed which would meet the proposed updated MEPS. This provides a valuable handle on potential impacts, due to the likeliness that manufacturers will continue to utilize these technologies in order to meet future requirements. In addition to efficiency, data are also available in the form of list prices for a wide range of motor models. The methodology used in assessing cost-effectiveness relies on product databases as an indicator of likely increases in consumer first costs and operating cost savings implied by implementation of the proposed standards. While we realize that current prices do not necessarily accurately reflect manufacturer costs, they do provide some indication of likely future consumer first costs.

The subsequent three sections cover three separate aspects of the new standards. These are: comparison of proposed minimum efficiency levels to international practices, potential for extension of MEPS to cover motors up to 500 horsepower, and the test procedures used for certification of motors efficiency in Brazil. The comparison of proposed MEPS to international practices was performed by collecting prevailing mandatory and voluntary efficiency ratings for several countries across all capacity categories. Comparison of test procedures involved a close study of the technical documentation of Brazilian procedures along with those corresponding to the two most widely used internationally recognized procedures. Finally, the potential for extension of MEPS to high capacity categories relied on the efficiency levels of these motors in the current market and prevailing use patterns.

The final and most extensive section provides an analysis of cost-effectiveness of substitution of motors meeting current standards with those meeting the proposed standards, which are significantly more stringent. The cost-benefit analysis considers three important perspectives. First, it presents a 'motor-by-motor' calculation of equipment price increases and operating cost savings for each product category provided in the database provided by manufacturers, which represents the whole market. Cost-effectiveness is determined for four separate scenarios for load and operating hours. In addition to considering efficiency improvements for each class of motors individually, we analyzed aggregate impacts based on known use patterns in various industrial sectors. This analysis benefited greatly from an in-depth study covering over 2000 motors in operation in 18 industrial facilities (GARCIA 2003).

These results are then extended to the commercial and residential sectors, with the caveat that use patterns may differ significantly in these sectors. Finally, the perspective of broader benefits to society are considered by evaluating the purchase of high-efficiency motors in terms of equivalent investments into the power grid, and comparing these to the marginal cost of capacity and delivery of electricity.

3 EFFICIENCY REGULATIONS FOR ELECTRIC MOTORS

3.1 The Market for Electric Motors in Brazil

The manufacturing segment consists of four plants in Brazil:

- **Weg** (http://www.weg.com.br/): holds 80% of the market, mainly for industrial motors. The leader of this sector in Latin America, it ranks among the world's top five manufacturers, exporting to more than fifty countries with branches and after-sales assistance facilities in five continents (*Fazendo o Mundo Girar*: Weg Motores Ltda. Mercosul Magazine, 2003). In 2004, it manufactured two million industrial three-phase motors with plants in Brazil, Mexico, Argentina, Portugal and China (WEG, 2005). Headquartered in Jaraguá do Sul, Santa Catarina State, where it was established in 1961, it heads up the supply of low-voltage motors to the industrial segment.
- **Eberle** (http://www.eberle.com.br/): headquartered in Caxias do Sul, Rio Grande do Sul State, where it has been manufacturing electric motors since 1939. Eberle has a market share of around 10%.
- **Kohlbach** (http://www.kohlbach.com.br/): also located in Jaraguá do Sul, Santa Catarina State, where it manufactures motors and generators. Its three-phase motors line includes models of up to 150 cv, with its main output consisting of motors of up to 30 cv and holding a share of around 8% of the three-phase motor market.
- **SEW** (http://www.sew.com.br/): its assembly plants in Brazil produce small motors that are generally coupled to speed variation devices such as motor reducers and electronic drives.

In addition to these, motors manufactured by General Electric, which dominated the market through to the 1970s, are still in operation, as well as by other brands such as Búfalo and Brasil that are no longer manufactured.

The arrival of motors manufactured outside Brazil occurs mainly through assembled equipment, particularly in the timber processing sector (furniture, etc.) and the mechanics industry. The motors market is currently dominated by Brazilian manufacturers, however, who probably control more than 90% of the market, although no exact data is publicly available.

3.2 Processes for establishing Technical Standards and Procedures in Brazil

Until the advent of the Energy Efficiency Act, Brazil's official product certification processes were assigned to the National Council for Metrology, Standardization and Industrial Quality (CONMETRO – *Conselho Nacional de Metrologia, Normalização e Qualidade Industrial)*, which is an interministerial entity handling the regulatory functions of the Brazilian Metrology, Industrial Quality and Conformity System.

One of the activities of this Council is to establish the standards underpinning the technical regulations, streamlining commercial activities and ushering in improvements in processes and products. The standardization area is assigned to the Brazilian Technical Standards Association (ABNT – *Associação Brasileira de Normas Técnicas*) which is a private non-profit organization authorized to accredit entities in various sectors to carry out standardization activities.

Brazil's National Metrology, Standardization and Industrial Quality Institute (INMETRO) is responsible only for accrediting the organizations in charge of assessing the conformity of products and other processes in the metrology field.

Consequently, Brazil's official product regulation and standardization processes may be summarized as follows:

- A Technical Standard is submitted for discussion by the Brazilian Technical Standards Association (ABNT), after a public consultation process, discussions and reviews by a theme-specific group;
- Once the Standard is approved, it forms part of the Brazilian Standardization System which, although not endowed with the power of the law as such, is taken as a legal benchmark for products and services by Brazilian Law (particularly after the introduction of the Consumer Protection Code – through Law N° 8,070/1990).

In principle, all product assessment, test and trial processes follow this scheme. Looking at the involvement of multiple agents specifically for energy efficiency regulations, however, other institutions are equally well qualified to establish the test and trial procedures and standards. The National Metrology, Standardization and

Industrial Quality Institute (INMETRO) has stipulated the procedures for classifying products in efficiency ranges for product labeling purposes.

Their institutional roles may be summarized as follows:

- **Brazilian Technical Standards Association (ABNT)**: is in charge of the preparation and approval of technical standards under the aegis of Brazil's Metrology, Standardization and Industrial Quality System (SINMETRO), as well as accrediting institutions for similar activities.
- **National Metrology, Standardization and Industrial Quality Institute (INMETRO)**: is in charge of accrediting entities for product trials and certification under the aegis of the Metrology, Standardization and Industrial Quality System (SINMETRO), in addition to sitting on the Technical Committees of the Energy Efficiency Level and Indicators Management Committee (CGIEE) (described below), while also establishing specific standards for product trials and consumption levels under the aegis of the Brazilian Labeling Program (PBE).
- **PROCEL Electricity Savings Program:** sits on the Technical Committees of the Energy Efficiency Level and Indicators Management Committee (CGIEE).
- **Energy Efficiency Level and Indicators Management Committee (CGIEE)**: approves the minimum energy efficiency or maximum consumption levels, as stipulated by the Energy Efficiency Act.

3.3 Energy Efficiency Act

The approval of the Energy Efficiency Act (Law N° 10,295 dated October 17, 2001 – BRASIL, 2001b) which was submitted to the National Congress in 1990, established the minimum energy efficiency or maximum consumption levels in Brazil, through a mechanism whose efficacy is acknowledged for ensuring more efficient electricity use. The first item of equipment to be regulated was the three-phase electric motor through Decree N° 4,508 dated December, 2002 (BRAZIL, 2002). It is estimated that this class of equipment may consume up to 32% of the electricity produced in Brazil (MME, 2001, page 23).

Labeling Programs, such as the Brazilian Labeling Program (PBE)[2], which is designed to supply consumers with information on product energy efficiency, and Standardization Programs (in order to eliminate inefficient products from the market, now established in Brazil through the Energy Efficiency Act) are established policies currently implemented in more than 40 countries (CLASP, 2004, page 21) in order to enhance end-use energy efficiency.

The best results have been obtained with combinations of voluntary and mandatory programs, as shown in Figure 1 (CLASP, 2001, page 11): Standards generally target the low end of the distribution of units sold versus efficiency in order to avoid overly severe adverse effects on manufacturers, but remove the least efficient units from the market. Consequently, manufacturers must redesign their equipment, shifting the curve towards higher efficiency[3]. Labeling programs act in a complimentary way, by heightening consumer awareness of efficiency and thereby shifting the curve more smoothly towards higher efficiency. Experience shows that the mandatory programs typically obtain more energy savings results, as consumer information remains imperfect under in a labeling program.

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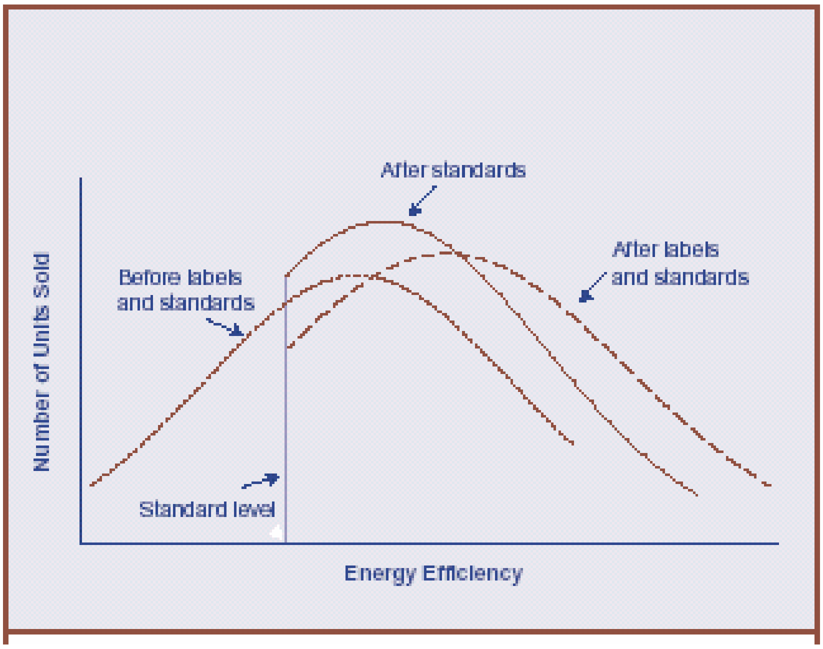
[2] Various aspects of the Brazilian Labeling Program (PBE) are presented on the website of the National Metrology, Standardization and Industrial Quality Institute (INMETRO - *Instituto Nacional de Metrologia, Normalização e Qualidade Industrial*) which is the Brazilian metrology and quality entity: http://www.inmetro.gov.br/consumidor/pbe.asp, in charge of this Program.

[3] Although this may produce excellent results. CLASP (2004, page 18) mentioned that the average amount of electricity required to run a new refrigerator in the USA dropped by 74% since the first standards were issued in California 25 years ago, although new appliances have far more features and greater capacity.



Source: CLASP, 2001.

Figure 1 – Impact of Energy Efficiency Programs on Sales

Three-phase motors have been covered by the Brazilian Labeling Program (PBE) since 1993. A Motors Working Group (known as *GT – Motores*) was set up by the manufacturers, the Eletrobras Research Center (CEPEL), which handled the testing, PROCEL[4] and INMETRO, which coordinate the Brazilian Labeling Program (PBE). According to the participants, this Motors Working Group acted through consensus, establishing increasingly more challenging targets for standard and high efficiency motors, implemented annually or biannually and always on a voluntary basis. The success of these efforts led motors to become the first item of equipment targeted for MEPS. Since Brazilian manufacturers had already implemented the proposed MEPS levels voluntarily, once the Law came into effect this eliminated the possibility of predatory foreign competition.

3.4 Decree N° 4,508/2002

In order to regulate this Act, Decree N° 4,059 (BRAZIL, 2001b) was promulgated on December 19, 2001, with the Energy Efficiency Level and Indicators Management Committee (CGIEE — *Comitê Gestor de Indicadores e Níveis de Eficiência Energética*) set up for this purpose by the Ministry of Mines and Energy (MME), the Ministry of Science and Technology (MCT) and the Ministry of Development, Industry

[4] Brazil's National Electricity Conservation Program, implemented under the aegis of Eletrobras.

and Foreign Trade (MDIC), as well as the Brazilian Regulatory Agencies of Electricity (ANEEL) and Oil (ANP), a university representative and a Brazilian citizen, both energy specialists.

The Energy Efficiency Level and Indicators Management Committee (CGIEE) drew up an extensive studies plan in late 2002 (CGIEE, 2002) and initially ensured the approval of Decree N° 4,508/2002, which regulated the energy efficiency of three-phase squirrel-cage rotor induction electric motors (BRAZIL, 2002, page 1). These motors account for at least 90% of the driving power produced by electricity in Brazil's industrial sector (GARCIA, 2003, page 13). They are also used in the residential, government, commercial and agricultural sectors for applications such as pumps, ventilation, cooling and air-conditioning systems, as well as a wide variety of machines, accounting for almost one-third of the electricity consumed in Brazil.

Oversight of the implementation of the standards established through this Decree was assigned to the National Metrology, Standardization and Industrial Quality Institute (INMETRO), (BRAZIL, 2002, Article 16).

Article 3 of Decree N° 4,508 stipulates that the: “energy efficiency indicator to be used is the rated efficiency” (BRAZIL, 2002, page 8). Two Minimum Rated Efficiency Tables were established; one for standard motors and the other for their high-efficiency counterparts. These are presented together in Table 2. These ratings were already under discussion by the Motors Working Group under the Brazilian Labeling Program (PBE), and were agreed to two years prior to the Law coming into effect.

Table 2 – Performance Levels under the Energy Efficiency Act

Rated capacity		**Standard**				**High-Efficiency**			
cv	**kW**	**S2**	**S4**	**S6**	**S8**	**HE2**	**HE4**	**HE6**	**HE8**
1	0.75	77.0	78.0	73.0	66.0	80.0	80.5	80.0	70.0
1.5	1.1	78.5	79.0	75.0	73.5	82.5	81.5	77.0	77.0
2	1.5	81.0	81.5	77.0	77.0	83.5	84.0	83.0	82.5
3	2.2	81.5	83.0	78.5	78.0	85.0	85.0	83.0	84.0
4	3	82.5	83.0	81.0	79.0	85.0	86.0	85.0	84.5
5	3.7	84.5	85.0	83.5	80.0	87.5	87.5	87.5	85.5
6	4.5	85.0	85.5	84.0	82.0	88.0	88.5	87.5	85.5
7.5	5.5	86.0	87.0	85.0	84.0	88.5	89.5	88.0	85.5
10	7.5	87.5	87.5	86.0	85.0	89.5	89.5	88.5	88.5
12.5	9.2	87.5	87.5	87.5	86.0	89.5	90.0	88.5	88.5
15	11	87.5	88.5	89.0	87.5	90.2	91.0	90.2	88.5
20	15	88.5	89.5	89.5	88.5	90.2	91.0	90.2	89.5
25	18.5	89.5	90.5	90.2	88.5	91.0	92.4	91.7	89.5

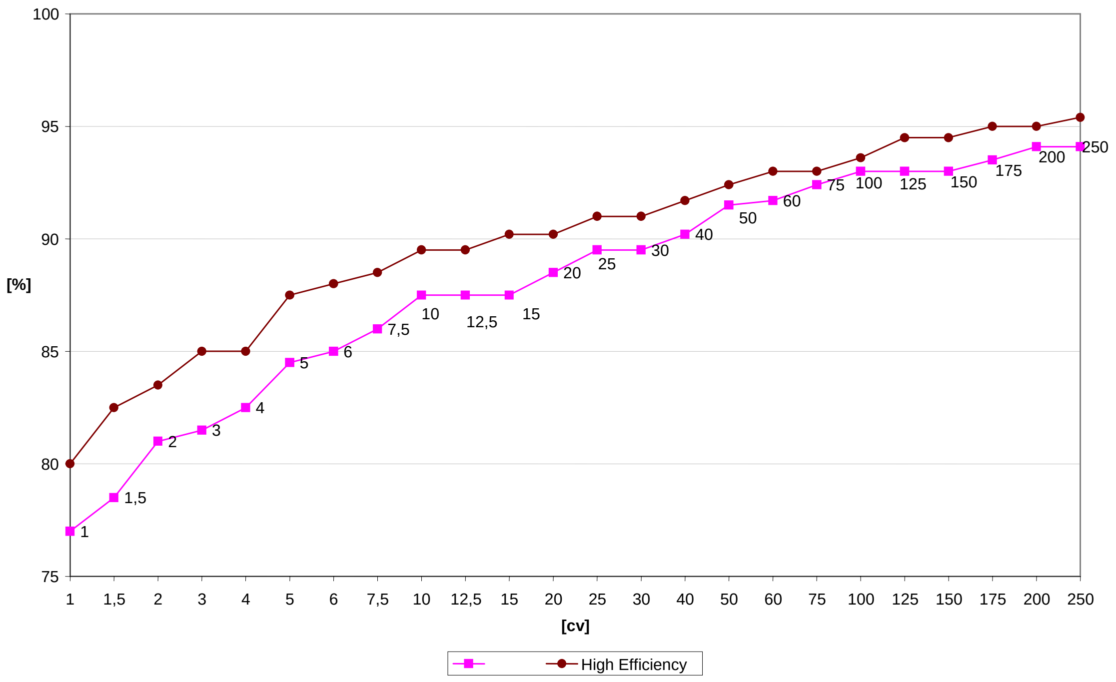
Rated capacity		Standard				High-Efficiency			
cv	**kW**	**S2**	**S4**	**S6**	**S8**	**HE2**	**HE4**	**HE6**	**HE8**
30	22	89.5	91.0	91.0	90.2	91.0	92.4	91.7	91.0
40	30	90.2	91.7	91.7	90.2	91.7	93.0	93.0	91.0
50	37	91.5	92.4	91.7	91.0	92.4	93.0	93.0	91.7
60	45	91.7	93.0	91.7	91.0	93.0	93.6	93.6	91.7
75	55	92.4	93.0	92.1	91.5	93.0	94.1	93.6	93.0
100	75	93.0	93.2	93.0	92.0	93.6	94.5	94.1	93.0
125	90	93.0	93.2	93.0	92.5	94.5	94.5	94.1	93.6
150	110	93.0	93.5	94.1	92.5	94.5	95.0	95.0	93.6
175	132	93.5	94.1	94.1		95.0	95.0	95.0	
200	150	94.1	94.5	94.1		95.0	95.0	95.0	
250	185	94.1	94.5			95.4	95.0		

Source: Decree N° 4,508 (BRAZIL, 2002).

The columns in Table 2 mean:

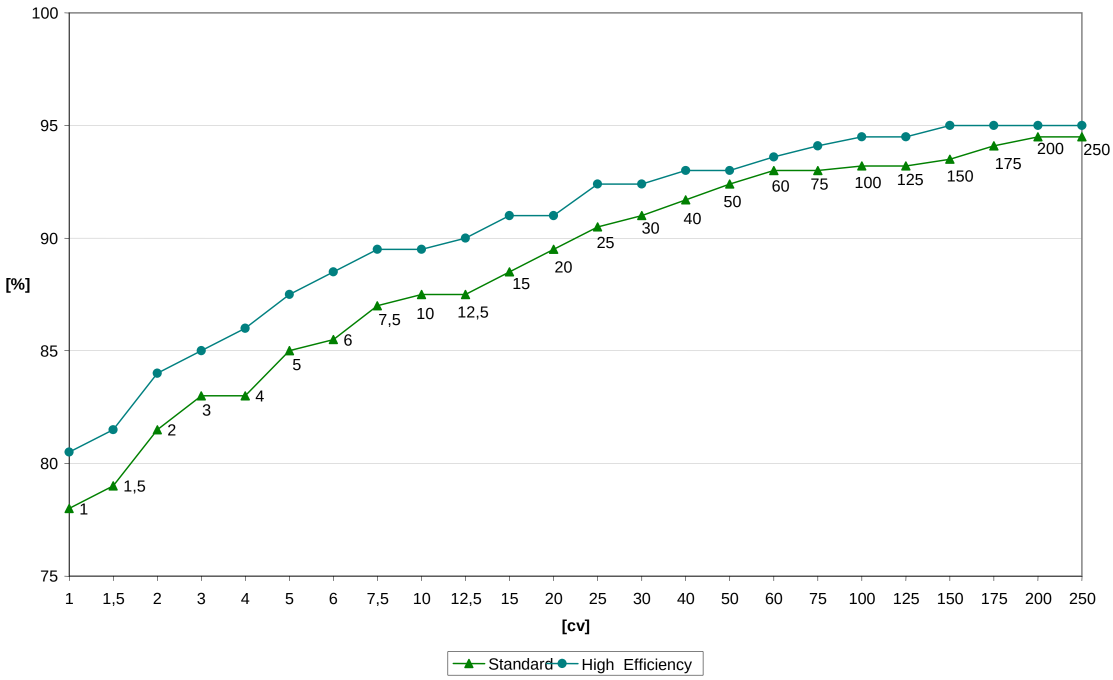
cv and kW	Rated capacity (mechanical in both cases) of the motors under consideration
S2, S4, S6 and S8	Standard motors with 2, 4, 6 and 8 poles respectively
HE2, HE4, HE6 and HE8	High-efficiency motors with 2, 4, 6 and 8 poles respectively

Six and eight pole motors are less widely used. In the sample analyzed in this report, 76% are four pole, 12% are two pole, 11% are six pole and only 1% are eight pole. Figure 2 and Figure 3 compare the ratings for the two and four pole motors. Some motors, such as the 50 cv and 60 cv four pole units posted an increase in efficiency of less than 1%.



Source: Prepared in-house, under Decree N° 4,508 (BRAZIL, 2002).

Figure 2 – Two Pole Ratings under Decree N° 4,508



Source: Prepared in-house, under Decree N° 4,508 (BRAZIL, 2002).

Figure 3 — Four Pole ratings Under Decree N° 4,508

3.4.1 Impact on the Brazilian Market

Comparing the efficiency levels stipulated by the Act with those in practice in 2001, using the BDMotor[5] database (CEPEL, 2003), it appears that all the efficiency levels were already complied with by at least one manufacturer, as shown in Figure 4 and Figure 5. These Figures present the ratings stipulated by Decree N° 4,508 subtracted from the rated efficiency levels of motors manufactured in 2001. Consequently, the negative figures show the motors requiring improvements, while the positive figures show those already compliant with the Act.

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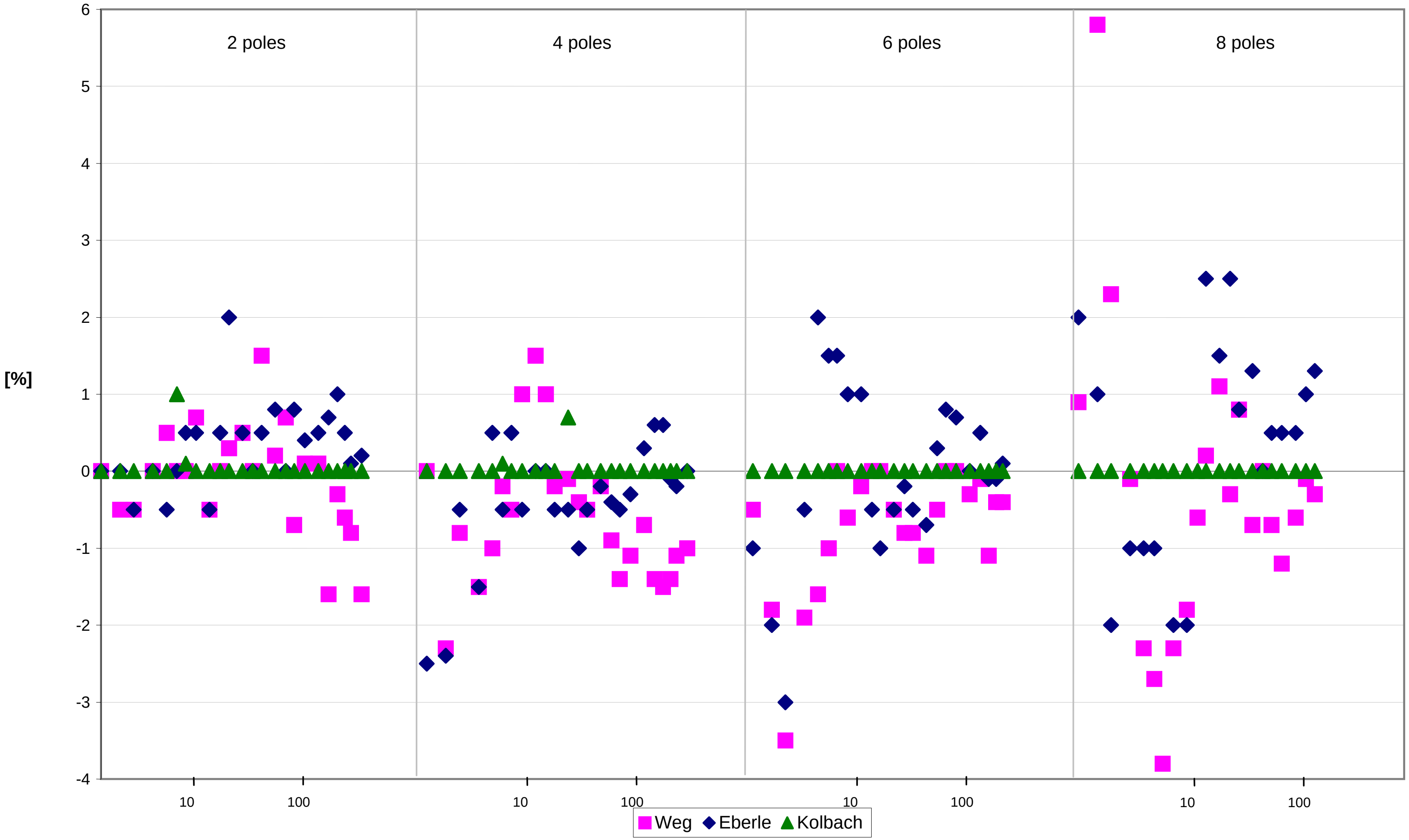
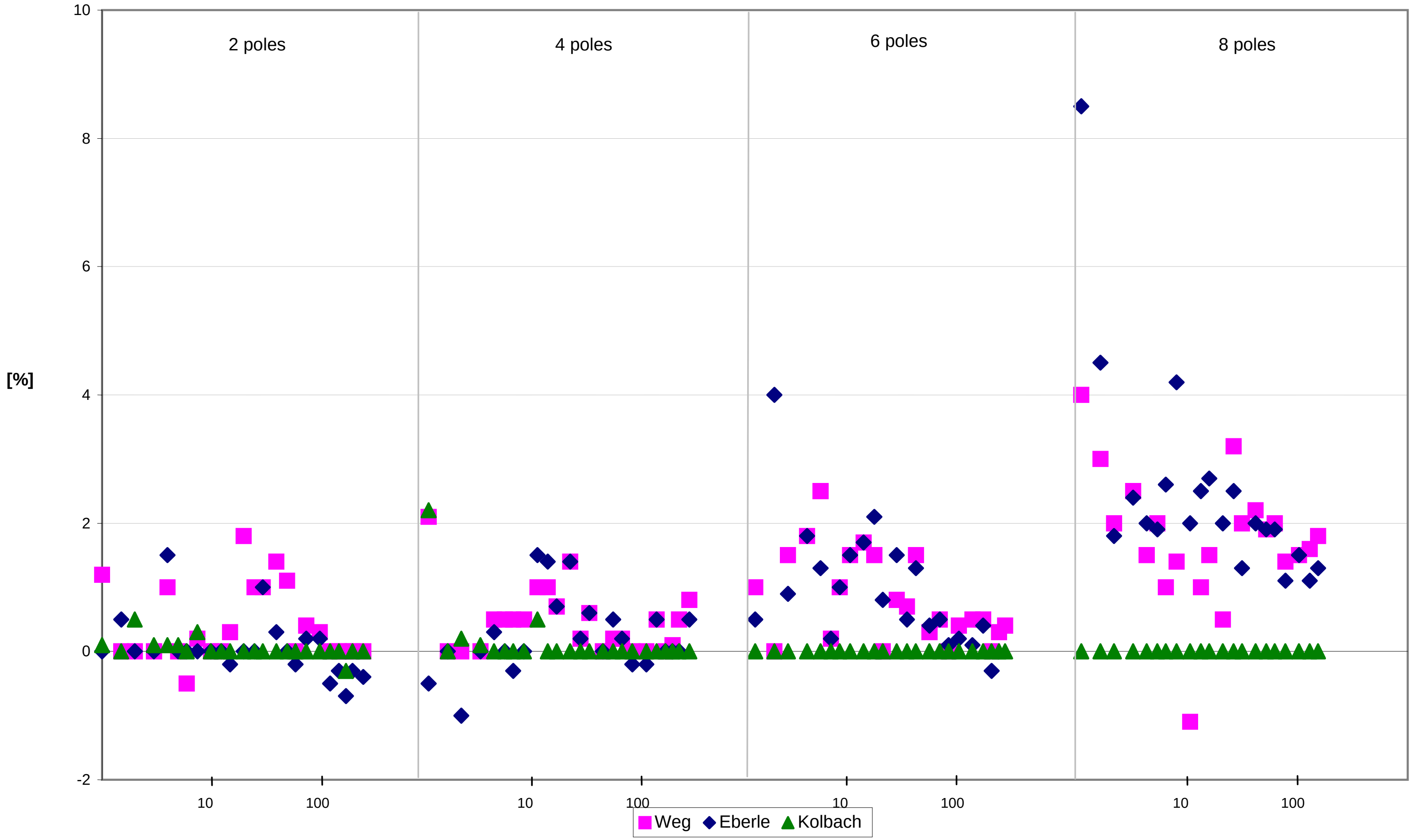
[5] Electric induction motor management software developed by the Eletrobrasás Research Center (CEPEL), under the Ministry of Mines and Energy (MME).



Source

Prepared in-house, based on BDMotor (2003) and Decree N° 4,508 (BRAZIL, 2002).

Figure 4 – Deviations for Standard Motors compared to Decree N° 4,508



Source: Prepared in-house, based on BDMotor (2003) and Decree N° 4,508 (BRAZIL, 2002).

Figure 5 — Deviations for High-Efficiency Motors compared to Decree N° 4,508

Although the adaptations were not particularly significant (19% of the motors were altered) these initial regulations took an important step towards the enforcement of the Energy Efficiency Act in Brazil (with electricity savings of around 1%, according to Garcia, 2003). As shown in the above graphs, the most significant efforts were made by Weg for the standard motors, which will result in electricity savings by this equipment in Brazil (GARCIA, 2003, page 91), due to the larger market share held by this manufacturer.

The implementation of this Act had no impact on sales, as motor prices are affected far more by the costs of materials, particularly metals (iron, copper and aluminum) that have increased significantly over the past few years. According to the manufacturers, for instance, copper has risen from US$ 1,500 to US$ 3,260 per ton over the past eighteen months.

The New Edict, which has not yet been numbered, is analyzed below, representing a second important step towards enhancing the efficiency of Brazilian motors.

3.4.2 Impact on Manufacturers

In fact, as mentioned previously, the process of upgrading the ratings began with the Motors Working Group under the Brazilian Labeling Program (PBE) in 1993, with Decree N° 4,508 establishing this process under the law and on a mandatory basis. For the manufacturers, the main advantage of this Act was the possibility of eliminating foreign competition offering less efficient motors.

According to statements from the manufacturers, tremendous efforts were made, particularly at the start, to adapt to the levels proposed as targets, which were always established through consensus by the Group – everyone in agreement, with the Group functioning harmoniously. Significant investments were allocated to engineering, developing and upgrading the motors, new die-stamping machines with the new plate dyes, plate treatment, automatic coil inserters and others. All manufacturers interviewed claimed that the investments were not transferred to the prices in this process, but were rather absorbed by other process improvements that helped cut costs. The lowest capacity motors showed the most improvement.

In parallel to this process, there is also competition to receive the PROCEL Electricity Savings Seal[6], which is viewed as a comparative advantage in the market, received by all the manufacturers for different power ratings and polarities (PROCEL, 2005). The efficiency enhancement techniques currently available are discussed in the next section.

[6] The PROCEL Seal is a promotional tool of the PROCEL Electricity Savings Program awarded annually since 1994 to equipment with the best energy efficiency ratings within their categories. It is intended to encourage domestic production of more efficient products in terms of electricity savings, guiding consumers to purchase equipment with higher energy efficiency levels (PROCEL - *Programa Nacional de Conservação de Energia Elétrica*) available at: http://www.eletrobras.gov.br/procel/site/seloprocel/apresentacao.asp, accessed on March 26, 2005).

4 EFFICIENCY ENHANCEMENT TECHNOLOGIES AND IMPACT ON EQUIPMENT PRICE

The efficiency level is defined as the output / input power ratio, shown in Equation 1.

$$\eta = \frac{P_{mec}}{P_{ele}} = \frac{P_{mec}}{P_{mec} + P_{los}} \quad \text{Equation 1}$$

η	Efficiency	[1]
P_{mec}	Mechanical power	[kW]
P_{ele}	Electric power	[kW]
P_{los}	Losses	[kW]

Consequently, boosting efficiency means reducing losses. In general, losses may be cut by 30% to 50% through optimizing designs and using better quality materials. In a three-phase electric induction motor, losses are usually divided into fixed losses that do not vary with the mechanical load, and variable losses that do vary. The fixed losses are:

a. **Core losses**: these are losses due to magnetic field circulation, through hysteresis and eddy currents. They depend on supply frequency (60 Hz in Brazil), field density (the less iron, the more dense the field), steel quality (silicon steel is more susceptible to magnetic fields), plate thickness and insulation. They represent 15% to 25% of the total losses when operating at rated power (ELETROBRÁS, 199 - page 93). According to the manufacturers, three types of steel are used: SAE 1006/1008, in 0.6 mm laminations, requiring treatment to reduce losses from 8 to 10 W/kg to 4 W/kg; “core” type, also at 0.6 mm with losses of 2.5 to 4 W/kg; and ferrosilicon laminations, with only one supplier in Brazil, 0.5 to 0.23 mm thick with losses of 1.3 to 2.5 W/kg, and a lower saturation curve, requiring larger volume. Additionally, they are almost three times more expensive (used in high-efficiency motors).
b. **Friction and windage losses**: these are losses due to friction in the bearings and windage, contributing from 5% to 15%. Developing more efficient fans has helped reduce these losses, with further research under way, according to the manufacturers. The use of low-friction bearings and seals may also lower these losses.

The variable losses are:

c. **Stator losses**: due to the Joule[7] effect caused by current circulating in the stator winding, meaning that losses from this effect are largest at rated capacity: 25% to 40%, depending on the conductor gauge and the coil length. Increasing the conductor gauge, improving the groove designs for more copper insertion, and automating the insertion process are the techniques used to reduce these losses.

d. **Rotor losses**: these are also called slip losses, caused largely by differences in rotation speeds between the magnetic field and the rotor. Rotor losses may account for 15% to 25% of the total losses in induction motors, depending on materials (generally aluminum for low voltage motors) as well as the cross-section and length of the bars. Increasing the amount of aluminum used helps reduce these losses.

e. **Stray losses**: arise due to various flaws in the magnetic fluxes and current distribution, air-gap flaws and irregularities in the gap magnetic flux. They may be reduced through a good motor design, with better-spaced rotor coil heads, heat-treated rotors and double-layer stator winding, accounting for a smaller proportion of the low voltage motors at 10% to 20%.

Manufacturing a high-efficiency motor requires addressing all or most of these losses. Manufacturers typically begin with a 20% increase in the stator copper, while also stepping up the size of the rotor conductor bars. Magnetic losses (in the rotor and stator cores) are usually reduced by using iron containing silicon, instead of regular carbon steel, increasing the core size and better interlaminar insulation. Special attention to design and manufacturing details helps reduce mechanical and stray losses. High-efficiency motors typically cost 10% to 25% more than their standard counterparts, although current prices are an average of 40% higher in Brazil, as shown in Table 3 – Incremental Price Increase for High Efficiency Motors, on page 32.

4.1 New Edict

The New Edict would establish only a single Efficiency Table, adopting the values stipulated in Decree N° 4,508 for the high-efficiency motors. The effect of the New Edict is to require that *all* future motors operate at least at the high-efficiency

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[7] The Joule Effect is the heating of the conductor as the current runs through it: it is equal to the conductor resistance times the square of the current.

performance level. A period of three years from publication of the Edict was established for adapting to the new structure (The New Edict has not yet been published, therefore it will not come into effect before June 2008).

4.1.1 Impact on the Market

Due to market impacts on the manufacturing process, which are discussed below, economies of scale arising from the exclusive fabrication of the high-efficiency motors may be offset by other costs. Therefore, the analysis assumes that, at least initially, current prices for these motors will prevail, resulting in an average price increase of 40% for the substitution. Table 3 presents the assumed increases, as explained below.

Table 3 – Incremental Price Increase for High Efficiency Motors

	Poles			
Rated capacity (cv)	**2**	**4**	**6**	**8**
1	36%	33%	25%	38%
1.5	25%	36%	43%	43%
2	27%	35%	34%	38%
3	24%	41%	46%	28%
4	47%	43%	36%	21%
5	39%	45%	35%	46%
6	34%	29%	35%	22%
7.5	44%	31%	44%	23%
10	36%	38%	44%	45%
12.5	44%	44%	34%	27%
15	43%	51%	31%	28%
20	17%	28%	43%	42%
25	44%	47%	44%	34%
30	42%	30%	35%	43%
40	21%	24%	56%	37%
50	24%	24%	44%	44%
60	32%	34%	48%	43%
75	25%	37%	45%	43%
100	40%	38%	43%	44%
125	36%	34%	43%	3%
150	38%	44%	43%	4%
175	43%	43%	44%	
200	35%	42%	45%	
250	45%	44%		

Source: Prepared in-house.

Prices were obtained from the current Weg and Kohlbach Price Lists (March 2005), supplied by the manufacturers themselves and known as the Full Lists. Common market practice is for manufacturers to offer a discount ranging from 33% to 50%. Consequently, we consider prices at 65% of the Full List value. The BDMotor prices were taken for the Eberle motors, which were in the same range as the other two. A weighted average was drawn up, based on the following assumed market distribution: 80% for Weg, 10% for Kohlbach and 10% for Eberle.

The efficiency enhancement based on the same market share obtained from the BDMotor standard and high-efficiency motor data for motors manufactured in 2003 is presented in Table 4.**Error! Reference source not found.**

Table 4 – Incremental Efficiency For High Efficiency Motors

	Poles			
Rated capacity (cv)	**2**	**4**	**6**	**8**
1	5.2%	4.0%	7.9%	7.0%
1.5	5.2%	2.6%	3.2%	6.3%
2	3.1%	2.1%	7.3%	5.2%
3	4.3%	2.4%	5.8%	6.2%
4	3.7%	4.1%	6.3%	5.3%
5	2.4%	2.9%	4.1%	3.8%
6	3.5%	3.9%	4.1%	1.8%
7.5	2.4%	2.4%	4.1%	1.8%
10	2.2%	2.5%	2.7%	2.0%
12.5	2.2%	3.0%	1.8%	1.7%
15	2.8%	3.5%	1.0%	1.2%
20	3.0%	2.4%	0.9%	0.4%
25	2.6%	1.8%	1.7%	1.1%
30	1.2%	2.1%	1.6%	0.9%
40	2.8%	1.4%	1.5%	1.0%
50	1.3%	0.8%	1.4%	1.0%
60	1.3%	0.9%	2.0%	0.9%
75	0.6%	1.2%	0.8%	1.3%
100	0.6%	1.4%	1.2%	1.2%
125	1.5%	1.4%	1.2%	0.1%
150	1.2%	1.5%	0.9%	0.1%
175	1.1%	0.9%	0.9%	
200	0.9%	0.9%	0.9%	
250	1.2%	0.9%		

Source: Prepared in-house, with BDMotor data (CEPEL, 2003) for 2003

We note that price increases are higher for large motors, with lower gains in efficiency. A good way of analyzing these variations is through calculating the price / efficiency elasticity.

Elasticity may be used as a measurement showing the sensitivity of the motor cost to variations in its efficiency. This may be defined as the percentage variation in the cost divided by the percentage variation in the efficiency. One of the advantages of working with measurement through variations in percentage terms is that it maintains the definition of free elasticity for the monetary or physical units.

Elasticity may be calculated through Equation 2:

$$\varepsilon = \frac{\frac{\Delta C}{C}}{\frac{\Delta \eta}{\eta}} \quad \text{Equation 2}$$

ΔC	Cost variation	[R$]
C	Cost	[R$]
$\Delta \eta$	Efficiency variation	[%]
η	Efficiency	[%]

In this study, since motor production costs were not available, the final market price was used. In this case, the elasticity expresses the impact on the end-price of the motor in relation to a percentage increase in its efficiency. It is not correct to attribute price alterations solely to efficiency variations, as they may also reflect variations in supply and demand, marketing strategies and other cost variations, including taxes etc. Consequently, these findings are merely an approximation of real costs, but nevertheless are very valuable in estimating net financial gains of implementing energy efficiency programs – **Error! Reference source not found.**Table 5.

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Table 5 – Price Efficiency Elasticity

	Poles			
Rated capacity (cv)	**2**	**4**	**6**	**8**
1	6.95	8.16	3.17	5.39
1.5	4.92	13.43	13.34	6.87
2	8.44	16.52	4.64	7.22
3	5.47	16.85	7.96	4.46
5	12.86	10.59	5.64	4.02
7.5	16.33	15.45	8.51	12.13
10	9.87	7.37	8.45	11.69
15	18.37	13.10	10.90	12.89
20	16.44	15.34	16.31	22.88
25	19.75	14.77	18.44	16.27
30	15.05	14.45	31.63	24.11
40	5.52	11.92	45.03	115.01
50	16.98	25.37	25.87	30.46
60	33.62	14.72	21.93	45.17
75	7.70	17.01	38.19	38.22
100	18.34	28.31	30.85	44.96

Rated capacity (cv)	Poles 2	4	6	8
125	23.78	36.99	24.21	46.73
150	39.93	31.37	57.70	33.74
200	65.43	28.07	36.42	37.08
250	23.61	24.27	35.00	24.80

Source: Prepared in-house.

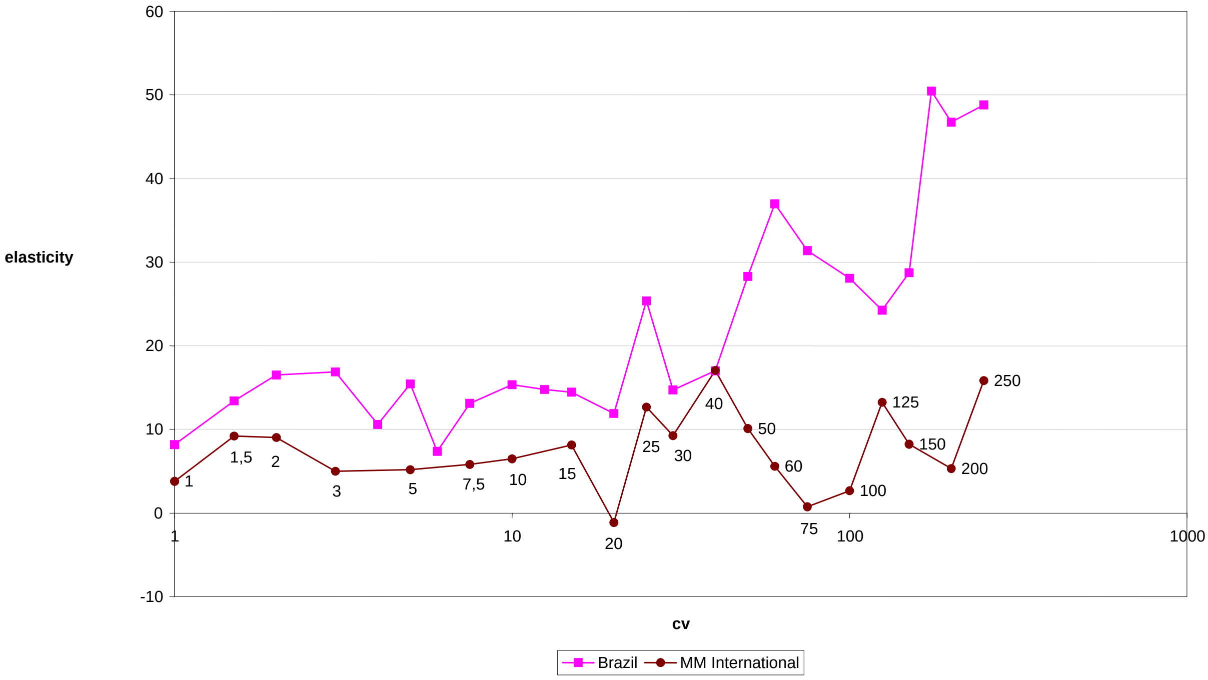
A comparison was drawn up with the data for motors on the US market, available in the software issued by the US Department of Energy (Motor Master International, US DOE, 2004) for motors of the same type with varying efficiency levels (NEMA 60 Hz, motors, totally closed with external ventilation, efficiency 1 and 2). These findings are presented in Table 6 (data not available for eight pole motors).

Table 6 – Price / Efficiency Elasticity for MMInt Motors

Rated capacity (hp)	Poles 2	4	6
1	2.63	3.81	7.18
1.5	7.69	9.19	10.16
2	7.77	9.03	2.29
3	6.06	4.99	12.22
5	10.00	5.20	8.15
7.5	10.09	5.82	-3.04
10	7.46	6.47	8.79
15	10.08	8.16	7.96
20	8.43	-1.12	7.10
25	6.27	12.67	11.06
30	10.09	9.27	5.12
40	10.83	17.06	14.54
50	10.84	10.10	8.91
60	11.57	5.60	4.41
75	8.53	0.73	7.48
100	5.79	2.68	16.84
125	4.49	13.24	13.13
150	3.99	8.22	8.64
200	12.41	5.30	17.29
250	22.34	15.84	38.61

Source: Prepared in-house, based on the Motor Master International data (US DOE, 2004).

The elasticity is far lower in the U.S. case than in the Brazilian case, which might be expected due to the current low market penetration of motors using high-efficiency design options in Brazil. Figure 6 presents the elasticity comparison between the two countries (for four pole motors, as an example). Differences are most significant for the large motors.



Source: Prepared in-house.

Figure 6 – Price / Efficiency Elasticity

The relatively high price elasticity with respect to efficiency for Brazilian motors indicates that efficiency is less likely to be cost-effective from a consumer perspective than in the U.S. case. As detailed below, however, cost effectiveness on a motor-by-motor basis is crucially dependent on use patterns and price of electricity paid in each sector.

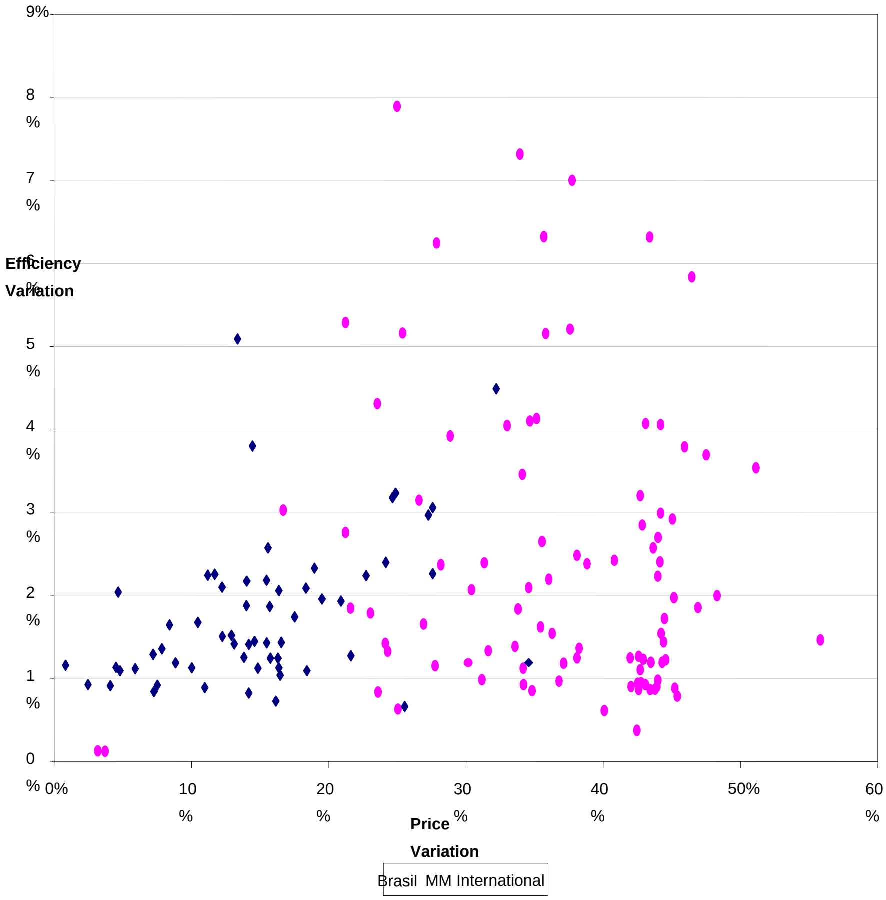


Figure 7 – Δ Efficiency x Δ Price

5 COMPARISON TO INTERNATIONAL PRACTICES

According to the survey carried out by APEC-ESIS (2003), comparisons among the levels established in the various "economies"[8] have three complicating factors: supply frequency (50 or 60 Hz); differences in test procedures; and differences in whether ratings were established according to weighted average or absolute minimum efficiency. The authors state that, although "no attempt is made to evaluate the economic costs and benefits of introducing any particular minimum energy performance standard", "it is probably fair to say that if a significant proportion of the global market adopts the same, stringent mandatory requirements, economies of scale will make that stringency level the most economic" (APEC-ESIS, 2003, p. 1).

Based on the power supply frequency, it is expected that motors designed for 50 Hz will operate at this frequency with an efficiency close to that of similar models designed for 60 Hz and operating at this frequency. However, small 50 Hz motors (under 7.5 cv) should run slightly less efficiently than 60 Hz models[9].

According to the authors, there are two basic performance test procedures: those based on the IEC 34-2 and those based on the IEEE 112 (including the IEC 61972 standard) which covers the Brazilian versions. The main difference lies in how stray losses are handled: the IEC procedure uses assumed values for these losses at 0.5% of the full load losses, while the IEEE procedure measures them (other standards such as that used in Japan simply ignore them). There are also standards in Australia and New Zealand that cover both situations, serving as a means of comparison.

The difference in the established efficiency levels may be significant, particularly for small motors. For example, the rated efficiency of a motor between 1 and 20 cv will be 2% lower through the IEEE method than by the IEC. The difference drops to around 0.5% above 125 cv. The European Union is currently adopting the IEC 61972 standard, which should be completed shortly. The new IEC test procedure offers the manufacturers the option of establishing the rated efficiency through a direct method similar to that of the IEEE 112 or estimating efficiency using far higher estimates (for small motors) for the stray losses.

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[8] The authors prefer to use the word "economy" rather than country, as there are now markets covering several countries, while others are limited to parts of a single country.

[9] The 50 Hz motors are larger because they contain more iron, which requires longer coils. In small motors, the stator winding losses prevail, making them less efficient.

The third difficulty lies in the concept of the minimum level adopted: if absolute, all units sold should exceed the target; if this is an average, some units may fall below the target. In this latter case, the minimum levels will consequently be lower. For example, the National Electrical Manufacturers Association (NEMA)[10] in the USA stipulates a link between the rated efficiency (average) and the minimum level (NADEL et al., 1992, page 61).

5.1 Canada and the USA

Both countries have the same minimum rated efficiency level for motors at full load, separated into open and closed motors (Brazil's Decree N° 4,508 covers only closed motors) varying from 1 to 200 hp (rather than cv), two to six poles, here called the standard level. A premium class is established by the National Electrical Manufacturers Association (NEMA) with rated and minimum efficiency levels for closed and open motors from two to six poles, and includes motors up to 500 cv. Compliance with the premium class is voluntary, and was not adopted by the US Government. Consequently, we compared the rated levels for closed motors with the ratings stipulated in Brazil's New Edict.

The findings are presented in Figure 8, Figure 9 and Figure 10 respectively for two, four and six poles. The indices are basically the same as those for the standard motors, other than small motors, especially six pole motors. Although lacking physical significance, the points are joined up by lines in the Figures to display the comparison more clearly.

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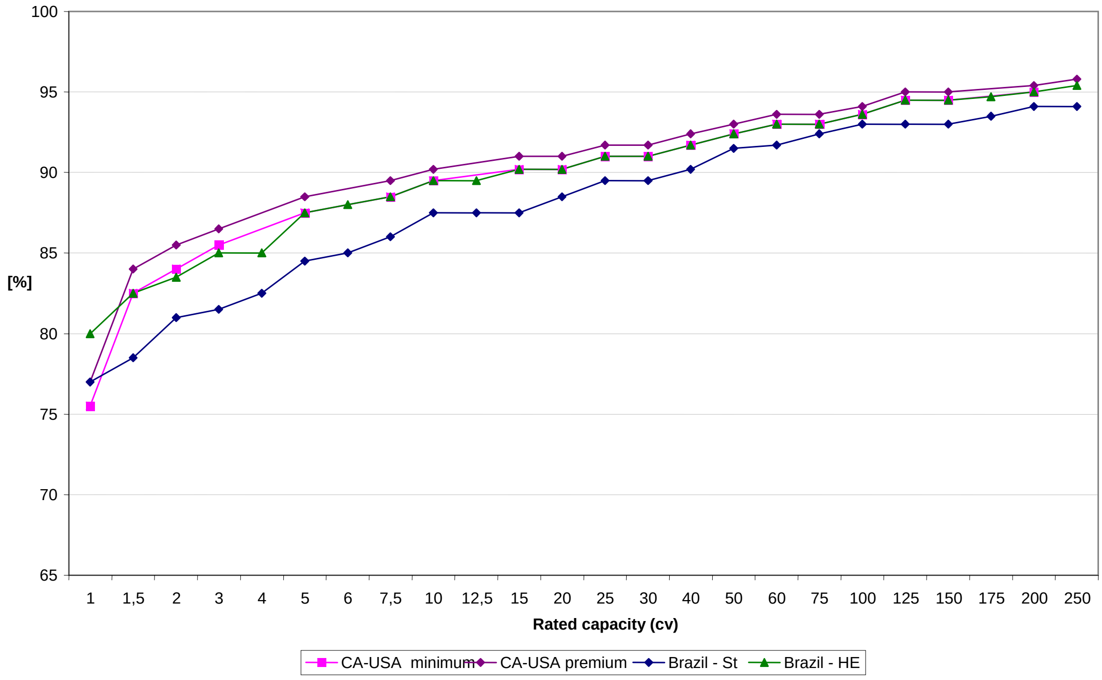
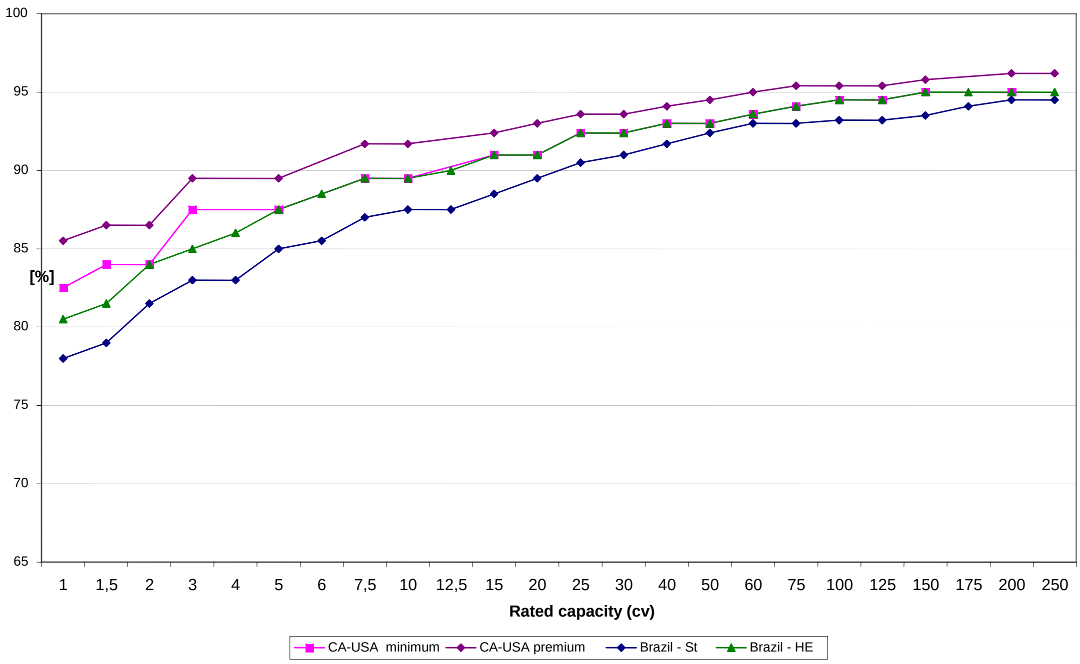
[10] A US Trade Association that is involved in developing standards.



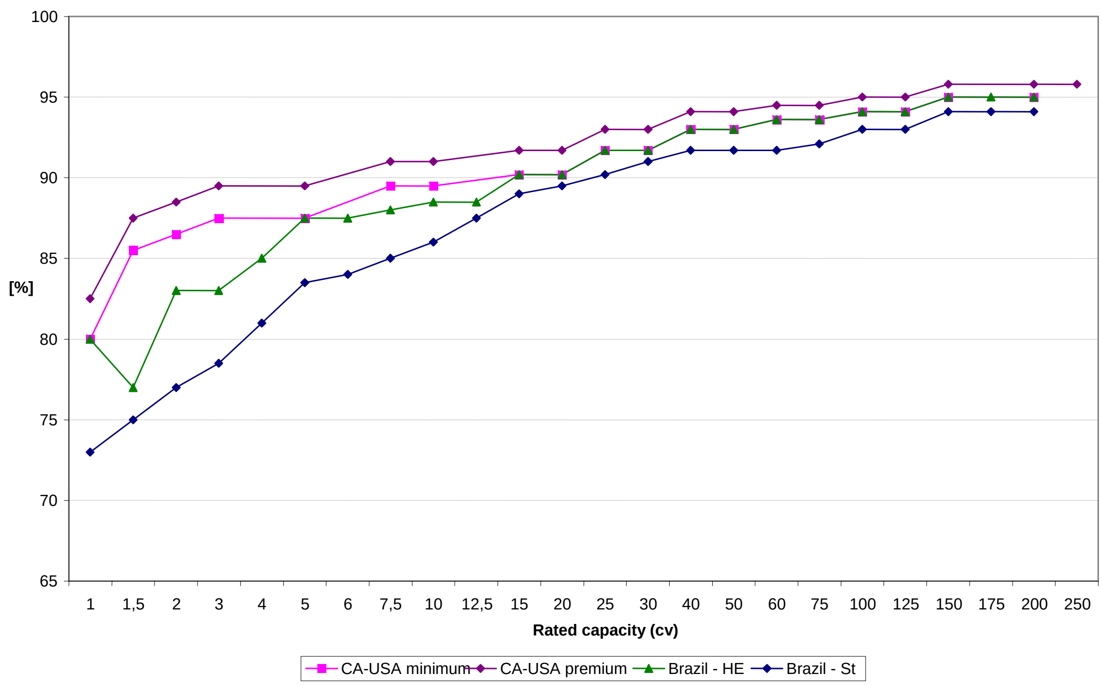
Source: Prepared in-house, based on APEC-ESIS (2003) and BRAZIL (2002).

Figure 8 – Comparison with the USA and Canada – Two Poles



Source: Prepared in-house, based on APEC-ESIS (2003) and BRAZIL (2002).

Figure 9 — Comparison with the USA and Canada – Four Poles



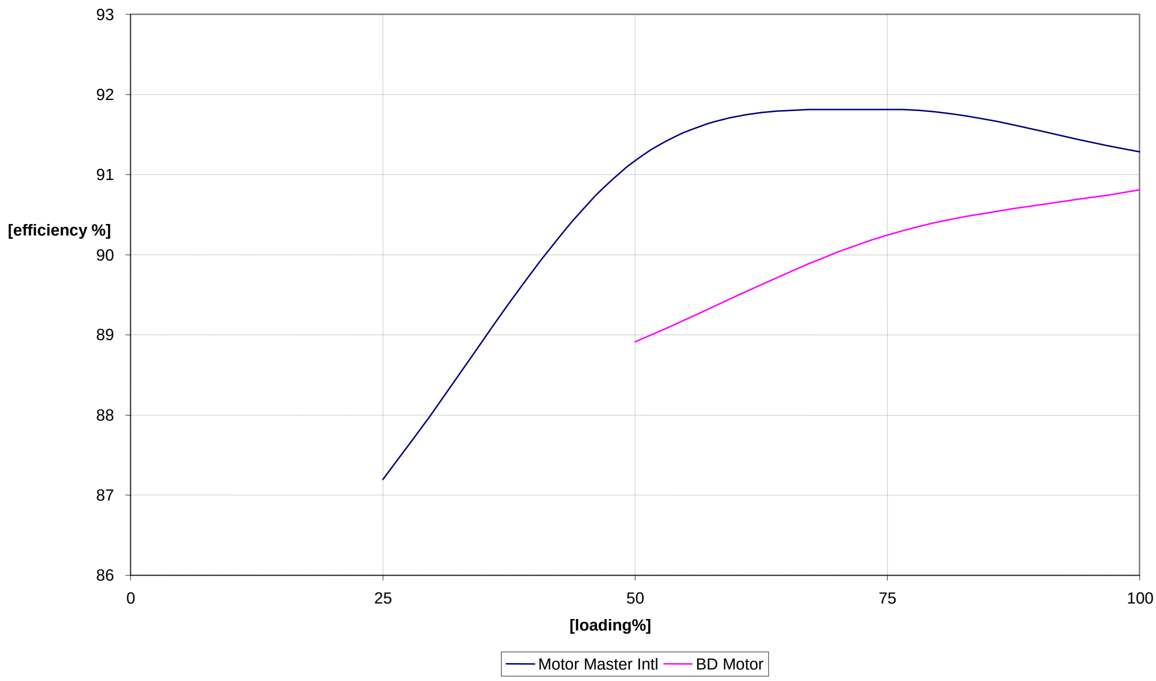
Source: Prepared in-house, based on APEC-ESIS (2003) and BRAZIL (2002).

Figure 10 — Comparison with the USA and Canada – Six Poles

In addition to their rated efficiency, Brazilian motors have a performance curve that differs from that of their North American counterparts, with the flatter part of the Efficiency versus load curve more marked, beginning at 60%, with the maximum efficiency frequently reaching 75% of the load (in contrast to the Brazilian models, which always reach 100%).

Figure 11 presents a comparison between the average efficiency levels of the motors available in the Motor Master International software (ten motors) and BD Motor (nineteen motors) for 20 cv / four pole motors[11]. This aspect is of the utmost importance when considering the operating efficiency, which generally falls below the rated level.

[11] Brazilian manufacturers do not publish estimated efficiency ratings for 25% of the load.



Source: Prepared in-house, based on DOE (2004) and CEPEL (2003)

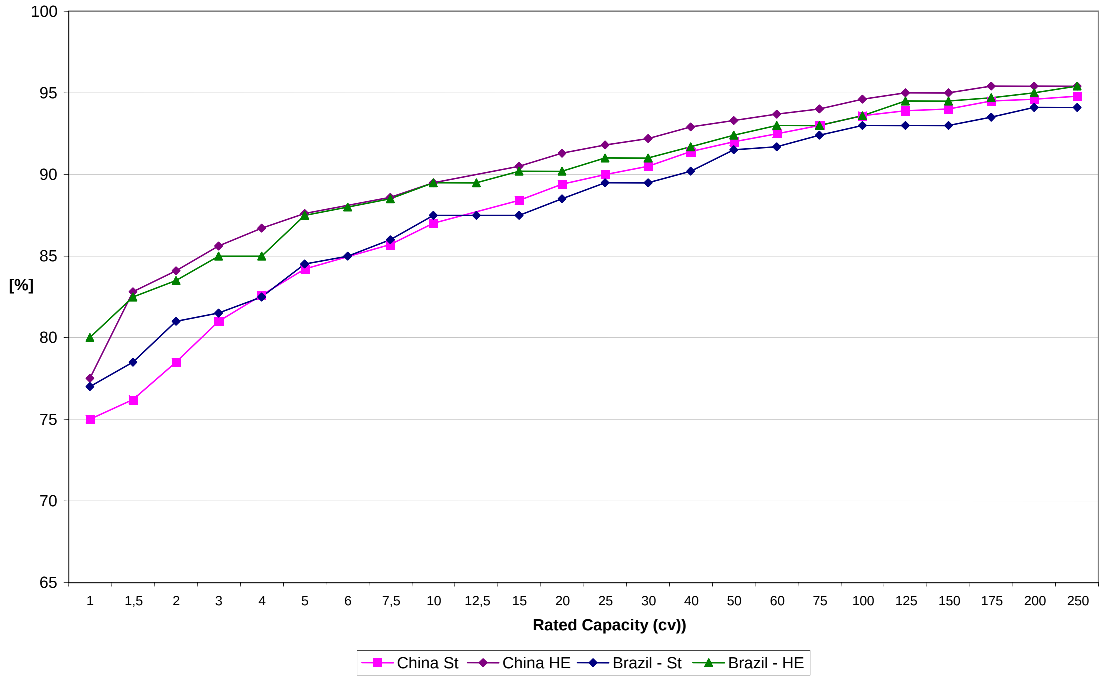
Figure 11 – Average Efficiency for 20 cv / Four Pole Motors

Consequently, the ideal situation would be for the standard to also consider values at 50% of the load.

5.2 China

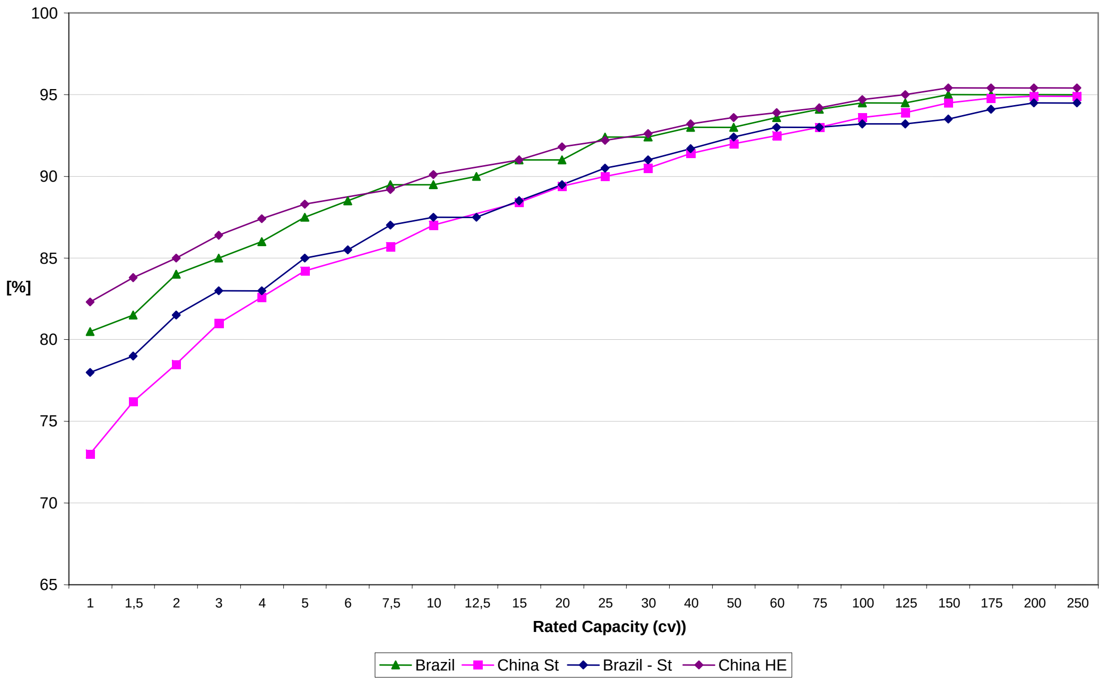
China has mandatory ratings for standard motors and voluntary ratings for high-efficiency motors from 0.75 to 350 cv (0.55 to 315 kW), and for two to six poles. The test procedure is similar to that of the IEC, although the Chinese standard assumes higher stray losses: from 2.5% for smaller motors up to 1.3% for motors over 250 cv.

The ratings in Brazil's New Edict are generally slightly lower than those for China's high-efficiency motors, unless differences in the test method are taken in consideration.



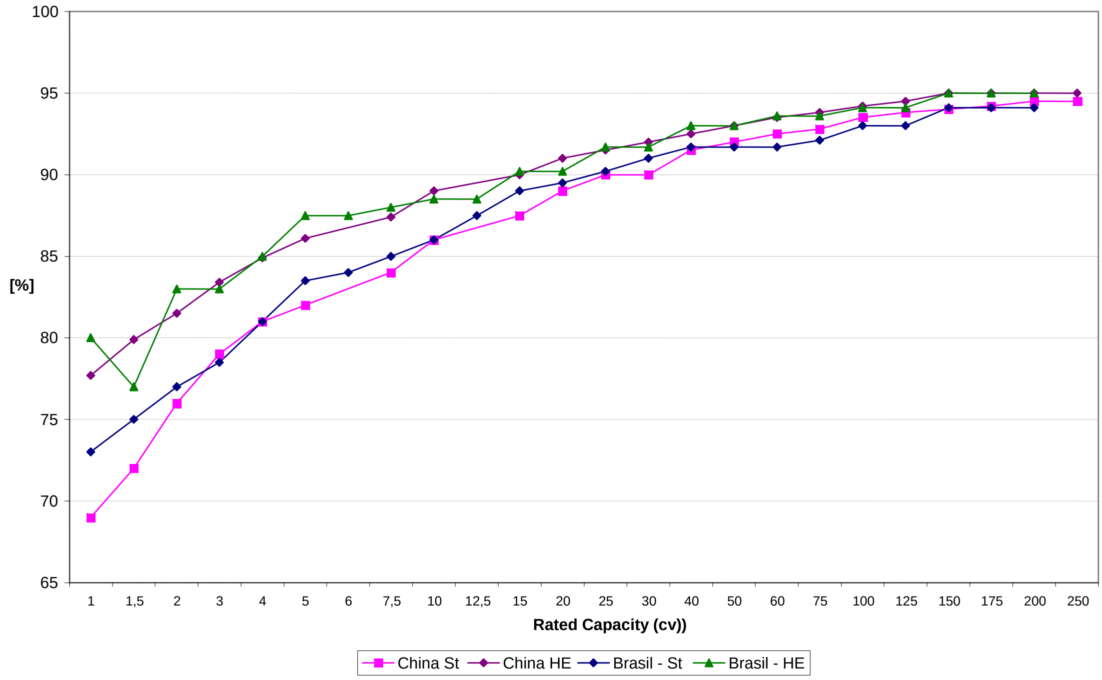
Source: Prepared in-house, based on APEC-ESIS (2003) and BRAZIL (2002).

Figure 12 — Comparison with China – Two Poles



Source: Prepared in-house, based on APEC-ESIS (2003) and BRAZIL (2002).

Figure 13 — Comparison with China – Four Poles

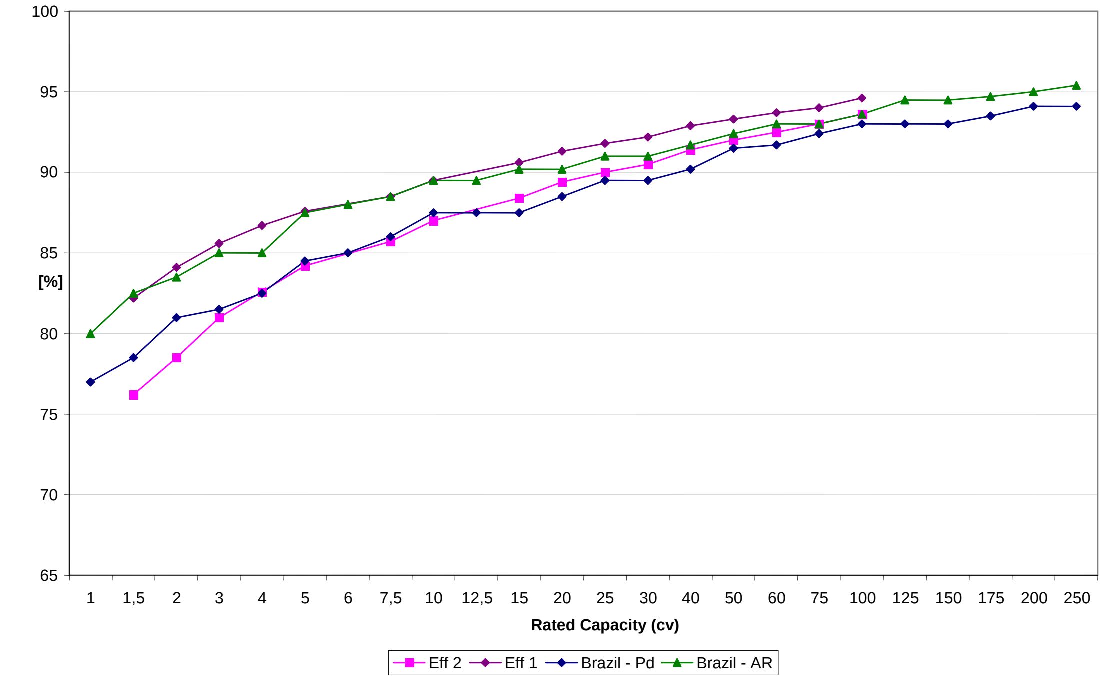


Source: Prepared in-house, based on APEC-ESIS (2003) and BRAZIL (2002).

Figure 14 — Comparison with China – Six Poles

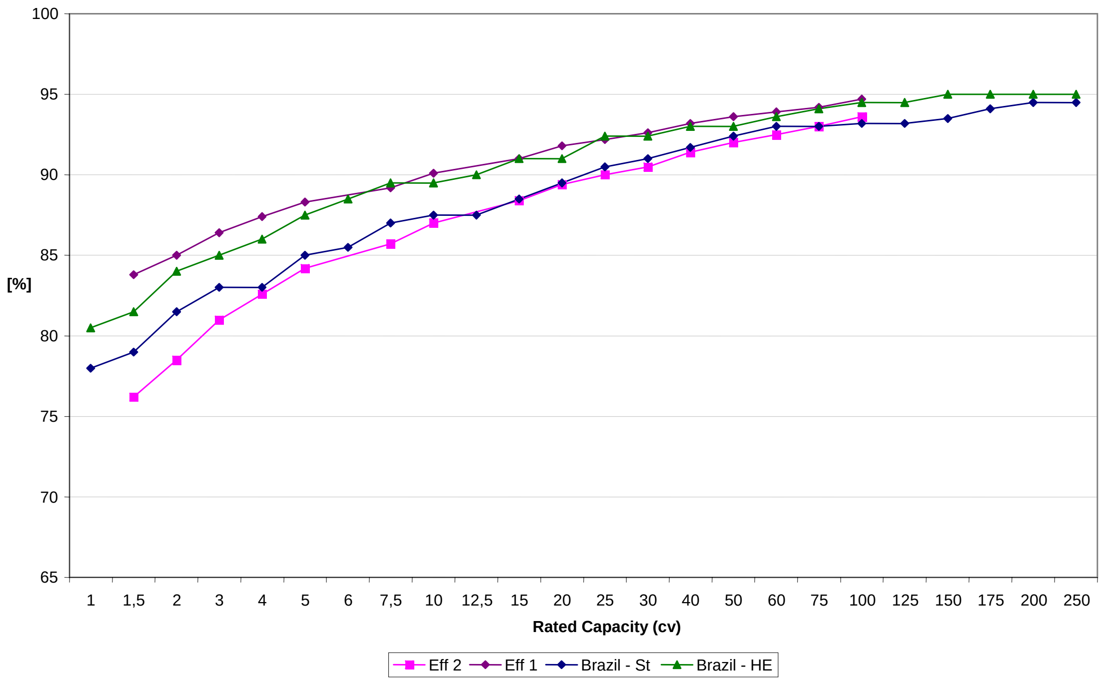
5.3 European Union (and India)

The European Union has three efficiency classes with voluntary compliance called **eff 1** (most efficient), **eff 2** and **eff 3**, for two and four pole motors from 1.5 to 100 cv (1.1 to 75 kW). The power supply voltage is 50 Hz, and the motors are tested according to the IEC test procedure. India also follows this standard for its voluntary standards. Taking the differences in the test methods into account, Brazilian indices are equivalent to the **eff 1** classification.



Source: Prepared in-house, based on APEC-ESIS (2003) and BRAZIL (2002).

Figure 15 — Comparison with Europe – Two Poles



Source: Prepared in-house, based on APEC-ESIS (2003) and BRAZIL (2002).

Figure 16 — Comparison with Europe – Four Poles

6 EXTENSION OF PRODUCTS COVERED TO 500 CV

In this power range (300 - 500 cv), efficiency exceeds 94%, reaching 95% for some units. The users are medium and large industries that generally have engineering structures able to assess the impact of poor efficiency in motors of this size. According to the manufacturers, the high-efficiency motors market consists of large industries with good engineering support, although paying lower electricity tariffs. These aspects lead to the belief that the impact of adopting minimum energy efficiency ratings for motors in this capacity range would not have very significant impacts.

Although impacts on motors from Brazilian manufacturers would be small, an important impact could be prevention of low-efficiency imports. A significant number of low-efficiency imports in this class have been detected by the current INMETRO, program.

Only Weg manufactures high-efficiency motors in this capacity range in Brazil (Kohlbach does not produce them, even in its standard line), although we were unable to access its Price List above 250 cv. The energy gains resulting from the adoption of high-efficiency ratings for motors functioning at rated loading levels ($\gamma = 1$) are presented in Table 7.

Table 7 – Energy Gains for > 250 cv and $\gamma = 1$ Motors

Rated capacity (cv)	Poles			
	2	4	6	8
300	1.0%	0.5%	0.9%	1.4%
350	0.8%	0.9%	0.6%	0.6%
400		0.6%	0.8%	
450		0.7%	1.0%	
500		0.8%		

Source: Prepared in-house.

At half load ($\gamma = 0.5$Table 8) some gains are lower while others are higher – it is noted that motors of this size generally present high loading levels, while also operating intensively**.**

Table 8 – Energy Gains for > 250 cv and $\gamma = 0.5$ Motors

Rated capacity (cv)	Poles			
	2	4	6	8
300	1.1%	0.0%	1.1%	1.1%
350	0.8%	1.4%	1.1%	1.9%
400		0.6%	0.6%	
450		0.4%	0.6%	
500		0.1%		

Source: Prepared in-house.

7 TEST PROCEDURES

7.1 Brazilian Test Procedure

Efficiency determination is not a simple calculation for electric motors. An electric motor is a rotating dynamic system that is generally under load. The tests should be carried out after stabilizing the motor temperature, which requires time and care. Furthermore, electrical readings of volts, amperes, watts and speed are not steady.

Determination of efficiency in Brazil is according to the Brazilian Standard NBR 5383/1:1999 (ABNT. 1999) using Method 2: dynamometric testing with indirect measurement of stray losses and direct measurement of stator losses (I^2R) and rotor losses (I^2R), as well as core losses and losses through friction and windage (ABNT, 1999, page 35).

This method is similar to that described in IEEE – 112:1991, Method B, with the difference that the winding temperature is assessed not through built-in thermocouples but rather through measuring the winding resistance (variation of Method 2, Section 15.4.2, NBR-5383) with the winding temperature used to correct resistance in the I^2R losses calculation.

Efficiency is determined through Equation 3.

$$\eta = \frac{P_{in} - P_{loss}}{P_{in}} \quad \text{.......... Equation 3}$$

During the test, the input and output power are measured, determining the *apparent loss* through subtracting these two figures. The stray loss is then calculated by subtracting other losses from the apparent loss, obtained through direct metering: the I^2R stator and rotor losses, core loss and loss through friction and windage. The stray loss is then corrected, using linear regression to adjust the losses obtained in the various tests at loads of 25%, 50%, 75%, 100%, 125% and 150% of the rated load against the square of the torque in each situation (the correlation factor should be greater than 0.9, and one point can be discarded). The purpose of this procedure is to increase accuracy, assuming that the true value of the stray losses should be closer to the value calculated through this analysis than that obtained through the difference found in the tests. The value obtained in the regression for 100% of the load is that adopted as the stray loss and used to calculate the efficiency.

The test is carried out in the following order: temperature increase, test with rated load to establish the temperature at which the stator and rotor losses will be corrected; test with load at four points, approximately 25%, 50%, 75% and rated load, and two points overload of no more than 150% (125% and 150% are generally used); no-load test (ABNT, 1999, page 36).

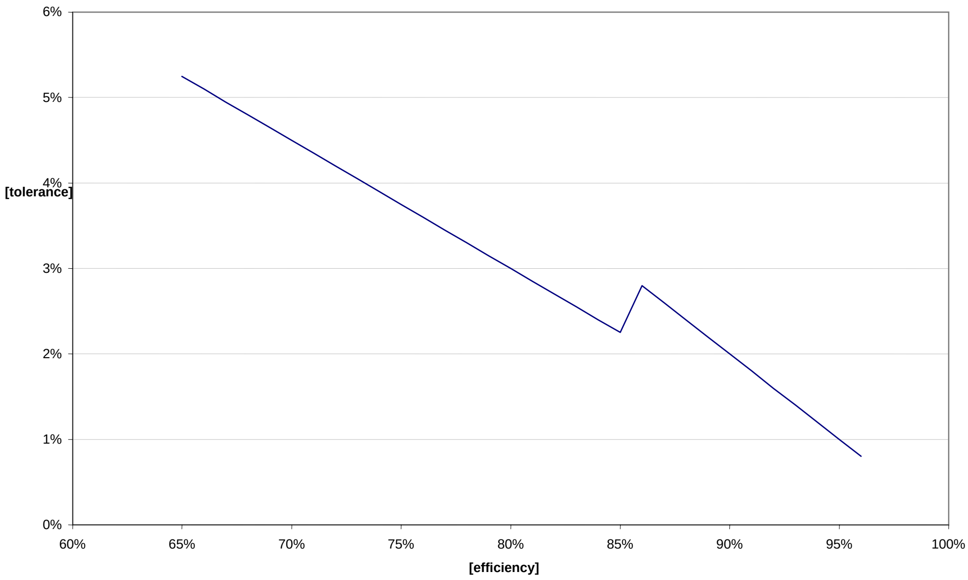
7.1.1 Systematic Confirmation of Efficiency

According to Reinaldo Shindo at the Eletrobras Research Center (CEPEL) who is in charge of motor testing[12], procedures confirming stated efficiency follow the systematization established by the Brazilian Labeling Program (PBE) for motors, in effect since 1993. During the first half year of the Targets Plan, which is reviewed every four years, motors are submitted for tests representing 25% of the available rated powers for two poles, 50% for four poles, 15% for six poles and 10% for eight poles (one motor for each power category). During the subsequent half-years, these figures move to 15% for two poles, 25% for four poles, one unit for six poles and one unit for eight poles. Efficiency levels are then measured and the findings are accepted if they fall within the tolerance range stipulated in NBR 7094:

Range	**Tolerance**
$\eta < 0.851$	$0.15\,(1 - \eta)$
$\eta \geq 0.851$	$0.2\,(1 - \eta)$

These values are presented in Figure 17.

[12] Verbal information provided at a meeting held on March 11, 2005.



Source: Prepared in-house. Based on NBR-7094.

Figure 17 – Efficiency Tolerances – NBR 7094

Should a specific motor fail to meet the minimum required efficiency level, two other units with the same power are requisitioned for tests, and the new final findings will be the average of the three units run through the trials.

In order to upgrade motor quality, the Eletrobras Research Center (CEPEL) also calculates the Measured to Declared Efficiency Gap Index (IAR – *Índice de Afastamento do Resultado*) according toEquation 4:

$$IAR = \frac{\eta_{dec} - \eta_{test}}{tol}\% \quad \text{Equation 4}$$

Consequently, the Measured to Declared Efficiency Gap Index varies from –100% to +100%, when the efficiency is at the lowest acceptable level. The manufacturers have been striving to lower this IAR index.

According to Weg, which exports to several countries, the number of motors tested abroad is far lower than in Brazil. When the international approval tests are run at the plant, the main concern among the certifiers is the acceptance of the plant laboratory that carries out the tests which are attended by inspectors, rather than the quality of the motors tested.

8 FINANCIAL IMPACTS

A major problem in estimating electricity consumption by motors is that consumption depends not only on the operating units, but also the use made of them – **how** they operate (at what loading, altering their efficiency and the power demands) and **when** they operate (hours/year). This is why some estimates of the distribution of these variables must be formulated.

8.1 Sample Analyzed

Based on the sample of motors available in Garcia (2003) of 2,119 motors in eighteen plants, data were obtained when carrying out the energy diagnosis in order to analyze the feasibility of high efficiency motor applications, with location-specific current or motor power measurements being taken. The following data are available for each motor:

Plant	Reference to the Plant where the motor is installed, according to Table 9
poles	Number of motor poles
cv	Rated motor capacity
Ipu	Current metered compared to the motor rating **or**
kW	Metered electric power
h/a	Estimated number of hours in operation p.a. for the motor

The loading for each motor was estimated by the current or measured power values, following the methodology described in Appendix A.

The Plants have the following characteristics:

Table 9 – Plant Characteristics

Plant	Sector*	State	Nº motors	Average Capacity [cv]	Annual Consumption [GWh]
A	Pig iron & steel	RJ	270	84	108
B	Pulp & paper	BA	132	30	17
C	Food & beverages	RJ	339	6	6
D	Chemicals	SP	25	26	2
E	Pulp & paper	PR	292	28	27
F	Chemicals	PR	91	36	9
G	Textiles	RJ	17	31	2
H	Textiles	SP	98	7	2
I	Others	SP	99	31	6
J	Others	SP	55	11	2
K	Textiles	SP	21	13	1
L	Textiles	SP	89	32	9
M	Iron alloys	SP	73	58	14
N	Textiles	SP	335	13	14

Plant	Sector*	State	Nº motors	Average Capacity [cv]	Annual Consumption [GWh]
O	Others	SP	67	80	24
P	Others	SP	13	14	0
Q	Others	SP	53	30	5
R	Others	SP	50	29	6
Total			2,119	31	254

According to the classification in the Brazilian Energy Balance (BEN) issued by the Ministry of Mines and Energy (MME 2002).
Source: GARCIA (2003. pages 78-79).

8.2 Motor Groups

For the purposes of this Report, the motors were clustered as shown in Table 10, following the criteria adopted by the Brazilian Electrical and Electronics Industry Association (ABINEE) which provided data on the number of motors sold over the past few years in Brazil.

Table 10 – Sales of Three-Phase Electric Motors in Brazil

000 Year	Up to 1 cv	Over 1 cv - 10 cv	Over 10 cv – 40 cv	Over 40 cv - 100 cv	Over 100 cv - 300 cv	Over 300 cv	Total
1991	256	465	55	9	3	0.2	789
1992	228	422	58	11	4	0.2	722
1993	236	446	59	11	4	0.3	757
1994	328	538	78	15	5	0.4	964
1995	443	717	99	19	7	1	1,286
1996	357	601	88	18	7	1	1,071
1997	396	712	113	23	10	1	1,255
1998	336	705	133	26	11	1	1,211
1999	355	676	115	22	9	1	1,178
2000	450	770	132	26	10	1	1,390
2001	433	761	133	28	11	1	1,368
2002	403	758	137	28	12	1	1,340
Total	4,222	7,570	1,200	236	94	9	13,330
	32%	57%	9%	1.8%	0.7%	0.1%	100%

Source: ABINEE (2003).

In comparison, Nadel et al. (2003, page 195 *apud*) U. S. Census Bureau. 1989. 1998b) list the motors sold in the USA.

Table 11 – Motor Sales on the US Market

000 Year	Up to 5 cv	Over 5 cv -20 cv	Over 20 cv - 50 cv	Over 50 cv - 100 cv	Over 100 cv - 200 cv	Over 200 cv - 500 cv	Over 500 cv	Total
1989	987	493	146	59	38	8.6	2,6	1,733
1997	1,232	516	175	64	36	18,4	6,1	2,047
	59%	27%	8%	3%	1.9%	0.7%	0.2%	100%

Source: Nadel et al. (2003).

The distribution is very close to that of Brazil, consisting of almost 90% small motors, some 10% intermediate, and the remainder being large motors (with the US market weighted slightly more toward large motors).

8.3 Current Situation

Applying the methodology described in Appendix A and taking the 1997 data for Weg Motors[13] available in BDMotor (2003), the results are presented in Table 12.

Table 12 – Current Situation Sample

	Motors	Rated cv	hours / year	kW	MWh /year	Operating cv	loading	Efficiency
1 cv	204	1.0	5,144	0.7	4.0	0.68	0.68	0.67
Over 1 cv – 10 cv	812	5.4	5,257	2.7	14.5	3.0	0.55	0.80
Over 10 cv – 40 cv	564	23.8	5,980	12.1	72.5	14.5	0.61	0.88
Over 40 cv – 100 cv	427	69.0	7,145	39.2	280.1	48.4	0.70	0.91
Over 100 cv – 300 cv	112	165.2	7,478	97.7	730.3	121.6	0.74	0.92
Total	2,119	31	5,936	17.4	120.3	21.2	0.68	0.90

Source: Garcia (2003).

The columns in Table 12 mean:

Motors	Number of units in each group
Rated cv	Average rated capacity in cv
hours / year	Average hours/year in operation
kW	Average capacity required of the motor
MWh/year	Average annual electricity
Operating cv	Average mechanical power
Loading	Average loading
Efficiency	Average efficiency

The average loading levels are low, as the optimum operating range lies between 75% and 100% of the rated capacity (GARCIA, 2003, page 53). The average loading levels reached 0.61, with the distribution shown in Figure 18. One third of the motors are oversized, with loading of under 50%; another third are also possibly operating at low loads between 50% and 75%, with only a third seeming to be correctly sized.

[13] Manufacturer holding a 75% market share, with an even larger presence in the industrial sector (GARCIA, 2003, page 13-14).

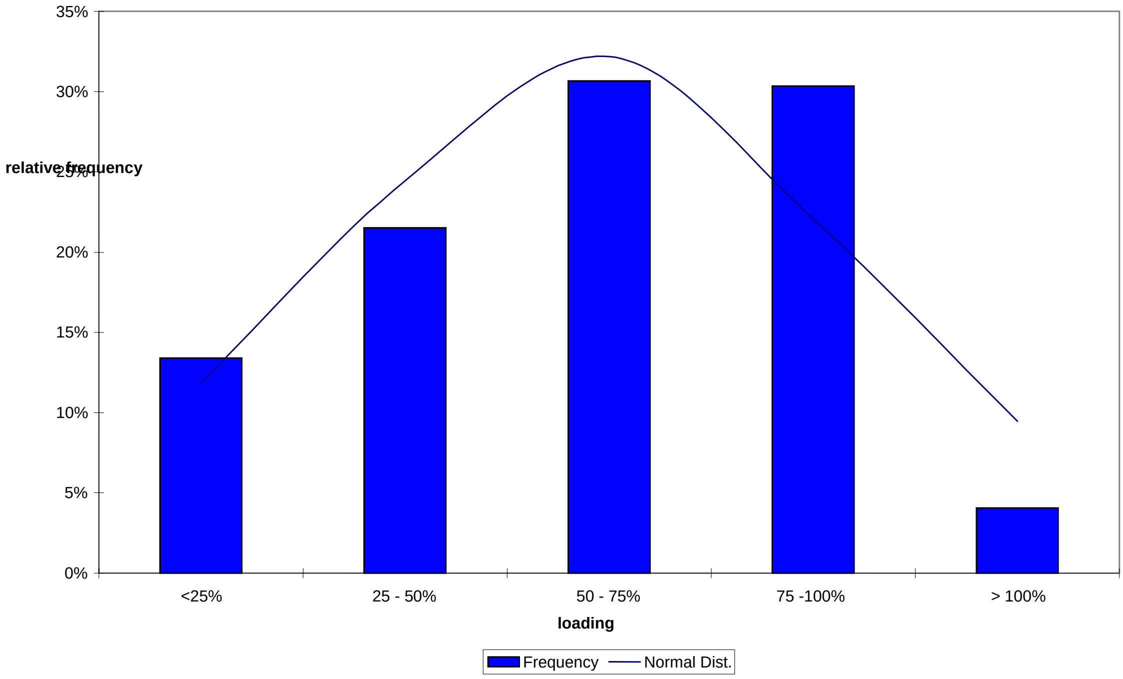


Figure 18 – Loading Distribution

Source: Prepared in-house.

Figure 19 shows the efficiency distribution. With efficiency of under 80%, one third certainly offer good opportunities for more efficient use.

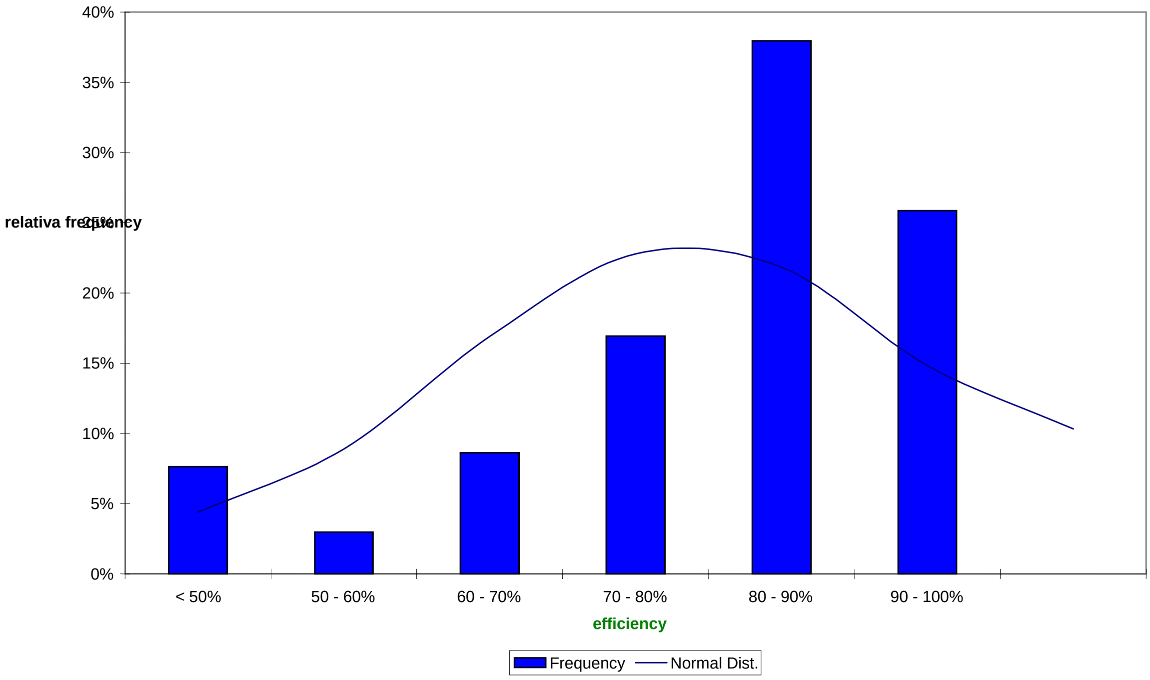


Figure 19 –Efficiency Distribution

Source: Prepared in-house.

If the findings presented in Table 12 are applied to the units sold in Table 10,[14] total motor electricity consumption appears be far higher than that assumed for three-phase motors in Brazil,[15] as shown in Table 13.

Table 13 – Electricity Consumed by Motors in Brazil

	Sample		Population	
	Motors	**MWh/year**	**Motors**	**TWh/year**
Up to 1 cv	204	4.0	4,221,566	17.0
Over 1 cv – 10 cv	812	14.5	7,569,770	109.9
Over 10 cv – 40 cv	564	72.5	1,199,655	86.9
Over 40 cv – 100 cv	427	280.1	236,128	66.1
Over 100 cv - 300 cv	112	730.3	93,674	68.4
Sub-total	2,119	120.3	13,320,793	348.4
Over 300 cv	0	1.112.9	8,760	9.7
Total	2,119	120.27	13,329,553	358.1

Source: Prepared in-house.

This discrepancy may be explained by the following factors:

- The data includes motors installed as components in other equipment (OEM – original equipment manufacturers) sold abroad.
- Motors used by industry are larger than the average for Brazil, and are used more intensively in terms of both loading as well as hours of operation.
- The estimated hours of operation were drawn up in some situations for a preliminary diagnosis of their substitution by high-efficiency motors, and may well be overestimated. Consequently, in some situations, only the larger motors were taken under consideration since they are more attractive for efficiency improvement.
- The average useful life of small motors should be less than twelve years, as in some industries it is common practice not to rewind small units.
- Industries requiring high levels of reliability normally work with two units for the same function, with one in operation and another on stand-by.

[14] Mean/average useful life of twelve years for the motors.

[15] It is estimated that three-phase motors may consume up to 32% of electricity generated in Brazil (MME, 2001, page 23). Applying this to the electricity consumed in 2002 (MME, 2003) gives 111 TWh/year.

- The 32% electricity rating for three-phase induction motors (MME, 2001, page 23) may be underestimated, as mentioned in Section 8.4.

8.4 Comparisons with other Available Samples

Using the 1989 sales data in Table 11 and estimating additional data from other studies, Nadel et al. (2003) drew up the electricity use profile by three-phase electric induction motors in the USA, presented in Table 14 (base: 1997).

Table 14 – Electricity Use Profile for Motors in the USA

	Up to 5 cv	**Over 5 cv – 20 cv**	**Over 20 cv – 50 cv**	**Over 50 cv – 100 cv**	**Over 100 cv – 200 cv**	**Over 200 cv – 500 cv**	**Over 500 cv**	**Total**
Inventory	16,774	9,367	3,208	1,646	1,059	251	76	32,381
	52%	29%	10%	5.1%	3.3%	0.8%	0.2%	100%
Average cv	2.1	11.9	32.5	65.0	135.0	300.0	1,200.0	20.6
Loading	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Efficiency	80.2%	86.8%	90.3%	92.5%	94.3%	95.0%	96.0%	95.4%
hours/year	2,745	3,391	4,067	5,329	5,200	6,132	7,311	
TWh/year	44	162	175	230	294	181	259	1,346
	3%	12%	13%	17%	22%	13%	19%	100%

Source: Nadel et al. (2003. page 197).

Adding this electricity to that consumed by single-phase, synchronous and direct current motors accounts for 59% of end-consumption in the USA. Compared to Table 10, it should be noted that consumption in the USA is ten times higher than in Brazil (taking 32% of the electricity consumed by three-phase motors would give 109 TWh for 2003) for a stock that is only three times larger (and for sales volumes that are not even twice as high – see Table 10 and Table 11). This suggests that the Brazilian sales data may include motors assembled in equipment that is then exported.

A study by Professor Walters is mentioned by APEC-ESIS (2003, page 26) based on another study undertaken for the European Union by Almeida and Fonseca, considering the following operating hours by rated power (with an assumed 75% loading in all cases).

Table 15 – Hours/Year in Operation (APEC-ESIS. 2003)

Rated power	**Hours/year**
1 – 10 cv	1,820
Over 1- cv 100 cv	2,830
Over 100 cv	3,080

As the table implies, a detailed dataset is lacking, even at the international level. Nadel et al. (2003, page 193) remark that “remarkably (...) less is known about the stock, performance and usage of motors than about any other major category of energy-using equipment ”.

8.5 User Viewpoint

By looking at motors manufactured in 2003 and assuming that new motors have the same characteristics as the high-efficiency motors manufactured that year, it is possible to forecast the impact of the new indices contained in the New Edict, even at the economic level.

Each user will see the savings achieved and the investments required (higher price of the new motors) according to each specific distribution of the motors required and the use made of them. In addition to motor-by-motor usage analysis, an attempt is made here to assess the expectations of an average user, according to the sectors under consideration.

It is assumed that new installations and replacements of motors would be with high-efficiency motors, instead of a motor at the 2003 standard level. Aggregate impacts are calculated by weighting the results by the market share mentioned in Table 17 (page 59).

Difficulties in estimating the gains posted by motors arise from the dependency on their operations: loading and hours/year in operation. This section attempts to present a motor-by-motor analysis, regardless of the number of units operating in each rated power and how they are used in the field. Consequently, all the motors listed in Table 2 – Performance Levels under the Energy Efficiency Act are analyzed, consisting of 92 units, made by three manufacturers (Weg, Kohlbach and Eberle), with scenarios of rated loading and half-load ($\gamma = 1$ and $\gamma = 0.5$), and annual operating hours of 8,000 and 4,000 hours/year. These scenarios indicate the limits of the operating system to some extent, which are in fact distributed as described in Section 8.3.

For each case, the operating efficiency levels were calculated for the old and new motors, in addition to the required power, and the gains in capacity, energy and costs, yielding the cost-benefit ratio of the investments as in Equation 5.

$$CBR = \frac{\Pr_{HE} - \Pr_{St}}{P_{rt} \cdot \gamma \cdot 0,736 \cdot \left(\frac{1}{\eta_{St}} - \frac{1}{\eta_{HE}} \right) \cdot h \cdot \frac{C_{ee}}{1000} \cdot \frac{(1+dr)^{ul} - 1}{dr \cdot \left(1+td\right)^{ul}}} \quad \text{................................ Equation 5}$$

CBR	Cost benefit Ratio	[1]
Pr_{St}	Standard motor price	[R$]
Pr_{HE}	High-efficiency motor price	[R$]
P_{rt}	Rated power	[cv]
γ	Load factor	[1]
0.736	cv – kW conversion	[kW/cv]
η_{st}	Standard motor efficiency for loading under consideration	[1]
η_{HE}	High-performance motor efficiency for loading under consideration	[1]
h	Hours in operation per year	[h]
C_{ee}	Electricity cost	[R$/MWh]
dr	Discount rate	[%]
ul	Useful life	[years]

The assumptions used in making the cost-benefit calculation are as follows:

- **Prices**: we worked with the current Weg and Kohlbach Price Lists (March 2005) supplied by the manufacturers, known as the “Full Lists”. Commonly, a discount is given, which varies from 33% to 50%. We therefore considered prices at 65% of the Full List. For the Eberle motors, the BDMotor prices were used. These are close to those considered for the other two manufacturers.
- **Useful Life**: Lifetime is assumed to be a function of the motor rated power, following De Almeida and Fonseca (1996, *apud* APEC-ESIS. 2003, page 26): — 12, 15 and 20 years for motors up to 10cv, 100cv and over 100cv respectively. Many industries generally do not rewind small motors, thus shortening their useful life even more.
- **Efficiency**: the operating efficiency for each loading value was estimated according to the methodology described in Appendix A.
- **Discount Rate**: this variable is hard to determine precisely as it depends on the higher or lower value assigned to the availability of present cash. Motor manufacturers report that the market works with expectations of a simple payback that vary from 1.5 to three years. We considered four discount rate scenarios, as shown in Table 16.

Table 16 – Savings Calculation Scenarios

Scenario	1	2	3	4
Consumer	Industry	Industry	Commerce	Residential
Capital	FINAME	Company	Company	Company
Discount rate	17%	24%	33%	46%

Scenario	**1**	**2**	**3**	**4**
R$/MWh	126.10	126.10	229.17	321.01

Source: Prepared in-house.

At this stage, some remarks are required on this important variable.

The decision-making mechanisms in Brazilian companies that involve financial profitability are more complex than one might assume. The implementation of electrical projects and specific energy efficiency programs, particularly those encouraging equipment substitution, are linked to technical, economic, financial or strategic corporate aspects that are important, as they shape the future of the company. The past is an indicator that allows trends to be identified, but investment decisions should be based mainly on future earnings expectations.

In Brazil, analyzing the future profitability of a project through only one stand-alone financial indicator may be unreliable. In order to assess the expected payback of an action, it must be compared with other actions in its sector, with the market average, or with other assets offering similar risk levels. In this report, which has the aim of evaluating the viewpoint of a motor user for a market offering motors with various efficiency levels, the discount rate makes a marked contribution to the findings reached in the analysis of consumer investment decisions.

In order to determine the payback period for an investment in motors, the analyst estimates the current economic value of the equipment and its expected cash flow for the useful life of the item. This cash flow – in this case the amount of savings that the higher-efficiency motor should generate in the future – is assessed for a significant number of years. This type of study requires the analyst to have a number of other parameters available, in addition to those used for the financial mathematics calculations. To mention only the main aspects, the analyst must know or be able to estimate: sales, prices, market share, competition, cost behavior, working capital requirements, investments in fixed assets and growth levels. These and other factors will forecast corporate cash flow, indicating what is expected to be achieved through investments over a given period. Future gains must then be brought up to present value.

Some companies opt for simple payback method to calculate the payback time of an investment, meaning that they do not bring the cash flow up to present value based on a discount rate. It is believed, however, that the use of simple payback may result in inconsistent findings.

The discount rate is a special instance of an interest rate. An interest rate must be defined that correctly represents the value of money over time. To define this interest rate, the analyst must draw close to the maximum economic scenario for the market segment in question and the relevant country, while also knowing the specific corporate risks. The discount rate is proportional to the risk that the company offers the investor. The higher the risk, the higher this discount rate. Consequently, Brazilian investors weigh the expected efficiency of a project by the complexity and magnitude of the financial indicators found on the domestic market, which in Brazil translates into applying high discount rates.

The market interest rate has a marked influence on the estimated discount rate values. Factors that may affect interest rate estimations include: risk and uncertainty, inflation, project duration or planning horizon, preference for liquidity, capital productivity and the specific stance of the investor.

Difficulties in estimating discount rates for this study consist mainly of the lack of information and conflicting data on the actual discount rate used in the motors market, the estimated risks foreseen by the companies, and the complexity of Brazil's macro-economic situation. Consequently, it was decided to use the average rates for the Brazilian market and the power sector to calculate the cost benefit ratio from the user standpoint, as well as for comparisons with investments in expanding the power grid.

- **Electricity cost**: we took the average rates (in R$/MWh) for 2004 (ANEEL. 2004): industry – 126.10; commerce – 229.17 and residential – 263.23 (in this sector, a non-transferable ICMS tax of 18% was taken under consideration, increasing the tariff seen by the consumer to R$ 321.01/MWh).

- **Market**: the following manufacturer market shares were used:

Table 17 – Market Shares Used

Manufacturer	Eberle	Kohlbach	Weg
Share	10%	10%	80%

8.5.1 Scenario 1 – Industry (FINAME)

8.5.1.1 Scenario Description

For industry, motor substitution was considered in two situations: initially, in order to expand capacity, when a loan is normally sought from Brazil’s National

Economic and Social Development Bank (BNDES)[16]. This development bank finances the acquisitions of machinery and equipment through the FINAME Machinery and Equipment Financing Fund, whose rates are generally lower than those offered by commercial banks on the financial market.

The composition of the FINAME interest rate is: Financial Cost + BNDES Remuneration + Remuneration for the Accredited Financial Institution.

- Financial Cost

The basis of the financial cost is the Long Term Interest Rate (TJLP) which has developed over the past few years as shown in Table 18.

Table 18 — Long Term Interest Rate Development (% p.a.)

Period	**2003**	**2004**	**2005**
January - March	11.0	10.0	9.75
April - June	12.0	9.75	9.75
July - September	12.0	9.75	
October - December	11.0	9.75	

Source: Brazilian Institute for Geography and Statistics (IBGE). 2005

- BNDES Remuneration
  - Individuals: 1% p.a.;
  - Micro, small and medium enterprises: 1% p.a. .;
  - Large corporations: 2.5% - 4% p.a.;
  - Direct Civil Service: 2.5% p.a.
- Remuneration of Accredited Financial Institution

This is negotiated between the accredited financial institution and the customer; for transactions guaranteed by the Competitiveness Promotion Guarantee Fund (FGPC) which provides surety for loans: up to 4% p.a.

Consequently, interest rates would reach some 16.75% for small enterprises and 20% for large corporations, depending on the financial analysis undertaken by the BNDES.

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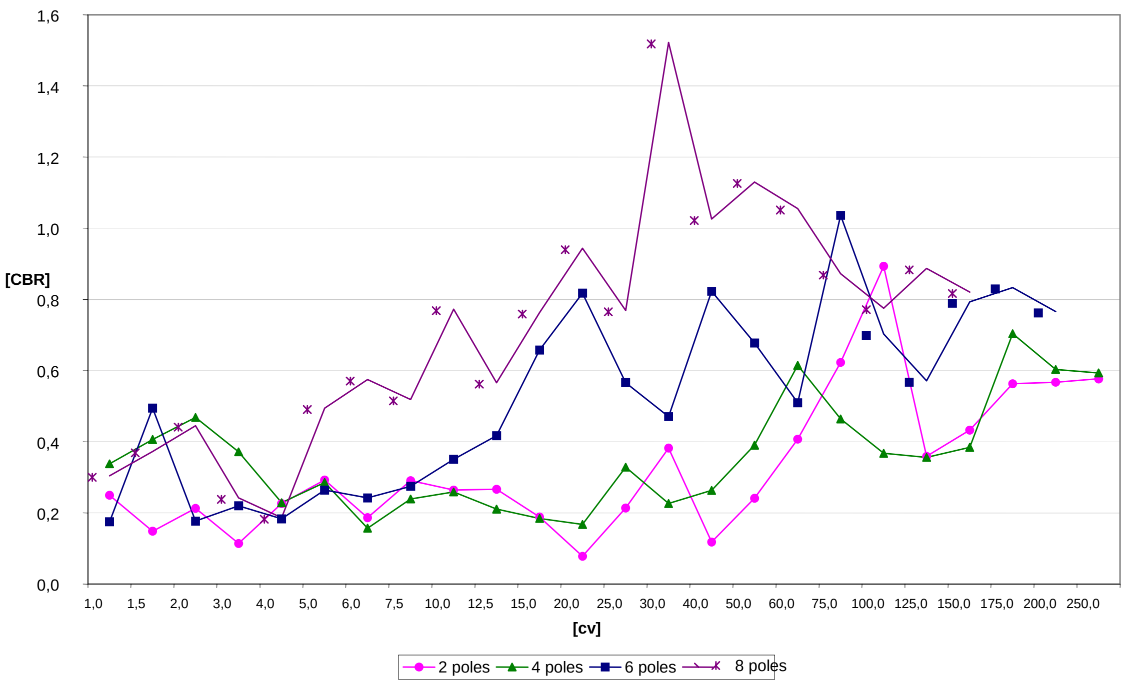
[16] Brazil's National Economic and Social Development Bank (BNDES) is a formerly autonomous Federal entity established by Law N° 1,628, on June 20, 1952, which was classified as a Federal Government enterprise whose corporate status is established under private law, with its own assets, by Law N° 5,662, dated June 21, 1971. The BNDES is an entity linked to the Ministry of Development, Industry and Foreign Trade, whose purpose is to provide backing for enterprises that foster the development of Brazil. These actions help endow the Brazilian economy with a keener competitive edge while enhancing the quality of life of its people (www.bndes.gov.br).

Another option for investors is to opt for a commercial bank, which may require less paperwork, although with higher capital costs. Loans taken out under the leasing system or as Direct Consumer Credit are available at rates of 1.87% per month to 2.24% per month, translating into annual values of around 22.4% and 26.88%, for financing over a period of 36 or 48 months. Credit analyses are based mainly on company revenues, with the bank assessing the potential indebtedness of the enterprise and checking the investment risk specifically for each company.

It is stressed that the interest rate serves as a reference for investors, with other variables being taken under consideration when deciding on profitability levels.

8.5.1.2 Motor-by-Motor Analysis

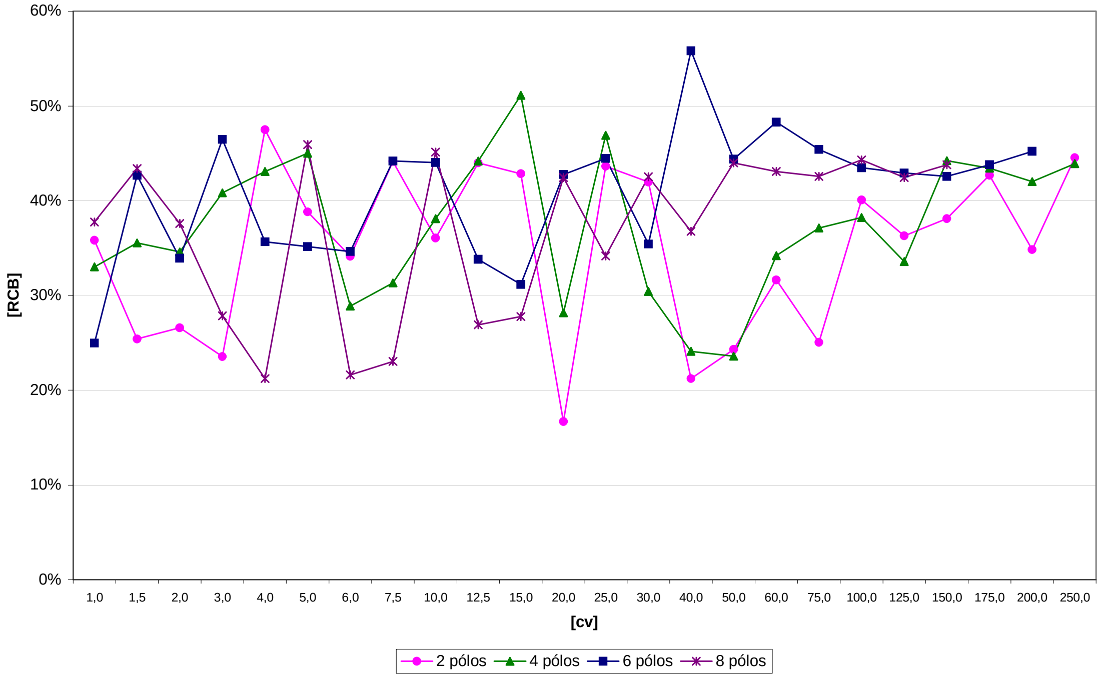
When considering the rated load and intensive operations (8,000 hours/year), almost all the motors present a favorable cost-benefit ratio (less than 1) as shown in Figure 20, except for some of the six and eight pole motors (speeds which are less widely used).



Source: Prepared in-house.

Figure 20 – Cost-Benefit Ratio for γ = 1 and 8,000 Hours/Year

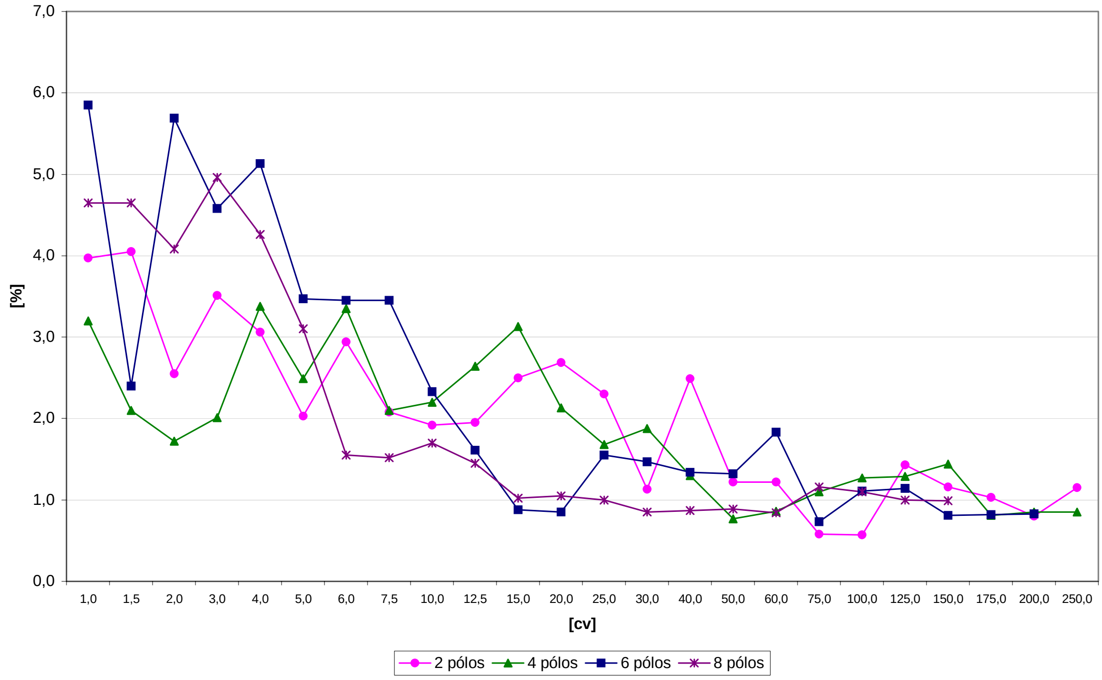
The price variations hover around 40%, varying little by power rating, as shown in Figure 21. However, marked price variations are found for some motors (such as 5 cv, eight poles) compared to nearby powers, not explained by corresponding gains in efficiency.



Source: Prepared in-house

Figure 21 – % Price Variation

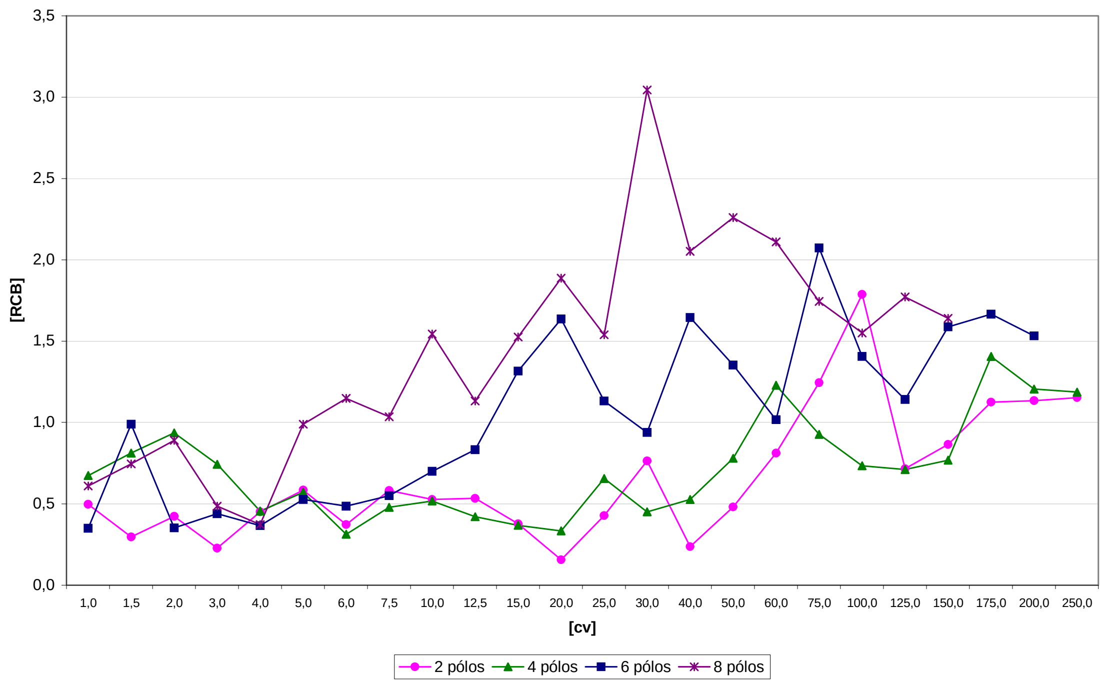
In contrast, gains in efficiency were lower for larger motors, explaining the rise in Cost-Benefit Ratios with rated power – see Figure 22.



Source: Prepared in-house

Figure 22 – % Gains in Rated Efficiency

Figure 23 shows the situation for unit loading and partial operation (4,000 hours/year). The Cost-Benefit Ratios for low power and two and four poles presented the most favorable results. At high power, the situation is not as favorable, and many cases are also not favorable for slower speed (6 and 8 pole) motors.

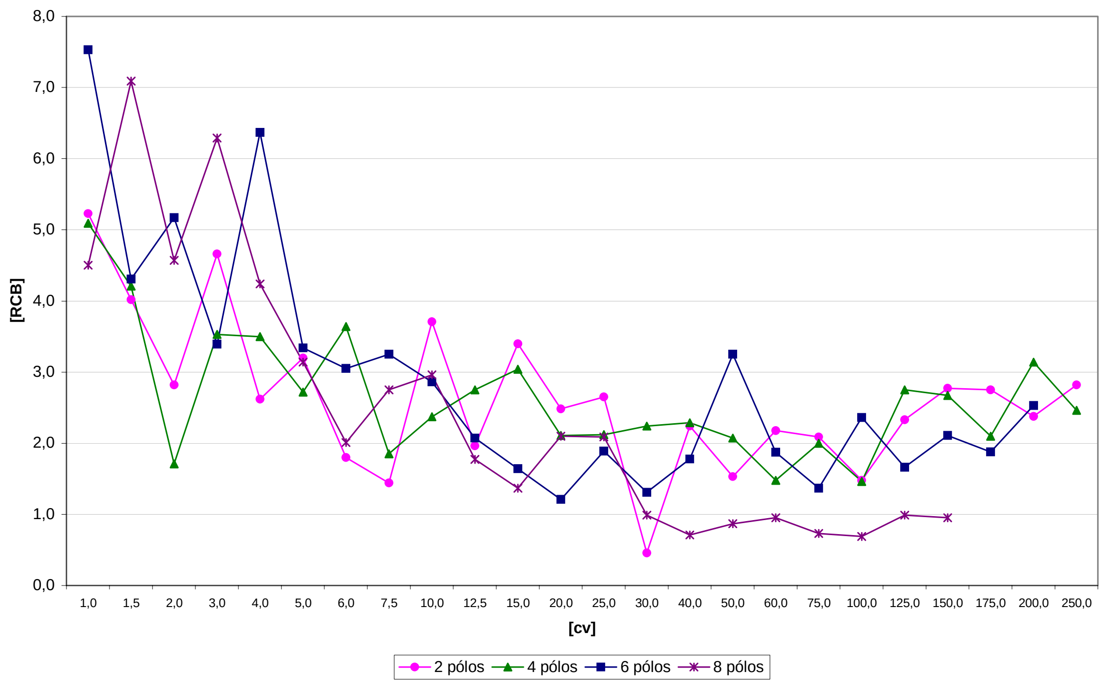


Source: Prepared in-house.

Figure 23 — Cost-Benefit Ratio for γ = 1 and 4,000 Hours/Year

The Cost-Benefit Ratio curves (loading at 1 and 0.5) have the same shape, although the half load curve is shifted upwards. Consequently, some medium and high power motors are not attractive for substitution. The six and eight pole motors (less used) are the least attractive, while the two and four pole motors hover around the boundaries of attractiveness at high powers.

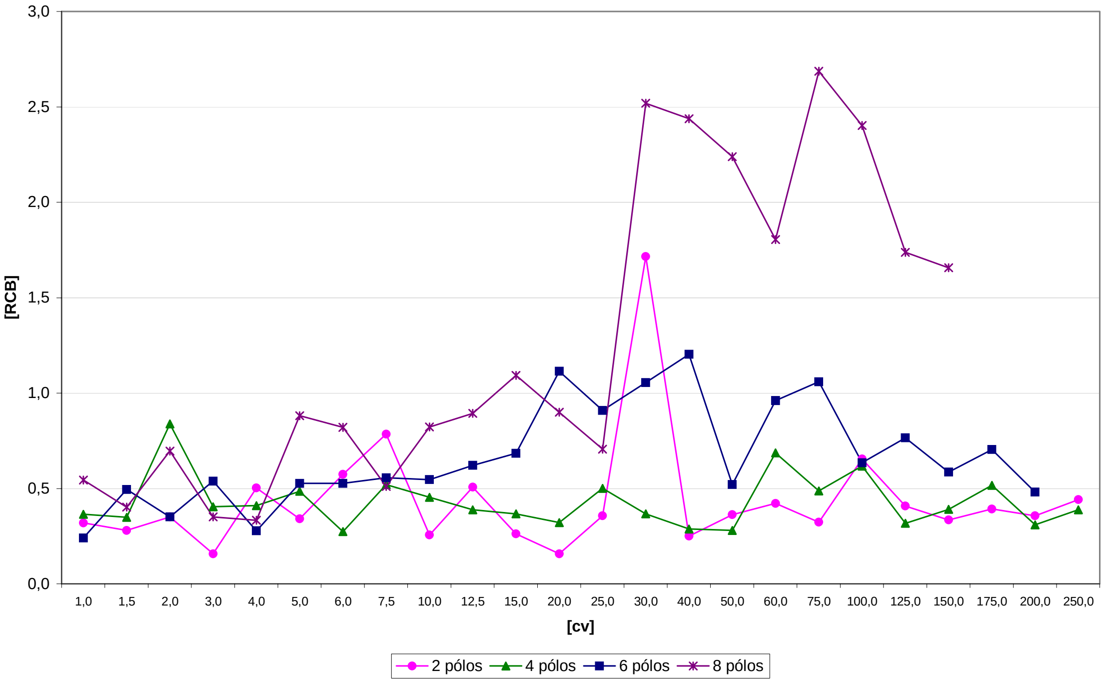
The situation grows worse for lower loadings, although gains in efficiency are generally higher, as shown in Figure 24.



Source: Prepared in-house.

Figure 24 – Gains in Efficiency for γ = 0.5

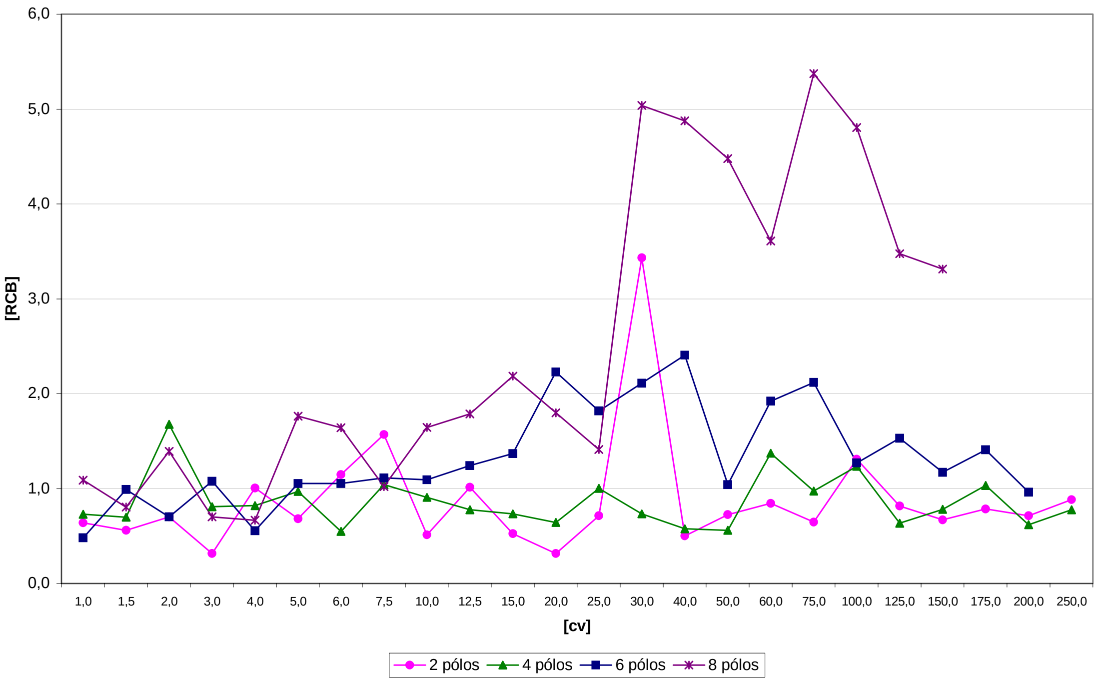
Figure 25 shows the behavior of motors operating at half-load at intensive operating levels (8,000 hours/year). Substitution is feasible for the two and four pole motors, with a single exception, while the six and eight pole motors present several unfavorable situations, particularly at high power.



Source: Prepared in-house.

Figure 25 — Cost-Benefit Ratio for γ = 0.5 and 8,000 hours/year

Finally, it is noted that some of the four pole motors already fulfill the acceptability limits for loading for 0.5 and 4,000 hours/year in operation – Figure 26.



Source: Prepared in-house.

Figure 26 — Cost-Benefit Ratio for γ = 0.5 and 4,000 hours/year

Tables B-1 and B-2 in Appendix B summarize the cost-benefit ratio values found. For the six and eight pole motors, substitution is not cost effective in most cases due to the large incremental cost of efficiency for these motors. For two and four pole motors, the situation is favorable in most cases, except for those with low duty factor. It is worthwhile noting that for motors working below the rated load, the efficiency vs. loading curve is just as important – or even more so – than the rated efficiency, which makes the half-load situation very different from its rated load counterpart.

8.5.1.3 Analysis of the "Average Consumer"

An analysis by motor group presents the gains shown in Table 19.

Table 19 – Gains with the New Edict – Industry (FINAME)

	Rated cv	Hours/ year	kW	MWh/ year	Efficiency	Savings	Investments	Gains	Cost-Benefit Ratio	R$/ MWh
Up to 10 cv	4.5	5,234	0.1	0.4	2.5%	228	146	81	0.6	81
Over 10 cv – 40 cv	23.8	5,980	0.3	1.5	2.0%	1,037	530	507	0.5	64
Over 40 cv – 100 cv	69.0	7,145	0.6	4.0	1.3%	2,710	1,531	1,179	0.6	71
Over 100 cv – 300 cv	165.2	7,478	1.6	12.2	1.6%	8,688	4,398	4,290	0.5	64
Average	31.1	5,936	0.3	2.0	1.6%	1,390	752	638	0.5	69

Source: Prepared in-house.

The cost-benefit ratio is well below the acceptable level of cost-benefit ratio, meaning that substitution is feasible with FINAME loans.

8.5.2 Scenario 2 – Industry (Company capital)

8.5.2.1 Scenario Description

A second scenario considers the replacement of motors using company capital. While varying among sectors, the sector discount rate is a well-kept secret. As estimated, an interest rate is used that is slightly above that charged by a commercial bank for working capital financing: 22.75% as shown in Figure 27.

Interest (% p.a.)		**Daily Var.**	**Future Interest**		**April 7**	**April 8**
Interbank Dep.Certs,	19.22%	0.00	DI-MAY (mat.May 1, 05)_		19.28%	19.31%
Swap Pre x DI (1 month)	19.35%	0.04	DI -JUL (mat.Jul 1, 05)_		19.44%	19.54%
CBD 30 days	19.22%	0.10	DI -OCT (mat.Oct 1, 05)		19.48%	19.64%
CBD 62 days	19.35%	0.14	DI -JAN (mat.Jan 3, 05)		19.34%	19.53%
Working capital	22.75%	-1.05	**Bradies**	**PU**	**Spread**	**Daily %**
ACV (% p.m.)	3.73%	0.31	C-Bond	99.64	364	-0.05%
Hot Money (% p.m.)	2.51%	-0.01	EI	100.13	93	-0.41%
Discount Dup.Invs (% p.m.)	1.95%	0.06	Brazil Par	90.50	224	-0.57%
Stock Exchanges		**Daily %**	**International**			**Daily Variation**

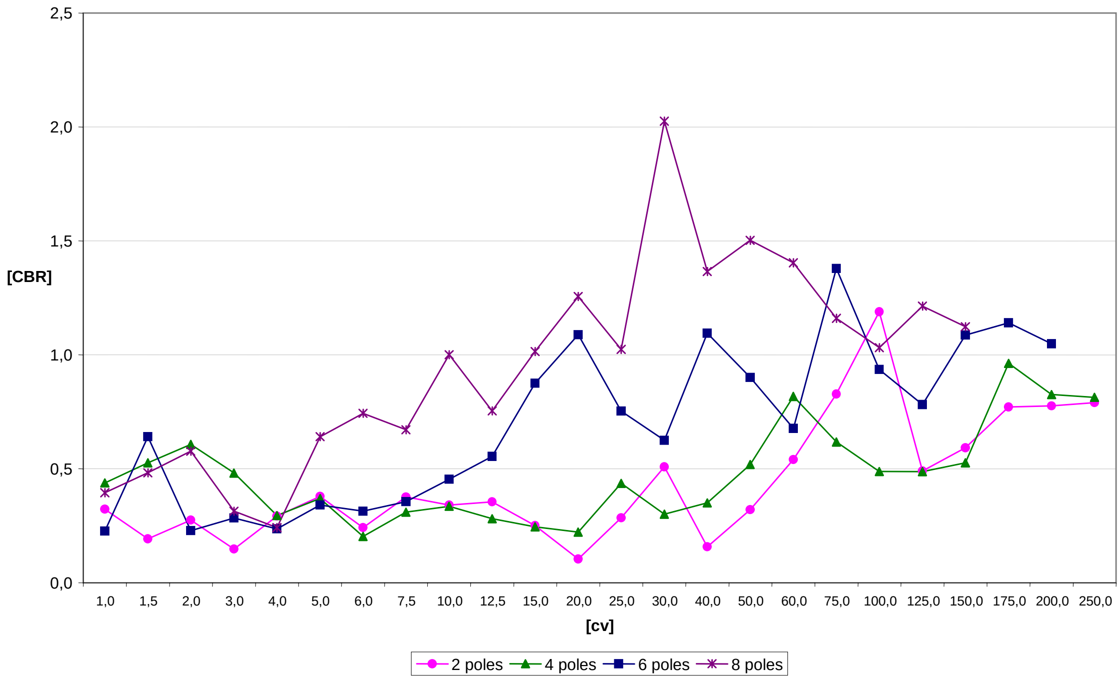
SP St.Ex.Index IBOVESPA	25,885	-1.61%	US-T bond 30 years %	4.76%	-0.63%
Dow Jones (points)	10,461	-0.81%	Yen/US$	108.26	0.34%
NASDAQ (points)	1,999	-0.96%	US$/Euro	1.2931	0.57%
Foreign Exchange		**Daily %**	**Future Foreign Exch.**	**Rate**	**Projected Deval.**
Commercial Rate	2.586	-0.39%	May (for last day April)	2.607	-2.22%
			Jun (for last day May)_	2.635	1.07%
Tourism Rate	2.710	-0.74%	July (for last day June)	2.670	1.33%
Note: All prices quoted for April 8, 2005					

Source: Banco Itaú (Available at http://www.itau.com.br. Accessed on April 9, 2005) – Daily Analysis.

Figure 27 – Interest Rate on April 8, 2005

8.5.2.2 Motor-by-Motor analysis

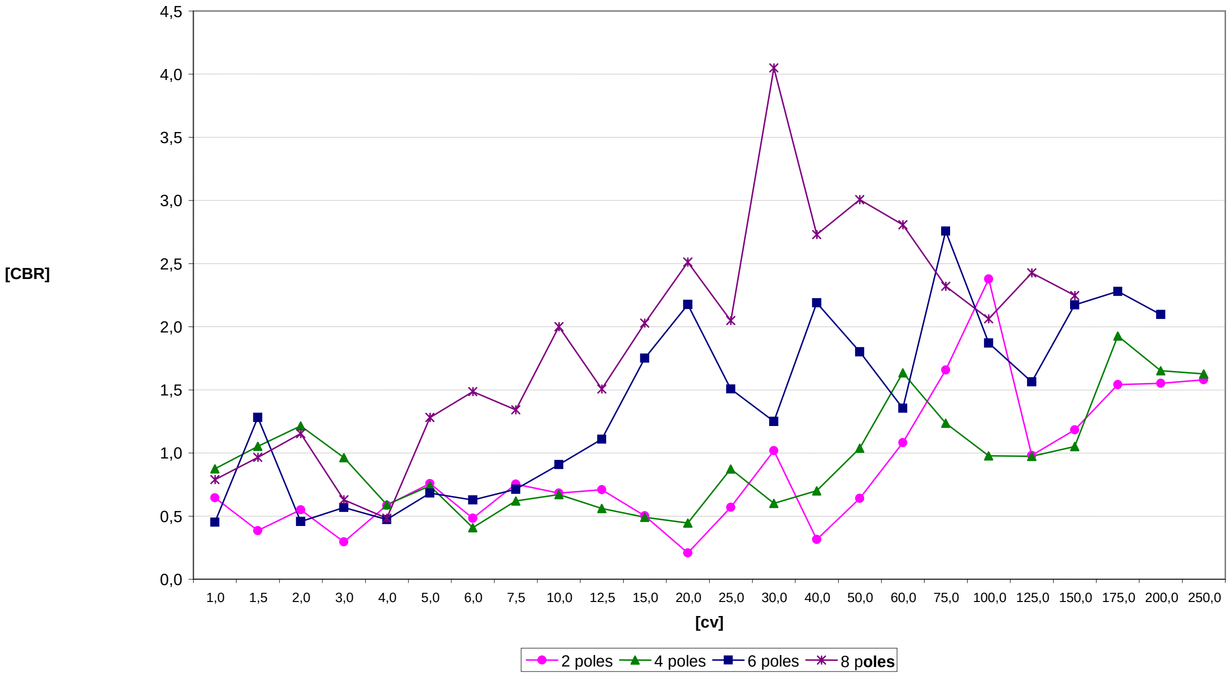
At rated load and intensive operations (8,000 hours/year) the two and four pole motors still remain within the feasible range, with a single exception. However, most of the eight pole motors are already beyond consideration, as well as many of the six pole models.



Source: Prepared in-house.

Figure 28 — Cost-Benefit Ratio for γ = 1 and 8,000 Hours/Year

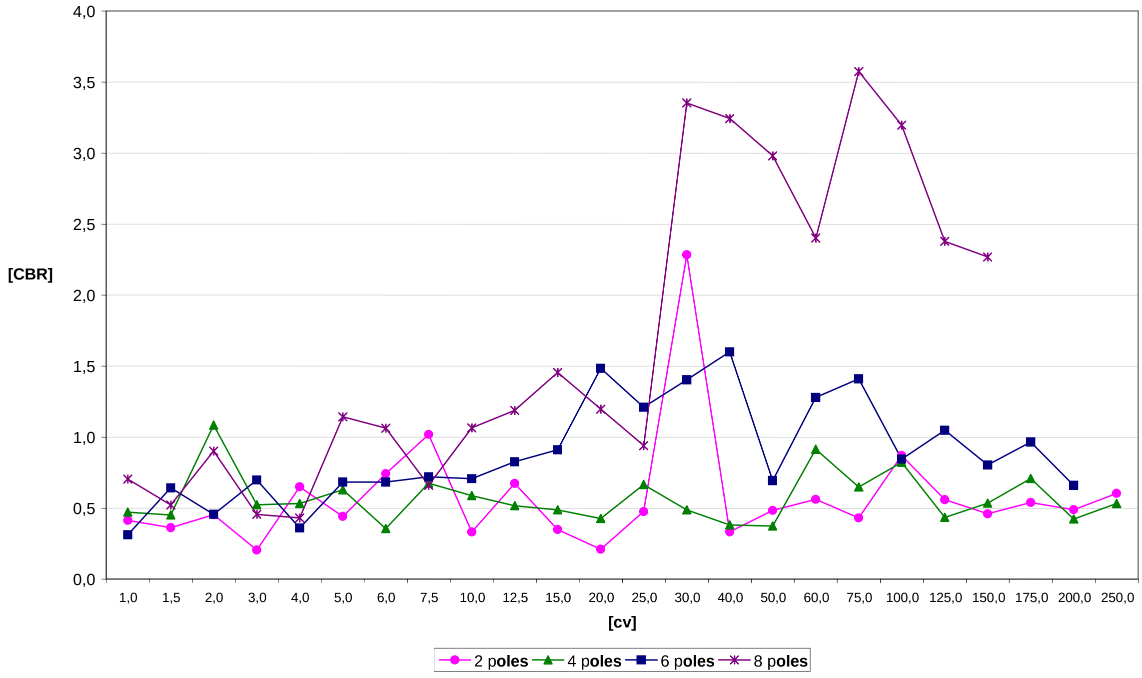
Figure 29 presents the situation for unit loading and partial operations (4,000 hours/year). Many motors no longer offer any advantages for substitution, particularly at high capacity, and in all cases the high rotation motors present better findings than their slower speed counterparts.



Source: Prepared in-house.

Figure 29 — Cost-Benefit Ratio for γ = 1 and 4,000 Hours/Year

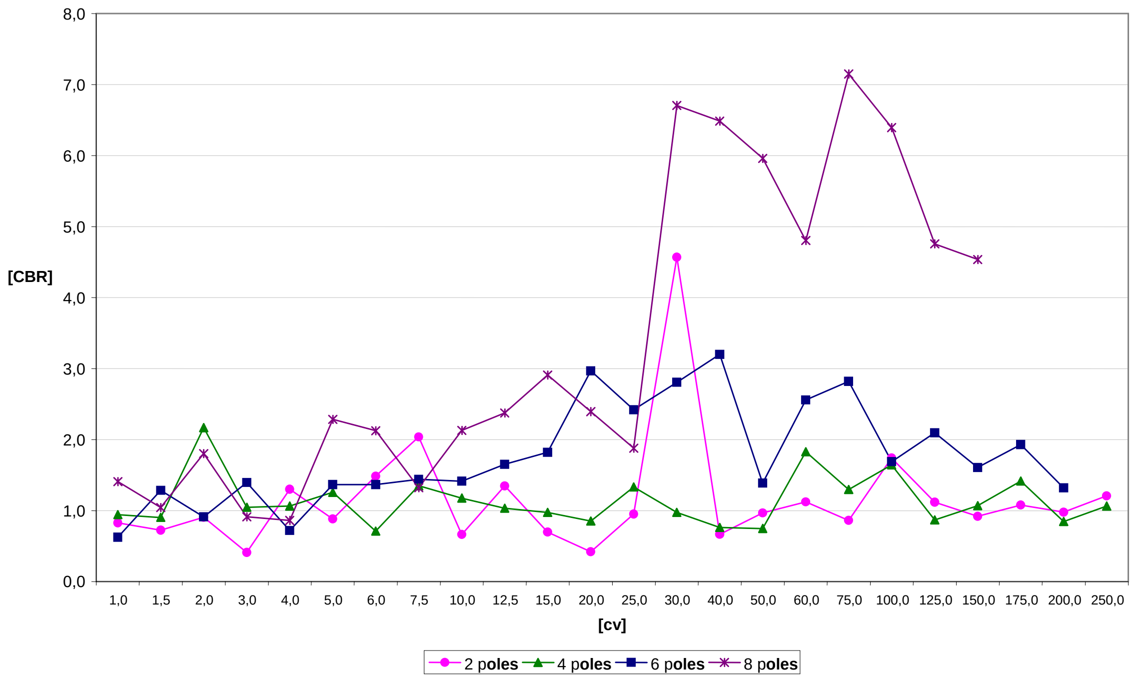
Figure 30 presents the half load situation at intensive operations (8,000 hours/year). The two and four pole motors remain feasible for substitution, with a few exceptions. However, the six and eight pole motors in particular are unfavorable in several situations, particularly at high power.



Source: Prepared in-house.

Figure 30 — Cost-Benefit Ratio for γ = 0.5 and 8,000 Hours/Year

Only half of the high rotation motors remain within the acceptability limits for loading at 0.5 and 4,000 hours/year in operation – Figure 31.



Source: Prepared in-house.

Figure 31 — Cost-Benefit Ratio for γ = 0.5 and 4,000 Hours/Year

Tables B-3 and B-4 summarize the cost-benefit ratio found. There are few opportunities for the six and eight pole motors, while the situation is not favorable for two and four pole models in some cases. It is worthwhile noting that, for motors working below the rated load, the efficiency x loading curve is just as important or more than the rated efficiency, which makes the half-load situation very different from the rated load situation.

8.5.2.3 Analysis of the "Average Consumer"

The analysis by group of motors presents the gains shown in Table 20.

Table 20 – Gains with the New Edict – Industry (Company)

	Rated cv	hours/ year	kW	MWh/ year	Efficiency	Savings	Investments	Gains	CRB	R$/ MWh
Up to 10 cv	4.5	5,234	0.1	0.4	2.5%	176	146	30	0.8	105
Over 10 cv – 40 cv	23.8	5,980	0.3	1.5	2.0%	779	530	250	0.7	86
Over 40 cv – 100 cv	69.0	7,145	0.6	4.0	1.3%	2,037	1,531	505	0.8	95
Over 100 cv – 300 cv	165.2	7,478	1.6	12.2	1.6%	6,346	4,398	1,948	0.7	87
Average	31.1	5,936	0.3	2.0	1.6%	1,038	752	285	0.7	92

Source: Prepared in-house.

The cost-benefit ratio remained within the acceptability limits, with substitution consequently being feasible, on average.

8.5.3 Scenario 3 – Commercial Sector

8.5.3.1 Scenario Description

In order to offer examples of practical cases of financing equipment substitution, it was decided to present the experience of Brazil's Small Business Bureau (SEBRAE)[17] in the energy efficiency field. The Rio de Janeiro branch of the Small Business Bureau (SEBRAE) and the German Technical Cooperation Agency (GTZ) implemented a project in Rio de Janeiro focused on Conserving Energy for Small and Medium Enterprises in Rio de Janeiro. This project lasted ten years and established several demonstration units whose main purpose was to present the results and experiences built up through this project. This practical experiment carried out with the commercial sector provided feedback for a better understanding of the economic logic guiding

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[17] Brazilian Small Business Bureau – (SEBRAE - *Serviço Brasileiro de Apoio às Micro e Pequenas Empresas*) (http://www.sebrae.com.br).

small-scale businessmen investing in energy efficiency. The case studies presented in this Report portray the experience of three commercial segments: red-clay pottery, tire retreaders and bakeries. The main modifications found in the companies were generally designed to lower fuel consumption in the red-clay pottery sector, and reduce electricity consumption in the others. To do so, these businessmen substituted equipment, seeking more efficient counterparts, with positive impacts on their productivity. The technology used by these enterprises is certainly quite unconnected with the topic of this study – three-phase motors – but the economic payback logic is the same for the potteries, the retreaders and the merchants (considering the investment capacity of each company individually) as for motor users. Consequently, based on the empirical case studies included in the experience of Brazil's Small Business Bureau (SEBRAE) it is noted that the Internal Rate of Return (IRR) for these projects varied between 29% and 233%, reflecting the need for payback on investment over extremely short periods. Consequently, a rate of 33% was adopted for the commercial sector, which is generally far lower than that achieved through energy efficiency projects implemented by the Small Business Bureau (SEBRAE) in Rio de Janeiro (WIPPLINGER & WITTWER, 2003).

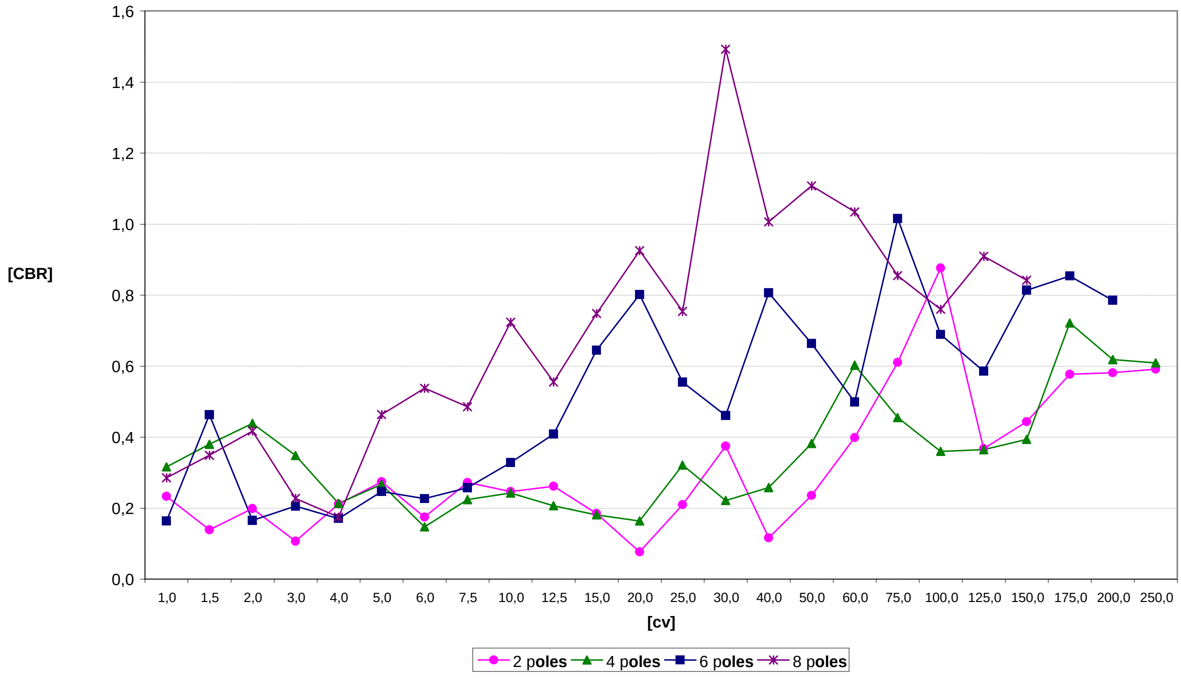
Table 21 – SEBRAE / Rio de Janeiro – Investments in Energy Efficiency

Sector	Company	Investments	Savings		IRR
Pottery	Tijolar	117,600.00	5 years	274,433.00	233%
	R. P. Pessanha	227,000.00	1st year	59,822.00	29%
			5 subsequent years	94,681.00	
	Argibem	1,163,673.00	1st year	2,000.00	-1%
			5 subsequent years	220,373.00	
Retreader	Itaipava	18,180.00	5 years	19,344.00	103%
	BR Campos	43,000.00	5 years	21,600.00	41%
Bakery	Sta Terezinha de Ramos	12,000.00	5 years	12,000.00	97%
	Estrela do Brasil	6,800.00	5 years	7,776.00	112%
	Danúbio Azul	13,000.00	5 years	5,678.00	33%

Source: Wipplinger and Wittwer. 2003.

8.5.3.2 Motor-by-Motor Analysis

Compared to industry, the higher electricity costs paid by commercial customers offset the higher discount rate to a certain extent, and the situation is quite similar, as shown in Figure 32 for rated power and intensive operations situations. Consequently, the situation is more favorable for the user, as small motors, which are more attractive, predominate in commercial enterprises, although they tend to be used less intensively.



Source: Prepared in-house.

Figure 32 — Cost-Benefit Ratio for γ = 1 and 8,000 Hours/Year (Commercial Sector)

8.5.3.3 Analysis of the "Average Consumer"

As we have no samples available for this sector, we used the existing sample, commenting on the findings, which are presented in Table 22.

Table 22 — Gains with the New Edict — Commercial Sector

	Rated cv	hours/ year	kW	MWh/ year	Efficiency	Savings	Investments	Gains	CBR	R$/ MWh
Up to 10 cv	4.5	5,234	0.1	0.4	2.5%	243	146	97	0.6	138
10 cv - 40 cv	23.8	5,980	0.3	1.5	2.0%	1,058	530	528	0.5	115
Over 40 cv – 100 cv	69.0	7,145	0.6	4.0	1.3%	2,764	1,531	1,233	0.6	127
Over 100 cv – 300 cv	165.2	7,478	1.6	12.2	1.6%	8,474	4,398	4,076	0.5	119
Average	31.1	5,936	0.3	2.0	1.6%	1,403	752	651	0.5	123

Source: Prepared in-house.

The situation is slightly more favorable, for small motors as well, which are more widely used in this sector. However, it is probable that they are less intensively used, which will tend to boost the cost-benefit ratio.

8.5.4 Scenario 4 – Residential Sector

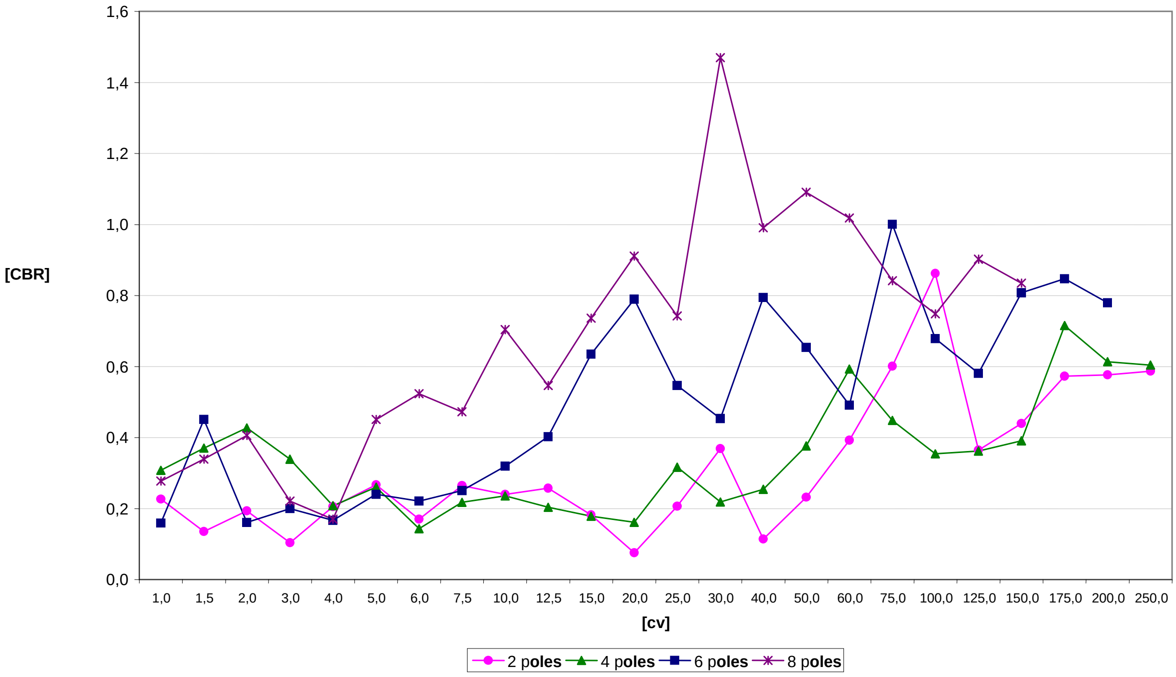
8.5.4.1 Scenario Description

In this sector the rates charged by a commercial bank (Banco do Brasil) for financing the purchase of household appliances (46%) were adopted, as follows:

Banco do Brasil Household Appliance Credit:
Amount Requested : R$ 1,000.00
Monthly Interest Rate : 3.21%
Annual Interest Rate : 46.10%

8.5.4.2 Motor-by-Motor Analysis

In the residential sector, the situation of the commercial sector is reproduced almost completely, as the higher tariff price offsets the increase in the discount rate, as shown in Figure 33.



Source: Prepared in-house.

Figure 33 — Cost-Benefit Ratio for γ = 1 and 8,000 Hours/Year (Residential Sector)

8.5.4.3 Analysis of the "Average Consumer"

Using the same sample, the findings presented in Table 23 were obtained.

Table 23 — Gains with the New Edict — Residential Sector

	Rated cv	hours/ year	kW	MWh/ year	Efficiency	Savings	Investments	Gains	CBR	R$/ MWh
Up to 10 cv	4.5	5,234	0.1	0.4	2.5%	250	146	104	0.6	188
Over 10 cv - 40 cv	23.8	5,980	0.3	1.5	2.0%	1,074	530	544	0.5	158
Over 40 cv - 100 cv	69.0	7,145	0.6	4.0	1.3%	2,807	1,531	1,276	0.5	175
Over 100 cv - 300 cv	165.2	7,478	1.6	12.2	1.6%	8,539	4,398	4,141	0.5	165
Average	31.1	5,936	0.3	2.0	1.6%	1,423	752	671	0.5	170

Source: Prepared in-house.

The situation in the residential sector is very similar to that in the commercial sector, with a higher tariff and a discount rate that is also higher. On the other hand, it is worthwhile noting that the loading and operations in this sector tend to be even lower.

This leads to the conclusion that, based on the assumptions presented, from the standpoint of the “aggregate” or “average” user, the application of the high-efficiency motor indices to all units will be positive from the financial standpoint. However, as this is an average case study, there will be situations above the average that will result in losses, while others will be lower, offering financial advantages.

8.6 Overview of Brazil's Electrical System

This section compares the investments required to extend Brazil's national grid with the savings achieved through reducing consumption by boosting motor efficiency through the New Edict.

Auctions are scheduled for this year to purchase “new” electricity, with the prices to be paid being solidly grounded. As these data are not available, a study by Schaeffer and Szklo (Energy Policy, 2001) was used, which lists the various power plant costs. Two types of power plants are taken under consideration, operating at the system base (high capacity factor): a medium-capacity hydro-power plant that is 500 kilometers away from the consumption point, and a thermo-power plant whose turbine is driven by natural gas, 100 kilometers away. The data taken under consideration and the calculations are presented in Table 24.

Table 24 – Energy Cost for New Power Plants

		Hydro-Power Plant	Natural Gas Processing Unit
Capital cost	US$/kW	1.230	495
Capacity factor	1	0.55	0.9

		Hydro-Power Plant	Natural Gas Processing Unit
O&M	US$/MWh	1.54	7
Fuel	US$/MWh	0	18
Useful life	Years	30	10
Discount rate	%	12%	12%
Transmission	US$/kW/kkm	180	180
Capacity factor	1	0.6	0.6
Losses	%	10%	5%
Distance considered	Kms	500	100
Useful life	Years	20	20
Generation cost	US$/MWh	33.23	36.11
Transmission cost	US$/MWh	2.55	0.48
Total cost	US$/MWh	35.78	36.59
	R$/MWh	98.04	100.27

Source: Prepared in-house based on Schaeffer and Szklo (Energy Policy, 2001).

Taking this discount rate used for expanding Brazil's national grid, the cost of electricity saved drops significantly, as shown in Table 25.

Table 25 – Cost of Energy Saved (Discount Rate = 12%)

	hours/year	kW	MWh/year	Investments	R$/MWh
Up to 10 cv	5,234	0.1	0.4	146	65
Over 10 cv - 40 cv	5,980	0.3	1.5	530	50
Over 40 cv - 100 cv	7,145	0.6	4.0	1,531	56
Over 100 cv - 300 cv	7,478	1.6	12.2	4,398	48
Average	5,936	0.3	2.0	752	54

Source: Prepared in-house.

The cost is 45% lower than a medium-sized hydro-power plant (380 MW) and 46% lower than a thermo-power plant fueled by natural gas (230 MW), even with efficiency at 50% and a capacity factor of 0.9. No less significant are the environmental impacts avoided – in the case of thermo-power, the avoided carbon emissions would reach some 55,000 tons/year.

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