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Energy Efficiency and Smart Grids for Low Carbon and Green Growth in Brazil

Knowledge Sharing Forum on Development Experiences: Comparative Experiences of Korea and Latin America and the Caribbean

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Executive Summary

The Brazilian continental dimensions and diversified natural resources are proportional to the challenges to develop its infrastructure sustainably and supply proper public services to more than 200 million inhabitants. Energy consumption has doubled since 1990, fostered by economic growth and the expansion of middle class. In this context, promote energy efficiency, in a broad sense, is urgent and rational.

Brazil has a relatively long history in promoting energy efficiency at final user level. A landmark of this process is the Brazilian Labeling Program, launched in 1984, as direct consequence of high prices of energy at that time. This program was coordinated by the National Institute of Metrology, Standardization and Industrial Quality, which sets standards for evaluation, ranks the performance of energy equipment and imposes a classificatory labeling to inform consumers, with a label similar to other countries. The National Electricity Conservation Program was created in 1985 by the Ministry of Mines and Energy (Ministério de Minas e Energia, MME) and is executed by ELETROBRÁS. The energy saving induced by this program in 2013 is equivalent to 2.1% of the total electric energy consumption in the period, corresponding to the annual energy consumption of about 5 million Brazilian households. In 2001, Federal Law 10,295, also known as the Energy Efficiency Law, was approved to reinforce those energy efficiency programs, allowing the Brazilian government to establish Minimum Energy Performance Standards for appliances and energy equipment, prohibiting the commercialization of low efficiency models and promoting the progressive withdrawal of low-efficiency models. According to the National Energy Plan 2030, up to 15.5 GW of electricity generation could be saved as a result of energy efficiency in the next 20 years.

The Smart Grids, adopting modern technologies in electricity distribution has been proposed in Brazil to improve the quality provided in the low voltage service, reduce losses, and reduce operating costs, among others. Several regulations related to this subject, dealing with grid connection for distributed small-scale generation, the establishment of the "hourly tariff", with the regulation of the use of PLC, and with the compulsory use of Geographic Information System. Currently, dozens of pilot projects on Smart Grids are underway in the country. Two projects are presented in detail: CEMIG and AES Eletropaulo, two Brazilian power utilities.

1. Introduction: Brazil at a Glance

The Brazilian continental dimensions, approx. 8.5 million km^2, correspond to an ample base of natural resources and proportional challenges to develop its infrastructure sustainably and supply proper public services to more than 200 million inhabitants (2013 estimate, IBGE, 2013), mostly living in urban areas. The economy is also relevant: the Gross Domestic Product (GDP), about US$2.246 trillion in 2013 (World Bank, 2014), places Brazil among the largest economies in the world. However, it has relatively high levels of inequality for a middle-income country, as confirmed by the rather slow reduction of the Gini index. There is also high asymmetry in regional development; the South, Central West and Southeast regions are richer, and the North and Northeast are poorer. Table 1 presents some basic indicators for Brazil, indicating the evolution observed during the last decades.

Table 1 Socioeconomic Indicators for Brazil

Indicator	**1990**	**2000**	**2010**
Population (total, million)*	149.6	174.5	195.2
Urban population (% of total)*	73.9	81.2	84.3
Child mortality rate, infant (per 1,000 live births)*	51.6	29.1	14.5
Life expectancy at birth, total (years)*	66.5	70.2	73.1
Literacy rate, adult total (% of people ages 15 and above)*	79.9	86.4	90.4
Improved sanitation facilities (% of population with access)*	79.2	82.8	86.3
Human Development Index (according to UNDP methodology)**	0.590	0.669	0.726
GDP per capita (constant 2005 US$)**	3,999	4,406	5,618
Poverty headcount ratio at $1.25 a day (PPP) (% of population)***	25.6	n.d.	8.4
Gini index*** (evaluates inequality, higher means more unequal)	0.611	0.606	0.526

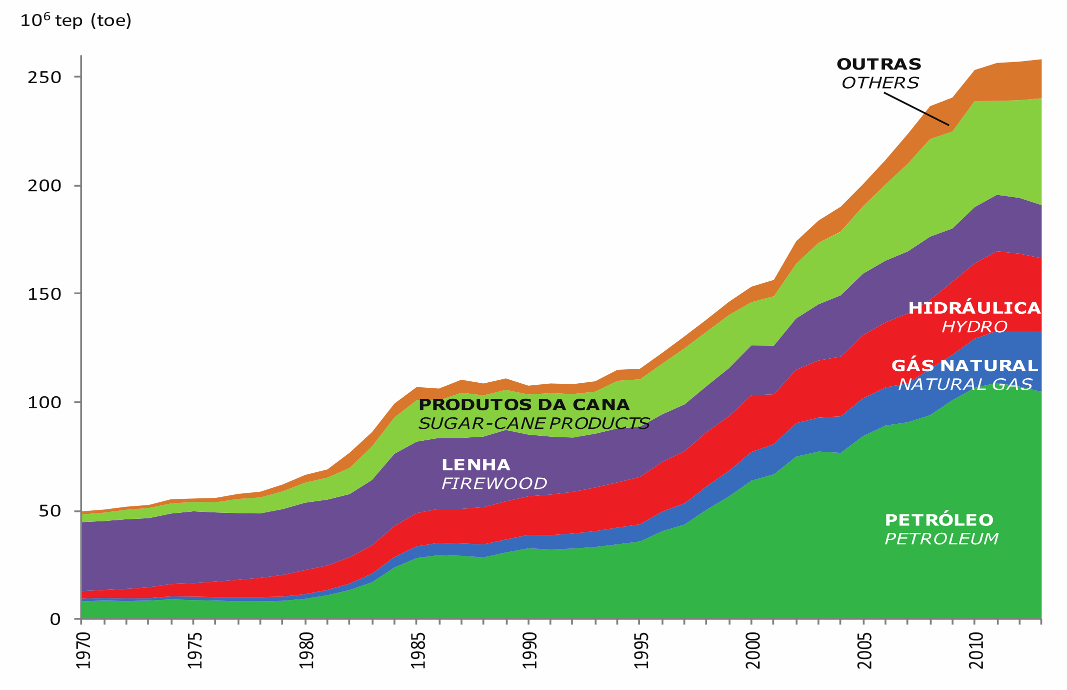
Source: *IBGE, 2014; **UNDP, 2013 and ***World Bank, 2014

The Brazilian economy is diversified, with a relevant extractive industry (mining and processing of iron, aluminum, manganese, tin, oil, natural gas, etc.), active agriculture (soy, corn, sugarcane, rice, coffee, orange and fruits, poultry and beef, etc.), wide-ranging processing and manufacturing industry (agroindustry, food and beverage, textiles, shoes, chemicals, cement, lumber, steel, aluminum, motor vehicles and parts, aircraft, machinery and equipment, home appliances), and tertiary sector (commerce, banking, services, transport, telecom, etc.). Thus, the Brazilian GDP is composed by the contribution from agriculture (5.2%), industry (26.3%) and services (68.5%). Some additional data completes this brief appraisal of the Brazilian economy:

in recent years (2010 to 2012), 74 million ton of cereals were produced annually, 22 million tons of meat, 48 million tons of steel, 63 million tons of cement, 20 million tons of paper and paperboard, 7.8 million household refrigerators and 2.9 million passenger cars (BRICS, 2013 and IBGE, 2014).

In 2013, the total primary energy production in Brazil reached 258.3 million tons of oil equivalent (toe) and the total energy consumption was 260.2 million toe, which means virtually self-sufficiency. Although, imports of electricity and oil products occurred as well as biofuels and petroleum were exported. In the same year, 46.4% of the total energy produced and 41.0% of the energy effectively supplied came from renewable sources, mostly from sugarcane and hydropower (EPE, 2014). Related to the population, the total domestic energy supply (production + imports), 296.2 million toe in 2013, corresponds to about 1.48 toe/capita, relatively near to the world average observed in 2010, 1.88 toe/capita (UNDATA, 2015). Figure 1 depicts the evolution of the energy supply in Brazil, highlighting the recent increase of oil and natural gas production, related to significant discoveries made on the continental shelf, and the relevant share of renewable sources.

Figure 1 Primary Energy Production in Brazil



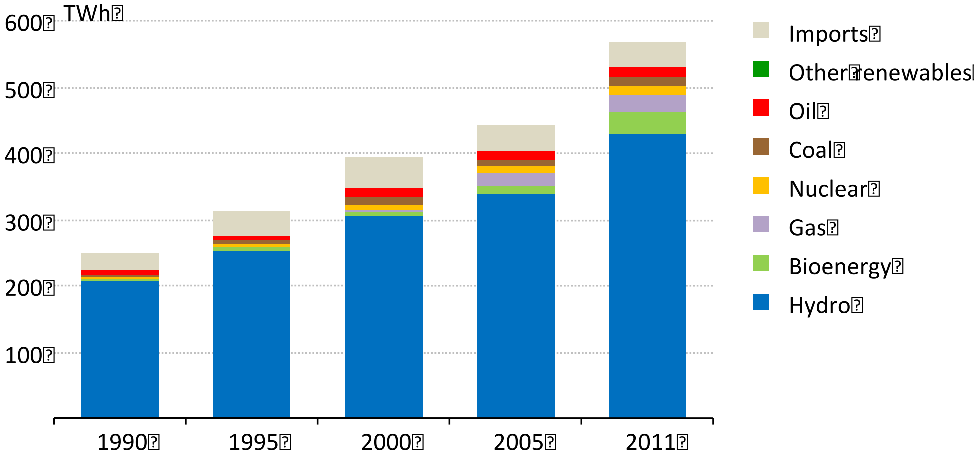
Source: EPE, 2014

In December 2014, the installed capacity for electricity generation in Brazil reached 138.7 GW, including public service and self-producers plants. Of this total, one third corresponds to hydropower plants, and 28.1% to thermal plants (9% fuelled with biomass, mainly sugarcane bagasse and black liquor, in cogeneration systems installed in sugarcane mills and pulp and paper plants), 3.6% to wind power plants and the balance (1.8%) using nuclear and solar energy (ANEEL, 2015). This distribution is in line with the natural resources available: the total potential of hydropower in Brazil is estimated at about 252 GW (not including small hydropower plants), of which just 30% is currently exploited (EPE, 2008). However, most of the available potential is located in Amazonia, far from the main load centers.

The annual generation of electricity by Brazilian power plants in 2013 was 570 TWh, 85% from public service units, which was complemented by independent generators. An additional 40 TWh, almost totally produced with hydropower, was imported from neighboring countries: Paraguay (which operates the bi-national 14 GW Itaipu Dam jointly with Brazil), Argentina, Venezuela and Uruguay. Losses related to transmission and distribution are estimated at 93.5 TWh. Thus, 516 TWh were effectively supplied to the consumers in 2013 (EPE, 2014). Figure 2 presents the evolution of the contribution of each energy source in electricity generation, stressing the importance of hydro energy in Brazil (IEA, 2013).

Energy consumption in Brazil has doubled since 1990. The average annual growth rate of electricity demand during the last decade was 3.3%, essentially due to the increase of income and expansion of electricity services among the population, as well as consequence of increase of production of energy intensive industries. Thus, electricity demand has augmented more than the annual GDP growth during the last decade, arising concerns on the need to reinforce energy efficiency programs (IEA 2013). Table 2 and Figure 3 introduce a sectorial perspective of energy consumption in Brazil (EPE, 2014). In the industrial sector, the use of fuel oil reduced significantly, while biomass, natural gas and electricity expanded proportionally. In the transport sector, the main change was the progressive adoption of ethanol and biodiesel, which currently displace about 50% of gasoline and 5% of diesel consumption, respectively. Regarding Brazilian households, the most relevant energy transition was the reduction of biomass use, largely replaced by liquefied petroleum gas (LPG), and the increase of electricity use. In fact, during the last years, the increase in electricity demand was concentrated in the residential and commercial sector.

Figure 2 Brazil Electricity Supply



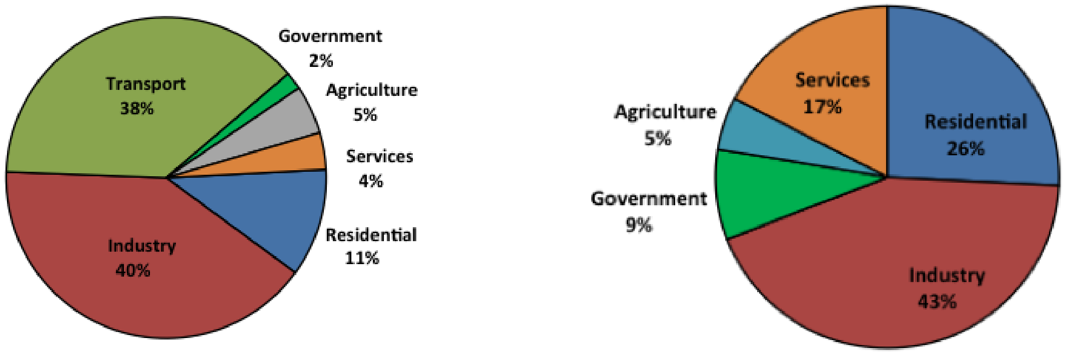
Source: IEA, 2013

Table 2 Sectorial Consumption of Energy and Electricity in Brazil in 2013

Item of Energy Balance	**Energy**	**Electricity**
	ktoe	**GWh**
Total Final Consumption	260,249	516,330
Non-energy use	16,338	-
Final Energy Consumption	243,911	486,667
Energy Sector	26,139	-
Residential	23,730	124,896
Industry	88,295	210,083
Transport	83,153	1,884
Government	3,868	41,288
Agriculture	10,662	24,129
Services	8,064	84,388

Source: EPE, 2014

Figure 3 Distribution of Energy and Electricity Consumption in Brazil in 2013

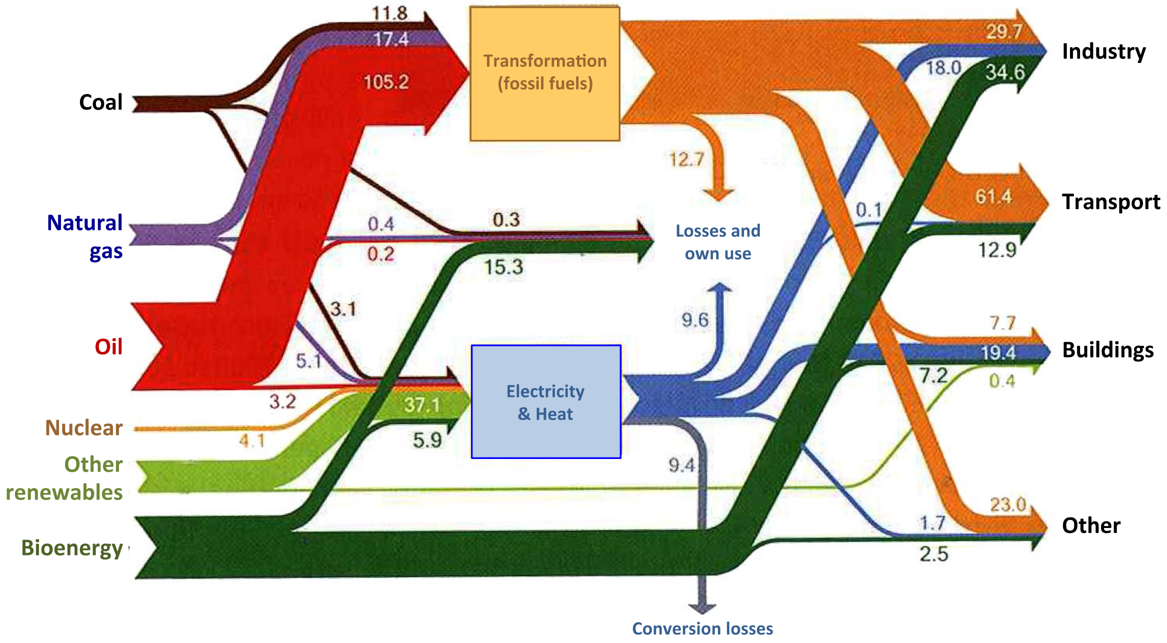


(a) Energy: 260.5 Mtoe **(b) Electricity: 516.3 TWh**

Source: EPE, 2014

Summarizing the Brazilian energy scenario, Figure 4 presents the flows from primary energy to end uses, confirming the diversity of sources, the substantial participation of renewable energy and the relevance of industry and transport as main consumers.

Figure 4 Brazilian Energy Balance in 2011 (values in Mtoe)

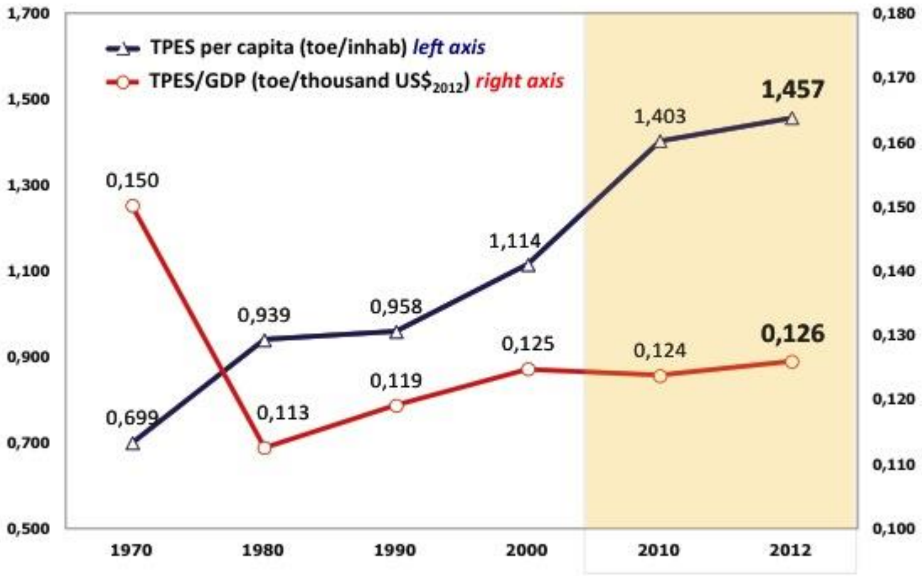


Source: IEA, 2013

1.1 Energy Intensity of Brazilian Economy

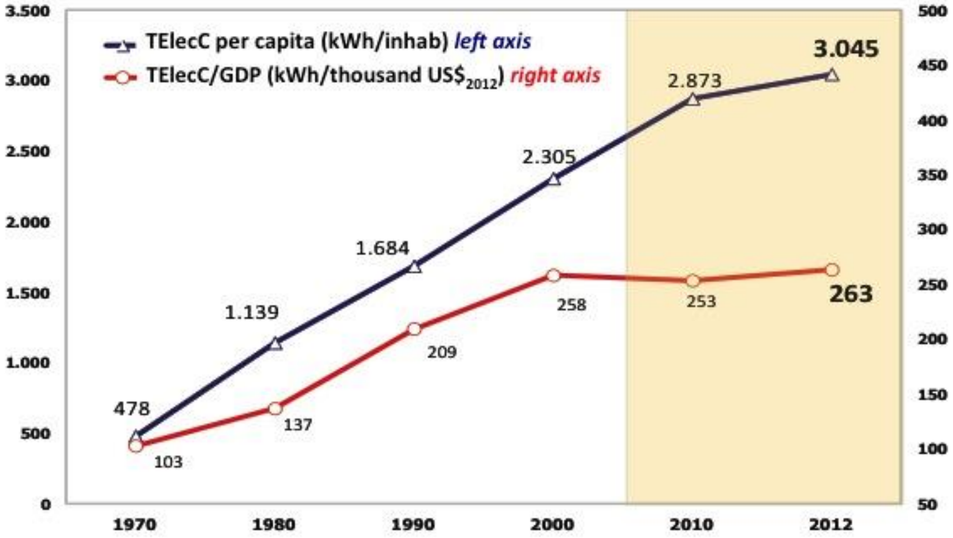
It is well known the strong relationship between economic development and energy consumption. However, energy efficiency can uncouple and relativize this relationship, keeping the level of production and welfare and reducing the energy consumption by reducing energy losses, not affecting the useful use of energy. With this regard, Figures 5 and 6 present the evolution of the Brazilian for the period 1970 up to 2012, with values of total primary energy supply (TEPS) and total electricity consumption per capita and per GDP, are also called energy and electricity intensities. For this period, it can be observed a relevant increase in the per capita demand of energy (more than 100%, including all sources) and electricity (more than 600%), in line with the universalization and income per capita expansion processes. However remarkable, after a decrease in the beginning of the period, the energy intensity remained approximately stable, while the electricity intensity increased, indicating the possibility of promoting more decisively the efficiency in energy and electricity use.

Figure 5 Evolution of Total Primary Energy Supply (TPES) Per Capita and Energy Intensity (TPES/GDP) in Brazil



Source: EPE, 2013

Figure 6 Evolution of Total Electricity Consumption (TElecC) Per Capita and Electricity Intensity (TElecC/GDP) in Brazil



Source: EPE, 2013

1.2 Institutional Aspects of the Brazilian Energy Sector

The Ministry of Mines and Energy (Ministério de Minas e Energia, MME) is the institution responsible for energy issues in Brazil, fostering sectorial investments, promoting research, efficiency and energy access. This Ministry through the Secretary of Energy formulates the guidelines and policies for the national energy sector and coordinates and supervises their execution. The final approval of energy planning and high-level guidance of the energy sector are responsibility of the National Council of Energy Policy, which is composed of the Minister of Mines and Energy as its chairman and eight ministers and three representatives appointed by the President. Two regulatory agencies are linked to the MME; the National Electricity Regulatory Agency (ANEEL), created in 1996 and the National Agency for Oil, Natural Gas and Biofuels (ANP), created in 1997, as well as mixed-capital companies, such as Petrobras and Eletrobras, operating in the oil and gas (upstream and downstream) and electricity markets, respectively. Also under MME is the Energy Research Company (Empresa de Pesquisa Energética (EPE).

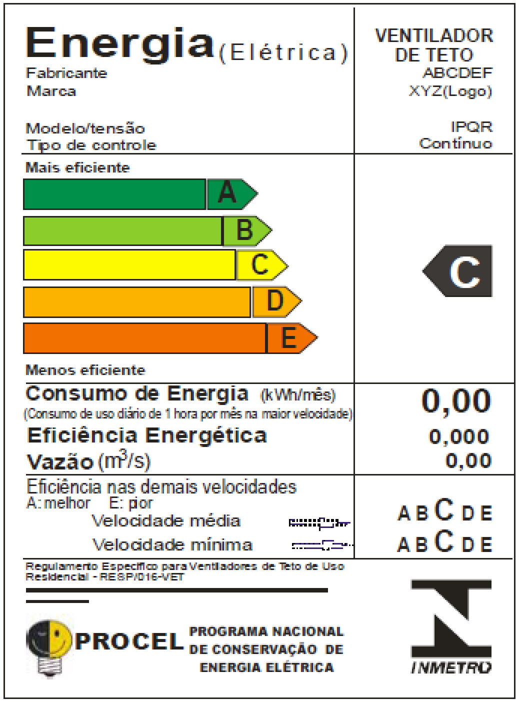
The ANEEL's roles are specially relevant in the context of the present study, including, among other functions: (i) regulating the production, transmission, distribution and commercialization of electricity; (ii) overseeing electricity concessions, permissions and services; (iii) implementing government policies and guidelines related to exploration of electricity; and (iv) defining the criteria and methodology for determining tariffs. To promote energy efficiency and develop smart grids in Brazil, the role of ANEEL is mandatory.

2. The Brazilian Efficient Appliance Labeling/MEPS Programs

2.1 Programs of Energy Efficiency in Brazil

Brazil has a relatively long history in promoting energy efficiency at final user level. Energy conservation was an important alternative to face the hard period of oil shocks when the country imported a substantial part of its energy demand. A landmark in this process is the Brazilian Labeling Program, launched in 1984, as direct consequence of high prices of energy in that time, with worrying impacts in the national economy. This program was coordinated by the National Institute of Metrology, Standardization and Industrial Quality (INMETRO), an agency under the Ministry of Development, Industry and Foreign Trade, which sets standards for evaluation, ranks the performance of energy equipment and imposes a classificatory labeling aiming to inform consumers. The National Label of Energy Efficiency (ENCE), shown in Figure 7, is similar to the classificatory label adopted in several other countries and is applied in a wide range of equipment (currently 48 types of energy consuming products) that includes home appliances, electric engines, stoves and gas-fired water heaters, as well as solar collectors and light vehicles. Depending on its energy performance, the equipment is classified usually into five classes of efficiency (A to E), with the A class attributed to the most efficient models, adding value to better technology and driving the market towards more efficient models. Such conformity evaluating process requires the establishment of standardized test procedures, as well as the implantation of performance measurement laboratories. These standards have been developed in cooperation with both the producers and suppliers. Today, this program is conducted jointly by INMETRO and other federal agencies in charge of energy efficiency.

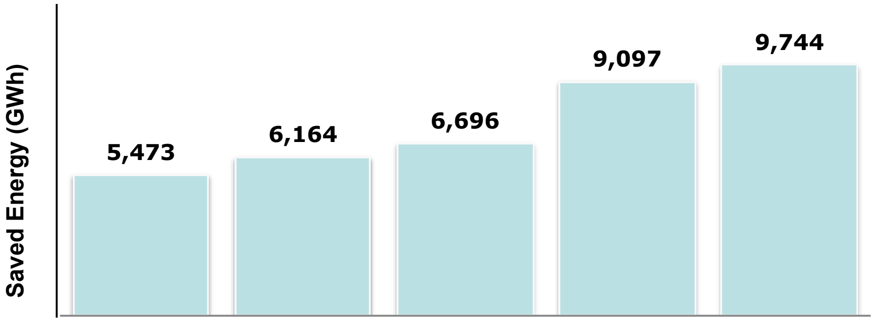
Figure 7 National Label of Energy Efficiency for Roof Fans



Source: INMETRO, 2008

In 1985, the National Electricity Conservation Program (PROCEL) was created by MME and since then executed by ELETROBRÁS, involving several subprograms, such as PROCEL Education, focused in diffusing energy conservation habits among students of elementary schools; PROCEL Info, a website promoting efficient use of energy, PROCEL Edifica, dedicated to promote energy efficiency in buildings, including their labeling; PROCEL EPP, active in public buildings; PROCEL GEM, focused in Municipal Energy Management; PROCEL Reluz, promoting efficient public lighting and traffic signals; PROCEL Sanear, focused in water and wastewater systems; and PROCEL PBE, active in energy performance labeling of equipment and appliances. Since 2003 PROCEL has evaluated its energy impact, as presented in Figure 8 (MME, 2014). The energy saving estimated for 2013 is 9,744 GWh, equivalent to 2.1% of the total electric energy consumption in Brazil in the period and corresponding to the annual energy consumption of about 5 million Brazilian households or a 3,769 MW reduction in the peak demand (PROCEL, 2014).

Figure 8 PROCEL Results



	2009	2010	2011	2012	2013
Residential Demand	**5.4%**	**5.8%**	**6.0%**	**7.7%**	**7.8%**
Total Demand	**1.4 %**	**1.5 %**	**1.6 %**	**2.0 %**	**2.1 %**
CO_2 avoided (kt CO_2e)	**135**	**316**	**196**	**624**	**935**

Source: MME, 2014

The PROCEL energy performance labeling is responsible for almost 70% of all results obtained by this program. This activity is managed in close cooperation with INMETRO and, in addition to the ENCE label, PROCEL launched in 1993 the Label of Energy Economy or simply the PROCEL Label with the objective of informing the consumer about better equipment and reinforcing the value of more efficient products. This endorsement label emphasizes the most efficient products, which means class A equipment according to the efficiency ranking label and additional quality attributes, such as safety, low noise and lower water consumption (for washing machines). In 2013 the PROCEL Label was applied to 36 different categories of products and has been granted to 3,748 models evaluated from 197 manufacturers (PROCEL, 2014). Taking into account analogous potentials for energy savings in the fuel sector, in 1991 the MME launched the National Program for the Rationalization of the Use of Oil Products and Natural Gas (CONPET), managed and supported by Petrobras. It promoted education, marketing actions focused on cargo and passenger transport companies, as well as labeling actions by the CONPET Label currently applied to gas stoves, domestic water heaters and light vehicles. PROCEL and CONPET Labels are presented in Figure 9.

Figure 9 PROCEL and CONPET Endorsement Labels of Energy Saving

Source: Leonelli, 2013

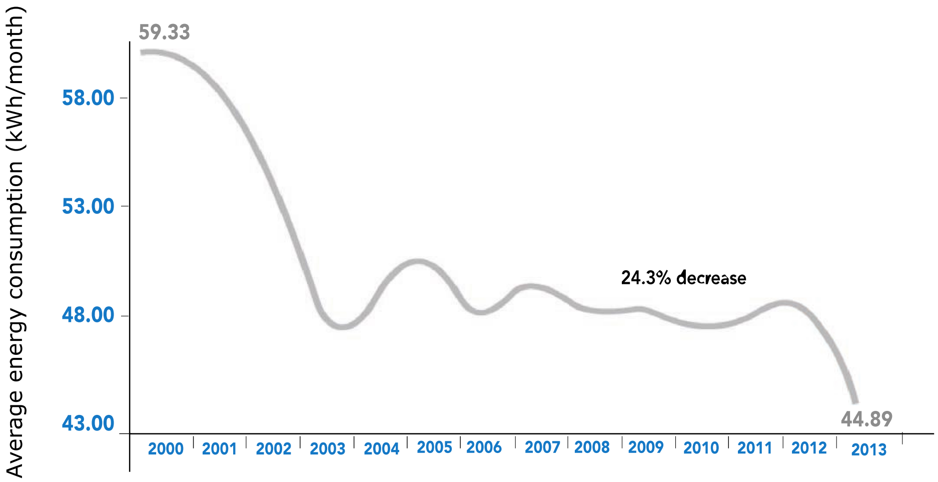
In 2001, Federal Law 10,295, also known as the Energy Efficiency Law, was approved to reinforce those energy efficiency programs, allowing the Brazilian government to establish Minimum Energy Performance Standards (MEPS) for appliances and energy equipment, thus prohibiting the commercialization of low efficiency models and promoting the progressive withdrawal of low-efficiency models from the market. The implementation of this law is supervised of the Management Committee of Levels of Energy Efficiency (CGIEE), composed by government officials and representatives of appliance makers and traders, academic community and consumers. In accordance to legislation, the CGIEE set the minimum performance requirements for refrigerators, air conditioners, electric motors, lamps, gas stoves and water heaters. It is worth noting how energy efficiency labels and the MEPS complement each other: minimum performance levels are more relevant for makers and traders, while the classificatory and endorsement labeling inform consumers and promote sales of better products.

According to the National Energy Plan 2030 (PNE 2030) between 4.0 to 15.5 GW of electricity generation capacity should be saved as a result of energy efficiency in the next 20 years, estimating that 5% of electricity demand will be reduced due to autonomous technological advance and another 5% in reduction can be accomplish by induced energy saving actions (EPE, 2008). In order to reach these goals, MME put forward the National Energy Efficiency Plan (PNEf) aiming to reduce electricity consumption by 10% in 2030 compared with a business-asusual situation, which means to save about 106 TWh (MME, 2012), thus accomplishing with the PNE 2030. However, this plan has not yet been implemented.

2.2 Impact of the Efficient Appliance Labeling Programs

Based on an open Monitoring and Verification (M&V) approach, adopting methodologies specific for each product, progressively implemented since 2003, the PROCEL PBE subprogram has been regularly assessed aiming to estimate its impact in energy and capacity saved. In this context, it has been possible to evaluate the progressive improvement of the equipment available for Brazilian consumers and the effect on consumption of electric energy in the country. For example, Figure 10 shows the evolution of the average monthly energy consumption of combined refrigerator awarded with the Procel Label during the last decade, when there was a decrease of more than 24% in energy consumption of this equipment, resulting from the technological development encouraged by the labeling programs.

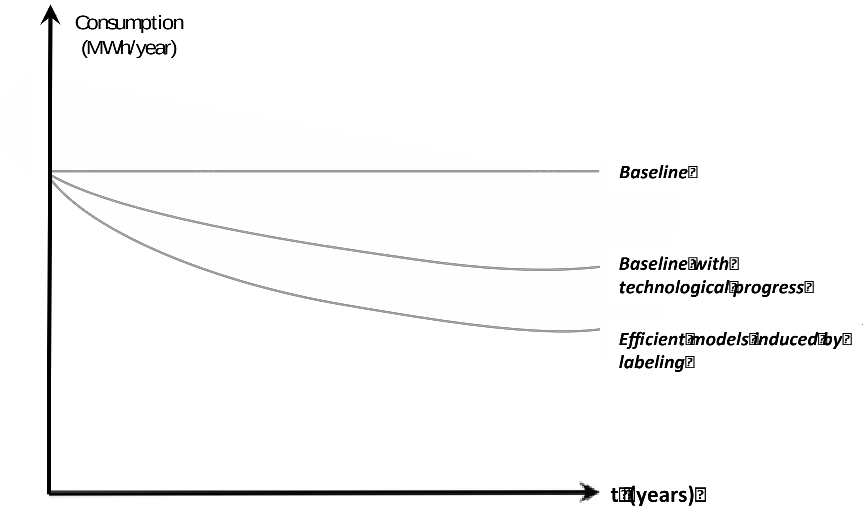
Figure 10 Evolution of Average Energy Consumption of Combined Refrigerators with PROCEL Label



Source: PROCEL, 2014

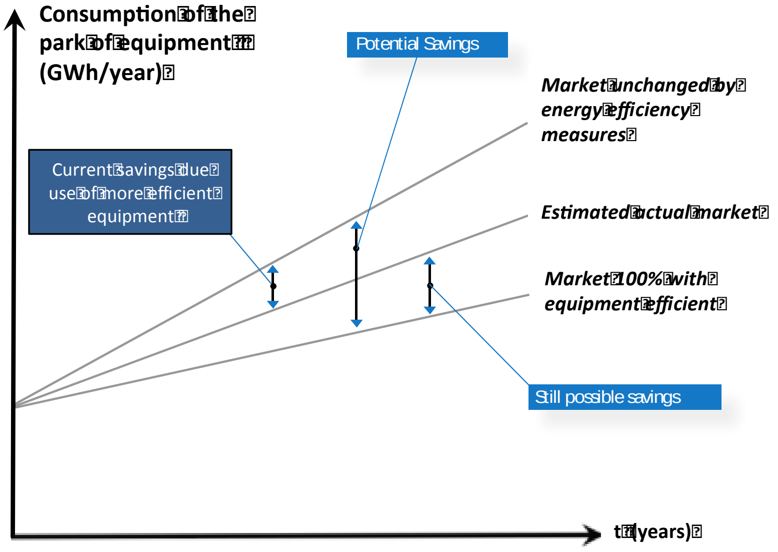
Assuming that the efficiency labeling induces changes in the market towards energy savings, the methodologies used by PROCEL for evaluating the energy benefits provided by appliances labeling take into account the sales and average useful life of each equipment as well as the unit consumption with and without labeling effects. Thus, as indicated by Figure 11, the total energy savings, for a given period and equipment will be given by the difference between the energy consumption in the baseline (reference situation) and the consumption after adopting energy efficiency measures. The energy savings includes the free rider effect, when there are efficiency gains not directly attributable to labeling, as well as the positive effect due to energy savings induced by labeling, when the purchase of efficient equipment is made regardless of the existence of labeling. Depending on the equipment, the methodology adopted by PROCEL also includes impacts from degradation effects of equipment efficiency throughout lifetime, of average environment temperature of operation, and the evolution of the park of equipment in operation, which can be estimated from sales and scrapping data. Figure 12 synthetizes the evolution of energy consumption for a park of equipment, for instance refrigerators in Brazilian households.

Figure 11 Evolution of Equipment Specific Energy Consumption



Source: PROCEL, 2014

Figure 12 Evolution of Energy Consumption for a Park of Equipment



Source: PROCEL, 2014

Under this conceptual framework and sponsored by PROCEL, EXCEN developed specific methodologies for evaluating the impact of efficient labeling in refrigerators and freezers, three-phase electric motors, air conditioners, compact fluorescent lamps, solar water heating systems, and ceiling fans, considering the Brazilian conditions (Cardoso et al., 2010; Cardoso et al., 2012; Bortoni et al., 2013).

According to the most recent report from PROCEL, the consolidated results for the PROCEL PBE subprogram, taking into account the combined effect of the INMETRO/PROCEL classificatory label and the PROCEL endorsement label, in 2013 was saved 9.578 GWh, resulting in 3,733 MW demand released from peak time. In addition, more than 62 million units of equipment with the Procel Label were sold in the same year (PROCEL, 2014). The energy savings associated to the labeling program for the most relevant equipment are present in Table 3, assuming as baseline the average market conditions before labeling and for the more efficient equipment in the improved market, the models awarded with the Procel Label.

Table 3 Results of PROCEL Labeling Program for Relevant Appliances in 2013

Equipment	Total equipment sales (1,000 units)	Fraction of sales with more efficient equipment (%)	Estimated energy saving (GWh)
Refrigerators and Freezers	8,111	55%	2,911
Air Conditioners	3,285	60%	1,123
Electric Motors	1,724	70%	1,304
Compact Fluorescent Lamps	269,427	20%	3,697
Ballast for Sodium Lamps	62	19%	5
Solar water heating system	394	20%	86
Roof fans	2,636	30%	452
Total	285,640	22%	9,578

Source: PROCEL, 2014

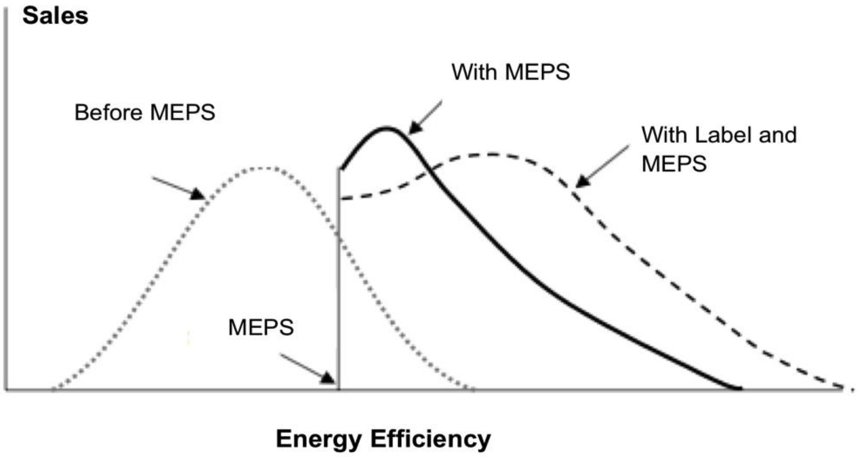
To evaluate energy performance of labeled equipment, PROCEL implemented and supervise a testing labs network, currently with more than 20 labs in research centers and universities, involving more than 280 professionals, and investments of about R$16 million (Brazilian real) from PROCEL. In 2013, close to 8,700 tests were performed concerning energy efficiency in equipment (PROCEL, 2014).

2.3 Impact of Implementing Minimum Energy Performance Standards

As established by the Energy Efficiency Law and complementing the classificatory and endorsement labeling, compulsory minimum levels of efficiency or Minimum Energy Performance Standards have been successively introduced in Brazil. While efficiency labeling drives the entire market towards more efficient products, the Energy Efficiency Law removes from the market just that portion of products with efficiencies lower than the minimum legal limit, as indicated in Figure 13 (CLASP, 2007).

The energy savings obtained after 10 years of the approval of Energy Efficiency Law (Law 10.295/2001) were evaluated, estimating the effect of introducing MEPS in the Brazilian market (CGEE, 2013 and Nogueira et al., 2015). These evaluation are done based on estimates of the amount of equipment in operation and the effect of MEPS on a representative model of equipment, in some cases considering the efficiency degradation and actual operation conditions different than those assumed in efficiency measurement. In the absence of detailed sales data before and after the MEPS adoption, the sales of models removed from the market were assumed as distributed among the efficiency classes according to their initial share in the market.

Figure 13 Impacts of MEPS and Labeling on the Market of Energy Equipment



Source: CLASP, 2007

The equipment which received MEPS during the first decade of the Energy Efficiency Law were: a) refrigerators and freezers, b) air conditioners, c) gas stoves, d) gas water heaters, e) electric motors, and f) compact fluorescent lamps. In Table 4, general information about the regulation introduced by that law for those products is presented, and for electric equipment in particular, Table 5 introduces the intermediate results of the appliance consumption in the baseline and in the excluded portion, indicating the decrease in the annual consumption in each case. The relative reduction in the consumption of refrigerators and air conditioners is more significant than the reduction in the consumption of electric motors. However, the energy impact of the motors is higher due to the large number of motors involved and greater operation time.

Table 4 Products Regulated by the Energy Efficiency Law up to 2010

Product	**Regulatory Legal Act**	**Entrance in force**	**Representative model(s) for the energy impact evaluation**	**Units in operation in 2010**	**Sales in 2010**
				(million units)	
Three-phase electric motors	Decree 4.508/2002 e Interministerial Orders 553/2005 and 238/2009	Aug/2003 Jan/2010	Motor, 5 cv	10.1	1.18
			Motor, 25 cv	2.6	0.3
			Motor, 75 cv	0.6	0.06
			Motor, 175 cv	0.2	0.02
Compact fluorescent lamps	Interministerial Orders 132/2006 and 1008/2010	Jan/2008 Jan/2013	Efficient 15 W lamp	514.9	47.6
Refrigerators and freezers	Interministerial Order 362/2007	Oct/2008	300-liter refrigerator with one door	43.5	3.99
			400-liter refrigerator, combined	5.96	0.55
			400-liter refrigerator, combined, frost-free	7.13	0.65
Gas stoves	Interministerial Order 363/2007	Jan/2009	Four-burner stove, with oven, without automatic firing	54.4	7.43
Air conditioners	Interministerial Order 364/2007	Jan/2009	Window air conditioner, 9 kBTU/h	6.56	0.62
			Window air conditioner, 21 kBTU/h	2.65	0.28
			Split air conditioner, 9 kBTU/h	4.66	0.62
			Split air conditioner, 21 kBTU/h	1.13	0.15
Gas water heaters	Interministerial Order 298/2008	Oct/2009	Fast water heater, natural draft, 5 liter/min capacity	2.85	0.35

Source: CGEE, 2014

Table 5 Intermediate Vales in the Evaluation of the Energy Impacts of the Energy Efficiency Law on Regulated Electric Appliances in 2010

Product	**Representative model(s) for energy impact evaluation**	**Average unit consumption,** (kWh/year)	**Average unit consumption of excluded models** (kWh/year)	**Unit consumption reduction**
Three-phase Electric Motors	Motor, 5 cv	3,493	3,528	0.98%
	Motor, 25 cv	20,355	20,620	1.29%
	Motor, 75 cv	66,377	71,657	7.4%
	Motor, 175 cv	271,346	273,944	1.0%
Refrigerators and freezers	Refrigerator, 300 liters, one door	208	329	36.7%
	Refrigerator, 400 liters, combined	398	518	23.2%
	Refrigerator, 400 liters, combined, frost-free	399	520	23.3%
Air conditioners	Window air conditioner, 9 kBTU/h	654	900	27.3%
	Window air conditioner, 21 kBTU/h	1,946	2,600	25.2%
	Split air conditioner, 9 kBTU/h	607	830	26.8%
	Split air conditioner, 21 kBTU/h	1,830	2,300	20.4%

Source: CGEE, 2014

Lamps deserve a particular consideration in this context. Compact fluorescent lamps have diffused quickly in the Brazilian market during the past decade, with a significant volume of annual sales and relevant potential energy impact. Due to relevant differences in the implementation process, the impact of establishing a minimum efficiency for these appliances should be estimated differently than those for the other products. The efficiency of lamps was regulated in Brazil in two stages: initially, with the establishment in June 2006 of minimum efficiency levels (in lumens/watt) and useful life for compact fluorescent lamps and, later, in December 2010 by the definition of efficiency levels for incandescent lamps at values that led to their progressive compulsory withdrawal from the market. It is difficult to estimate the energy impact of the first stage because lamps are typically bought by their power (real or equivalent, in the case of efficient lamps) and not by considering lighting intensity (luminance). In addition, it seems incorrect to attribute the adoption of more efficient lamps in Brazil in recent years to the Energy Efficiency Law alone because other factors have fostered their use, such as programs for the subsidized substitution of incandescent bulbs. Under these conditions, no energy impact is attributed up to 2012, when the progressive withdrawal of inefficient lamps will start. According to the regulation issued in the framework of the Energy Efficiency Law, from July 2012, incandescent lamps with more than 150 W will not be allowed to be sold in Brazil, beginning the process of the gradual banning of these lamps and their substitution by more efficient models. In July 2014, 60 W incandescent lamps, which are more widely used, were included. In these conditions, the transformation of the market will occur essentially due to the Energy Efficiency Law, justifying the estimate of the energy impact in this context.

In Table 6, the final results are summarized, indicating the fraction of the sales substituted by more efficient models, which corresponds to the portion of the products affected by the definition of a minimum limit of efficiency. According to this study, the Energy Efficiency Law promoted a total economy of 182.8 GWh (enough to supply approximately 120,000 residences) and a peak demand reduction of 70.3 MW, which was distributed among the three regulated electric appliances. The demand reduction was estimated based on the values of the energy saved and equivalent capacity factors (York et al., 2007), a procedure adopted in the PROCEL Label results assessment (PROCEL, 2010).

Table 6 Impacts of the Energy Efficiency Law on Electricity Consumption in 2010

Product	**Representative model(s) for energy impact evaluation**	**Sales fraction affected by the efficiency regulation**	**Energy saved (GWh)**	**Peak demand reduction (MW)**
Three-phase Electric Motors	Motor, 5 cv	<7%	43.1	17.7
	Motor, 25 cv	<7%	3.1	1.3
	Motor, 75 cv	<7%	3.6	1,5
	Motor, 175 cv	<7%	16.7	9.1
Refrigerators and freezers	Refrigerator, 300 liters, one door	<5%	20.5	8.3
	Refrigerator, 400 liters, combined	<3%	13.2	7.2
	Refrigerator, 400 liters, combined, frost-free	<3%	4.6	1.8
Air conditioners	Window air conditioner, 9 kBTU/h	<6%	14.0	6.1
	Window air conditioner, 21 kBTU/h	<6%	27.4	9.6
	Split air conditioner, 9 kBTU/h	<6%	12.0	3.5
	Split air conditioner, 21 kBTU/h	<4%	24.6	4.3
Total			182.8	70.4

Source: CGEE, 2014

According to this assessment, up to 2010 the impact of MEPS was relatively reduced on the Brazilian energy market. However, these impacts were limited due to the low number of models replaced in the market and the relatively recent introduction of efficiency regulation for refrigerators (2008) and air conditioners (2009). Using the same methodology for estimating energy impacts associated to MEPS in forthcoming scenarios and incorporating projections for the park of equipment, the energy impacts of the Energy Efficiency Law will be increasingly significant in the future. It is expected that the energy savings will reach 14,325 GWh in 2030 (sufficient to supply approximately 6 million households), and the demand reduction will be approximately 9,2 GW (9% of the currently installed generation capacity in Brazil). These prospective impacts were strongly based on the ban of incandescent bulbs, which is currently happening and will account for 82% of the foreseen total economy (Nogueira et al., 2015).

2.4 Perspectives for Energy Efficiency Labeling and MEPS in Brazil

Although the large experience accumulated in appliances labeling and more recently also with MEPS implementation, with interesting results already achieved and promising outcome in the near future, the governmental attitude with regards to energy efficiency can be reinforced in Brazil. Energy efficiency should be introduced more explicitly in the government agenda, particularly in the energy planning activities, defining strategies and implementing programs, with feasible targets, supported by proper human resources and sufficient financing. These actions should be conducted with continuity, involving and co-ordinating activities with stakeholders, and at last but not least, keep the society permanently informed about the programs achievements and impacts.

Particularly in relation to labeling and MEPS, both regulatory measures would be certainly more effective if marketing campaigns were introduced to inform consumers about them. Additionally, permanent efforts to review efficiency limits and expand the amount of regulated equipment should be undertaken and supported by efficiency monitoring programs for traded products and the enforcement of the new regulation. In a developing country like Brazil, performance standards should be established to reinforce the goals of supporting economic activity, reducing environmental impacts, achieving social goals, and finally, improving the rationality of energy use in the country.

3. Smart Grids Programs in Brazil

3.1 Smart Grids Fundamentals

Smart grids can be defined as the insertion, in large-scale, of new technologies and digital information elements in the electrical system, particularly in the electrical distribution networks. According to the US Department of Energy (DOE, 2009), smart grids are "*an automated system, characterized by a two-way flow of electricity and information able to monitor everything from plants to consumer preferences. This system incorporates in the network the benefits of distributed computing and communications to provide real-time information and allow almost instantaneous balance of supply and demand*".

This concept will transform the existing power grid in an "Internet" of energy, combining transport of electrons and information. According to Rifkin (2011), "Smart Grids will be so significant to nations, in the twenty-first century, as the First Industrial Revolution has been in the XIX century: promoting renewable energy; transforming homes and buildings in energy microgenerators, injecting energy coming from clean sources on the local network; allowing the use of the Internet to transform the power grid across the country in a power sharing network that acts as the Internet technology."

Most of the current distribution networks are based on technologies developed in the ‘50s (or earlier) and the current electrical system is designed to meet traditional loads. The electricity utilities show up to be out of date to deal with this new load demand. Also, they will have to manage the numerous sources of distributed generation. Therefore, the perspective of integrating decentralized generation with distribution will change the current relationship between utility and consumer.

Similar to the Internet, the Smart Grid will be interactive for both consumers and energy companies in all segments: Generation, Transmission, Distribution and Consumption. This concept will allow end-users to produce their own electricity and participate in Demand Side Management programs (DSM). Supported by a high-speed, bi-directional communications infrastructure, smart metering and electronic control technologies represent the gateway to access the network of the future. Figure 14 shows a diagram of the technologies connected in a Smart Grid.

Figure 14 Diagram Showing an Intelligent Network Technologies or "Smart Grids"

3.2 Initial Studies for Smart Grid in Brazil

The ANEEL carried out studies and developed regulation to face the new environment for electric distribution systems. In fact, these systems will tackle significant changes integrating distribution networks with automation technologies, information and telecommunications in the coming years. The new demands will transform the electrical low-voltage network into a new superhighway to transport electrons. Such changes will be driven mainly by the significant increase of distributed generation, allowing Brazilians consumers to produce their own energy and share the surplus among partners.

In September 2008, ANEEL promoted in Brasilia the "International Seminar on Electronic Measurement" stimulating discussion on: electronic measurement at low voltage consumers, regulatory guidelines, functions and implementation experiences. The participants were electrical utilities companies, associations of the Brazilian Electric Sector and international speakers from Italy, Spain and Canada. After that, it was introduced by ANEEL the Public Consultation 15/2009 to guide discussions on the subject. In April 2009, a technical mission to Portugal, Spain and Italy was carried out in order to make contact with the experiences in large-scale deployment of smart metering. In September 2009, a technical mission was carried out to the United States to learn more about its experience in the implementation of smart metering.

In fact, the international experience was a relevant step for the studies and plans of Smart Grids in Brazil. In 2009, the European Union published the Directive 2009/72/EC, which established the obligation of member states to assess the implementation of smart metering. Before the implementation, however, this Directive established that state members should evaluate the economy arising from the replacement of meters by September 2012. If the cost-benefit analysis was positive, the authorities should require that at least 80% of consumers should be covered with intelligent metering systems by 2020. The speed to roll-out the process of replacing meters was different from country to country. In Europe, the objective was to increase network reliability, reduce the cost of maintenance, keep more accurate records of use per customer and, above all, reduce CO2 emissions.

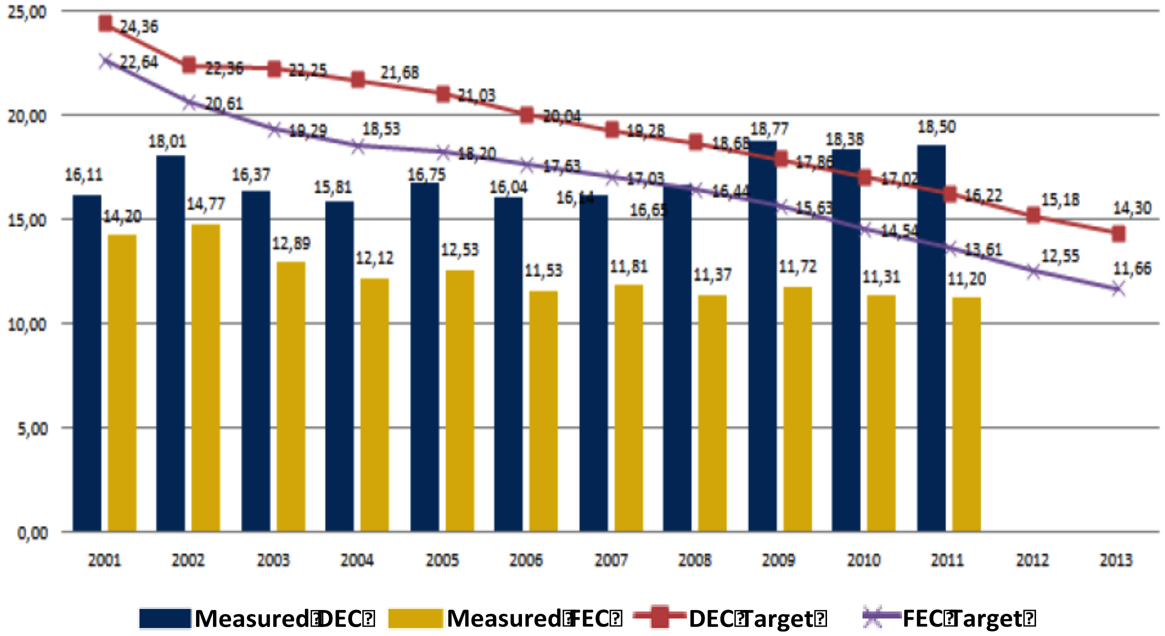
The United States also presents important initiatives related to Smart Grids. Across the country, there are several pilot projects, but the most significant use of smart metering is found in Texas and California, whose main vectors are i) reduced demand at peak times, and ii) the promotion of energy efficiency. At the US federal level, the Recovery and Reinvestment Act was launched in 2009, which allocated US$3.4 billion to the deployment of Smart Grids. For the US Government, the technology enables more reliable electricity system, environmental gains, generating tens of thousands of jobs and savings around US$20 billion over the next decade. In the United States, as in Europe, job creation and economic recovery are also reasons for the deployment of the technology.

3.3 Drivers for Implementing Smart Grids in Brazil

In Brazil, although there is not a clear public policy or the government setting towards Smart Grids, several actions have been developed in this direction. However, the Brazilian motivation differs from the other countries firstly because the country has a clean energy matrix, as indicated in this report, and the hurdles to overcome are diverse. The main motivations to deploy Smart Grids in Brazil are to i) improve the quality provided in the low voltage service, ii) reduce losses, and iii) reduce operating costs, among others.

Figure 15 shows the situation of the distribution utilities companies in terms of quality of service. Since 2009 they do not reach the minimum quality level set by ANEEL. The number of interruptions (FEC) and duration of interruptions (DEC) are above the target proposed by the ANEEL. In 2011, the annual average number of interruptions tolerated for 63 utilities was 16.22h and the real was 18.50h. For comparison, Japan's annual tolerance was 16 minutes and the United States average value came to 240 minutes. In the European Community countries, the desired value is around 140 minutes.

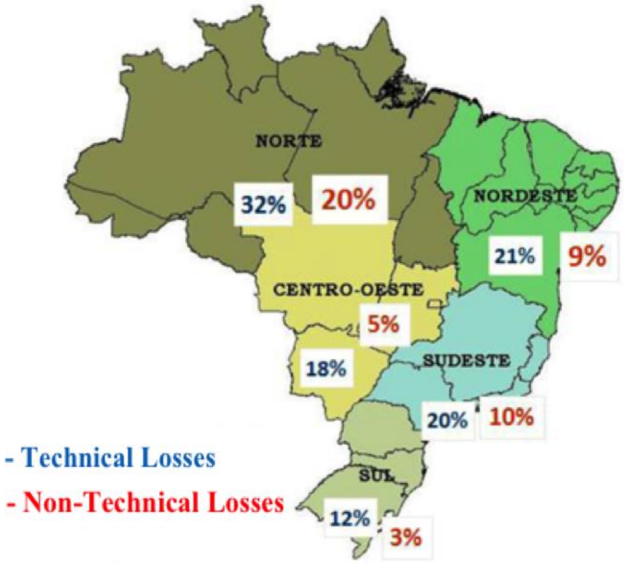
Figure 15 Quality of Service - DEC / FEC Brazil 2001-2011



Source: ANEEL, 2013

Figure 16 shows the average technical and non-technical losses in electricity distribution by region in Brazil, at levels that can be considered very high compared to the world paradigms and justify the implementation of Smart Grids aiming to reduce the non-technical losses. In recent years, some utilities started replacing electromechanical meters for electronic meters in their concession areas, in order to promote reduction on non-technical losses and improve efficiency in the measurement of energy consumption.

Figure 16 Electrical Losses in Brazil by Region in 2011



Source: ANEEL, 2014

3.4 Evolution of Regulatory Framework for Smart Grids in Brazil

Under its mandate, ANEEL is pursuing regulatory mechanisms for the implementation of Smart Grids, balancing the trade-offs benefit versus cost, modernity of service versus reasonable tariffs. One of clear action in this context is the adoption of smart meters, which can bring interesting benefits to society, such as: a) potential reduction in consumption, driven by better information, b) optimization of distribution networks, c) remote readings and better monitoring of the network, d) reduction of technical and non-technical losses, and e) peak load management.

Specifically related to Smart Grids, ANEEL issued several regulations:

a) Resolutions 345/2008 and 395/2008, dealing with the compulsory use of Geographic Information System (GIS) for grid and consumer mapping.

b) Normative Resolution 375/2009, dealing with the regulation of the use of Power Line Communication (PLC).

c) Normative Resolution 464/2011, establishing the “white tariff”, a new scheme of hourly tariffs for energy billing, a step towards Charging Horo-Seasonal (CHS), currently serving only consumers of high and medium voltage, and setting the Tariff Adjustment Procedures (Proret), which goal is to treat equally all consumers in relation to the payment of network usage.

d) Normative Resolution 482/2012, allowing grid connection for distributed micro and mini-generation, including cogeneration and photovoltaic generation.
e) Normative Resolution 502/2012, focusing smart meters.

In addition to these, other studies such as prepayment, was recently submitted to the Public Hearing number 48/2012.

The Resolution 502/2012, although does not define the strategy of smart meters use or ends the discussion on the minimum functionality required, deserves a special attention since it represents a starting point for modernization of energy metering in Brazil, trying to balance technology development and low tariffs. This resolution defined what kind of measurements the new meters has to perform: voltage, active power, tariff divisions, reactive power, date and time of start and end of the interruptions, voltage violations, communication and remote operations. Also, the meters should have devices that enable two-way communication between the meter and the distribution center. Furthermore, the suspension and reconnection of supply activities, as well as monitoring and control of certain parameters of the meter should be able to be performed remotely by the utility. Although some countries will adopt the communication system to reduce operating costs, in Brazil this reality it is not observed in all regions, given the high cost of communication infrastructure and the relatively low cost of human labor. ANEEL understood that the regulator should use regulatory instruments to promote the modernization of the measurement park without, however, select a single technical solution and standardize it across the country.

In the framework of Normative Resolution 464/2011, for residential customers, a new tariff (white tariff) was created, divided into three periods: peak load, intermediate and out-of-peak-load, valid from Monday to Friday (Saturdays, Sundays and holidays shall be regarded as entirely out of peak load). The timetables for each period will be defined by the utilities. The consumer can decide migrate to the white tariff or remain in conventional tariff, with a single value. Residential consumers, who pay a flat rate regardless the period of the day, can choose the plan that provides cheaper energy at lower demand time. However, the adoption of the white tariff will be possible only with the replacement of the electromechanical meters for intelligent electronic meters, throughout the country.

An important modification in the Brazilian electricity market was the implementation of the tariff flags from January 2015, informing consumers about the prospective cost of energy. In this scheme, the green flag means energy cost is accordingly the forecast. The yellow flag indicates a warning signal that the energy costs are increasing. In turn, the red flag indicates that the previous situation is worsening and the supply of energy, to meet consumer demand, occurs with higher costs. For example, the use of large amount of thermal power plants to generate energy, which is a more expensive source than hydroelectric plants.

Currently, dozens pilot projects on Smart Grids are underway in the country and smart meters have been installed. At the same time, manufacturers and distributors are seeking the best technical solutions to the national market. Excessive standardization or regulation, at this time, can disrupt the full development of the technology rather than stimulate it. Research has being increasingly encouraged, but the effort to introduce Smart Grid in Brazil is sizable: for instance, to replace the whole national park of meters, it will be required approximately about 70 million meters.

As follows, two Smart Grids projects are presented in detail: CEMIG and AES Eletropaulo, two Brazilian power utilities.

3.5 Smart Grids in CEMIG

CEMIG is one of the most important group of electric energy industry in Brazil, participating in more than 204 other companies, as well as consortia and equity funds. Publicly traded company, controlled by the Government of the State of Minas Gerais, has 114 thousand shareholders in 44 countries. Its shares are traded on the stock exchanges of São Paulo, New York and Madrid. CEMIG develops business in 23 Brazilian States, plus Chile, with the operation of a transmission line. CEMIG also has participation in transmitting electrical energy companies, investments in the natural gas segment, telecommunications and energy efficiency (Efficientia, an ESCO subsidiary). It is also the largest supplier of energy to free clients in the country, with 25% of the market, and one of the largest generating groups, responsible for the operation of 70 power plants with an installed capacity of 7,295 MW.

The concession area of the public utility CEMIG Distribuição S/A (CEMIG-D) in Minas Gerais State covers 567,740 km2, approximately 96% of the State of Minas Gerais, accounting for more than 7.5 million consumers in 774 municipalities and serving 18.2 million inhabitants. In network extension, CEMIG-D is the largest utility of electrical energy in Brazil, with 453 thousand km of distribution networks (20% urban and 80% rural). It serves approximately 2.4 million low-income consumers, i.e. 42.9% of total residential-class consumers.

Smart Grids in CEMIG - Cities of the Future Project

The major characteristics of the project are:

- Location: the chosen area was the region serviced by substations Sete Lagoas 1, 2 and 3. Initially, the advanced measurement infrastructure facilities and distribution automation will be concentrated in the following cities: Sete Lagoas (the main municipality, about 60 km from Belo Horizonte, the capital of the State of Minas Gerais), Santana de Pirapama, Santana do Riacho, Baldim, Funilândia, Prudente de Morais and Jequitibá.
- Investiment (phase 1): approximately US$45 million, including US$25 million for a solar plant.
- Number of customers in the geoelectric region including the Sete Lagoas 1, 2 and 3 substations: 95,000 customers (75,000 in the city of Sete Lagoas). Potentially can be involved in the program 290,000 inhabitants.

CEMIG intends to apply all the concepts Smart Grids in their electrical installations, telecommunications, computer systems and interface with consumers and distributed generators. The plan of action intends to corroborate Proof of Concept Project (PCP) and ensure that consumers remain involved in this initiative until its completion. The motivation of CEMIG in implementing the Cities of the Future Project includes, among others:

- Search for leadership in the application of cutting-edge technology;
- Development of knowledge on Smart Grid technologies;
- Test of technologies for consumers of different profiles, evaluating and measuring the benefits, as the basis for an expansion to other regions of CEMIG;
- Improvement operational efficiency, through access to more accurate information;
- Necessity of a creation options to the current tariff structure, extending the use of variable rate for low voltage consumers, anticipating the changes laid out in the regulation of the electricity sector from the third cycle of rate review of electric power distributors;
- The recognition that the interaction between dealers and consumers is the basis for a new era of integrated services, including communications and IT solutions;

- Improving energy efficiency in a country with growing energy needs, helping to meet the demand of energy with less impact to the environment and reducing greenhouse gas emissions.

The main objectives of the Project Cities of the Future are: validate, in representative scale, products, services and innovative solutions of Smart Grid; analyze the technical and economic feasibility involving the new technology of Smart Grids; identify the acceptance by the consumer seeking their engagement and participation; implement a reference model for deployment of Smart Grid architecture; contribute to the company process of transformation and disseminate the knowledge on this new technology to agents in the sector.

The Cities of the Future Project has the following sources of funds, listed from the greater financial participation: (i) ANEEL R&D Program; (ii) CEMIG's Energy Efficiency Program (Intelligent Energy Program); (iii) CEMIG's own resources; (iv) Grants from the United States Government (non-refunding financing) by United States Trade and Development Agency – USTDA. The total amount of resources involved is around R$45 million for the period 2011 to 2014. It is worth to note that although the support from US Government it is not the greater participation (US$710 million) in the project, it is one of the largest ever awarded in the USTDA history and it can be understood as a recognition and appreciation of actions under development by CEMIG. It should also mentioned that, via an agreement with the Inter-American Development Bank (BID), CEMIG developed a diagnose on government consumption and energy habits, study which supported the project design.

In December 2009, the Cities of the Future Project were officially launched. Technical factors related to the electric and telecommunications system, as well as the proximity to the capital of the State of Minas Gerais, Belo Horizonte, and the presence of UniverCemig (Cemig's University and Training Center, located in Sete Lagoas), motivated the decision to choose the city of Sete Lagoas.

The year 2010 was dedicated to planning and structuring the projects. In November 2010 two agreements were signed: one in partnership with CPqD -Center for Research and Development in Telecom and another with the FITec-Foundation for Technological Innovations. The projects are named respectively: Development of functional model Smart Grid through systemic integrations of intelligent solutions for distribution network automation, advanced metering infrastructure and consumer participation and Compliance testing platform and interoperability of devices "smart metering" and network automation solution - based on safe WMAN-WiMAX hybrid communication.

In 2011, the R&D projects have already presented partial products. Also in 2011, the agreement with the United States Trade and Development Agency – USTDA was signed and initiated the process of acquisition of the first batch of advanced metering infrastructure. The deployment of systems for AMI (Advanced Metering Infrastructure), from 2012 to 2013, focus was given to the deployment of the infrastructure of information technology and telecommunications, sensors developed in R&Ds, automation of networks, distributed generation, electric mobility and residential automation. The results were new equipment and services serving as basis for the CEMIG’s development plan concerning Smart Grids in its concession area.

3.6 Smart Grid in AES Eletropaulo

AES Eletropaulo is a public utility with shares listed on Bovespa BM&F stock market. It is considered the largest utility of electricity in Brazil in terms of energy supplied, according to the ranking of the Brazilian Association of Electricity Distributors held in 2012. The company is responsible to supply 6.7 million consumers, attending 20.1 million of inhabitants in 24 municipalities in the metropolitan region of São Paulo, the major economic and financial in Brazil.

The company's concession area is 4,526 km², harboring the highest demographic density and concentrate the largest GDP (Gross Domestic Product) of Brazil. AES Eletropaulo provides 34.1% of the total electricity consumed in the state of São Paulo and 10.5% of Brazil. AES Eletropaulo main indicators are:

- 6,208 employees own and 9,293 outsourced;
- 151 substations;
- 13,999 MVA of installed capacity;
- 41,497 km of distribution network;
- 2,532 km of underground distribution network;
- 1.805 km of sub-transmission line;
- 202 thousand distribution transformers;
- 1.2 million of poles;

- R$9.01 billion of the net operating revenue;
- 46,215.8 GWh of distributed energy for the captive market and free consumers; and
- R$1.26 billion of share capital.

The Eletropaulo Smart Grid Project

The AES Eletropaulo Smart Grid project is under development since January 2013 in the municipality of Barueri, metropolitan area of São Paulo. The first action was the investment of more than R$40 million to modernizing the Distribution Control Center (DCC), which relies on cutting-edge technologies, and integrated systems able to monitor and minimize disruptions. The DCC is installed in the administrative headquarters of AES Brazil in Barueri.

The main goal of this project is to implement technological infrastructures, applications and features of Smart Grids. Also, AES intend to create a replicable deployment model throughout its concession area and develop a strategic Road Map. The deployment period started in January 2013 and goes to December 2015.

In November 2014 AES Eletropaulo announced a second stage of its Smart Grid project, signing contracts with Siemens, WEG, and Itron, to manufacture 62 thousand smart electronic meters, which will be installed in Barueri households from 2015. AES Eletropaulo has a deal with Cisco to enable network communication, using radio technologies, wireless network (RF MESH 6LowPAN) and PLC (Power Line Communication). These partnerships result in R$29 million in contracts. In total, AES Eletropaulo is allocating approximately R$75 million, within the ANEEL’s program of Research and Development.

The project is planned to cover 84,000 consumers, representing 250 thousand people, including low-income communities, households, commerce and industries. The network is to be automated as 678 km, involving 5 substations and 38 feeders.

4. Final Comments: The Challenge of Promoting Energy Efficiency amid Energy Abundance

Improving energy efficiency and reducing energy losses in Brazil is a major challenge. The relative abundance of energy sources, the necessity to expand the energy infrastructure and the mandatory order to spread the electrical energy service to all Brazilians, have placed energy efficiency and Smart Grid Initiatives in a non priority position on the Brazilian government’s agenda. Although the existing efficiency programs have accumulated relevant results, they still can’t rely on the adequate visibility to be included in regular and permanent public policies. Nevertheless, the expertise and the technological resources available make these alternatives effective alternatives to improve the rationality and sustainability, in a broad sense, of energy sector and energy companies.

Although nowadays the quantitative impact and the outcome of energy efficiency programs is better known in Brazil due to a systematic follow up develop by PROCEL, there is a relatively limited information and data about the effective and/or potential outcome of Smart Grid programs in Brazil. Usually the only information available is the amount of investment done in this subject, without an actual evaluation or forecast of its energy impact. It is advisable that these programs, since their startup, take into account the monitoring and evaluation of their activities.

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