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REVIEW ARTICLE

Cost-effectiveness of CO_2 emissions reduction through energy efficiency in Brazilian building sector

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Abstract This paper calculates the cost-effectiveness of CO_2 emissions reduction in Brazilian buildings sector. The evaluation takes into account the implementation of three public policy mechanisms which the focus is the promotion of energy efficiency (EE). The mechanisms evaluated are minimum energy performance standards (MEPS), EE requirements in public procurement regulation, and building codes. The evaluation performed through marginal abatement cost curves (MACC) shows a wide range of cost-effective EE measures, i.e., EE technologies that represent negative abatement costs once the additional investments in EE are paid back through energy savings. The main specific findings are that (1) MEPS could be broader and reach the use of energy in standby mode and tubular fluorescent lamps and should be more stringent, mainly in the case of large air conditioning devices, and (2) there is a significant cost-effective potential of emissions reduction that could be captured through mechanisms not implemented yet in the country, as public procurement regulation and building codes. In general, the total impacts are very significant and could represent an energy saving potential of 795 TWh and emissions reduction of 74 million tons of CO_2 over the period from the year 2014 to the year 2030.

Keywords Energy efficiency · CO2 emissions · Buildings · Policy mechanisms · Brazil

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Introduction

There are many energy efficiency (EE) opportunities in residential, public, and commercial buildings. Some obvious opportunities are related to, for instance, changes in building design for natural lighting and ventilation, and the direct use of solar energy for water heating. Other options include the adoption of high efficiency appliances (refrigerators, air conditioners, washing machines, etc.), fluorescent lamps and new lighting technologies (LEDs), low energy consumption in standby mode, heat and cold recovery systems, among others. These technological options are in the majority cost-effective (IEA 2008; McKinsey and Company 2009) in many countries, and its diffusion could potentially minimize the energy demand and the need for future expanded power generation.

Energy use by buildings, and related greenhouse gas emissions (GHG, mostly in the form of carbon dioxide, CO_2) are very significant around the world. Some studies (e.g., IPCC 2007; UNEP 2009; DOE 2012; PBL 2012) have highlighted the role of buildings in climate change and indicated the large potential of CO_2 emissions mitigation that can be achieved in this sector through the dissemination of EE and renewable energy sources (RES). According to UNEP (2007a) and IEA (2005), 30–40 % of all primary energy is used in buildings, for end uses such as heating, cooking, and plug loads, and constitute the main source of CO_2 emissions in many countries. For instance, the combustion of fossil fuels in the residential sector accounted for about 15 % of all CO_2 emissions in the UK (DECC 2012). In the USA, commercial and residential buildings accounts for 39 % of energy-related CO_2 emissions (EIA 2009). Moreover, in some developing countries such as China and India, the rapid increase in building construction and expansion of infrastructure are the main drivers for increasing fossil fuel consumption and CO_2 emissions (PBL 2012; DOE 2012).

In Brazil, the main sources of GHG emissions in residential, commercial, and public buildings are (1) the direct fuel combustion, mainly firewood and LPG for cooking, that accounts for about 0.91 % of total CO_2 emissions in the country[1] and (2) indirect emissions through the use of electricity, that accounts for about 0.6 % of total CO_2 emissions in Brazil. In the year 2010, for operation and maintenance, the Brazilian buildings consumed 48 % of the total electricity in the country (MME & EPE 2011). Most of this consumption (105.2 TWh) was in the residential sector, where the main end uses are electric water heating (23.9 %), food refrigeration (21.9 %), air conditioning (19.9 %), and lighting (13.9 %). In the commercial (total consumption of 66.5 TWh) and public (total consumption of 40.7 TWh) sectors, the main end uses are air conditioning with 48 % and lighting with 23 % (ELETROBRAS 2005). Table 1 shows a summary of the CO_2 emissions from fuel combustion and electricity use in residential, commercial, and public buildings in Brazil.

GHG emissions from Brazilian buildings sector is significantly lower when compared with other countries. For instance, in absolute terms, in the year 2010, Brazilian residential buildings accounted for 15.5 million tons of CO_2 from fuel combustion while in the same year this value was 321.7 in the USA, 303.1 in China, 82.4 in the UK, and 74.8 in India (IEA 2011). Besides the differences related to the wealth of these countries (e.g., stock of buildings, ownership of appliances, level of public and commercial activities, etc.), two main factors contributed to this comparatively low CO_2 emission in Brazilian buildings: the low need for heating (which is only needed in the southern part of the country) and a power generation matrix that is predominantly (75.9 %) hydro-based (MME & EPE 2011).

However, Brazilian energy use and GHG emissions from buildings is expected to grow in the next decades. While in 1990 the use of electricity accounted for only 13.5 % of buildings CO_2 emissions, this grew to 20 and 39.8 % in the years 2005 and 2010, respectively. This trend will continue for the foreseeable future: according to the National Energy Plan 2030 (EPE 2007), by the year 2030, the electricity consumption is expected to, at a minimum, triple in public and commercial buildings and double in residential buildings. This increase in building-related electricity demand will certainly result in higher CO_2 emissions and is likely to come from the increasing use of coal and other fossil fuels.

An effective diffusion of EE technologies requires the implementation of public policy mechanisms[2] specifically addressed to overcome barriers that limits the broad adoption of these technologies. There are various mechanisms that have been applied around the world and they are classified into different categories according to their main characteristics: (1) regulatory and control mechanisms, that are laws and regulations that require certain devices, practices, or system designs to improve energy efficiency; (2) economic/market-based instruments that use market forces to encourage behavioral changes by end users and electricity (Vine et al 2003); (3) fiscal instruments and incentives that usually correct energy prices either by a tax aimed at reducing energy consumption or by financial support if first-cost related barriers are to be addressed (UNEP 2007a, b; Brown 2014); (4) support, information, and voluntary action; these instruments aim at persuading consumers to change their behavior by providing information and examples of successful implementation (IEA 2005); and (5) funding mechanisms that provide funding for other mechanisms (Vine et al 2003).

This paper summarize the results of the evaluation regarding energy efficiency in buildings sector from the project entitled "The evaluation of energy efficiency and CO_2 equivalent abatement potentials according to

[1] In the year 2005, the total emissions of CO_2-equivalent in Brazil was 2.2 billion of tons, which represented approximately 4.5 % of global emissions in the same year. The sector "change in land use and forestry," which includes the deforestation in the Amazon and other biomes (Cerrado, Caatinga, Pantanal, Pampas, and Atlantic forest) took part with 61 % of these emissions (MCT 2010).

[2] Vine et al (2003) define public policy mechanisms as "initiatives that aim to overcome policy and program barriers that prevent the pursuit of cost-effective energy efficiency and load management activities and the achievement of national energy policy goals."

Table 1 CO_2 emissions from Brazilian buildings

Sector	Emission source	1990		2005		2010	
		1000 ton	%	1000 ton	%	1000 ton	%
Residential	Electricity	1376	9.1 %	2354	13.2 %	6386	29.2 %
	Fuels	13,818	90.9 %	15,484	86.8 %	15,484	70.8 %
	Total	15,194		17,838		21,870	
Commercial	Electricity	674	24.5 %	1,513	43.6 %	4,105	67.8 %
	Fuels	2,075	75.5 %	1,954	56.4 %	1,954	32.2 %
	Total	2749		3467		6059	
Public	Electricity	513	50.1 %	926	34.7 %	2179	55.6 %
	Fuels	510	49.9 %	1739	65.3 %	1739	44.4 %
	Total	1023		2665		3918	
Total	Electricity	2563	13.5 %	4793	20.0 %	12,670	39.8 %
	Fuels	16,403	86.5 %	19,177	80.0 %	19,177	60.2 %
	Total	18,966		23,970		31,847	

Source: own estimations and MCT (2010)

different technology dissemination policies: guidelines to public policy-makers" which is part of the FAPESP Research Program on Global Climate Change (RPGCC). An overview on the general results of this project were published by Melo et al (2013), and specific results on grid-connected photovoltaic were published by Jannuzzi and Melo (2012). This paper provides estimations of energy saving potential according to three options of public policy mechanisms related to diffusion of EE technologies: (1) improvement of minimum energy performance standards (MEPS), mechanism already implemented in Brazil; (2) implementation of public procurement regulation regarding EE, not implemented in Brazil; and (3) implementation of EE requirements in building codes regarding EE for new buildings, not implemented in Brazil. The estimates are performed for commercial, public, and residential buildings assuming projections over the period starting in the year 2014 up to the year 2030, which is the horizon year in the National Energy Plan (EPE 2007). From these results is performed a cost-effectiveness analysis of each CO_2 abatement option through marginal abatement cost curves (MACC). In the next section, the paper presents the methodological approach, the scenarios, and the respective assumptions. In the "Results" section are presented the results in terms of energy saving and CO_2 mitigation potential and the MACC analysis. The paper concludes discussing the main findings and pointing out some advantages and limitations of this type of approach.

Methodology

In this study, expert-based[3] MACC analysis is applied to evaluate the cost-effectiveness of three policy mechanisms related to the diffusion of energy efficiency technologies in the buildings sector: MEPS, public procurement regulation, and building codes. Given the difficulty in providing estimates for a large number of EE solutions and for the related mechanisms, it was decided to perform a qualitative selection of mechanisms aiming to identify the options more suitable for the Brazilian buildings. This first evaluation was qualitative and based on a review of the international experience (documents, papers, studies, and reports) related to EE mechanisms implemented around the world. This literature review was published by Jannuzzi et al. (2012), and the results of a multi-criteria analysis (MCA) developed to rank the mechanisms were published by Melo et al. (2013). From these results were selected specific cases of EE options to be evaluated through MACC analysis, described as follows.

Marginal abatement costs curves (MACC) are a useful tool for evaluating CO_2 mitigations options. It is defined as a graph that indicates the cost associate with the last unit (the marginal cost) of emission abatement

[3] Expert-based approaches are one means of deriving estimates of the expected costs and energy savings of a particular measure to be included in the marginal cost curves.

for varying amounts of emission reduction (Kesicki 2010). Several studies have applied this method for technology assessment and for comparing projects and opportunities for mitigation GHG emissions, for instance, IEA (2008) and McKinsey and Company (2009). In order to apply the MACC method, two scenarios are projected: (1) a baseline scenario (*base*), which reflects the continuity of the current MEPS restrictions for appliances used in Brazil and the absence of energy efficiency public procurement regulation and EE requirements in building codes, and (2) an alternative scenario (*alt*) based on a more stringent MEPS, on the implementation of codes for new buildings and on the application of public procurement regulation concerning EE. The potential impacts in terms of energy savings and related CO_2 mitigation of each policy mechanism regarding specific technologies are estimated from the differences between these scenarios. The projection methods and assumptions used in the estimates are described as follow for each kind of mechanism.

Minimum energy performance standards

In Brazil, energy efficiency standards policy formally begins with the Energy Efficient Act—enacted in 2001. In the context of this Law, a set of MEPS for electric motors, solar water heaters, furnaces and gas stoves, air conditioners, fluorescent and incandescent lamps, ballasts, refrigerators, and freezers have been implemented over the last decade. This paper performs estimates assuming a more stringent MEPS and its broadening to reach other appliances. Specifically, we estimate the impacts of MEPS (referenced as "P"[4] from here on) for the following cases: (1) residential (R) sector: refrigerators (REF) (alternative P REF R), air conditioning (AC) devices (alternative P AC R), incandescent bulbs (LAMP) (alternative P LAMP R), and standby (STB) power (alternative P STB R); (2) commercial (C) sector: air conditioning devices (alternative P AC C), tubular fluorescent lamps (P LAMP C), and standby power (P STB C); (3) public sector (Pb): air conditioning devices (alternative P AC Pb), tubular fluorescent lamps (P LAMP Pb), and standby power (P STB Pb).

The model used to simulate MEPS impacts is based on Melo and Jannuzzi (2010), which combines a bottom-up analysis based on detailed engineering appliance data with a stock forecast model. A sales model determines the fraction of appliances that will be affected by efficiency programs at any point in the forecast. In Brazil, there is a combined effect of economic growth and increase of number of buildings, which the "first purchase" component is a considerable driver of sales. Sales due to increased ownership are given by Eq. 1.

$$PC(y) = NR(y) \times S(y) - NR(y-1) \times S(y-1) \tag{1}$$

Where *PC* stands for first purchase, *NR*(*y*) is the number of households in each year, and *S*(*y*) is the appliance ownership in the year *y*. In the approach, the evolution of the ownership is based on EPE (2011). In addition to first purchases, the model describes the replacement of an appliance in terms of an annual retirement probability that varies as a function of the appliance age. It is given by Eq. 2.

$$P_e(Id) = \frac{1}{1 + e^{-\left(\frac{Id - Vu}{Did}\right)}} \tag{2}$$

Where *P*(*Id*) is the probability of retirement at a given appliance age (*Id*), *Vu* is the average lifetime of the product, and *Did* is the mean deviation of replacement ages, assumed to be two years. In this way, the appliances replacement in each year is given by Eq. 3.

$$\mathrm{Sub}(y) = \sum_{Id=1}^{Vu} \mathrm{stock}(y-1, Id) \times P_e(Id) \tag{3}$$

Where Sub(*y*) is the number of equipment replaced in year *y*. Stock(*y-1*, *Id*) is the number of products of vintage *Id* remaining in each year. At last, the total sales (TS) for the each year are given by Eq. 4.

$$\mathrm{TS}(y) = Sub(y) + PC(y) \tag{4}$$

The total conserved energy is given by Eq. 5.

$$\mathrm{ES}(y) = \mathrm{CE}_{\mathrm{BASE}}(y) - \mathrm{CE}_{\mathrm{MEPS}}(y) \tag{5}$$

where ES is the total energy saving, CE is the energy consumption in each scenario given by Eq. 6:

$$\mathrm{CE}(y) = \sum_{Id=1}^{Vu} \mathrm{stock}(y, Id) \times \mathrm{Ce}(yp) \tag{6}$$

Ce is determined according to the year of purchase (*yp*). The Ce differs between the baseline and the

[4] P means "Padrões," that is the translation for standards in Brazilian-Portuguese language.

alternative MEPS scenario for the year after the new MEPS implementation.

Table 2 shows the assumptions considered for estimating the potential impacts of MEPS. The parameters and assumptions employed in the simulations are detailed in the Appendix (for refrigerators Table 4, for air conditioning devices Table 5, for lamps Table 6, and for standby power Table 7). The impacts are accounted as the difference between a baseline scenario where the appliances are assumed to be operating at the current MEPS energy efficiency and an alternative scenario where those appliances purchased after the new MEPS implementation are more efficient. While in the baseline scenario, the MEPS prohibits manufacturers and importers to supply the market with appliances rated as F and G (according to the Brazilian Labeling Program (PBE), in the alternative scenario the minimum energy performance required is the A, which is the only rate with PROCEL label.[5] In the first year of implementation, the new MEPS affects only new products, excluding those already installed before the implementation year. As a consequence, in the first years after the implementation of more stringent MEPS, the estimated energy savings are small. However, as time goes on, more appliances are impacted by the new MEPS, contributing to more effective results.

Public procurement regulation

Public procurement regulations can be a very effective instrument to promote market transformation toward EE. In several countries, the public sector is the larger consumer of energy and goods. Countries such as Germany, France, UK, Italy, and USA have introduced regulations with provisions related to EE and environmental issues in public procurement. The specifications are performed in different ways and include different technologies and energy end uses. For instance, UK requires life-cycle cost analysis, Italy specifications concern about buildings, and in USA federal agencies are required to purchase ENERGY STAR qualified or Federal Energy Management Program (FEMP) designed products as well as to purchase products using less power in the standby mode (FEMP 2013). Furthermore, some developing countries such as China, South Korea, Mexico, Thailand, South Africa, and Ghana have also applied regulations aimed at energy saving (UNEP 2007b).

In Brazil, the Law N° 8,666/93 regulates public purchasing at three different levels, namely federal, state, and municipal. This law stipulates that all procurement services and goods have to be tendered based on the best-price criteria. This regulation does not define criteria other than prices to be taking into account in the process of public purchasing. Then, a great potential of energy saving that could be reached through this mechanism is not captured, and the public sector still purchases inefficient appliances low rated according to PBE.

In order to estimate potential impacts of EE provisions in public procurement in Brazil, this study evaluates two opportunities for public buildings. These options are based in the assumption that the public sector should lead by example and pull the market aiming at its transformation. The assumptions for public procurement regulations relate to high efficient tubular fluorescent lamps T5 replacing T8, T10, and T12 (alternative RC LAMP P), as well as standby power for electrical and electronic public office equipment (alternative RC STB P), which shall not exceed 0.5 W, both cases starting from 2014. The goal is to estimate the impacts in terms of electricity savings and their potential to mitigate CO_2 emissions in the public sector that can be achieved with these regulations.

Building codes

This mechanism has the purpose of setting specifications of energy consumption for the building as a whole or for the building systems such as heating or air conditioning. There are prescriptive codes, which define different levels of performance for the building envelope and its components, such as the minimum thermal resistance of the walls, and also codes that consider the overall performance, prescribing only annual energy consumption levels. Building codes including EE specifications are applied in almost all developed countries and has been confirmed as an interesting mechanism to promote the diffusion of innovative technologies which result in energy conservation (UNEP 2007b).

[5] PROCEL is the Brazilian National Program of Electric Energy Conservation and its "PROCEL" label is a voluntary label which aims to offer a way to distinguish the most efficient products in a particular category. Originally focused on home appliances (refrigerators, freezers, washing machines, and air conditioners), the PROCEL label is now taking aim at labeling consumer electronic products such as set-top boxes, computer monitors, DVDs, and TVs.

Table 2 Baseline MEPS and MEPS assumptions for alternative scenario

Sector	Appliances	Baseline—current MEPS regulation	Alternative scenario assumptions
Residential	Refrigerators	Ordinance MME-MCT-MDIC 362/2007—establishes maximum levels of energy consumption for refrigerators and freezers.	The current A rating of PBE label as standard of maximum consumption starting from 2014
Residential, public, and commercial	Air conditioning devices	Ordinance MME-MCT-MDIC 364/2007—establishes specific regulations defining the minimum levels of energy efficiency of air conditioning devices	The current A rating of PBE label as minimum levels of energy efficiency from 2014
Residential	Lamps	Ordinance MME/MCT/MDIC 132/2006 and 1.007/2010—regulations that specify minimum levels of energy efficiency of incandescent and prohibit their manufacture and sale	Technological standard that prohibits the sale of incandescent light bulbs starting from 2014
Residential, public, and commercial	Standby (electronic devices)	Nonexistent	1 W as maximum of power in standby mode starting from 2014
Public and commercial	Tubular fluorescent lamps	Nonexistent	Fluorescent lamps T5 and electronic ballasts as technological standard starting from 2014

In Brazil, the building codes have no specifications related to EE as yet. There is in the country the PROCEL-Edifica program, which is a voluntary labeling program (an informational mechanism) which specifies, for commercial and public buildings, methods for EE rating and includes requirements to meet energy saving measures related to lighting systems, air conditioning system, and envelope. Nevertheless, some regional initiatives have been developed in order to promote EE by applying building codes.

In this paper, we simulate two possible specifications for building codes (COD) as a mandatory system. The first one is related to the obligation of use of solar water heaters (AQS) in new residential (R) buildings (alternative COD AQS R) as a measure to replace the use of electrical showers. The second case covers public (Pb) and commercial (C) buildings and establishes codes (alternatives COD ENV C and COD ENV P) to reduce the energy use for environmental conditioning, with air conditioning devices, by applying envelope (ENV) technologies. For example, improved windows, doors and walls, insulation and air sealing, and reflective roof materials. It was assumed that these technologies can reduce the energy demand for cooling by 10 % in new buildings.

The marginal abatement cost curves

The marginal abatement cost curves (MACC) is calculated based on net present value (NPV) of benefits and costs incurred due the implementation of mechanisms for the society as whole. The NPV is the difference of upfront investment plus the operating and maintenance costs in each scenario over the period of evaluation. These cash flows are discounted back to the first year of implementation of mechanisms (2014). For example, the implementation of more restrictive MEPS for air conditioners devices result in incremental costs for customers since manufacturers incur additional costs to provide more energy efficient equipment on the markets. However, the MEPS reflect in benefits of energy savings (lower operating costs) that are accounted through savings in energy bills. The benefits for the society are accounted as the total economic savings due the reductions in the electricity bills. Equation 7 illustrates the model for accounting the benefits (BS).

$$BS(y) - ES(y) \times Tariff(y) \quad (7)$$

where ES(y) is the impact of energy saving due the implementation of each mechanism, and Tariff(y) is the average of prices of electricity to final consumers.

On the other hand, the total costs for the society of each mechanism is the sum of costs of all customers that adopt the EE measures. Equation 8 illustrates the model of accounting the costs (CS).

$$CS(y) = (TS_{alt}(y) \times UC_{alt}(y)) - (TS_{base}(y) \times UC_{base}(y)) \quad (8)$$

where TS is the total units sold (equipments in the case of MEPS and public procurement regulation and new buildings in the case of building codes) and UC is the unit cost of the EE measure. The total units sold per year are the same in both scenarios.

The NPV of each option is then defined as the sum, over the forecast period, of the differences of benefits and costs as given by Eq. 9.

$$NPV = \sum_{y} [BS(y) - CS(y)] \times \left[\frac{1}{(1+r)^{y-y_0}} \right] \quad (9)$$

where r is the discounting rate considered 8 %[6] in the simulations.

Then, the abatement costs are calculated according to the estimates of CO_2 mitigation resultants of the EE mechanisms implemented. Equation 10 shows the model used to calculate the marginal abatement cost curves.

$$MAC_m = \frac{NPV_m}{M_m} \quad (10)$$

where MAC_m is the marginal abatement cost of mechanism m and M_m is the total amount of CO_2 mitigation proportionate by the implementation of mechanism m.

Results

Table 3 shows the results of estimations in terms of energy savings and CO_2 mitigation potential. The greatest potential identified is the application of MEPS for air conditioners devices in commercial buildings. A total of 270 TWh could be saved by restricting the MEPS for this appliances. The second largest potential, 165 TWh, results from the application of technological standard for EE lighting in residential buildings. Regarding all policy mechanisms, the total potential for electricity saving is about 795 TWh and for CO_2 mitigation is about 74 million tons of CO_2e over the period 2014 to 2030. These potential impacts are very significant and represent an average of 13 % of electricity saving per year and an average of mitigation of 15 % per year between 2014 and 2030. Figures 1 and 2 show the projected results for energy savings and CO_2 mitigation, respectively. The total electricity consumption of the buildings sector projected up to the year 2030 is the estimate provided by the National Energy Plan 2030 (EPE 2007), which is the last official long-term projection for the energy sector in Brazil.

Figure 3 shows the MACC related to the impacts of EE policy mechanisms and its respective CO_2e mitigation potential. The height of the bar represents the cost per ton of CO_2e emissions reduction, and the measures are ranked according to their unit cost. More cost-effective measures are on the left side of the figure and have negative abatement costs, which mean that these measures have potential to save money while reducing CO_2 emissions. The marginal abatement costs proved to be negative in 13 of the 15 options evaluated. The most cost-effective options are MEPS for lamps (compact fluorescent lamp (CFL) for residential sector and tubular fluorescent lamps (TFL) for public and commercial sectors), for standby power, and air conditioners devices. The highest potential of CO_2e mitigation is associated to the improvement of EE of air conditioners devices in the commercial sector and the replacement of incandescent technology for compact fluorescent lamps in residential sector. The building codes for new commercial and public buildings were the only mechanisms that showed positive costs. In fact, building codes present high upfront costs for conforming new buildings to specific energy norms. In simulations, the initial costs to minimize the operation of air conditioning devices, through the application of envelope technologies, were assumed as 1 % of the total cost of the building, a conservative premise but very significant in terms of costs.

Final remarks

In Brazil, the electricity demand in the buildings sector is still rising as well as the related CO_2 emissions. In this scenario, EE options can represent interesting opportunities to capture economic benefits while

[6] It is the discounting rate applied in the National Energy Plan 2030 (EPE 2007).

Table 3 Impacts of the policy mechanisms in terms of energy saving potential and abatement of CO_2 potential

Residential buildings—R (cumulative total from 2014 to 2030)			Commercial buildings—C (cumulative total from 2014 to 2030)			Public buildings—P (cumulative total from 2014 to 2030)		
Mechanism	Energy saving potential (TWh)	Abatement potential[a] (million tons of CO_2)	Mechanism	Energy saving potential (TWh)	Abatement potential (Million tons of CO_2)	Mechanism	Energy saving potential (TWh)	Abatement potential (Million tons of CO_2)
P REF R	9.67	0.90	P AC C	269.76	25.10	P AC PUB	67.44	6.27
P AC R	5.49	0.51	P LAMP C	65.90	6.13	P LAMP P	17.35	1.61
P LAMP R	165.62	15.41	P STB C	35.15	3.27	P STB P	11.12	1.03
P STB R	59.33	5.52	COD ENV C	3.54	0.33	RC STB P	12.88	1.20
COD AQS R	69.38	6.45				RC LAMP P	1.81	0.17
						COD ENV P	0.15	0.01
Total	309.49	29.74	Total	374.35	34.83	Total	110.76	10.30

[a] To estimate the weight of buildings electricity consumption in CO_2 emissions from power generation, we apply an emission factor of 0.080 t CO_2e per megawatt hour that is an average of official assumptions in the PNE 2030 (EPE 2007) and an loss factor for the Brazilian Interconnected System of 15 % (EPE 2011)

simultaneously minimizing the required expansion of power generation and its associated greenhouse gas emissions. However, to reach these benefits is not an easy task. The international experience has shown that the implementation of public policy mechanisms designed to improve the dissemination of EE technologies are decisive to overcome EE barriers. Brazil has implemented a few mechanisms that are broadly applied around the world, such as EE labeling and MEPS. However, the country is still losing opportunities due to the lack of stringency in the case of mandatory mechanisms and absence of mechanisms such as public

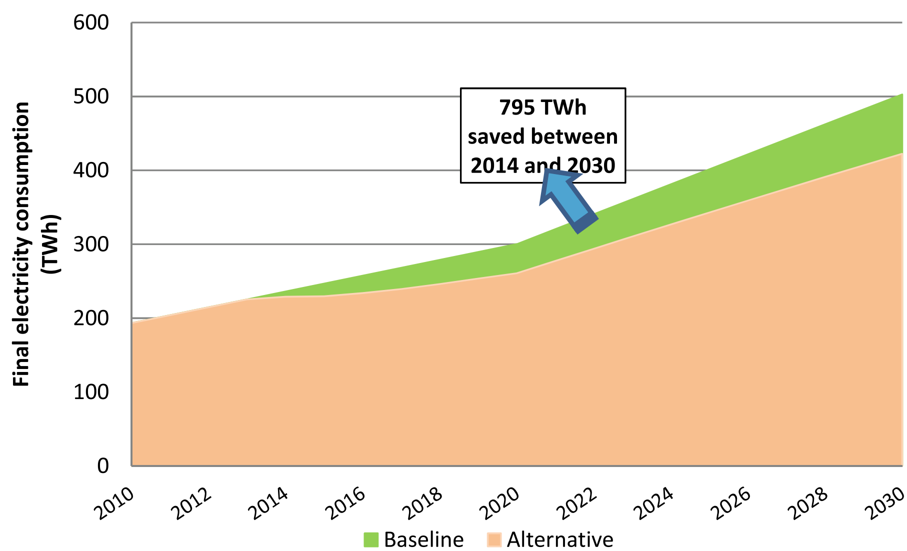

Fig. 1 Projected scenarios: potential for electricity savings in buildings sector

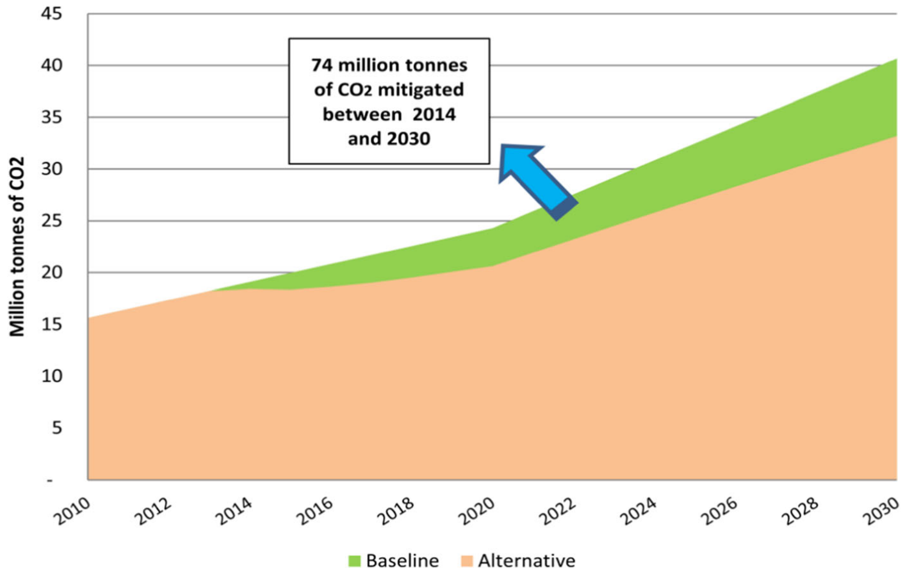

Fig. 2 Projected scenarios: potential for CO_2 mitigation in buildings sector

procurement regulation and building codes associated to EE specifications.

This paper provided an impact evaluation regarding three EE policy mechanisms. The goal was to account

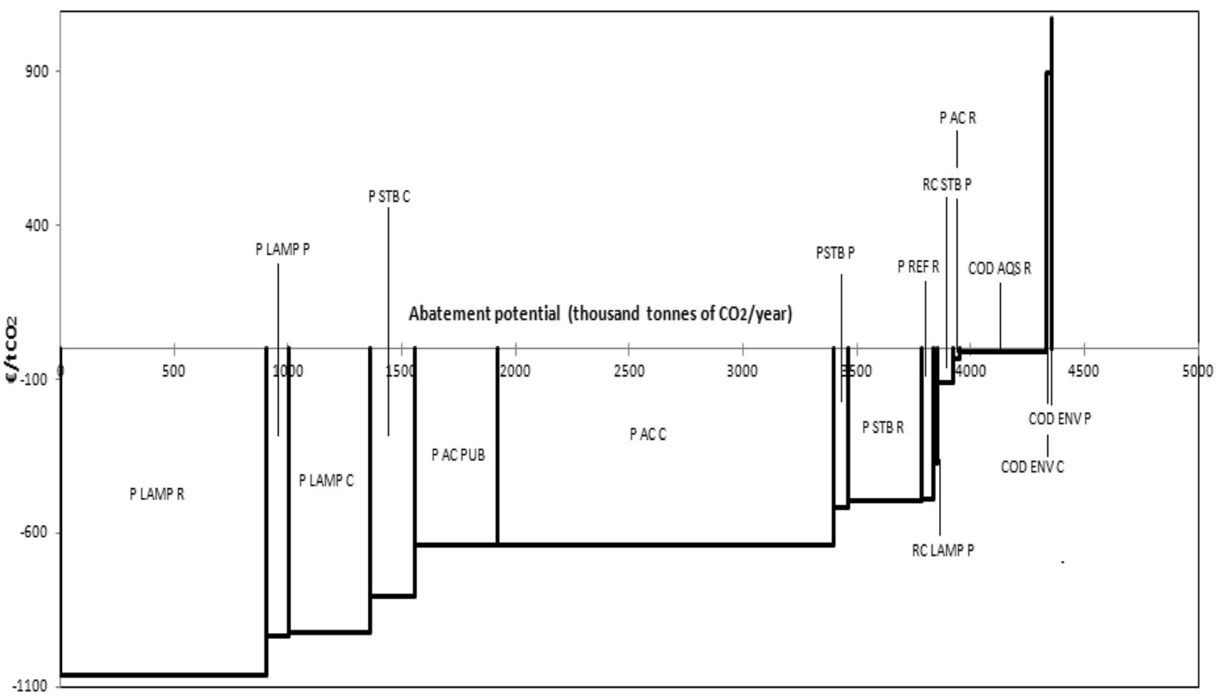

Fig. 3 MACC for EE alternatives

the potential benefits from the diffusion of EE technologies and the related CO_2 emissions reduction. The estimates shown that 13 of 15 alternatives associated with the mechanisms evaluated are cost-effective and would represent a total of 795 TWh of electricity savings and 75 million tons of CO_2 emissions reduction between the year 2014 and 2030. According to the MACC method, the best classified alternatives are MEPS for lighting appliances, the introduction of MEPS for standby power mode, and more stringent MEPS for air conditioning devices and refrigerators. In terms of CO_2 emissions reduction, the highest potential is the use of air conditioning devices in commercial and public buildings. This occurs due to a wide availability of low efficiency appliances in the market where just approximately 5 % has PROCEL label A.

It is important to point out that this type of methodological approach is useful to understand how much EE policy mechanisms can contributes toward the CO_2 emissions reduction efforts and what are the magnitude of the related costs. However, MACC methodology has some limitations; first, it is based on a simplification of reality, and therefore, it could not include cost components that affect the results of the abatement costs, for instance, the costs of mechanisms implementation and transaction costs. In addition, barriers to EE, such as lack of management awareness, lack of information, and lack of financing, are not taken into account. In fact, to capture these potential benefits is not an easy task, and it requires well-designed public policies and strong institutions concerned with a more sustainable energy development. Other limitation of this analysis is that the studied examples, both mechanisms and EE technologies options, despite being broadly implemented around the world, are only a short list of the probable solutions for Brazilian buildings. The total results in terms of potential electricity savings from these few measures is not an estimate of the full potential of energy savings or CO_2 emissions reductions.

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Appendix Parameters and assumptions for appliances

Table 4 Parameters and assumptions for refrigerators

Refrigerators	Equivalent models		
	One door	Combined	Combined frost free
Market share (%)—total Brazil	78 %	10 %	12 %
Volume (l)	260	360	490
Label A[a]—consumption (KWh/year)	240	576	720
Label A—market share (%)[b]	80 %	85 %	95 %
Average of other labels (B, C, D, and E)[c]—consumption (KWh/year)	300	732	876
Average of other labels (B, C, D, and E)—market share (%)[d]	20 %	15 %	5 %
Incremental cost[e,f] (US$)	52.6	105.3	157,9

[a,b,c, and d] Based on INMETRO 2012

[e] 1,9 R$/US$ as for November 2012

[f] Based on market survey

Table 5 Parameters and assumptions for air conditioning devices

Air conditioning devices	Equivalent models		
	Residential		Public and commercial
	Window	Split	Split (floor/ceiling—triphasic)
Market share (%)—total Brazil	50 %	50 %	100 %
Capacity (Btu/h)	7500	9000	60,000
Label A[a]—consumption (KWh/year)	1011.2	1075.2	6816.0
Label A—market share (%)[b]	60 %	25 %	5 %
Average of other labels (B, C, D, and E)[c]—consumption (KWh/year)	1075.2	1126.4	8883.2
Average of other labels (B, C, D, and E)—market share (%)[d]	40 %	75 %	95 %
Incremental cost[e,f] (US$)	78.8	105.3	894.7

[a, b, c, and d] Based on INMETRO 2012

[e] 1,9 R$/US$ as for November 2012

[f] Based on market survey

Table 6 Parameters and assumptions for lamps

Lamps	Models			
	Residential		Public and commercial	
	CFL	Incandescent	T5	T8/T10/T12[a]
Lamp potency (W)	15	60	28	36
Ballast potency (W)	–	–	4	11
Consumption (KWh/year)	16.2	64.8	92.2	132.5
Lifetime (years)	5	1	5	5
Equipment cost[b,c] (US$)	5.3	1.6	5.8	3.7

[a] Average based on market survey

[b] 1,9 R$/US$ as for November 2012

[c] Based on market survey

Table 7 Parameters and assumptions for standby power

Standby devices	Residential		Public and commercial	
	Baseline	Alternative	Baseline	Alternative
Average potency (W) per device[a]	3.1	1	3.1	1
Total consumption per building (KWh/year)[b]	27.3	8.7	203.7	65.2
Equipment cost[c,d] (US$)	52.6	73.7	52.6	73.7

[a] Average based on market survey

[b] Based on average consumption of commercial and public buildings

[c] 1,9 R$/US$ as for November 2012

[d] Based on market survey

References

Brown, M. A. (2014). “Innovative Energy-Efficiency Policies: An International Review,” Wiley Interdisciplinary Reviews (WIREs): Energy and Environment.

DECC. (2012). *Statistical Release—2011 UK greenhouse gas emissions, provisional figures and 2010 UK greenhouse gas emissions, final figures by fuel type and end-user*. London: Department of Energy & Climate Change.

DOE. (2012). *China's Building Energy Use: A Long-Term Perspective based on a Detailed Assessment*. Washington: Pacific Northwest National Laboratory.

EIA. (2009). *Emissions of greenhouse gases in the United States*. Washington: U.S. Energy Information Administration.

ELETROBRAS (2005). Survey of Appliances and Consumer Habits. Available at: http://www.eletrobras.com/pci/main.aspS (accessed in May 2008).

EPE. (2007). *Plano Nacional de Energia 2030*. Rio de Janeiro: Empresa de Pesquisa Energética.

EPE. (2011). *Projeção da demanda de energia elétrica para os próximos 10 anos (2011-2020)*. Rio de Janeiro: Empresa de Pesquisa Energética.

FEMP (2013). *Federal Energy Management Program.* [Online] Available at: http://www1.eere.energy.gov/femp/technologies/eep_resources.html.

IEA. (2005). *Evaluating Energy Efficiency Policy Measures & DSM Programmes Volume I Evaluation Guidebook*. Paris: International Energy Agency.

IEA. (2008). *Energy Technology and Perspectives 2008 – Scenarios & Strategies to 2050*. Paris: International Energy Agency.

IEA. (2011). *CO2 Emissions from Fuel Combustion—Annual Historical Series (1971–2010)*. Paris: International Energy Agency.

INMETRO (2012). National Institute of Metrology, Quality and Technology. Tabelas de consumo/eficiência energética. Available at: http://www.inmetro.gov.br/consumidor/tabelas.asp.

IPCC. (2007). *Climate Change 2007. Final report of Working Group 3*. London: Cambridge University Press.

Jannuzzi, G. M., & Melo, C. A. (2012). Grid-connected photovoltaic in Brazil: Policies and potential impacts for 2030. *Energy for Sustainable Development, 17*(2013), 40–46.

Jannuzzi, G. M., Melo, C. A., Tripodi, A. (2012). Políticas Públicas para Promoção da Eficiência Energética no Brasil: Uma Análise Multicritério. [Online] Available at: ⟨http://www.iei-la.org/index.php/publications/politicas-publicas-para-promocao-da-eficiencia-energetica-e-microgeracao-renovavel-em-edificacoes-no-brasil-uma-analise-multicriterio⟩.

Kesicki (2010). Marginal abatement cost curves for policy making – expert-based vs. model-derived curves. Paper presented at the 33rd IAEE International Conference, 6-9 June 2010, Rio de Janeiro, Brazil.

McKinsey & Company. (2009). *Pathways to a low carbon economy v 2.0*. São Paulo: McKinsey & Company.

MCT. (2010). *Segundo Inventário Brasileiro sobre Mudanças Climáticas*. Brasília: Ministério de Ciência e Tecnologia e Inovação.

Melo, C., & Jannuzzi, G. (2010). Energy efficiency standards for refrigerators in Brazil: a methodology for impact evaluation. *Energy Policy, 38*, 6545–6550.

Melo, C. A., Jannuzzi, G. M., & Tripodi, A. (2013). Evaluating public policy mechanisms for climate change mitigation in Brazilian buildings sector. *Energy Policy, 61*, 1200–1211.

MME &EPE (2011). National Energy Balance. Available at: http://www.epe.gov.br.

PBL. (2012). *Trends in global CO2 emissions - 2012 Report*. The Hague: PBL Netherlands Environmental Assessment Agency.

UNEP. (2007a). *Assessment of policy instruments for reducing greenhouse gas emissions from buildings*. Budapeste: United Nations Environment Programme.

UNEP. (2007b). *Buildings and Climate Change Status, Challenges and Opportunities*. Nairobi: United Nations Environment Programme.

UNEP. (2009). *Greenhouse Gas Emission Baselines and Reduction Potentials from Buildings in South Africa*. Paris: United Nations Environment Programme – Sustainable Buildings & Climate Initiative.

Vine, E., Hamrin, J., Eyre, N., Crossley, D., Maloney, M., & Watt, G. (2003). Public policy analysis of energy efficiency and load management in changing electricity businesses. *Energy Policy, 31*, 405–430.