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Evaluating public policy mechanisms for climate change mitigation in Brazilian buildings sector

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HIGHLIGHTS

- We apply a multi-criteria analysis to evaluate EE and RES policies mechanisms.
- We apply marginal abatement cost curves to evaluate EE and RES policies mechanisms.
- We provide rankings of mechanisms according to their prospective potential impacts.
- There is a significant cost effective energy saving potential in Brazilian buildings.
- Brazil should improve MEPS and implement other policy mechanisms.

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ABSTRACT

This paper applies a multi-criteria analysis (MCA) and marginal abatement cost curves (MACC) to evaluate public policies mechanisms to promote the dissemination of energy efficiency (EE) and on-site renewable energy sources (RES) technologies in Brazilian buildings sector. The objective here is to bring together the advantages of both methods in order to provide more valuable insights to policy makers. The MCA results show that in the case of more integrative policies, which considers, for instance, potential of jobs creation, the mechanisms to foster distributed RES and solar water heaters are better ranked than in MACC analysis, where only cost-effectiveness of each option is evaluated. Other key finding is that: (1) there is a significant cost effective potential that could be reached through alternative mechanisms not implemented yet in the country, such as public procurement regulation and building codes and; (2) minimum energy performance standards (MEPS) could be broader in scope and more stringent and include the use of energy in standby mode and tubular fluorescent lamps. In particular, some important appliances such as large air conditioning devices should have more aggressive MEPS.

1. Introduction

Several studies (e.g. IPCC, 2007; IEA, 2008; McKinsey and Company, 2009; 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 energy efficiency (EE) and renewable energy sources (RES). 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. According to UNEP (2007a) and IEA (2005b) 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 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 the increase in fossil fuel consumption and related CO_2 emissions (PBL, 2012; DOE, 2012).

In Brazil, the fuel combustion in residential, commercial and public buildings only accounts for about 2% of total CO_2 emissions in the country[1] and about 10% of energy-related CO_2 emissions. In absolute terms, in the year 2010, residential buildings accounted

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[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).

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Table 1
CO_2 emissions from Brazilian buildings.
Source: Own estimations and MCT (2010).

Sector	Emission source	1990		2005		2010	
		1000 t	(%)	1000 t	(%)	1000 t	(%)
Residential	Electricity	1,376	9.1	2,354	13.2	6,386	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	2,749		3,467		6,059	
Public	Electricity	513	50.1	926	34.7	2,179	55.6
	Fuels	510	49.9	1,739	65.3	1,739	44.4
	Total	1,023		2,665		3,918	
Total	Electricity	2,563	13.5	4,793	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	

for 15.5 million tonnes of CO_2 from fuel combustion (mainly firewood and LPG for cooking), while in comparison, in the same year this value was 321.7 in United States, 303.1 in China, 82.4 in United Kingdom 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 (EPE, 2011). Again for comparison, in the year 2010, while India, China, US and UK emitted, respectively, 912, 766, 522 and 457 g of CO_2 per kWh generated, in Brazil this value was 87 g of CO_2 per kWh (IEA, 2011).

However, Brazilian energy use and GHG emissions from buildings is expected to grow in the next decades. Table 1 shows a summary of the CO_2 emissions from fuel combustion and electricity use in residential, commercial and public buildings in Brazil. 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.

In the year 2010, for operation and maintenance, the Brazilian buildings consumed 48% of the total electricity in the country (BEN, 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% (Eletrobrás, 2007).

This paper assumes that wider use of EE technologies that are currently available to the Brazilian buildings sector represent a cost-effective potential contribution towards the global efforts in stabilizing the atmospheric concentration of GHGs. 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 efficient appliances (refrigerators, air conditioning, washing machine, etc), new lighting technologies (LEDs and fluorescent lamps), 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) and together with on-site generation options (mainly photovoltaic (PV) and wind generation), could potentially minimize the need for future expanded power generation based on fossil fuels, as is currently being planned by Brazilian Government in the Decennial Plan of Energy Expansion 2020 (EPE, 2011).

In a context of limited budgets, divergent interests and legal obligations, decision makers in Brazil face several difficulties in the process of finding appropriate and reliable solutions towards GHG mitigation. Priorities and strategies to disseminate low carbon technologies often compete in multiple aspects. To overcome these challenges, policy makers have made use of models and tools in order to assist in the process of finding solutions.

This paper applies two of the most applied methodologies in the process of taking decisions, Marginal Abatement Cost Curves (MACC) and the Multi-Criteria Analysis (MCA). The objective here is to bring together the advantages of both methods for evaluating policy mechanisms for dissemination of EE and RES in Brazilian buildings sector, in order to provide more valuable insights to policy makers than the use of just one method. The main advantage of MACC is that this method presents the cost necessary to abate a defined amount of carbon emissions according to different technologies/measures. While the cost-effectiveness of the solutions is crucial in the process of decision-making, other issues are also relevant, such as ease of implementation and impacts on potential job creation. MCA methods are therefore enable the evaluation of policies on criteria other than cost, even when different policy goals conflict.

The next section will explain the methodology and describe the fundamentals of MCA and MACC methods. Section 3 then turns towards the general concept of public policy mechanisms related to the promotion of EE and RES and its classifications. Section 4 applies the MCA method for providing a qualitative evaluation of mechanisms. Section 5 explains the process of estimating the potential impacts and gives the results. In Sections 6 and 7 the MACC and MCA (quantitative analysis) methods are applied in the results and a portfolio is generated with rankings of policy mechanisms according to MACC and MCA analysis. The paper concludes with some general remarks on Brazilian EE and RES policies, and limitations of the methodology of this paper.

2. Approach and methodologies

Decision-making in the EE and RES areas requires tools that provide policy makers better understanding of how to find appropriate and reliable policies, and their possible outcomes. Decision makers often need to deal with conflicting objectives and priorities, such as the cost of various technology options, environmental impacts, security of supply and economic externalities such as jobs creation potential need to be considered in the evaluation of policies instruments. Besides a cost-effectiveness evaluation which can be provided by MACC, MCA allows the inclusion and evaluation of different criteria. This can be useful to support the decision in selecting the best options to be implemented according to the policy priorities and goals.

Fig. 1 shows the flow chart of the methodological approach. The first step is to develop a broad base of data regarding policy mechanisms (types, implementation issues, impacts, etc.), technology solutions (EE and RES for buildings) and other data related to Brazilian current conditions (economic, demography and technical). The second step is a qualitative evaluation of policy mechanism through MCA. The objective of this step is filter some mechanisms which have already had their potential impacts (costs, energy savings, CO_2 mitigations, and jobs potential)

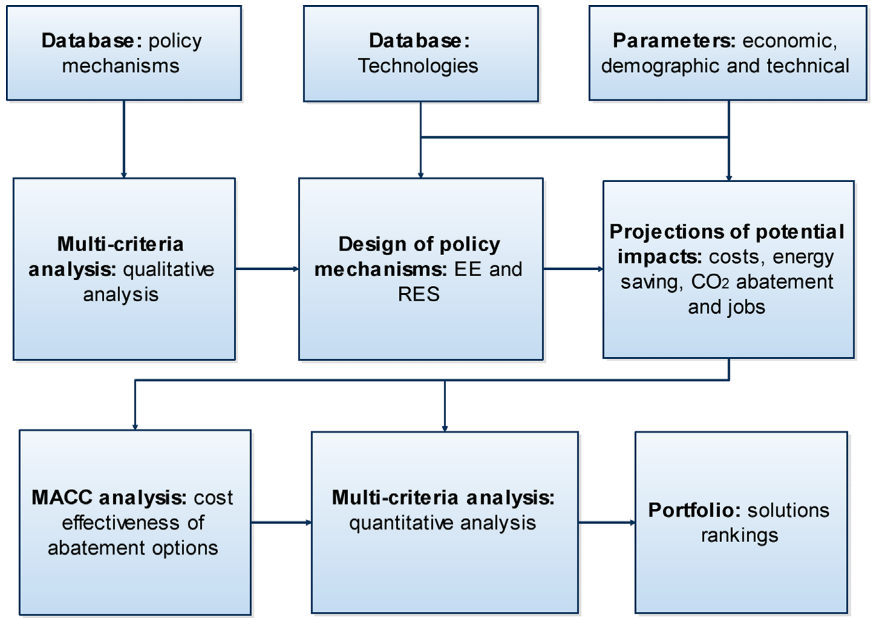

Fig. 1. Flowchart of the methodological approach.

estimated in the literature. The third step consists of estimating, for the previous selected mechanisms, the potential impacts in terms costs to society, energy savings (specific by end uses and type of buildings), job creation potential and CO_2 mitigations. Finally, from these results, MACC and MCA methods are applied in order to create a portfolio of options that can assist the decision making process.

2.1. MCA

The MCA methods have been widely used in analysis of energy and climate issues such as in Greening and Bernow (2004), Ren et al. (2009), Tsoutsos, et al. (2009), Mourmouris and Potolias (2013) and specifically in the evaluation of energy and climate policy mechanisms as in Konidari and Mavrakis (2007), Blechinger and Shah (2011). The main advantages of these type of methods are that (1) they are designed for decision support; (2) they promote the description and understanding of the problem; (3) they can aggregate criteria with very distinctive nature; and (4) they establish a rank order of alternatives according to different goals.

In this paper the method PROMETHEE II developed by Brans et al., (1986) – standing for "Preference Ranking Organization Method for Enrichment Evaluations") – was selected to perform the MCA. It is one of the best known and most widely used in research and evaluation of alternatives in numerous areas including sustainable energy planning (Oberschmidt et al., 2010). Some examples of PROMETHEE application in energy area are the comparison of energy technologies based on renewable, fossil and nuclear (Topcu and Ulengin, 2004); the design of energy policy mechanisms (Madlener and Stagl, 2005; Doukas et al., 2006); the prioritization of clean development mechanism projects (Diakoulaki and Karangelis, 2007); evaluation of residential energy systems (Ren et al., 2009); and for assesssing energy technologies (Oberschmidt et al., 2010).

PROMETHEE is an outranking method which allows the evaluation of a broad spectrum of criteria with different weighting and goals. First, the method determines the differences d_i between the values of jth alternative and the kth alternative (a_k) on the ith criterion (Eq. (1)).

$$d_i(a_j, a_k) = x_{i,j} - x_{i,k} \tag{1}$$

Following is applied the preference function P which denotes the preference of alternative (a_j) regard to alternative (a_k) on each criterion as described by Eq. (2).

$$P_i(a_j, a_k) = F_i[d_i(a_j, a_k)] \tag{2}$$

There are six typical types of preference functions described by Mareschal (2012). In this paper we apply two types of preferences functions describes by Eqs. (3) and (4). The "Usual" function (Eq. (3)) is appropriate to make qualitative comparison of alternatives in terms of "worse or better". On the other hand, the Linear preference function (Eq. (4)) is indicated for making quantitative analysis. This function is calculated based on the value of differences and allows the analyst to define a upper boundary (s).

$$p(d) = \begin{cases} 0 & \text{when } d \le 0 \\ 1 & \text{when } d > 0 \end{cases} \tag{3}$$

$$p(d) = \begin{cases} 0 & \text{when } \ d \le 0 \\ \frac{d}{s} & \text{when } \ 0 < d \le s \\ 1 & \text{when } d > 0 \end{cases} \tag{4}$$

Then is calculated the global preference index $\pi(a_j,a_k)$ which is defined as the weighted sum of $p(a_j,a_k)$ for each criteria as showed in Eq. (5).

$$\pi(a_j, a_k) = \sum_{i=1}^{m} P_i(a_j, a_k) W_i \tag{5}$$

where W_i is weight of the ith criterion being $\sum_{i=1}^{m} W_i = 1$. Finally are calculated the positive and negative outranking flows according to PROMETHEE I as showed by Eqs. (6) and (7), respectively.

$$\varnothing_j^+ = \sum_{k=1}^{n} \pi(a_j, a_k) \tag{6}$$

$$\varnothing_j^- = \sum_{k=1}^{n} \pi(a_k, a_j) \tag{7}$$

In the PROMETHEE II a net outranking flow is calculated to define a complete preorder on the set of alternatives (Eq. (8)). In order to apply PROMETHEE I and II this paper applies the Software

Visual PROMETHEE (Mareschal, 2012).

$$\varnothing_j = \varnothing_j^{+} - \varnothing_j^{-} \tag{8}$$

2.2. MACC

Marginal Abatement Costs Curve (MACC) is a useful tool for evaluating CO_2 mitigations options. Several studies have applied this method for technology assessment and for comparing projects and opportunities for mitigation of GHG emissions (IEA, 2008; McKinsey and Company, 2009). In this study, MACC analysis offers a representation of the mechanisms implementation costs and the corresponding abatement potential that is estimated from a bottom-up analysis of data on mitigation options in buildings sector. In this sense, the marginal costs curves represent the net costs to society resulting from the mechanisms implementation and their respective CO_2e potential mitigation in a period of time. The net cost is the up-front investment in the technology plus the operating and maintenance costs over the period of evaluation (2014 to 2030) minus the cost savings over the life of the action. 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 will ultimately result in incremental costs for customers since manufacturers incur additional costs to provide the most efficient equipment. On the other hand, the MEPS also delivers benefits to final consumers as the energy savings results in lower operating costs.

3. Public policy mechanisms to promote EE and RES

Public policies concerned with energy savings and climate change mitigation will try mainly to address and overcome barriers for the dissemination of EE and RES technologies. These mechanisms have been classified into different categories according to their main characteristics, as for example in Vine et al. (2003), IEA (2005a) and UNEP (2007b). The main categories are:

– Regulatory and control mechanisms: "laws and implementation regulations that require certain devices, practices or system designs to improve energy efficiency (IEA, 2005a).
– Economic/market-based instruments: Mechanisms that use market forces to encourage behavioral changes by end users and electricity consumers (Vine et al., 2003).
– Fiscal instruments and incentives 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, 2007b).
– Support, information and voluntary action: Aim at persuading consumers to change their behavior by providing information and examples of successful implementation (IEA, 2005a).
– Funding mechanisms: Provide funding for other mechanisms (Vine, et al., 2003).

Several mechanisms have been applied around the word in order to promote EE. The most widely adopted are Labeling, which inform the consumers about product performance in terms of energy consumption; Minimum Energy Performance Standards (MEPS) that applies minimum energy performance standards to energy-using devices such as domestic appliances and equipment; Building Codes that contain provisions specifying required physical or performance characteristics for buildings or building subsystems; and Project or product-related subsidies (rebates) which are offered for the documented use of specific products or construction techniques and are generally gauged according to the efficiency level and quantity of equipment installed (IEA, 2005a).

In the case of RES the most applied policy mechanism is the Premium Feed-in tariffs which have been introduced in 20 EU countries (Campoccia et al., 2009). Other mechanisms such as Tradable Green Certificates (TGCs) and Renewable Portfolio Standards (RPS) directly promote the market of RES suppliers by establishing a minimum renewable energy quota that the utilities need to include in their energy mix. Additional instruments that act more directly by reducing the cost of RES are tax incentives which have been applied in the USA (Bolinger, 2009), France, and Belgium (SEI, 2012); and cash incentives (often known as "buy-down" or "rebate" programs) that have offered primarily up-front incentives to on-site RES installation. Net Metering, which enables utility customers with approved systems of onsite generation not only to interconnect with, and draw power from the grid when on-site power consumption exceeds on-site power generation and, also to feed power back into the grid when the reverse is true. This mechanism has been used in 44 states of the USA and in countries such as, Canada, Japan, Denmark and Italy.

4. MCA for selecting policy mechanisms alternatives

This section presents the first step in the application of MCA which is used for the selection of policy public mechanisms. In the literature review 14 policy mechanisms related to the promotion of EE and 6 related to the dissemination of RES were found. Given the difficulty in providing estimates for this large number of mechanisms it was decided to perform a qualitative selection of mechanisms aiming to point out the best options for proceed with the analysis. The next step consisted in making projections for the selected options to estimate potential impacts in terms of costs to society, energy savings (specific by end uses and type of buildings) and CO_2 mitigations. This proved necessary to minimize technical difficulties related to the design of each mechanism and issues such as superposition of mechanisms impacts. This first evaluation is qualitative and based on a review of international experience (documents, papers, studies and reports) related to EE and RES mechanisms implementation around the world. This collection was published by Jannuzzi et al. (2012). The authors analyzed the results from the literature survey and assembled the information as a decision matrix (Tables 3 and 4), in which values are attributed according to the performance for each policy mechanism alternative for each different criterion of evaluation.

The PROMETHEE analysis starts with the definition of the evaluation criteria. For our case study seven criteria were applied, as shown in Table 2. These criterion were chosen considering literature research, international experience with the mechanisms, and authors suggestions. These criteria aims, in a qualitative way, to measure comparatively some relevant aspects of the mechanisms evaluated.

Tables 3 and 4 show the decision matrices for the evaluation of EE and RES mechanisms, respectively. Based on the literature review and on the authors' expertise, all criteria are handled as qualitative criteria, even the costs related. It is emphasized that this analysis has intrinsic difficulties in measuring certain quantitative criteria due to the complexity in methods and data provided from the literature. In this evaluation, each alternative (policy mechanism) receives a value (score) ranging from 0 to 10 regarding to each criterion. The preference function applied is the Usual (described in Section 2.1) function which is suggested for qualitative criteria (Mareschal, 2012). This Usual function type and absolute thresholds (absolute difference) are selected for all the criteria.

Table 2
Evaluation criteria–description.

Criteria	Description
Prior experience (Expp)	This criterion reflects how much each mechanism has been used around the world. The greater the number of countries adopting the mechanism and time of adoption, the greater is the score that the mechanism receives, so the reverse is also true
Impacts demonstrated (IMPD)	This criterion rates each mechanism according to the impacts effectively demonstrated in relation to energy conservation and greenhouse gases mitigation
Ease of implementation (EA)	This criterion aims at identifying key points regarding the implementation of each mechanism. Issues ashuman resources, laboratory infrastructure and support, legal and regulatory framework are considered. This review is based on international experience and Brazilian's organizational and political context
Potential for market transformation (Ptm)	The score of this criterion is defined based on the potential for market transformation towards EE and RES. The contribution of each policy mechanism for changes in companies's structure towards more availability of efficient equipments and RES tecnologies in the market are considered for this criterion
Cost to Society (CS)	This criterion is scored according to the whole costs incurred by society resultant from the implementation and monitoring of each mechanism
Cost to Consumer (CC)	This criterion is scored according to the costs of each mechanism to consumers individually
Compatibility with the strategic objectives of the government (Coeg)	This criterion assesses how each mechanism is compliant with energy policies and climate change strategies in Brazil

Table 3
Decision matrix for the evaluation of policy mechanisms related to EE.

Id	Mechanism	Criteria						
		ExpP	ImpD	FacI	Ptm	CS	CC	Coeg
	Min/Max	Max.	Max.	Max.	Max.	Min.	Min.	Max.
EE1	**Minimum energy performance standards**	10	10	4	10	3	2	10
EE2	**Building codes**	4	4	5	5	2	3	10
EE3	**Mandatory labelling program**	2	1	5	3	2	4	8
EE4	**Mandatory audit programs**	2	2	4	3	1	1	10
EE5	**Public procurement regulations**	3	4	10	7	5	2	6
EE6	**Mandatory zero energy buildings**	1	1	5	6	2	10	5
EE7	**Energy efficiency certificate schemes**	1	1	3	3	0	2	6
EE8	**Energy performance contracting**	1	1	5	6	0	2	5
EE9	**Tax exemptions/ reductions**	3	3	6	4	7	0	3
EE10	**Capital subsidies, grants, subsidized loans**	3	2	3	3	9	0	4
EE11	**Information campaigns**	6	2	7	2	3	0	5
EE12	**Detailed billing and disclosure programs**	2	2	9	2	1	0	2
EE13	**Voluntary and negotiated agreements**	1	1	4	3	0	2	6
EE14	**Public leadership programs**	2	2	4	3	1	2	4

Table 4
Decision matrix for the evaluation of policy mechanisms related to on-site RES.

Id	Mechanism	Criteria						
		ExpP	ImpD	FacI	Ptm	CusS	CusC	Coeg
	Min/Max	Max.	Max.	Max.	Max.	Min.	Min.	Max.
RES1	**Capital grants, subsidized loans**	5	5	4	6	5	4	6
RES2	**Supply-push**	1	1	4	5	3	5	5
RES3	**Tax exemptions/reductions**	2	1	5	4	6	0	4
RES4	**Loans at reduced rates**	1	1	4	4	6	0	4
RES5	**Feed-in tariff**	7	9	2	9	10	1	4
RES6	**Net metering**	5	5	7	7	0	1	6

4.1. Results

Table 5 shows the results from the application of the PROMETHEE method. There are three outranking flows. The two partial preference flows (PROMETHEE I) are $\boldsymbol{\Phi}^{+}$ that represents the relative strength and the $\boldsymbol{\Phi}^{-}$ that corresponds to the relative weakness of the policy mechanisms alternatives. The general preference flow $\boldsymbol{\Phi}=\boldsymbol{\Phi}^{+}-\boldsymbol{\Phi}^{-}$ is the net flow of the alternatives resultant from the application of PROMETHEE II. In this first MCA application for the selection of some mechanisms, the evaluation criteria are equally weighted between themselves. For EE mechanisms, the greatest relative strengths were assigned to MEPS (EE1) with $\Phi=0.3956$, Procurement Regulation (EE5) with $\Phi=0.3407$ and Buildings codes (EE2) with $\Phi=0.2967$. The other mechanisms showed to be weaker in overall performance. In the case of RES, the betters mechanisms options are the Net Metering (RES6) with $\Phi=0.600$, Subsidies (RES1) with $\Phi=0.1714$ and the Feed-in tariff (RES5) with $\Phi=0.0571$. It is noteworthy that Net Metering has a high relative strength in this analysis due to the fact that this mechanism alternative receives low score in the criterion cost to society (CS), which means that this alternative presents a low cost to society as a whole, besides receiving high

Table 5
Net preference flows of alternatives.

Ranking	EE options				On-site RES options			
	Mechanism	**Φ**	**Φ+**	**Φ−**	**Mechanism**	**Φ**	**Φ+**	**Φ−**
1°	**EE1**	0.3956	0.6374	0.2418	**RES6**	0.6000	0.7429	0.1429
2°	**EE5**	0.3407	0.6154	0.2747	**RES1**	0.1714	0.5143	0.3429
3°	**EE2**	0.2967	0.6044	0.3077	**RES5**	0.0571	0.4857	0.4286
4°	**EE9**	0.1099	0.5275	0.4176	**RES3**	−0.1714	0.3143	0.4857
5°	**EE4**	0.1099	0.4505	0.3407	**RES2**	−0.2857	0.2857	0.5714
6°	**EE11**	0.1099	0.4945	0.3846	**RES4**	−0.3714	0.1714	0.5429
7°	**EE12**	0.0000	0.4286	0.4286	–	–	–	–
8°	**EE8**	−0.0330	0.3736	0.4066	–	–	–	–
9°	**EE14**	−0.1758	0.2857	0.4615	–	–	–	–
10°	**EE13**	−0.1868	0.2747	0.4615	–	–	–	–
11°	**EE3**	−0.1978	0.3077	0.5055	–	–	–	–
12°	**EE10**	−0.2308	0.2967	0.5275	–	–	–	–
13°	**EE7**	−0.2527	0.2527	0.5055	–	–	–	–
14°	**EE6**	−0.2857	0.2747	0.5604	–	–	–	–

Table 6
Weight stability intervals with regard to net flow.

Criteria	EE		RES	
	Weight$_{min}$ (%)	**Weight$_{max}$** (%)	**Weight$_{min}$** (%)	**Weight$_{max}$** (%)
ExpP	5.88	25.00	0	28.00
ImpD	0	100	0	28.00
EA	9.59	17.39	0	25.00
Ptm	5.26	64.71	1.82	25.00
CS	0	20.00	5.26	29.41
CC	6.67	24.00	0	28.00
Coeg	5.88	20.00	6.67	40.00

scores in criteria such as Potential for market transformation (Ptm), Ease of implementation (EA) and Compatibility with the strategic objectives of the government (Coeg).

4.2. Sensitivity analysis

The sensitivity analysis aims to identify how changes in the weight of each criterion can influence in the net preference flow of alternatives. In this analysis, while varying the weight of a criterion, the weight of the other criteria remains constant. Thus, it is possible to identify stability intervals (weight$_{min}$; weight$_{max}$) in which the variation of the weight does not influence the rating of alternatives.

Table 6 shows the results of the sensitivity analysis. All criteria show a large range of stability which demonstrates reliability in the classification found earlier. This indicates that even varying significantly the weight of a criterion in regards to the others, the ranking obtained remains unchanged. For example, even for the criterion EA, which represents the lower stability interval, the weight can varying between 9.59% (weight$_{min}$) and 17.79% (weight$_{max}$) without changing the net preference flow of alternative mechanisms for EE. This analysis was performed with the Visual Promethee-Software Beta Version 0.99.5.1 (Mareschal, 2012).

5. Potential impact of selected mechanisms

This section presents detailed estimates of potential impacts in terms of energy savings and mitigation of CO_2e emissions for the three best ranked mechanisms for EE (MEPS, Procurement Regulation and Building Codes) as described in Section 4. These estimates cover the period 2014–2030. The year 2014 is when we assume the implementation and/or reinforcement of the mechanism and 2030 is chosen to coincide with the official energy projections (EPE, 2007). The details, projection methods and assumptions used are described below.

5.1. MEPS alternatives

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. However, in the absence of official projections of MEPS potential impacts (Melo and Jannuzzi, 2010) this paper performs estimates of this mechanisms considering Brazilian current conditions. Er estimate the impacts of new MEPS (referenced as "P" 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).

Table 7 shows the assumptions considered for estimating the potential impacts of MEPS for the main electricity end-uses in public, commercial and residential buildings in Brazil. The model used to simulate MEPS impacts is based on Melo and Jannuzzi (2010), which takes into account the stock of buildings, population, stock of appliances, ownership, yearly sales, retirement of appliances and the fraction of appliance sales that will be affected by MEPS. The impacts are calculated as the difference between a Baseline scenario, in which the appliances are assumed to be operating at the currently established MEPS and an Alternative scenario, in which the appliances purchased after the implementation of new MEPS are more efficent. The parameters applied in the simulations are detailed in Annex A. 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

Table 7
MEPS assumptions: Baseline and alternative scenario.

Sector	Appliances	Currently MEPS regulamentation (Baseline scenario)	Assumptions of new MEPS
Residential	Refrigerators	Ordinance MME-MCT-MDIC 362/2007—Establishes maximum levels of energy consumption for refrigerators and freezers.	The current A category 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 category 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 (Eletronic devices)	Nonexistent	1W 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

is the only category that receives the PROCEL[2] label. 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 morestringent MEPS, the esetimated energy savings are small. However, as time goes on, more appliances are impacted by the new MEPS, contributing to more effective results.

5.2. Public procurement regulation alternatives

Public procurement regulations can be a very effective instrument to promote market transformation towards EE and RES. 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 FEMP (Federal Energy Management Program) 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 aiming energy saving (UNEP, 2007b).

In Brazil, the Law No. deg. 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. Thus, the regulation of public procurement, as drawn here, determines high efficient lamps with LED technology requirement for public purchasing from 2020 (alternative RC LAMP Pb), as well as standby power for electrical and electronic public office equipment (alternative RC STB Pb), which shall not exceed 0.5 W 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.

5.3. Building codes alternatives

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).

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 building's 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.

5.4. On-site RES

This study use the results published by Jannuzzi and Melo (2012) to investigate the impact of on-site RES mechanisms alternatives as mitigation alternatives. The chosen mechanisms were: net-metering, subsidies and feed-in tariffs. These are evaluated regarding costs to society and electricity production potential for the case of on-site solar photovoltaic (PV) generation in residential buildings. The on-site PV technology was chosen as it represents immediate opportunity for Brazil, as there is regulatory provisions in place that can facilitate its deployment. The potential market is estimated using the application of a logistic function based on a special solution of the Fisher-Pry model (PNNL, 2007)

[2] 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 8
Impacts of the policy mechanisms in terms of energy saving potential and abatement of CO_2e potential.

Residential buildings—R (cumulative total from 2014 to 2030)			Commercial buildings—C (cumulative total from 2014 to 2030)			Public buildings—Pb (cumulative total from 2014 to 2030)		
Mechanism	Energy saving potential (TWh)	Abatement potential[d] (Million tonnes of CO_2e)	Mechanism	Energy saving potential (TWh)	Abatement potential (Million tonnes of CO_2e)	Mechanism	Energy saving potential (TWh)	Abatement potential (Million tonnes of CO_2e)
P[a] REF R	9.67	0.90	P AC C	269.76	25.10	P AC Pb	67.44	6.27
P AC R	5.49	0.51	P LAMP C	65.90	6.13	P LAMP Pb	17.35	1.61
P LAMP R	165.62	15.41	P STB C	35.15	3.27	P STB Pb	11.12	1.03
P STB R	59.33	5.52	COD ENV C	3.54	0.33	RC STB Pb	12.88	1.20
COD[b] AQS R	69.38	6.45				RC LAMP Pb	1.81	0.17
FV NM	11.72	0.95				COD ENV Pb	0.15	0.01
FV (other)[c]	9.15	0.74						
Total	330.36	30.48	Total	374.35	34.83	Total	110.76	10.30

[a] P means Minimum energy performance standards.
[b] COD means energy efficiency codes.
[c] Other FV refers to the application of only one of the options beyond net metering (subsidies or feed-in tariff).
[d] To estimate the weight of buildings electricity consumption in CO_2e emissions from power generation we apply an emission factor of 0.080tCO_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).

and also electricity tariff parity, and the technical performance of PV systems considering the country's solar irradiation.

5.5. Results of potential impacts

Table 8 shows the results of the estimations of potential impacts in the cases of EE and RES mechanisms. The greatest potential identified, in terms of the energy savings, is the application of MEPS for air conditioners devices in commercial buildings. A total of 270 TWh could be saved with the reinforcement of this mechanism. The second largest potential, 165 TWh, results from the application of technological standard for EE lighting in residential buildings, considered as the elimination of incandescent technology as of 2014. For all mechanisms the total impacts are very significant and represent a saving potential of 815 TWh and a mitigation of 75 million tons of CO_2e over the period 2014 to 2030.

6. MACC analysis

Fig. 2 shows the MACC analysis related to policy mechanisms impacts (associated with EE and RES technologies) and their respective CO_2e mitigation potential. The height of the bar represents the cost per tonne of CO_2e saved and the measures are ranked according to their unit cost. More cost effective measures are on the left hand side and have negative abatement costs, which means that these measures have potential to save money as well as CO_2. The marginal abatement costs proved to be negative in 16 of the 19 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, respectively), 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 and feed-in tariff for PV systems (with total purchase of electricity generated) were the only mechanisms that showed positive costs. In fact, building codes present high upfront costs for conforming new buildings to specific energy norms. For the 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. In the case of PV generation, the high cost to society to support the feed-in tariffs made this option low attractive under the financial point of view.

7. MCA of potential impacts

In this section we develop another type of MCA. While the first MCA (Section 4) was a qualitative evaluation for selecting policy instruments (evaluation based on literature review and authors' judgment), this second evaluation relies on the PROMETHEE II method using quantitative data (the estimated projections results presented in Table 8). In this case we apply quantitative criteria: CO_2e mitigation potential, CO_2 mitigation costs, jobs creation potential. A qualitative criterion is also included in the analysis: ease of mechanism implementation (EA).

With this analysis we intended to facilitate the decision making process by supporting the decision makers with a general view of potential impacts beyond costs. Different goals of EE and RES policies are evaluated bringing new understanding and perspectives regarding each mechanism. Table 9 provides a description of the criteria considered in this analysis.

Table 10 shows the decision matrix of this second MCA. The potential of jobs creation were estimated based on literature review (AGAMA Energy, 2003; NREL, 2009; ESTIF, 2010; Romero-Hernadez et al., 2012) and were considered the following conservative assumptions: PV with 3 Jobs/ano per MWp installed and for solar heater 441 Jobs/year per TWh/year saved. In the case of codes for commercial and public buildings we assume a conservative value of 500 jobs that would be created in period evaluated (2014 to 2030). The preference function applied in the case of quantitative criteria is the Liner function (Eq. (4)) which is suggested for quantitative criteria (Mareschal, 2012). The Usual function is applied in the case of EA criterion and absolute thresholds (absolute difference) are selected for all the criteria.

7.1. Results

Table 11 shows the results in terms of net preference flows (PROMETHEE II) and partials preference flow (negative and positive—PROMETHEE I). The differences in the partial rankings are reflects of the strengths (positive) and weakness (negative) of each alternative. On the other hand, the net-outranking flows give us a general evaluation of alternatives. In this application all criteria are equally weighted between themselves. The alternative P LAMP P is

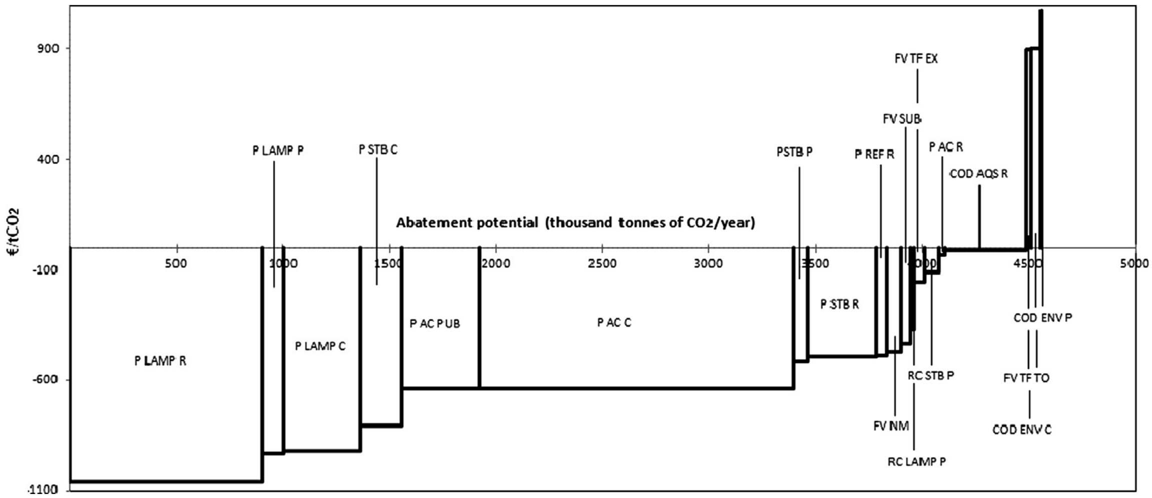

Fig. 2. MACC related to policy mechanisms impacts.

Table 9
Evaluation criteria–description.

Criteria	Description
Mitigation (Mit)	This is a quantitative criterion in which the performance of each mechanism is the direct results of potential impacts of CO_2 mitigation in Brazilian buildings
Costs to Society (CS)	This is a quantitative criteria representing the net costs to society of CO_2 abatement of each alternative according to the MACC analysis
Potential for employment generation (PotGEmp)	This criterion is related to the potential of jobs creation resultant of the technology dissemination. For example, the development of an industry of solar water heaters would expand the number of jobs in manufacturing, selling and services related to the installation and maintenance of these equipments. The valuation of this potential is based on international studies
Ease of implementation mechanism (EA)	This qualitative criterion is based on the current conditions of Brazilian policies, institutional structure and framework for implementing each proposed mechanism. Alternatives already implemented in the country receive a better rating than those that are no implemented yet

Table 10
Decision matrix.

Mechanism	Criteria			
	CS	Mit	EA	PotGEmp
Preference function	Linear	Linear	Usual	Linear
Min./Max	Min.	Max.	Max.	Max.
P LAMP R	(2.831)	906.399	10	–
P LAMP P	(2.489)	94.954	3	–
P LAMP C	(2.458)	360.648	3	–
P STB C	(2.144)	192.363	3	–
P AC PUB	(1.707)	369.069	4	–
P AC C	(1.707)	1.476.274	4	–
PSTB P	(1.371)	60.875	3	–
P STB R	(1.310)	324.685	3	–
P REF R	(1.305)	52.937	7	–
FV NM	(1.261)	60.990	10	38.661
FV SUB	(1.151)	47.551	2	31.453
RC LAMP P	(982)	15.287	3	–
FV TF EX	(407)	47.551	1	31.453
RC STB P	(299)	70.512	2	–
P AC R	(80)	30.069	7	–
COD AQS R	(20)	379.696	3	30.000
COD ENV C	2.393	19.394	3	500
FV TF TO	2.408	47.551	1	31.453
COD ENV P	2.857	837	3	500

ranked first based on PROMETHEE II followed by FV NM. Although MEPS mechanism is lower evaluated in jobs generation, these options have high performance in all others criteria analysed. In the case of net metering to promote on-site FV generation the potential of jobs creation and the ease of implementation were fundamental for the high classification of this alternative.

Table 11
Net preference flows of alternatives.

Ranking	Alternative	Φ	Φ^+	Φ^-
1°	P LAMP R	0.6111	0.7222	0.1111
2°	FV NM	0.4861	0.7361	0.2500
3°	P STB C	0.2639	0.5417	0.2778
4°	P AC C	0.2222	0.4722	0.2500
5°	P LAMP C	0.1806	0.4583	0.2778
6°	P STB R	0.1806	0.5000	0.3194
7°	P AC PUB	0.1389	0.4306	0.2917
8°	P LAMP P	0.1250	0.4306	0.3056
9°	COD AQS R	0.1111	0.5000	0.3889
10°	PSTB P	0.0694	0.4444	0.3750
11°	P REF R	0.0556	0.4444	0.3889
12°	FV SUB	−0.1389	0.4028	0.5417
13°	P AC R	−0.2222	0.3056	0.5278
14°	FV TF EX	−0.2361	0.3472	0.5833
15°	RC STB P	−0.2361	0.2500	0.4861
16°	COD ENV C	−0.3472	0.2639	0.6111
17°	FV TF TO	−0.3750	0.2778	0.6528
18°	RC LAMP P	−0.4306	0.1528	0.5833
19°	COD ENV P	−0.4583	0.2083	0.6667

Table 12
Weight stability intervals with regard to net flow.

Criteria	Stability interval	
	Weight$_{min}$ (%)	**Weight$_{max}$** (%)
Mit	12.73	83.33
CS	14.29	100
PotGEmp	0.00	31.19
EA	0.00	100

Table 13
MACC and MCA comparative net flows.

Ranking	MACC	MCA
1°	P LAMP R	P LAMP R
2°	P LAMP P	FV NM
3°	P LAMP C	P STB C
4°	P STB C	P AC C
5°	P AC PUB	P LAMP C
6°	P AC C	P STB R
7°	PSTB P	P AC PUB
8°	P STB R	P LAMP P
9°	P REF R	COD AQS R
10°	FV NM	PSTB P
11°	FV SUB	P REF R
12°	RC LAMP P	FV SUB
13°	FV TF EX	P AC R
14°	RC STB P	FV TF EX
15°	P AC R	RC STB P
16°	COD AQS R	COD ENV C
17°	COD ENV C	FV TF TO
18°	FV TF TO	RC LAMP P
19°	COD ENV P	COD ENV P

7.2. Sensitivity analysis

A sensitivity analysis usually serves to demonstrate the influence of different values of the weights given to different criteria on the results of the assessment. In this study, we assumed the same weight for all criteria used and calculated the range of variation that would maintain the original ranking of the alternatives (Table 12 shows the variation in percentage of the original weight). For all criteria, the stability intervals are large, which shows that the preference flows according PROMETHEE II remains unchanged even varying significantly the relative weight of each criterion.

8. MCA and MACC comparison

As shown in Table 13 the MCA and MACC analysis provide different rankings of alternatives. While in MACC analysis the alternatives are ranked according financial evaluation in the MCA method non financial criteria are taken into account. However in both analysis MEPS for lamps, standby power and for air conditioning devices are top rated presenting high benefits in terms of saving money and CO_2 mitigation. In the MCA, the net metering mechanism appears in second place once this mechanism has good performance in jobs creation with low costs to society and is relatively easy to implement.

9. Final remarks

Brazil certainly will face in the next years an increasing demand for electricity in the building sector while the probability of electric demand being supplied by thermoelectric power plants based on coal and natural gas is high. If this trend remains, the Brazilian grid's average emissions factor definitely will be greater than officially projected in the Brazilian Energy Plan 2030 (EPE, 2007). Thus, the role of public policy mechanisms in the dissemination of EE and RES technologies is crucial as strategies towards the efforts in stabilizing CO_2 emissions.

A methodological approach based on MCA and MACC has been applied to evaluate policy mechanisms to promote the dissemination of EE and RES in Brazilian building sector. The use of both methodologies to ranking policy instruments proved to be advantageous for this kind of evaluation. I fact, this approach allow the decision makers have multiple views of the problem. The qualitative MCA demonstrates that Brazil has implemented the same mechanisms that are broadly used around the world, mainly in developed countries. Instruments such as labeling and MEPS are present in some of the main energy consuming appliances in buildings sector. In the case of on-site generation the Brazilian Electricity Regulatory Agency (ANEEL) approved in the year 2012 the regulation 482 (ANEEL, 2012) aiming to reduce the barriers to develop the photovoltaic sector and establishes the conditions for access to distribution systems by distributed microgeneration and minigeneration and the compensation rules. However the country is still missing other opportunities of energy saving and respective CO_2 mitigation that could be reached through the implementation of mechanisms such as public procurement regulation and building codes.

From the estimates of potential impacts of selected mechanisms a quantitative evaluation based on MACC and MCA was performed. The MACC results shows that 16 of 19 alternatives evaluated are cost effective and could represent a total of 4.5 millions tones of CO_2 mitigation per year from the year 2014 to 2030. According to MACC method the top ranked alternatives were: MEPS for lighting appliances, standby power mode, air conditioning devices and refrigerators. In terms of CO_2 mitigation the highest potential is related to the use for air conditioning devices in commercial sector. This occurs due the wide availability of inefficient appliances in the market (where approximately only 5% has PROCEL label A) and the great ownership of air conditioning devices in office and commercial buildings. Additionally the evaluation points out to a need to expand the range of MEPS mainly in the cases of standby mode and tubular fluorescent lamps and the importance of more stringent standards for large air conditioning devices used in commercial and public sectors.

The quantitative MCA approach revealed a somewhat different ranking of alternatives. The main difference is the net metering mechanism appearing in second place. When other non financial criteria are taken into account, as potential of jobs creation, for instance, alternatives such as net metering and building codes with specific norms related to solar water heaters are better classified in MCA ranking than in MACC analysis. In that way net metering (or the Brazilian compensation system) seems to be a very adequate choice to promote on-site RES while potentiates positive externalities. It is important to remember that in the MCA simulation all criteria were weighted equally and were not considered preferences of a specific stakeholder group. MCA methodology has demonstrated to be a very interesting tool with broad applicability to evaluate policy mechanisms and help the decision making process. This kind of analysis allows decision makers to articulate preferences according to different policy goals (e.g. jobs creation, CO_2 mitigation, industry development, etc).

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Appendix A

See Tables A1–A4.

Table A1
Applied parameters for refrigerators.

Refrigerators	Equivalent models		
	One door	Combined	Combined frost free
Market share (%)—Total Brazil	78%	10%	12%
Volume (Liters)	260	360	490
Label A[1]—Consumption (kW h/year)	240	576	720
Label A—Market share (%)[2]	80%	85%	95%
Average of other labels (B,C,D and E)[3]—Consumption (kW h/year)	300	732	876
Average of other labels (B,C,D and E)—Market share (%)[4]	20%	15%	5%
Incremental cost[5,6] (US$)	52.6	105.3	157.9

[1,2,3 and 4] Based on INMETRO 2012;
[5] 1,9 R$/US$ as for November 2012;
[6] Based on market survey.

Table A2
Applied parameters 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)	7.500	9.000	60,000
Label A[1]—Consumption (kW h/year)	1011.2	1075.2	6816.0
Label A—Market share (%)[2]	60%	25%	5%
Average of other labels (B,C,D and E)[3]—Consumption (kW h/year)	1075.2	1126.4	8883.2
Average of other labels (B,C,D and E) -Market share (%)[4]	40%	75%	95%
Incremental cost[5,6] (US$)	78.8	105.3	894.7

[1,2,3 and 4] Based on INMETRO 2012;
[5] 1,9 R$/US$ as for November 2012;
[6] Based on market survey.

Table A3
Applied parameters 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 (kW h/year)	64.8	16.2	92.2	132.5
Lifetime (years)	5	1	5	5
Equipment cost[b,c] (US$)	78.8	105.3	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 A4
Applied parameters for Standby.

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 (kW h/year)[b]	27.3	8.7	203.7	65.2
Equipment cost[c,d] (US$)	52.6	73.7	5.8	3.7

[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.

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