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Review

The impact of energy efficiency standards on residential electricity consumption in Mexico

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ABSTRACT

Minimum Energy Efficiency Standards (MEES) for residential appliances have been part of the Mexican national energy policy since the early nineties. This study analyzes the impact of MEES on residential electricity consumption and the carbon dioxide (CO_2) emissions related to refrigerators, washing machines, air conditioners, televisions and lighting products in Mexico. The paper presents estimated achievements of MEES from 1990 to 2012 and future scenarios until 2030 by implementing stricter MEES based on the best technology available. A replacement technology model was developed to estimate, saved energy and avoided CO_2 emissions for different appliances' lifetimes. Considering a 16-year average lifetime of appliances and 80% penetration of efficient lighting technologies, in 2013 energy savings were estimated to be 16.06-TWh (emission reduction of 9.5 Tg CO_2). Different scenarios are presented assuming different average lifetimes of appliances as well as an increase in renewable energy sources in electricity production.

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Introduction

Energy efficiency measures have been important since the 1973 oil embargo, and they have taken on renewed importance with global climate change (Gillingham et al., 2009). Within this context, Minimum Energy Efficiency Standards (MEES) for appliances have been a key strategy for increasing energy security, and mitigating climate change (Van Buskirk et al., 2014). Energy efficiency programs for appliances started in the US (Meyers et al., 2014), with the Energy Policy and Conservation Act (EPCA) in 1975 that established a program consisting of labeling and energy conservation targets for different types of consumer products. Later on, in 1987 with the National Appliance Energy Conservation Act (NAECA), EPCA was amended to establish the first US national energy conservation standards for consumer products (Meyers et al.,

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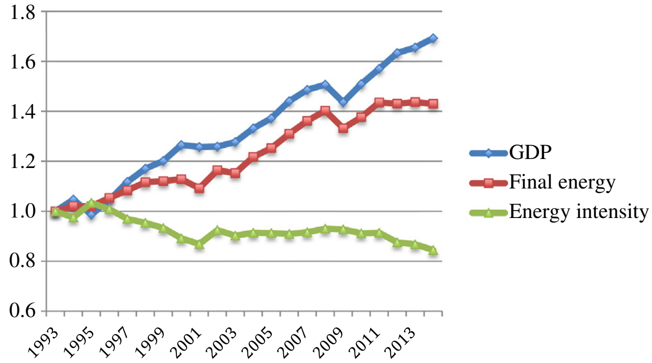

Fig. 1. Changes in Mexican indicators considering 1993 as base year.
Source: INEGI (2016) and SENER (2016).

2014). Since then, subsequent modifications have been made, as well as other energy efficiency programs such as Energy Star, a voluntary program to identify and promote energy-efficient consumer products.

In the case of Mexico, MEES for appliances have been part of Mexican national energy policies since the early nineties (Masera et al., 1993; Friedmann and Sheinbaum, 1998). MEES in Mexico, remote to 1989 with the creation of The National Commission for Energy Savings (today CONUEE — Comisión Nacional para el Uso Eficiente de la Energía), the Electricity Sector's Energy Saving Program (Programa de Ahorro de Energía del Sector Eléctrico — PAESE) and the Revolving-loan trust Fund to Save Electricity (Fideicomiso Para el Ahorro de Energía — FIDE). In 1995 the first mandatory MEES for water pumps, gas heaters and refrigerators were published. By now, 27 MEES are in place in Mexico (CONUEE, 2013; SENER, 2008; SENER; 2010; 2012a; 2012b).

Since the establishment of MEES, several academic papers have analyzed their importance and their impacts. Some of the most recognized studies are Shipper and Meyers (1992), Levine et al. (1995), Koomey et al. (1995), Turiel (1999), Nadel (2002), and Meyers et al. (2003). Recent studies that analyze the benefits and weakness of MEES after 20 years of the application are for example Davis (2011), who examines the saturation of Energy Star appliances using US Residential Energy Consumption Survey; Shimoda et al. (2010) that featured greenhouse gas reduction potential in Japanese residential sector by residential energy end-use model and the application of MEES; Dixon et al. (2010), who summarize the history of US energy conservation and efficiency policies; Jiang (2011) that develop an analysis of national and local energy-efficiency design standards in the public building sector in China. Meyers et al. (2013) estimated the key impacts of Federal energy and water conservation standards adopted from 1987 through evaluating the reduction in CO_2 emissions associated with their application. The last publication estimated a reduction of 198 million metric tons of CO_2 emissions, equivalent to 3% of total U.S in 2012.

Also, Van Buskirk et al. (2014) developed a retrospective investigation of energy efficiency standards and the declination in appliance costs. Parry et al. (2010) developed an analytical framework for comparing the welfare effects of energy efficiency standards and pricing policies for reducing gasoline, electricity, and nationwide carbon emissions. Borg and Kelly (2011) also studied the effect of appliance energy efficiency improvements on domestic electric loads in European households; and Kalavase et al. (2012) projected impacts of global energy efficiency standards for appliances implemented in Super-efficient Equipment and Appliance Deployment Initiative (SEAD) countries. Also, Nogueira et al. (2015) studied the impact of energy efficiency measures in Brazil.

In the case of Mexico, Masera et al. (1993) presented the first end use analysis of residential sector in Mexico and the possibilities of energy efficiency standards, followed by Sheinbaum et al. (1996). Friedman et al. (1995) developed one of the first studies on residential lighting energy efficiency opportunities, and Friedmann and Sheinbaum (1998) analyzed energy efficiency policies in Mexico. Years later, Arroyo-Cabañas et al. (2009) analyzed saving potential for refrigerators, Ruchansky et al. (2011) evaluated energy efficiency programs in different Latin-American countries including Mexico; Gopal et al. (2014) studied self financing of energy efficiency incentives in Mexico and recently CONUEE (2013) developed a balance of MEES in Mexico.

The aim of this paper is to estimate the impact of MEES for different appliances in residential electricity consumption in Mexico and estimate future energy savings due to the scaling up of energy standards. The appliances analyzed are refrigerators, washing machines, and air conditioners; televisions are also included in the analysis, because of its importance in residential energy consumption, although there are no MEES for them. Lighting is also included in the analysis; in this case a standard published in December 2010 (SENER, 2010) established a ban to sold incandescent bulbs of 100 W in December 2011; 75 W in December 2012 and 40 to 60 W in December 2013.

As mentioned above, there have been some studies on the analysis of appliance energy efficiency standards in Mexico; the novelty of this

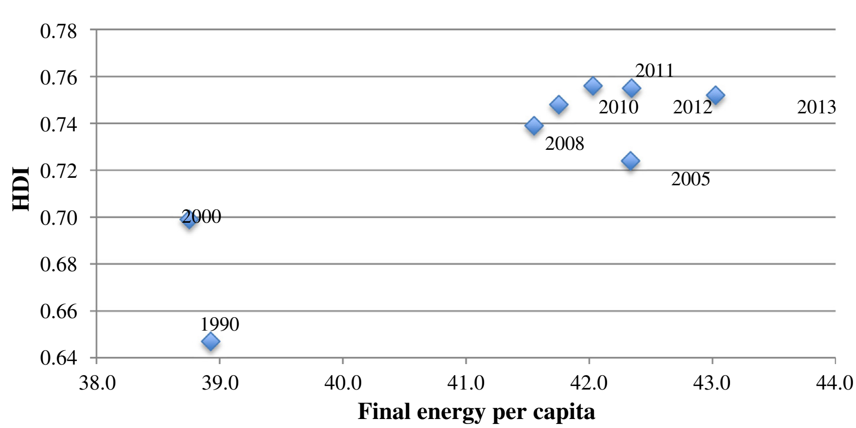

Fig. 2. Final energy per capita and Human Development Index.
Source: SENER (2016) and UNDP (2016). Final energy per capita in GJ/cap.

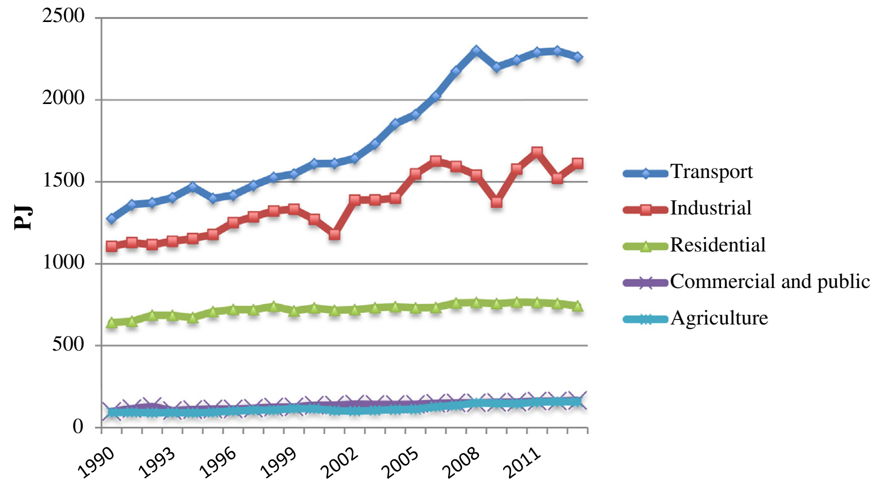

Fig. 3. Final energy use by sectors in Mexico.

study is the evaluation of past impacts and future perspectives, as well as the presentation of a mathematical model to evaluate appliance substitution, which allows estimating past and future energy savings. The study also presents a sensitivity analysis that takes into account the rebound effect (Greening et al., 2000).

An overview of energy consumption in Mexico

Final energy consumption in Mexico has grown at an annual rate of 1.8% from 1993 to 2013, while GDP grew at an average annual rate of 2.6%. Fig. 1 shows these changes, along with energy intensity (final energy/GDP), considering 1993 as a base year. As shown in 20 years Mexico had a 20% reduction in energy intensity, although from 2002 to 2011 it remained almost constant.

On the other hand, Fig. 2 shows Mexican final energy consumption vs. Human Development Index (a composite statistic of life expectancy, education, and income per capita indicators). As shown the change from 1990 (when Mexico started energy efficiency programs) to 2000 shows that it is possible to improve HDI while reducing energy consumption; however from 2000 to 2008 HDI while energy consumption increased, and from 2008 to 2013 HDI has remained roughly constant, while energy use increased considerably. This is due to the higher rate of increase in transport energy consumption.

Residential energy consumption

Mexican households use over 15% of total final energy. According to the National Energy Balances (SENER, 2015) between 1990 and 2013, residential energy consumption, including fuel-wood grew by only 0.64%/year (to a value of 743 PJ), compared to energy use for transport sector that grew 2.5%/year, industry, 1.65%/year; and agriculture and commercial sectors 2.30%/year (Fig. 3).

The slightly increase in final residential energy consumption compared to other sectors represented a reduction in energy consumption per dwelling and almost a constant value of energy consumption per capita as shown in Fig.4. The difference is clearly related to the reduction in persons per dwelling that changed from 5.4 in. 1990 to 3.8 in. 2013.

When analyzing the residential energy use by final energy source, it is clear that the reduction in energy intensity came from the decrease in fuelwood and LPG consumption. In the case of LPG, the reduction is probably related to the increased efficiency in water heaters and cook stoves, although a specific study is needed to analyze it. On the other hand, the reduction in fuelwood consumption represents a transition

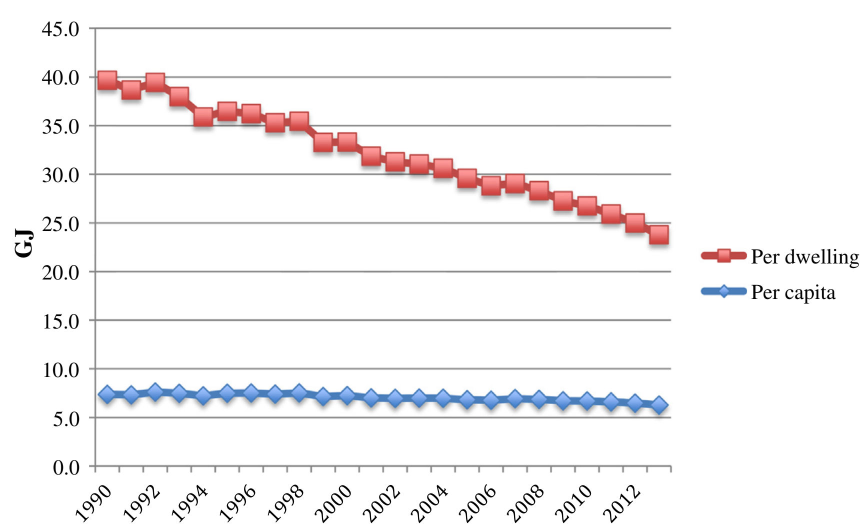

Fig. 4. Final residential energy.

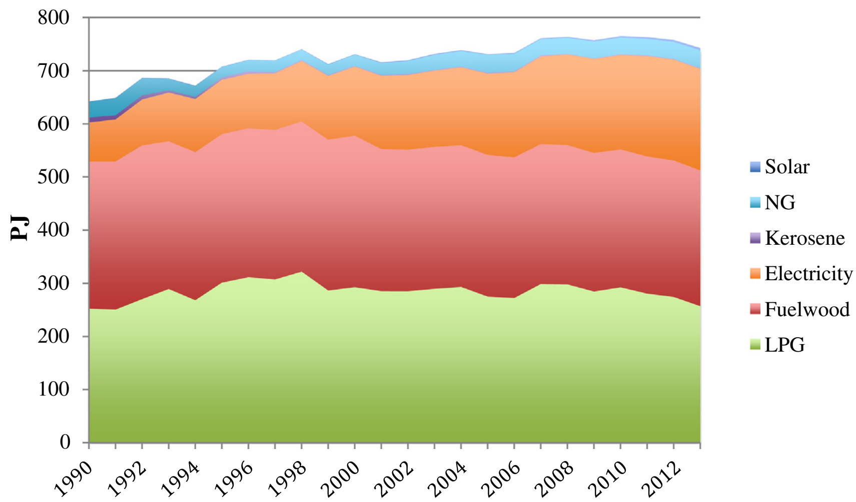

Fig. 5. Residential energy use by final source.

to commercial fuels (manly LPG), related to the increase in the urban population. From 1990 to 2010, Mexican rural inhabitants decreased from 27.5 million to 25.8 million. In the same years the share of urban population increased from 65% to 77%. In contrast to LPG and fuelwood, residential electricity grew by 4.3%/year between 1990 and 2013 (Fig. 5); which meant a 2.9%/year increase in per capita electricity use (from 234 kWh/cap in 1990 to 448 kWh/cap in 2013) and 1.3%/year in per dwelling electricity use (from 1260 kWh/dwelling in 1990 to 1700 kWh/dwelling in 2013).

There is no official information on residential electricity use by end uses; the only available information is from the National income expenditure surveys and the National population census is appliance ownership (Table 1; INEGI, 1996, 2000, 2010, 2012). Nevertheless, a publication by Rosas et al. (2010), estimated that in 2006, 30% of Mexican residential electricity consumption was for refrigerators, 22% for lighting, 19% for air conditioners, 14% for TVs, 6% for cloth washing, and 9% for other appliances (Table 2).

It is clear that one of the most important drivers in the rise of residential electricity consumption is the growth in appliance ownership, as shown in Table 1. But appliance ownership is only a part of the information necessary for a complete analysis of energy consumption. It is also necessary to know how much energy each appliance uses. The unit energy consumption (UEC) of appliances (energy consumption per appliance per year) depends mainly on the power of the appliance and the time the appliance is used. The MEES regulate the maximum power and energy consumption an appliance can have under certain test procedures.

MEES are designed for new appliances; therefore, the impact of MEES in residential energy consumption depends on both, the acquisition of new appliances by new households and the rate of renewal or average useful life of the appliances in use. The consideration of these variables is presented in the methodology (Methodology and data section).

UEC for new appliances

Minimum Energy Efficiency Standards in Mexico

Table 3 shows the MEES for the three of the five appliances analyzed in this study, and Fig. 6 presents the average UEC established in the MEES and their updates.

TV and lighting

In addition to the appliances regulated by MEES we included the use of electricity for TVs and lighting in the analysis. Flat screen TVs cut the average electricity consumption by more than half compared to the old cathode ray tubes (CRT) they replaced (Table 4, USEPA, 2015); therefore, their impacts in residential energy consumption is very important. The same is for Compact Fluorescent Lamps and LEDs in comparison to incandescent bulbs. As mentioned in the introduction, a standard that prohibited the sales of incandescent bulbs was published in December 2010 (SENER, 2010).

Table 5 presents an estimation of the average UEC for new appliances for past and future years. Table 6 presents an estimation of

Table 1
Appliance ownership in Mexico.
Source: Lighting refers to dwellings with electricity: Census data (INEGI, 1990, 2000, 2010). TV: Based on income-expenditure household survey INEGI (1996, 2006, 2012). More than one TV per dwelling. Refrigerator and cloth washer: Census (INEGI, 2000, 2010). Air conditioner: Income-expenditure household survey INEGI (1996, 2012). Interpolation and extrapolation based on exponential annual rate of growth.

	1990	2000	2010	2013
Dwellings (million)	16.2	21.9	28.6	31.2
Lighting	88%	95%	98%	98%
TV	93%	126%	170%	186%
Refrigerator	60%	68%	82%	87%
Cloth washer	39%	52%	66%	72%
Air conditioner	8%	10%	12%	13%

Table 2
Residential energy by end uses (2006).
Source: Rosas et al. (2010). Per capita considers total population.

	TWh	%	kWh/cap/year
Lighting	9.9	22	91.2
TV	6.1	14	56.6
Refrigerator	13.4	30	123.5
Cloth washers	2.7	6	24.9
Air conditioner	8.6	19	78.9
Others	3.8	9	34.8
Total	44.4	100	410.0

Table 3
Minimum Energy Efficiency Standards in Mexico.
Source: CONUEE (2013).

	Refrigerator	Cloth washing	Air conditioner
Name of standard	NOM-015-ENER	NOM-005-ENER	NOM-021-ENER/SCFI
In force	1995	1997	1995
First upgrade	1997	2000	2000
Second upgrade	2002	2010	2008
Third upgrade	2012	2012	

Table 4
Power for different TV technologies.
Source: Energy star database (USEPA, 2015; Aoe et al., 2003).

Average TV (35–50 in.)	Power consumption in on mode (W)
LCD with direct lit-LED	28.8–35.4
LCD with edge lit-LED	28.9–66.9
LCD	36–85
CRT (19 in.)	204

Table 5
UEC for new appliances (average kWh/year).
Source: Rosas et al. (2010), CONUEE (2013), Energy Star database: USEPA (2015), and IPCC (2015).

	Refrigerator	Washing machines	AC	TV
1990	829	166	2725	153
1995	734	166	2028	153
1997	626	150	2028	153
2000	626	150	2028	153
2002	626	120	1862	153
2008	442	120	1862	60
2010	442	120	1862	60
2012	372	95	1862	50
2020	268	49	931	40
2030	214	31	931	40

Average considering a refrigerator of $14 ft^3$, a washing machine of 10 kg, an air conditioner of 1000 BTU/h and a television of 32 in.

saturation of lighting technologies based on sales INEGI (2016) and (Rosas et al., 2010).

Methodology and data

Electricity consumption for the residential sector in year t can be expressed as:

$$E_t = D_t \sum_i S_{it} \mathrm{UEC}_{it} \quad (1)$$

where D is the number of dwellings in year t, S is the saturation of appliance i in year t and UEC is the Unit Energy Consumption (kWh/year). Data of dwellings and appliance saturation is obtained from INEGI (1990, 2000, 2010) and INEGI (2006, 2012). UEC for new appliances is showed in Table 5.

Number of appliances

In order to calculate the number of appliances by age in certain year, we developed the “Replacement technology model for electrical appliances (RTMEA)”, which assumes that when an electrical appliance reaches the end of its lifetime, it should be replaced with a new one produced in accordance with the current official standards, or new technology development for the case of TVs. For base year (1990), the share of appliances by year is estimated based on a logarithmic decrease.

Total number of appliances in certain year is:

$$A_T = A_t + A_{t-1} + A_{t-2}.......... + A_{t-(n-1)} \quad (2)$$

where A_T is the total number of certain appliances in year t, A_t is the number of appliances acquired in year t, A_{t-1} is the number of appliances acquired in year $t-1$, and n is the lifetime of the appliance. Arroyo-

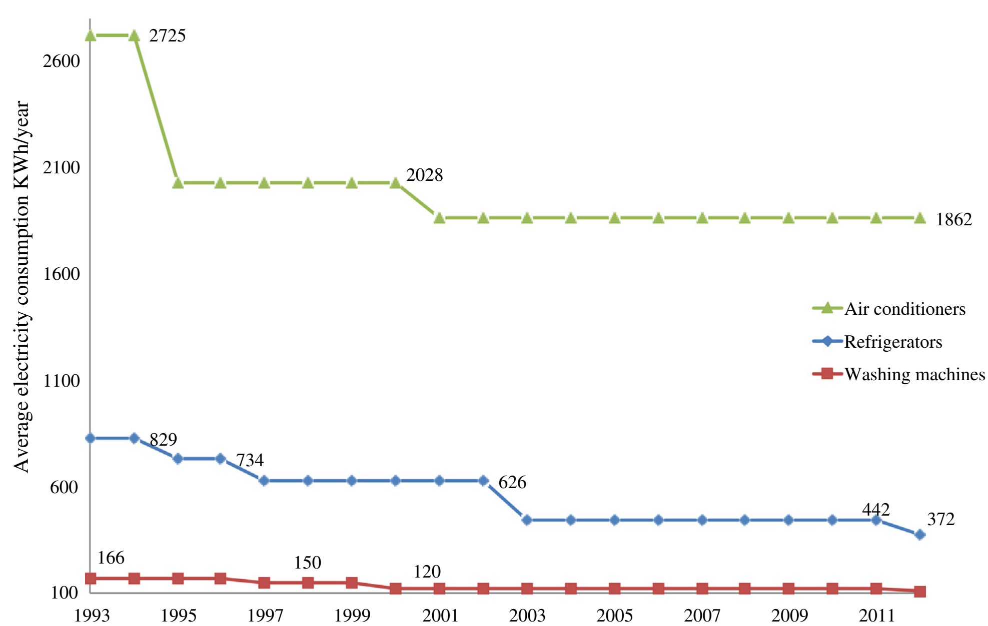

Fig. 6. Average UEC enforced by MEES in Mexico. Note: Average considers a medium size appliance.

Table 6
Average UEC for lighting.
Source: Rosas et al. (2010), INEGI (2010), Energy star database USEPA (2015).

Year	Average UEC (kWh/year)	Number of light bulbs per dwelling	Incandescent		Fluorescent		CFL		LEDS	
			S	UEC	S	UEC	S	UEC	S	UEC
1990	299.5	5.1	82.4%	50	13.3%	30	4.3%	18	0.0%	10
1995	299	5.1	82.4%	50	13.3%	30	4.3%	18	0.0%	10
2000	382	5.6	79.9%	60	12.0%	30	8.1%	18	0.0%	10
2005	423	7.3	76.8%	60	10.6%	30	10.6%	18	0.0%	10
2010	344	7.8	40.9%	60	10.2%	30	47.9%	18	1.0%	10
2013	209	8.4	20.0%	30	10.0%	25	65.0%	18	5.0%	10
2015	192	9.6	0.0%		9.2%	25	84.0%	18	6.8%	10
2020	204	9.6	0.0%		7.5%	25	78.1%	18	14.4%	10
2025	203	11.0	0.0%		6.1%	25	63.3%	18	30.6%	10
2030	138	11.0	0.0%		5.0%	25	30.0%	18	65.0%	10

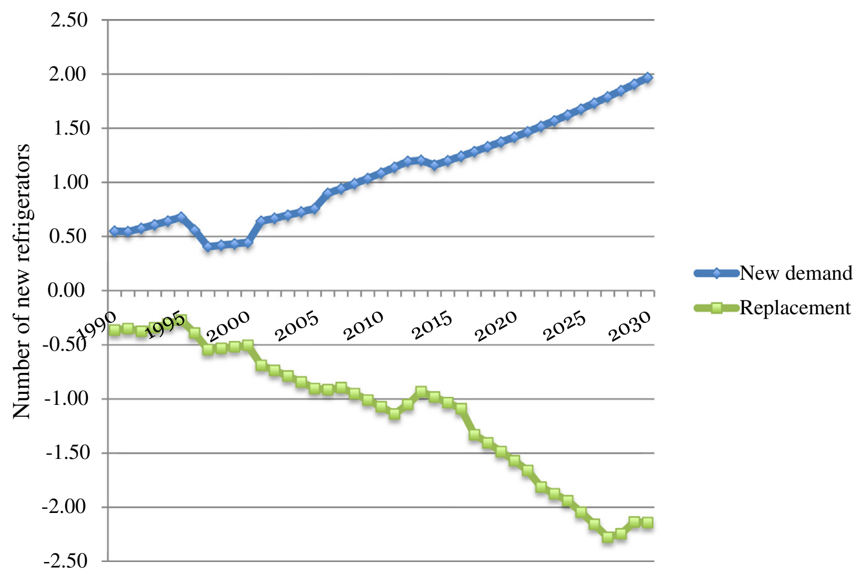

Fig. 7. Estimation of new refrigerators by year. Note: reductions of new demand are related to years of economic stagnation or GDP decrease in the country. Assuming an average lifetime of 16 years. Replacements represent the number of refrigerators that are not in use because they reached their average lifetime (the same amount has to be purchased in the same year to replace the old ones). Replacement is shown negative representing the refrigerators that are no longer is use. Total sales for certain year are the sum of the absolute value of new plus replacement.

Cabañas et al. (2009) estimated a 16-year average lifetime of refrigerators. We assume the same lifetime for other appliances.

Now, A_t is the sum up of the new appliances related to the increase of new dwellings (An_{it}) and new appliances related to the replacement of the appliances that have reached its lifetime (Ar_{it}) therefore:

$$A_t = An_{it} + Ar_{it} \quad (3)$$

where:

$$An_{it} = S_{it}D_t - S_{it-1}D_{t-1} \quad (4)$$

where S_{it} is the saturation of appliance in year t and D_t is the number of dwellings. The model assumes that all appliances acquired in certain year will last until the end of its lifetime. Thus, the number of appliances replaced in year t is just:

$$Ar_{it} = A_{it-n}. \quad (5)$$

For instance, the refrigerators acquired in 1990 will last until year 2006, year in which they have to be replaced. In the case of lighting, average energy consumption is estimated based on Table 5. Fig. 7, for example, presents new refrigerators by year divided in new dwellings and replacement.

Scenarios for year 2030

Scenarios for year 2030 are built with the same methodology than past trends, considering a 2000–2013 annual rate of growth in appliance ownership (Table 7). Estimation of UEC per appliance by year is presented in Tables 5 and 6 based on USEPA (USEPA, 2015).

Table 7
Appliance saturation based on 2000–2013 annual rate of growth.

	2013	2020	2025	2030
Dwellings (millions)	31.2	37.2	41.7	46.6
Lighting	98%	100%	100%	100%
TV	186%	225%	258%	295%
Refrigerator	87%	97%	105%	114%
Cloth washing	72%	83%	93%	104%
Air conditioning	13%	16%	18%	20%

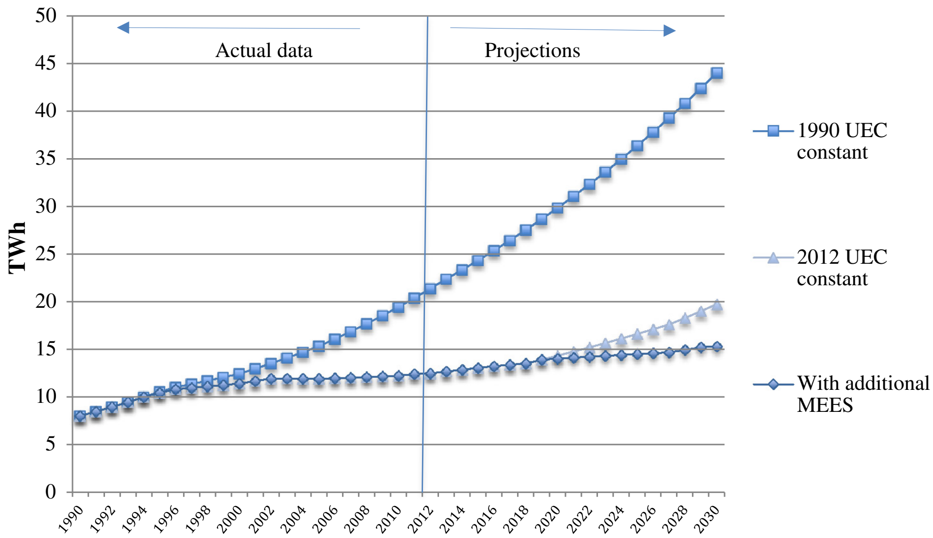

Fig. 8. Electricity consumption for refrigerators in Mexico with and without MEES.

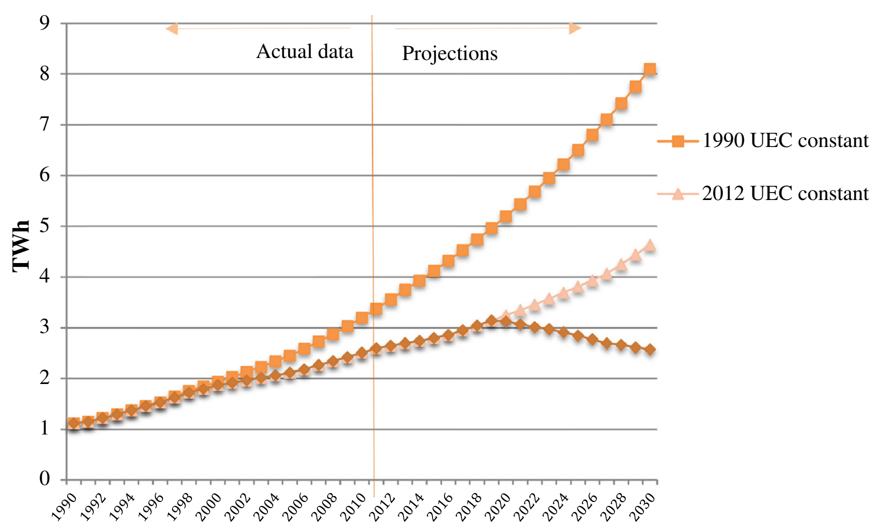

Fig. 9. Electricity consumption for clothes washers with and without MEES.

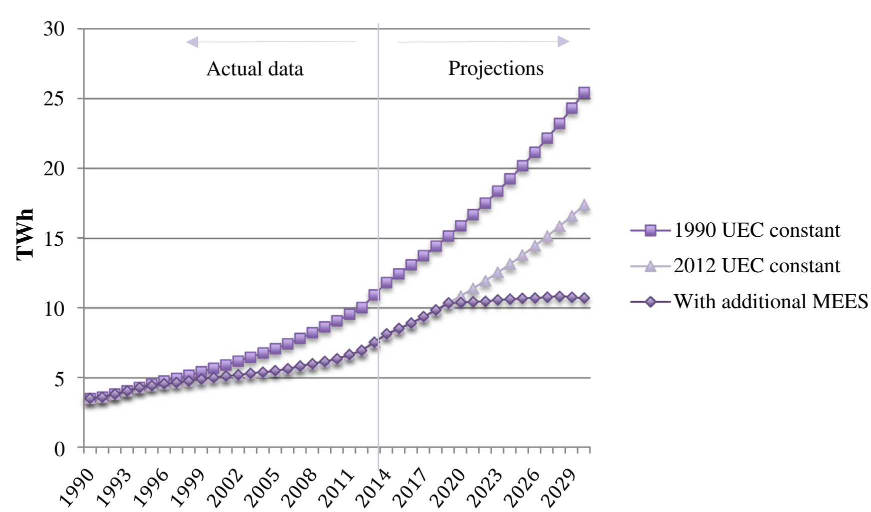

Fig. 10. Air conditioning electricity consumption in Mexico with and without MEES.

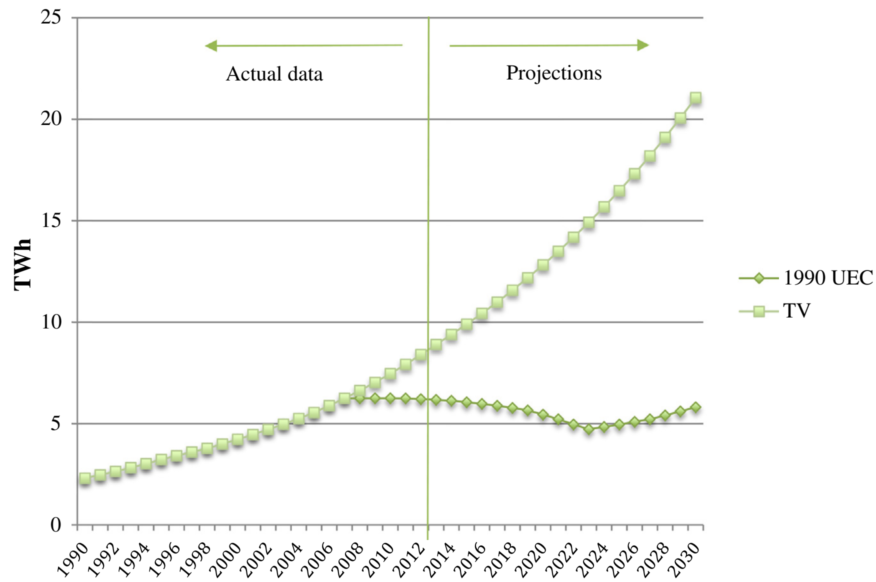

Fig. 11. Electricity consumption for TVs in Mexico.

Avoided CO_2 emissions

In order to estimate CO_2 emissions avoided due to the application of MEES, it is important to estimate the CO_2 electricity emission factor.

$$CO_{2\ t} = E_t * EEF_t \tag{6}$$

where CO_2 are the emissions in year t, E_t is electricity consumption in year t and EEF_t is the electricity emission factor in year t. The electricity emission factor varied over time, depending on the mix of primary energy sources and the power generation, according to:

$$EEF_t = \frac{\sum_{ij} F_{jt} EF_j}{GE_t\,(1 - L_t)} \tag{7}$$

where F is the amount of fuel consumption j used to produce electricity in year t, EF is the CO_2 emission factor of fuel j; GE is the total electricity generation in year t and L is the percentage of loses in electricity transmission and distribution in year t (CONUEE, 2009).

Results

Figs. 8 to 13 present the trends and prospects in electricity consumption by appliance (or end-use) considering: a) UECs constant at their 1990 value; b) UECs constant at their 2012 value and, c) UECs considering new MEES. Table 8 shows the electricity savings from 1990 to 2012 and the estimated baseline scenario for year 2030. Energy savings of 16.06 TWh were achieved in 2012 because of MEES, in comparison to a scenario where UECs would have been constant at its 1990 value. In year 2030 electricity savings will reach 69.55 TWh based on the same comparison.

As shown in Fig. 10, total electricity consumption for these end-uses is estimated to reach 43 TWh in 2030, nearly two times larger than in

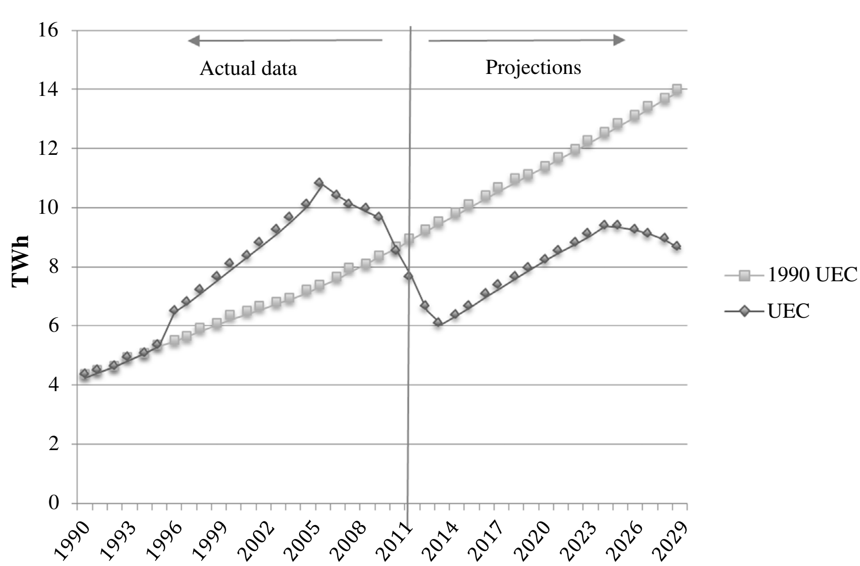

Fig. 12. Electricity consumption for residential lighting in Mexico with and without MEES.

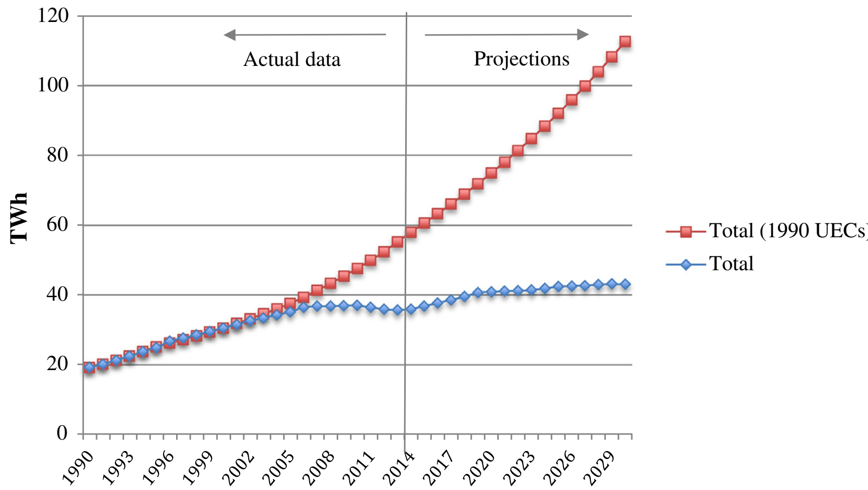

Fig. 13. Residential electricity consumption in Mexico for 5 end uses with and without MEES (baseline scenario).

1990, but 5 times less if UECs would have been constant at its 1990 values.

Avoided CO_2 emissions

The CO_2 emission factor for electricity generation is based on historical data and official projections (CFE, 2014), and IPCC (2006) emission factors, as presented in Table 9.

CO_2 emission due to electrical appliances use from 1990 to 2013 and estimations from 2014 to 2030 are presented in Fig. 14, considering UECs constant at its 1990 value and UECs applying MEES. MEES implied a CO_2 emission reduction of 9.5Tg of CO_2 in 2012, which represented 6.5% of CO_2 emissions of electricity production for the same year. By 2030, the updating of MEES (MEES scenario) would imply 30.9Tg of CO_2 emissions avoided, 14% of total emissions related to electricity production in 2030.

Table 10 shows the changes of each variable in the determination of final CO_2 emissions. It is not a decomposition analysis but a simple explanation of the importance of each variable in the construction of this analysis. As shown, number of dwellings and number of lamps per dwelling promote the increase in electricity consumption for lighting. In the case of ACs and TVs, the increase in appliance saturation is higher that the decrease in their respective UEC.

Based on the analysis of Table 10, and considering that the UECs presented in MEES baseline scenario are the best technological change possible so far, it is clear that an additional CO_2 mitigation strategy related to electricity use for residential appliances is possible with the following considerations: a) accelerating the penetration of more efficient appliances; b) increasing the share of renewable sources in electricity production.

Table 8
Electricity savings. UECs constant at its 1990 value and UECs with MEES. Baseline scenario (TWh).

	2012	2030
Lighting	0.98	5.34
Refrigerator	8.90	28.70
Cloth washing	0.91	5.52
AC	3.07	14.73
TV	2.19	15.25
Total	16.06	69.55

Considering the above assumptions, two additional scenarios are built; a) 10 year average lifetime for the 4 appliance considered, and 80% penetration of LEDS (instead of 65%); and b) A 50% share of renewables in the electricity generation mix (Table 11). Results are shown in Fig. 15 and Table 12.Reductions of electricity consumption because of changes in average lifetime of appliances (10 years instead of 16 years of the baseline scenario) represented an additional 4.0 TWh in 2012 and extra 5.2 TWh in 2030. Considering a 50% of renewables in electricity mix will represent emissions of 10.52 $TgCO_2$ in 2030 (an additional reduction of 6.3 Tg of CO_2).

Sensitivity analysis and rebound effect

Some authors explain that energy-efficiency improvements due to technological progress tend to overestimate the potential saving effects because they frequently ignore the behavioral responses, naming this phenomenon the rebound effect (Greening et al., 2000; Binswanger, 2001; Borg and Kelly, 2011). Other authors explain that the rebound effect has been overplayed (Gillingham et al., 2013). Without entering this debate it is interesting as a sensitivity analysis, to estimate the difference in results assuming a 10% increase in UECs than the average established in the above scenarios. Compared to

Table 9
Electricity generation by fuel in Mexico, and associated CO_2 emissions.

	1990	2000	2010	2020	2030
Nuclear	4.2%	5.8%	3.2%	2.6%	2.0%
Hydro	27.1%	22.6%	11.4%	9.7%	7.9%
Geothermal	3.0%	2.8%	2.1%	1.9%	1.7%
Wind			0.6%	1.4%	3.6%
Solar			0.0%	0.0%	0.6%
Biomass	0.2%	0.2%	0.7%	1.1%	1.8%
Coal	5.0%	13.3%	12.4%	6.4%	2.8%
Diesel	0.2%	0.2%	0.5%	0.4%	0.4%
Fuel oil	47.1%	40.3%	20%	16.4%	1.8%
LPG	0.1%	0.1%	0.0%	0.1%	0.1%
Petrol coke			0.7%	0.8%	1.1%
NG	13.1%	14.7%	48.4%	59.2%	76.2%
Total (TWh)	126.34	186.03	274.30	358.9	537.3
Emission factor ($kgCO_2/kWh$)	0.68	0.69	0.59	0.45	0.44
T&D losses[a]	13.15%	14.77%	16.06%	11%	11%
CO_2 emissions due to electricity production in Mexico (Mt)	67.73	113.80	130.57	142.34	219.62

[a] Source: SENER (2016) and CFE (2014).

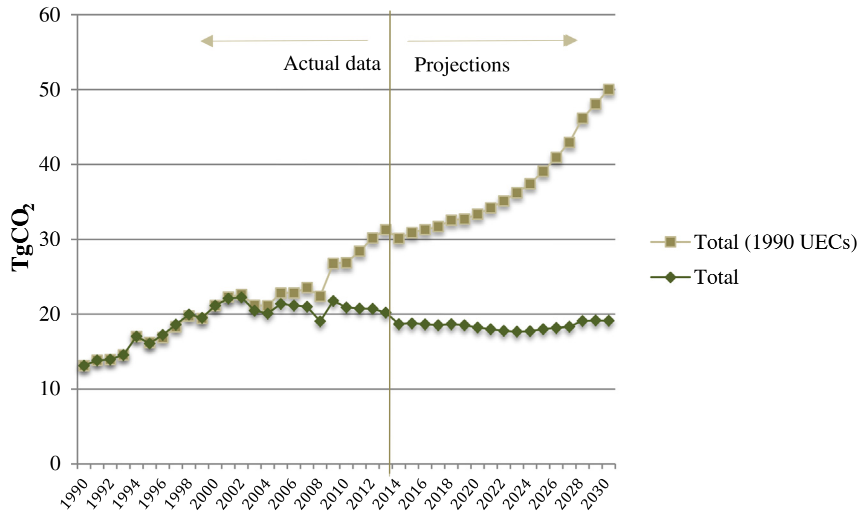

Fig. 14. CO_2 emissions for electricity consumption of 5 end uses with and without MEES (baseline scenario).

baseline scenario, reductions in 2030 will be 4.6% compared to 2012 electricity consumption instead of 12%. This sensitivity analysis gives an idea of the margin of uncertainty around the number presented for the reference scenario.

Conclusions

Residential final energy consumption in Mexico grew by only 0.64%/year between 1990 and 2013. This is manly related to reduction in fuelwood consumption (because of increase urban population), and energy efficiency measures in LPG and electricity appliances.

Minimum Energy Efficiency Standards for residential appliances has been a successful policy in Mexico. Nevertheless, the quantification of the energy savings and related reductions in CO_2 emissions are not an easy task because there is no official data on average unit energy consumption. Since MEES are designed for new appliances, their impact in residential electricity consumption depends on both, the acquisition of new appliances by new households and the rate of renewal or average useful life of the appliances in use. For this reason the impact of MEES in total residential electricity consumption has to be calculated based on an estimation of the average lifetime of appliances.

If UECs had been constant at its 1990 value, electricity consumption for the five end uses analyzed in this paper would have been 52.3 TWh in 2012 and 112.6 TWh in 2030 (representing an avoided emission of 30.2 $TgCO_2$ in 2012 and 50.0 $TgCO_2$ in 2030). Results for baseline scenario that considers 16-year average lifetime of appliances, application of MEES, and 65% saturation of LEDs in 2030, represent a reduction of electricity consumption of 16.4 TWh in 2012 and 69.5 TWh in 2030 (9.5 $TgCO_2$ in 2012, and 30.9 $TgCO_2$ in 2030 of avoided emissions). If average lifetime of appliances reduces to 10 year and saturation of LEDs in 2030 increases to 80%, reduction in electricity consumption will be an additional 2 TWh in 2012 and 24.8 TWh in 2030 (0.5 $TgCO_2$ in 2012 and 2.3 $TgCO_2$ in 2030). Increasing the participation of renewables in electricity generation mix from 15.6% in 2030 to 50% will represent an additional reduction of CO_2 emissions of 6.3 $TGCO_2$. However, these reductions might be attenuated by the rebound effect.

The climate change mitigation policy needs to continue promoting the scaling up in the efficiency of the main residential appliances. Additional reduction in CO_2 emissions requires a necessary vigorous policy toward the promotion of renewable energy sources in electricity production in Mexico instead of natural gas as it has been projected in

Table 10
Variables that explain electricity consumption and CO_2 emissions.

	1990	2012	Change (1990–2012)	2030	Change (2012–2030)
Baseline scenario ($TgCO_2$)	13.1	21.7	65.6%	19.1	−12.0%
Dwellings (millions)	16.2	30.3	87.4%	46.6	53.6%
Lamps per dwelling	5.1	7.8	53.2%	11.0	40.8%
Lighting UEC (kWh/year)	299.5	255.2	−14.8%	184.8	−27.6%
Refrigerator					
Saturation	60%	85%	41.8%	114%	34.0%
UEC (kWh/year)	829	372	−55.1%	214	−42.4%
Cloth washer					
Saturation	40%	70%	74.4%	104%	49.2%
UEC (kWh/year)	166	95	−42.8%	31	−67.0%
AC					
Saturation	8%	12%	53.7%	20%	63.9%
UEC (kWh/year)	2725	1862	−31.7%	931	−50.0%
TV					
Saturation	93%	181%	94.0%	295%	63.3%
UEC (kWh/year)	153	50	−67.4%	40	−20.0%
Electricity emission factor (Tg/TWh)	0.68	0.58	−15.5%	0.44	−22.9%

Table 11
Electricity generation mix in 2030 (50% renewables).
Sources: Based on scenarios of Vidal-Amaro et al. (2015).

Coal	2.84%
Nuclear	2.00%
Hydro	10.07%
Geothermal	2.40%
Wind	14.40%
Solar	14.02%
Biogas	8.83%
Diesel	0.42%
Fuel oil	1.53%
NG	42.11%
Petroleum coke	1.09%
LPG	0.13%
Others	0.17%
Total (GWh)	537,271.7

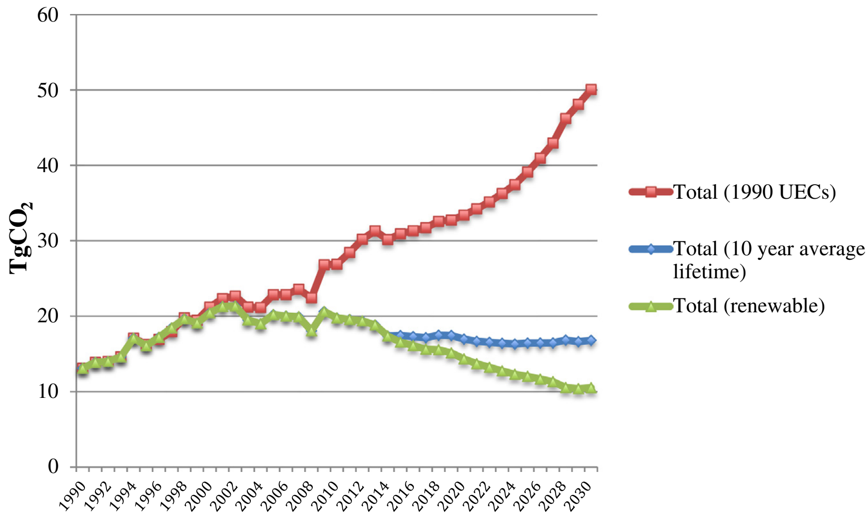

Fig. 15. CO_2 emissions for electricity consumption of 5 end uses with and without MEES considering 10 years as average appliance lifetime and 50% renewables.

Table 12
Variables that explain electricity consumption and CO_2 emissions (10 year appliance lifetime and 50% renewable electricity generation mix).

	1990	2012	Change (1990–2012)	2030	Change (2012–2030)
Total (10 year average lifetime) $TgCO_2$	13.1	19.4	47.9%	16.8	−13.2%
Total (10 year average lifetime and 50% renewable) $TgCO_2$	13.1	19.4	47.9%	10.5	−45.7%
Dwellings (millions)	16.2	30.3	87.4%	46.6	53.6%
Bulbs per dwelling	5.1	7.8	53.2%	11.0	40.8%
Lighting UEC (kWh/year)	299.5	255.2	−14.8%	167.9	−34.2%
Refrigerator					
Saturation	60%	85%	41.8%	114%	34.0%
UEC (kWh/year)	829	372	−55.1%	214	−42.4%
Cloth washer					
Saturation	40%	70%	74.4%	104%	49.2%
UEC (kWh/year)	166	95	−42.8%	31	−67.0%
AC					
Saturation	8%	12%	53.7%	20%	63.9%
UEC (kWh/year)	2725	1862	−31.7%	931	−50.0%
TV					
Saturation	93%	181%	94.0%	295%	63.3%
UEC (kWh/year)	153	50	−67.4%	40	−20.0%
Electricity emission factor (Tg/TWh)	0.68	0.58	−15.5%	0.44	−22.9%
Electricity emission factor (Tg/TWh)	0.68	0.58	−15.5%	0.28	−51.8%

recent years. This is one example of the goals that Mexico can achieve in the context of climate change.

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