Energy for Sustainable Development 41 (2017) 149–156

Contents lists available at ScienceDirect

Energy for Sustainable Development

“Socially neglected effect” in the implementation of energy technologies to mitigate climate change: Sustainable building program in social housing

Felicitas Hernandez-Roman, Claudia Sheinbaum-Pardo *, Andrea Calderon-Irazoque

Engineering Institute, National Autonomous University of Mexico, Mexico

ARTICLE INFO

Article history:
Received 26 March 2017
Revised 13 September 2017
Accepted 13 September 2017
Available online xxxx

Keywords:
Sustainable social housing
Mexico City
Social acceptance
Neglected effect

ABSTRACT

The residential sector is the third largest energy-consuming sector in Mexico and an important contributor to energy related carbon dioxide emissions after transport and industry. The objective of this study is to evaluate the implementation and social acceptance of energy efficient technologies and renewable technologies in the so called sustainable social housing program in Mexico City, and compare the real reduction of CO_2 emissions to the theoretical potential. To do so, two estimations are developed: 1) the technical and economic CO_2 emission reduction potential of energy efficiency and renewable energy technologies in new social housing in Mexico City, and 2) the real avoided emissions based on social acceptance of technologies obtained by housing surveys and physical revision of performance status of implemented technologies. We found that due to lack of information and training to households an important part of dwellers ended up rejecting mitigation technologies developing what we called the socially neglected effect of mitigation technologies. These results were used to estimate three scenarios for year 2025: baseline, mitigation and neglected effect. Due to the neglected effect a reduction of 25% with respect to the baseline scenario was obtained instead of 45% of emission reduction in year 2025. In the case of efficient lighting and refrigerators, where Minimum Energy Efficient Standards are in place the socially neglected effect disappears once the replacement of old to new technologies takes place. This result shows that minimum energy performance standards are the main mitigation policy to eliminate socially neglected effect in the long run. Obligatory standards for installation of solar water heaters can be developed as well, although it is important to develop additional follow-up policies for adequate installation of these technologies.

Introduction

Climate change is one of the greatest and most urgent challenges facing humanity. Cities are an essential part of the problem, as they consume 60 to 80% of the energy produced globally and are responsible for a similar percentage of CO_2 emissions in the world (Kamal-Chaoui and Robert, 2009). In 2014, Mexico City's Metropolitan Area (MCMA), composed by Mexico City and 59 municipalities of the State of Mexico, was ranked as the fourth largest urban agglomeration, with a population of 20.84 million people, projected to grow to 23.87 million in 2030 (CONAPO, 2016). In 2013 emissions from Mexico City were around 37.5 Mt. CO_2e, including electricity consumption accounting for 6% of total emissions in the country (SEDEMA, 2012; INECC, 2013).

According to the growth rates of housing it is estimated that each year 579,036 new homes will be required nationwide in urban areas; from which 48,966 will be needed in Mexico City (SHF, 2016). This could imply a growing demand for energy and an increase in CO_2 emissions if further mitigation policies are not implemented in the country. Nationwide, the residential sector accounted for 15% of total final energy used in 2013 (743 PJ), being the third largest energy consuming sector below transportation and industry (SENER, 2014). Within Mexico City, residential final energy consumption accounts for 14% of CO_2e emissions (including electricity consumption (SEDEMA, 2012), also after transportation (59%) and industry (25%).

Several programs to reduce energy consumption in the residential sector have been developed nationwide since the early 1990s (Friedmann and Sheinbaum, 1998). These programs have had important achievements, especially mandatory minimum energy efficiency standards for residential appliances (Martínez-Montejo and Sheinbaum-Pardo, 2016). In 2007, the National Housing Commission (CONAVI) promoted the green mortgage for sustainable housing that provides additional funds to install energy and water efficient technologies, thermal insulation, as well as solar heaters in new and existing dwellings. From 2007 to 2010 the green mortgage was a voluntary program, but since 2011, it started to be mandatory for all new urban

* Corresponding author.
E-mail address: csp@pumas.iingen.unam.mx (C. Sheinbaum-Pardo)

http://dx.doi.org/10.1016/j.esd.2017.09.005

dwellings[1]. The Institute for National Housing Funds for Workers (Instituto del Fondo Nacional de la Vivienda para los Trabajadores - INFONAVIT) that give loans for social housing (Table 1), developed this program in new homes (Isunza, 2011). By 2014 it was estimated that 90 thousand dwellings per year were constructed under green mortgage model. More recently, CONAVI introduced new mechanisms for sustainable social housing, under the Nationally Appropriate Mitigation Actions (a set of policies and actions that countries undertake as part of a commitment to reduce greenhouse gas emissions): Mexican sustainable housing NAMA for new and existing dwellings (CONAVI, 2016). As pointed out in the CONAVI document, unlike previous Mexican programs, which have focused on promoting and measuring the impact of specific eco-technologies, the NAMA approaches energy efficiency from a 'whole building' approach. With this perspective, efficiency benchmarks are set for total primary energy demand based on building type and climate. Building developers and home-owners are then able to employ any combination of interventions that achieve the targeted efficiency level (CONAVI and GIZ, 2012).

At the Mexico City level, the local government entity responsible for financing social interest housing is the Housing Institute of Mexico City (INVI) which is responsible for enforcing legal action and to design, propose and contribute to the integration, coordination, analysis and implementation of housing policy and housing programs in Mexico City. From 2008 to 2012, a sustainable building project for social housing was implemented in Mexico City as part of the City's Climate Change Action Plan (SEDEMA, 2008; INVI, 2008). Some of the technologies that have been incorporated in the Sustainable Housing Program are: solar water heating systems, efficient lighting (compact fluorescent lamps, CFLs), photovoltaic cells for outdoor lighting, water saving devices (aerators, low-flow showers and taps dual-flush toilets), water recovery systems, grey or soapy water treatment for reuse in toilets, and rainwater harvesting systems for watering gardens and washing cars.

The objective of this study is to evaluate the implementation and social acceptance of energy efficient technologies and renewable technologies in the sustainable housing program in Mexico City, and compare the real reduction of CO_2 emissions to the theoretical potential. To do so, two estimations are made: 1) the technical and economic CO_2 emission potential of energy efficiency and renewable energy technologies in new social housing in Mexico City, and 2) the real avoided emissions based on social acceptance of technologies obtained by housing surveys and physical revision of performance status of implemented technologies.

There are several studies on consumer appropriation of energy saving technologies. Egan et al. (1996) studied how customers interpret and use comparative graphics of their energy use. In the early eighties Khazzoom (1980) introduced the concept of rebound effect, meaning that technological progress makes equipment more energy efficient, and a price decrease normally leads to increased consumption in the same commodity or in the acquisition of others. Since then, many discussions and estimations of the rebound effect have been developed (Berkhout et al., 2000; Binswanger, 2001; Herring, 2006; Gillingham et al., 2016). In the case of the rebound effect, it is assumed that either energy efficient or renewable energy technologies are adopted by the consumer. However, there are multiple cases of not socially acceptance of technologies or "socially neglected effect", especially related to energy and environmental governmental programs. For this reason it is highly important to evaluate sustainable housing programs and the reason of the "socially neglected effect" of energy technologies. The discussion on socially acceptance of renewable energy and energy savings technologies in households is gaining importance in recent years.

[1] There have been some criticism about these program because most of the new dwellings were built in housing compounds outside the city limits. For example Centro Mario Molina (2012) presents a life cycle analysis that shows an important increase in home-work trips that increased emissions from transportation, from inhabitants in social housing compounds.

Table 1
Social housing in Mexico City (thousands).

	Population	Total dwellings	New housing	New social housing	INVI Housing
2010	8847	2454	4.78	2.99	2.07
2015	8919	2601	11.08	1.13	1.69
2020	8991	2758	13.23	8.20	2.29
2025	9065	2924	14.03	8.69	2.43

Data for population and dwellings from 2010 to 2025 is from CONAPO (2016). New housing from 2010 to 2015 is from CONAVI (2016); INVI housing from 2010 to 2015 is from INVI (2012). Projections for 2020 and 2025 for the two last columns are estimated based on the annual rate of growth of total dwellings.

Many recent academic articles discuss behavioral, cultural, comfort and other social variables that influence real energy savings and avoid greenhouse gas (GHG) emissions. Some of them are cited below.

In a study of energy intervention in the residential sector in the south of Spain authors found that in many cases there is no direct relationship between estimated energy demand and real energy use, and the low energy rate (the reduction in electricity tariff due to implementation of energy efficient technology) is combined with deficiencies in comfort conditions (Sendra et al., 2013). Gabriel and Watson (2013), studied how occupants and their dwellings are adapting to reduce home energy consumption and established that drawing on people's experiences of installing solar hot water systems, sustainable home adaptation was not a straightforward process whereby occupant aspirations were delivered through building adaptation. The role that comfort, habit, and knowledge play in the energy savings for space heating system in London were also developed by Huebner et al. (2015). They explained that some important variables are a deficit in the quality and quantity of instruction on how to use the heating systems.

Moezzi and Kathryn (2014) discussed a notion of "social potential" that affords a broader possible contribution of social sciences to improved understanding of building energy use and how policies might reshape this use. They suggest social potential as a formulation that complements and transcends the technical and behavioral savings potential concepts underpinning much of today's building energy efficiency policies, programs, and research. Heinonen and Junnila (2014) studied residential energy consumption patterns in urban and rural households in Finland, and they found that behavioral differences seem significant between different housing modes.

A research on retrofitting social housing in the UK show that retrofit programs will reduce carbon emissions to some degree, whereas the bigger challenge is addressing habitual household energy consumption (Elsharkawy and Rutherford, 2015). Morgenstern et al. (2015) in relation to the heat consumption measured by meters, they found that it is influenced by both the dwelling characteristics and the behavior of the occupant, but heating charges would ideally relate to occupant behavior only. In a research by Huebner et al. (2015) on comparative contribution of building factors, socio-demographics, behaviors and attitudes, they found that retrofitting and behavior change initiatives remain important avenues to reduce consumption. Another important study on energy technologies conducted in the municipality of Kil in west central Sweden assessed using a questionnaire. Results indicate that respondents have such a low level of information and knowledge about new energy technologies that they are unable to discriminately rank them (Assefa and Frostell, 2007). Monreal et al. (2016) explore energy consumption through the appreciation and appropriation of domestic lighting in the UK, explaining that moving towards more sustainable lighting futures, more attention should be paid to how lighting is appreciated and appropriated through everyday practices in the home.

Huelsz et al. (2011), analyzed passive solar systems in dwellings constructed under the green mortgage in five regions of Mexico. They found that less than 50% of the dwellings were developed correctly,

Table 2
Unit energy consumption (UEC) by technology.

Technology		Appliance per dwelling	Daily hours	Annual consumption	Units (/year/dwelling)	Ref.
Lighting	Conventional	6	4	525.6	kWh	(1)
	Efficient (CFL)	6	4	157.7	kWh	(1)
	Efficient (LED)	6	4	87.6		(1)
Refrigeration	Conventional	1	9	626	kWh	(1)
	Efficient (2010−2011)	1	9	442	kWh	(1)
	Efficient (2012)			372	kWh	(1)
	Efficient (2020)	1	9	268	kWh	(1)
Water heater	LPG	1		7.8	MJ	(2)
	Hybrid (solar-LPG)	1		3.9	MJ	(*)
Water efficiency devises	Conventional	0.16	1	43.6	kWh	(+)
	Efficient	0.16	0.5	21.8	kWh	(++)

(1) Martínez-Montejo and Sheinbaum-Pardo (2016). (2) Rosas et al. (2010).
(*) Considering that solar water heater represents 50% of thermal energy provided during the year.
(+) 1 hp. of water pumping, for 16 apartments in each building. It is assumed a 50% reduction in water consumption and therefore 50% reduction in water pumping.
(++) Efficient water devices save 50% of water use, and therefore 50% pumping energy consumption.

leading to increase use of energy and less comfort for inhabitants. In a study of Green mortgage dwellings in Nuevo Leon, Mexico, Urrutia and Tamez (2009) recalled the importance of education, communication and training for both, engineers that design and installed the energy and water technologies, and users, for a better implementation of the sustainable housing program. In another study on sustainable housing in Mexico (Arias-Gómez et al., 2013) they recommend to implement a culture of energy and water savings for users to have a better success.

Methodology and database

This paper presents an estimation of theoretical CO_2 emission reduction of the sustainable housing program in Mexico City and the actual reduction. In the first case, estimations are based on the following simple equation:

$$CO_2 = \sum D_i \, UEC_{if} \, EF_{if} \tag{1}$$

where, D_i is the number of dwellings with technology i; UEC_{if}, is the Unit Energy Consumption per year per dwelling of technology i, and final energy f; and EF_{if} is the emission factor of final energy f, including electricity. In the second case, interviews and review of performance status of implemented technologies are undertaken in order to establish the real number of dwellings D that use technology i.

Estimation of technical and economic potential of avoided CO_2 emission of sustainable housing program in Mexico City

Four technologies are evaluated: CFL, refrigerator, water efficiency devices, and solar water heaters. In order to estimate CO_2 emissions avoided for 2025, a baseline and mitigation scenarios are considered. Annual energy consumption is the result of multiplying the number of dwellings (total social housing in Mexico City, Table 1) by the UEC for each technology as shown in Eq. (1) (Table 2). CO_2 emissions are estimated using electricity emission factor for the first three technologies and LPG emission factor for the last one (water heating), respectively (IPCC, 2006). Electricity emission factor (including transmission losses) is presented in Table 3 based on National Electricity Prospects (SENER, 2015).

Because of low water pressure in Mexico City, most social housing requires water pumping. It is assumed that a 50% reduction in water consumption (SEDEMA, 2008; INVI, 2008) will led to a 50% reduction in water pumped and therefore in energy consumption for this end-use. Annual costs of CO_2 avoided emissions is estimated based on Sheinbaum and Masera (2000), considering the data presented in Table 4.

Table 3
Electricity generation mix and CO_2 emissions Factor.

Generation	2010	2015	2020	2025
Total (TWh)	275.6	310.4	360.1	417.7
Coal	15%	14.9%	5.9%	2.3%
Nuclear	2.8%	4.9%	5.9%	7.1%
Hydro	5.8%	4.6%	6.4%	8.9%
Geothermal-energy	6.5%	5.5%	4.9%	4.4%
Other renewables	0.3%	1.4%	2.8%	5.5%
Diesel (including cogeneration)	1.2%	1.1%	1.2%	2.9%
Fuel oil	16.1%	10.2%	0.0%	0.0%
Natural gas	48.8%	52.8%	53.8%	54.8%
Sugarcane bagasse	2.0%	2.8%	2.8%	2.8%
Fuel oil	1.5%	1.6%	0.0%	0.0%
LPG	0.0%	0.2%	0.0%	0.0%
Electricity EF (ton CO_2/MWh)	0.53	0.48	0.24	0.18

Estimation based of SENER (2017) and IPCC (2006).

The household survey

The survey was carried out in 2014, evaluating the dwellings that include the installation of the four technologies selected, as a part of the INVI's sustainable housing program from 2007 to 2012 (Table 5).

The following equation is used to determine the sample size (Fink, 2012),

$$n = \frac{N^* Z_\alpha^2 p^* q}{d^{2^*}(N-1) + Z_\alpha^{2^*} p^* q} \tag{2}$$

Table 4
Technology costs and life.

	Cost/unit (2010 USD)	Life (years)
Lighting		
Incandescent	1	0.68
CFL	6	4
LED	10	7
Refrigerator		
442 kWh	600	15
372 kWh	600	15
268 kWh	600	15
Water heating		
LPG	400	15
Hybrid (solar-LPG)	1200	15
Water savings		
Regular device	10	15
Low-flow shower	12	15

Cost of refrigerator is the same, because it follows energy efficient standard. Source: Martínez-Montejo and Sheinbaum-Pardo (2016).

Table 5
Dwellings under the sustainable housing program and estimations to 2025.

Period	Total	With at least the three selected technologies for the analysis
2007	180	152
2008	1684	1423
2009	1896	1603
2010–2012	1255	1202
Total	5015	4380
2013–2015		3684
2016–2020		6435
2021–2025		6820
Total (2007–2015)		21,320

INVI (2012). Projections for 2020 and 2025 for the two last columns are estimated based on the annual rate of growth of total dwellings in Mexico City (Table 1).

where,

N is the total population.
n is the sample size.
Z_{α}^{2} is the confidence interval of the distribution (considered normal when there is no information about the phenomenon). Generally, a value of $Z = 1.96$ is taken to have a confidence level of 95%.
p is the probability of positive response to your item. Taken $p = 0.5$ when there is no prior information.
$q = 1 - \mathrm{p}$ is the probability of negative response. If $p = 0.05$ then $q = 0.95$.
d is the acceptable percentage of error. Usually $\mathrm{d} = 3\%$ and it is not related to the 95% confidence level.

Since dwellings are similar, they have same size and number of eco-technologies, a systematic random sampling is applied. The properties of this sampling method have been listed and numbered. Subsequently, the constant interval between each element was calculated to determine the sample interval as the number obtained by dividing total universe (N) by sample size (n). As a result 23 questionnaires and physical evaluations where applied to different housing.

Questionnaire design

Aiming to obtain specific information on the current use of technologies and calculate the effective potential resulting from the technology change, and thus evaluate the success or failure of the INVI sustainable social housing program, we developed structured questionnaires as an evaluation method. The questionnaire has 42 questions designed to have immediate results and minimize the risk of manipulation of questionnaire responses. The survey was made in a face-to-face manner. The answers are confidential and will not be used for any purpose other than for academic research. The survey questions are grouped into four sections: general information, solar water heater, efficient lighting, and water saving equipment. The first section provides information about the age of the housing, the number of dwellers per apartment and the knowledge and usage of the eco-technological installed. The last three sections give us information about the current usages and equipment conditions, the technology acceptance and spending or savings observed due to the use of efficient equipment.

Results

Theoretical scenario

Based on data presented in the section above, energy consumption and related CO_2 emissions considering four of the technologies analyzed in social housing in Mexico City are presented in Table 6. Baseline scenario considers LPG water heater, and conventional shower (Table 2). In the case of refrigerator, new devices consider the Minimum Energy Efficient Standard, with an average of 372 kWh/year since 2012 (Martínez-Montejo and Sheinbaum-Pardo, 2016). In the case of lighting baseline scenario considers CFL since 2013. A standard that prohibited the sales of incandescent bulbs was published in December 2010 starting from 2013 (SENER, 2010). Baseline scenarios do not contemplate the actualization of energy standards.

Real scenario with socially neglected effect

As presented in the introduction, we define socially neglected effect as the social behavior of consumers that reject energy efficient or renewable energy technologies because they are not satisfied with the energy service they provide in comparison to the conventional (earlier) technologies that they use to used. As shown in this paper, the socially neglected effect is not always related to the technology per se but to a bad installation or lack of information and capacitation to the final consumer.

Table 6
Energy use, CO_2 emissions and mitigation cost (cost of CO_2 emissions avoided) costs in 2025.

	Description	Total energy consumption	Units	CO_2 Thousands of tonnes	CO_2 Avoided costs (2010 USD/tonCO_2)
Lighting					
Baseline	From 2010 to 2012 CFL 53%; incandescent bulbs 47% From 2013 to 2025 CFL	2.30	GWh	0.41	
Mitigation	From 2010 to 2017: CFL; From 2018 to 2025 LED	1.28	GWh	0.23	0.24
Solar water heating					
Baseline	LPG water heater	166.29	GJ	10.49	
Mitigation	Hybrid water heater (50% solar)	83.15	GJ	5.25	−58.56
Shower water saving device					
Baseline	Standard	0.93	GWh	0.17	
Mitigation	Water shower saving device	0.46	GWh	0.08	−355.78
Refrigerator					
Baseline	2010 to 2012: 442 kWh/year 2013 to 2025: 372 kWh/year	8.15	GWh	1.47	
Mitigation	2010 to 2012: 442 kWh/year 2013 to 2020: 372 kWh/year 2021 to 2025: 268 kWh/year	7.31	GWh	1.32	−5.56

Note: Considers Minimum Energy Efficiency Standards (MEES) for lighting (sale of incandescent bulbs was prohibited in 2013) and refrigerators (average of 442 kWh/year before 2013 and 372 kWh/year after 2012). It considers no actualization of MEES for baseline scenario.

Table 7
Real use of mitigation technologies.

	Total	%
Number of households surveyed	194	100
Dwellings with solar water heating	191	98
Use of solar heaters	112	58
Use of CFL	103	53
Use of water saving devices	146	75
Installed efficient refrigerator	136	70

Survey results

The results from the 194 surveys in 44 different households in 2013 are summarized below.

Household size. 1–3 persons per household: 7%; 5 persons per household: 78% and more than 6: 15%.

Recognition of program. Only 7% of the interviewers knew that their dwelling was under the sustainable housing program. 61% knew that they have solar water heaters, 39% knew that they have efficient lighting and only 7% knew that they have water saving devices. None of the tenants have had information in the convenient use of water saving equipment or efficient lighting devices (especially for those that received their dwellings before the CFL standard), and only 17% had training provided by the administrators for the solar heating systems.

Technology use

Solar heating systems. When asked if in their previous home had solar water heaters, all surveyed dwellings answered no. The types of water heaters they previously used were: LPG storage water heaters (34%), LPG instantaneous/continuous flow water heaters (43%), electric water heaters (9%), LPG cookstoves (13%), and firewood (2%).

All dwellings use hot water in the shower, 22% of them also use hot water in the kitchen and 15% in the sink. For showering, 96% use hot water every day and 4% only 4 to 6 days per week. The time of hot water use is 10–15 min for 61% of the surveyed people and between 16 and 21 min for the remaining 38%.

From the questionnaire as well as physical inspection, results show that only 58% of households use solar water heating systems (Table 7). On the other hand, 72% of solar water heater users reported to have had economic savings through their use, ranging from 30% to 50%. Moreover, and 46% of them have given maintenance to the solar heater once or twice a year consisting solely of cleaning the surface.

From their personal experience, 70% of solar water heater users strongly recommend the use of solar heating. For the remaining 30% there is a need to improve the system of gas supply for complementing solar water heating, and water quality. Over 50% of users whose solar heaters never worked because of problems with the installation, would recommend having solar heaters, by recognizing the savings of their neighbors.

Efficient lighting. According to INVI housing prototypes, 91% of the visited dwellings have efficient lighting systems. Unlike in the use and knowledge of solar heaters, only 9% of respondents reported that they had used saving and efficient lamps in their previous home and 91% had not.

The questionnaire results show that only 53% of tenants have CFL installed (Table 7). On the other hand, 56% of households reported that the type of light from their saving lamps is not pleasant because it is too “white”; they do not like it, but they still use it for electricity bill savings.

Furthermore, and even if the questionnaire only aimed to assess the use of energy-saving lamps in each home, it is worth mentioning that in 11% of the buildings that were visited saving and efficient lighting systems for common areas and corridors were installed, consisting mainly of lamps controlled by motion sensors.

However, for each dwelling, motion sensors lighting systems have not been adequately adopted by users. 85% of surveys showed that since the beginning the sustainable housing had not installed the motion detection systems so the users installed energy saving light bulbs (10%) or an incandescent bulbs (90%). Another factor that has influenced the improper use of efficient lighting system is that 60% of users think that the time the motion detector lighting is on is not enough and also, that motion activation system has caused excessive electricity costs.

Water efficiency devices. Results from survey and physical inspection show the following regarding installation of water devices: 75% in showers, 80% in WC (toilets), and 56% in sinks. Since shower is the main use of water after WC, it is taken for the evaluation of technology use (Table 7). WC once installed is not easy to change. The main

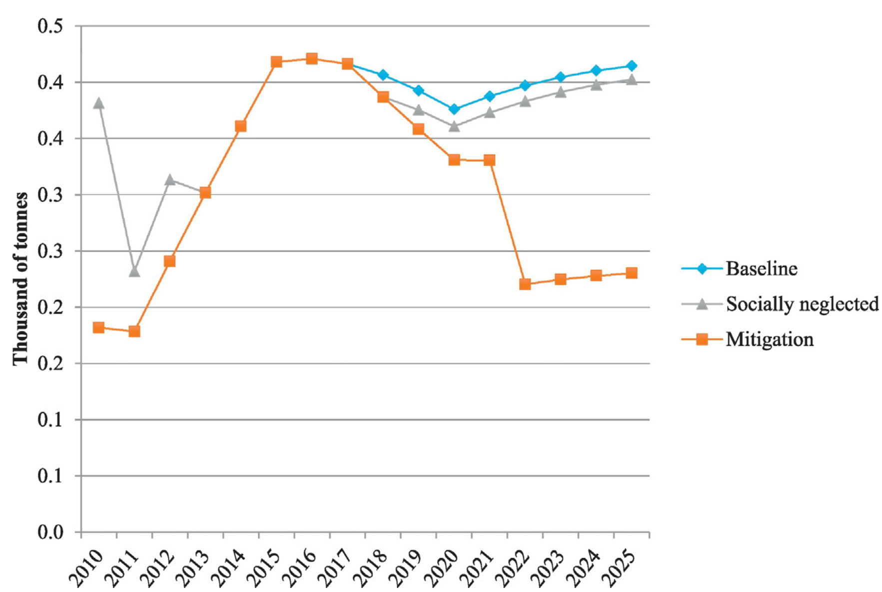

Fig. 1. CO_2 emissions from lighting electricity consumption. Note: Baseline scenario considers no actualization of energy standard after 2013.

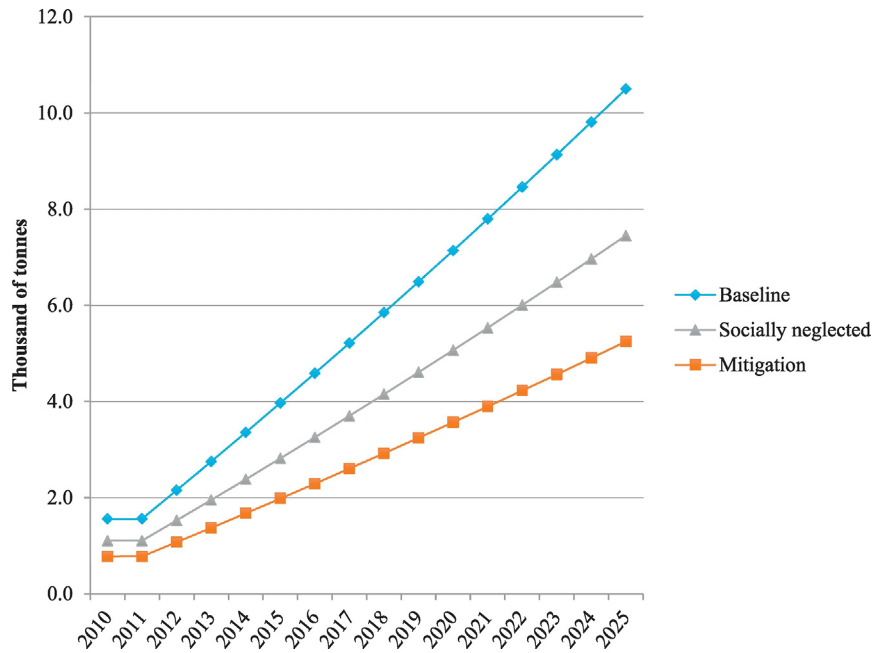

Fig. 2. CO_2 emissions from water heating energy consumption (LPG and hybrid solar-LPG).

problem with no dissatisfaction of water saving devices is that they need adequate water pressure for better performance. However physical inspection showed that only 45% of dwellings use hydro-pneumatic systems and the remaining 55% use the "gravity" pumping system, which does not give enough water pressure for good service. Moreover, since the hydro-pneumatic pumping system is more expensive, 60% of these users have taken steps to reduce the time of use of the water pumping equipment.

In the same way, as with the efficient lighting analysis, only the interior of the housing unit was studied. However, during visits we observed that in all the surveyed buildings rainwater harvesting was considered in the architectural design but currently these systems are not being used due to design failures or maintenance problems. According to INVI's housing prototypes and standards, buildings with more than 100 units must have water treatment and rainwater harvesting systems. Reused and treated rainwater was designed for reuse in toilets: However, for lack of maintenance, users have chosen to cancel the recycling toilet system and connect their equipment to the drinking water network.

Refrigerator. Although INVI's sustainable housing program included the installation of new efficient refrigerators, none of the households received their dwelling with this device. Questionnaire results show that 70% of tenants have installed new refrigerators while the rest brought used refrigerators to the new apartment.

Baseline, mitigation and "socially neglected" scenarios

Expanding survey results to the total universe of INVI's sustainable housing program (Table 1), Figs. 1 to 4 show CO_2 emissions for baseline, mitigation and socially neglected scenarios for different penetration of technologies. Assumptions for socially neglected scenario are presented in Table 8 (Table 6 presents assumptions for baseline and mitigation scenarios). The socially neglected scenario assumes that the rejection

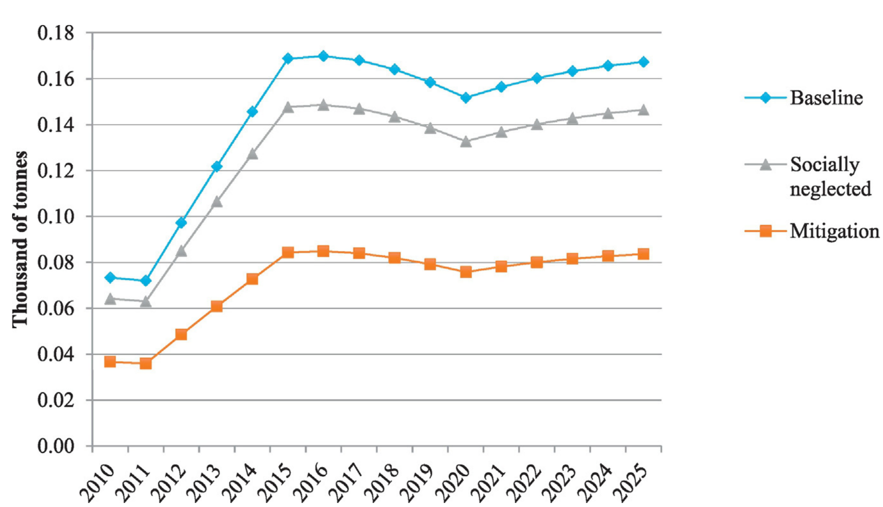

Fig. 3. CO_2 emissions from electricity consumption for water pumping for shower devices. Note: CO_2 emission reduction is due to reduction in electricity emission factor.

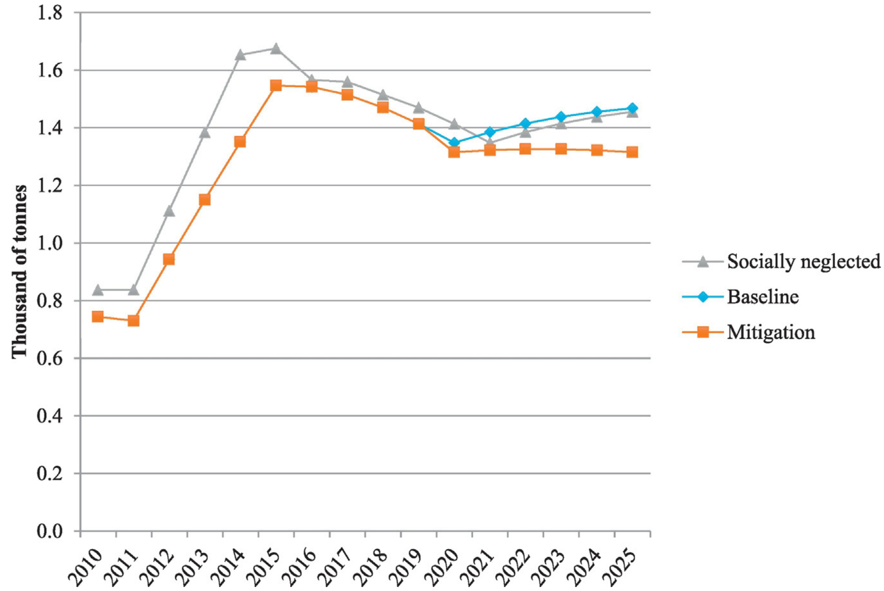

Fig. 4. CO_2 emissions from electricity consumption for refrigerator. Note: The difference between baseline and mitigation is considering that there is no standard for new refrigerators in 2020.Socially neglected scenario considers that 30% of households did not have new refrigerator in 2010 considering an average lifetime of old refrigerators in 2010 of 5 years (total lifetime 16 years); and from 2020 similar to baseline scenario; considering that 70% of new homes will have new efficient refrigerators (Table 7).

of new technologies as observed in the survey results (Table 7) will continue over time.

Conclusions

Sustainable housing program in Mexico City consists of the installation of energy efficiency, water saving, and renewable energy technologies in new dwellings. Considering technology adoption, and what we called "socially neglected effect" the reduction in CO_2 emissions is 22% less than the expected (an expected reduction of 45% from theoretical scenario in 2025 to a 25% real) without considering the rebound effect in either case.

Although the governmental policy is correct in the sense that new housing is delivered with the installation of mitigation technologies and therefore it is not a decision from the household owner, this study shows that additional efforts are needed to inform and involve the household owner about of the benefits of energy efficient and renewable energy technologies, otherwise this technologies could be abandoned and replaced for less efficient technologies.

From literature review and results of this study, it is clear that mitigation technology appropriation and adoption goes beyond economic benefits and information barriers, and therefore, sustainable housing programs need to address social and behavioral appropriation of technologies, if they do not want to end up with a large socially neglected effect.

A very important conclusion is that it is clear that in the case of efficient lighting and refrigerators, where Minimum Energy Efficiency Standards are in place the socially neglected effect disappears once the replacement of old to new technologies takes place. This result shows that energy standards as the main mitigation policy to eliminate socially neglected effect in the long run.

Table 8
Assumptions for socially neglected scenario based on survey results (new technologies).

Technology	Considerations
Lighting	2010 to 2012: CFL 53%; incandescent bulbs 47% 2013 to 2017: 100% CFL because of energy standard 2018 to 2025: LED 53%; CFL: 47%
Solar water heating	From 2010 to 2025: Hybrid systems 58%; LPG: 42%
Shower	From 2010 to 2025: Conventional 25%; efficient: 75%
Refrigerator	From 2010 to 2012: 70% old refrigerators (628 kWh/year) and 30% new (442 kWh) From 2012 to 2020: 372 kWh/year From 2021 to 2025: 70% 268 kWh/year and 30% 372 kWh/year

Note: For lighting and refrigerator there will be a lag in results due to continuing use of old technology based on equipment lifetime (Table 2).

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