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ENERGY CONSUMPTION DRIVERS: DEMAND SIDE MANAGEMENT VS DEVICE PENETRATION, WHICH IS STRONGER? IMPLICATIONS IN CLIMATE CHANGE IN ARID MEXICO

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ABSTRACT

Baja California Sur (BCS) is an isolated and arid state in Northwestern Mexico. Departing from a global and national framework, the state's trends and characteristics of electricity consumption, generation and policies and factors modeling these are depicted. The trends of parameters such as energy intensity of GDP, GHG emissions by energy unit produced, and share of renewables are first analyzed. Then, a test for detecting a decoupling of electricity consumption from weather is carried on, using correlation in subsets of time series together with statistical trend detection, for assessing an overall state-level change, instead of punctual savings or estimations, which is attributable to building and appliance efficiency standards. The work focuses on the residential and tourism sectors, which demand above 70% of the electricity in the State, intending to develop an approach to regional scale change assessments, instead of estimations or punctual saving calculation in warm regions, with a comprehensive data input requirement for developing countries. The findings show that GDP has grown slightly more energy intensive, the share of renewables in the mix has diminished, and, in spite of punctual savings from demand side management measures, due to an overall increase in air conditioning and other devices penetration, there is no significant decoupling in energy consumption from temperature, a main driver of consumption in BCS, where total summer demand is about 50% greater than that of winter and the state which ranks second in non industrial GHG emissions per capita in Mexico. Implications in GHG emissions and development of policies seeking to mitigate climate change are discussed.

KEYWORDS:
Greenhouse gas emissions; Climate change; Energy efficiency; demand side management; arid regions.

INTRODUCTION

In some regions, such as the one depicted in this work, conditions such as isolation, high temperatures in summer, a large share of residential demand, little availability for wind and none for hydro power, as well as nightly peaks of consumption which cannot be covered with solar power make demand side management, i. e. energy efficiency, the most feasible option to better the sustainability of the energy system. Policies on demand side management seek to decrease energy intensity by means of technical and legislative policies and encouraging the rational use of energy, while, on the opposite side, there is a steadily growing electrification of the everyday life [1], as new appliances that use electricity are developed and adopted by the people, which cause increases in consumption.

As an approach to ponder the results of demand side management policies enforced in Baja California Sur (BCS) during the last two decades, a time series analysis for detecting a decoupling of energy use from temperature is carried out, at the state scale, instead of estimations or punctual reckoning of savings, which are more conventional in the literature. The method has a comprehensive data disaggregation requirement, for warm regions where consumption data is offered on a monthly basis.

The present work is intended to increase understanding about the challenges and barriers of using electricity in a sustainable fashion in arid regions of developing countries, with high weather-sensitive residential demand. The final purpose of the work is to provide a different and medium scale insight for addressing climate change and sustainability issues in future planning.

MATERIAL AND METHODS

Study area. BCS is the most arid and isolated State of Mexico, its population in 2010 was 637,026 inhabitants. It is among the Mexican States with the fastest economic and demographic growth, around 7% in the last decade, due to the recent development of the tourism industry and to an ever increasing number of American and Canadian citizens who look for a place to retire [2].

The State Energy Grid relies on fossil fuel based facilities, which make up 98.2% of the total. Besides the fossil-fuel-based, BCS has geothermal and solar power plants; since there are no perennial rivers in the State, hydropower is absent in BCS [3]. The resulting hourly cost of production of this technology mix ranges from US$0.094 before dawn in winter to US$0.371 per kWh in the afternoon (15:00 to 17:00) and before midnight (21:00 to 23:00) [4]; power is sold for an annual average of US$0.098 per kWh to residential customers and US$0.12 per kWh average to all other sectors [5].

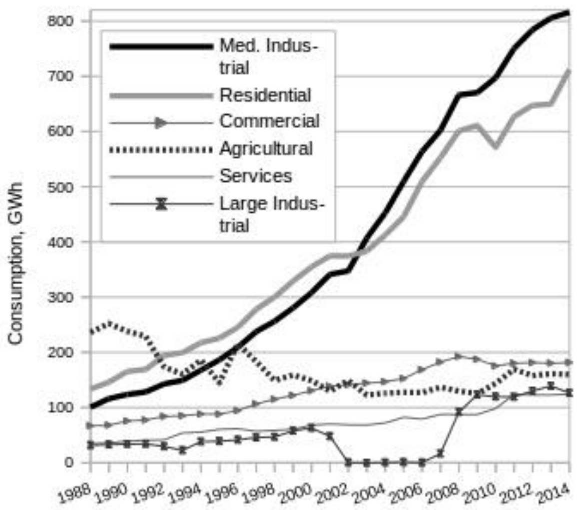

FIGURE 1
Power consumption by sectors of activity, 1988-2014. Data source: [7].

Electric consumption in BCS. In BCS, large Industries demand 10.3% of the total power consumption, compared with a 27.5% at a national level; meanwhile, in the state, residential demand is 33.14%, high above the 26% average for the Country. Medium sized industries (MSI) are the top consumers (37.8%)(Fig. 1); MSI Tariff is used mainly by the tourism sector, as well as in other economical activities such as welding shops, bakeries, automotive shops, etc. This sector has a 20% weather sensitive consumption, a figure obtained by subtracting the winter consumption as a baseline demand, when air conditioning is not used, an approach used in warm regions to determine air conditioning loads [6]. Residential sector has a 35% weather dependent consumption.

Due to isolation, the predominantly fossil fueled energy mix and the warm weather, the State ranks second place nationally in non-industrial energy related GHG emissions per capita, with 0.7 Tons CO_{2Eq} per capita yearly, only after Quintana Roo, well ahead of states with large industries, such as Coahuila, Nuevo León, Veracruz, San Luis Potosí and Tamaulipas, which in consequence of its industrial activity have larger GHG emissions (Fig. 2). Overall emissions from the eight greatest facilities added 1.6 million tons of CO_{2EQ} in 2010, yielding 752 tons of CO_{2EQ} per GWh produced, from a former value of 740 in 2007 [8][9]. A comparison of per capita energy consumption, GHG emissions and GDP among BCS, Mexico and the OECD is presented in Table 1.

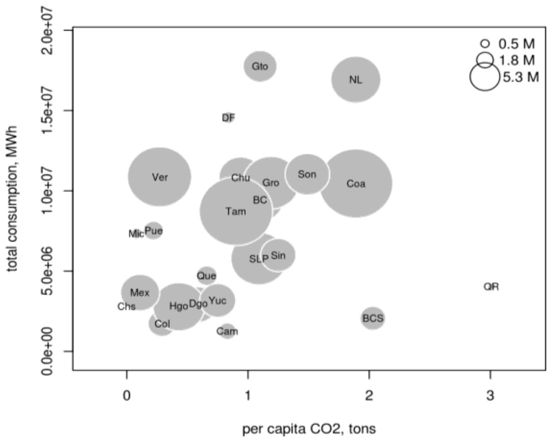

FIGURE 2
CO2 Emissions from energy production per capita, excluding industrial consumption. Size of bubble represents the total CO2 emissions in tons.

Energy intensity has grown in the recent years: in the 2005-2009 period, energy consumption from all conventional sources (gasoline, gas, diesel, fuel oil, kerosene and electricity) grew at an average yearly 1.07 rate [7], exceeding the pace of GDP, which only grew at an average 1.03 rate in the period. Elasticity from energy use is a desirable and non-controversial sign of a sustainable economy [10].

In BCS, the highest consumption loads, with its consequent highest costs of production, occur in summer, peaking around 15:00 hrs, when outdoor temperature is highest, and around sleeping time at midnight, when comfort is needed the most, as it happens in warm regions in the world [3]. Energy consumption is lowest in winter, since gas or electrical heating are scarce, present in less than 0.6% homes [13].

TABLE 1
Comparison of energy, emission and GDP indicators for BCS, Mexico and the OECD

	GDP per capita USD constant prices, 2005 PPP		GHG Emissions, kg, per capita		Electricity consumption, MWh per capita		Emission intensity, kg GHG/1000 USD	
	2000	2010	2000	2010	2000	2010	2000	2010
BCS		17,717	6.33 (2005)		2.53	2.83	0.59 (2005)	
Mexico	11,946	12,741	5.6	6.14	1.70	1.92	0.46	0.48
OECD	28,252	30,574	14.03	12.92	7.93	8.27	0.50	0.42

Sources: [11][2], [11], [12]; values for BCS were calculated from [2], [7], [9]

A net growth in consumption per household has occurred in the State in the last two decades (Fig. 3), although some pulses have driven energy consumption to a temporarily decrease, such as a Tariff re-structure in 2002 [14], a Tariff change for Los Cabos to a cheaper Tariff in 2006 and the World Financial Crisis in 2009, when the trend in tourism GDP in BCS, which rose from US$389.629 million to US$752.93 million in the 2003-2007 period, dropped dramatically to US$560 million in 2010 [2]. The trend in consumption *per household* is less steep than the *per capita*, due to the long term household size reduction in the country.

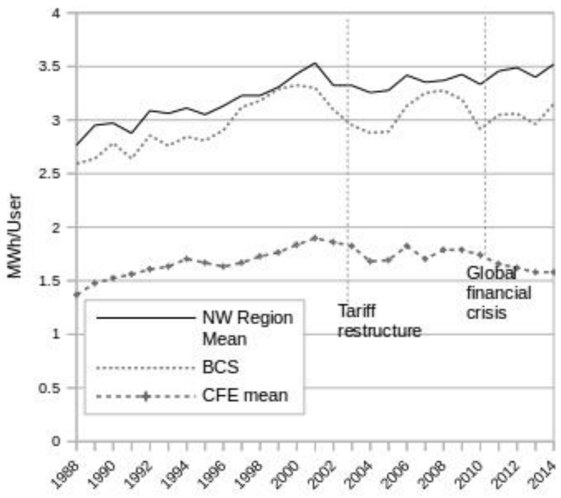

FIGURE 3
Residential consumption average for NW region, BCS and Nationwide. Source: [7].

The perceivable overall rise in energy consumption per household is related to technological penetration -as more households acquire newly developed appliances, economic growth, as well as changes in housing type [15]. In BCS, electric appliances have spread widely in the past decade. Table 2 summarizes the increase of availability per household for the most widespread and most energy consuming devices in the 2000-2014 period.

TABLE 2
Device penetration in BCS

Device	2000(%)	2010 (%)	2014(%)
Refrigerators	82	89	91
Air conditioners	23	30	36
Laundry machines	54	68	72
TV sets	89	98	99
Computers	11	39	42

Source: [13].

Other factor influencing the rising trend in consumption is the increase in temperatures in the main cities, which, for La Paz, the city with the longest records, adds up to 2.5° C for the period 1923-2013. Considering the need for air conditioning, government subsidizes up to 80% of consumption during summer. Meteorological phenomena, such as hurricanes and heavy rainfall temporarily affect energy consumption due to interruptions of the supply.

Energy efficiency measures in Mexico. First Mexican Official Standards (NOM, initials in Spanish) regarding power consumption appeared in the mid nineties, these focused primarily on industrial devices; the first standard directed to a domestic device was published in 2002, establishing efficiency limits for refrigerators; it was followed by standards limiting energy consumption for air conditioners (2006) laundry machines (2010), domestic fluorescent lamps (2010) and refrigerators (2012), complemented by standards for passive efficiency measures for office buildings (2001) and residential buildings (2011)[16]. The results of most of these recent controls are yet to be analyzed, hence, an approach is presented in this work for doing so.

The National Commission for the Efficient Use of Energy (CONUEE, initials in Spanish) operates programs for substituting inefficient domestic appliances, giving credits for the acquisition of refrigerators and air conditioners, since 2009. The replacement of both cooling devices by this initiative in the first year reached has reached 3,773,000 replacements in the country [17]. Along with the cooling device substitution, the Fund for the Energy Transition and the Sustainable Use of Energy (FOTEASE, initials in Spanish) program substituted eight incandescent light bulbs for fluorescent lamps in every household in the country. Previous to this programs, ASI, a trust for energy efficiency, replaced 10,600 devices from 2004 to 2008 in BCS, giving benefits to a considerable fraction among 198,500 households, whose power savings may reach 30% by switching to new devices [18]

Time series analysis of the coupling of energy consumption and temperature. Considering all the aforementioned regulatory and financial measures to improve energy efficiency on the cooling devices -which are the highest in power consumption, from standards for electronic devices and building designs and financial support schemes, a perceivable decoupling on the relation between the consumption and the temperature should be expected, if the effects of the undertaken measures were exceeding the rising trends on electric consumption, which are due mainly to device penetration and population growth.

Energy savings from efficiency measures have been regarded as difficult to assess [19], [20]. Testing for a decoupling has to overcome factors that may mislead the findings, to find whether occurrence of savings is truly related to optimization, or whether it is masked by changes in the demand shares, economic recession, migration or milder summers, for instance. Among the scarce literature about decoupling, [21] reported a decoupling of energy use from temperature in specific buildings constructed according to the bioclimatic architecture in the US and UK.

In the present work, a test was made for detecting decoupling of energy use from temperature, as an approach to assess the achievements of energy conservation policies by using the Monthly State Electricity Index (IEME, initials in Spanish) [2], as the electricity consumption variable, together with data from meteorological observatories [22], under the assumption that if a decoupling occurred during the evaluated period, it should be noticeable among subsets of the time series.

The IEME synthesizes generation and demand volume and cost information for all activity sectors, presented as a Physical Volume Index, fixed at a base year, so it takes into account the effects of variability in electricity pricing. It is readily available information, updated every other month, and time series depart from 2003 on, so it is useful to detect changes in trends in the past decade.

Monthly temperature data for the meteorological stations in BCS were kindly supplied by the observatories of the CONAGUA [22], from 2003 to 2012. For each year in the period, Pearson linear correlation was obtained for annual, warm (April to October) and temperate (November to March) seasons subsets of data. As should be expected, correlation IEME-temperature was highest for the warm (0.91) and lowest for the temperate (0.61) seasons. Annual correlation was high, averaging 0.88. Standard deviation was 0.06, 0.05 and 0.3, for the annual, warm and temperate groups, respectively.

Finally, for statistically detecting any monotonic trend in the temperature-consumption correlation within the period 2003-2012 (Fig. 4), the non-parametric test Mann-Kendall Z was carried on using R Studio [23].

Z values were 0.36, 1.07 and -0.18 for annual, warm and temperate subsets, respectively, meaning that no trend in any of the subsets was significant, not even at α=0.1. Warm season had the highest positive value, but not enough to be considered a trend from the test outcome.

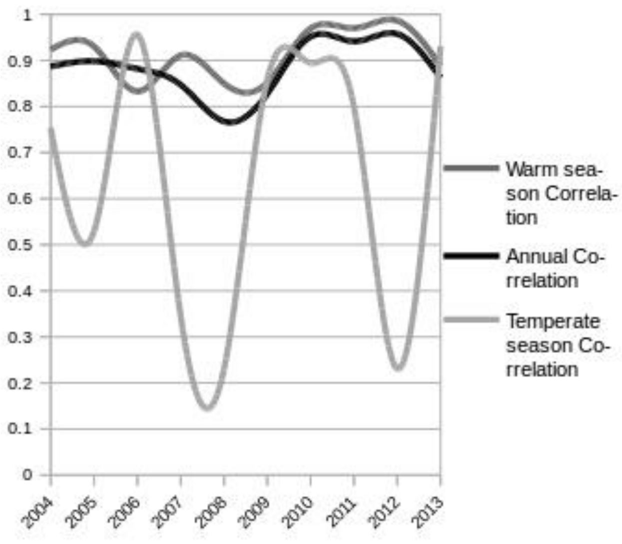

FIGURE 4
Energy consumption (IEME)-mean temperature correlations for BCS, annual and seasonal, 2004-2013.

On Figure 5 a Holt Winters [23] forecast of the current trends and conditions for the climate sensitive consumption (med tension and residential) is plotted; if these persist, by 2020 the peak of consumption in summer and the winter baseline would be 50,000 MWh and 60,000 MWh higher, respectively.

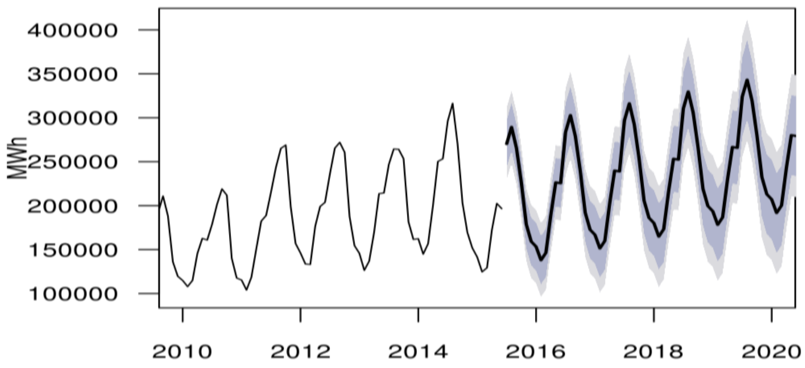

FIGURE 5

Climate sensitive consumption 2009-2015 and 5 year forecast with 95% confidence prediction intervals.

RESULTS

The present attempt to study the effect of policies regarding air conditioning efficiency and passive temperature control in BCS does not suggest that they have been unworthy, but that they yet do not seem to curb the same opposing forces that policies on refrigerators did overcome on the national scale, which related emissions decreased from 9.9 Tg to 8.6 Tg CO_2 in the 1996-2006 period, outpacing even a 13% growth in population and an increase from 9% to 16% in penetration, while those of air conditioning increased 3.9 Tg to 5.5 Tg in the same period, according to [24].

Large correlations, as those occurring in summer, difficult the detection of growing trends, although the absence of a positive trend is to be remarked, since a number of studies around the world have found increasing dependence, mostly within temperate climates, where warmer summers are occurring, such as the regions of Maryland in the USA [25] or the Netherlands [26].

Demand side management policies have not matched the speed of growth in economy and population in the state. The first passive control standard, the NOM for office buildings, was published in 2001; ten years later, the NOM for residential buildings appeared, in 2011. Air conditioning efficiency standards are also relatively young, without yet having reached a decade since their appearance: the first was published in 2006, for central air conditioning; the standard for regulating room systems appeared in 2008, when air conditioning had reached almost 30% of penetration in BCS dwellings. The challenge of mitigating GHG emissions from the electric sector can only be overcome including more stringent demand side management measures.

As can also be observed from the records, winter demand has increased by 215%, exceeding the rate of summer, which grew by 207%. This is linked to an increase in tourist arrival during winter, from a total of 593,000 in 2003 to 726,000 in 2011 in the March season, which attracts 24% more tourism than the monthly average throughout the year in the period of study.

CONCLUSION

This work has shown that parameters related to sustainability of the electric system have had little progress or receded at the state level; GDP grew more energy intensive, renewable generation decreased in the electricity generation mix, GHG emissions per energy unit increased due to fuel mix and device penetration and consumption remains tightly coupled to temperature. Institutional, market and behavioral barriers have to be broken in the state to counter these trends and to achieve sustainability.

Policies in BCS must be tailored differently to those of the rest of Mexico, taking into account the very different conditions the state has, seeking to mitigate its GHG emissions and to optimize the energy use. This should be solved through the creation of a state energy commission, an approach that has been already taken in the states of Baja California, Sinaloa, Jalisco and Hidalgo. An outstanding case of success in state planning is that of the California Energy Commission, which has been at the vanguard of energy efficiency in the US ever since the publication of its first standard -the first in the US as well, in 1974 [27]. Dependence from centralized planning is an institutional barrier that has to be overcome.

Education has remained overlooked within policy development: neither the Energy Reform, the LAERFTE nor the ENE 2013 take into account any educational measure; the LASE does mention including rational use of energy in educational programs in Mexico, as well as fostering research. Previous literature has pointed out that education can outperform other measures for conserving energy, through breaking behavioral barriers among end users [28] hence, since BCS residential users are a significant share of the total users, education can be a valuable tool for breaking behavioral barriers thus saving energy and achieving climate change mitigation goals.

A more rational use of energy can be achieved through tariffs, as was pointed from the overall changes in consumption when electricity became more expensive or when economy receded, but it should not be the first neither the only policy approach to use.

GHG emission savings from efficiency standards need to be assessed and the pace of its publication should not lag behind that of the appearance of new devices: in BCS, energy related emissions per capita increased from 1.7 tons CO_{2EQ} 2005 to 2.4 tons CO_{2EQ} in 2013 [2, 9] and electricity generation makes up 35.6% of the total emissions, after transport, with 52%, so promoting the rational use of energy through all its different forms, i.e. efficiency standards, education, tariffs and regulation should be a critical strategy for mitigating GHG emissions.

The path towards energy sustainability through demand side management has been steep in these decades. Although some true achievements have been made, and more changes are to be expected from the new measures and policies, population growth and the electrification of the everyday life still seem to be outpacing the accomplished advances. In the isolated and arid BCS, fostering a change in the currently intensive end-user behavior is crucial for achieving the real sustainability of the energy system.

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REFERENCES

[1] Sánchez-Ramos, I. and Pérez-Rebolledo, H. (2011) Consumo de energía por potencia en espera en casas y oficinas, Bol. Inst. Investig. Eléctricas, 2011 143–149.

[2] INEGI, Banco de Información Económica (BIE) (2015). [Online]. Available: http://www.inegi.org.mx/sistemas/bie/. [Accessed: 10-Sep-2015].

[3] SENER (2012), Prospectiva del Sector Eléctrico 2012-2026. Secretaría de Energía, México, D.F.

[4] CFE (2014) Costos totales de corto plazo incurridos. 2014. Comisión Federal de Electricidad, México, D.F.

[5] CFE (2015) Tarifas autorizadas por la Comisión Federal de Electricidad. [Online]. Available: http://app.cfe.gob.mx/Aplicaciones/CCFE/Tarifas/Tarifas/tarifas_casa.asp. [Accessed: 10-Sep-2015]. Comisión Federal de Electricidad, México, D.F.

[6] Pereira, I. M. and Assis, E. S. D. (2013) Urban energy consumption mapping for energy management, Energy Policy, vol. 59, 257–269.

[7] SENER (2015) Sistema de Información Energética. [Online]. Available: http://sie.energia.gob.mx/. [Accessed: 10-Sep-2015].

[8] Lagunes-Díaz, E., Beltran-Morales, L. Stoyan, S. and Ortega-Rubio, A. (2011) Pasado, presente y futuro del consumo y generación de energía eléctrica en Baja California Sur: planeación y optimización para el estado más árido y aislado de la República., in Hacia la sustentabilidad ambiental de la producción de energía en México., M. E. González-Ávila, G. Muñoz-Meléndez, and A. Ortega-Rubio, Eds. Tijuana: El Colegio de la Frontera Norte y CIBNOR, 139–172.

[9] SEMARNAT (2015) Registro de Emisiones y Transferencia de Contaminantes. Secretaría de Medio Ambiente y Recursos Naturales, México, D.F.

[10] Manzini, F., Islas, J. and Macías, P. (2011) Model for evaluating the environmental sustainability of energy projects, Technol. Forecast. Soc. Change, vol. 78, no. 6, 931–944.

[11] World Bank (2015), GDP per unit of energy use (constant 2011 PPP $ per kg of oil equivalent) | Data | Table, 2015. [Online]. Available: http://data.worldbank.org/indicator/EG.GDP.PUSE.KO.PP.KD. [Accessed: 10-Sep-2015].

[12] OECD (2015) Greenhouse gas emissions. [Online]. Available: https://stats.oecd.org/Index.aspx?DataSetCode=AIR_GHG. [Accessed: 10-Sep-2015].

[13] INEGI (2015) Encuesta Nacional de Ingresos y Gastos de los Hogares (ENIGH). [Online]. Available: http://www.inegi.org.mx/est/contenidos/proyectos/encuestas/hogares/regulares/enigh/default.aspx. [Accessed: 10-Sep-2015].

[14] Cámara de Diputados (2003), Impacto en los hogares Mexicanos por el incremento de las tarifas eléctricas residenciales. Análisis por deciles de ingresos.

[15] Rosas-Flores J., and Gálvez, D. (2010) What goes up: Recent trends in Mexican residential energy use, Energy, vol. 35, no. 6, 2596–2602.

[16] SENER (2010), Evaluación y plan de manejo ambiental del programa de eficiencia energética. Secretaría de Energía, México, D.F.
[17] Auditoría Superior de la Federación (2012), Secretaría de Energía. Administración y Desarrollo de Programas de Ahorro de Energía por Fideicomisos Públicos. [Online]. Available: http://www.asf.gob.mx/Trans/Informes/IR2012i/Documentos/Auditorias/2012_0443_a.pdf. [Accessed: 14-Sep-2015].
[18] ASI (2008), Acciones financiadas por el fideicomiso para el aislamiento térmico de la vivienda en BCS, Ahorro Sistemático Integral.
[19] Rosenow, J. and Galvin, R. (2013) Evaluating the evaluations: Evidence from energy efficiency programmes in Germany and the UK, Energy Build., vol. 62, 450–458.
[20] Escrivá-Escrivá, G. Álvarez-Bel, C., and Peñalvo-López, E. (2011) New indices to assess building energy efficiency at the use stage, Energy Build., vol. 43, no. 2–3, 476–484.
[21] Mohareb, E. a. Kennedy, C., Harvey, D. and Pressnail, K. (2011) Decoupling of building energy use and climate, Energy Build., vol. 43, no. 10, 2961–2963.
[22] CONAGUA, Registro estación meteorológica WMO 76405, 2003-2012, 2012. Comisión Nacional del Agua, La Paz, BCS, México.
[23] R Core team (2014) R: A language and environment for statistical computing. R foundation for statistical computing.
[24] Rosas, J. Sheinbaum, C. and Morillon, D. (2010) The structure of household energy consumption and related CO2 emissions by income group in Mexico, Energy Sustain. Dev., vol. 14, no. 2, 127–133.
[25] Ruth, M. and Lin, A (2006) Regional energy demand and adaptations to climate change: Methodology and application to the state of Maryland, USA, Energy Policy, vol. 34, no. 17, 2820–2833.
[26] Hekkenberg, M., Benders, R., Moll, R. and Schoot-Uiterkamp, A. (2009). Indications for a changing electricity demand pattern: The temperature dependence of electricity demand in the Netherlands, Energy Policy, vol. 37, no. 4, 1542–1551.
[27] Alliance to Save Energy (2013) The history of energy efficiency. Washington, D.C..
[28] Dias, R., Mattos, C. and Balestieri, P. (2004) Energy education: breaking up the rational energy use barriers, Energy Policy, vol. 32, no. 11, 1339–1347.

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