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Temperature Effects on Electricity and Gas Consumption: Empirical Evidence from Mexico and Projections under Future Climate Conditions

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Abstract: Fixed effects panel models are used to estimate how the electricity and gas consumption of various sectors and residents relate to temperature in Mexico, while controlling for the effects of income, manufacturing output per capita, electricity and gas prices and household size. We find non-linear relationships between energy consumption and temperature, which are heterogeneous per state. Electricity consumption increases with temperature, and this effect is stronger in warm states. Liquified petroleum gas consumption declines with temperature, and this effect is slightly stronger in cold states. Extrapolations of electricity and gas consumption under a high warming scenario reveal that electricity consumption by the end of the century for Mexico increases by 12%, while gas consumption declines with 10%, resulting in substantial net economic costs of 43 billion pesos per year. The increase in net energy consumption implies greater efforts to comply with the mitigation commitments of Mexico and requires a much faster energy transition and substantial improvements in energy efficiency. The results suggest that challenges posed by climate change also provide important opportunities for advancing social sustainability goals and the 2030 Agenda for Sustainable Development. This study is part of Mexico's Sixth National Communication to the United Nations Framework Convention on Climate Change.

Keywords: electricity consumption; LP gas consumption; temperature; fixed effects panel data

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1. Introduction

A net increase in energy use due to global warming may comprise one of the main economic costs of climate change [1] The relation between climate change and energy demand works through different channels, which can have opposite effects. Global warming is expected to increase cooling demand, which would increase electricity consumption. In contrast, warmer winters are expected to reduce heating demand, which limits consumption of electricity, oil, and natural gas. Empirical studies on the relationships between temperature and energy consumption can provide insights into the net effects of these channels. A net increase in energy consumption can again contribute to more greenhouse gas emissions, which worsens the climate change externality if this consumption originates from fossil fuels, and increases in net energy consumption hamper countries efforts towards sustainable development. Clean energy transition and more efficient uses of energy, as well as improving social sustainability performance, are of prime importance both for climate change mitigation and for attaining the goals of the 2030 Agenda for Sustainable Development [2]. There are important opportunities for designing and implementing integrated strategies for energy transition, climate change mitigation and sustainable development [3]. This is particularly relevant in the context of the Paris Agreement as countries are looking for strategies to interweave their emissions reduction commitments with their other national energy and development policies. Mexico's goals, expressed in its Nationally Determined Contributions (NDC), illustrate current efforts for transitioning towards a greener, sustainable development path based on coalitions between different organizational units and a multilevel governance approach [4]. The analysis presented here is part of the initiatives of the Mexican government for producing information about impact and vulnerability assessment, mitigation and adaptation, with the aim to support national climate policy and the achievement of the Sustainable Development Goals. These results were included in Mexico's Sixth National Communication to the United Nations Framework Convention on Climate Change [5]. The objective of this study was twofold: (1) to assess the economic costs of climate change caused by changes in energy consumption; (2) to offer estimates of how much electricity and gas demands could change, which could be useful for calculating the emission reduction efforts needed to comply with the country's NDC goals.

A variety of empirical approaches have been applied in studies that estimate relationships between weather and energy consumption, which are reviewed by Auffhammer and Mansur [6]. These studies can be divided into (i) examinations of how energy consumption differs between consumers in different climate zones, and (ii) analyses of how energy consumption changes in response to changing weather conditions or shocks. A challenge with the first cross-sectional approach is that estimates can be influenced by omitted variable bias when unobserved differences in consumers are related to climate. Hence, the cross-sectional method is not recommended for assessing the effects of climate change [6]. The second approach uses simple time series or panel data methods to estimate how energy consumption changes in response to variations in weather. A disadvantage of the time series approach is that it cannot control for unobserved factors, as is the case with cross-sectional data. An advantage of panel data is that it can control for omitted variables through introducing fixed effects.

Applications of panel studies involve micro-studies of household panels [7,8] and studies at the zip code [9,10], state [11], province [12] or national level [13,14]. Even though these panel data approaches mainly capture short-run instead of long-run responses to weather, Auffhammer and Mansur [6] conclude that they are the most promising method for estimating the effects of weather on energy consumption because of their capacity to deal with unobserved variables. The estimated relationships between energy consumption and weather variables can subsequently be used for extrapolations, which project how energy consumption may change under future weather conditions as represented by climate change scenarios.

To the best knowledge of the authors, most of the studies regarding climate change and the energy sector in Mexico have focused on the feasibility and costs of complying with its international mitigation commitments [15–19], but not on how temperature increase may affect energy demand. In this study, we focus on the demand side of the problem and apply fixed effects panel data methods to examine relationships between energy consumption and temperature for all 32 states in Mexico, while controlling for other variables of influence on energy consumption, like time and geography as well as socioeconomic drivers that are known to be important determinants of energy consumption [20,21]. Auffhammer and Mansur [6] reveal that most previous studies have focused on electricity consumption in the residential sector, while coverage of the commercial and industrial sectors and other fuels is sparse. Our study aims to provide a more comprehensive assessment by focusing on aggregate electricity as well as liquified petroleum (LP) gas consumption, which comprises all possible end users, including the residential, commercial, industrial and public sectors. What is especially interesting regarding this application in Mexico is that it is a large country consisting of 32 states with different climate zones (see Figure 1), which allows for examining how responses in energy consumption differ between states with different average temperature conditions, of which there is currently limited knowledge [6]. Changes in demand and consumption between the different states can have important implications for determining the requirements and location of electricity generation capacity, transmission infrastructure and energy policy in general [22]. Our assessment of both electricity and LP gas consumption allows for examining whether the expected positive effects of global warming on electricity consumption offset the expected decline in LP gas consumption for heating. Moreover, how electricity and gas demand changes due to temperature increases is an important factor for evaluating the efforts needed to comply with international mitigation commitments, as well as for assessing the costs of climate change for the Mexican economy.

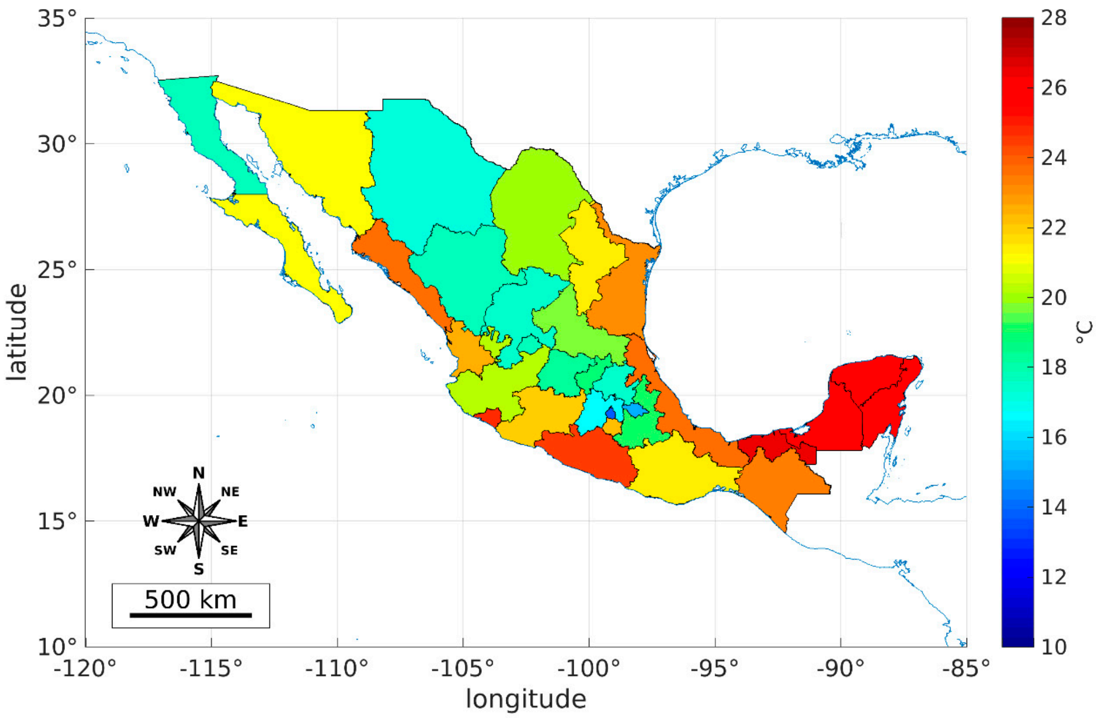

Figure 1. Map of Mexico with average annual temperature levels per state.

Based on the estimated relationships between energy consumption and temperature, we explore how climate change may impact energy consumption and associated costs, by projecting how electricity and gas consumption is expected to change for each Mexican state under future scenarios of climate change. This is relevant since an important channel through which climate change can affect the economy can be the energy sector. Mexico is a country with relatively high average temperatures, a large population, and a current low saturation of air conditioners, which may increase due to global warming [23].

The remainder of this paper is structured as follows. Section 2 describes the data and methods. Section 3 presents the results of simple relations between temperature and energy consumption, the statistical models, and extrapolations of energy consumption under future climate change scenarios. Section 4 provides a discussion and conclusion.

2. Data and Methods

2.1. Dependent Variables

Our empirical analysis aims to establish relationships between electricity consumption and temperature and between LP gas consumption and temperature, while controlling for other variables that influence electricity and gas consumption, like geographical and time variables as well as socioeconomic drivers such as income, energy prices and manufacturing output to represent industrial activity and household size, which are important determinants of energy consumption [20,21]. Data on electricity and LP gas consumption were provided by the Secretaría de Energía (SENER) in Mexico for this study per Mexican state and on a monthly time interval. Electricity consumption is available for the years 2002 until 2016 and measured in megawatt–hours (MWh). LP gas data are reported in barrels (86 kg) and available for the years 1995 to 2014. Preliminary numbers are forecasted by SENER for the years 2015 and 2016, however, we excluded the year 2016 because it is judged as being unreliably estimated by local experts (Based on a focus group meeting held in May 2017 with Mexican energy experts from the National Institute of Ecology and Climate Change (INECC) in Mexico City). Per capita electricity and gas consumption variables per state are used as dependent variables to account for differences in population between Mexican states.

It should be noted that data on fuel oil, diesel, coal and natural gas consumption are not available in Mexico on a state level or monthly basis, and hence these energy sources were excluded from our analysis. Moreover, from SENER it is known that fuel oil, diesel, coal and natural gas are used for electricity generation in Mexico. This gives further justification to exclude these fuels from the analysis, since changes in the use of these energy sources cannot be clearly separated from electricity consumption.

Electricity and LP gas are the predominant types of energy for cooling and heating applications in Mexico. Electricity is used to power refrigerators and air conditioners. Air conditioning is a widespread and energy-intensive cooling device. Compared to refrigerators and freezers, it is usually not activated permanently but selectively switched on at times of temperature-related discomfort. Its use is, therefore, sensitive to changes in temperature. Currently, 99% of Mexican households have access to electricity [24]. LP gas in Mexico has been replacing the traditional high use of fuel-wood for heating and cooking [25]. Gas is burned to heat water and living spaces [24]. The extensive use of LP gas makes Mexico one of the countries with the highest LP gas consumption in the world [26].

2.2. Explanatory Variables

The main explanatory variable of interest in this study is temperature. When outdoors temperature changes, the discrepancy between comfortable temperature indoors and outdoors temperature can either diverge or converge. Comfortable temperature can be defined as room temperature, which represents a temperature of air that is neither too cold nor too warm when wearing indoor clothing. Room temperature is defined as a range of temperature between 15 and 25 °C [27]. Based on this concept, it is expected that rising temperatures would increase electricity consumption more in locations with average temperatures around or above comfortable levels. The temperature induced discomfort is expected to be compensated by using electricity-consuming cooling devices. Gas consumption should decrease with higher temperatures as less heating would be needed, and it would be predominantly used for this purpose in colder states. In warmer states, a relatively larger share of gas is used for cooking and other non-heating services. Hence, it would be expected that gas consumption would decrease more in cold states when temperature increases. The climate change indicator used in this study is state-level monthly mean temperature, measured in °C. Temperature data were obtained from the Climate Research Unit for the period from 1901 to 2015 and updated with data from the Mexican National Water Commission [28] for the year 2016.

The proposed statistical models account for time and geographical effects (Section 2.3), and we used income per capita, manufacturing output per capita, electricity and gas prices and household size as control variables In case of missing observations or when data were only available on an annual frequency, linear extrapolation or interpolation was applied to construct a complete monthly times series of these control variables. In particular, linear interpolation of annual per capita GDP and manufacturing output is used to derive monthly values. Annual LP gas prices between 1995 and 2014 are linearly extrapolated for the year 2015, and linearly interpolated to obtain a monthly time series. From three surveys about household size in 2005, 2010 and 2015, linear extrapolation is used to derive the unmeasured annual values between 2002 and 2005 and the year 2016 and linear interpolation is used to derive a monthly time series. Although the interpolations and extrapolations used may introduce measurement error, we do prefer to include these control variables since the adjusted-R^2 increases slightly when they are included: namely, by 0.01 in the model for electricity consumption and with 0.015 in the model with LP gas consumption. Recent studies have underlined the importance of changes in demography, income and industrial structure for energy demand, in addition to energy prices [9,10,22]. A higher income can increase electricity and gas consumption because households with more income may buy more appliances that use electricity and gas, and have larger houses that need to be cooled or heated, and those households have a higher disposable income for paying their energy bills [11,23]. Moreover, high income reflects higher economic activity, which requires energy as input [22]. This effect is also partly captured by the manufacturing output variable [21] (The correlation between GDP per capita and manufacturing output per capita is only 0.53, which is why it is useful to include both explanatory variables). On the other hand, a higher income may enable the application of better insulation practices which lower electricity and gas consumption [29]. Note that these socioeconomic determinants are included in the model as control variables [30] to produce better estimates of the relationship between electricity/gas consumption and temperature, not to investigate their effect path on energy demand. We proxy income with the per state per capita real GDP, which is obtained from the annual real GDP in millions of pesos and population statistics in number of people per state from Vicente German-Soto's data collection [31,32] (https://works.bepress.com/vicente_german_soto/#database). From the same source, data on real manufacturing output in thousands of pesos were obtained and transformed to per capita values.

Consumer prices for electricity and gas are expected to negatively influence electricity and gas consumption, respectively. However, this effect may be small since studies in the context of other countries have found low price elasticities for the short- and medium-term for electricity consumption [33,34]. Electricity prices are measured in centavos per kilowatt–hour (KWh), and are obtained from SENER for the agricultural, commercial, industrial, residential and service sectors in monthly time intervals for the years from 2002 to 2016 on a national level. Prices for LP gas in pesos per kg are available on a national level.

While population size should have a positive relationship with total electricity and gas consumption in a state, household size can have a negative relationship if consumption is measured per capita, as is done in this study. Households with a larger number of individuals can share heating and cooling services. For instance, a family is likely to use relatively less energy per person for heating and cooling than a one-person household, as heating and cooling is, to a certain degree, shared in common living spaces. The variable on household size was obtained from the National Institute of Statistics and Geography (INEGI) and is based on state-level surveys.

2.3. Model Speciation and Statistical Methods

Panel data methods are applied to estimate the relationships between electricity/LP gas consumption and temperature. The panel data approach makes use of short-term fluctuations in weather in a state to explain variations in electricity and gas consumption, while controlling for other variables of influence on consumption, as well as time and geographical effects.

The general equation we estimate is

$$y_{it} = \alpha_i + \beta' T_{it} + \gamma' TIME_t + \theta x_{it} + u_{it} \quad (1)$$

The dependent variable, y_{it}, is either per capita electricity consumption or per capita LP gas consumption and varies across time t and state i. The intercept α_i depends on state i. The vector of temperature variables T_{it} varies over t and i and has coefficients β. The coefficients γ of the TIME trend can capture annual and/or monthly fluctuations in y_{it}.

The vector of control variables x_{it} has coefficients θ. The idiosyncratic error u_{it} captures unobserved factors.

The model in Equation (1) can be estimated by means of pooled OLS or random or fixed effects panel models. Pooled OLS treats every datapoint as an independent observation and, thereby, neglects the panel structure of the data. Pooled OLS is only a consistent and efficient estimator if, among other assumptions, strict exogeneity holds, which means that there are no unobserved effects (captured by the error term) that are related to the explanatory variables. Alternatively, a random effects panel model can be used to estimate Equation (1) to account for the panel structure of the data by introducing state-specific random effects. Like the pooled OLS model, it depends on strict exogeneity to hold. We test for exogeneity by the Mundlak test [35] for endogeneity with regard to the time-invariant fixed effects contained in the error term and find that it is rejected at the 5% level. For this reason, we employ the fixed effects panel model in this study, which is a specification of the first-differences estimator. It deviates from simple differences in present and lagged values by differencing the over-time averaged value of a variable from each of its observations. The fixed effects estimator of Equation (1) become

$$y_{it} - \overline{y}_i = \beta\prime\left(T_{it} - \overline{T}_i\right) + \gamma\prime\left(TIME_t - \overline{TIME}_i\right) + \theta(x_{it} - \overline{x}_i) + u_{it} - \overline{u}_i \tag{2}$$

Here, the average values of the variables per state are shown with a bar. In the fixed effects estimator, time-invariant variables, like α_i, drop out of the equation. The purpose of this procedure is to remove any of the time-invariant unobserved variables that could be correlated with the explanatory variables. Cluster-robust standard errors are used to account for the presence of heteroscedasticity and autocorrelation. Moreover, we apply the Ramsey RESET test [36] to examine whether the model is misspecified, for example due to omitted variables or a wrong functional form. The results from this test confirm that our final model does not have this specification problem.

The final model specification for electricity consumption per capita is

$$\begin{aligned} y_{it} = \alpha_0 + \beta_1 T_{it} \quad & +\beta_2 T_{it}^2 \; + \; \beta_3\prime State_i \times T_{it} + \; \beta_3\prime State_i \times T_{it}^2 \; + \; \gamma_1 Year_t \\ & + \theta_1 ElecPrice_t \; + \; \theta_2 ManuOutput_{it} \; + \; \theta_3 HousholdSize_{it} \\ & + u_{it} \end{aligned} \tag{3}$$

Here, β_1 and β_2, respectively, are the coefficients of monthly mean temperature T_{it} and monthly mean temperature squared T_{it}^2 of a baseline state (State 1), and the vectors β_3 and β_4, respectively, represent the coefficients of interaction variables of state dummies $State_i$ of the remaining 31 states with T_{it} and T_{it}^2. Including both the linear and squared temperature variables allows for capturing non-linear relations between electricity consumption and temperature that have also been observed in other studies [37]. Moreover, the interaction variables allow for these relationships between electricity consumption to differ between the Mexican states, which is relevant due to the large spatial variability of the country's climate (Figure 1). Based on the adjusted-R^2, we found that allowing for this non-linearity and state interactions improved model fit. The adjusted-R^2 may be a more suitable indicator for deciding about the inclusion of these variables since the t-statistics may be unreliable due to possible multi-collinearity between the temperature variables [38]. We report the states as numbers in this paper. The corresponding names are given in Table A1 in Appendix A. The variable $Year_t$ captures potential time effects. Including, in addition, a linear monthly time trend variable is insignificant. Including year and month as dummy variables results in a miss-specified model according to the Ramsey RESET test, which is why the linear year trend variable is preferred. $ElecPrice_t$ is the residential electricity price. Electricity prices in Mexico are set on a national level and differ for the agricultural, commercial, industrial, residential and service sectors. Since these price variables are highly correlated, we include only one of these variables. The residential electricity price variable resulted in the highest adjusted-R^2, and is hence preferred over the other price variables. $ManuOutput_{it}$ is manufacturing output per capita, and $HousholdSize_{it}$ is the average household size per state.

The final model specification for LP gas consumption per capita is

$$\begin{aligned} y_{it} = \alpha_0 + \beta_1 T_{it} \quad & + \beta_2 T_{it}^2 + \beta_3\prime State_i \times T_{it} + \beta_3' State_i \times T_{it}^2 + \gamma_1 Year_t \\ & + \theta_1 GasPrice_t + \theta_2 ManuOutput_{it} + \theta_3 HousholdSize_{it} \\ & + u_{it} \end{aligned} \tag{4}$$

where $GasPrice_t$ is the LP gas price per kg and $Year_t$ consists of dummies instead of a linear time trend, which results in a higher adjusted-R. In addition, including month as a dummy or a linear trend variable is statistically insignificant, which is why we account for only the yearly trend.

2.4. Extrapolations under Climate Change Scenarios

The estimated empirical relationships between electricity consumption and temperature in Equation (3) and between LP gas consumption and temperature in Equation (4) are used to project how consumption and related spending is expected to change under climate change, ceteris paribus. This approach is consistent with studies that use statistical methods for assessing the economic consequences of climate change based on extrapolations of empirical relationships between economic variables and weather indicators under climate change [39], and has been applied to project future changes in energy use in a variety of countries, like China [40]. For these extrapolations, we obtain monthly mean temperature predictions per Mexican state up to the year 2100, produced by four climate models. These models are the ESM2M from the Geophysical Fluid Dynamics Laboratory (GFDL), HadGEM2 from the Met Office Hadley Centre, CM5A-LR from the Institut Pierre Simon Laplace (IPSL) and the ESM-MR model from the Max Planck Institute for Meteorology. The temperature scenarios were obtained for two greenhouse gas emission scenarios: namely, the RCP2.6 and RCP8.5 [41]. The RCP2.6 scenario represents a low greenhouse gas (GHG) emissions pathway that can be achieved by a stringent global climate policy that substantially reduces GHG emissions after 2020. This scenario is consistent with the goals of the Paris Agreement as it limits average global temperature rise between 0.4 and 1.6 °C for the years from 2046 to 2065 and in the range of 0.3 and 1.7 °C for the period from 2081 to 2100 (with respect to the reference period 1986–2005). The RCP8.5 represents a very high emissions scenario with no climate policy in which GHG emissions continue to increase, resulting in an average global temperature rise between 2.6 to 4.8 °C in the period from 2081 to 2100.

The temperature projections from the four models were used to compute the state-level, monthly climatological values (30-year averages) for the 2020, 2050 and 2100 horizons. Using the coefficients in Equations (3) and (4) associated with temperature and the projected changes in temperature, we calculated, for each state and horizon, the change in average monthly per capita electricity and gas consumption with respect to the 2006–2015 reference period, ceteris paribus. In order to reduce the effects of possible climate models' biases, the results are averaged for each horizon and state. These projected changes in consumption are added to the average monthly consumption in the reference period in order to estimate absolute levels of monthly per capita electricity and gas consumption in the years 2020, 2050 and 2100. Based on these absolute consumption levels, the percentage change in consumption compared with the reference period is calculated. Moreover, the changes in consumption are expressed in changes in the electricity or gas bill in centavos per person per month using the average 2016 electricity and gas prices. Moreover, these costs are expressed as yearly total cost per state by transferring monthly per capita cost to yearly cost and multiplying with the population in a state in 2020, 2050 and 2100. These future population levels are derived from the current population per state, which is assumed to increase in accordance with Mexico's population growth rates in the SSP3 scenario of the IPCC [41].

3. Results

3.1. Simple Scatter Plots of Electricity and Gas Consumption

Figure A1 in Appendix A provides scatter plots of the relationship between monthly electricity consumption in MWh per person and mean temperature in °C for each of the 32 states in Mexico. While higher temperatures are positively correlated with higher electricity consumption in all states, the relationship between these two variables varies from linear to non-linear between the states. As an illustration, Figure 2 shows that a close to linear relationship between electricity consumption and temperature is observed for the states Baja California Sur, Coahuila, Nuevo León and Tamaulipas. Figure 3 shows that the relationship is more non-linear for the states Aguascalientes, Durango, Nayarit and Yucatán.

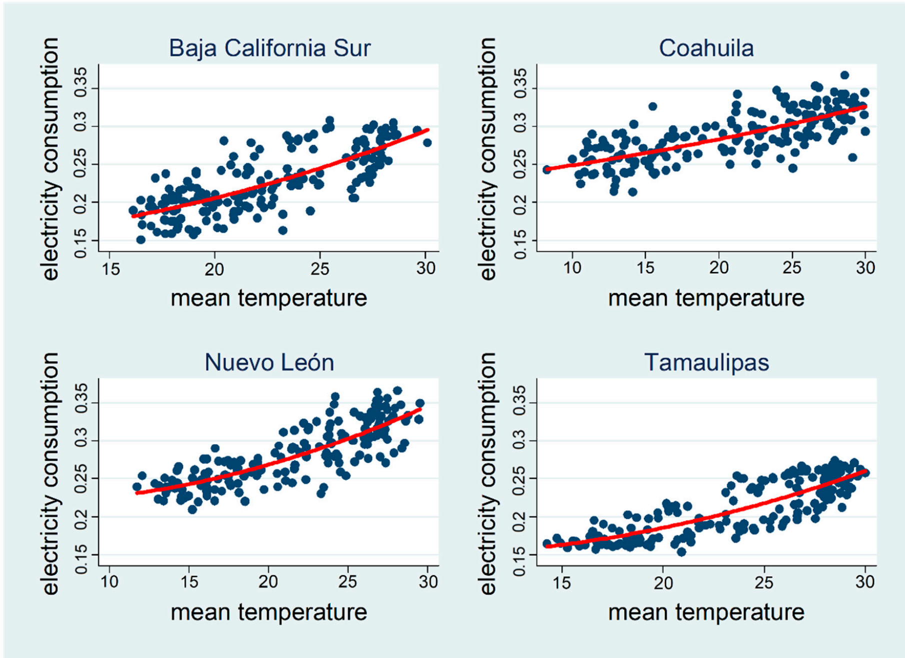

Figure 2. Monthly electricity consumption in MWh per capita over mean temperature for the states Baja California Sur, Coahuila, Nuevo León and Tamaulipas.

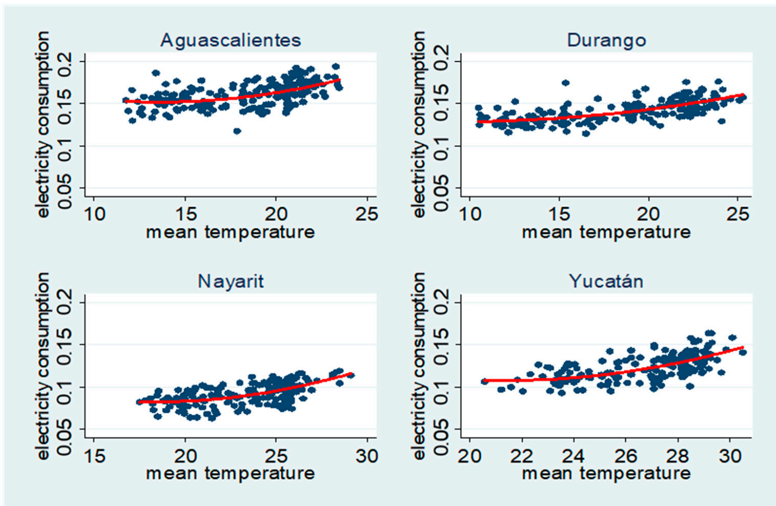

Figure 3. Monthly electricity consumption in MWh per capita over mean temperature for the states Aguascalientes, Durango, Nayarit and Yucatán.

Figure A2 in Appendix A provides scatter plots of the relationship between consumed LP gas in barrels per person and mean temperature in °C for each of the 32 states in Mexico. This relationship is the opposite to that for electricity consumption since gas consumption declines with high temperatures. The shape of the curves differs per state. Figure 4 shows that the relationship is close to linear for the states Coahuila, Durango, Guanajuato and Jalisco. Figure 5 shows the relationship for a selection of states with more non-linear relationships, namely, Baja California, Baja California Sur, Chihuahua and Puebla. The decline in LP gas consumption with rising temperatures is stronger at low temperatures of about from 10 to 20 °C than at higher temperatures of above 20 °C.

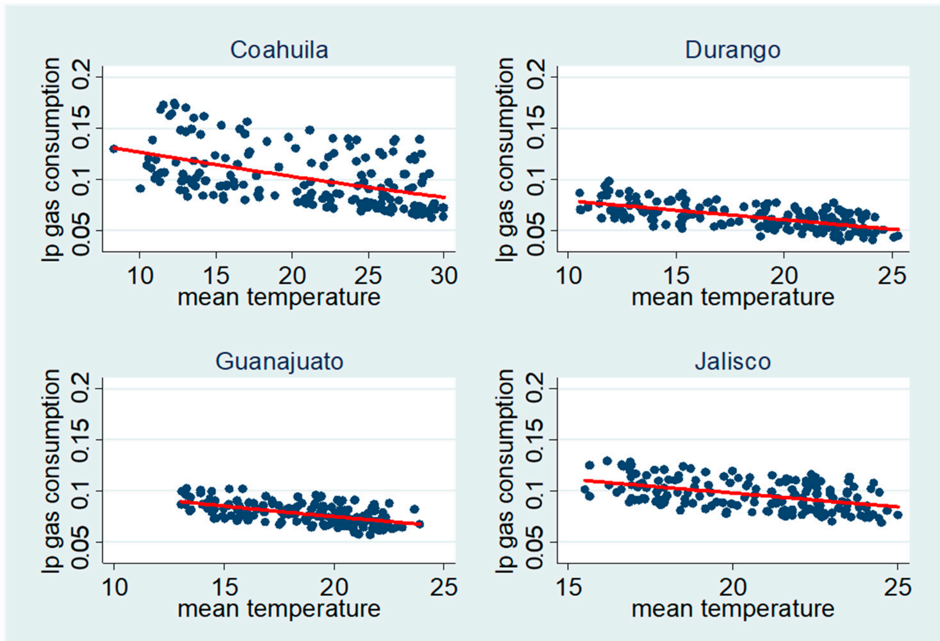

Figure 4. Monthly LP gas consumption per capita over mean temperature for the states Coahuila, Durango, Guanajuato and Jalisco.

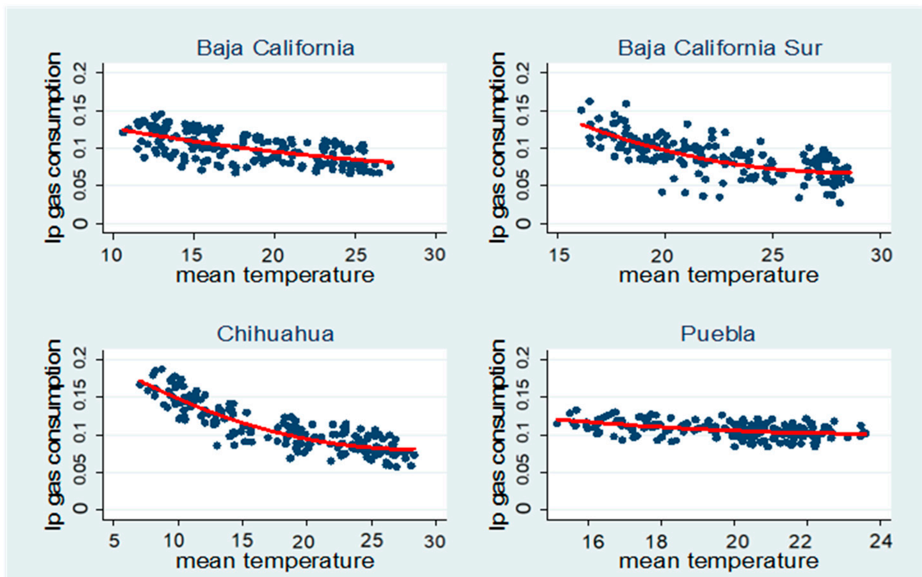

Figure 5. Monthly LP gas consumption per capita over mean temperature for the states Baja California, Baja California Sur, Chihuahua and Puebla.

3.2. Panel Models of Electricity and Gas Consumption

Table 1 shows the estimated coefficients of the final fixed effects model for electricity consumption. The overall fit of the model is good with a total adjusted-R^2 of 0.63. The higher within than between R^2 value implies that the model captures variation in electricity consumption better within states than between states. Electricity price is statistically significant and has the expected negative sign. The adjusted-R^2 is higher in this model in which the insignificant control variables are also included compared to a model in which they are excluded. The signs of the other control variables are as expected and imply that per capita electricity consumption is higher in states with high manufacturing output per capita, and lower in states with a high household size. The latter finding means that a larger household size implies a more efficient electricity use per person. The negative coefficient of year suggests that improvements in energy efficiency lower electricity consumption over time.

Table 1. Fixed effects model of electricity consumption.

Explanatory Variables	Coefficient
Electricity price	−0.000200 **
Manufacturing output per capita	0.000108
Household size	−0.0580
Year	−0.000639
Temperature	−0.00889 ***
Temperature^2	0.000302 ***
State 2 × Temperature	0.00303 ***
State 3 × Temperature	0.00636 ***
State 4 × Temperature	0.00005.96
State 5 × Temperature	0.0109 ***
State 6 × Temperature	0.00739
State 7 × Temperature	−0.00407
State 8 × Temperature	0.00945 ***
State 9 × Temperature	0.00853 ***
State 10 × Temperature	0.00629 ***
State 11 × Temperature	−0.00692 ***
State 12 × Temperature	−0.0145 **
State 13 × Temperature	0.0134 ***
State 14 × Temperature	0.00167 **
State 15 × Temperature	0.00735 ***
State 16 × Temperature	−0.00232
State 17 × Temperature	−0.00195
State 18 × Temperature	0.00249
State 19 × Temperature	0.00778 ***
State 20 × Temperature	0.0124 ***
State 21 × Temperature	0.00589 ***
State 22 × Temperature	0.00308 ***
State 23 × Temperature	−0.0377 ***
State 24 × Temperature	0.0177 ***
State 25 × Temperature	−0.00231 ***
State 26 × Temperature	0.00383 ***
State 27 × Temperature	0.00830 ***
State 28 × Temperature	0.00659 ***
State 29 × Temperature	0.0104 ***
State 30 × Temperature	0.00915 ***
State 31 × Temperature	-0.00652 ***
State 32 × Temperature	−0.00742 ***
State 2 × Temperature^2	0.0000657 ***
State 3 × Temperature^2	−0.0000837 ***
State 4 × Temperature^2	−0.0000666 ***

Table 1. *Cont.*

Explanatory Variables	Coefficient
State 5 × Temperature^2	−0.000261 ***
State 6 × Temperature^2	−0.000222 **
State 7 × Temperature^2	−0.0000394
State 8 × Temperature^2	−0.000129 ***
State 9 × Temperature^2	−0.000289 ***
State 10 × Temperature^2	−0.000180 ***
State 11 × Temperature^2	0.000176 ***
State 12 × Temperature^2	0.000158
State 13 × Temperature^2	−0.000410 ***
State 14 × Temperature^2	−0.0000992 ***
State 15 × Temperature^2	−0.000240 ***
State 16 × Temperature^2	−0.0000156
State 17 × Temperature^2	−0.0000368
State 18 × Temperature^2	−0.000122 **
State 19 × Temperature^2	−0.000131 ***
State 20 × Temperature^2	−0.000398 ***
State 21 × Temperature^2	−0.000205 ***
State 22 × Temperature^2	−0.0000857 ***
State 23 × Temperature^2	0.000768 ***
State 24 × Temperature^2	−0.000486 ***
State 25 × Temperature^2	0.0000954 ***
State 26 × Temperature^2	0.0000216 **
State 27 × Temperature^2	−0.000233 ***
State 28 × Temperature^2	−0.000114 ***
State 29 × Temperature^2	−0.000341 ***
State 30 × Temperature^2	−0.000261 ***
State 31 × Temperature^2	0.0000635 **
State 32 × Temperature^2	0.000282 ***
Constant	1.715
Observations	5760
Within R-squared	0.63
Between R-squared	0.11
Total adjusted R-squared	0.63
Number of states	32

Notes: *** p-value < 0.01, ** p-value < 0.05.

The interaction variables between the state dummies and the linear and quadratic terms of temperature are in general statistically significant and illustrate that the relationship between electricity consumption and temperature is heterogeneous between states. These variables also contribute to increasing the explanatory power of the model, as shown by the adjusted-R^2: a model without these interaction variables has an adjusted-R^2 of only 0.50. The coefficients of the linear and quadratic temperature terms represent the effects of this variable over electricity consumption with respect to the reference state (State 1, which is Aguascalientes). The estimated relation for this state is $-0.00889\ T_{it} + 0.000302\ T_{it}^2$. This relationship implies that for low temperature levels the negative coefficient dominates, while for high temperature levels the positive coefficient of the quadratic term dominates. For this state, the optimal temperature level that results in the smallest electricity consumption is about 15 °C. Temperature values that deviate from this optimal value would increase electricity consumption. For other states, the relation of electricity consumption between temperature and temperature squared can be found by adding the respective estimated coefficients of the interaction variable for that state to those of the baseline state. As an illustration, for state 2 (Baja California) the final coefficient of the linear term of temperature is $-0.00889 + 0.00303 = -0.00586$ and for the quadratic term, it is $0.000302 + 0.0000657 = 0.00037$, which implies a lower optimal temperature level than the baseline state and a stronger response of electricity consumption to temperature increases.

Depending on the signs of the coefficients of the linear and quadratic temperature terms for a state, changes in electricity consumption for a state either follow a convex or concave curve when plotted against changes in temperature. It can be expected that changes in temperature have a different effect on energy consumption when they occur in relatively cold and warm states. This is examined as follows. First, the state level reference temperatures are calculated as the average temperature of each of the 32 states during the period from 2006 to 2015. These reference temperatures are used to order states from the coldest to the warmest. Then, to illustrate the heterogeneity in the response to changes in temperatures, the average temperatures of the 5 and 16 coldest and warmest states are used to estimate the corresponding electricity consumption and to estimate how electricity consumption changes when the reference temperature increases by 1 °C. The average temperatures of the reference period are 16.64 and 18.56 °C for the 5 and 16 coldest states and 26.41 and 24.33 °C for the 5 and 16 warmest states. When the average temperature increases by 1 °C, the 5 and 16 coldest states increase monthly consumption of electricity by 1.26 and 2.83 KWh per capita. For the warmest states, the same rise in temperatures increases monthly electricity consumption by 5.04 and 4.09 KWh per capita. The comparison between the five coldest and warmest states reveals a fourfold increase in consumption in the warmest states. In the case of the 16 coldest and warmest states, the difference amounts to a 1.4 times larger increase in consumption for the warmest states.

Table 2 shows the estimates of the final fixed effects model for LP gas consumption. The overall fit of the model is good, with a total adjusted-R^2 of 0.57. As in the previous model, the difference between within and between R^2 values implies that the model captures variation in gas consumption better within states than between states. Of the control variables, only manufacturing output is statistically significant at the 10% level. This coefficient has a positive sign, which suggests that more industrialized states use fewer barrels of gas. An explanation for this result is that more industrialized states have a more developed infrastructure of natural gas grids, which replace LP gas. The adjusted-R^2 is higher in this model, in which the insignificant control variable household size is also included compared to a model in which it is excluded, but this is not the case for the gas price variable. The coefficient of household size implies that per capita LP gas consumption is lower in states with a high household size. This means that a larger household size implies more efficient gas use per person. The coefficients of the year dummy variables suggest that improvements in energy efficiency lower LP gas consumption over time, for example, due to improved insulation.

Table 2. Fixed effects model of LP gas consumption.

Explanatory Variables	Coefficient
Gas price	0.00000562
Manufacturing output per capita	−0.0000301 *
Household size	−0.0017569
Year 2003	−0.0001044
Year 2004	−0.0002404
Year 2005	−0.0004383
Year 2006	−0.000637 *
Year 2007	−0.00081 **
Year 2008	−0.0010093 **
Year 2009	−0.0012074 **
Year 2010	−0.0012942 **
Year 2011	−0.0013497 *
Year 2012	−0.0014234 *
Year 2013	−0.0015545 *
Year 2014	−0.0017081 *
Year 2015	−0.0018303 *
Temperature	0.0001457 ***

Table 2. *Cont.*

Explanatory Variables	Coefficient
Temperature^2	−0.00000621 ***
State 2 × Temperature	−0.0003106 ***
State 3 × Temperature	−0.0009325 ***
State 4 × Temperature	−0.00038 ***
State 5 × Temperature	−0.0002805 ***
State 6 × Temperature	−0.0009427 ***
State 7 × Temperature	−0.0005262 ***
State 8 × Temperature	−0.0005394 ***
State 9 × Temperature	−0.0002305 ***
State 10 × Temperature	−0.0002721 ***
State 11 × Temperature	−0.0002543 ***
State 12 × Temperature	−0.0008861 ***
State 13 × Temperature	−0.0000743 ***
State 14 × Temperature	−0.0003259 ***
State 15 × Temperature	−0.0002232 ***
State 16 × Temperature	−0.0005084 ***
State 17 × Temperature	−0.0003795 ***
State 18 × Temperature	−0.0003553 ***
State 19 × Temperature	−0.0002296 ***
State 20 × Temperature	−0.0002955
State 21 × Temperature	−0.0004345 ***
State 22 × Temperature	−0.0002287 ***
State 23 × Temperature	−0.0002365 *
State 24 × Temperature	−0.0002751 ***
State 25 × Temperature	−0.0001965 ***
State 26 × Temperature	−0.0003234 ***
State 27 × Temperature	−0.0002028 *
State 28 × Temperature	−0.0002181 ***
State 29 × Temperature	−0.0004275 ***
State 30 × Temperature	−0.0002647 ***
State 31 × Temperature	−0.0000738
State 32 × Temperature	−0.0001676 ***
State 2 × Temperature^2	0.0000084 ***
State 3 × Temperature^2	0.0000201 ***
State 4 × Temperature^2	0.0000099 ***
State 5 × Temperature^2	0.0000078 ***
State 6 × Temperature^2	0.0000203 ***
State 7 × Temperature^2	0.0000134 ***
State 8 × Temperature^2	0.0000134 ***
State 9 × Temperature^2	0.0000066 ***
State 10 × Temperature^2	0.0000081 ***
State 11 × Temperature^2	0.0000074 ***
State 12 × Temperature^2	0.0000206 ***
State 13 × Temperature^2	0.0000026 ***
State 14 × Temperature^2	0.0000085 ***
State 15 × Temperature^2	0.0000064 ***
State 16 × Temperature^2	0.0000128 ***
State 17 × Temperature^2	0.0000097 ***
State 18 × Temperature^2	0.0000092 ***
State 19 × Temperature^2	0.0000073 ***
State 20 × Temperature^2	0.0000090
State 21 × Temperature^2	0.0000118 ***
State 22 × Temperature^2	0.0000070 ***
State 23 × Temperature^2	0.0000066 **
State 24 × Temperature^2	0.0000081 ***
State 25 × Temperature^2	0.0000061 ***

Table 2. *Cont.*

Explanatory Variables	Coefficient
State 26 × Temperature^2	0.0000085 ***
State 27 × Temperature^2	0.0000064 ***
State 28 × Temperature^2	0.0000066 ***
State 29 × Temperature^2	0.0000131 ***
State 30 × Temperature^2	0.0000077 ***
State 31 × Temperature^2	0.0000036 **
State 32 × Temperature^2	0.0000049 ***
Constant	0.0135207
Observations	5376
Within R-squared	0.58
Between R-squared	0.01
Total adjusted R-squared	0.57
Number of states	32

Notes: *** p-value < 0.01, ** p-value < 0.05, * p-value < 0.1.

As is the case for the electricity consumption model, the interaction variables between the state dummies and temperature and temperature squared are usually significant. The estimated relationship for the reference state (Aguascalientes) is 0.0001457 $T_{it}-0.00000621$ T_{it}^2. The signs of these coefficients are the opposite of those in the electricity consumption model. This relationship for LP gas implies that, for high temperature levels, the negative coefficient of temperature squared dominates the positive coefficient of temperature, which means that (at least eventually) increases in temperature lower LP gas consumption.

In order to show how temperature change can differently affect LP gas consumption in cold and warm states, we conducted a similar calculation as for electricity consumption to estimate the effect on LP gas consumption of a 1 °C increase from the average temperature of the reference period (2006–2015) for the 5 and 16 coldest and warmest states. It turns out that the decrease in consumption of 0.0019851 of LP barrels per person per month in the five coldest states is not much larger than for the five warmest states with a decrease of 0.0017509 barrels per capita and month. The difference increases slightly when the 16 coldest states are compared with the 16 warmest. Although these differences between cold and warm states are in the expected direction, their small size suggests that differences in the relationship between LP gas consumption and temperature are less dependent on current differences in climate than was the case for electricity consumption.

3.3. Extrapolations of Electricity and Gas Consumption under Future Climate Change Scenarios

Tables 3 and 4 show the results of the extrapolations of electricity and gas consumption for future climate conditions that are consistent with the RCP8.5 emissions scenario. Results are given in (1) percentage change in total consumption compared with the 2006–2015 reference period, (2) the change in the monthly electricity or gas bill in centavos per person, and (3) the total impact in pesos per year per state. Appendix A reports these results for climate conditions under the RCP2.6 emission scenario, which represents stringent international mitigation efforts consistent with the goals of the Paris Agreement.

An increase in temperature is, for almost all states, followed by an increase in electricity consumption and spending (Table 3). For instance, in the year 2050, the average temperature for all of Mexico increases from 21.45 °C in the reference period to 23.24 °C under the RCP8.5 scenario. This increase in temperatures produces a rise in average consumption of about 4% (or 6.21 KWh) and in spending by 942 centavos per capita and month. This results in a total annual cost for Mexico of about 17 billion pesos. Under the RCP8.5 scenario, electricity consumption in 2100 for Mexico as a whole further increases by about 12% compared with the reference period and increases the electricity bill by about 2846 centavos per month, resulting in a total annual cost of about 69 billion pesos. These results differ per state depending on differences in projected temperature increases and the estimated relationship between temperature and electricity consumption: for instance, six states experience increases in consumption in excess of 20%.

The results in Table A2 under the RCP2.6 scenario in Appendix A reveal the important influence that achieving the goals of the Paris Agreement could have on limiting the cost of more electricity consumption. In the RCP2.6 scenario, temperature peaks in the year 2050 and declines slightly afterwards. This results in an increase in electricity consumption and associated cost in 2050 that are about half of the projected estimates under the RCP8.5 scenario and save about 8.5 billion pesos in cost for Mexico in that year. Prevented electricity cost in 2100 would be about 66 billion pesos under RCP2.6 compared with RCP8.5.

Table 3. Extrapolations of electricity consumption under the RCP8.5 climate scenario in % compared to the reference period (2006–2015), in centavos per person per month, and in total impacts in millions of pesos per state per year.

State ID	2020 Change in:			2050 Change in:			2100 Change in:		
	%	Centavos per Person	Total mln pesos per State	%	Centavos per Person	Total mln pesos per State	%	Centavos per Person	Total mln pesos Per State
1	0.6	123	20.2	5.0	959	213.6	14.3	2722	822.0
2	2.3	821	362.8	6.0	2086	1252.8	18.5	6460	5264.0
3	1.1	430	39.7	3.7	1478	185.5	12.3	4908	835.5
4	0.8	157	18.1	4.5	865	135.2	14.6	2794	592.5
5	0.3	117	78.3	2.6	1030	938.6	7.5	2951	3649.0
6	0.4	149	71.1	2.3	771	500.3	5.9	1963	1729.7
7	0.0	0	0.0	5.4	75	38.8	45.0	625	436.9
8	−1.2	−499	−45.4	3.8	1641	202.9	13.2	5625	943.7
9	0.0	1	0.2	0.0	13	3.9	0.2	54	22.5
10	−0.1	−22	−16.7	2.2	603	616.2	6.4	1771	2456.7
11	2.4	180	83.7	15.3	1173	740.4	45.6	3490	2989.6
12	0.1	−10	−3.8	−0.8	138	68.9	−6.1	1070	725.3
13	0.1	26	25.9	0.3	107	147.5	0.2	85	158.6
14	0.3	64	137.2	2.6	504	1463.8	8.1	1558	6143.9
15	0.1	26	15.6	0.8	213	172.5	2.4	637	701.3
16	0.7	88	21.7	5.8	696	232.4	17.7	2115	958.2
17	0.5	63	9.6	3.8	520	108.3	13.4	1815	513.4
18	0.3	72	46.4	2.9	669	587.5	8.6	1944	2317.4
19	1.8	713	372.0	6.0	2333	1654.4	14.3	5503	5294.9
20	−0.2	−57	−45.7	−0.6	−209	−226.2	−2.1	−692	−1016.3
21	0.1	32	8.2	1.1	268	92.3	3.5	834	390.5
22	0.8	188	36.0	4.0	961	249.7	11.3	2701	952.4
23	−1.0	404	143.5	−4.8	1988	959.8	−17.1	7150	4682.8
24	0.5	199	76.7	1.1	459	240.6	1.3	558	397.1
25	−0.3	−84	−31.3	8.8	2189	1109.7	28.5	7051	4850.1
26	0.3	107	32.8	6.0	2393	997.0	20.8	8265	4671.8
27	0.7	250	113.6	2.6	887	547.3	6.8	2297	1923.0
28	1.1	412	67.0	5.2	2040	450.7	12.8	4997	1498.0
29	0.0	6	6.5	0.2	51	71.8	0.2	70	134.1
30	0.4	124	33.5	1.7	602	221.4	4.4	1523	759.3
31	−1.1	−73	−14.8	8.5	555	153.9	37.1	2431	914.4
32	3.0	401	473.5	15.5	2078	3341.7	43.4	5808	12,669.9
Total	0.6	138	2136.2	4.0	942	17,473.3	12.2	2846	69,382.0

Table 4. Extrapolations of LP gas consumption under the RCP8.5 climate scenario in % compared to the reference period (2006–2015), in centavos per person per month, and in total impacts in millions of pesos per state per year.

State ID	2020 Change in:			2050 Change in:			2100 Change in:		
	%	Centavos per Person	Total mln pesos per State	%	Centavos per Person	Total mln pesos per State	%	Centavos per Person	Total mln pesos per State
1	−0.6	−108	−17.6	−4.3	−785	−174.7	−11.2	−2041	−616.6
2	−1.8	−202	−89.2	−4.3	−491	−294.8	−10.7	−1216	−990.7
3	1.3	−219	−20.2	4.0	−689	−86.5	8.9	−1537	−261.7
4	−0.3	−33	−3.8	−1.5	−146	−22.8	−3.0	−295	−62.6
5	−0.5	−46	−30.9	−4.8	−441	−401.5	−12.4	−1144	−1414.0
6	0.6	−110	−52.4	2.0	−398	−258.2	1.8	−345	−304.3
7	−1.0	−45	−16.9	−2.2	−100	−51.7	0.3	14	9.8
8	9.7	260	23.7	−23.8	−641	−79.3	−59.9	−1613	−270.7
9	−0.4	−66	−15.0	−3.1	−497	−153.2	−7.6	−1221	−511.2
10	0.2	29	21.6	−3.2	−373	−381.4	−7.2	−853	−1183.0
11	−1.0	−111	−51.5	−5.0	−530	−334.5	−10.1	−1080	−925.3
12	0.2	−22	−8.1	−0.4	48	23.9	−5.1	680	461.1
13	−0.4	−68	−69.4	−2.3	−441	−608.6	−6.6	−1243	−2325.3
14	−1.2	−99	−210.9	−7.4	−598	−1738.6	−16.0	−1283	−5058.7
15	−0.5	−71	−42.5	−3.8	−503	−407.7	−9.3	−1222	−1344.1
16	−3.2	−76	−18.8	−16.4	−393	−131.3	−25.7	−614	−278.3
17	−1.2	−73	−11.2	−7.5	−450	−93.8	−16.5	−995	−281.5
18	−0.7	−60	−39.0	−5.4	−476	−418.1	−11.4	−1009	−1202.3
19	−0.8	−92	−48.0	−2.4	−280	−198.5	−4.8	−565	−544.1
20	−0.3	−50	−40.2	−1.0	−142	−153.5	−1.8	−262	−384.5
21	−1.4	−60	−15.2	−8.7	−363	−125.3	−16.6	−696	−325.8
22	−0.7	−90	−17.2	−3.3	−400	−103.9	−7.4	−911	−321.3
23	−0.4	−65	−23.0	−1.6	−294	−142.1	−4.8	−867	−567.8
24	−1.6	−177	−68.3	−4.3	−484	−253.7	−8.1	−912	−648.5
25	0.1	15	5.7	−2.4	−335	−169.6	−6.7	−955	−657.1
26	−0.2	−19	−5.9	−4.7	−424	−176.8	−13.0	−1166	−659.0
27	−0.5	−93	−42.2	−1.9	−317	−195.9	−4.5	−777	−650.2
28	−0.6	−83	−13.5	−2.7	−397	−87.8	−6.2	−906	−271.6
29	−0.5	−36	−37.4	−4.5	−312	−441.8	−7.7	−540	−1038.9
30	−0.5	−62	−16.9	−2.1	−280	−103.0	−4.7	−631	−314.6
31	0.1	30	6.2	−0.9	−216	−59.9	−3.8	−869	−326.8
32	−0.8	−135	−159.1	−3.8	−614	−987.5	−8.7	−1409	−3073.8
Total	−0.7	−64	−1126.9	−4.4	−399	−8811.9	−9.9	−890	−26,343.4

Increases in temperatures lead to decreases in LP gas consumption and spending in almost every state. By mid-century, under the RCP8.5 scenario the average LP gas consumption is projected to decrease by 4.4% and spending on gas declines by 399 centavos per capita and month, resulting in a total annual saving for Mexico of 8.8 billion Pesos. LP gas consumption in 2100 for Mexico declines 10% compared with the reference period. As a consequence, the gas bill is reduced in about 890 centavos per month and in total annual savings of 26 billion pesos for Mexico. These effects are highly heterogenous between states. While in five states the decline in LP gas consumption is larger than 15%, three states experience increases in demand.

The overall decline in LP gas consumption is smaller under the RCP2.6 scenario, as shown in Table A3 in Appendix A. By 2050, when temperatures peak, the declines in LP gas consumption are about half of those under the RCP8.5 scenario and in annual savings that are about 4 billion pesos lower for Mexico. Moreover, because of the strong divergence in temperatures between the RCP8.5 and RCP2.6 scenarios in the second part of this century, the savings of LP gas consumption are substantially lower compared with those of the RCP8.5. Namely, under the RCP2.6 scenario, savings are only 66 instead of 890 centavos per person per month and 2 billion pesos in total annual savings, compared with 26 billion pesos in 2100 under the RCP8.5.

4. Discussion and Conclusions

Statistical tests showed that panel fixed effects models are a suitable approach for estimating relationships between energy consumption and temperature to account for other, potentially unobserved, variables. This is in line with Auffhammer and Mansur [6], who propose this approach as the state-of-the-art methodology in this field of study. Due to the diversity in climate between states in Mexico, our application allows for examining how the relationships between energy consumption and weather conditions differ between states that have different temperature levels. Our statistical models, which allow for state-specific relationships with temperature, reveal that there is a substantial heterogeneity in responses of electricity and gas consumption to temperature changes between states. In particular, we find that, in general, electricity consumption increases with temperature and that this effect is substantially stronger in warm compared with cold states. As expected, LP gas consumption declines with temperature increase, and this effect is slightly stronger in relatively cold states. Moreover, our results show that adjustments in electricity and gas consumption to temperature change are generally non-linear. Lessons for future research about relationships between energy consumption and weather are to examine non-linear responses and allow for differences in relationships between different areas with varying climate conditions. The net increase in energy consumption observed in our study can contribute to more greenhouse gas emissions, which worsens the climate change externality and hampers achieving a more sustainable energy transition, unless policies are put in place that ensure that the increased energy demand will be met from renewable energy sources, such as wind and solar energy.

The use of dependent variables of aggregate per state electricity and LP gas consumption that cover demand from residential and public and private sectors allows for obtaining comprehensive insights into how energy consumption is expected to change as a result of climate change. Our extrapolations of electricity and LP gas consumption under the RCP8.5 scenario reveal that, by the end of the century, electricity consumption would increase by about 12% for Mexico, while LP gas consumption would decline by about 10%. Substantial variability in these predictions exist per state: for example, electricity consumption could increase by as much as 46%. Our average results are in line with other studies. For instance, based on their fixed effects panel model, Deschênes and Greenstone [11] project an overall increase in residential energy consumption of 11% at the end of the century in the USA. Zheng et al. [40] estimate that total electricity consumption in China is expected to increase by between 3.1% and 6.1% in 2050. The costs associated with the increased electricity consumption are substantial and can represent up to 69 billion pesos per year for Mexico at the end of this century under a business-as-usual greenhouse gas emission scenario. This is partly offset by an expected decline in LP gas consumption, which saves costs by up to 26 billion pesos, but a large net annual cost of 43 billion pesos remains. The increases in net energy consumption imply much greater efforts to comply with the NDC mitigation commitments of Mexico and would require a much faster energy transition and substantial improvements in energy efficiency. If unaccounted, similar effects on energy consumption in other countries could lead to underestimating the efforts needed to reduce greenhouse gas emissions at the regional and global scales. The results under the RCP2.6 scenario—a stringent international climate policy that mitigates greenhouse gasses—show that the net cost can be reduced significantly and amounts to only about 1 billion pesos annually at the end of the century. This suggests that a stringent international climate agreement can have important benefits for Mexico in terms of saved energy cost. The overall results indicate that the effects of climate change on energy consumption in Mexico provide strong economic incentives for transitioning towards a more sustainable development, promoting green innovation and firms' investment in environmental management, as well as improving multilevel governance and partnership between government and social actors [42].

Challenges posed by climate change can also represent important opportunities at the global and the local scales for advancing social sustainability goals and the 2030 Agenda for Sustainable Development [3].

It should be noted that our extrapolations only account for changes in climate, ceteris paribus. For instance, changes in behavior, consumer preferences, and technological changes are not considered, which influence energy consumption over time. Our estimates can overestimate climate change damages when energy consumers adapt to gradual changes in temperature, a result of climate change, in better ways than when they adjusted their consumption to weather changes in our sample period. Under the current COVID-19 pandemic, global- and country-level emissions have been reduced drastically during lockdowns [43]. However, COVID-19 impacts on global emissions are unlikely to produce significant divergences in terms of climate change scenarios [43,44] and, even at the local scales, effects on atmospheric pollution are mixed [45]. On the other hand, our estimates can understate damages when, for example, consumers purchase additional equipment in the future that make them more susceptible to increasing energy consumption when temperatures rise. Future research can focus on examining long-run adaptations related to energy consumption to changes in climate, such as energy efficiency improvements and insulation in buildings, of which there is currently only limited knowledge [6]. Moreover, the effects of climate change over energy consumption could have important implications regarding the costs and feasibility of reaching national NDC goals. For example, Mexico's NDC reduction commitments are calculated with respect to a reference emissions baseline up to 2050, which does not account for changes in energy consumption due to increases in temperatures. The present study could be used to calculate a mitigation plan that includes the changes in emissions due to the effects of climate change in energy consumption and to update the estimates of the costs to fulfill Mexico's NDC goals.

Author Contributions: Conceptualization, W.J.W.B. and F.E.; methodology, W.J.W.B., T.N. and F.E.; formal analysis, T.N. and W.J.W.B.; data curation, T.N. and F.E.; writing—original draft preparation W.J.W.B. and T.N.; writing—review and editing, W.J.W.B., T.N. and F.E.; Funding acquisition, F.E. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Data of present study, will be available on request from corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

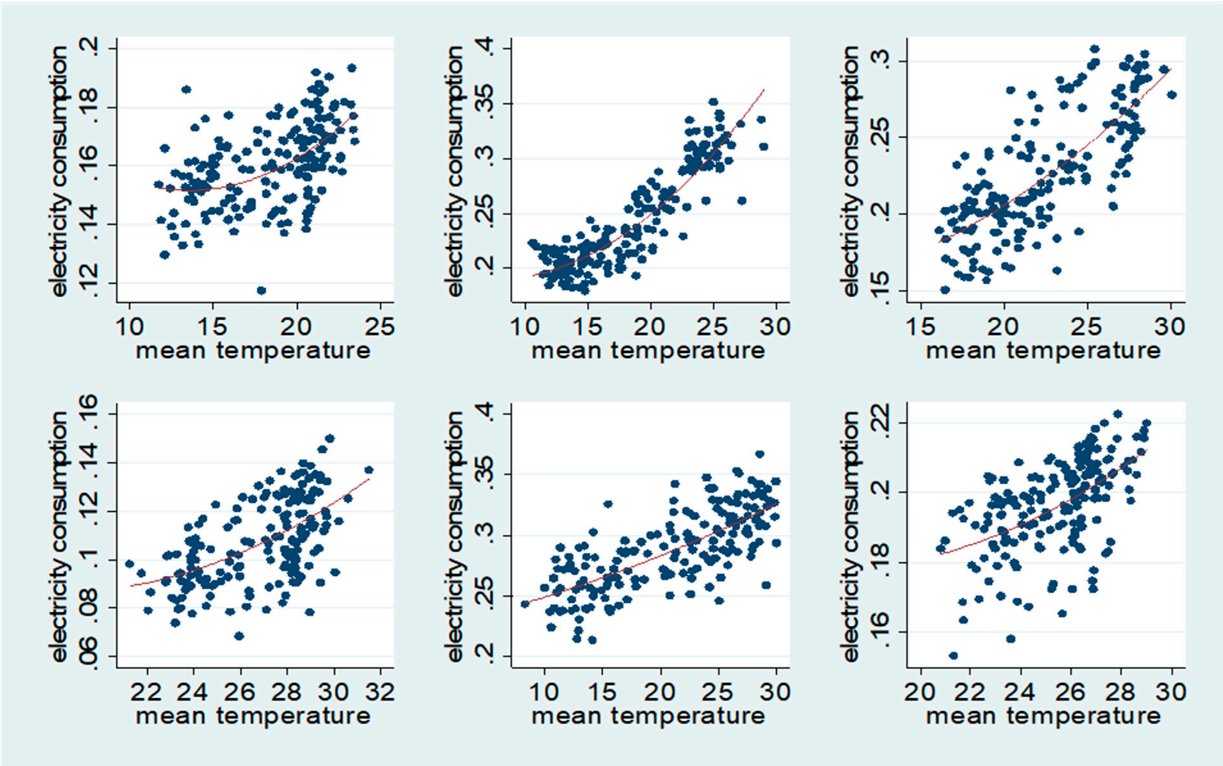
Appendix A

Appendix A.1. State Numbers and Names

Table A1. Numbers assigned to states.

1 AGUASCALIENTES	2 BAJA CALIFORNIA	3 BAJA CALIFORNIA SUR	4 CAMPECHE
5 COAHUILA	6 COLIMA	7 CHIAPAS	8 CHIHUAHUA
9 DISTRITO FEDERAL	10 DURANGO	11 GUANAJUATO	12 GUERRERO
13 HIDALGO	14 JALISCO	15 MEXICO	16 MICHOACAN
17 MORELOS	18 NAYARIT	19 NUEVO LEON	20 OAXACA
21 PUEBLA	22 QUERETARO	23 QUINTANA ROO	24 SAN LUIS POTOSI
25 SINALOA	26 SONORA	27 TABASCO	28 TAMAULIPAS
29 TLAXCALA	30 VERACRUZ	31 YUCATAN	32 ZACATECAS

Appendix A.2. Scatter Plots of Simple Relations between Energy Consumption and Temperatures



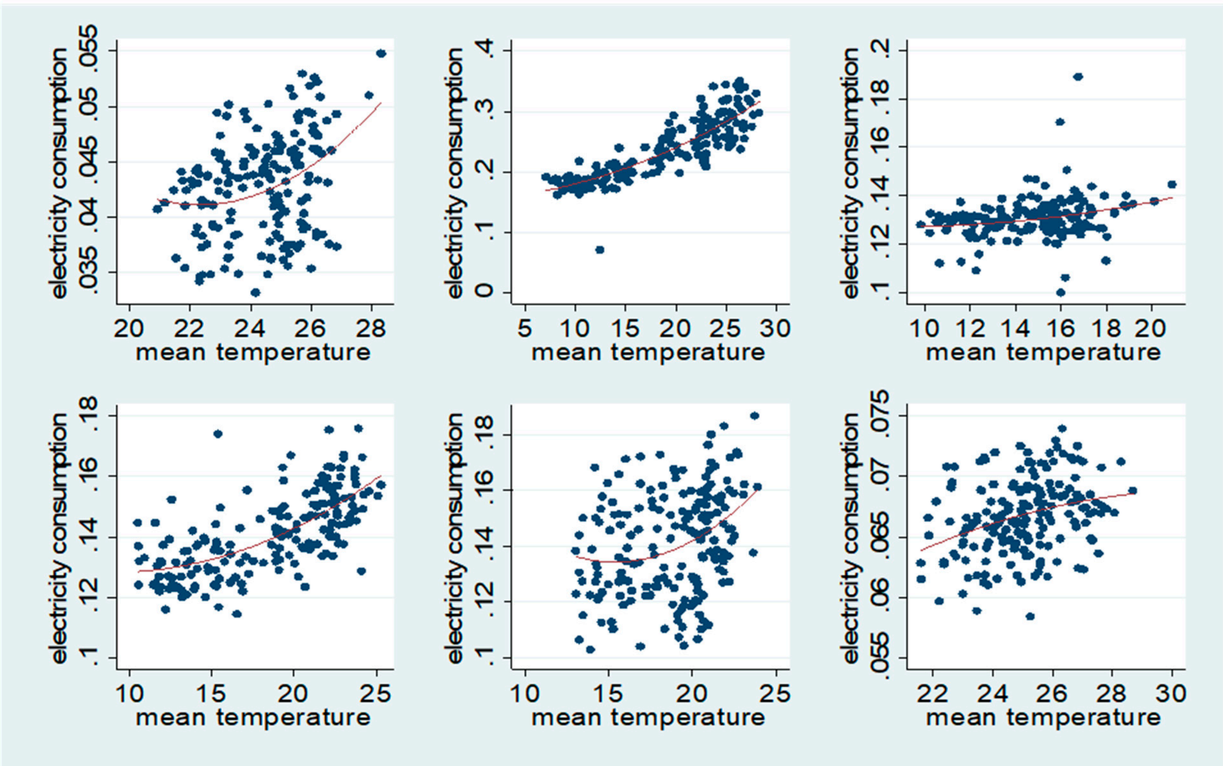


Figure A1. *Cont*.

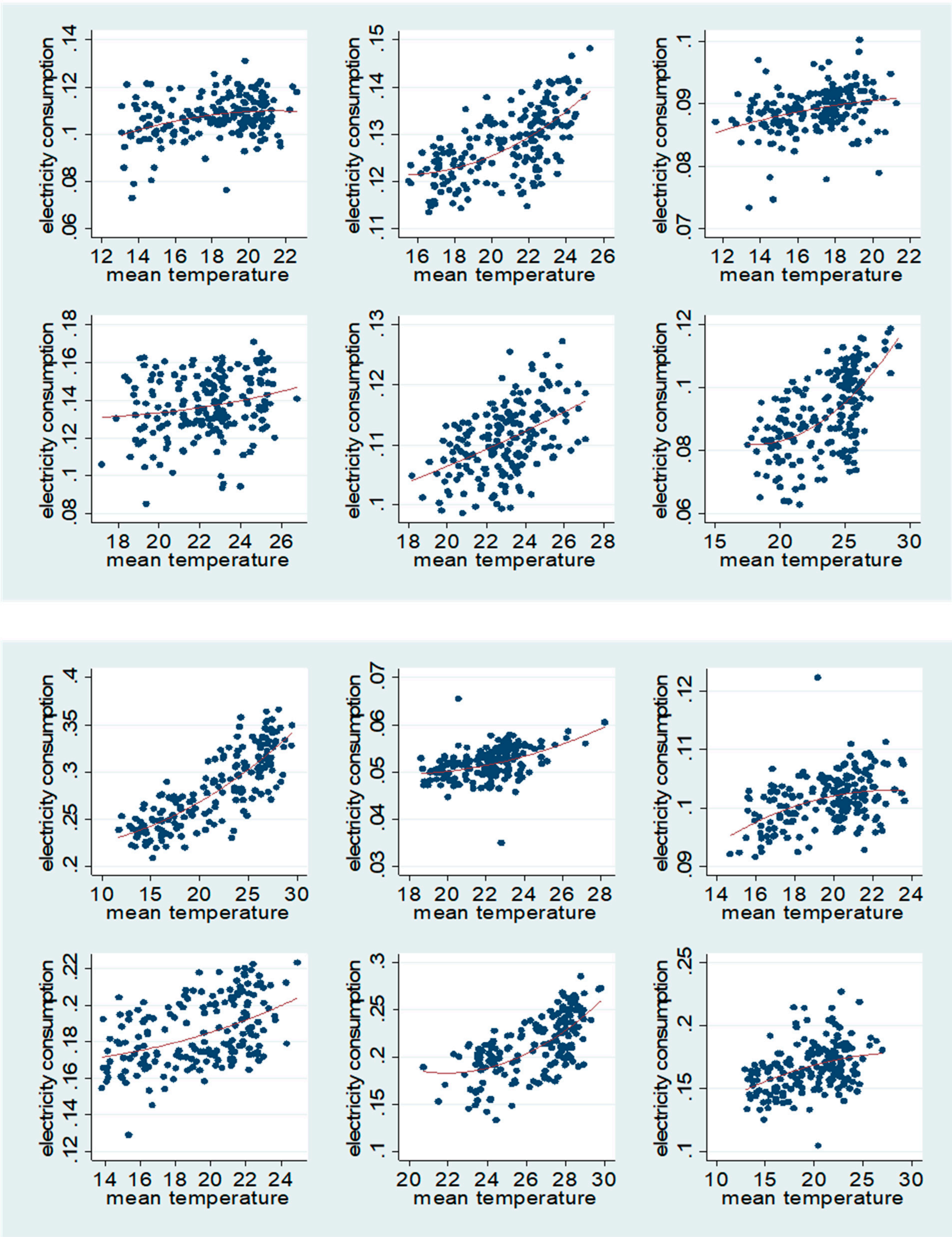


Figure A1. *Cont.*

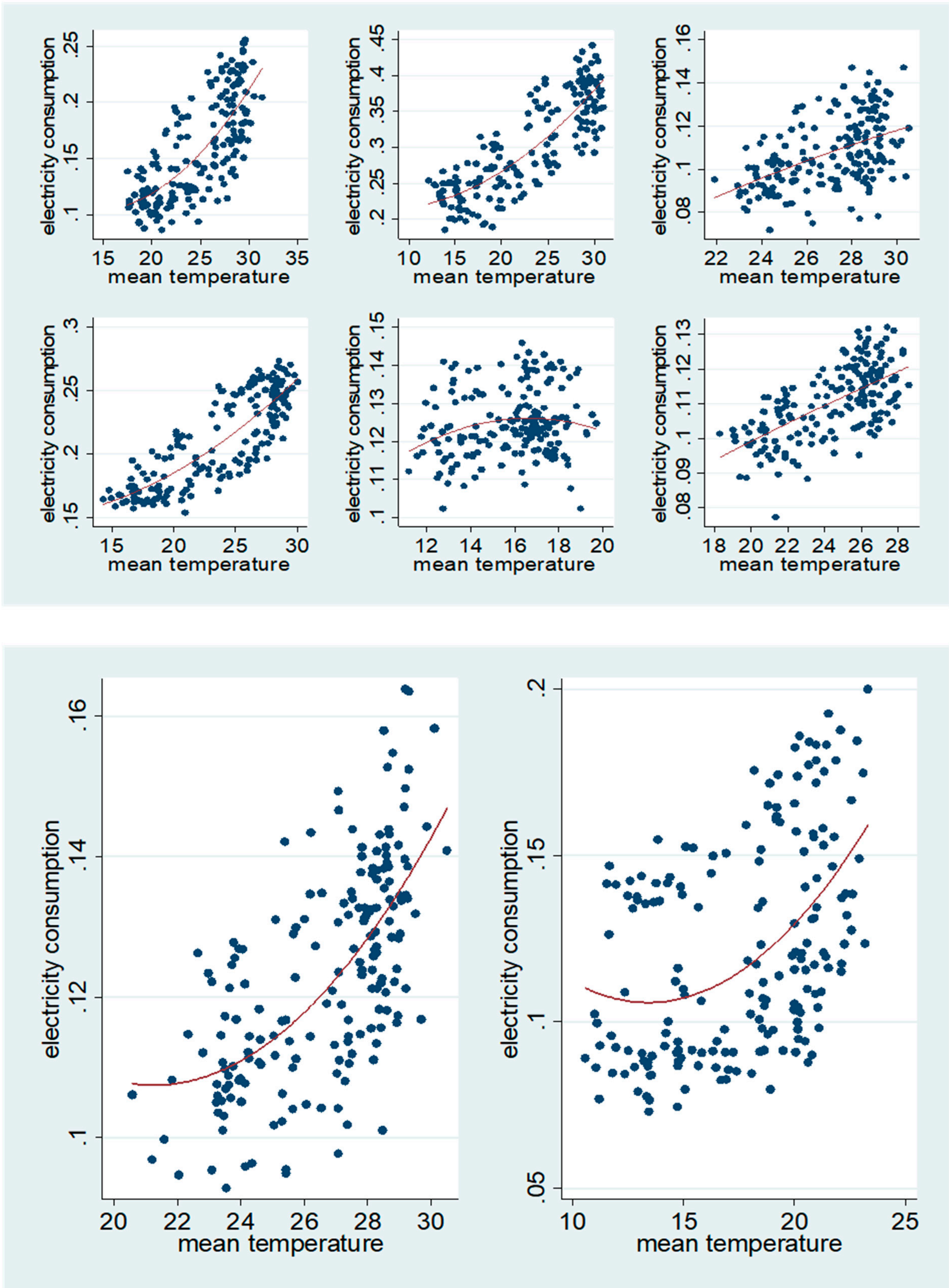


Figure A1. Monthly electricity consumption per capita over mean temperature for all 32 states in Mexico (shown in numerical order starting with state 1 in the top left and state 32 in the bottom right).

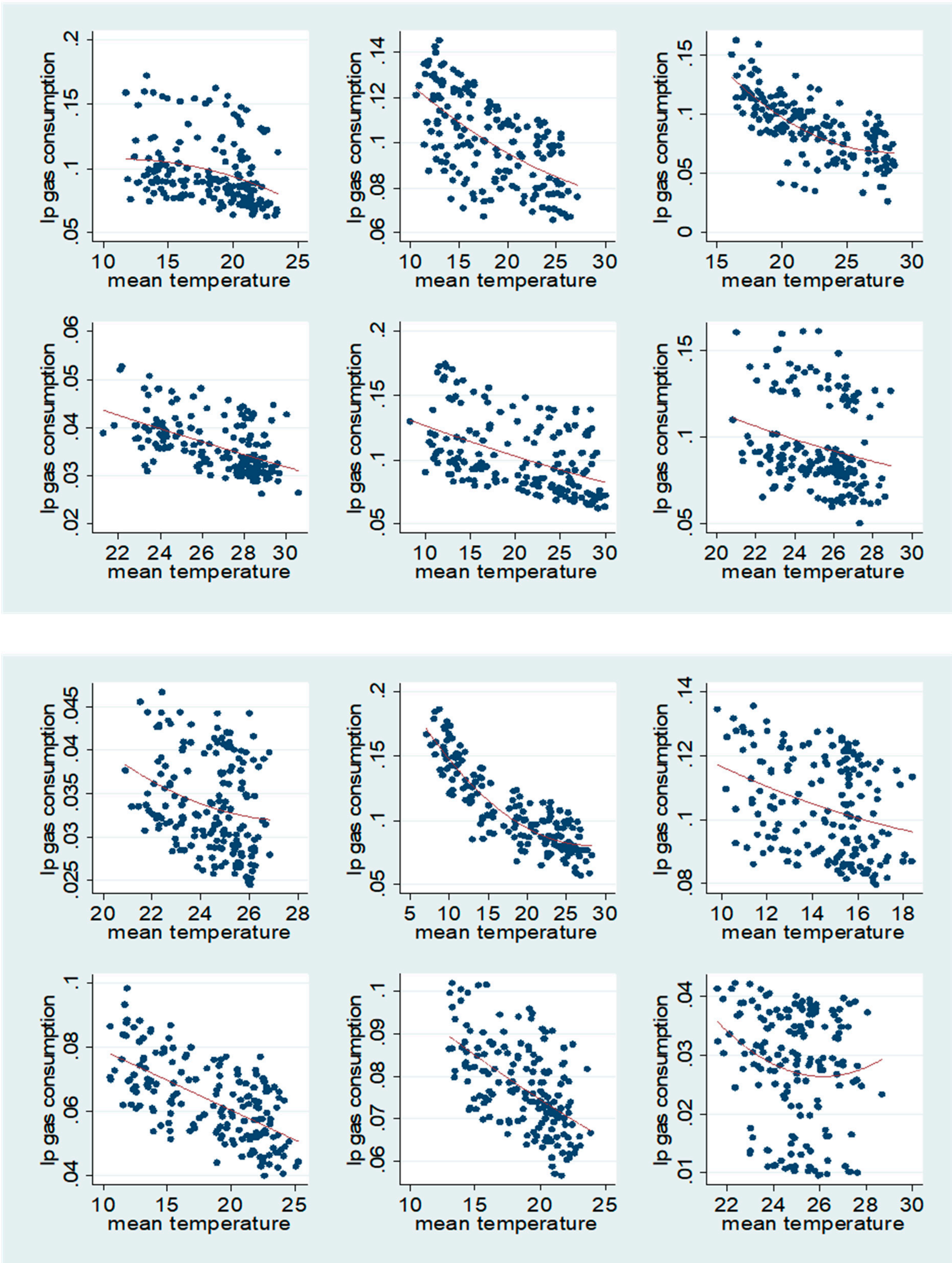


Figure A2. *Cont.*

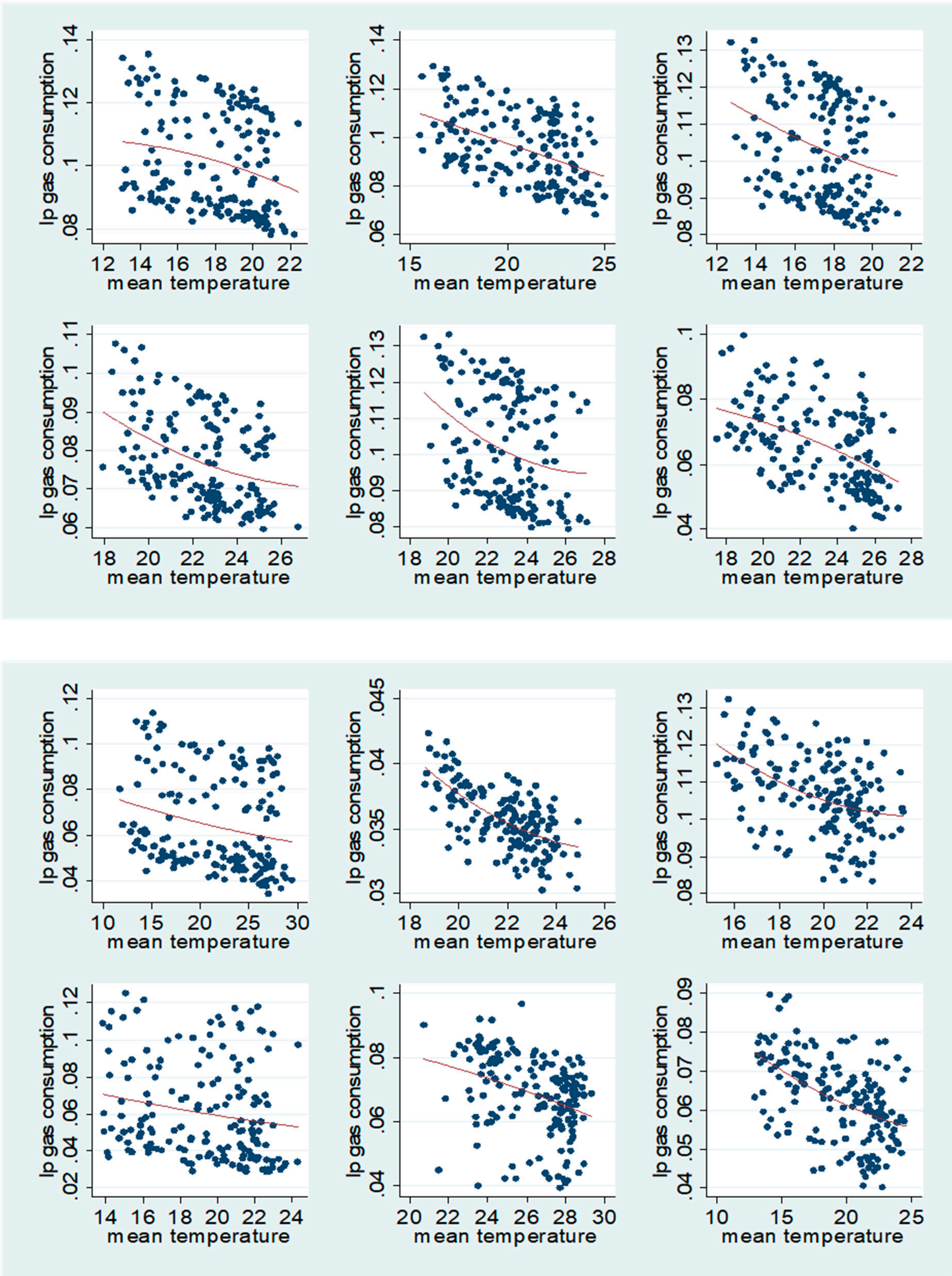


Figure A2. *Cont.*

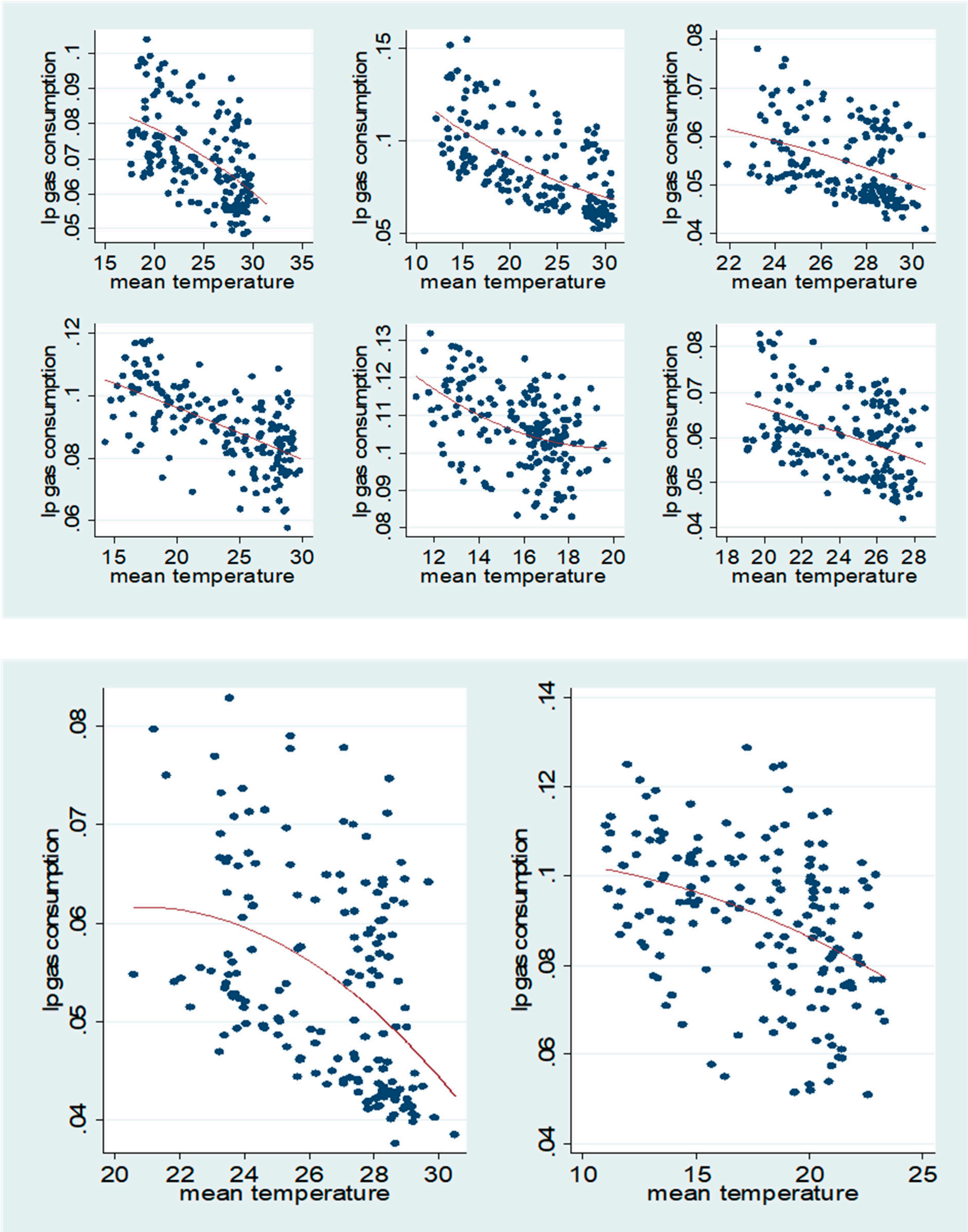


Figure A2. Monthly LP gas consumption in barrels per capita over mean temperature for all 32 states in Mexico (shown in numerical order starting with state 1 in the top left and state 32 in the bottom right).

Appendix A.3. Extrapolations of Electricity and Gas Consumption under the RCP2.6 Climate Scenario

Table A2. Extrapolations of electricity consumption under the RCP2.6 climate scenario in % compared to the reference period (2006–2015), in centavos per person per month, and in total impacts in millions of pesos per state per year.

State ID	2020 Change in:			2050 Change in:			2100 Change in:		
	%	Centavos per Person	Total mln pesos per State	%	Centavos per Person	Total mln pesos per State	%	Centavos per Person	Total mln pesos per State
1	1.8	345	56.4	2.1	405	90.3	0.9	163	49.3
2	1.7	593	261.9	3.2	1114	668.8	2.0	700	570.0
3	0.7	288	26.5	2.2	886	111.1	0.4	167	28.4
4	0.4	81	9.3	1.4	265	41.5	0.7	134	28.3
5	0.3	130	87.1	2.1	834	760.1	−0.4	−147	−182.2
6	0.7	219	104.6	0.9	310	201.0	0.4	141	124.5
7	0.0	1	0.2	0.2	3	1.5	1.4	20	13.7
8	−0.9	−391	−35.5	2.0	834	103.2	−1.4	−618	−103.7
9	0.0	3	0.8	0.0	3	0.8	0.0	3	1.2
10	0.4	102	76.6	1.1	304	311.4	−0.1	−26	−36.3
11	5.8	447	207.3	6.6	504	318.4	3.4	258	221.4
12	0.0	3	1.0	0.0	−6	−3.0	0.0	−4	−2.5
13	0.2	59	59.7	0.2	65	90.1	0.1	31	57.3
14	0.7	132	282.8	1.1	206	598.8	0.4	86	339.6
15	0.3	74	44.0	0.3	70	57.1	0.2	60	66.1
16	1.9	228	56.0	1.9	232	77.4	1.2	146	66.2
17	1.3	170	26.0	1.1	147	30.7	1.1	148	41.8
18	0.7	159	102.8	1.4	319	280.3	0.4	90	107.4
19	2.2	859	447.9	4.7	1825	1294.3	1.0	374	359.6
20	−0.2	−58	−46.5	−0.2	−63	−67.9	−0.2	−65	−95.0
21	0.3	77	19.6	0.4	86	29.6	0.3	78	36.5
22	1.6	391	74.7	2.0	476	123.6	1.0	227	80.0
23	−0.5	221	78.4	−1.2	503	242.8	−1.1	471	308.6
24	0.7	318	122.7	0.8	352	184.4	0.4	174	124.0
25	0.6	140	52.1	3.9	965	489.3	0.1	28	19.5
26	−0.7	−290	−88.8	2.7	1055	439.6	−0.8	−301	−170.2
27	0.6	214	97.3	1.0	325	200.8	0.7	249	208.6
28	2.2	854	138.8	3.8	1483	327.7	0.7	259	77.7
29	0.1	21	22.3	0.1	20	28.1	0.1	18	34.7
30	0.5	171	46.1	0.7	248	91.0	0.4	143	71.5
31	−1.6	−108	−21.9	−0.2	−13	−3.5	−1.5	−98	−36.9
32	5.7	769	909.3	8.5	1139	1831.5	2.7	360	785.1
Total	0.8	194	3219.6	2.0	466	8950.9	0.4	102	3194.3

Table A3. Extrapolations of LP gas consumption under the RCP2.6 climate scenario in % compared to the reference period (2006–2015), in centavos per person per month, and in total impacts in millions of pesos per state per year.

State ID	2020 Change in:			2050 Change in:			2100 Change in:		
	%	Centavos per Person	total mln pesos per State	%	Centavos per Person	total mln pesos per State	%	Centavos per Person	total mln pesos per State
1	−1.6	−300	−49.2	−1.9	−351	−78.2	−0.8	−142	−42.8
2	−1.3	−149	−65.8	−2.4	−274	−164.5	−1.6	−178	−144.8
3	0.8	−146	−13.5	2.5	−438	−55.0	0.5	−89	−15.2
4	−0.1	−10	−1.1	−0.5	−52	−8.1	−0.2	−20	−4.3
5	−0.6	−58	−38.8	−4.0	−366	−333.9	0.8	76	94.2
6	0.8	−152	−72.5	1.1	−207	−134.2	0.5	−107	−93.8
7	−0.7	−31	−11.6	−0.9	−39	−19.9	−0.7	−30	−20.7

Table A3. *Cont.*

State ID	2020 Change in: %	Centavos per Person	total mln pesos per State	2050 Change in: %	Centavos per Person	total mln pesos per State	2100 Change in: %	Centavos per Person	total mln pesos per State
8	7.2	194	17.6	−13.1	−352	−43.5	11.1	300	50.3
9	−1.2	−194	−43.9	−1.0	−162	−50.1	−1.0	−155	−65.1
10	−0.6	−74	−55.5	−1.8	−208	−212.8	0.2	24	33.7
11	−2.4	−256	−118.7	−2.7	−286	−180.7	−1.4	−145	−124.6
12	0.1	−18	−6.5	0.2	−24	−12.2	0.2	−21	−14.0
13	−0.9	−169	−171.3	−1.0	−185	−255.8	−0.6	−106	−197.5
14	−2.5	−200	−426.6	−3.7	−294	−853.4	−1.7	−133	−524.6
15	−1.5	−194	−115.7	−1.4	−188	−152.8	−1.2	−156	−171.7
16	−7.3	−174	−42.7	−7.7	−184	−61.5	−5.0	−119	−53.8
17	−3.0	−181	−27.8	−2.7	−165	−34.3	−2.6	−159	−45.0
18	−1.6	−138	−89.1	−2.9	−257	−225.8	−0.9	−79	−93.8
19	−1.0	−114	−59.3	−1.9	−230	−163.1	−0.4	−43	−41.5
20	−0.3	−49	−39.0	−0.4	−55	−60.0	−0.4	−53	−77.8
21	−3.1	−130	−32.9	−3.5	−147	−50.8	−3.0	−125	−58.6
22	−1.5	−182	−34.9	−1.8	−220	−57.1	−0.8	−100	−35.2
23	−0.2	−36	−12.6	−0.4	−82	−39.4	−0.4	−74	−48.5
24	−2.6	−294	−113.4	−3.0	−331	−173.3	−1.5	−162	−115.6
25	−0.2	−23	−8.4	−1.1	−153	−77.4	0.0	−4	−3.0
26	0.7	65	19.8	−2.2	−193	−80.5	0.7	60	34.1
27	−0.5	−79	−36.0	−0.7	−120	−74.0	−0.5	−89	−74.7
28	−1.2	−174	−28.3	−2.0	−297	−65.7	−0.3	−48	−14.3
29	−1.8	−126	−131.4	−1.6	−115	−163.0	−1.5	−107	−204.9
30	−0.6	−85	−23.0	−0.9	−123	−45.0	−0.5	−68	−34.0
31	0.2	46	9.3	0.0	6	1.6	0.2	43	16.3
32	−1.6	−261	−308.6	−2.3	−371	−596.1	−0.7	−118	−257.5
Total	−1.3	−115	−2131.2	−2.2	−202	−4520.5	−0.7	−66	−2348.5

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