STATE-LEVEL RESIDENTIAL ENERGY CONSUMPTION, INCOME INEQUALITY, AND DEMOGRAPHICS

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INTRODUCTION

Income Inequality has long been the subject of social inquiry; however, in studies of energy use and consumption it has largely been ignored both theoretically and empirically. This leaves important questions related to how inequality works in relation to energy use, as previous studies have been unable to address it or ignored it entirely. Towards this end, we are not well versed in the effect of income inequality over time on energy use for the residential sector. A variety of researchers have long been interested in demographic and social drivers of energy use, especially in aggregate, given the challenges posed by the contribution of population and socio-economic drivers of climate change (O'Neill and Chen 2002). Work has commonly focused on individual households, and with few exceptions, ignores the theoretical contributions of relevant socio-economic contextual factors (Lutzenhiser 2001). The work done at the aggregate level has often been done using nations as a unit of analysis, comparing countries and their energy use and demographic trends across time to isolate key drivers. These studies ignore important internal variation in social and demographic trends and factors influencing energy use , as well as internal dynamics that produce the aggregate numbers, such as inequality. This leaves an important gap in the literature addressing the mid-level aggregations like States in the United States, that are contained in Nations, but exhibit different characteristics and drivers that could impact how a policy might work in that State. This study intends to interrogate this level of aggregation in the United States.

Empirically, inequality is an important and often ignored topic in most studies of aggregate trends and drivers of energy use or CO_2 emissions, which leaves an understanding of this central sociological concept unaddressed by this level of study. Across the United States the amount of a household's income spent on energy is vastly higher for lower income households, as compared to higher income households. In the U.S. the more affluent have more influence on overall CO_2 emissions than lower income households based on their level of consumption, something that policies need to take into account; especially as the same pattern is likely with energy use (York 2010). These large differences are driven by increasing inequality where income (followed by consumption) is increasingly concentrated in the higher income groups.

Theoretical development in energy consumption studies of residential areas has been slowly integrated into more economic-based empirical articles designed specifically for policy analysis, largely clustered among a few authors with the bulk of the field content to remain highly empirical (Lutzenhiser 1994). This research lays a baseline model for incorporating sociological concerns, such as culture and inequality; however, often do not explicitly do so. It is important to note that energy has been central or very important to several social theorists, however their work largely focused on social organization, not the consumption itself (Lutzenhiser et al. 2001).

In general, at lower levels of aggregation, little work has been done to understand historical trends in energy use , especially concerning residential energy, nor specifically how inequality and demographic changes have influenced those trends. In an effort to address this gap and bring additional socio-contextual variables into the literature, this study will focus on residential energy use and its drivers. Specifically, this study will evaluate the relative contributions of inequality and population growth/size to the per capita and total energy use in the United States from 1977-2006. This will allow the study to address the central research questions: (1) how do these important drivers of energy use at the national level function at a lower, more local, level of aggregation?, and (2) what is the role that inequality plays in this, relative to population measures?

Literature Review

Residential energy use is a product of consumption and activity at the household level, involving all energy use done in homes and neighborhoods. This consumption and activity is determined by a host of factors, some internal to the residential sphere, some existing external to the residential sector (Lutzenhiser et al. 2001, O'Neill and Chen 2002, Wilson and Dowlatabadi 2007) . While the residential energy consumption level is largely a product of micro-level behaviors and actions, there are important aggregate trends that are working to also produce energy use , which may not be evident at the micro-level. Energy use has momentum; for example, once you start using energy at a certain level, it is likely that you will use at that same level or higher into the future. At the aggregate level this momentum is both a product of micro-level decisions , but also of larger contextual factors constraining decisions and moderating their effect (CITE).Momentum in residential settings may in part be due to prior decisions around housing stock as well as consumption decisions, such as A/C and refrigerators that are not frequent purchases for households, and once made, their effects are drawn out over the life of the appliance (CITE). Much of this momentum at the aggregate level is often driven by the type of macro-factors that national level studies are interested in, such as Gross Domestic Product and population size (O'Neill and Chen 2002, York 2010). These factors are related to momentum, but each functions through distinct processes. The economic situation within States is an important driver of overall energy use, and can also have an important effect on residential energy use (Rosa et al. 2004). In general, economic activity requires energy use for production of goods, maintenance of buildings, and powering the vast infrastructure network needed to support businesses and consumers that drive this activity. Therefore, growth in economic activity can be expected to increase the overall energy usage within a State (DeSherbinin et al. 2007). This economic activity requires people to fulfill many roles, from consumers to workers, however, and these roles also require or imply certain amounts of energy use. "Workers" in this case broadly refers to people executing a job or trade, merely in the workforce. Workers need to get to work and back home, at which point they become consumers, purchasing items that maintain their household or provide utility in some other way (Wilson and Dowlatabadi 2007). While this paper does not take it up, the economic activity level may also be important for determining transportation energy use of households. Many of these purchases and activities use energy, especially considering household maintenance involves heating and cooling the home.

This transition from worker to consumer is central to how the level of economic activity can influence the residential sector's energy use. The level of economic activity in an area can loosely determine the amount of money households have to spend, which means that they can consume in ways that lead to increased or decreased energy consumption depending on whether this consumption leads to more energy use or more energy efficiency. While this relationship is vastly more complicated at the individual level, the aggregate level impact of the economic activity level is more simply connected to the consumption levels and average choices due to the way that energy is embedded into the economy (Curran et al. 2004). Higher levels of economic activity should lead to higher levels of energy use in the residential sector as a byproduct of the level of income and required activity that it determines for the residents of the State . This correlation is not necessarily direct, in part because economic activity does not directly drive the level of energy use in the residential sector, as it might for the commercial and industrial sectors; however, as people that make up both sectors are impacted by the level of activity and the perceived well-being, they make decisions that result in the trends we see.

Economic activity does not reap uniform rewards for all people, and in our economy it does not easily allow someone to avoid participation if they so choose. This means that the relative distribution of wealth and income within the States importantly determines energy use, in ways different from the overall level of economic activity. Two important factors influence how inequality can influence energy use; the first is the level of consumption for each group within the distribution directly relating it to the level of economic activity. Second are the social processes and opportunities that inequality can produce. In general those at the top, given their ability to consume at higher levels, carry more weight in determining consumption than those at the lower level, as inequality increases. This effect likely differs based on the overall level of economic activity, because those at the bottom of the distribution in lower economic activity areas are less able to consume than those in the same portion of the distribution would be in higher economic activity areas. When considering inequality, it is insufficient to only consider how the levels of income are effecting energy use; we must also briefly think about how inequality is not a stationary measure, but reflective of a process of changing income levels for each group, relative to one another. Higher levels of inequality may lead the lower income groups to use more energy than they otherwise would. This implication may stem from the desire of higher groups to differentiate from lower groups, and from lower groups to strive upward, often leading to more consumption with embedded energy use (Bourdieu and Nice 1984, Spaargaren and Van Vilet 2000). It may also work in the opposite direction for higher inequality, where fewer people have more of the income, but they do not linearly increase their energy use as their wealth increases, leading to less energy use. Additionally, it may be that due to the greater effectiveness of purchased energy conservation behaviors compared to conservation habits that lower income households are more likely to have less ability to curtail their usage meaningfully (Barr et al. 2005). Similarly, as the income becomes more unequally distributed, those at the bottom are less able to consume, and because they represent the bulk of the population in this situation, they bring down aggregate energy use.

A the household level, household size and age composition are important drivers of energy use in addition to functioning at the aggregate population level with population growth and size (Ironmonger 1995, MacKellar et al. 1995, O'Neill and Chen 2002, York 2010). It has been noted that there is an economy of scale effect within a household in terms of energy use. At first, each additional household member adds nearly the same amount of energy requirements to a household, but as you go from 2 to 3 and 3 to 4 household members, they are able to share more energy using resources and the effect is diminished (Ironmonger 1995).

Inequality has been increasing in the US over time, and this is also true for most of the States (Kerbo 2009). The meaning of inequality may have changed over time,. It may also be that inequality has become more entrenched, and thus the effect is larger in 2006 than it was in the late 1970's, due to its pervasiveness and depth.

DATA AND METHODS

Data

This study makes use of a data set spanning 1977 to 2006 including information on each State's residential energy consumption, median incomes, population characteristics, and economic indicators. The data for this study was collected by the authors from a variety of sources. The energy data for this study comes from the Energy Information Administration's State Energy Database System, and includes data on Gross Domestic Product and Population Size. Income data comes from the Current Population Survey March Supplement for each year and was obtained in time series from the Integrated Public Use Microdata Series - Current Population Survey (King 2010). These data are nationally representative (with provided weights) and income is adjusted for inflation using the provided CPI-adjustment factor for each year. This data is used to calculate the income inequality Gini coefficients, median incomes, and mean household size.

Variables and Measurement

The dependent variable for the analysis is residential energy use per capita, measured by a variable that represents the total residential energy use for each state, in each year, in million British Thermal Units (BTU), per capita. This per capita measure implicitly controls for population size in each state for each year by including in the denominator of the dependent variable.

The key independent variables for our analysis are: population growth, household size, and income inequality. Population growth is measured in % points (ranging from -100 to 100) and indicates the year-over-year change in population size. Household size is measured using two variables: a basic variable indicating household size, and a squared term, each of which is a continuous variable. Inequality is measured using the Gini index of inequality, and has been multiplied by 100 to assist in coefficient interpretation; it ranges from 0-100 now rather than 0-1.

(Table 1 about here)

Table 1 provides descriptive statistics for each independent and dependent variable in five-year groups. The key dependent variable, million BTU per capita Residential energy use, shows a marked increase over the whole period; however, it was not linear, showing a decrease from the 1977-1981 time period to the 1982-1986 period; from here the level of consumption increases substantially, through 2006. Population growth over the study period is highly variable, but trends lower over time. Gini scores and logged GDP are both trending higher over the study period, with Gini scores increasing more in relative terms over the period (6.6% increase compared to a 14.5% increase). Median household income has increased over the period, but high variability cast doubt on real increases. Household size is lower at the end of the period compared to the beginning, but again, there is great variability that increases the uncertainty of the true trend.

Methods

Utilizing data with multiple observations for each main unit can lead to several problems with error correlation. Fortunately, another approach remains that can handle this data while providing a flexible and familiar analysis framework - multi-level models (Luke 2004). This study makes use of the nested nature of the dataset, meaning that each state has 30 years of data nested within it making multi-level models and latent growth curve models possible for this analysis. The level-2 unit is the States themselves, and the level-1 unit of observation, then, is each year from 1977-2006. Traditional Multi-level models make up the first portion of the analysis, specifically the basic trajectory models, and provide statistical significance testing. The latent growth curve models make up the second half of the analysis and are used to describe the different clusters of trajectories and patterns in a concise way.

The multi-level models allow for the nesting of years in states to produce trajectories by allowing there to be a unique intercept for each state, and by allowing the slope for time to be different for each state as well. Using this approach, sequentially more complex models are estimated, adding in demographic and economic variables. The final model adds an interaction term for inequality with time. These models are estimated in R using the nlme package for multi-level models.

Latent growth curve models operate in a similar fashion to the multi-level models; however, they add a wrinkle to the process. They estimate a model predicting latent class membership for each state, then, after assessing and sorting each state into a class, they estimate a model of the trajectory for each class separately. Class membership probabilities are provided, as well as classification tables for additional reference in appendix A. The estimation software used does not provide standard error estimates for the parameters, and thusly these estimates should be considered descriptive of the data rather than estimates used for statistical inference. All latent growth curve models are estimated using the mmlcr package in R.

RESULTS

The results of our various analyses highlight the salience of population factors, especially household size, in predicting the level of per capita residential energy use, however they also point to the importance of inequality as a process. Additionally, the effect of income inequality is different for States that have higher energy use compared to those with lower energy use, and while this finding is the result of descriptive evidence and is to be taken as such, it warrants further investigation as a potentially important driver of energy use in currently low-using States or regions.

Table 2 presents results from a series of standard multi-level models regressing time (and time squared) on per capita energy use. All of the statistical inference-based findings in this study are in this table. Model 1 shows a moderate, but significant effect of time and its squared term; this model is the basic trajectory or baseline model, showing energy use as a function of time.

Time seems to decrease energy use on average over time, but at a diminishing rate. The effect of time is allowed to be different for each state in the model, and the variance around the slope parameter under the fixed effects is substantial across states, more than 3 times the effect size. Adding population growth very slightly diminished the effect of time, but in the absence of other controls does not improve the model very much. Adding income inequality, as measured by the Gini Coefficient, proves to alter the time effect more than population growth; while close, however, it does not reach statistical significance on its own, and the model fit is worse than including just population growth. This does not nullify inequality as unimportant; in fact, it may well be suppressed or it could be a process, which is consistent with our theories relating it to consumption types and attitudes.

Testing for suppression of an inequality effect, Model 4 introduces a series of controls - GDP, income, and household size. Holding with theory and prior empirical knowledge, household size and its squared term are very significant and decrease energy use at a decreasing rate. This is a bit different than the individual level data show, where household size increases energy use at a decreasing rate. The aggregate data are not similar to the individual data, in that they reflect yearly average household sizes, which do not begin with a single person, but are more likely to include families with at least one child. This higher starting value and its implications lead us to expect this effect. It is interesting to note that adding these controls eliminates the effect of population growth and further diminishes the already insignificant effect of inequality.

Model 5, the best fitting model (BIC of 8524.671 compared to the BIC of 8561.675 for the baseline model, and reduces State-year error by 5%), adds an interaction of the Gini coefficient variable with time and time squared. This is done to test the hypothesis that income inequality might function as a process over time to decrease energy use at the aggregate level, by concentrating more households in lower income brackets with less consumption. The model shows a very significant effect, where each Gini point decreases energy use by .43 million BTU per capita, but that over time the effect increases and becomes positive after 6 years. This provides evidence of a process based effect of inequality on energy use. The effects of household size and income remain the same, as does population growth and GDP. The effect of GDP was not significant in any model, indicating a more loose relationship with residential energy use compared to total energy use.

(Table 2 and Figure 1 about here)

Figure 1 presents the descriptive results of using a latent growth curve model to first predict membership in a latent class, and then to assess the trajectories of each class using the same covariates as Model 5 from Table 2. The primary reason for this analysis is to understand how the model varies across groups of States, clustered based on their energy use[1]. The model shows three classes: two that are very similar, and one group of States (Class 3) that is made up of lower energy users, and which has markedly different effects. Table 3 presents ANOVA results for our key variables across classes. While all F tests are

[1] Models testing the variability of the effect of inequality and household size across individual states were run and found to provide no support that variation exists on a state by state basis, but there is clustering of States by energy use.

significant, the classes look similar on most variables, except that the third class has considerably lower energy use and higher inequality.

(Table 3 about here)

DISCUSSION AND CONCLUSIONS

This study set out to investigate, in a novel way, how drivers of energy use behave at mid-level aggregations , as well as the role of population and inequality measures in understanding these trajectories, in an attempt to inform the broader empirical and theoretical work on residential energy use. We used multi-level models and latent growth curves to investigate State level energy use trends and factors from 1977-2006. From a demographic perspective, we found that while on its own, population growth is important, accounting for household size erases the effect, indicating the salience of demographic composition and structure. These findings are net of population size as well, a common theme in energy literature popularly, and among many scholars (e.g. Erlich et al. 1972, York 2010). Interestingly, inequality was found to have a cumulative effect, which seems to indicate a process where inequality works to influence energy, but that the effect of this cumulation varies based on the usage of the State in question. These findings provide ample fodder for future research, while providing original insight into the drivers of energy use more broadly. Specifically future studies should investigate the ways that cumultation of inequality might work through pathways like poverty concentration or urban expansion.

It has long been known that household size was an important driver of energy use at the individual level and at the National level (Ironmonger 1995, O'Neill and Chen 2002). The findings of this study provide support for these prior findings, and in fact may add to their richness by finding that average household size can decrease energy use directly at an aggregate level. Our study finds that household size decreases energy use, but that the rate is lower at larger average household sizes. This is important because it is not the positive squared relationship we see in the individual level studies, but a negative one, pointing out that because on average, States have higher household size values on average than individual households. The salience of household size is not to be understated as an important driver of energy use and a policy concern as the population ages, decreasing the average household size as it does.

Perhaps the most theoretically intriguing finding is that of income inequality. It would make sense that as a population is more concentrated in lower incomes, and therefore unable to consume as much energy, this disparity widens, but this is only part of what we find. The descriptive results point to differential effects based on the level of energy use of the State, where lower energy using states see energy use increases from higher levels of inequality. This is intriguing in that it points to a process that plays out differently based on the level of energy use. This process could be related to a series of important drivers of inequality as well as indicate a variety of other social drivers that inequality may reflect, such as segregation or household stock differences. This finding provides empirical justification for a large variety of inequality and energy use studies at a population level, or at least in a representative way that includes varying aggregations.

Future research needs to take into account inequality construed as a process and understand how it may be working to impact energy use in conjunction with other important household drivers, such as size or age. This work needs to amply consider how household composition and various contextual factors, like inequality, are at work in producing the energy use trends we see today. To do this, better data with nested structures will be needed, as well as longitudinal insights.

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TABLES AND FIGURES

Figure 1. Predicted Trajectories of Energy Use by Latent Class, U.S., 1977-2006

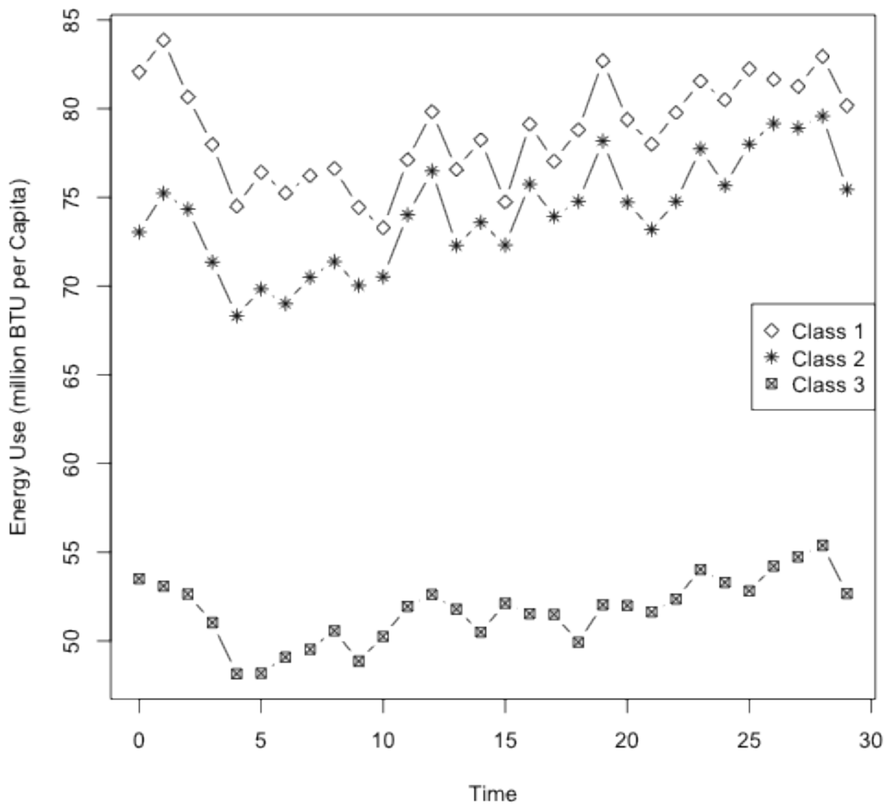

Table 1.Descriptive Statistics for Residential Sector Energy Use, 1977-2006, U.S.

	1977-1981		1982-1986		1987-1991		1992-1996		1997-2001		2002-2006	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Energy Use Variables												
Residential Sector (Million BTU per capita)	72.66	12.65	69.71	11.12	72.07	10.59	73.44	11.10	74.20	10.89	76.56	11.63
Socio-Economic/Demographic Variables												
Population Growth (%)	1.26	1.26	0.86	1.21	0.88	1.24	1.35	0.97	1.01	0.86	0.88	0.89
Gini Coefficient (0-100)	38.83	1.97	40.12	2.10	40.59	2.24	41.45	2.47	43.88	2.42	44.46	2.45
Logged GDP	10.99	1.02	11.10	1.03	11.26	1.05	11.40	1.03	11.60	1.06	11.72	1.05
Median Household Income (2000 $)	36760.15	5738.96	34905.39	5624.76	37504.23	6440.88	36148.32	5818.83	39423.60	6182.58	41106.64	6509.92
Household Size	2.78	0.15	2.65	0.13	2.56	0.13	2.52	0.14	2.52	0.16	2.64	0.14

able 2. Multi-Level Models of Per Capita State-Level Energy Use (Million BTU per capita), 1977-2006, U.S.

	Model 1			Model 2			Model 3			Model 4			Model 5		
	Parameter	S.E	P	Parameter	S.E	P	Parameter	S.E	P	Parameter	S.E	P	Parameter	S.E	P
ixed															
Time	-0.255	0.098	0.009	-0.252	0.099	0.011	-0.233	0.100	0.020	-0.310	0.122	0.011	-4.47	0.83	0.00
Time^2	0.015	0.002	0.000	0.015	0.002	0.000	0.016	0.002	0.000	0.015	0.003	0.000	0.18	0.03	0.00
Pop. Growth				0.387	0.143	0.007	0.357	0.143	0.013	0.224	0.145	0.124	0.18	0.14	0.22
Gini Coeff.							-0.137	0.070	0.051	-0.028	0.073	0.698	-0.43	0.20	0.03
Ln(GDP)										0.709	1.203	0.556	0.02	1.21	0.99
Median Income										0.0003	0.000	0.000	0.0002	0.00	0.00
Household Size										-100.051	17.082	0.000	-64.38	17.87	0.00
Household Size^2										18.414	3.275	0.000	11.63	3.42	0.00
Gini*Time													0.10	0.02	0.00
Gini*Time^2													0.00	0.00	0.00
Intercept	72.40049	1.748	#####	71.96	1.77	0.00	77.2802	3.245	0	192.165	25.73	0.000	169.80	25.84	0.00
andom															
Intercept	12.219			12.320			12.300			14.623			12.454		
Time	0.630			0.636			0.641			0.323			0.616		
Time^2	0.014			0.015			0.015			0.000			0.016		
Residual	3.494			3.482			3.478			3.561			3.316		
IC	8561.675			8561.641			8565.141			8524.671			8498.67		

Table 3. ANOVA Results for Latent Classes, 1977-2006, U.S.

	Class 1	Class 2	Class 3	F- Statistic	P-Values
Energy Use	78.80	74.10	51.72	**765.00**	0.0000
Pop. Growth	0.89	1.07	1.37	**13.49**	0.0000
Gini Coeff.	41.58	41.29	42.65	**14.89**	0.0000
Ln(GDP)	11.25	11.35	11.62	**7.77**	0.0004
Median Income	$ 35,922.37	$ 38,714.02	$ 38,150.36	**32.33**	0.0000
Household Size	2.63	2.58	2.69	**33.25**	0.0000

Note: **Bold** indicates F test is significant at the .001 level

Appendix A. Class Membership of States for the Latent Growth Curve Model

Class 1	Class 2	Class 3
AK	CO	AZ
AL	CT	CA
AR	DE	HI
ID	FL	NM
IL	GA	NY
IN	KS	RI
KY	IA	
ME	LA	
MI	MA	
MO	MD	
MS	MN	
MT	NC	
NE	ND	
OH	NH	
OK	NJ	
TN	NV	
UT	OR	
WA	PA	
	SC	
	SD	
	TX	
	VA	
	VT	
	WI	
	WV	
	WY	