The Human Dimensions of Climate Change

A Micro-Level Assessment of Views from the Ecological Modernization, Political Economy and
Human Ecology Perspectives

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ABSTRACT

Understanding the manifold human and physical dimensions of climate change has become an area of great interest to researchers in recent decades. Using a U.S. nationally-representative data set and drawing on the ecological modernization, political economy, and human ecology perspectives, this study examines the impacts of energy efficiency technologies, affluence, household demographics, and biophysical characteristics on residential CO₂ emissions. Overall, the study provides mixed support for the ecological modernization perspective. While several findings are consistent with the theory's expectation that modern societies can harness technology to mitigate human impacts on the environment, others directly contradict it. Also, the theory's prediction of an inverted U-shaped relationship between affluence and environmental impacts is contradicted. The evidence is somewhat more supportive of the political economy and human ecology perspectives, with affluence, some indicators of technology, household demographics, and biophysical characteristics emerging as important drivers of residential CO₂ emissions.

INTRODUCTION

The earth's atmosphere is steadily warming. Global surface temperatures in the eleven years between 1995 and 2006 were the highest since 1850, and average temperatures continue to rise (IPCC 2007, 2013, 2014). Some of the most dramatic indicators of the higher-than-normal global surface temperatures come from the Arctic Region where age-old ice-sheets (in Greenland) and glaciers are thawing. The crisis of global climate change, largely caused by human-driven increases in atmospheric concentration of long-lived greenhouse gases (GHGs), has become the most daunting modern-era environmental challenge to humans and ecosystems. This study addresses human dimensions of climate change, focusing specifically on household level drivers of carbon dioxide (CO₂) emissions, the GHG that contributes most to climate change. Drawing on the ecological modernization (EM), political economy (PE), and human ecology (HE) perspectives, we examine the impacts of specific energy efficiency technologies, affluence, household demographics, and biophysical characteristics on residential carbon dioxide emissions in the United States.

EM is a theoretical perspective that focuses on how the central institutions of modern societies may be restructured to “solve the fundamental problem of the ecological crisis” (Spaargaren and Mol 2009, p. 68). A key proposition of the EM perspective is that technological innovations can pave the way for the “greening” of production and consumption (Christoff 1996; Huber 2009a, 2009b; Jensen and Gram-Hanssen 2008; Mol and Janicke 2009). The PE perspective, on the other hand, questions the extent to which efficiency technologies can counteract the impacts of the rising scales of production and consumption that generally accompany modernization. It argues that technological innovation often accelerates resource consumption (Foster et al. 2010; Schnaiberg 1980; Schor 2005). The HE perspective, which

compliments the PE perspective (York and Mancus 2009), focuses on the dynamic interrelationships between human populations and their natural, social and cultural environments. It recognizes that population characteristics, affluence, and biophysical features influence anthropogenic environmental impacts (Catton 1980; Catton and Dunlap 1980; Dietz and Rosa 1994, 1997), and may sometimes overrun technological advancements.

There is widespread recognition of climate change's ominous potential to disrupt the functioning of social and biological systems, and of the need to act to reduce human effects on the climate. Some of the social impacts of climate change include global and localized food security challenges (IPCC 2007, 2014; Parry et al. 2004); disruption of the traditional lifestyles of native and aboriginal people (Furgal and Seguin 2006); increased prevalence of food-borne, water-borne and viral diseases (IPCC 2007; Bultó et al. 2006); increased injuries and deaths from severe weather events (CCSP 2008; IPCC 2014; Karl et al. 2009; Melillo et al. 2014); and water supply difficulties in some locations (CCSP 2008; IPCC 2007; Karl 2009; Melillo et al. 2014). While social systems are already being buffeted by the negative impacts of climate change, the IPCC (2007, 2014) observes that failure to act quickly and decisively to mitigate rising emissions of GHGs will likely lead to the grave situation where these impacts exceed the capacity of natural and human systems to adapt.

An important precondition for effective response to this global menace is a better understanding of its physical and human dimensions. Consistent with this need for understanding and the overwhelming importance of global climate change, there is a growing body of social scientific literature on the subject (Clement and Schultz 2011; Dietz and Rosa 1994, 1997; Dietz et al. 2013; Jorgenson and Clark 2012; Lutzenhiser and Hackett 1993; Marquart-Pyatt et al. 2011; Pellow et al. 2000; Rosa and Dietz 1998, 2012; Rosa et al. 2004; Rudel 2001; Weidner

2002; York 2012; York and Rosa 2012; York et al. 2003a). A good proportion of these studies has examined the socio-structural and demographic drivers of climate change. The reality, though, is that this line of research and its associated theory testing has yet to reach a reasonable closure on the key facts of climate change's human dimensions. Contemporary social science theories on the environment still require substantial empirical evaluation. We contribute to this important endeavor by harnessing a recent nationally-representative U.S. household (micro-level) data set to evaluate some propositions of the theories identified above (the EM, PE, and HE perspectives). Our focus on households is warranted by the fact that they are important loci of many of society's environmentally-significant decisions and choices. While several studies have analyzed the anthropogenic drivers of climate change at this level, focusing especially on energy consumption (Abrahamse and Steg 2011; Adua 2010; Lutzenhiser 1993, 1997; Lutzenhiser and Hackett 1993; O'Neill and Chen. 2002), a good proportion of them were either based on subnational data or excluded several important variables.

In terms of practical significance, this study represents a de facto evaluation of one of the United States' top approaches to mitigating the emission of GHGs, efficiency improvement in energy utilization. As a result of a well-orchestrated disinformation campaign concerning the science of climate change (Dunlap and McCright 2011), and whipped up fears about the economic consequences of limiting the emission of GHGs, the nation's current policy focuses quite heavily on efficiency improvement via technological innovations.¹ This paper provides an analysis of how anthropogenic factors at the household level are helping drive the ongoing atmospheric concentration of GHGs. In the remainder of this paper, we first briefly discuss

¹ Another strategy heavily favored by policy-makers today, especially the Obama administration, is the development and use of renewable energy sources. While the nation is yet to enact a coherent climate change policy, the Obama administration (via the EPA) is also currently considering rules to tighten the emissions of greenhouse gases by power plants.

climate change and its associated human dimensions. Second, we discuss the theoretical perspectives we are drawing upon. Third, we describe our data and methods. Finally, we report and discuss our findings.

CLIMATE CHANGE AND ITS HUMAN DIMENSIONS

In its Fourth Assessment Report, the IPCC characterized climate change as “any change in climate over time, whether due to natural variability or as a result of human activity” (IPCC 2007, p. 30). While the term does encompass global cooling, the current concern is about global warming. Global warming is caused largely by the rising concentration of GHGs (principally CO₂, CH₄ and N₂O) in the earth’s atmosphere, which helps trap excess heat. The atmospheric concentration of these gases now greatly exceeds pre-industrial levels (IPCC 2007, 2014). The concentration of the most important greenhouse gas, CO₂, crossed the frightening milestone of 400 ppm in May 2013 (Kunzig 2013)².

In newly released reports, the IPCC (2013, 2014) clearly asserts that humans are primarily responsible for the rising atmospheric concentration of GHGs over the past two centuries. The fastest rates of growth in GHGs between 1970 and 2005 were associated with energy supply, transportation, and industry (IPCC 2007, 2013). As noted earlier, climate change will have disrupting effects on social and biological systems. Indeed, climate change is expected to have wide-ranging impacts on societies -- including effects on the economy, public health, and migration patterns -- and to be one of the leading causes of social problems in this century and beyond (Melillo et al. 2014).

Understandably therefore, the human dimensions of climate change have become the most widely researched environment-related subjects in the social sciences. A review of the

² NOAA reported that on May 9, 2013, daily concentration of CO₂ crossed the 400ppm milestone. This milestone was last reached during the Pliocene epoch (about 5.3 to about 2.6 million years ago). The pre-industrial era concentration of CO₂ was around 280ppm (IPCC 2007).

interdisciplinary literature on the subject revealed several important research domains (see Adger et al. 2009; Alcott 2005; Beilin et al. 2012; Bultó et al. 2006; Crenshaw and Jenkins 1996; Dietz et al. 2013; Dunlap and Brulle 2015; Furgal and Seguin 2006; Herring and Sorrell 2008; Hoffman and Jennings 2012; Jorgenson 2009; Lutzenhiser and Hackett 1993; Marquart-Pyatt et al. 2011; O'Brien and Leichenko 2003; Rosenzweig and Parry 1994; Scruggs and Benegal 2012). These domains include: 1) anthropogenic drivers of climate change; 2) the effects of climate change on social systems; 3) mitigation or efforts to curb the emission of GHGs, the driving forces of global warming; 4) resilience and adaptation to the impacts of climate change; and 5) public opinions and perceptions about climate change.

Our analysis addresses two of these domains. First, it considers the role of human systems (anthropogenic drivers) in the increasing atmospheric concentration of GHGs. Several studies draw a direct and strong link between consumption/lifestyle and the emissions of GHGs (see Dietz and Rosa 1994, 1997; Herring and Sorrell 2009; IPCC 2007, 2014; Jorgenson 2009; Jorgenson and Clark 2012; Lutzenhiser and Hackett 1993). Our analysis speaks to this literature by examining how energy efficiency technologies, affluence, household level population characteristics, and other variables are driving the emission of CO₂. Secondly, this study also interrogates mitigation or efforts to curb emissions of the culprit gases, GHGs (see Alcott 2005; Dietz et al. 2013; Gardner and Stern 2008; Herring and Sorrell 2009; Owen 2011). We speak to the mitigation domain by examining the relationships between several residential energy efficiency technologies and CO₂ emissions. The question addressed here is whether household level technological innovations will lead to lower CO₂ emissions. This study thus straddles analyses of the human drivers of climate change and mitigation measures.

THEORETICAL PERSPECTIVES

As noted above, we draw on three theoretical perspectives to inform our analysis: ecological modernization (EM), political economy (PE), and human ecology (HE). While these theories were for the most part developed and typically applied to considerations at the macro-level, we develop their implications for micro-level processes. These perspectives share some commonalities, but also contrast sharply with one another on several points. Within the limitations of our data, our aim is to assess their merits empirically.

One of the basic organizing frameworks that is often used as a starting point for analyses of human effects on the environment is the well-known I=PAT equation that emerged from the debate in the early 1970s between Paul Ehrlich and John Holdren on one side and Barry Commoner on the other over the key driving forces behind environmental degradation (Ehrlich and Holdren 1971, 1972; Commoner 1971; Commoner et al. 1971). We introduce the I=PAT equation since it is helpful in highlighting where the HE, PE, and EM perspectives variously focus their respective attentions. The I=PAT equation posits that the environmental impacts of human societies (such as pollution emissions) can be conceptually determined by a multiplicative function of population size (P), per capita consumption or affluence (A), and the impact per unit of production stemming from the types of technologies used in production (T). Although the I=PAT equation is recognized as limited and in many respects fairly crude, it also is generally acknowledged to capture the main factors contributing to environmental problems (Harrison 1993). In practice, affluence is often measured as GDP per capita, and technology as impact divided by GDP per capita, so that technology (T) represents the portion of impact that remains unexplained. The equation has been refined in various ways so that it can be used to test hypotheses, incorporate a variety of additional factors, and allow for non-linear relationships, so that it now forms the basis of many empirical analyses by human ecologists and ecological

economists (York, Rosa, and Dietz 2003c). Although the EM, PE, and HE perspectives do not always explicitly reference I=PAT, population, affluence, and technology are the major factors they focus on in various ways.

Two leading proponents of EM describe the perspective as studying “...the ecological restructuring of the processes of production and consumption” in modern societies due to environmental considerations (Spaargaren and Mol 2009: 68). Central to the EM perspective is the argument that key institutions of modern societies can be re-structured to address the ecological crisis confronting society (Buttel 2009; Murphy and Gouldson 2009; Spaargaren and Mol 2009). It argues that structural innovations in production processes and improvements in efficiency will help reduce human impacts on the environment. While acknowledging that the early stages of modernization typically have been associated with escalating environmental problems, EM theorists argue that as the modernization process matures, it leads to ecological reforms, which curb environmental problems. The reasoning, in part, is that modernization will eventually lead to greater awareness of and concern for environmental problems among experts and the general public. This will spur governments and industry to incorporate ecological considerations into the central institutions of modern societies (Mol and Sonnenfeld 2000). The EM perspective views technological innovation as an important factor in the quest to “green” production and consumption processes. However, it also argues that environmental politics and the policy process as they develop in late modernity play a key role in leading to environmental reform (Eckersley 2004; Hajer 1995; Scerri and Holden 2014).

The EM perspective is closely allied with the environmental Kuznets curve thesis, which posits that there is an inverted U-shaped relationship between per capita income or GDP and environmental degradation, where pollution and other environmental impacts increase in early

stages of economic development, but level off and decline once a nation (or other political unit) reaches the requisite level of affluence (Grossman and Krueger 1995). This relationship is proposed to be due to the technological and social changes that come with affluence, fitting with the expectations of EM theorists (Dinda 2004).

Although principally focused on how governments, businesses, and organizations respond to environmental problems, EM scholars have also argued that citizens in modern societies respond to environmental problems by changing their behaviors and lifestyles (Spaargaren and van Vliet 2000; Spaargaren and Oosterveer 2010). With affluence, households, like industry, are expected to ‘green’ their consumption by investing in appropriate technology, which is one of the key factors our analyses focus on. Thus, the EM perspective suggests that modern societies should be able to surmount the ongoing ecological crisis without departing from the path of modernity.

The EM perspective contrasts with the more critical stance of the PE perspective on modernization and its consequences. PE theorists note that, while modern societies acknowledge environmental problems and take some actions to address them, the dictates of capitalism, as well as other growth-dependent modern economic systems (such as those in the former Soviet Union and China), provide a contradictory drive to continually expand production and consumption in order to increase profits. This fuels incessant and expanding resource exploitation, consequently resulting in environmental degradation (Cohen 2010; Foster et al. 2010; Schnaiberg 1980; Schor 2005). Political economists note that while technological advances often improve efficiency, they also increase profits, which are often reinvested to further expand production. This can paradoxically lead to rising resource consumption, even as efficiency improves (Foster et al. 2010). Polimeni et al. (2008) have noted that it is common for

efficiency improvements in a variety of production processes to lead to greater resource consumption due to their connection with expanding production. Thus, while the PE perspective recognizes that technology-driven improvements in efficiency can reduce consumption in the short-term *all else remaining equal*, it suggests that efficiency is often connected in various ways – directly and indirectly – to other factors that drive production growth and rising resource consumption. In light of the political-economic dynamics of production and consumption, it is possible for “green” technologies to produce environmental benefits once the impact of affluence is held constant, but show no substantial benefits if the consequences of their connection with rising production and consumption are taken into account.

Empirical evaluations of the proposed impacts of rising affluence and technological advances on ecological improvements have focused, largely, on how macro-level economic development impacts the environment (Jorgenson and Clark 2012; Rosa et al. 2004; York and Rosa 2012). The results from these and other studies have been mixed, and generally depend on the types of environmental impacts examined, the sector of the economy or society focused on (e.g., industrial, transportation, residential, etc.), the unit of analysis used, and the degree to which the role of international trade is taken into consideration (Dinda 2004; Pattison, Habans, and Clement 2014; Stern 2004; York, Rosa, and Dietz 2003a, 2003b). While several studies report findings supportive of declines in some types of impacts at high levels of affluence (e.g., Goklany 2009), others failed to support it, finding that more affluent nations continue to generate greater environmental impacts, particularly CO₂ emissions and overall resource consumption and waste production (Harte 2007; Jorgenson 2009; York et al. 2003a, 2003b).

A key link between households (within nations) and these macro level perspectives and analyses comes from theories about the effects of rising affluence on individual level

environmental values. In particular, Ronald Inglehart's (1977, 1990, 1997) thesis of postmaterialist values suggests that as societies modernize and become more affluent, people's values shift so that they are increasingly concerned with non-material aspects of life, such as aesthetics and ethics. Inglehart's theory is closely connected with the logic of Maslow's (1943) hierarchy of needs, which posits that people only begin to appreciate aesthetic and ethical concerns once their basic needs (e.g., food, shelter) are met. Inglehart's theory combines Maslow's ideas with the broad features of modernization theory to posit that economic development will increasingly shift societal values away from strictly materialist ones and toward postmaterialist ones, of which, some argue, environmental values are examples (Inglehart 1995; Kidd and Lee 1997; see Dunlap and York 2008 for a review of this extensive literature and for examples of scholars who argue environmental values are materialist, not postmaterialist). Thus, the postmaterialist values thesis, at least as developed by its key proponent, Inglehart (1995), suggests that more affluent individuals, as well as people in more affluent nations, will exhibit greater concern for the environment than the less affluent, and that these values will lead more affluent people to behave in a more environmentally-friendly manner. The postmaterialist values thesis is closely linked with EM in that it sees the forces of modernity, particularly the rise of affluence stemming from economic growth, as spurring environmental reform, not only at the level of producers, but also among members of the general public. Indeed, EM theorists have come to focus on changes in consumption and lifestyle among citizens of modern societies in response to environmental concerns (Murphy and Gouldson 2009; Spaargaren 2003; Spaargaren and Oosterveer 2010; Spaargaren and van Vliet 2000). Therefore, when applied at the level of the household, the EM theory suggests that more affluent households will be more likely than others to take actions to limit their impacts on the environment.

These views contrast with those of PE, which sees consumer behavior as principally driven by the forces of production, and expects that rising affluence will only lead to more consumption and, therefore, more environmental impacts. Based on the contrasting views of these theories, a legitimate question to ask is: what will be the nature of the impacts of household level affluence on CO₂ emissions? Will they be linear or non-linear? An inverted U-shaped relationship between household level affluence (income) and CO₂ emissions will suggest some support for the EM theory (and by extension, the environmental Kuznets Curve), while a consistently positive relationship will suggest support for the PE perspective.

Since affluence and technology are closely intertwined, theories of the connections between affluence and the environment are closely connected with theories about the effects of technology on the environment. What are the empirical findings about the relationship between technology and environmental degradation? A good number of studies examining this relationship, following the I=PAT logic, treat technology as part of the residual, once the effects of several empirically measured indicators are accounted for (see Dietz and Rosa 1994, 1997; Rosa et al. 2004). Studies that directly analyze the effects of technology tend to measure it as impact per unit of GDP ($T=I/GDP$), consistent with I=PAT (see Goklany 2009). However, several studies have indirectly examined the environmental impacts of technological innovation by analyzing energy consumption. These studies have reported mixed or moderate relationships (Adua 2010; Adua and Sharp 2011; Binswanger 2001; Lutzenhiser and Hackett 1993). We further this work by analyzing the relationship between several energy efficiency technologies and CO₂ emissions, using a recent large-scale nationally representative sample. Any negative relationships between these technologies and CO₂ emissions, even if moderate, will suggest some support for the EM perspective. The EM theory regards *structural innovations* as the ones

capable of producing large-scale ecological benefits and, therefore, it anticipates only moderate effects from the technology indicators addressed in this study. On the other hand, a positive relationship will suggest that efficient technologies spur consumption and fit more with PE. However, a key consideration is the extent to which efficient technologies are connected with affluence, a point we will address in the interpretation of our findings.

The HE perspective, which has been a long-standing interdisciplinary social theory about the environment, is in many respects broader than PE and EM in that it is not just concerned with the particular features of modern economies, but also considers the ecological factors that influence all types of societies. The perspective highlights the dynamic relationships that exist between human populations and their natural, social and cultural environments (Catton 1980; Catton and Dunlap 1980; Duncan 1964; Harrison 1993). Human ecology researchers consider humans as part of the ecosystem. Thus, despite their ingenuity and culture, humans are not exempt from ecological constraints (Catton and Dunlap 1980; Dunlap 1980, 1982). The HE perspective recognizes that population characteristics (size, rate of growth, density, age structure) and affluence are important drivers of anthropogenic environmental impacts (Catton 1980; Dietz and Rosa 1994; Duncan 1964; Rosa and Dietz 1998; York et al. 2003a, 2003b; York and Rosa 2012). The perspective further contends that biophysical characteristics (e.g. climatic conditions) mediate anthropogenic environmental impacts (Dietz and Rosa 1994; Harrison 1993).

There is a large volume of empirical literature on the impacts of population characteristics on environmental change, most of which are in the HE tradition (Dietz and Rosa 1994, 1997; Harte 2007; Jorgenson 2009; Rosa et al. 2004; York and Rosa 2012; York et al. 2003a). These studies generally find positive relationships between population size and/or growth rate and environmental degradation. York and Rosa (2012) also discovered that

population can be disaggregated into the number of households and average household size and these two aspects of population have somewhat different, but still positive, effects on national air pollution emissions. Most studies in this area are based on cross-national analysis. A key question we address here is: Will the environmental impacts of household level population characteristics mirror the cross-national patterns?

While the role of biophysical characteristics in influencing anthropogenic environmental impacts has been noted in the HE perspective, only a few empirical studies have actually considered it. Consistent with the perspective, York et al. (2003a, 2003b, 2003c) found that tropical nations emit less CO₂ than non-tropical nations, holding constant the effects of other variables. The question is: Will biophysical characteristics influence anthropogenic environmental impacts at the household level? We anticipate this will be the case based on the logic of the HE perspective, where human behavior is contingent upon the environment in which it occurs.

We apply the HE perspective in a novel fashion to examine the impacts of household-level demographic characteristics (household size, presence in a household of seniors and/or minors, and whether a household member is always at home) and affluence on residential CO₂ emissions. Following the HE perspective and past literature (O'Neill and Chen 2002; York and Rosa 2012), we expect all, but the two age-related indicators, to be positively related to CO₂ emissions. We expect age to influence household CO₂ emissions due to potential differences in age-related dependency ratio. Age may imply more or less disposable income/resources, which can in turn affect energy consumption (CO₂ emissions) in one direction or the other. Generally, working age people consume the most resources, so having minors or seniors in the home, once

the total number of people in the household is controlled for, should be negatively associated with emissions.

In line with the HE perspective, we also analyze how several biophysical characteristics influence residential CO₂ emission. We expect these variables to mediate households' use of energy and, therefore, their CO₂ emissions. We expect that households in contexts where more energy use provides particular benefits, such as cold climates where heating is advantageous or hot climates where cooling is advantageous, will consume more energy and, therefore, have higher emissions.

DATA AND MEASURES

The data for this study come from the 2009 Residential Energy Consumption Survey, a large cross-sectional survey (N=12083) conducted by the Energy Information Administration (EIA) of the U.S. Department of Energy.³ This survey is part of several others conducted by EIA since 1978, which are collectively referred to as the Residential Energy Consumption Survey (RECS). The RECS are national area-probability sample surveys that collect environment and energy-related data from occupied housing units in the United States. The surveys, conducted every four years, are authorized by the Federal Energy Administration Act of 1974 (PL 93-275) as amended, and the Energy Policy Act of 1992 (EIA 2013). The 2009 iteration is the most recent (publicly available) version of the survey.

In the 2009 iteration of the survey, trained professional interviewers were used to administer standardized survey instruments to households and rental agents. The household interviews, which averaged 51 minutes, “were conducted with a household member knowledgeable about energy use in the home” (EIA 2013: 7). The interview was conducted in

³ While the gold standard for evaluating these theories we are drawing on entails using longitudinal data (see Jorgenson and Clark 2012), good cross-sectional datasets, such as the one we employ in this study, can provide illuminating insights.

person, to allow interviewers to physically measure the dimensions of the housing units visited (EIA 2013). Additional interviews were held with rental agents for sampled housing units where some or all energy costs were included in the rent. A total of 829 rental agents were contacted, with 583 (70%) responding. With respondents' permission, their energy suppliers were also surveyed for information on actual monthly energy consumption and expenditures. These figures were annualized to provide annual energy consumption and expenditure estimates (EIA 2013). The surveys overall response rate was 79%. Refer to the 2009 RECS technical documentation for more information on the survey (EIA 2013).

Analyzing the 2009 iteration of the RECS will provide an important and less-dated snapshot of the extent to which human factors are continuing to drive atmospheric concentration of GHGs (or climate change). It also contains variables of interest to us not available in the previous iterations of the survey.

Measures

The dependent variable we consider is residential CO₂ emissions from the consumption of energy (electricity and natural gas). For our independent variables, we use several indicators related to the theories previously discussed in this paper. These variables include ones that tap technological innovations, affluence, household level demographic characteristics, biophysical characteristics of respondents' places of residence, and other statistical controls. The EIA employed several strategies to insure the accuracy of these and other variables contained in the data. As needed, interviewers relied on *help screens* within the survey instrument to offer respondents with standardized definitions or examples to help them provide accurate responses. Also, checks and edits were built into the Blaise interviewing software used to reduce missing or invalid responses (EIA 2013). Further, show cards providing response options were provided to

respondents where necessary. Additionally, the EIA took care to address the issues of item and unit nonresponse (that is, missing data and outright nonparticipation respectively). Item nonresponse occurs when respondents fail to provide answers to some survey questions. According to EIA, hot-deck imputation methodology was used to fill in values for item nonresponses. The EIA included in the data set a sampling weight that was appropriately adjusted to account for unit nonresponse (outright nonparticipation) (EIA 2013). In our regression analysis, we employed this weighting variable (weighted regression). Descriptive statistics for all variables analyzed in this paper are reported in Table 1.

Table 1: Descriptive Statistics of Dependent and Independent Variables

	Mean/ Proportion	Linearized Std. Error ^a	Range	
			Min	Max
<i>Dependent Variable: CO₂ Emissions</i>				
CO ₂ emissions from residential electricity use (metric tons) ^b	6.812	0.047	0.01	88.69
CO ₂ emissions from residential natural gas use (metric				

tons) ^b	2.193	0.028	0	24.49
Total CO ₂ emissions from residential electricity and natural gas use (metric tons) ^b	8.875	0.052	0.01	88.69
Technological Innovations				
Adequacy of home insulation ^c :				
Well insulated	0.358	0.006	0	1
Adequately insulated	0.445	0.006	0	1
Poorly insulated	0.191	0.005	0	1
No insulation	0.005	0.001	0	1
Programmable thermostat in central heater? (Yes=1)	0.367	0.005	0	1
Programmable thermostat in central heater? (Not Applicable=1)	0.156	0.004	0	1
Type of glass (Less efficient to more efficient) ^c				
Single pane	0.394	0.006	0	1
Double pane	0.592	0.006	0	1
Triple pane	0.014	0.001	0	1
Ratio of efficient to inefficient bulbs ^b	0.572	0.006	0	1
Hot water heater insulated? (Yes=1) ^c	0.120	0.004	0	1
Caulked/weather stripped home? (Yes=1)	0.359	0.005	0	1
Energy Star-rated dish washer? (Yes=1)	0.239	0.004	0	1
Energy Star-rated dish washer? (Not Applicable=1)	0.628	0.005	0	1
Affluence:				
Household income ^b	54347.00	396.288	1250	129999.50
Home size (Square Feet) ^b	2108.711	15.133	100	16122
Home ownership (Own=1) ^c	0.673	0.005	0	1
Household Demographics				
Household size ^b	2.572	0.016	1	14
Someone always at home? (Yes=1) ^c	0.574	0.005	0	1
Children under 9 years of age in household? (Yes=1) ^c	0.220	0.004	0	1
Adults 65 years or more in household? (Yes=1) ^c	0.111	0.003	0	1
Biophysical Characteristics				
Heating degree days (30-years average) ^b	4191.91	20.48	0	13346
Cooling degree days (30-years average) ^b	1416.41	9.30	0	5357
Home covered by large trees? (Yes=1)	0.442	0.005	0	1
Control Variables:				
Education ^{b,e}	3.326	0.017	0	8
Female ^c	0.531	0.005	0	1
White ^c	0.799	0.004	0	1
Age of home ^b	37.904	0.265	0	89

^aLinearization (Taylor) corrects for the design characteristics of the sample (area probability sampling). The survey was not based on a simple random sample. Computing these descriptive statistics involved use of the sampling weights provided.

^bContinuous variables

^cOrdinal or dichotomous variables

^dThese "Not Applicable" categories are included in our regression analyses as dummy variables so as not to lose too many observations. While we are not reporting them in our regression Tables (Table 2-4), we thought it prudent to report their descriptive statistics here.

^eThe values for education ranged from 0 (no education) to 8 (doctoral degree), which explains why the mean appears to be low.

Dependent Variable: CO₂ Emissions

The dependent variable we analyze in this study is residential CO₂ emissions. CO₂ is regarded as the most important of the long-lived greenhouse gases trapping excess heat in the earth's atmosphere. To measure *residential CO₂ emissions*, we converted households' actual annualized electricity (in KWH) and natural gas (in Cubic Feet) consumption to their equivalent CO₂ emissions in metric tons (see Lutzenhiser and Hackett 1993 for a similar approach).⁴ As noted earlier, respondents' electricity and natural gas consumption figures were obtained from their utility providers. We relied upon conversion schemas suggested by the EIA⁵ and the Environmental Protection Agency (EPA)⁶. We acknowledge that using a national conversion schema masks some regional variability in CO₂ emissions. This notwithstanding, adequate variability remains within the variables to sustain our analyses. By converting households' electricity and natural gas consumption into equivalent CO₂ emissions, we spare the reader the burden of trying to determine what a unit or percent increase (or decrease) in energy consumption implies for CO₂ emissions.

Energy Efficiency Technology

Improving residential energy efficiency is regarded as an important techno-centric strategy to minimize households' environmental impacts. This study assesses the extent to which residential energy efficiency innovations help to mitigate households' CO₂ emissions. The first indicator of energy efficiency considered in this study is *adequacy of home insulation*. To

⁴ In 2009, in the United States 1 MWH of electricity was on average equivalent to 1301 lbs of CO₂. Thus, we obtained equivalent CO₂ emissions from electricity consumption by multiplying electricity consumption in megawatt hours (MWH) by 1301. We converted this to metric tons (2204 lbs of CO₂=1 metric ton of CO₂). We obtained households' equivalent CO₂ emissions from natural gas by multiplying natural gas consumption in cubic feet by 0.0544 (1 cubic feet = 0.0544 Kg of CO₂). Similarly, we converted this emissions figures to metric tons (1000 Kg of CO₂= 1 metric ton of CO₂).

⁵ Form EIA-1605 (2007). *Voluntary Reporting of Greenhouse Gases*. (Appendix F: Electricity Emission Factors). Retrieved on April 4, 2013 from: http://www.eia.gov/survey/form/eia_1605/emission_factors.html.

⁶ See the EPA's emissions calculations and references at: <http://www.co2benchmark.com/EPA-calculations-and-conversions> (Retrieved on April 4, 2013).

measure this indicator, respondents were asked: “Overall, would you say that this home/apartment is well insulated, adequately insulated, or poorly insulated.” The response options included: 1 (well insulated), 2 (adequately insulated), 3 (poorly insulated), and 4 (no insulation) (see Adua 2010). The fourth response option was volunteered by the respondents. The second indicator is *type of glass* in the windows of respondents’ home, with the response options: single pane; double pane; and triple pane. For our analyses, we recoded this indicator into dummy variables. Whether or not the *thermostat in a home’s central heating unit is programmable* is the third indicator of energy efficiency technology we use. The response options were: no, yes, and not applicable. Although not of any particular interest to us, we maintained the “not applicable” category as a dummy-coded variable (0/1, where 1 indicates not applicable) in our regression analysis so as to not lose cases. We maintain this strategy with other variables with similar “not applicable” categories. The fourth indicator is the use of *energy efficient bulbs*. Households were asked about the number of energy efficient bulbs (fluorescent and compact fluorescent bulbs) used 1-4 hours per day. These bulbs are more energy-efficient than the common incandescent bulbs. For our analysis, we computed the ratio of number of energy-efficient bulbs used 1-4 hours per day to all bulbs used in the home for the same number of hours daily. The fifth technology-related variable is whether or not a home’s *hot water heater is insulated* (that is, covered with heat-conserving blankets). The response options for this indicator were no, yes, and not applicable, which we dummy-coded. The sixth indicator of energy efficiency is *caulking or weather-stripping*. Respondents were asked if they had caulked or weather-stripped their homes. The response options were no, yes, and not applicable. These response options were also dummy-coded for our analyses. The final indicator is whether a respondent’s main dishwasher is Energy Star-rated. Energy Star rating is an industry standard for

the efficiency of electronic gadgets and devices. As with other variables, the response options were no (0), yes (1), and not applicable. As noted above, several mechanisms were built into the data collection process to insure the validity of these measures.

Based on the common sense notion that efficiency improvement reduces energy use and propositions associated with EM theory, we would expect all the above-described indicators of technological innovation to be negatively related to CO₂ emissions, albeit, modestly. From the PE perspective, however, the presence of these efficiency technologies in a housing unit (or home) may not help reduce energy consumption.

Affluence

The EM, PE and HE perspectives regard affluence as an important determinant of anthropogenic environmental impacts. We analyze several indicators of affluence in this study. The first indicator is *household income*. It is measured by the combined pre-tax income of all household members from all sources (wages, interest, alimony, social security, and so forth) for the 12 months preceding the survey. The response options were recorded as income ranges. For our analyses, we recoded these options to their category midpoints (see Adua 2010). Household income is analogous to GDP per capita, often used as a measure of affluence in cross-national analysis of anthropogenic environmental impacts. The EM perspective suggests income may have an inverted U-shaped relationship with CO₂ emission at the national level, and the postmaterialist values thesis, which is closely allied with EM, suggests that we should expect this type of relationship at the individual or household level as well: CO₂ emissions should rise as income goes up until a turning point is reached, after which they should decline with further increases in income. However, since level of affluence is connected with capacity for consumption, it is expected under PE and HE theories to be positively related to CO₂ emissions.

A visible symbol of affluence in many societies is housing, and for all intents and purposes, home ownership and size are two pre-eminent housing-related markers of social and economic standing. We use two variables, *home ownership* and *home size*, which are expected to be positively correlated to CO₂ emissions, as additional measures of affluence. *Home ownership* is measured by whether or not a respondent owns his/her current residence (Own=1; Otherwise=0). *Home size* is the total square footage of the respondent's housing unit. We acknowledge that market price of a person's residence is an important aspect of affluence that we do not measure, and it is related not only to home size, but location, and other factors, but we only have data on home size and ownership status. As with income, we will seek to find out if home size has a non-linear relationship with CO₂ emissions.

Household Demographics

The HE perspective regards population and its associated characteristics as important drivers of anthropogenic environmental impacts. Studies examining this relationship have largely focused on cross-national analyses, relying on national level aggregate population characteristics. We further consider this important relationship, but focus our efforts on micro-level (household level) population characteristics. The first household-level demographic feature we consider is household size. *Household size*, which is expected to be positively related to residential CO₂ emissions, is measured by number of household members. This variable is analogous to population size in cross-national analyses. The second variable we consider is whether or not there are any individuals aged 65 or older (*seniors*) in a household (Yes=1; No=0). We also consider the presence in the household of children under 9 years of age (*minors*). As noted earlier, we expect age to influence household CO₂ emissions due to potential differences in the age-related dependency ratio, which may imply more or less disposable income/resources.

Another pertinent household-level demographic variable we analyze is whether or not someone is always at home (Yes=1; No=0). The presence of someone at home always should result in greater use of energy, *ceteris paribus*, which in turn directly impacts residential CO₂ emissions.

Biophysical Characteristics

Based on suggestions from the HE perspective that anthropogenic environmental impacts are mediated by biophysical characteristics, we include in our analysis indicators that tap this factor: cooling and heating degree days and shading of a home. *Cooling degree days* is measured by the number of degrees per day that average temperature exceeds the reference temperature of 65°F; a base temperature level adopted by the Department of Energy. *Heating degree days*, on the other hand, is measured by the number of degrees per day that the average temperature is lower than the reference temperature of 65°F. For our analyses, we use 30-year averages of cooling and heating degree days. Both variables are expected to be positively related to residential CO₂ emissions. We also measure biophysical characteristics by whether or not a *home is shaded by large trees*, with the response options of yes (1) or no (0), to tap a home's micro-climate. All things remaining the same, homes shielded by large trees should emit less CO₂ from energy consumption.

Statistical Controls

We control for the effects of several variables which are not directly related to the theories assessed in this paper, but are known to influence residential energy consumption. These include: education (highest level of education completed by household head [0=no education and 8=doctoral degree]); gender of household head (female=1); race of household head (non-Hispanic Whites=1); and age of home in years (see Adua 2010; Lutzenhiser and Hackett 1993; O'Neill and Chen 2002).

RESULTS

In this section, we present several ordinary least squares (OLS) regression models of the relationships between residential energy efficiency innovations, affluence, household demographics and biophysical characteristics, on the one hand, and CO₂ emissions from residential energy consumption, on the other. We present models for households CO₂ emissions from electricity consumption, natural gas consumption, and combined electricity and natural gas consumption (see Tables 2-4).

Our model specification was driven by theory. We use variables that tap the EM, PE and HE perspectives. Initial unweighted OLS regression analyses of our saturated models (Models 6 in Table 2-4) suggested the variance of the errors of prediction were heteroskedastic, that is, they were not constant for all values of the independent variables. Given that heteroskedasticity only biases standard errors, we estimated our models employing probability weighted regression analyses with robust standard errors. Regression with robust standard errors relaxes the homoscedasticity assumption in OLS (i.e. $Var(u_i) = \sigma_u^2$ for all i). As noted earlier, the weighting variable used here also addressed the issue of survey nonparticipation. In further diagnostics, we tested for interactions between education and several of our energy efficiency technology and affluence indicators. We reasoned that level of education, which raises general awareness, might influence how people interact with and utilize technology, as well as how they employ resources at their disposal. Our tests revealed only one interaction effect: the interaction of education (household head's educational level) and owning a central heating system equipped with a programmable thermostat. This effect pertains only to one model, the natural gas CO₂ model (i.e. Table 3). Informed by the EM theory, the environmental Kuznets curve thesis, and the postmaterialist values thesis, we also tested for non-linear relationships between income and

CO₂ emissions and home square footage and CO₂ emissions: only income is shown to have non-linear relationships with CO₂ emissions. Finally, variance inflation factors, quantified measures of multicollinearity, revealed no high collinearity in any of our models.

Electricity-Related CO₂:

The impacts of energy efficiency technologies, affluence, household demographics and biophysical characteristics on household CO₂ emissions from residential electricity consumption are shown in Table 2. The saturated model (Model 6) explains 36% of the variance of electricity-related CO₂ emissions, which is reasonably good for a cross-sectional survey. Without controlling for the effects of any other predictors considered in this study, we find that only one indicator of energy efficiency technology (insulated hot water heater) is significantly associated with electricity-related CO₂ emissions in the expected direction (Model 1). The rest are either not significant or are, in fact, positively related to electricity-related CO₂ emissions. Residing in a well-insulated home, having a programmable thermostat-equipped water heater, having caulked or weather stripped one's home, and having an Energy Star-rated dishwasher are all positively related to CO₂ emissions from electricity use. However, once the indicators of affluence are included (Model 5), we find several of the indicators of technology become significantly related to CO₂ emissions from electricity consumption in the expected direction (negative). Also, only two of the four indicators revealed initially to be positively related to electricity consumption CO₂ emissions in Model 1 maintain this direction of relationship. While these relationships seem to confirm some claims of the EM theory, the fact that they only arise when indicators of affluence are included in the model provides support for the political-economic argument that the environmental benefits of technological innovation may be conditional on its dynamic relationship with affluence. The PE perspective posits that the adoption of efficiency

technologies, which can in principle reduce environmental impacts, are generally connected with rising consumption, which escalates environmental impacts, countermanding gains from efficiency.

Without controlling for the effects of other variables, we find a pattern of relationship between affluence and electricity consumption CO₂ emissions that is consistent with our expectation and theory, that is, positive (Model 2). This is also generally true with respect to the patterns of relationships between household demographics and biophysical characteristics and electricity consumption CO₂ (Model 3 & 4). These findings are consistent with the PE and HE perspectives.

In Model 6 (Table 2), we report the partial effects of the sets of indicators included in our analyses. Holding constant the effects of other variables in the model, the analyses reveal modest relationships between five indicators of technological innovations and CO₂ emissions from electricity consumption. The results indicate that: homes that are well- or adequately insulated respectively emit 3% and 4% less electricity-related CO₂; homes with central heating units equipped with programmable thermostats emit 8% less electricity-related CO₂ than those with non-programmable thermostats; a unit change in the ratio of efficient to inefficient bulbs used in a home is associated with 0.06% lower electricity-related CO₂ emissions; and having an insulated hot water heater is associated with lower electricity-related CO₂ emissions. These findings are consistent with the EM perspective, which expects modest negative relationships between these kinds of technology and environmental degradation. Contrary to this theory and popular assumptions, however, we find that respondents reporting they caulked or weather-stripped their homes emit 8% more electricity-related CO₂. While this finding seems counterintuitive, it may simply be that respondents more likely to caulk or weather-strip their

homes start with housing units that are relatively less efficient. It may also suggest efficiency improvements are connected with other factors which increase consumption.

The data indicate that affluence is a significant driver of electricity-related CO₂ emissions: all our indicators of affluence are positively related to CO₂ emissions from electricity consumption (Model 6, Table 2). The analyses, for instance, reveal an escalating positive relationship between annual household income and electricity-related CO₂. Home size has a clear positive effect, with every 1% increase in home square footage generating a 0.22% increase in electricity-related CO₂ emissions (Model 6). Home ownership is also associated with 13% difference in CO₂ emissions from electricity consumption. These findings are consistent with views from the PE and HE perspectives, which expect affluence to be positively related to environmental degradation. The findings, however, contradict the EM perspective, which proposes a concave down (inverted U-Shaped) relationship between affluence and environmental stress, which would require the quadratic of income to be negative, when in fact it is positive. This suggests more affluent households may not be taking actions sufficient enough to reduce their environmental impacts, contrary to what would be expected from the EM, environmental Kuznets curve, and postmaterialist values perspectives.

In terms of the demographic variables, we find evidence supporting the HE perspective, which expects demographic pressures to drive environmental stress. The data reveal that electricity-related CO₂ emissions are positively related to household size (analogous to population size in cross-national analysis) and having a household member at home always. We also find that having minors (children under nine years old) and seniors (persons 65 years or older) in a household are respectively associated with 8% and 4% lower electricity-related CO₂ emissions. This is consistent with our earlier explanation that age-related dependency ratio may

imply more or less disposable income/resources, which can in turn affect energy consumption in one direction or the other. Also consistent with the HE perspective, the data do support the notion that biophysical characteristics influence anthropogenic environmental impacts: 1% differences in 30-years average heating and cooling degree days are respectively associated with 0.02% and 0.16% differences in electricity-related CO₂ emissions (Model 6). As will be discussed later, this finding raises an important climate or environmental policy question. Contrary to our expectation and a widely held assumption, we find that housing units shaded by large trees actually emit more electricity-related CO₂. One plausible explanation is that such housing units receive comparatively less sunlight, making their inhabitants significantly more likely to use artificial light during the day. This may also be related to aspects not captured by our model of the type and location of housing associated with having large trees. Another potential explanation of this unusual finding is that homes shaded by large trees are older and, therefore, less efficient. However, the wrinkle to this explanation is that our model partials out the impacts of home age.

Table 2: The Effects of Technological Innovations, Affluence, Household Demographics and Biophysical Characteristics on Log Residential CO₂ Emissions from Electricity Consumption, 2009

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	b (S.E.)	b (S.E.)	b (S.E.)	b (S.E.)	b (S.E.)	b (S.E.)
Technological Innovations						
Home well-insulated (Ref.=poorly/not insulated)	0.04 (0.02)*				-0.02 (0.02)	-0.03 (0.02)*
Home adequately insulated (Ref.= poorly/not insulated)	-0.00 (0.02)				-0.03 (0.02)*	-0.04 (0.01)**
Thermostat in central heater programmable? (Yes=1) ^a	0.04 (0.01)**				-0.06 (0.01)***	-0.08 (0.01)***
Type of glass in window: Double pane (Ref.=single pane)	0.01 (0.01)				-0.06 (0.01)***	-0.00 (0.01)
Type of glass in window: Triple pane (Ref.=single pane)	0.05 (0.05)				-0.11 (0.05)*	-0.02 (0.04)
Ratio of efficient to inefficient bulbs ^b	-0.01 (0.02)				-0.03 (0.02)	-0.06 (0.02)***
Insulated hot water heater? (Yes=1)	-0.04 (0.02)*				-0.04 (0.02)*	-0.03 (0.02)*
Caulked/weather stripped home? (Yes=1)	0.14 (0.01)***				0.04 (0.01)***	0.08 (0.01)***
Energy Star-rated dish washer? (Yes=1) ^a	0.14 (0.02)***				0.04 (0.02)*	0.03 (0.02)
Affluence:						
Annual household income ^b		0.05 (0.01)***			0.03 (0.01)**	0.02 (0.01)
Log Annual household income ²		0.02 (0.00)***			0.01 (0.00)**	0.01 (0.00)**
Home ownership (Own=1)		0.14 (0.01)***			0.16 (0.02)***	0.13 (0.02)***
Home size in square feet ^b		0.30 (0.01)***			0.28 (0.01)***	0.22 (0.01)***
Household Demographics:						
Household size ^b			0.42 (0.01)***			0.28 (0.01)***
Someone always at home? (Yes=1)			0.08 (0.01)***			0.06 (0.01)***
Children under 9 years of age in household? (Yes=1)			-0.14 (0.02)***			-0.08 (0.02)***
Adults 65 years or more in household? (Yes=1)			0.03 (0.02)			-0.04 (0.02)*
Biophysical Characteristics:						
Heating degree days (30-years average) ^b				0.04 (0.01)***		-0.02 (0.01)*
Cooling degree days (30-years average) ^b				0.20 (0.01)***		0.16 (0.01)***
Home shaded by large trees? (Yes=1)				0.08 (0.01)***		0.05 (0.01)***
Control Variables:						
Education of household head ^b						-0.04 (0.02)*
Gender of household head (Female=1)						0.01 (0.01)
Race of household head (White=1)						0.09 (0.01)***
Age of home ^b						-0.09 (0.01)***
Model Statistics:						
Intercept	1.88	-0.49	1.53	0.11	-0.13	-0.65***
R ²	0.09	0.22	0.16	0.07	0.22	0.37
N	9705	12083	12083	12047	9705	9540

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

^a Although not included in this table the “Not Applicable” categories of these variables were included in the regression analysis as dummy variables so as to not lose too many case. They are not germane to our interest.

^b Log-transformed (natural log). We logged these variables because of very large ranges in the values (see Table 1), which generated instability in model estimations. Logging these predictors as well as the dependent variable significantly improved model fit.

Natural Gas CO₂:

In Table 3, we report the relationships between our predictors and households' emission of CO₂ from natural gas consumption. The variables analyzed in the saturated model explain 22 percent of the variance in natural gas CO₂ emissions, a reasonable fit. Model 1, the technological innovation model, shows negative relationships between several indicators of technological innovations and natural gas-related CO₂ emissions. For instance, respondents reporting that their homes are well-insulated emit 17% less natural gas CO₂ than those reporting their homes are poorly or not insulated, and homes with insulated water heaters emit 9% less CO₂ from natural gas consumption. On the other hand, several indicators of energy efficiency technology are positively related to natural gas consumption CO₂ emissions. The inclusion of affluence in the model (Model 5) slightly moderates these relationships, further suggesting a dynamic relationship between affluence and technological innovations, albeit not as strong as the electricity-related CO₂ model (i.e. Table 2). Models 2, 3 & 4 do show statistically significant relationships between the indicators of affluence, household demographics and biophysical characteristics on the one hand and CO₂ emissions from natural gas consumption on the other. Although these models do not partial out the effects of other variables, they reveal relationships that are in the expected direction.

As reported in Model 6 (Table 3), we find three modest negative relationships between the indicators of energy efficiency technological innovations and natural gas CO₂ emissions. The data indicate that: respondents with well-insulated homes have 8% lower emissions; homes with insulated water heaters are associated with 6% lower natural gas CO₂ emissions; and respondents reporting they caulked or weather-stripped their homes emit 7% less CO₂ from natural gas consumption. These findings are consistent with the EM perspective, which expects technology

to positively benefit the environment, although the non-significant effects for most of the technology variables make the support for EM quite modest. Between Models 1 and 6, it is evident technology's impact diminished considerably, suggesting some of the often touted relationships between technology and environmental impacts are mediated by other variables. Consistent with our expectation, we find that the impact of having a programmable thermostat in a home's central heating unit is connected with level of education (Model 6). This makes sense as individuals with higher education may be more aware of human impacts on nature and how technology may be harnessed to limit these impacts.

As in the electricity analyses (see Table 2), the natural gas analyses show some noteworthy relationships between affluence and environmental impacts (Model 6, Table 3). We find, for instance, that a 1% increase in home size results in .26% increase in CO₂ emissions from natural gas consumption. Also, annual household income maintains an escalating positive relationship with natural gas-related CO₂ emissions (Model 6). Home ownership per se is unrelated to CO₂ from natural gas use (Model 6, Table 3). As noted earlier, these findings are supportive of views from the PE and HE perspective. Both of these perspectives expect affluence to positively drive environmental degradation.

Our analyses reveal only modest relationships between household demographics and CO₂ emissions from natural gas consumption. Of the four indicators analyzed, only two are found to influence natural gas CO₂ emission: a 1% difference in household size is associated with a 0.07% difference in natural gas-related CO₂ emissions, while having a household member at home always is associated with 7% higher CO₂ emissions from natural gas consumption. These relationships provide some support for the HE perspective. As explained earlier in this paper, the

HE perspective views population characteristics, including those at the household level, as important drivers of environmental degradation.

In terms of the impacts of biophysical characteristics of respondents' places of residence, we find results consistent with social theory and popular expectations (Model 6). The data show that a 1% difference in 30-years average heating degree days is associated with a .24% difference in natural gas CO₂ emissions. This makes sense as heating degree days is an indication of the extent to which households need to burn energy to raise home ambient air temperature to at least 65°F. The analyses also show that respondents living in homes shaded by large trees emit 6% less CO₂ from natural gas use. These findings corroborate claims under the HE perspective that biophysical characteristics (e.g. climatic conditions) do mediate anthropogenic environmental impacts.

Table 3: The Effects of Technological Innovations, Affluence, Household Demographics and Biophysical Characteristics on Log Residential CO₂ Emissions from Natural Gas Consumption, 2009

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	b (S.E.)	b (S.E.)	b (S.E.)	b (S.E.)	b (S.E.)	b (S.E.)
Technological Innovations						
Home well-insulated (Ref.=poorly/not insulated)	-0.17 (0.03)***				-0.20 (0.03)***	-0.08 (0.03)**
Home adequately insulated (Ref.= poorly/not insulated)	-0.07 (0.02)**				-0.08 (0.02)***	-0.02 (0.02)
Thermostat in central heater programmable? (Yes=1) ^a	0.30 (0.02)***				0.22 (0.02)***	0.09 (0.06)
Type of glass in window: Double pane (Ref.=single pane)	0.12 (0.02)***				0.06 (0.02)**	-0.03 (0.02)
Type of glass in window: Triple pane (Ref.=single pane)	0.18 (0.07)*				0.04 (0.07)	-0.06 (0.07)
Ratio of efficient to inefficient bulbs ^b	-0.07 (0.03)*				-0.07 (0.03)**	-0.04 (0.03)
Insulated hot water heater? (Yes=1)	-0.09 (0.03)***				-0.09 (0.02)***	-0.06 (0.02)**
Caulked/weather stripped home? (Yes=1)	0.06 (0.02)**				0.02 (0.02)	-0.07 (0.02)***
Energy Star-rated dish washer? (Yes=1) ^a	0.03 (0.03)				-0.03 (0.03)	-0.00 (0.03)
Affluence:						
Annual household income ^b		0.07 (0.01)***			0.07 (0.01)***	0.08 (0.02)***
Log Annual household income ²		0.03 (0.01)***			0.02 (0.01)***	0.02 (0.01)***
Home ownership (Own=1)		-0.10 (0.02)***			-0.13 (0.03)***	-0.05 (0.02)***
Home size in square feet ^b		0.34 (0.02)***			0.31 (0.02)***	0.26 (0.02)***
Household Demographics						
Household size ^b			0.21 (0.02)***			0.07 (0.02)***
Someone always at home? (Yes=1)			0.06 (0.02)***			0.07 (0.02)**
Children under 9 years of age in household? (Yes=1)			-0.07 (0.03)**			-0.04 (0.02)
Adults 65 years or more in household? (Yes=1)			0.04 (0.03)			0.01 (0.03)
Biophysical Characteristics						
Heating degree days (30-years average) ^b				0.28 (0.01)***		0.24 (0.01)***
Cooling degree days (30-years average) ^b				-0.01 (0.01)		-0.02 (0.01)
Home shaded by large trees? (Yes=1)				0.03 (0.02)		-0.06 (0.02)**
Other Interactions:						
Education*programmable thermostat use						0.11 (0.04)**
Control Variables						
Education of household head ^b						-0.00 (0.03)
Gender of household head (Female=1)						0.04 (0.02)*
Race of household head (White=1)						-0.13 (0.02)***
Age of home ^b						0.20 (0.01)***
Model Statistics:						
Intercept	0.77	-1.61	0.66	-1.38	-1.41	-3.53***
R ²	0.07	0.09	0.02	0.09	0.13	0.23
N	9705	12083	12083	12047	9705	9540

Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

^a Although not included in this table the “Not Applicable” categories of these variables were included in the regression analysis so as to not lose too many case. They are not germane to our interest.

^b Log-transformed (natural log). We logged these variables because of very large ranges in the values (see Table 1), which generated instability in model estimations. Logging these predictors as well as the dependent variable significantly improved model fit.

Combined Electricity and Natural Gas CO₂:

In Table 4, we report the relationship between the independent variables considered in this study and households' CO₂ emissions from the consumption of both electricity and natural gas (hereinafter referred to as total CO₂). The full model, Model 6, explains about 42% of the variance in total CO₂ emissions, providing a reasonably good fit between our model and the data.

When the effects of other sets of variables considered in this study are not held constant, the data reveal quite mixed relationships between technology and total CO₂ emissions (Model 1, Table 4). While homes that are well- or adequately insulated and homes equipped with insulated hot water heaters are associated with lower total CO₂ emissions, those that are caulked/weather-stripped, furnished with central heating units equipped with programmable thermostats (as opposed to ones not equipped with programmable thermostats), equipped with double and triple pane glass windows (as opposed to single pane), or are furnished with Energy Star-rated dishwashers are associated with higher total CO₂ emissions. However, once the indicators of affluence are added to the model, these counter-intuitive relationships essentially disappear: all but only two of the several indicators of energy efficiency technological innovations now show expected negative relationships with total CO₂ emissions (see Model 5). These relationships remain essentially stable even when the remaining sets of independent variables are included in the model (Model 6). This finding provides the strongest indication yet of a potential dynamic relationship between the indicators of affluence and technological innovation as they relate to environmental impacts. It supports political economists' suggestion that "green" technologies have only limited potential to curb environmental impacts, and their connection with other factors that spur consumption needs to be recognized.

In Models 2, 3, and 4, we report the impacts of affluence, household demographics and biophysical characteristics on total CO₂ emissions respectively when the effects of other independent variables are not held constant. These initial models reveal results that are consistent with our expectations and theory, and they remain consistent in Model 6.

Net the effects of the other sets of independent variables, several indicators of technological innovations are revealed to be negatively related to total CO₂ emissions (Model 6). The results indicate that: well- and adequately insulated homes respectively emit 6% and 4% less CO₂ than those with no insulation; a unit increase in the ratio of efficient to inefficient bulbs generates 0.05% reduction in total CO₂ emissions; and homes with insulated hot water heaters emit 6% less total CO₂. We note, again, that these findings are consistent with the EM perspective. However, contrary to the expectation of the EM theory and consistent with the PE perspective and our findings in the saturated model in Table 4, we find a positive relationship between caulking or weather-stripping a home and total CO₂ emissions.

Consistent with both the PE and HE perspectives, all our indicators of affluence are positively related to total CO₂ emissions. Home size influences emission, with every 1% increase in home square footage resulting in .27% increase in total CO₂ emissions (Model 6). Annual household income continues to maintain an escalating positive relationship with total CO₂ emissions, contradicting expectations under the EM perspective, and fully providing support for expectations from the PE perspective. Home owners, on the average emit 11% more CO₂ from the use of electricity and natural gas than non-home owners.

In terms of household demographic characteristics, household size and having a member at home always are both positively related to total CO₂ emissions (Model 6). These findings, as

in the previous models, are consistent with the HE perspective. The data reveal that households with minors (child or children under nine years) emit slightly lower total CO₂.

The analyses reveal significant relationships between all indicators of biophysical characteristics and total CO₂. As shown in Table 4 (Model 6), a 1% increase in 30-years average heating degree days results in .07% increase in total CO₂ emissions. Also, a 1% difference in 30-years average cooling degree days is associated with .12% difference in total CO₂ emissions. Similar to the results in our electricity CO₂ model, we find, quite strangely, that housing units shaded by large trees are associated with slightly higher total CO₂ emissions. We offered an explanation of this pattern of relationship above, but once again note that it is a peculiar finding.

Table 4: The Effects of Technological Innovations, Affluence, Household Demographics and Biophysical Characteristics on Log Total^a Residential CO₂ Emissions from Combined Electricity and Natural Gas Consumption, 2009

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	b (S.E.)	b (S.E.)	b (S.E.)	b (S.E.)	b (S.E.)	b (S.E.)
Technological Innovations:						
Home well-insulated (Ref.=poorly/not insulated)	-0.04 (0.02)**				-0.10 (0.01)***	-0.06 (0.01)***
Home adequately insulated (Ref.= poorly/not insulated)	-0.03 (0.01)*				-0.06 (0.01)***	-0.04 (0.01)***
Thermostat in central heater programmable? (Yes=1)	0.12 (0.01)***				0.01 (0.01)	-0.00 (0.01)
Type of glass in window: Double pane (Ref.=single pane)	0.06 (0.01)***				-0.02 (0.01)*	-0.01 (0.01)
Type of glass in window: Triple pane (Ref.=single pane)	0.09 (0.04)*				-0.08 (0.03)*	-0.05 (0.03)
Ratio of efficient to inefficient bulbs ^b	-0.02 (0.02)				-0.04 (0.02)*	-0.05 (0.01)***
Insulated hot water heater? (Yes=1)	-0.08 (0.02)***				-0.08 (0.01)***	-0.06 (0.01)***
Caulked/weather stripped home? (Yes=1)	0.14 (0.01)***				0.04 (0.01)***	0.04 (0.01)***
Energy Star-rated dish washer? (Yes=1)	0.13 (0.02)***				0.02 (0.02)	0.02 (0.01)
Affluence:						
Annual household income (logged)		0.05 (0.01)***			0.04 (0.01)***	0.03 (0.01)***
Annual household income ²		0.02 (0.00)***			0.02 (0.00)***	0.02 (0.00)***
Home ownership (Own=1)		0.09 (0.01)***			0.10 (0.02)***	0.11 (0.01)***
Home size square feet (logged)		0.37 (0.01)***			0.34 (0.01)***	0.27 (0.01)***
Household Demographics:						
Household size ^b			0.42 (0.01)***			0.26 (0.01)***
Someone always at home? (Yes=1)			0.10 (0.01)***			0.08 (0.01)***
Children under 9 years of age in household? (Yes=1)			-0.15 (0.01)***			-0.08 (0.01)***
Adults 65 years or more in household? (Yes=1)			0.04 (0.02)*			-0.03 (0.01)
Biophysical Characteristics:						
Heating degree days (30-years average) ^b				0.15 (0.01)***		0.07 (0.01)***
Cooling degree days (30-years average) ^b				0.16 (0.01)***		0.12 (0.01)***
Home shaded by large trees? (Yes=1)				0.07 (0.01)***		0.02 (0.01)*
Control Variables:						
Education of household head ^b						-0.02 (0.01)
Gender of household head (Female=1)						0.02 (0.01)
Race of household head (White=1)						0.03 (0.01)**
Age of home ^b						0.00 (0.01)
Model Statistics:						
Intercept	2.15	-0.67	1.81	-0.15	-0.31	-1.49
R ²	0.15	0.34	0.20	0.05	0.36	0.46
N	9705	12083	12083	12047	9705	9540

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

^a Although not included in this table the “Not Applicable” categories of these variables were included in the regression analysis so as to not lose too many case. They are not germane to our interest.

^b Logtransformed (natural log). We logged these variables because of very large ranges in the values (see Table 1), which generated instability in model estimations. Logging these predictors as well as the dependent variable significantly improved model fit.

SUMMARY OF FINDINGS IN RELATION TO THE ECOLOGICAL MODERNIZATION (EM), POLITICAL ECONOMY (PE), AND HUMAN ECOLOGY PERSPECTIVES (HE)

In Table 5, we summarize our overall findings in relations to the theories evaluated: the EM, PE, and HE perspectives. The table provides information on the direction of the relationship between each of the primary independent variables and our three measures of CO₂ emissions (positive or negative), based on the most saturated models (Model 6 for each dependent variable). It also provides information on the theory (or theories) supported by each statistically significant finding, along with clarifying remarks. Table 5 shows that each of the theories receives some support from the data, although the evidence, overall, is somewhat more supportive of the PE and HE perspectives, especially when considering the results for total CO₂ emissions. This table, of course, does not capture some of the subtleties of our findings. Importantly, PE does not deny the possibility of efficiency technologies helping conserve resources, but rather it argues that efficiency technologies may spur resource use through their connection with affluence and other factors. The fact that several technology variables are positively associated with CO₂ emissions when affluence is not controlled for (Models 1), and some of these associations only become negative and/or non-significant when affluence and other factors are controlled for (Models 5 and 6) is consistent with PE. It shows households with efficiency technologies often have higher emissions than other households, but this is likely due to the fact that they are more affluent than other households, not because the technologies themselves directly lead to higher emissions. Therefore, when all models are considered, PE receives more support, and EM less support, than the summary table may suggest.

Table 5: Summary of Relative Support for EM, PE, and HE Perspectives

Variable	Direction of Effect			Theory Supported			Remarks/Comments
	Electricity CO ₂	Natural Gas CO ₂	Total CO ₂	EM	PE	HE	
Technological Innovations:							
Home insulation quality	-	-	-	√ √ √			(-) EM supported; (+) PE supported
Thermostat in central heater programmable? (Yes=1)	-	NS	NS	√			(-) EM supported; (+) PE supported
Multi-pane glass in window	NS	NS	NS				(-) EM supported; (+) PE supported
Ratio of efficient to inefficient bulbs	-	NS	-	√ √			(-) EM supported; (+) PE supported
Insulated hot water heater? (Yes=1)	-	-	-	√ √ √			(-) EM supported; (+) PE supported
Caulked/weather stripped home? (Yes=1)	+	-	+	√	√ √		(-) EM supported; (+) PE supported
Energy Star-rated dish washer? (Yes=1)	NS	NS	NS				(-) EM supported; (+) PE supported
Affluence:							
Annual household income	+	+	+		√ √ √	√ √ √	(-)* EM supported; (+) PE, HE supported
Home ownership (Own=1)	+	NS	+		√ √	√ √	(-) EM supported; (+) PE, HE supported
Home size square feet	+	+	+		√ √ √	√ √ √	(-) EM supported; (+) PE, HE supported
Household Demographics:							
Household size	+	+	+			√ √ √	(+) HE supported
Someone always at home? (Yes=1)	+	+	+			√ √ √	(+) HE supported
Children under 9 years of age in household? (Yes=1)	-	NS	-			√ √	(-) HE supported
Adults 65 years or more in household? (Yes=1)	NS	NS	NS				(-) HE supported
Biophysical Characteristics:							
Heating degree days (30-years average)	+	+	+			√ √ √	(+) HE supported
Cooling degree days (30-years average)	+	NS	+			√ √	(+) HE supported
Home shaded by large trees? (Yes=1)	+	-	+			√ ^{***}	(-) HE supported

Note: EM=Ecological Modernization; PE=Political Economy; HE=Human Ecology; “-”=significant negative relationship; “+”=significant positive relationship; “NS”=not significant; √ indicates which theory (or theories) is (or are) supported by each statistically significant finding. For dummy-coded variables with multiple categories (home insulation and type of glass in windows) we present a summary for the variable as a whole rather than for each dummy-coded category, where a significant effect in at least one category is noted. Similarly, for income, where the models include a log-linear and a quadratic term, we present one summary for the variable as a whole based on the shape of the curve estimated by the linear and quadratic terms combined.

* EM does not necessarily predict a monotonically negative relationship, but it suggests that the relationship should become negative at higher levels of affluence. In all of the models, the effect of income is consistently positive, clearly contradicting the predictions of EM.

** Although the direction of influence for the natural gas model is in the direction predicted by HE, it is in the opposite direction in the other two models. Therefore, for this variable, the combined results from all three models do not support HE.

CONCLUSIONS

In this paper, we addressed two important domains of the human dimensions of climate change: 1) anthropogenic drivers of climate change and; 2) mitigation measures. Our analyses considered the roles of energy efficiency technological innovations, affluence, household level demographics, and biophysical characteristics. To theoretically ground our analyses, we drew on the ecological modernization (EM), political economy (PE) and human ecology (HE) perspectives. The ecological modernization perspective argues that modern societies can be restructured to “solve the fundamental problem of the ecological crisis” (Spaargaren and Mol 2009, p. 68) without sacrificing economic growth. It regards technological innovation as a holy grail of human efforts to mitigate the adverse environmental consequences of modern economic growth. EM views environmental policy as playing an important role in leading to environmental reform and the development and application of green technologies. The PE perspective questions this view, noting that while green technologies may produce environmental benefits, these benefits are often counteracted by affluence-induced increased consumption. The HE perspective focuses on the dynamic relationships that exist between populations and their environment, arguing that population characteristics, affluence and biophysical characteristics are key drivers of anthropogenic environmental degradation.

Our findings both support and challenge the EM perspective. Consistent with the theory, we find negative relationships between several indicators of technological innovations and CO₂ emissions. As noted earlier, EM theory expects technological innovation to play an important role in mitigating human impacts on the environment. The data show that home insulation, having a central heating system equipped with a programmable thermostat, having an insulated hot water heater and the ratio of efficient to all light bulbs used 1-4 hours daily in a home are all

associated with modest reductions in residential CO₂ emissions. Though modest, these relationships do confirm expectations under EM theory, proponents of which acknowledge that these types of technological innovations will likely produce only minimal environmental benefits (Huber 2009a).

The study, on the other hand, also provides evidence that directly contradict the EM theory. First, we find positive relationships between caulking/weather-stripping a home and two of our CO₂ emissions variables. These techniques have been touted as effective strategies to stem heat loss in homes over many years. The mixed effects from the technology variables, with some having positive effects on CO₂ emissions, others having negative effects, and some having no significant effects at all, taken together do suggest that technology alone may not provide a path to substantial reductions in CO₂ emissions. Furthermore, when only technology variables are included in the models, they are more prone to showing positive correlations with emissions. This suggests that they are associated with other factors that increase consumption, which counter-balance, and in some cases overwhelm the potential benefits of efficient technologies. More tellingly, rather than showing an inverted U-shaped relationship between annual household income and CO₂ emissions, we find, rather, an escalating positive relationship, where more affluent households emit more CO₂ and do so at an increasing rate. This clearly contradicts the expectation that postmaterialist values associated with affluence will lead people to reduce their impacts on the environment. Two other indicators of affluence considered in this study (home ownership and home size) are both also positively related to total residential CO₂ emissions, without any indication of the existence of a threshold point where their impacts will begin to diminish.

It is important to note that EM is largely a macro-level theory that posits that changes in policy, industrial production methods, and organizational structures are necessary to bring about environmental reform (Hajer 1995; Mol and Janicke 2009). Much of the theorization from the EM perspective does not necessarily expect individuals and households to take the main steps needed to curtail environmental degradation without larger scale changes occurring. Therefore, our analysis at the household level does not directly address many of the societal features that EM theorists emphasize. However, as noted above, some EM theorists have explicitly focused on consumer behavior and lifestyles (Spaargaren 2003; Spaargaren and Oostervant 2009; Spaargaren and van Vliet 2000), indicating that EM does expect technology and affluence to affect household level environmental impacts, making the household an appropriate level of analysis for testing a subset of the theoretical expectations of EM.

Overall, our findings are consistent with several cross-national studies that failed to find support for the expected inverted U-shaped relationship between affluence and environmental degradations (Harte 2007; Jorgenson 2009; York et al. 2003). They provide support for the PE and HE perspectives, which expect the level of affluence to drive environmental degradation. Also consistent with the PE perspective, our analyses suggest the relationship between technology and environmental degradation may be contingent upon technology's connection with affluence.

The data, as expected, indicate that household-level demographic characteristics are important anthropogenic drivers of CO₂ emissions. In all of our models, household size (number of household members) and having a household member at home always are positively related to households' CO₂ emissions. Not only do these findings corroborate cross-national empirical studies examining the relationship between population characteristics and environmental

degradation, they are consistent with the HE perspective. Another household-level demographic feature found to be significantly related to CO₂ emissions is the presence of at least one child in a household. Having a minor in a household is negatively related to CO₂ emissions. This finding appears to apply to only CO₂ emissions from electricity consumption. An unknown factor, such as poverty or life-cycle stage, or higher age-dependency ratio may be forcing households with children to skimp on energy consumption, despite the fact that children tend to need very comfortable home ambient air temperatures (Basu and Samet 2002; WHO 1987). Since we controlled for number of household members, this finding could be suggesting that children, while contributing to higher energy consumption, on average consume less energy than adults.

Although it recognizes the importance of culture, the HE perspective nevertheless regards humans as not exempt from ecological constraints. As discussed earlier, this theory expects human interactions with and impacts on the physical environment to be mediated by biophysical factors. While this is an important view of the HE perspective, rather few recent studies have empirically considered the impacts of biophysical factors on anthropogenic environmental impacts, especially at the micro-level. Hoping to shed light on this important relationship, we analyzed the impacts of cooling and heating degree days of a respondent's place of residence on CO₂ emissions. Supportive of this view, we did find that these variables are strong and consistent predictors of residential CO₂ emissions. This finding raises an important question. If biophysical characteristics do play such an important role in driving anthropogenic environmental impacts, what measures can be put in place to address them? While more research will be needed to adequately answer this question, we believe such measures should include deliberately considered housing-related technologies and changes in lifestyles. The findings also suggest the need for society to be circumspect about where human settlements are erected.

It is important to recognize that the energy consumption and emissions patterns of homes are influenced to a substantial degree by factors beyond the control of individuals, such as present development patterns regarding urban form, housing density and type, and infrastructure. The nature of urban development and processes of suburbanization, for example, have greatly affected residential energy consumption (Clement 2010; Hoorweg, Sugar and Gomez 2011). The politics and policy affecting urbanization, urban development, and urban revitalization clearly play important roles in determining household energy use, as do larger political-economic factors (Clement 2010; Serri and Holden 2014). Our study does not address these issues, which are clearly important to recognize if we are to substantially curtail the environmental impacts of households.

It is also important to note that energy use and CO₂ emissions in homes are surely connected with energy use and emissions outside the home. It is possible that people who use less energy in the home may use more elsewhere. For example, someone who eats out rather than cook at home and travels away from home frequently may use less energy in the home due to less cooking, less heating and cooling, and so forth, while using more energy in other ways, such as by flying or driving more and requiring energy use to provide them with goods and services outside the home. The relationship between energy use in the home and outside of it may partially explain why an environmental Kuznets curve is found in some studies and not others depending on what unit of analysis is used, what sector of society or the economy is examined, or whether one focuses on consumption or production based measures. For example, at the county level, Pattison et al. (2014) found a Kuznets curve for production based carbon emissions (e.g., those coming from industries within counties) but a consistently positive effect of income on consumption based emissions (e.g., those coming from producing the goods and services

consumed within counties even if those goods and services were produced elsewhere). The emissions associated with producing consumer goods and emissions from transportation are major contributors to total emissions, and these are not taken into account by our data. Future analyses could benefit from examining the overall contribution of individuals' lifestyles to energy consumption and emissions, not just their contribution stemming directly from activities in the home.

The findings also indicate that public policies that are designed to reduce overall energy consumption and CO₂ emissions must consider more than just technological innovation and adoption. Technologies alone will not address these issues, as our study shows, though technologies can certainly be an important part of the menu of solutions. That is, technology is not the only panacea to reducing energy use. Public policies must also aim to address the socio-economic aspects of energy use. In addition, the results show that public policies may need to be tailored to different socio-economic groups, reflecting their different lifestyles and consumption patterns.

Here we have provided a unique evaluation of the EM, PE and HE perspectives on the environment at the micro-level (that is, the household rather than nation-state level). Most contemporary empirical studies drawing directly on these theories have been based on cross-national analysis. While these studies have contributed immensely to our understanding of human impacts on the environment, the near-absence of rigorous micro-level evaluations of these important social theories of the environment means we have only a one-sided view of the phenomenon. As noted earlier, a good proportion of studies analyzing household level drivers of environmental disruption (energy consumption, generally) either used regional data or were not comprehensive enough in terms of the set of predictors considered. Our study thus represents an

important contribution to the expanding literature on anthropogenic drivers of environmental degradation.

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