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Analysis of Pre- & Intra-COVID-19 Pandemic U.S. Residential Sector Energy Consumption: A Novel Survey of American Household Usage During the Pandemic

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Abstract— The COVID-19 pandemic has fundamentally altered the way people around the world live, and although some impacts are yet to be realized, many changes have already occurred. Along with a climate crisis that is not going away any time soon, and an ever-increasing energy demand, the United States is about to endure consequences long thought to be for future generations. Given the lengthy and widespread stay-at-home orders, which forced residences to become makeshift schools and office spaces, the residential energy sector has certainly felt the impacts of the pandemic. Herein, we analyze pre- and intra-pandemic energy consumption in the residential sector in the United States. Students in a graduate-level engineering class at the University of Dayton were surveyed on their utility usage from 2019 through 2020 in an attempt to develop an understanding of how and where energy use changed over the period. Data collected included household city, state, occupancy, thermostat temperature setpoint, and electricity, gas, and water consumption for the household as presented on their utility bill. Data was analyzed on four categories – season, year, state, and number of occupants – to determine the influence of each of these factors on energy consumption. Overall electricity consumption increased 10% among the surveyed group, compared to a 2% increase in national consumption in the residential sector. While exact numerical findings were quite a bit higher than those nationally, the trend in increased consumption held true across all four categories studied. The findings of annual national energy consumption surveys are thereby reciprocated and enhanced by this limited, yet novel study.

Keywords— COVID-19, Pandemic, Household energy consumption, Residential sector

I. INTRODUCTION

Life as we know it has been fundamentally changed since the onset of the COVID-19 pandemic. Activities which were taken for granted just over a year ago - grocery shopping, going to bars and restaurants, taking in a sporting event or concert, visiting friends and family, school, and even work - are now completely different and seem to be altered for the foreseeable future. Like the daily routines of people around the globe, how Americans - in particular - use energy has been altered by the pandemic [1]. Comparing second quarter data alone from 2019 to 2020, national power consumption decreased by 4% as electricity demand dipped to Sunday levels during the shutdown [1]. The commercial sector saw an 11% decrease, the industrial sector a 9% drop, while residential demand increased 8% [1]. Looking at the whole of 2020 *(Figure 1)*, energy consumption fell by 7%, the largest decrease since the metric was first measured by the Energy Information Administration in 1949 [2]-[4], while the residential sector saw an increase of 2% as companies were forced to implement work-from-home policies [2]. How Americans got their electricity also experienced a shift; away from coal and towards renewables where solar and wind power saw gains of 10% and 19%, respectively [2]. In the residential sector alone, natural gas saw a 7% decline due to a mild winter, but saw an increase in the electricity sector along with renewables, replacing coal [2]-[4].

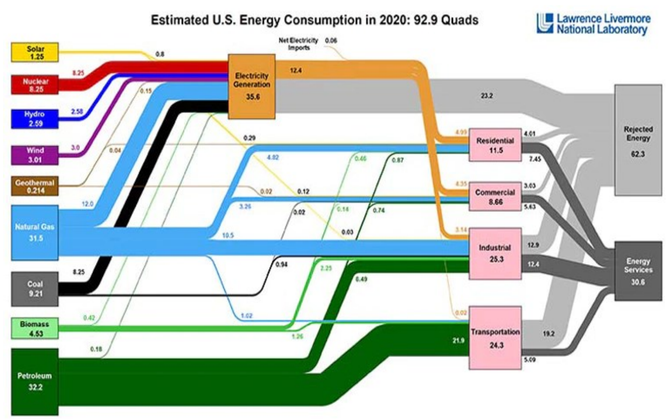

Figure 1: Estimated U.S. Energy Consumption in 2020. Flowchart released annually by Lawrence Livermore National Laboratory (LLNL). [2]

The decline in U.S. energy use, however, is not an anomaly solely caused by the pandemic, the drastic nature of the decline, however, is. Energy consumption in the U.S. has been on the decline since it peaked at 101.2 quads in 2018 *(Figure 2)* [5], falling less than a percent to 100.2 quads in 2019 *(Figure 3)* [6], and is currently at a 16-year low at 92.9 quads [6] [7]. With the recent decline in energy consumption, however, has come a steady increase in renewable energy technologies. From LLNL's 2018 report, total renewable production had doubled over the previous decade and wind and solar power had increased five-fold and 48-fold, respectively [5]. In 2019, LLNL reported wind and solar power had again grown, this time by 10% and 8%, respectively, with solar power exceeding 1 quad for the first time [6]. With renewable energy production trending upward, and national energy consumption, for the time being, trending downward, now is an important time for the renewable

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energy sector to step-up and take over as the leading source of energy production for the country.

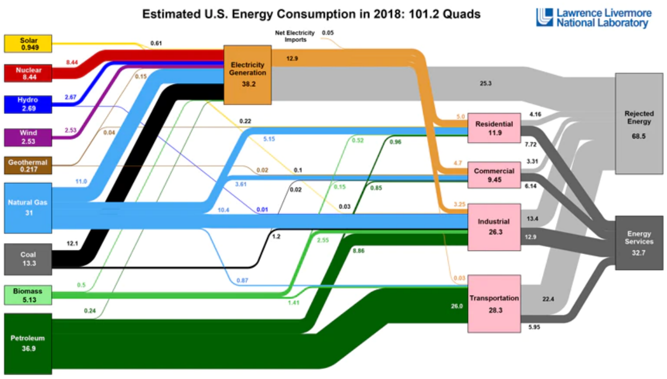

Figure 2: Estimated U.S. Energy Consumption in 2018. Flowchart released annually by Lawrence Livermore National Laboratory. [5]

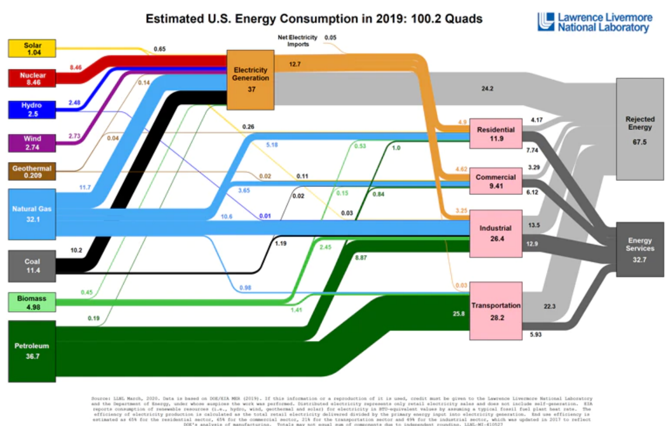

Figure 3: Estimated U.S. Energy Consumption in 2019. Flowchart released annually by Lawrence Livermore National Laboratory. [6]

As early as 1935, the Iberdrola Group as it would become known later, began their foray into renewable energy with the opening of the first major hydroelectric plant in Spain [8]. Officially born in 1992, the Iberdrola Group is now the third largest power company in the world and recognized globally as a leader in renewable energy [8]. Their business vision, “continues to anticipate trends in the sector, which sees how strong growth in global energy demands requires clean and sustainable sources to be satisfied.” [8] By this faculty, the Iberdrola Group understands the necessity of sustainable energy sources moving forward and has positioned themselves well to promote clean energy for the foreseeable future. As it stands, offshore wind is the company’s main focus and has plans in place to expand this activity to the United Kingdom, Germany, France, and the United States in the coming years [8]. Iberdrola’s current 2020-2025 plan - which has since been extended to 2030 - is an ambitious investment of 150 billion euros to double their installed renewable power to 60 gigawatts (GW) by 2025, and triple the current total to 95 GW by 2030 [9]. This on top of the corporate sustainability initiative to, “reduce its emission intensity to 50 gCO_2/kWh globally in 2030, achieving an 86% reduction in three decades, as well as being carbon neutral globally by 2050.” [10] To support the plan as well as position themselves for future growth, Iberdrola increased its renewable project portfolio by 25 GW in 2020, which now totals 74.4 GW across solar photovoltaics (32 GW), offshore wind (22 GW), land-based wind (16.2 GW), hydroelectric (3.3 GW), and battery storage technology (0.9 GW) [9] [11]. U.S.-based projects scheduled to be part of the current plan include off-shore wind installations in Kitty Hawk, NC (2,500 MW), Park City, CT (804 MW), and Vineyard Wind project (800 MW) in Massachusetts which altogether will be able to support the energy needs of roughly 1.5 million homes [12]. Other large-scale off-shore wind farms, located in the Baltic Sea (Germany) and North Sea (England and France), are also part of Iberdrola’s 2020-2025 plan [12]. With more renewable energy capacity on the way - 17.4 GW currently under construction or insured - Iberdrola has positioned itself well to lead the post-pandemic charge towards renewable energy via a “green recovery” [9] [11].

Given the recent prominence of the COVID-19 pandemic, many of the effects are still unknown and are certain to be studied for at least the next decade. This holds true with relevant studies in the energy sector as there is still much to be learned. Few studies have been conducted regarding the impacts of the pandemic on the energy sector, especially in the U.S., and have previously focused on Canada [13], China [14], and energy efficiency [15]. Herein is presented an analysis of utility data collected from the households of a single graduate-level engineering class at the University of Dayton. Processing and collection of the surveyed information are summarized to give a better understanding of results generated based on the surveyed sample. Furthermore, analysis of the data is discussed in the greater context of the COVID-19 pandemic and the estimated U.S. energy consumption for 2020 posted by Lawrence Livermore National Laboratory with specific focus on the residential sector.

II. Methodology

For this study, household utility data was collected via class survey wherein water, gas, and electricity use were reported for the 12 month period prior to, and during the COVID-19 pandemic - March 2019 through February 2021. Along with this data, each household provided their city, state, household occupancy, and their average thermostat temperature. In total, this study encompasses 38 households from 26 cities over 11 states *(Figure 4)*. The data was compiled using RStudio, and was further analyzed, with graphical representations produced, using Microsoft Excel.

Fewer households were able to report gas *(Figure 5)* and water *(Figure 6)* consumption, and it is assumed that those households use no gas and were unable to acquire the pertinent water usage data at the time of collection. It is also hypothesized that some households do not pay for their water as is the case in many apartment complexes where many college-aged students live. The lack of this data is not concerning for the overall goal of the study. Moreover, it is assumed that electricity usage was derived from the household’s utility bills. In some instances, utility data was only available for the past 12 months, free of charge and exact kilowatt hours (kWh) could not be obtained. In these cases, usage for the previous 12 months was estimated with graphical data provided on the utility bill. Data for the

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unspecified period was omitted. Given the variability of responses to gas and water consumption data, it was determined that no analyses could be performed with the data provided. Herein, only electricity usage *(Figure 7)* is explored for its pre- and intra-COVID-19 pandemic levels.

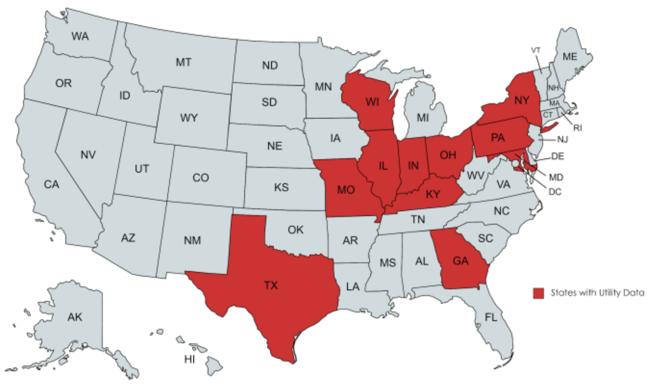

Figure 4: Map of states from which utility data was collected

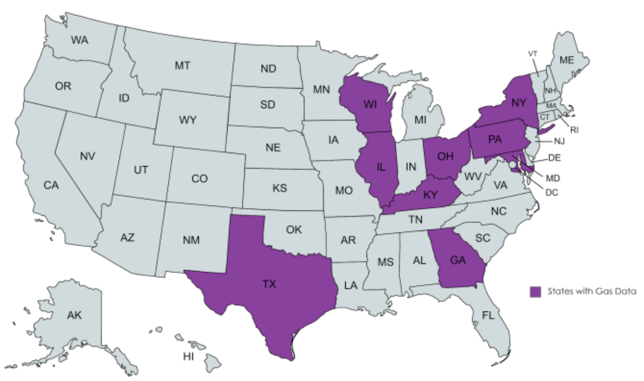

Figure 5: Map of states from which gas data was collected

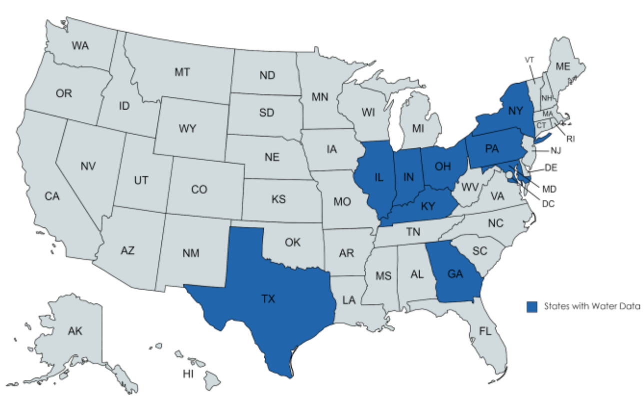

Figure 6: Map of states from which water data was collected

Analysis of the data centered around comparison of 2019 and 2020 figures. For each household, electrical, gas, and water differences were calculated, respectively, as shown in equation 1. Calculated monthly, the usage difference allowed for realization of household utility savings from month to month.

$$Eq.1 \quad Usage\ Difference = 2020\ value - 2019\ value$$

Having discounted the ability to effectively analyze gas and water data, total electrical consumption was calculated for each household to conclude total electrical savings or increases over the specified periods. Compiling household data, differences in total electrical use were also calculated seasonally, annually, by state, and by the number of occupants. Average state differences, on a monthly basis, for each of the utility categories were also calculated in an attempt to better understand usage breakdown by state.

Sample randomness, particularly when considering the variability of local weather conditions, made it difficult to draw widespread conclusions. The small sample size also made analysis difficult. In the future, greater planning would be needed to ensure a large, representative sample encompassing more cities and states as well as a greater survey of household sizes in each of the represented locations. With a larger sample size, regional lines could be drawn and further analyzed to account for typical weather patterns rather than analyzing the collective whole. Regional climates play a key role in household heating and cooling practices, and thus households from different regions cannot simply be compared without understanding the underlying differences which already exist with regards to utility usage.

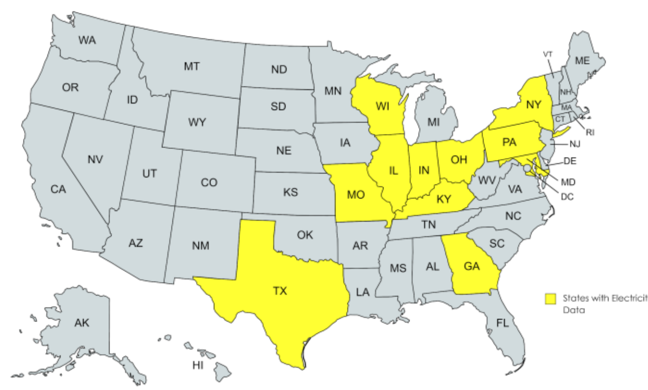

Figure 7: Map of states from which electricity data was collected

III. Results

Collection and organization of the data by occupancy level and state in relation to the number of households was conducted to understand the representation of each of the groupings *(Tables 1 & 2)*. Based on this data, households of 6-, 7-, 8-, or single occupancy are underrepresented and reasonable conclusions cannot be drawn without increased sampling of these demographics. Likewise, all states with the exception of Ohio are underrepresented in this study and further sampling is recommended to increase the applicability of the results. Boxplots were initially created to get a visual understanding of the collected data. Figure 9 gives a good example of the variety in the electricity consumption differences for the households

Occupants	Number of Households Represented
1	1
2	4
3	7
4	14
5	8
6	1
7	1
8	1
Blank	1

Table 1: Number of Households per Occupancy Level

State	Number of Households Represented
GA	1
IL	2
IN	2
KY	1
MD	1
MO	1
NY	1
OH	24
PA	2
TX	1
WI	1
Blank	1

Table 2: Number of Households per State

sampled. To determine what data to focus on, Figures 10-12 were used along with the variability of responses to gas and water consumption data discussed previously to turn the focus on electricity usage only.

Analysis of the collected utility data yielded widespread increased usage among seasonal, statewide, and occupancy subcategories as can be seen in Table 3. In the United States, space heating and cooling make up roughly 47% of annual building energy consumption while lighting (9%), electronics (6%), and appliances (~7%) make up far less of annual electricity consumption *(Figure 8)* [16]. As more people were forced to work from home and conduct online schooling, these increases were expected based on increased use of electronics, lighting, appliances, and televisions, as well as heating and cooling systems. Due to the large annual consumption percentage of heating and cooling systems, seasonal comparisons were thought to be of great importance when considering pandemic level energy consumption. As can be seen, both summer and winter saw increased electricity consumption during the pandemic. The increase in summertime consumption, ~15%, tripled that of the winter, ~5%. While space heating typically accounts for nearly four times the energy of space cooling, widespread warmer winter temperatures and more occupants help decrease the demand for heating. Warmer summertime temperatures, along with increased occupancy and humidity factors, helped drive up energy consumption during the summer months, explaining not only the increase, but wide discrepancy between the seasonal figures. Variability in household setpoint temperatures could also influence the increases seen here.

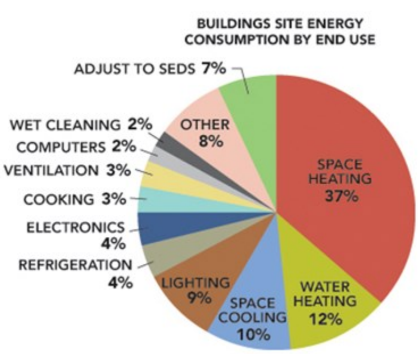

Figure 8: Building Energy Consumption by End Use [16]

Sizeable increases in energy consumption were also observed at the regional level based on state. With uneven sample sizes across the states represented, percent

By Season *(Summer = June-Aug & Winter = Nov-Feb)*

Season	2019	2020	Diff.	% Change
Summer	121,622	139,268	17,646	14.51%
Summer Avg.	1,096	1,266	170	15.55%
Winter	95,240	100,216	4,976	5.22%
Winter Avg.	858	903	45	5.22%

By Year

	2019	2020	Diff.	% Change
Total	401,217	442,244	41,027	10.23%
Averaged	904	998	95	10.47%

By State

State	2019	2020	Diff.	% Change
GA	19,208	19,211	3	0.02%
IL	14,274	18,121	3,847	26.95%
IN	22,250	25,200	2,950	13.26%
KY	2,117	4,351	2,234	105.53%
MD	27,738	28,468	730	2.63%
MO	12,367	11,054	-1,313	-10.62%
NY	11,785	13,945	2,160	18.33%
OH	235,734	258,519	22,785	9.67%
PA	22,305	23,565	1,260	5.65%
TX	14,065	17,709	3,644	25.91%
WI	17,523	18,199	676	3.86%

By Number of People

Occupants	2019	2020	Diff.	% Change
1	2,973	3,468	495	16.65%
2	15,008	14,525	-483	-3.22%
3	67,600	77,299	9,699	14.35%
4	166,354	179,464	13,110	7.88%
5	112,225	122,842	10,617	9.46%
6	15,298	17,761	2,463	16.10%
7	5,656	6,961	1,305	23.07%
8	14,252	14,706	454	3.19%

Table 3: Breakdown of Seasonal, Annual, Statewide, & Occupancy Electrical Consumption Results

changes could be based on one or two households in some cases, and upwards of 24 in the case of Ohio. States which saw smaller increases in consumption were Georgia, Indiana, Maryland, Ohio, Pennsylvania, and Wisconsin, all of which saw increases of less than 25%. Of those, Georgia was the nearest to breaking even with a mere increase of 0.02%, which can be interpreted as negligible. Only one state - Missouri - saw a decrease in consumption, lessening their electrical consumption by over 10% during the pandemic. All other states represented - Illinois, Kentucky, New York, and Texas - showed significant increases in energy consumption during the pandemic as students returned home to finish the semester remotely and working from home became the standard. While all but two states saw increases in electricity consumption during the pandemic, it should be noted that many saw relatively understandable increases of less than

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15% over the course of the year. Although the overarching goal is to continuously reduce energy consumption, thereby improving overall building efficiency, the surveyed residential energy increases of less than 15% are neither surprising nor alarming given the many challenges people around the globe have had to endure over the past year-and-a-half.

Unsurprisingly, energy consumption increased on an occupancy basis as well. Households containing 3-7 residents saw increases in electrical consumption on the order of 8-23%, with 4-occupant households using less energy than 5-, 6-, and 7-occupant households. Single occupant households were also among that grouping with an approximately 17% consumption increase. 8-occupant residences saw a mere 3% increase in consumption during the pandemic. Because the residence already has a high occupancy number and a nearly non-stop schedule, it is likely that extended hours at home or adding another occupant would do little to influence the energy consumption of the residence. Therefore, the minor increase in electricity consumption is not considered a fluke. 2-occupant households were the only occupancy level to see a decrease in consumption over the period. These households saw a decrease of roughly 3.2%, a figure which - although it deviates from the norm - is what would ideally be realized moving forward; as decreased energy consumption means higher efficiency appliances and equipment, and more conscientious electricity use practices are being implemented.

Total electricity consumption for both 2019 and 2020 was figured for all the residences provided. Given the previous increases by subgrouping, it is unsurprising that total electricity consumption saw an increase of 10% from the pre- to intra-pandemic timeline. The increase seen here, however, differs from total residential consumption for the United States from 2019 to 2020 as calculated and presented by Lawrence Livermore National Laboratory *(Figure 1)* in their annual flow chart, which saw a 2% increase in residential consumption [2]. The discrepancy between these values can be attributed to this study's small sample size as well as its randomness given a single class from the University of Dayton was surveyed on their utility use over the period.

IV. CONCLUSIONS AND DISCUSSION

Analysis of pre- and intra-COVID-19 pandemic energy consumption was explored from a survey of household utility data usage for 2019 and 2020, from a single class at the University of Dayton. Due to the variability of responses to gas and water consumption data, the analysis focused solely on electricity consumption. Four subgroups were examined in the analysis which included yearly, seasonal, statewide, and occupancy. Increased consumption from 2019 to 2020 was observed for every subgroup with the exception of Missouri, by state, and 2-occupant households by number of people. Overall, the percent increases on an occupancy basis ranged from approximately 3% to 23%, and for the states it ranged from roughly no change to 105%, with only three states exceeding a consumption increase of 20%. Seasonally, summer saw an increase in electricity consumption of ~15%, while winter saw ~5% increase. A roughly 10% increase in consumption was seen over the whole year from 2019 to the pandemic year of 2020.

Figure 9: Household Breakdown of Difference in Electricity Consumption

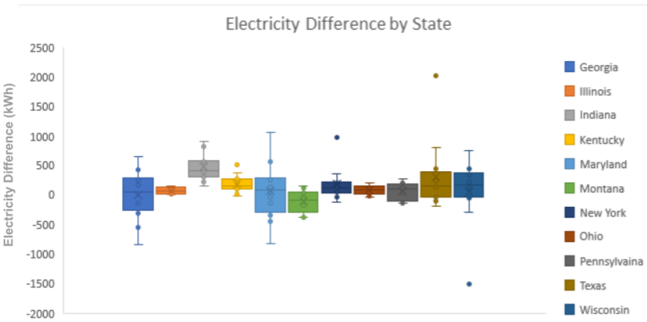

Figure 10: Difference in Electricity Consumption by State

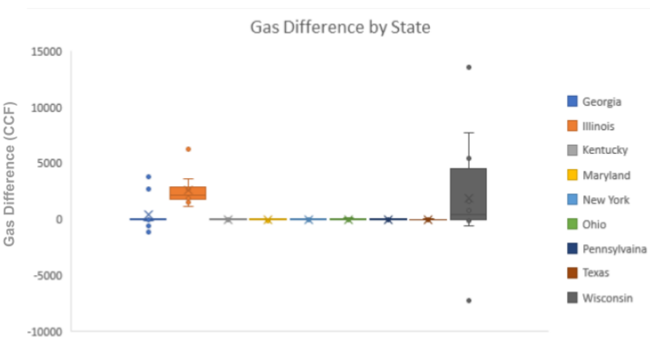

Figure 11: Difference in Gas Consumption by State

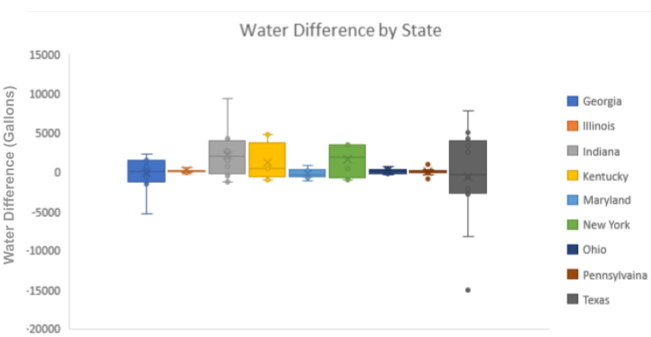

Figure 12: Difference in Water Consumption by State

US consumption in the residential sector actually increased 2% according to LLNL, which makes the 10% increase observed in this study five times greater. As stated previously, the discrepancy between these values can be attributed to this study's small sample size as well as its randomness given a single class from the University of Dayton was surveyed on their utility use over the period. To get a more accurate correlation between the study results and the energy consumption of the nation, the scale of this study would need to be drastically increased. Further analysis should be done if more data is collected to see if the electricity consumption difference is affected by region, occupancy, or thermostat temperature.

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

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