Demand & Conservation Planning Research Whitepaper

Extracting Insights and Trends from Residential and Small Commercial Electricity Data

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1. Executive Summary

Ontario is one of the few jurisdictions in the world where a full-scale smart-meter roll out was mandated by the provincial government in 2004[1]. The IESO was made responsible for handling what is now one of the largest smart-meter databases in the world, the Meter Data Management Repository (MDM/R), that contains hourly electricity data on residential and small commercial consumers that is managed by the Smart Metering Entity (SME). The Demand and Conservation Planning (DCP) team has been working closely with the SME team to develop datasets to better understand and analyze how this data might better enable its work moving forward. This paper is part of a series of DCP demand research papers that aim to shed light on historical demand trends and how these trends will help inform elements of the DCP team's ongoing and future work engagements.

All of the analyses presented in this paper represent results for aggregated residential and small commercial consumers aggregated at a forward sortation area level or higher. None of these results represent an individual residential or small commercial consumer, however, electricity consumption and demand behaviours for an average residential and small commercial consumer will be discussed. This paper also presents new analyses and graphical representations of electricity consumption of residential and small commercial consumers in Ontario.

At a high-level, our analysis of the SME data has resulted in the following:

- **Production of energy statistics** to aid in the understanding of historical residential and small commercial consumer electricity consumption and demand behaviour. For example, Table 0.1 below present average monthly energy statistics for residential and small commercial consumers that highlight the differences for these consumers across each IESO electrical zone and electricity price plan. For the table below we observe the stark contrast in average monthly energy usage for both types of consumers on a retail contract. The gradient in Table 0.1 highlights small (red) and large (green) values conditional on commodity rate class.

[1] https://www.oeb.ca/industry/policy-initiatives-and-consultations/smart-metering-initiative-history

Table 0.1: Average Monthly Energy in kWh for January through November 2021, by Distribution and Commodity Rate Class, and IESO Electrical Zone

IESO Zone	Commodity Rate Class					
	Residential			Small Commercial		
	Distribution Rate Class					
	Retailer	Tiered	TOU	Retailer	Tiered	TOU
Bruce	1,489	787	931	3,340	1,680	1,787
East	1,174	776	905	3,747	3,694	1,912
Essa	1,111	733	876	3,472	1,872	1,918
Niagara	921	632	735	4,444	1,586	2,145
Northeast	917	740	821	3,764	2,706	1,931
Northwest	843	616	730	3,522	1,273	2,046
Ottawa	974	591	716	4,641	1,326	2,054
Southwest	1,172	632	755	3,938	1,435	2,175
Toronto	777	589	724	4,062	1,922	2,060
West	953	649	748	4,268	2,290	2,062
Average	1,003	634	769	4,014	1,868	2,070

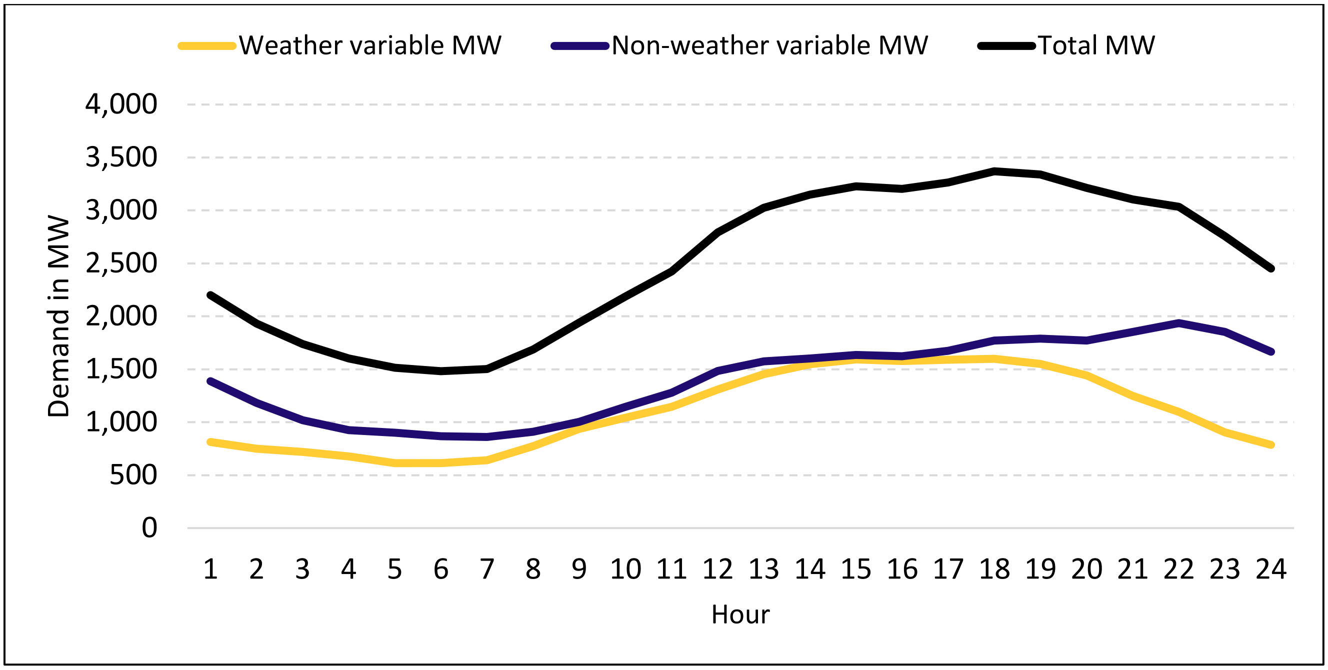
- **Production of a series of hourly electricity demand machine learning models** to capture and isolate the contribution of weather on hourly residential and small commercial electricity consumption, which will help improve demand forecast processes and models, moving forward. Figure 0.1 presents a breakdown of one day's worth of hourly load data in the Toronto IESO electrical zone being broken down by weather and non-weather variables using a machine learning model.

Machine Learning is a discipline that lies at the intersection of computer science and statistics where algorithms are developed to make inferences on a set of data.

A **Machine Learning Model** refers to some function $y = f(x)$ that uses a set of inputs and outputs, in this case x and y to infer values of y with varying values of x.

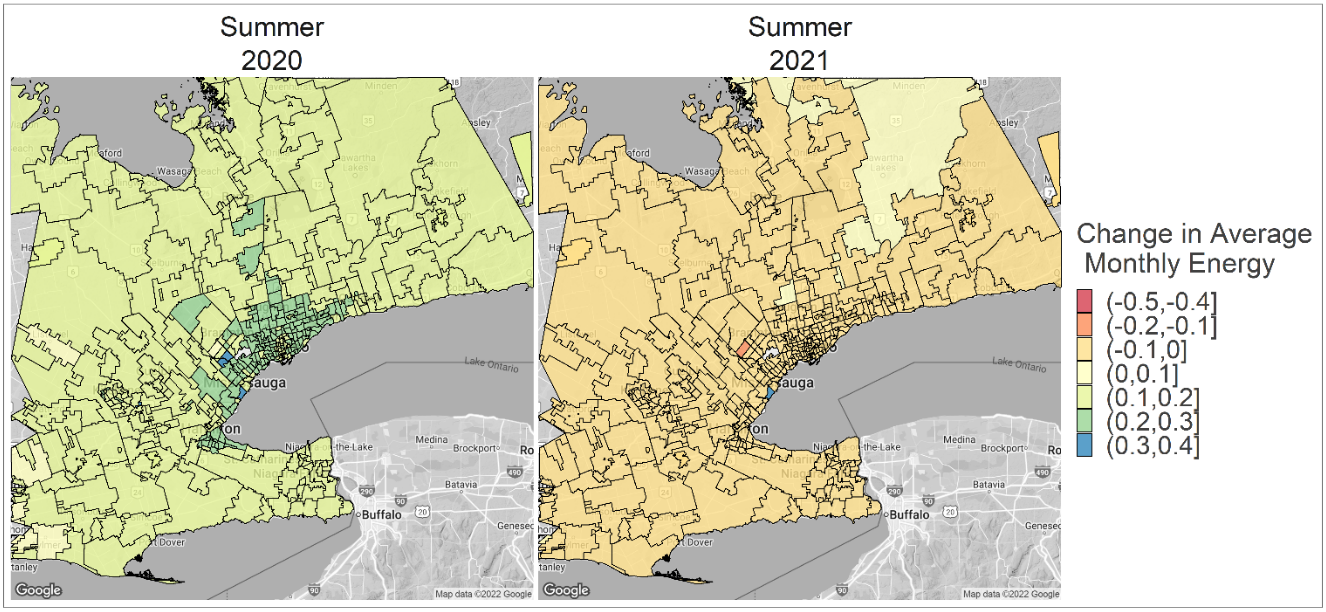
In the context of this paper, **Weather Variables** refers to information such as dry bulb temperature in degrees Celsius or the amount of cloud cover for a given hour of the day. **Non-weather Variables** refers to calendar variables such as hour of the day or what month it might be.

Figure 0.1: Toronto IESO Electrical Zone Residential Load Profile for July 20, 2019, Broken Down by Weather and Non-weather Variables



- **Production of geographical visualizations** to identify forward sortation areas with the highest average monthly residential and small commercial electricity consumption to better enable geo-targeting for demand management activities such as energy conservation and demand response programs. Figure 0.2 below presents a geospatial visualization, that takes advantage of the forward sortation area information to produce percent changes in average monthly energy statistics for the summer of 2020 and 2021. What we see is an increase in average monthly energy use for most FSA's for 2020, compared to 2019 and a decrease in average monthly energy use in summer 2021, compared to 2020. The increases at the FSA-level appear to be between 10% and 20% in 2020, whereas the decreases in 2021 appear to be between 0% and 10%.

Figure 0.2: Percent Change in Average Monthly Residential Energy for Summer 2020 and 2021, Broken Down by Forward Sortation Area



Taken together, each of these streams of work has provided novel insight into residential and small commercial behaviour through three unique use-case examples and generated observations that were previously unavailable to the IESO.

Future work will move forward as follows:

1. continue to generate the statistics in this paper to monitor residential and small commercial behaviour as new data becomes available;
2. work with the SME to build new datasets that will more deeply examine the observations made within this paper to further understand historical energy and demand behaviour within the residential and small commercial sectors; and
3. apply the learnings from this paper on medium and large commercial as well as industrial consumer data as it becomes available within the SME's DataMart.

The remainder of this paper is structured as follows: Section 2 introduces the paper and provides rationale and benefits of this stream of work; Section 3 identifies main findings based on three different approaches to analyzing the SME data; and Section 4 discusses next steps and how this work will continue as more load data becomes available.

2. Introduction

The IESO recently identified a new set of Core Strategies based on anticipated changes to the Energy Sector over the next 20 years. These Core Strategies, taken together, will shape how the IESO engages in its work over the next 5 years. We believe that there is a relationship with this stream of work to items 1.2, 3.2, 3.3 that will support and feed into 2.2 & 2.3 by conducting analyses and finding results that can be leveraged in the development of future demand forecasts for system planning.

Figure 1: The IESO's Strategic Plan

One of the IESO's Core Strategies identifies how the IESO will transform its business by enhancing workplace culture, building skills, new tool and technology adoption, and extracting value from data. This paper demonstrates how a combination of new data science skills, technologies, and tools can lead to value extraction from a set of data from the SME and hopefully encourages the development of new data products that will drive organizational change.

The analysis throughout this paper focuses on SME data pertaining to residential and general service less than 50 kW (small commercial) consumers, which can be further categorized by the type of commodity rate class or electricity price plan they prescribe to, either time-of-use or a tiered price plan, or a retail contract.

Three use-cases are discussed that focus on analyzing SME data with the Demand and Conservation Planning group in-mind. However, we anticipate that the results from these use-cases will be relevant to a broader audience at the IESO and the Ontario energy sector. Specifically, our analysis aims to provide insight into:

- historical electricity consumption and demand patterns that will aid day-ahead forecasting adjustments and allow short-term demand forecasting planners to review previous forecast assumptions in more detail;
- residential and small commercial consumer load profile shapes by consumer class and IESO electrical zone that will serve as a new potential input into a future Annual Planning Outlook and Reliability Outlook work stream; and
- historical electricity consumption and demand patterns that will allow conservation and transmission planners to identify IESO electrical zones or postal code areas with high energy consumption and-or peak demand.

3. Analysis

All of the analysis below represents results for residential and small commercial consumers aggregated at an IESO electrical zone level or higher based on data queried from the SME DataMart at the time of writing his paper. None of the results presented below represent an individual residential or small commercial consumer, however, electricity consumption and demand behaviours for an average residential and small commercial consumer will be discussed.

Its important to note that the analysis undertaken throughout this document represents only the residential distribution rate class in the SME flagged as 201 or "Residential-Regular", two other residential distribution rate classes exist within the SME DataMart flagged as 202 and 203 or "Residential-Seasonal" and "Residential-Condominium" but we have chosen to exclude them as the focus of this paper is separately metered residential households. For small commercial consumers only a single flag exists as 301 or "Small General Service (< 50 kWh)" no restrictions are made to this class of consumers. Throughout our analysis, seasons are defined as follows: Winter = [December, January, February]; Spring = [March, April, May]; Summer = [June, July, August]; and Fall = [September, October, November]. Similarly, we define periods of the day as follows: Morning = [5,6,7,8,9,10,11]; Afternoon = [12,13,14,15,16]; Evening = [17,18,19,20,21]; and Night = [0,1,2,3,4,22,23].

We also note that the data in this section spans from January 2018 through November 2021, inclusive. All references to 2021 data throughout this paper assumes the lack of availability of December 2021 data at the time this analysis was performed.

3.1 Energy Statistics to Update Residential and Small Commercial Assumptions

In this sub-section we present a variety of Energy Statistics we produce using the SME dataset. In the context of this paper, an Energy Statistic can be any aggregation or statistical transformation of the SME dataset. For example, an Energy Statistic that we present below is average monthly electricity consumption for residential and small commercial consumers in kWh broken down by IESO electrical zone and electricity price plan. The collection of Energy Statistics provided below were developed to provide the IESO with insight into residential and small commercial consumer behaviour through time at a more granular level than previously available. These Energy Statistics may also enable more sophisticated analyses to be conducted on these groups of consumers for energy policy-related decisions, moving forward. We discuss our main results and their implications, below.

3.1.1 Total Energy Statistics

Main Observations

- Total annual residential energy was 40.52 TWh in 2018; 39.72 TWh in 2019; and 42.54 TWh in 2020.
- Total small commercial energy was 10.28 TWh in 2018; 10.05 TWh in 2019; and 9.49 TWh in 2020.
- Small commercial consumers on a retail contract, which represent 9.1% of small commercial consumers, use 16.4% of the total annual energy within the small commercial group, no other residential or small commercial group exhibits this behaviour.

Detailed Findings

This section presents statistics on annual residential and small commercial energy use in terms of Terawatt hours (TWh). Table 1.1 shows that residential and small commercial consumers on a TOU price plan represent the largest fraction of overall energy use between January and November 2021 for their respective distribution rate class. However, the second largest group differs depending on the distribution rate class. For residential and small commercial consumers, the second largest commodity rate plan group is for those who prescribe to the tiered price plan or retail contract, respectively.

Table 1.0: Total Population Statistics, Broken Down by Distribution and Commodity Rate Class, and IESO Electrical Zone

IESO Zone	Distribution Rate Class						Total
	Residential			Small Commercial			
	Commodity Rate Class						
	Retailer	Tiered	TOU	Retailer	Tiered	TOU	
Bruce	803	1,973	37,026	741	79	3,995	44,616
East	7,905	20,021	373,999	3,950	489	34,749	441,112
Essa	6,288	15,540	331,615	2,902	472	25,891	382,708
Niagara	3,299	10,457	195,521	1,498	636	17,093	228,505
Northeast	3,705	8,029	198,385	2,131	387	21,372	234,009
Northwest	408	3,120	52,362	327	77	3,866	60,159
Ottawa	5,017	40,925	353,142	2,254	828	26,908	429,075
Southwest	17,220	52,311	948,663	10,109	2,684	79,492	1,110,479
Toronto	18,785	93,994	1,295,525	6,236	2,305	79,638	1,496,483
West	9,370	35,106	417,028	3,734	1,272	37,984	504,493
Total	72,801	281,476	4,203,265	33,883	9,227	330,987	4,931,640
% of DRC Total	1.6%	6.2%	92.2%	9.1%	2.5%	88.5%	100.0%

Small commercial consumers on retail contracts represent a large fraction of total consumption between January and November 2021 given their customer count. This group, which only represents 8.9% of small commercial consumers represents 16.2% of the total energy consumed in that group. Compared to small commercial consumers on a retail contract, small commercial consumers on a time-of-use price plan represent 88.6% of small commercial consumers but only 81.6% of the total annual energy use in that group. This suggests that small commercial consumers on a retail contract likely consume considerably more, on average, than either tiered or TOU small commercial consumers.

Table 1.1: Total Energy in TWh for Jan through Nov 2021, Broken Down by Distribution and Commodity Rate Class, and IESO Electrical Zone

IESO Zone	Distribution Rate Class						Total
	Residential			Small Commercial			
	Commodity Rate Class						
	Retailer	Tiered	TOU	Retailer	Tiered	TOU	
Bruce	0.01	0.02	0.34	0.02	0.00	0.07	0.47
East	0.09	0.16	3.39	0.14	0.02	0.64	4.44
Essa	0.07	0.11	2.92	0.10	0.01	0.48	3.70
Niagara	0.03	0.07	1.48	0.06	0.01	0.34	2.00
Northeast	0.03	0.06	1.57	0.08	0.01	0.38	2.12
Northwest	0.00	0.02	0.38	0.01	0.00	0.07	0.48
Ottawa	0.05	0.24	2.55	0.10	0.01	0.53	3.48
Southwest	0.20	0.33	7.32	0.38	0.04	1.63	9.91
Toronto	0.15	0.57	9.62	0.25	0.05	1.57	12.20
West	0.09	0.23	3.21	0.16	0.03	0.77	4.50
Total	0.73	1.81	32.78	1.31	0.17	6.49	43.30
% of DRC Total	2.1%	5.1%	92.8%	16.4%	2.2%	81.4%	100.0%

Table 2 presents total annual residential and small commercial energy use in TWh for each year in our dataset and identifies that residential energy use within our dataset increased from 39.72 TWh in 2019 to 42.54 TWh in 2020, an increase of approximately 2.79 TWh or 7.1% relative to annual residential energy use in 2019. Small commercial energy use decreased from 10.05 TWh in 2019 to 9.49 TWh in 2020, a 5.5% decrease relative to 2019. At the time of writing this document we do not possess a full year's worth of data for either distribution rate class in 2021 and cannot comment on the change from 2020 to 2021. However, this is also an opportunity to investigate these changes further in a follow-up analysis.

Table 2: Total Energy in TWh for 2018 through 2021, Broken Down by Distribution Rate Class and IESO Electrical Zone

IESO Zone	Year							
	2018	2019	2020	2021	2018	2019	2020	2021
	Distribution Rate Class							
	Residential				Small Commercial			
Bruce	0.43	0.44	0.45	0.37	0.12	0.12	0.12	0.10
East	4.22	4.24	4.44	3.64	1.02	1.01	0.97	0.80
Essa	3.56	3.54	3.77	3.11	0.73	0.74	0.70	0.59
Niagara	1.77	1.73	1.86	1.58	0.58	0.52	0.49	0.42
Northeast	2.01	2.04	2.09	1.66	0.61	0.61	0.57	0.47
Northwest	0.48	0.48	0.50	0.40	0.11	0.11	0.11	0.09
Ottawa	3.27	3.21	3.43	2.85	0.81	0.81	0.76	0.64
Southwest	8.98	8.75	9.40	7.86	2.75	2.60	2.46	2.06
Toronto	11.80	11.37	12.44	10.33	2.36	2.35	2.21	1.87
West	4.02	3.92	4.16	3.54	1.19	1.18	1.11	0.96
Total	40.52	39.72	42.54	35.33	10.28	10.05	9.49	7.97

3.1.2 Average Monthly Energy Statistics

Main Observations

- Substantial differences in average monthly energy use exists for residential and small commercial consumers across IESO electrical zone and electricity price plan as well as summer and winter season.
- Residential consumers on a retail contract, on average, use 1,003 kWh/month; on a tiered price plan, on average, use 634 kWh/month; and on a time-of-use price plan, on average, use 769 kWh/month.
- Small commercial consumers on a retail contract, on average, use 4,014 kWh/month; on a tiered price plan, on average, use 1,868 kWh/month; and on a time-of-use price plan, on average, use 2,070 kWh/month.
- An additional analysis would be required in order to identify the drivers of these differences in average monthly energy use at the price plan level.

Detailed Findings

This section presents statistics on monthly energy use in terms of kilowatt hours per month (kWh) for residential and small commercial consumers.

Our analysis has identified that within each residential and small commercial consumer group significant differences in average monthly energy use exists between consumers who belong to a retail, tiered, or time-of-use price plan. In most cases, differences also exist across each IESO electrical zone. For example, Table 3 shows that Residential consumers on a retail price plan consume 1,003 kWh/month compared to 634 kWh/month on a tiered price plan and 769 kWh per month on a time-of-use price plan. Similarly, we observe that small commercial consumers on retail price plans consume 4,014 kWh per month, on average, compared to 1,868 kWh per month for those on tiered price plans, and 2,070 kWh per month for those on the time-of-use price plan.

Table 3: Average Monthly Energy in kWh for Jan 2018 through Nov 2021, by Distribution and Commodity Rate Class, and IESO Electrical Zone

IESO Zone	Commodity Rate Class					
	Residential			Small Commercial		
	Distribution Rate Class					
	Retailer	Tiered	TOU	Retailer	Tiered	TOU
Bruce	1,489	787	931	3,340	1,680	1,787
East	1,174	776	905	3,747	3,694	1,912
Essa	1,111	733	876	3,472	1,872	1,918
Niagara	921	632	735	4,444	1,586	2,145
Northeast	917	740	821	3,764	2,706	1,931
Northwest	843	616	730	3,522	1,273	2,046
Ottawa	974	591	716	4,641	1,326	2,054
Southwest	1,172	632	755	3,938	1,435	2,175
Toronto	777	589	724	4,062	1,922	2,060
West	953	649	748	4,268	2,290	2,062
Average	1,003	634	769	4,014	1,868	2,070

Table 4 presents average monthly energy use statistics by season and IESO electrical zone. We observe that average monthly energy use is significantly higher during the winter season for northern electrical zones (e.g., Northeast and Northwest) compared to southern electrical zones (e.g., Ottawa, Southwest, Toronto). An example of the difference in potential heating load can be seen in Table 4 for residential consumers in the northeast electrical zone, during the winter season average monthly electricity consumption is 1,055 kWh/month vs. 697 kWh/month in the summer season. Similarly, an example of increased electricity consumption during the summer season can be seen in the Toronto electrical zone, in the summer season average monthly electricity consumption is 883 kWh/month vs. 718 kWh/month in the winter season.

Table 4: Average Monthly Energy in kWh for Jan 2018 through Nov 2021, Broken Down by Distribution Rate Class, Season, and IESO Electrical Zone

IESO Zone	Distribution Rate Class							
	Residential				Small Commercial			
	Season							
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Bruce	1,157	923	842	828	2,243	1,899	2,090	1,874
East	1,075	853	900	791	2,390	1,973	2,177	1,957
Essa	1,016	826	889	767	2,317	1,941	2,120	1,931
Niagara	730	633	912	646	2,463	2,117	2,581	2,143
Northeast	1,055	813	697	729	2,551	2,056	1,929	1,938
Northwest	936	702	610	662	2,711	2,070	1,882	1,977
Ottawa	773	641	791	615	2,509	2,095	2,269	2,068
Southwest	787	679	877	671	2,524	2,197	2,501	2,216
Toronto	718	631	883	620	2,343	2,065	2,329	2,080
West	743	645	919	660	2,316	2,071	2,500	2,152
Average	823	694	869	673	2,459	2,105	2,349	2,107

Table 5 and 6 contain average monthly energy use statistics for residential and small commercial consumers by year, distribution and commodity rate class, and IESO electrical zone. Across all years we observe that residential and small commercial consumers on a retail contract used considerably more energy, on average, than either TOU or tiered price plan residential and small commercial consumers, conditional on IESO electrical zone.

Table 5: Average Residential Monthly Energy in kWh, Broken Down by Year, and IESO Electrical Zone

IESO Zone	Year											
	2018			2019			2020			2021		
	Distribution Rate Class											
	Retailer	Tiered	TOU	Retailer	Tiered	TOU	Retailer	Tiered	TOU	Retailer	Tiered	TOU
Bruce	1,453	790	923	1,490	784	930	1,516	795	945	1,496	779	923
East	1,176	774	897	1,158	761	894	1,189	789	923	1,172	779	906
Essa	1,120	736	872	1,091	710	856	1,123	746	894	1,109	739	882
Niagara	931	637	732	893	607	702	926	641	748	934	641	759
Northeast	920	741	817	938	738	827	938	753	840	874	728	800
Northwest	853	606	723	852	611	733	849	627	745	817	619	717
Ottawa	981	598	714	958	566	693	984	602	732	972	598	723
Southwest	1,168	645	751	1,143	602	724	1,185	641	771	1,190	640	771
Toronto	771	592	719	746	554	686	800	609	748	791	602	742
West	964	654	743	930	621	720	953	654	758	963	664	771
Average	1,005	639	764	983	606	742	1,018	646	787	1,007	642	781

We also observe that average monthly residential electricity consumption in 2020 increases, relative to average monthly residential electricity consumption in 2019 across all commodity price plans. Specifically, we observe that average monthly electricity consumption for a residential consumer increased by 3.6% on a retail price plan, 6.6% on a tiered price plan, and 6.1% on a time-of-use price plan.

Table 6: Average Small Commercial Monthly Energy in kWh, Broken Down by Year and IESO Electrical Zone

IESO Zone	Year											
	2018			2019			2020			2021		
	Distribution Rate Class											
	Retailer	Tiered	TOU	Retailer	Tiered	TOU	Retailer	Tiered	TOU	Retailer	Tiered	TOU
Bruce	3,347	1,712	1,818	3,363	1,693	1,821	3,279	1,511	1,759	3,373	1,799	1,753
East	3,881	3,853	1,990	3,852	3,781	1,962	3,640	3,555	1,847	3,619	3,581	1,850
Essa	3,559	2,009	1,988	3,538	1,908	1,978	3,387	1,705	1,856	3,405	1,854	1,852
Niagara	4,985	1,884	2,492	4,433	1,565	2,128	4,156	1,469	1,975	4,236	1,437	2,006
Northeast	3,936	3,119	2,030	3,887	3,186	2,014	3,626	2,733	1,864	3,612	1,980	1,818
Northwest	3,662	1,354	2,159	3,686	1,238	2,139	3,451	1,144	1,981	3,295	1,353	1,907
Ottawa	4,736	1,502	2,166	4,782	1,360	2,133	4,551	1,178	1,967	4,504	1,246	1,958
Southwest	4,217	1,443	2,408	3,991	1,367	2,200	3,748	1,429	2,051	3,804	1,499	2,052
Toronto	4,163	1,715	2,185	4,157	1,889	2,128	3,940	1,980	1,961	3,989	2,110	1,970
West	4,354	2,550	2,153	4,349	2,252	2,104	4,143	2,132	1,958	4,230	2,217	2,033
Average	4,188	1,925	2,217	4,095	1,860	2,121	3,871	1,809	1,972	3,909	1,875	1,977

For average monthly small commercial electricity consumption in 2020 we observe the opposite result, decreases in 2020 relative 2019 across all commodity price plans. Specifically, we observe that average monthly electricity consumption for a small commercial consumer decreases by 5.5% on a retail price plan, 2.7% on a tiered price plan, and 7.0% on a time-of-use price plan.

3.1.3 Peak Demand Timing Statistics

Main Observations

- The top-five peak demand hours of the year typically differs between zonal-level, residential-level, and small commercial-level demand data across each IESO electrical zone. We suspect this may be due to small commercial consumers operating within typical business hours (i.e., 9am to 5pm).

- The top 5 annual zonal and residential peak demand hours typically occur in July and August between hour ending 16 through 19 and January and February between hour ending 18 through 21.
- The top 5 annual small commercial peak demand hours occur earlier in the day in the summer and winter months typically between hour ending 11 and 16.
- On zonal peak demand days, we identify that the contribution of residential demand to zonal demand increases, on average, by approximately four percentage points; we observe little-to-no change for share of small commercial consumer demand.

Detailed Findings

As part of this section we analyze multiple aspects of residential and small commercial consumer peak demand. Specifically, in this section we investigate:

- Which hours of the day residential and small commercial consumer's use the most energy by season and IESO electrical zone
- Which are the top 5 days of the year when residential and small commercial use the most energy and how that compares to system energy by season and IESO electrical zone
- The contribution of residential and small commercial electricity consumption on the top 5 days where zonal demand is the highest

Tables 7, 8, and 9 identify the hours and months when the top 5 peak hours occur across each of the 10 IESO electrical zones between 2018 and November 2021 for zonal demand, residential zonal demand, and small commercial zonal demand. This results in a set of 50 peak demand values per year for each of the 4 years in our dataset, hence the 200 values you see in Tables 7, 8, and 9. These values are aggregated, so we do not specifically identify the month-hour combination for any particular IESO electrical zone in any given table below. However, we will make reference to which month-hour combinations are due to a particular IESO electrical zone. To start, we will make observations as they pertain to each individual table and then compare the results across tables.

Table 7 presents results for zonal demand only, from these results we observe that the majority of peak demand hours occur in summer months between June and July for hours 14 through 18 and winter months between January and February for hours 17 through 21. If we look at results at the IESO electrical zone level, not shown here but available in Appendix A, we see that this seasonal divergence in system demand at the IESO electrical zone level is due to geographic location. Southern IESO electrical zones primarily peak in the summer months, whereas northern IESO electrical zones primarily peak in the winter months.

Table 7: Top 5 Peak Demand Hour and Month Combinations For Each IESO Electrical Zone, Aggregated

Month	Hour Ending																								Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
1									2	2	1	2						12	11	5	1	3		1	40
2							1		1									1	4	5	7	3	1		23
3									2	1										1	2				6
4								1																	1
5							1		1					1											3
6									1				2				2		1						6
7											1	2	3	4	6	11	20	8	7		1				63
8													4	2	1	5	15	10	3	2					42
9													1		1		3	2	2						9
10																									
11						1								1				1							3
12																		1	2		1				4
Total						1	2	1	7	3	2	4	10	8	8	16	40	35	30	13	12	6	1	1	200

When we look at the residential demand results in Table 8 we see similar winter and summer peaking activity, compared to our zonal system demand results, in Table 7. However, the range of peak hours in the summer season is less broad than the zonal demand results. A majority of peak demand hours in the summer season occur between June and July between the hours of 18 and 19, inclusive. Peak demand hours in winter months occur between December through February, mostly between hours 18 and 20.

Table 8: Top 5 Residential Peak Demand Hour and Month Combinations For Each IESO Electrical Zone, Aggregated

Month	Hour Ending																								Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
1																			30	13	7	4			54
2																			5	6	2				13
3																									
4																									
5																									
6																	1	3	6						10
7															1	1		48	29	2					81
8																		20	5						25
9																		3	1						4
10																									
11																									
12																		1	10	1	1				13
Total															1	1	1	75	86	22	10	4			200

Small commercial peak demand hours deviate from our zonal and residential demand results. In both the summer and winter season, small commercial peak demand hours occur earlier on in the day. Most peak demand hours in the summer season occur between June and July between the hours of 11 and 16, inclusive. Peak demand hours in winter months occur between December through February, primarily between hours 10 and 12. Deviations in the small commercial results, compared to residential and zonal peak demand hour results are likely due to small commercial consumers operating within a set of core working hours tied to a typical work day (e.g., 9am to 5pm). However additional analysis beyond what is done in this report would be required to better understand the drivers that led to these small commercial peak demand timing results.

Table 9: Top 5 Small Commercial Peak Demand Hour and Month Combinations For Each IESO Electrical Zone, Aggregated

Month	Hour																								Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
1	4										1	18	8							1				1	33
2											1	16	2												19
3												1													1
4																									
5																									
6															3		1								4
7												4	8	27	42	5									86
8														8	36	7									51
9																									
10																									
11																									
12												4			1			1							6
Total	4										2	43	18	35	82	12	1	1		1				1	200

Finally, we compare the contribution of residential and small commercial load on the top 5 zonal peak demand days for each IESO electrical zone. We also look at the contribution of residential and small commercial demand for all remaining non-peak days as well as the fractional change between peak and non-peak days.

Tables 10 identifies the minimum, maximum, and average hourly fractional contribution of residential consumers to system demand. What the table shows is that within an IESO electrical zone there can be significant change on an hourly basis, for example, within the Toronto electrical zone the difference between the minimum and the maximum hourly share of residential consumption differs by 6.9 percentage points. We also see that minimum and maximum residential share of consumption across IESO electrical zones varies widely with a minimum value of 24.8% and a maximum of 42.8%, a 17.9 percentage point difference.

Table 10: Fractional Contribution of Residential Hourly Demand to Zonal Hourly Demand

IESO Zone	% Share of Zonal Demand on Peak Days			% Share of Zonal Demand on Non-peak Days			% Change in Share of Zonal Demand		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Bruce	0.2	0.3	0.3	0.3	0.4	0.3	-27.1	-7.7	-17.1
East	2.3	3.7	3.0	2.7	3.7	3.2	-18.3	5.9	-5.8
Essa	1.9	3.3	2.6	2.3	3.1	2.7	-15.8	10.2	-3.6
Niagara	1.2	2.1	1.7	1.0	1.6	1.3	11.3	40.1	26.0
Northeast	0.9	1.3	1.1	1.2	1.6	1.4	-30.8	-18.8	-23.6
Northwest	0.2	0.3	0.2	0.3	0.4	0.3	-39.1	-26.8	-32.2
Ottawa	1.9	3.2	2.6	1.9	2.9	2.4	-3.4	19.4	9.8
Southwest	5.7	9.8	7.8	5.2	8.1	6.7	3.1	26.8	16.3
Toronto	7.6	14.5	11.3	6.5	11.1	8.8	13.1	38.3	27.6
West	2.7	4.7	3.8	2.3	3.7	3.0	9.9	36.0	25.6
Total*	24.8	42.8	34.3	23.7	36.5	30.1	-0.3	24.3	13.5

** Column sums across IESO electrical zones do not equate to the values in the cells in `Total` row*

We can also identify the difference in residential share on zonal peak and non-peak days. Using our Toronto example, we can compare the average hourly residential share for both types of days 11.3% vs. 8.8% which suggests that on peak days the average hourly residential contribution to system demand increases by 2.5%. Similarly, the average total residential share on zonal peak days is 34.3% vs. 30.1% on non-peak days, a 4.3 percentage point difference. Overall, this tells us that residential demand can fluctuate significantly on zonal peak and non-peak days and these changes are driven by the most populated IESO electrical zones.

The small commercial results we present in Table 17 differ from our residential results and in most cases suggest that the small commercial share of demand on peak zonal demand days stays the same or decreases or in the very rare case of the Toronto electrical zone, the opposite and we see an increase in share on non-peak days. If we look at the total share of small commercial consumption relative total we see a modest increase in hourly minimum share when we compare peak and non-peak days 5.84% vs. 6.21%, a decrease in hourly maximum share 8.85% vs. 8.65% and an overall increase in average hourly share of 7.14% vs. 7.21%.

Table 11: Fractional Contribution of Small Commercial Hourly Demand to Zonal Hourly Demand

IESO Zone	% Share of Zonal Demand on Peak Days			% Share of Zonal Demand on Non-peak Days			% Change in Share of Zonal Demand		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Bruce	0.1	0.1	0.1	0.1	0.1	0.1	-11.8	0.7	-7.0
East	0.6	0.9	0.7	0.7	0.9	0.7	-12.8	2.1	-5.1
Essa	0.4	0.6	0.5	0.5	0.6	0.5	-16.0	1.3	-7.8
Niagara	0.4	0.5	0.4	0.3	0.4	0.4	1.3	14.3	8.4
Northeast	0.3	0.4	0.3	0.4	0.5	0.4	-22.9	-11.9	-17.4
Northwest	0.0	0.1	0.1	0.1	0.1	0.1	-30.4	-20.6	-25.5
Ottawa	0.5	0.7	0.5	0.5	0.7	0.6	-9.0	-0.5	-4.7
Southwest	1.6	2.3	1.9	1.6	2.2	1.9	-4.4	6.9	0.1
Toronto	1.3	2.2	1.7	1.4	2.1	1.7	-6.0	8.2	0.8
West	0.7	1.1	0.9	0.7	1.0	0.9	1.4	13.2	6.6
Total*	5.84	8.85	7.14	6.21	8.65	7.21	-6.75	5.47	-1.38

** Column sums across IESO electrical zones do not equate to the values in the cells in `Total` row*

Taken together, these results suggest that, historically, residential demand as a fraction of zonal peak demand increases on zonal peak demand days whereas small commercial demand relative to zonal peak demand changes modestly or not at all on zonal peak demand days.

3.2 Identifying the Contribution of Weather Variables in an Hourly Residential and Small Commercial Regression Model Prediction

In this section we investigate the contribution of weather-specific variables for a set hourly residential and small commercial regression models, broken down by IESO electrical zone. This analysis is a first-step in understanding the effect that weather variables have on consumer-specific demand that can, as data becomes available, be extended upon to more broadly understand and breakdown the impacts of weather variables across consumer sub-groups. Moving forward this will be a valuable tool to understand how each consumer group within the province behaves to changes in weather variables within regression models

Our approach for this analysis is to use the same set of variables that would appear in the IESO's current short-term demand forecasting models, but use more recent advances in machine learning regression modelling to capture the effect of weather variables. In this section we use a series of gradient boosting regression models to perform this task[2][3][4]. The main draw of using a gradient

[2] Greedy Function Approximation: A Gradient Boosting Machine - https://www.jstor.org/stable/2699986
[3] Gradient boosting machines, a tutorial - https://www.frontiersin.org/articles/10.3389/fnbot.2013.00021/full
[4] https://scikit-learn.org/stable/auto_examples/ensemble/plot_gradient_boosting_regression.html

boosting regression model as opposed to a linear regression model is that it is what is referred to in the machine learning community as an ensemble model, meaning that by default it combines multiple models together to create a model, in most cases, with stronger predictive performance. The only drawback to this approach is that unlike a linear regression model you cannot simply look at the parametric equation of this model – you must use alternative approaches to capture the effect of a particular variable[5][6].

Throughout this analysis we categorize the time-of-day in order to view results more easily and capture the average contribution that we might expect in those time periods. Our time-of-day categories are defined as follow for each group of hour ending values: morning = [6,7,8,9,10,11,12]; afternoon = [13,14,15,16,17]; evening = [18,19,20,21,22]; night = [1,2,3,4,5,23,24]. This analysis only uses data between 2018 and 2020, inclusive. As more data becomes available it will be included in this analysis.

Below we capture the main highlights of the section followed by a more in-depth discussion of the analysis.

Main Observations

- Our residential regression models for more northern IESO electrical zones identify that weather variables, on average, contribute more to predicting total hourly zone-specific hourly demand, in winter months, we theorize this may be due to increased heating load in these IESO electrical zones.
- Our residential regression models indicate that across all IESO electrical zones weather variables, on average, contribute more to predicting total hourly zone-specific hourly demand, in summer months, we theorize this may be due to increased cooling load in these IESO electrical zones.
- Our small commercial regression models indicate that this consumer group are less weather dependent, particularly in the summer season, however, in the winter season we see comparable results to residential consumers.
- Residential test set MAPE ranges between 5.4% and 6.6% across IESO electrical zones, similarly small commercial test set MAPE ranges between 4.3% and 12.3%, we suspect that improvements can be made to these models over time as more data is collected and alternative model specification are explored.

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[5] https://github.com/slundberg/shap
[6] A Unified Approach to Interpreting Model Predictions - https://doi.org/10.48550/arXiv.1705.07874

Detailed Findings

Table 12 and 13 breaks down the contribution of weather variables for the residential and small commercial regression models predictions that were developed for this section, represented in percent values and broken down by season, time-of-day, and IESO electrical zone.

From our residential regression model results we find that our weather variables contribute significantly more, on average, to total residential hourly demand in the Northeast, Northwest, East, and Essa IESO electrical zones during winter months. For spring and fall months our results are similar across seasons and within IESO electrical zones, we observe increased contribution of weather variables across each time-of-day periods for most IESO electrical zones compared to the winter months with little-to-no increase or decrease in contribution from weather variables in the Northeast, Northwest, East, and Essa IESO electrical zones. In summer months we find increased contribution of weather variables in all zones and time-of-day-categories.

Table 12: Average Contribution of Weather Variables to Hourly Residential Demand Prediction, Broken Down by Season, Time-of-day, and IESO Electrical Zone

Electrical Zone	Winter				Spring				Summer				Fall			
	Morn	Aft	Eve	Night	Morn	Aft	Eve	Night	Morn	Aft	Eve	Night	Morn	Aft	Eve	Night
East	12%	10%	8%	12%	11%	11%	9%	13%	14%	13%	11%	15%	12%	13%	10%	16%
Essa	11%	9%	7%	11%	10%	11%	8%	11%	15%	14%	12%	15%	12%	12%	9%	15%
Niagara	6%	5%	5%	7%	13%	13%	13%	17%	20%	24%	20%	19%	15%	14%	13%	19%
Northeast	16%	14%	12%	16%	12%	12%	10%	13%	22%	15%	13%	23%	15%	14%	11%	18%
Northwest	16%	14%	11%	15%	11%	11%	9%	12%	22%	13%	11%	21%	12%	11%	9%	14%
Ottawa	9%	7%	5%	8%	10%	11%	9%	13%	15%	17%	14%	15%	12%	12%	10%	16%
Southwest	6%	5%	4%	6%	10%	11%	10%	12%	15%	19%	15%	15%	12%	12%	10%	15%
Toronto	6%	5%	5%	7%	14%	13%	13%	18%	22%	27%	20%	18%	16%	14%	13%	21%
West	6%	6%	5%	7%	12%	13%	13%	17%	19%	24%	18%	16%	15%	14%	12%	18%
Avg.	9%	7%	6%	9%	10%	11%	9%	13%	16%	16%	13%	16%	12%	11%	10%	15%

We theorize that our residential regression model results point towards the following:

- regression models using data from more northern IESO electrical zones see greater contribution from weather variables in winter months, we suspect this is likely due to increased heating load in those months, compared to other IESO electrical zones;
- regression models across all IESO electrical zones find increased contribution from weather variables in Summer months, we suspect this is likely due to increased cooling load in those months; and

- a phenomenon exists across all seasons where we see an increased contribution of weather variables during night-time hours, further investigation is required to understand what might contribute to these results.

For our small commercial regression model results we find that, broadly speaking, weather variables contribute less to predicting total hourly small commercial electricity demand, especially in the summer season, relative to our residential regression results. However, we do observe a similar pattern of behaviour to our residential regression model results, where weather variables contribute more in the winter season for our more northern (Northeast and Northwest) IESO electrical zone regression models.

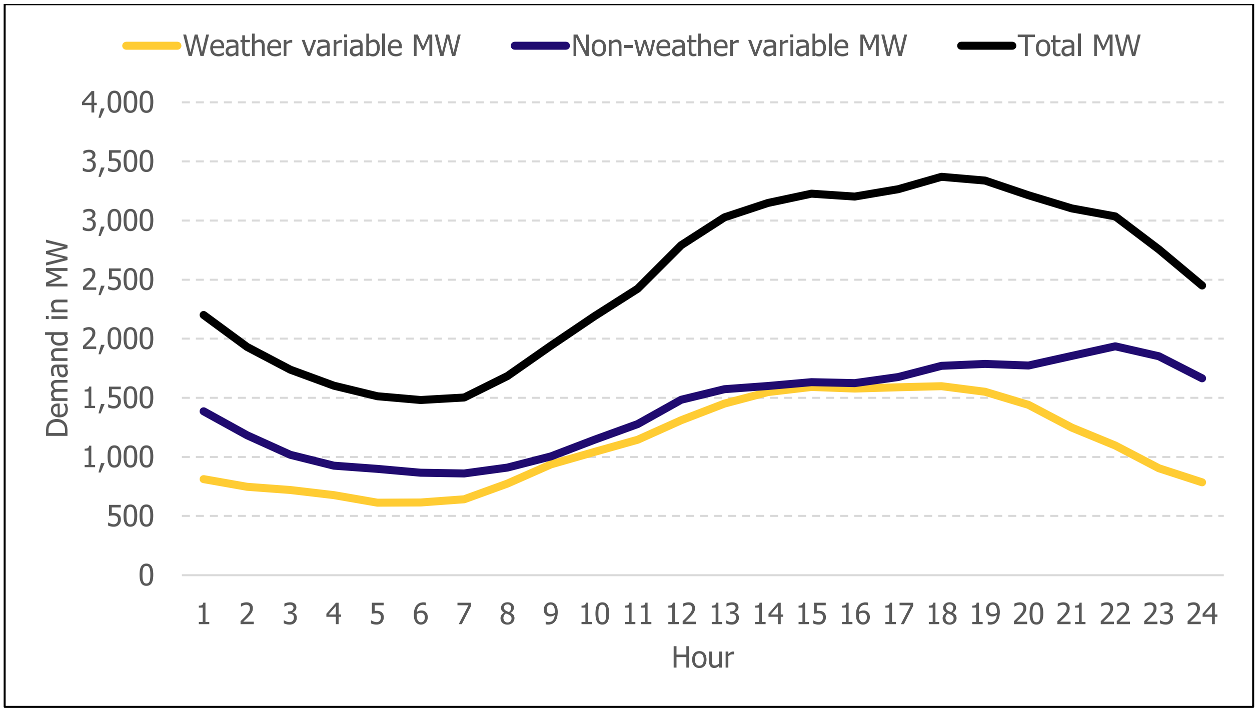
Table 13: Average Contribution of Weather Variables to Hourly Small Commercial Demand Prediction, Broken Down by Season, Time-of-day, and IESO Electrical Zone

Electrical Zone	Winter				Spring				Summer				Fall			
	Morn	Aft	Eve	Night	Morn	Aft	Eve	Night	Morn	Aft	Eve	Night	Morn	Aft	Eve	Night
East	7%	6%	6%	8%	7%	7%	9%	9%	7%	8%	7%	9%	8%	7%	9%	11%
Essa	7%	6%	5%	7%	6%	6%	7%	7%	7%	7%	6%	9%	7%	6%	8%	9%
Niagara	5%	4%	5%	6%	8%	7%	10%	11%	9%	12%	9%	10%	8%	6%	9%	12%
Northeast	12%	13%	10%	11%	9%	8%	11%	12%	12%	5%	11%	23%	10%	7%	14%	17%
Northwest	14%	14%	12%	14%	9%	8%	11%	12%	15%	5%	13%	24%	11%	8%	13%	16%
Ottawa	7%	5%	5%	7%	7%	7%	8%	8%	7%	8%	6%	8%	8%	7%	8%	10%
Southwest	5%	5%	4%	5%	6%	6%	9%	9%	8%	10%	7%	9%	6%	5%	8%	11%
Toronto	4%	4%	3%	5%	6%	7%	8%	6%	7%	9%	7%	7%	7%	6%	7%	8%
West	4%	4%	4%	5%	7%	7%	10%	9%	9%	13%	9%	7%	7%	7%	9%	10%
Avg.	6%	6%	5%	7%	7%	6%	8%	8%	8%	8%	8%	10%	7%	6%	9%	10%

Moving on, we provide a summer and winter season example of using our analysis to break down a residential daily load profile into its weather-variable and non-weather variable components. This type of analysis can be extended to any length of time within our dataset.

Figure 2 and Table 14 presents a breakdown of one summer season daily load profile for residential consumers on the warmest day in 2019, July 20, for the Toronto IESO electrical zone.

Figure 2: Toronto IESO Electrical Zone Residential Load Profile for July 20, 2019, Broken Down by Weather and Non-weather Variables



Throughout this particular day, weather variables contributed to approximately 40% of the prediction for total hourly energy for the Toronto electrical zone, on average with a low of 33% and a high of 45%.

Table 14: Toronto IESO Electrical Zone Residential Load Profile Data for July 20, 2019, Broken Down by Weather and Non-weather Variables

Hour Ending	Weather variable MW	Non-weather variable MW	Weather Percent	Non-weather Percent	Total MW
1	813	1,387	37%	63%	2,200
2	749	1,182	39%	61%	1,931
3	720	1,019	41%	59%	1,739
4	677	926	42%	58%	1,602
5	613	900	41%	59%	1,513
6	615	867	41%	59%	1,482
7	641	860	43%	57%	1,502
8	775	910	46%	54%	1,686
9	937	1,004	48%	52%	1,941
10	1,044	1,146	48%	52%	2,190
11	1,145	1,277	47%	53%	2,422
12	1,309	1,483	47%	53%	2,792
13	1,453	1,574	48%	52%	3,026
14	1,548	1,601	49%	51%	3,149
15	1,593	1,634	49%	51%	3,227
16	1,578	1,624	49%	51%	3,202
17	1,589	1,676	49%	51%	3,264
18	1,599	1,771	47%	53%	3,370
19	1,551	1,788	46%	54%	3,339
20	1,440	1,772	45%	55%	3,213
21	1,249	1,854	40%	60%	3,103
22	1,098	1,936	36%	64%	3,034
23	904	1,852	33%	67%	2,757
24	787	1,664	32%	68%	2,451
Min	613	860	32%	51%	1,482
Max	1,599	1,936	49%	68%	3,370
Average	1,101	1,404	44%	56%	2,506

If we compare this result to the coldest day in 2019, January 21, our regression model results identify that weather variables contribute far less to our overall prediction, on average, only 15%, with a range between 6% and 23%.

Figure 3: Toronto IESO Electrical Zone Residential Load Profile for January 21, 2019, Broken Down by Weather and Non-weather Variables

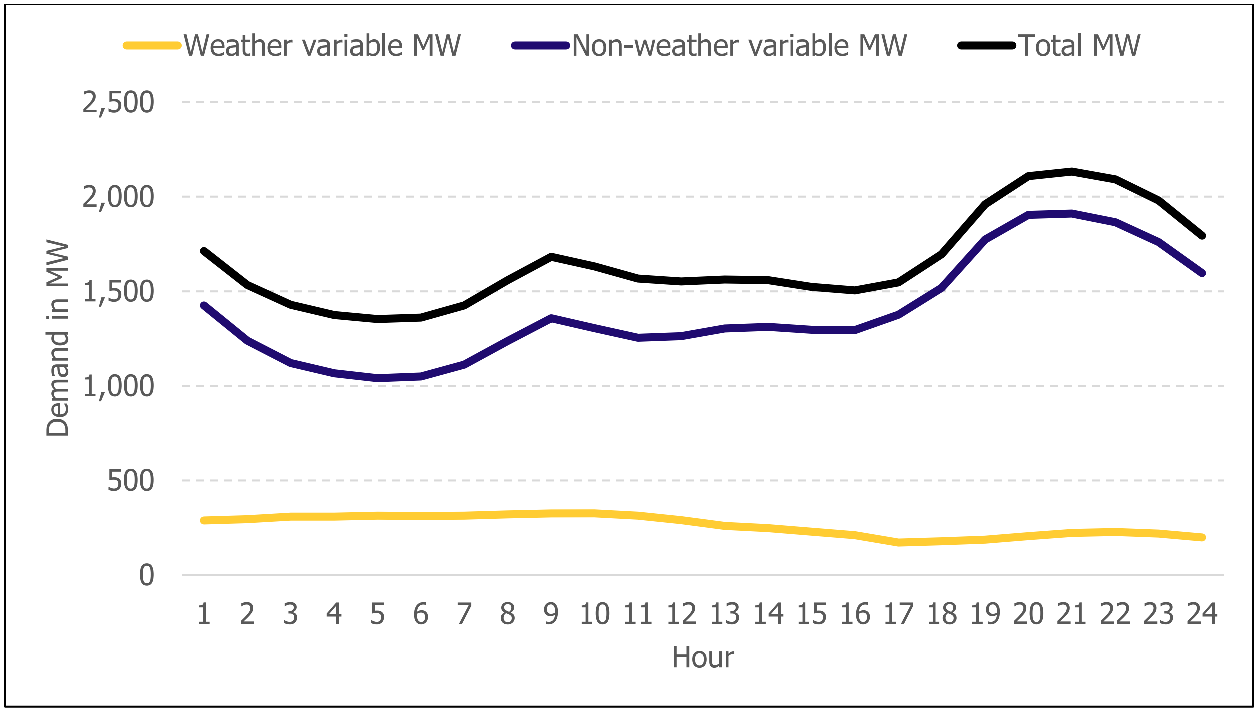


Table 15: Toronto IESO Electrical Zone Residential Load Profile Data for January 21, 2019, Broken Down by Weather and Non-weather Variables

Hour Ending	Weather variable MW	Non-weather variable MW	Weather Percent	Non-weather Percent	Total MW
1	288	1,424	17%	83%	1,712
2	294	1,238	19%	81%	1,532
3	308	1,120	22%	78%	1,428
4	308	1,066	22%	78%	1,374
5	313	1,040	23%	77%	1,353
6	312	1,049	23%	77%	1,361
7	314	1,111	22%	78%	1,425
8	320	1,238	21%	79%	1,558
9	325	1,356	19%	81%	1,681
10	326	1,305	20%	80%	1,631
11	313	1,254	20%	80%	1,567
12	289	1,262	19%	81%	1,552
13	259	1,303	17%	83%	1,563
14	248	1,311	16%	84%	1,558
15	228	1,295	15%	85%	1,523
16	211	1,294	14%	86%	1,505
17	171	1,376	11%	89%	1,547
18	178	1,519	10%	90%	1,696
19	187	1,773	10%	90%	1,960
20	204	1,904	10%	90%	2,108
21	222	1,911	10%	90%	2,132
22	227	1,865	11%	89%	2,092
23	219	1,760	11%	89%	1,979
24	198	1,596	11%	89%	1,794
Min	171	1,040	10%	77%	1,353
Max	326	1,911	23%	90%	2,132
Average	261	1,390	16%	84%	1,651

Moving forward, this form of analysis can be extended to identify the contribution of weather variables in regression models of other groups of customers, IESO electrical zones, MRP demand forecast areas, and total system-wide electricity demand. In addition to this we can extend this analysis to other forms of customer-specific variables, for example larger commercial consumers may be more susceptible to price response signals than residential or small commercial consumers, and determine what, if any affect those variables have on those consumer’s demand.

We finalize this section by providing some insight into the performance of the model's that were trained to perform this analysis. The metric that we present to identify model performance is Mean Absolute Percent Error (MAPE)[7]. A MAPE statistic identifies in percentage terms how far off are predicted values are from our actual observed values, on average. Table 16 present MAPE statistics by IESO electrical zone and commodity rate class. More specifically, these MAPE values are an average of the test-set predictions produced from performing a three-fold cross-validation[8] on our dataset, which typically provides a more accurate depiction of how these models will perform when presented with new unforeseen data.

Table 16: Mean Absolute Percent Error Statistics, Broken Down by Distribution Rate Class and IESO Electrical Zone

IESO Zone	Distribution Rate Class	
	Res-reg	GSLT50
East	6.2%	4.3%
Essa	6.6%	4.3%
Niagara	6.2%	12.3%
Northeast	5.6%	4.7%
Northwest	5.6%	5.0%
Ottawa	6.4%	5.0%
Southwest	5.9%	8.5%
Toronto	6.6%	5.4%
West	5.4%	4.9%

Residential test set MAPE ranges between 5.4% and 6.6% across IESO electrical zones, similarly small commercial test set MAPE ranges between 4.3% and 12.3%. Improvements can likely be made to the individual residential and small commercial models to improve performance; we also note that that each of these models were developed using three years of data, of which, one year corresponds to a global pandemic that has had a material impact on how residential and small commercial consumers use electricity that would impact model performance.

3.3 Identification of Residential Energy and Demand Trends Using Geospatial Features

In this section we use the geospatial features of the SME dataset to investigate monthly energy use and peak demand at a forward sortation area level for residential consumers only. We do this in two ways: producing geospatial visualizations to identify changes in average monthly energy use across

[7] https://en.wikipedia.org/wiki/Mean_absolute_percentage_error
[8] https://en.wikipedia.org/wiki/Cross-validation_(statistics)

time and to select the 10 forward sortation areas in each IESO electrical zone with the highest average monthly energy usage for summer months only. For our peak demand analysis, we look at the top 10 system-wide demand days in each year, and calculate average demand for that set of peak hours for each forward sortation area. This analysis was done for January 2019 through November 2021 and can be extended to other consumer classes and years as the data becomes available. Below we present the highlights to this section and continue with a more in-depth discussion of the analysis.

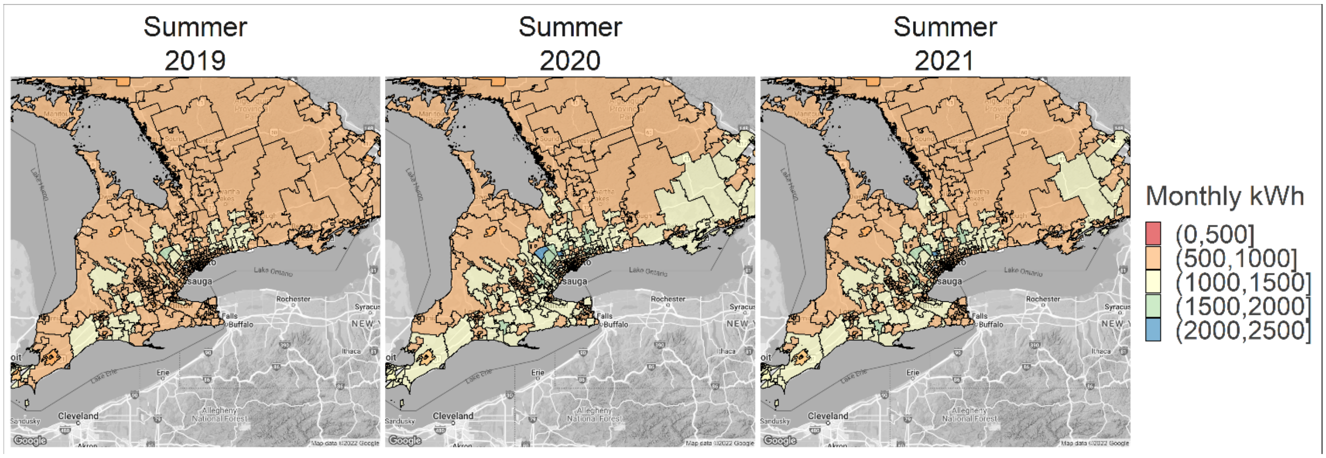
Main Observations

- Our analysis provides insight into:
    - average monthly residential energy use behaviour at an FSA level and identifies, for each of the years in our dataset, the 10 FSA's with the largest average monthly energy use.
    - FSA-level percent change in average monthly energy use from 2019 to 2020 and 2020 to 2021 and identifies that average monthly energy use increased approximately 17.5% from 2019 to 2020 and decreased 4.6% from 2020 to 2021.
    - Average hourly demand during the top 10 peak hours of each of 2019, 2020, and 2021.

Detailed Findings

As an example we focus on a single area of Ontario, centered around Toronto, in order to demonstrate how one could use the geospatial features in the SME data to observe changes in average monthly household energy usage at the FSA-level. A visual inspection of the left-and-right-hand graphics in Figure 4 suggests some sort-of shifting in average monthly energy as we move from summer 2019 to summer 2020 and as we continue into summer 2021 it looks like a slight regression to summer 2019 values.

Figure 4: Average Residential Monthly Energy in kWh, Broken down by Forward Sortation Area, Season, and Year



However, it's not absolutely clear how large these shifts are and in order to investigate that we can produce additional figures to illustrate the change in average monthly energy at the FSA-level. For example, Figure 5 maps the distribution of average monthly energy statistic by FSA for each year and summer season and shows the exact shift in the distribution of average monthly energy. Table 17 presents average monthly energy statistics for each year and summer season and identifies that in the summer of 2019 average monthly energy at the FSA-level is 798 kWh/month, in the summer of 2020 this increases to 938 kWh/month; and finally in the summer of 2021 this decreases to 895 kWh/month.

Figure 5: Average Residential Monthly Energy Density Function, Broken down by Year, Averaged at the FSA-level

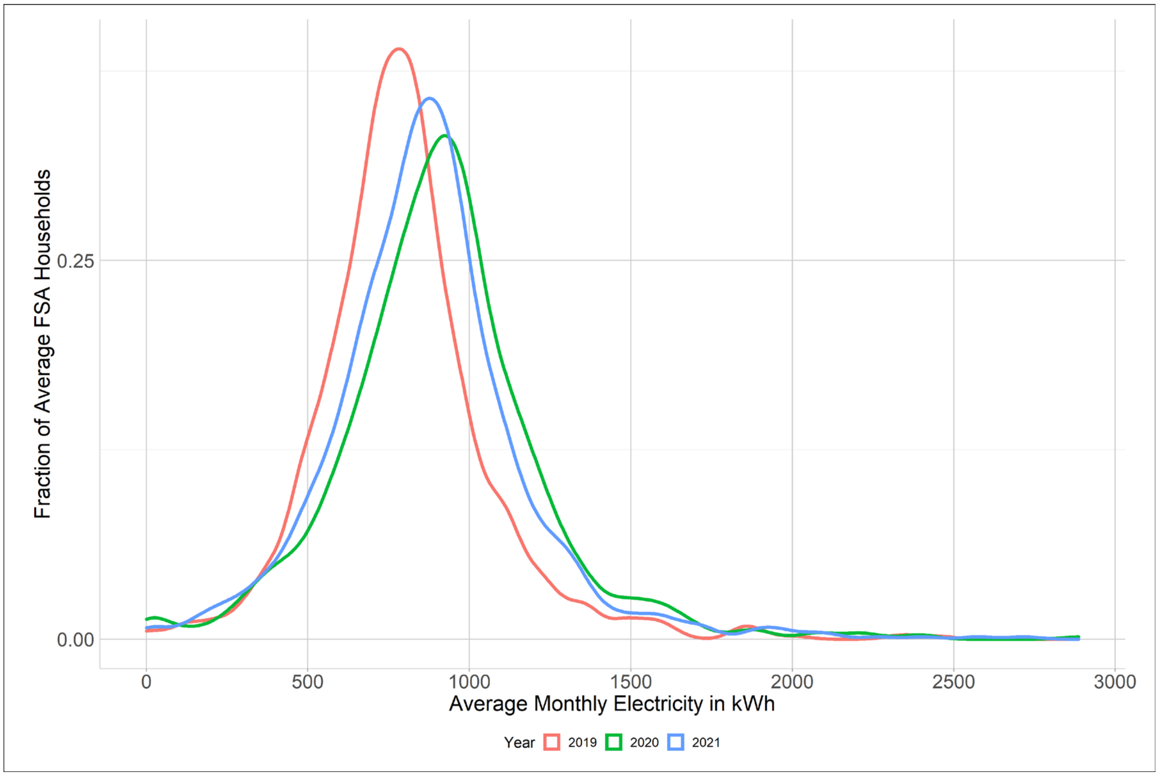
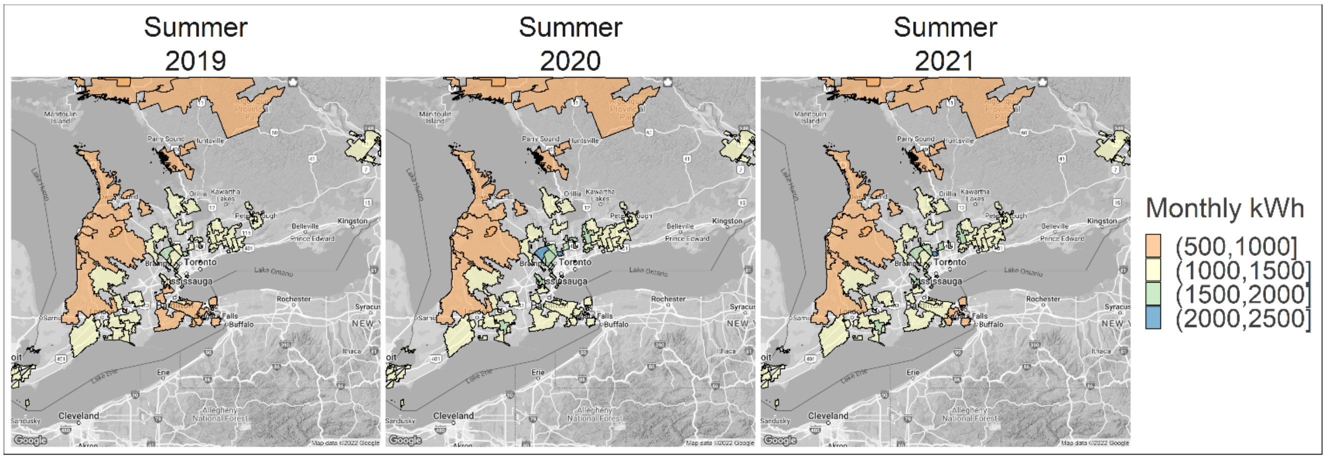


Table 17: FSA-level Monthly Energy Statistics, Broken Down by Year

Year	2019	2020	2021
Average Monthly Energy in kWh	798	938	895

We can break down the statistics in Figure 5 further by focusing on the FSA's in each IESO electrical zone that have the 10 largest average monthly energy statistics.

Figure 6: Top 10 FSA-level Average Residential Monthly Energy Statistics in kWh for each IESO Electrical Zone



Year-over-year comparisons allow us to determine if these FSA's consistently fall within this top 10 average monthly energy category, or any size less than or greater than 10 that we prefer, moving forward. The FSA L0J appears in the first or second position across all years in our dataset.

Table 18: Top 10 FSA-level Average Residential Monthly Energy Statistics in kWh for the Toronto IESO Electrical Zone Only

Rank	Toronto								
	2019			2020			2021		
	FSA	Average Monthly Energy in kWh	Premise Count	FSA	Average Monthly Energy in kWh	Premise Count	FSA	Average Monthly Energy in kWh	Premise Count
1	L0J	1,925	1,523	L0J	2,193	1,536	L3L	2,117	10
2	L3Y	1,882	67	L6L	1,891	31	L0J	2,094	1,560
3	L6L	1,579	32	L3Y	1,588	70	L6L	1,970	31
4	M2L	1,325	3,858	M2L	1,538	3,843	L0H	1,473	1,203
5	L0H	1,295	1,216	L0H	1,507	1,208	L9P	1,463	826
6	L9P	1,284	810	L9P	1,492	834	L7B	1,436	3,926
7	L1Y	1,281	737	L7B	1,470	3,951	M2L	1,428	3,879
8	L7B	1,263	3,405	L1Y	1,442	737	L1Y	1,380	733
9	L9L	1,255	283	L5H	1,428	5,597	L5H	1,360	5,598
10	L5H	1,222	5,554	L6J	1,397	8,099	L9L	1,354	284

We can also produce a similar analysis to the one above but investigate the change average monthly energy at the FSA level. Figure 7, below, presents the same geographic subsection of Ontario where each FSA is filled in with the percent change in average monthly energy from the year prior. For summer 2020 we see percent changes in each FSA using 2019 as our base, similarly for 2021 we see percent changes using 2020 as our base. Simply looking at Figure 7 we can see that the FSA-level percent changes are largely increases that range from 0% to 40%, with a majority of values ranging from 10% to 30%. Similarly, for 2021 we primarily see, visually, negative changes, less than 0 but greater than -50%, again with a majority of values between -10% and 0%.

Figure 7: Percent Change in Average Residential Monthly Energy, Broken down by Forward Sortation Area, Season, and Year

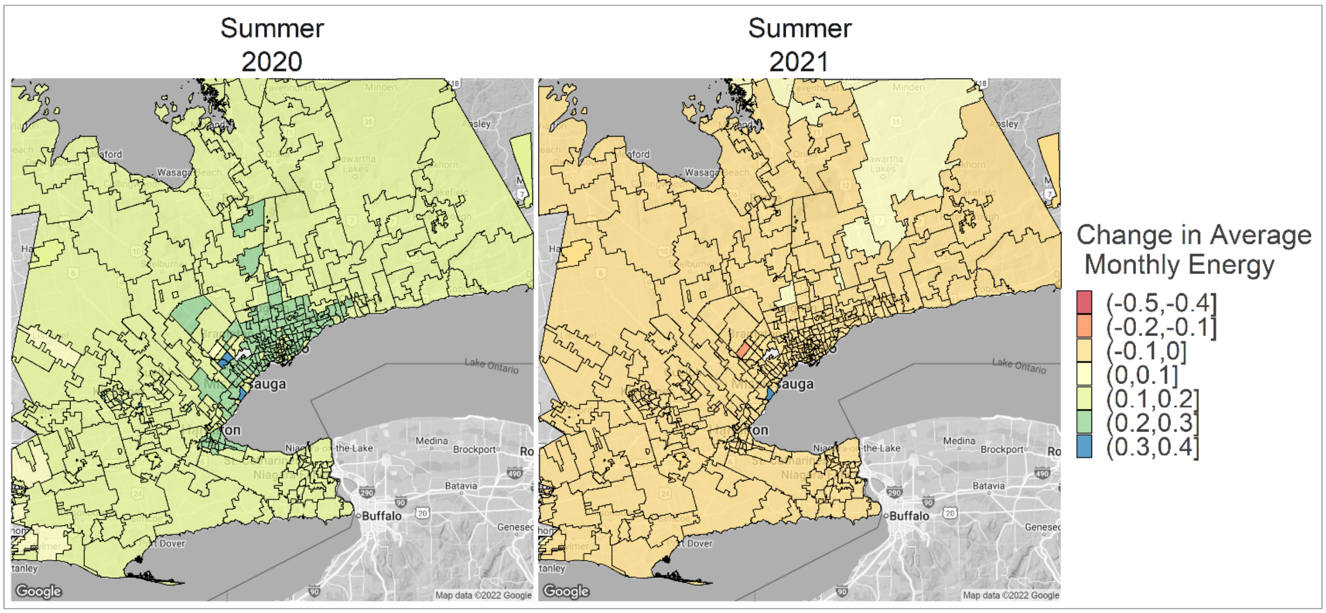


Figure 8 and Table 19 presents additional information on the FSA-level percent change statistics in Figure 7 and shows that the average change in monthly energy was approximately 17.5% in 2020 and -4.6% in 2021.

Figure 8: Percent Change Average Residential Monthly Energy Density Function, Broken down by Year, Averaged at the FSA-level

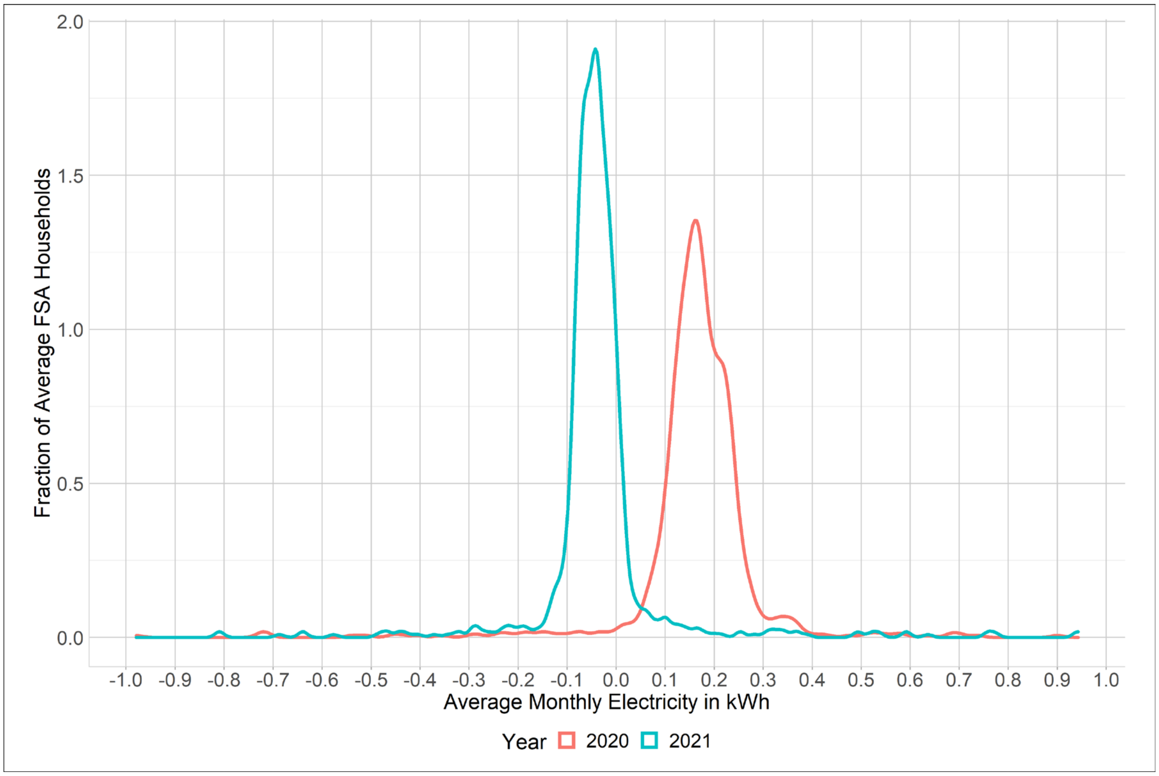


Table 19: FSA-level Percent Change Monthly Energy Statistics, Broken Down by Year

Year	2019	2020	2021
Percent Change in Average Monthly Energy	N/A	17.5	-4.6

Changing the lens on this analysis and switching from energy to demand statistics allows us to assess FSAs within a different context and focus on each FSA's average household demand on the top 10 system-wide demand days of 2019, 2020, and 2021. Standardizing by the number of households within each FSA will allow us to look for FSA's where higher than normal demand is used on a per-household basis for the peak system-wide days in each of the years previously mentioned. For reference, below are the top 10 days for each of 2019, 2020, and 2021 in Table 20[9].

[9] https://www.ieso.ca/en/Sector-Participants/Settlements/Peak-Tracker

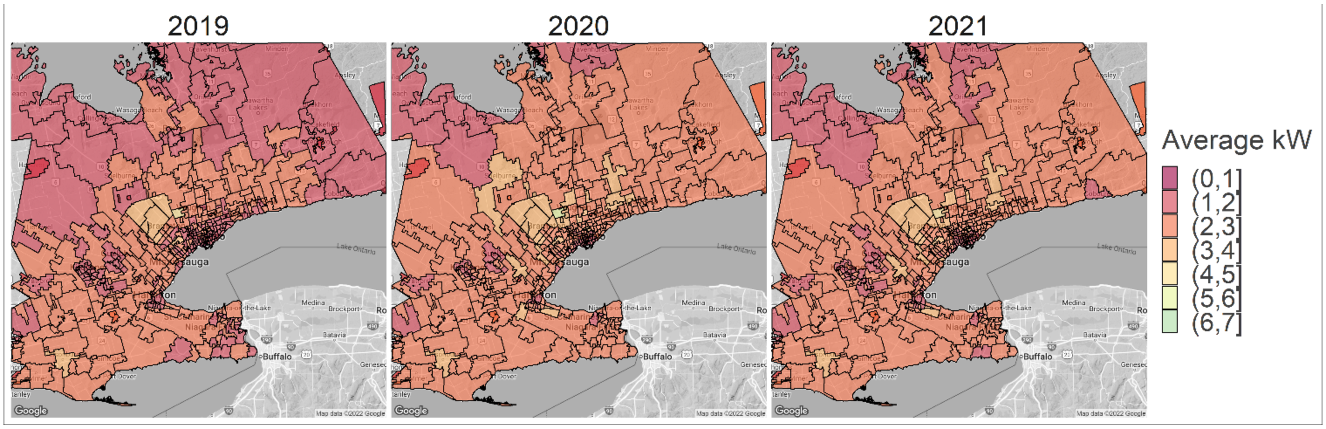
Table 20: System-wide Peak Demand Days, Broken Down by Year

Top Demand Day	2019	2020	2021
1	July 29, 2019	July 9, 2020	August 24, 2021
2	July 5, 2019	July 7, 2020	August 26, 2021
3	July 20, 2019	July 8, 2020	August 9, 2021
4	July 19, 2019	July 27, 2020	August 25, 2021
5	July 4, 2019	August 10, 2020	August 23, 2021
6	August 21, 2019	July 10, 2020	June 28, 2021
7	July 30, 2019	August 24, 2020	August 11, 2021
8	August 20, 2019	July 6, 2020	August 29, 2021
9	July 10, 2019	July 26, 2020	August 19, 2021
10	August 7, 2019	July 3, 2020	August 12, 2021

We use average hourly household demand for each FSA across each of the top 10 demand day hours as our statistic in the figures and tables below. Put another way, we take the demand for the peak demand hour for a given year across each of the top 10 days in Table 20 above and calculate the average across those 10 days to determine the average monthly peak consumption for each year across each FSA.

Figure 9 captures the average residential household peak demand for each of the top 10 system-wide peak days for this part of Ontario whereas Figure 11 focuses on the 10 FSA's within each IESO electrical zone. Taken together, these figures allow us to visualize, using the geospatial elements of the SME data, which areas of the province contain households that are on average greater contributors to system-wide demand.

Figure 9: Average Residential Peak Demand in Top 10 Peak Demand Hours, Broken down by Forward Sortation Area, Season, and Year



Similar to our analysis of monthly energy statistics, we can produce distributions for the peak demand statistics we created to observe shifts in these statistics over time. We can see that from 2019 to 2020 these peak demand statistics shifted to the right, indicating that on average in those top 10 peak demand days' average household demand at the FSA-level was higher. From 2020 to 2021 we see a regression of our distribution to something in between our 2019 and 2021 distributions.

Figure 10: Average Residential Peak Demand Density Function, Broken down by Year, Averaged at the FSA-level

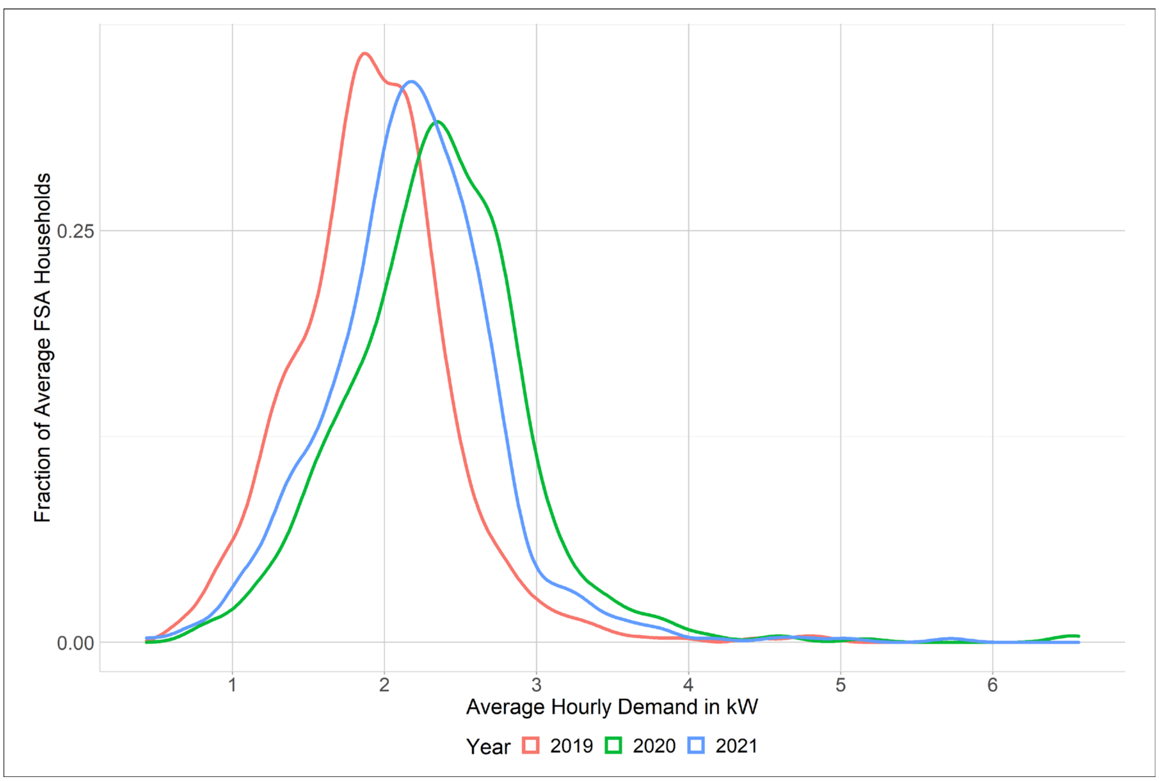


Table 21: FSA-level Peak Demand Statistics, Broken Down by Year

Year	2019	2020	2021
Average Hourly Peak Demand	1.93	2.35	2.18

The cause of this regression could be for multiple reasons: weather and/or the gradual removal of COVID restrictions in the summer of 2021 seem most likely but are speculative until further analysis is done. Similar to our monthly energy analysis we can also focus on the top 10 FSA's in each IESO electrical zone and output those results, as seen in Figure 11 and Table 22.

Figure 11: FSA-level Average Residential Peak Demand Statistics in kW for each IESO Electrical Zone, Averaged Across Top 10 Peak Demand Hours by Year

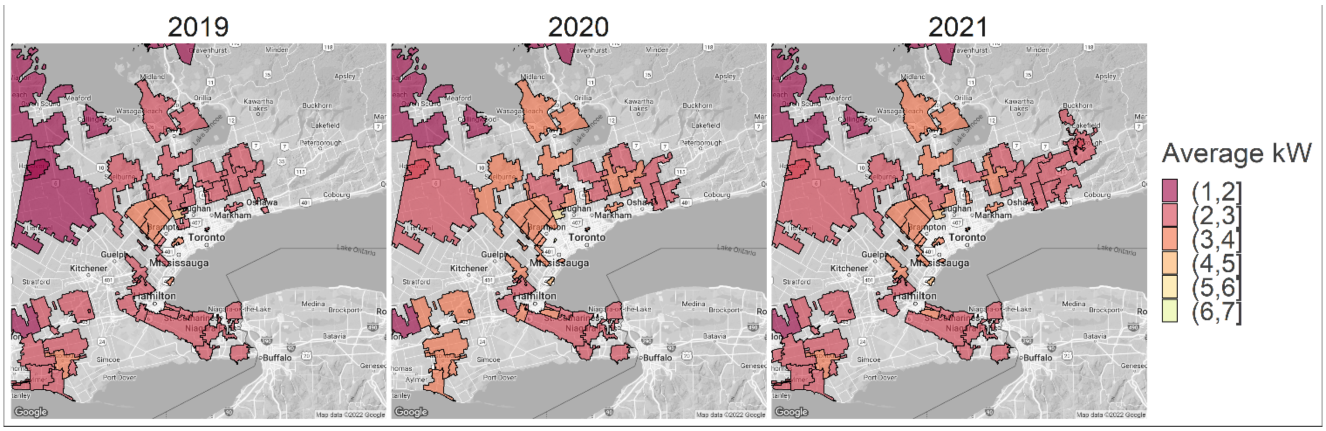


Table 22: FSA-level Average Residential Peak Demand Statistics in kW, Averaged Across Top 10 Peak Demand Hours by Year for the Toronto IESO Electrical Zone Only

Rank	Toronto								
	2019			2020			2021		
	FSA	Average Peak Demand in kW	Premise Count	FSA	Average Peak Demand in kW	Premise Count	FSA	Average Peak Demand in kW	Premise Count
1	L0J	4.4	1,523	L0J	5.2	1,536	L3L	5.0	10
2	L3Y	4.0	67	L6L	4.5	31	L0J	4.8	1,560
3	L6L	3.7	32	L7B	3.8	3,951	L6L	4.6	31
4	L7B	3.1	3,405	M2L	3.6	3,843	L7B	3.5	3,926
5	M2L	2.9	3,858	L0H	3.6	1,208	L0H	3.3	1,203
6	L4L	2.8	15,713	L6P	3.4	19,603	M2L	3.3	3,879
7	L0H	2.8	1,216	L5H	3.4	5,597	L5H	3.2	5,598
8	L5H	2.8	5,554	L9P	3.4	834	L9P	3.2	826
9	L6P	2.8	19,536	L4L	3.4	15,807	L6P	3.2	19,615
10	L1Y	2.8	737	M3B	3.4	3,770	L4L	3.1	15,820

To conclude, throughout this section we have demonstrated how the various geospatial features within the SME data could be used to identify energy and demand patterns in residential consumer's specifically but also note that this analysis could be applied to any consumer class across multiple years to identify within-or-across-year consumer energy or demand behaviour changes. Next steps in this work will be to work with the SME to investigate high energy usage forward sortation areas and potentially build custom datasets to investigate individual level energy behaviour.

4. Conclusion and Next Steps

As previously mentioned, this paper is a part of a series of DCP demand research papers that aim to shed light on historical demand trends and how these trends will help inform elements of the DCP team's ongoing and future work engagements.

At a high-level, our analysis has resulted in the following:

- **Production of energy statistics** to aid in the understanding of historical residential and small commercial consumer electricity consumption and demand behaviour.
- **Production of a series of hourly residential and small commercial electricity demand machine learning models** to capture and isolate the effect of weather on hourly residential and small commercial electricity consumption to improve demand forecast processes and models.
- **Production of geographical visualizations** to identify forward sortation areas with the highest average monthly residential and small commercial electricity consumption to better enable geo-targeting for demand management activities such as energy conservation and demand response programs.

Moving forward, the DCP group has already committed to produce research on the electric vehicle and mining sectors as well as investigate the impacts of climate change on electricity demand. The analysis conducted within this paper will continue to evolve and investigate the changing behaviour of residential and small commercial consumers, and additional commodity and distribution rate classes as that information becomes available.

The SME has identified that it is creating comparable version of this dataset that would allow the IESO to continue to create the statistics produced within this document and continue to observe changes in residential and small commercial demand behaviour.

The weather sensitivities section of this paper investigates one form of machine learning, specifically supervised machine learning for regression, subsequent papers will likely investigate other areas of machine learning, for example, supervised machine learning for classification purposes, where your predicted or outcome variable is not continuous (e.g., a label like "low", "medium", or "high") or unsupervised machine learning, which explores grouping data based on similar characteristics.

DCP staff have met with the SME to discuss the creation of additional datasets that would investigate individual-level consumer behaviour while still ensuring anonymity and privacy are protected.

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