Factors Affecting Electricity Consumption in Calgary, Alberta and Their Relationships Between Land-Use Classifications

Jason Hawkins

University of Calgary
2500 University Dr NW
Calgary, AB T2N 1N4

Abstract

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.

Keywords:

1. Introduction

Concerns about human-induced climate change and the availability of energy resources have placed increasing pressure on the electricity sector to innovate. This is especially true in Alberta where electricity and heating production accounts for 23% of total green-house gas emissions [1]. In an effort to address the high carbon content of the provincial electricity grid, the provincial government has enacted policy to move towards the phasing out of coal-fired power plants [2], to be replaced with a mix of natural-gas fired plants and renewable sources. This is an important effort, but efficiency of consumption remains vital and this will require a more clear picture of the factors that contribute towards higher rates of consumption. Electricity consumption is enmeshed in our utilization of a wide variety of services in both the home and at work. It is a necessary component in the illumination of our homes, proper functioning of an increasingly technologically-dependent system of production, and is likely to form an increasing component of transportation energy in the future. This research employs statistical and spatial analytic methods to ascertain the socioeconomic and spatial influences on electricity consumption. A variety of statistical sources are utilized to provide a more granular analysis of socioeconomic and built-form classifications than previous studies of this nature. The study area is the City of Calgary in the Canadian province of Alberta and analysis is performed for the year 2014. Consumptive patterns are differentiated between residential, commercial, and industrial sources.

Most studies of electricity use in cities have focused on residential consumption and placed it in the context of overall energy consumption. Lenzen et al. [3] perform an extensive study across multiple countries, with a focus on the validity of a Kuznets curve assumption. This is the principle that energy consumption grows with increasing national GDP, before falling again for the highest GDP nations, according to a bell curve. They do not find evidence to support this assumption, but rather find energy consumption to increase monotonically with the income of a nation. However, the rate of increase in consumption diminishes in higher income nations as a higher proportion of additional income is devoted to the acquisition of goods and services rather than satisfying basic energy needs. They find average income to be a dominant factor in energy consumption across countries, but do not provide an indication within each country of its influence on consumption. Lariviére and Lafrance [4] find population density to be a significant factor in reduced electricity consumption, but note the influence is not as strong as that for transportation fuel consumption.

They also find property value in a city and the age of residents to be significant factors. Similar studies of energy characteristics have been performed by many other authors, but few in-depth studies of the relationships across a single city have been conducted. Howard et al. [5] examine the spatial distribution of energy across the city of New York NY at the level of ZIP codes. They build a predictive model of energy consumption with residences disaggregated by building type and land-use differentiated by employment sector. They find that a single large facility can skew the results for an employment sector. For example, a hospital with a focus on energy conservation will have significantly different energy consumption patterns than the average hospital in the region. They also find spatially local deviations in residential energy consumption, which they believe to be the result of income differences that were not included in the model. The literature suggests a gap in analysis between large-scale comparisons between cities [3][4][6][7] and modelling of energy demand in individual buildings [8]. This research aims to contribute to filling this gap by considering the electricity consumption patterns across the City of Calgary.

2. Methodology

2.1. Data Sources

Electricity consumption data were acquired from ENMAX Power Corp. as annual totals for 2014 by postal code. This was taken as the model year and all other data were obtained for, or factored to, this year. ENMAX provides the overwhelming majority of electricity to residents and firms located in the Calgary CMA. For reasons of confidentiality and coverage by other firms, ENMAX was not able to provide the full set of data. The data provided were deficient in their coverage of the region, with totals missing for several postal codes. A system was developed to fill gaps in coverage by utilizing land-use and parcel data available from City of Calgary and Statistics Canada sources. The first step in this process was to count land parcels in each postal code. These results were then used to obtain an average electricity consumption per parcel in each postal code for which data were available. These averages were then transferred to proximate postal codes for which measured data were not available. In some instances the nearest postal code to a residential postal code was coded as commercial or industrial. These parcels would not have similar average consumption patterns and a check was included for this situation, such that the minimum adjacent value was utilized in approximating postal code consumption totals. This assumption errs on the side of conservatism in that it is assumed unknown postal codes have a minimum reasonable consumption total. Finally, a visual check was performed by mapping consumption totals as dots sized by their magnitude and confirming the reasonableness of values at institutions, shopping centres, and large industrial facilities. Consumption totals were then aggregated to the census community geography to match the level of detail at which socioeconomic data were available.

A second stage in the development of the model data was to differentiate between consumption by residential, commercial, institutional, industrial, and other sources. Land-use polygons were available from the City of Calgary at a mid-level aggregation, above dissemination areas. Postal code consumption totals were classified by their location within these land-use polygons. Aggregating to the census community provides an approximation of the relative contributions of residential and non-residential sectors. It is important to note that census communities do not necessarily represent residential neighbourhoods. This is a statistical geography defined by Statistics Canada and a community can also represent a business district, industrial park, or large natural area within the Calgary CMA.//

The final component of data preparation was to derive an estimate of the employment totals in each census community and the sectoral composition of employment in each community. Employment data were available from Statistics Canada by dissemination area (DA) in the form of establishment totals categorized into ranges of employees per establishment. In addition to these data, total employees in each sector were available for the Calgary CMA for the year 2014. These totals were taken as controls and it was assumed the total number of employees for each establishment corresponded to the minimum employee category bound. Totals were then factored to match the Calgary CMA control totals by employment sector. Transferring these data into census communities proved challenging as there is not a consistent relationship across the Calgary CMA between these two statistical geographies. For the majority of the region, DA nest within census communities, but there are several instances of multiple census communities nesting within DA or DA crossing census community boundaries. These inconsistencies were addressed by breaking out DA into their smaller dissemination blocks (DB). Assuming an even distribution of employment across the DA, the totals were apportioned between DB by their share of the area for the DA in which they were located. This assumption was deemed acceptable because totals were subsequently aggregated into census communities, which largely do not bisect DB. In the rare instance of such an occurrence, the magnitude of the consumption split between two communities was negligible in comparison to community totals.

2.2. Statistical Methods

The most basic form of linear regression, termed ordinary least squares (OLS), can be defined as

$$y_i = \beta_1 x_{i1} + \beta_2 x_{i2} + ...\beta_n x_{in} + \epsilon \quad (1)$$

Translated into the terms of the present work, y_i is then total electricity consumption in census community i, x_{in} is the value of explanatory variable n for census community i, βn is the parameter value associated with variable n, and ϵ is a random error term. This model forms a good first approximation, but does not account for spatial auto-correlation between variables. Spatial statistics research has found the characteristics of adjacent communities can have strong effects on the behaviour of a community. This is similar to the principle of temporal autocorrelation, which states that the value of a variable in a previous time period may affect its current value. For example, a person who was wealthy last year is more likely to be wealthy this year than an otherwise similar person with a lower level of wealth in the previous year. Spatial auto-correlations have been identified in urban spatial systems in previous work on the consumptive patterns of water [9][10].

The OLS regression model has been extended to include spatial effects via the spatial autocorrelation regression (SAR) model. This introduces an additional explanatory variable representing a spatial lag

$$y_i = \beta_1 x_{i1} + \beta_2 x_{i2} + ...\beta_n x_{in} + \rho W y_i + \epsilon \quad (2)$$

In this formulation, ρ represents the magnitude of the spatial autocorrelation with 0 denoting no autocorrelation and values approaching unity representing high levels of autocorrelation. The matrix W is a an adjacency graph. In the approach utilized in this research, this matrix is determined from Delauney Triangulation to obtain the adjacent communities. The matrix is row stochastic, such that each row sums to unity and equal weights are assigned to every adjacent community. The solution algorithm for the SAR model uses simulated maximum likelihood estimation (SMLE) rather than OLS, which is biased in its determination of ρ because it ignores spatial dependence between observations [11].

The common method of Moran I testing was used to measure spatial autocorrelation in this research. LeSage's Arc_Mat toolbox [12] was used to standardize values and create plots of the Moran I statistics. This toolbox plots the normalized value in each community against the weighted average of the adjacent communities. Cliff and Ord [13][14] have shown the slope of this relationship to correspond to the Moran I statistic. This statistic can be interpreted to show perfect positive spatial autocorrelation at unity, no autocorrelation at a value of zero, and perfect negative spatial autocorrelation at negative unity. A positively correlated variable is said to show clustering in the region, while a negative value is said to represent dispersion across the region. The Moran I statistic is equivalent to ρ in the SAR model [11].

3. Results and Discussion

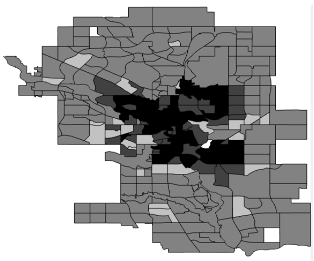
The results of the regression analyses are presented in tabular form below. A total of 12 models are included, which can be defined as in Table 1.

Table 1: Summary of Regression Models

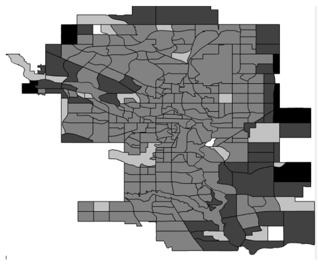
Model #	Model Description	Consumptive Sectors
1	total community population and employment (in 100s)	all
2	total population + employment areal density (in 100s per ha)	all
3	total community dwellings and industry establishments (in 25s)	all
4	detailed community dwellings and industry establishments (in 10s)	all
5	total community dwellings (in 25s) and their ownership rate (as %)	residential
6	detailed community dwellings (in 10s)	residential
7	date of community dwelling construction	residential
8	number of rooms in community dwellings	residential
9	total employment areal density (in 100s per ha)	commercial
10	detailed community industry establishments (in 10s)	commercial
11	total employment areal density (in 100s per ha)	industrial
12	detailed community industry establishments (in 10s)	industrial

3.1. Total Electricity Consumption

The first set of analysis was performed for total electricity consumption. This provides a first measure of the effects of various factors on overall electricity consumption of communities, irrespective of their residential, commercial, and industrial composition. This can be illustrated by examining the spatial autocorrelation of consumption across census communities by the area of the community, then weighting community area by its total population and employment. Figure 1a shows total electricity consumption by community area, with a darker shade denoting higher consumption. This suggests a higher consumption in the inner city and clustering of highly consuming communities around the CBD. This darker pattern continues into the south-east to include industrial regions.



(a) By Community Area



(b) By Community Population and Employment Density

Figure 1: Total 2014 Electricity Consumption

Figure 2 presents a scatterplot of these results with standardization about the mean. The slope of this plot is analogous to the Moran I statistic for global spatial autocorrelation. It shows a fairly strong correlation for community area of 0.5111 with an r-squared of 0.544. Accounting for total population and employment, the spatial concentration disperses to the fringes of the region (Figure 1b). This is a function of the high employment density of CBD and industrial areas. The Calgary CBD is characterized by high office towers, such that the total floor space for a given land area is high. Industrial parks also have high employment concentrations and will contain more persons per land area than a similarly sized community of single-family dwellings.

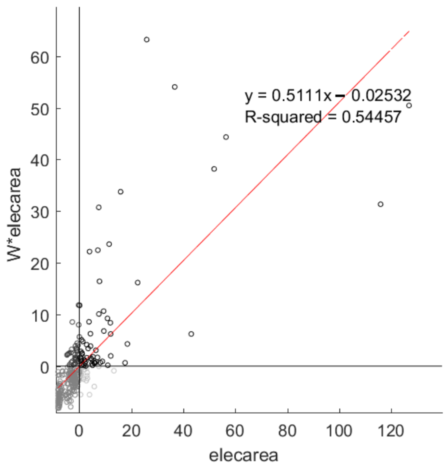


Figure 2: Moran I Test for Total 2014 Electricity Consumption by Community Area

Table 2 presents an overview of the regression models for total electricity consumption. The first model suggests population has a greater effect on electricity consumption than employment. With electricity measured in kWh and population measured per 100 residents, it is suggested that an additional 100 new residents will increase demand for electricity by approximately 2.62x105 kWh annually. The effect of population and employment density is found to be significant and suggests the addition of 100 persons to each hectare of community area would add 9.61x106 kWh of demand. This is an average across the range of densities. It is possible that the increase would vary depending on the previous state of density. That is, a transition from low density to medium density population and employment would have a different effect than a similar magnitude shift from medium density to high density. This behaviour would result from a combination of changes in the operation of buildings at each density. Such a test was explored, but performing a categorical regression has several challenges. Firstly, the number of data points in each category must be sufficient to represent a statistically significant result. Secondly, the definition of density will vary between jurisdictions: what would be considered high density in Calgary may be considered mid-density in Manhattan. A percentile system is likely the most neutral method; however, an initial analysis using three percentiles found the 33%ile is 20.8 persons-ha, the 66%ile 44.4, while the largest value of density is 1834 persons-ha. This suggests a minimal difference between low and medium density across communities. An analysis based on these categories gives a 75-fold decrease in electricity consumption when transitioning from medium to high density compared to a transition from low density to medium density. The data suggest that more categories would not help as the 90% density is only 114 persons-ha. This analysis illustrates densities are relatively similar across the majority of census communities and an analysis by continuous variables provides better results than categorical analysis for density.

The effects of various forms of dwellings and establishments on consumptive patterns is examined. A model of the total dwellings and establishments (model 3) is included for comparison with this more detailed model (model 4). Each of the dwelling and establishment types was compared and it was determined that no two parameters are statistically similar. The number of each dwelling type in a community will affect its influence on electricity totals. It was found that only single-family, apartment, and unclassified other dwellings have a significant influence on consumption. Industrial and manufacturing establishments have high demands for energy of all types and their contribution to electricity consumption by community was found to be significant. Wholesale/retail, industrial, and arts/recreational establishments are large facilities that will dominate their community electricity demands. Government and commercial establishments were found to be significant as they represent large office complexes with high demands for lighting and computer resources. The signs of each of these parameters is also important in interpreting these results. Office and retail establishments have significant negative influences on the electricity consumption of communities, not because they reduce the demand for electricity, but due to their influence on demand relative to the less efficient use of residential dwellings. Agriculture was found to be significant, but has a negative sign because it does not represent a substantial draw on electricity resources relative to the geographic size of establishments in this sector. Other resource draws for agriculture can be high (e.g. fuel and fertilizer), but the dwellings in rural communities have a more significant positive influence on electricity demand. Comparing model 3 and 4, it was found that distinguishing between types of dwellings and establishments increases the model fit by 25%. This suggests the type of dwellings and/or establishments in a neighbourhood has an influence on its demand for electricity. This is further examined in subsequent sections by distinguishing electricity demand between the various sectors.

Table 2: SAR Regression Results for Total 2014 Electricity Consumption

	Model 1		Model 2		Model 3		Model 4	
Parameter	**Estimate**	**SD**	**Estimate**	**SD**	**Estimate**	**SD**	**Estimate**	**SD**
Population (x100)	$2.62x10^{5+}$	$2.04x10^{4}$						
Employment (x100)	$5.95x10^{4+}$	3000						
Population and Employment Areal Density (100s per ha)			$9.61x10^{6+}$	$1.09x10^{6}$				
Population : Employment			$3.39x10^{6+}$	$1.21x10^{6}$				
Dwellings (x25)					$1.99x10^{5+}$	$1.18x10^{4}$		
Establishments (x25)					$2.87x10^{4+}$	1344		
Single-Family Dwellings (x10)							$9.42x10^{4+}$	$9.23x10^{3}$
Duplex Dwellings (x10)							$1.05x10^{4}$	$7.09x10^{4}$
Manufactured Dwellings (x10)							$7.09x10^{4}$	$1.42x10^{5}$
Apartment Dwellings (x10)							$1.54x10^{5+}$	$1.08x10^{4}$
Townhouse Dwellings (x10)							$4.64x10^{4}$	$4.55x10^{4}$
Multi-Family Dwellings (x10)							$-1.41x10^{5}$	$4.30x10^{5}$
Conventional Dwellings (x10)							$-1.16x10^{5}$	$1.09x10^{5}$
Other Dwellings (x10)							$2.53x10^{6+}$	$4.00x10^{3}$
Agriculture Establishments (x10)							$-4.54x10^{5+}$	$2.03x10^{4}$
Forestry Establishments (x10)							$1.14x10^{6}$	$^{+}4.54x10^{3}$
Industrial Establishments (x10)							$7.63x10^{4+}$	$2.45x10^{4}$
Construction Establishments (x10)							$-2.55x10^{4}$	$2.35x10^{4}$
Manufacturing Establishments (x10)							$7.33x10^{4+}$	$1.10x10^{4}$
Wholesale/Retail Establishments (x10)							$-1.96x10^{4}$	$1.16x10^{4}$
Commercial Establishments (x10)							$-3.74x10^{4+}$	$1.89x10^{4}$
Institutional Establishments (x10)							$4.45x10^{4+}$	$1.64x10^{4}$
Arts and Recreational Establishments (x10)							$1.31x10^{4}$	$9.59x10^{4}$
Miscellaneous Establishments (x10)							$2.33x10^{5}$	$1.27x10^{5}$
Government Establishments (x10)							$-4.19x10^{5+}$	$1.11x10^{4}$
Spatial Autocorrelation (rho)	0.211^{+}	0.044	0.476^{+}	0.062	0.144^{+}	0.040	0.140^{+}	0.034
R-Squared	0.685		0.161		0.755		0.836	

$^{+}$ Sig 95% CI.

3.2. Residential Electricity Consumption

Residential consumption of electricity was considered in more detail by including the rate of ownership in a community and considering the age and size of dwellings in each community. In the previous set of models, population and employment were both considered to contribute to total electricity consumption; however, it was found that there is only a weak correlation between the number of residents and size of employment for a community ($\tilde{0}$.022). This suggests a more accurate picture of each sector can be drawn by distinguishing between the two types of consumption. Model 5 found both the number of dwellings and ownership rate to be significant factors in electricity consumption. Conventional wisdom might suggest this is a result of renters being generally lower income and more cognizant of their electricity usage. There is no evidence in the model data to support this notion, but an examination of model 6 provides some indication of potential causes for this correlation. The two largest dwelling categories in Calgary are single-family homes and apartments, accounting for 57% and 21% of dwellings, respectively. The data suggest ownership is 87% for single-family dwellings, but only 31% for apartments. In model 6, the parameter for single-family dwellings was 14 times that of apartments. The combination of higher ownership rates and contribution to electricity demand, suggests the presence of single-family dwellings in a community would explain the cause of ownership being a significant factor in consumption in model 5. Data were also available on the count of dwellings in each community by their age and the number of rooms in each dwelling. An initial assumption is that older dwellings will be less efficient in their electricity consumption and more rooms in a dwelling will increase its electricity consumption. Model 7 represents an analysis of consumption by the age of the dwelling. One of the considerations in this model is that older dwellings are typically smaller and may not have the same occupancy rates as newer, larger dwellings. The number of dwellings constructed in each time period was therefore factored by the average occupancy in its community. This provides an approximate standardization of the data so as to compare dwellings with similar occupancy that were constructed in different decades. Each parameter in this model was found to be significant and a general trend of decreasing consumption was observed as the age of dwellings decreased. Spikes were observed in the parameters for 1991-2000 and 2006 and later, relative to previous time periods. There is no empirical explanation for these variations, but they correspond with significant booms in the oil and gas sector. This is a vital sector to the Calgary economy and the period of 2006-2014 was a period of rapid expansion of the city, including construction of new dwellings. The combination of high demand for dwellings and increasing household incomes may have produced a reduction in the quality of construction and increase in the size of dwellings. Both these factors would contribute to higher per capita demand for electricity. This would translate into higher electricity consumption in newer communities than would be otherwise expected. The final model of residential consumption distinguishes between dwellings by their number of rooms. These results suggest electricity consumption increases as the size of the dwelling increases. Parameters for dwellings with 4 rooms or fewer and for 7 rooms were not found to be significant. There is no intuitive reason why this should be the case, but an analysis of the data provides an indication of its causes. It was found that dwellings with 7 rooms are not the dominant size in any community. This suggests 7 room dwellings are not a distinguishing characteristic between communities and this type of dwelling is ubiquitous across the Calgary CMA. In the case of dwellings with 4 or fewer rooms, they do dominate many communities, particularly those with high numbers of apartments. An analysis of median income by community provides some measure of support for smaller dwellings not having significant impacts on community consumption of electricity. The median income was found to increase with the number of rooms, from $27,717 for communities dominated by dwellings with 4 or fewer rooms to $100,583 for communities dominated by dwellings with 8 or more rooms. Communities dominated by dwellings with 4 or fewer rooms were also found to have more industry establishments. The consumption of these establishments was removed for residential analysis and it is likely that such communities have higher heterogeneity in their composition than those dominated by larger dwelling types. This could explain the lack of explanatory power for this dwelling category and the relatively high standard deviation of its parameter.

Table 3: SAR Regression Results for Residential 2014 Electricity Consumption

	Model 5		**Model 6**		**Model 7**		**Model 8**	
Parameter	**Estimate**	**SD**	**Estimate**	**SD**	**Estimate**	**SD**	**Estimate**	**SD**
Dwellings (x25)	1.08x10^{5+}	6053						
Ownership (per 5%)	3.41x10^{5+}	5.75x10^{4}						
Single-Family Dwellings (x10)			8.56x10^{4+}	2408				
Duplex Dwellings (x10)			6.38x10^{4+}	1.88x10^{4}				
Manufactured Dwellings (x10)			4.02x10^{4}	3.91x10^{4}				
Apartment Dwellings (x10)			6354^{+}	2267				
Townhouse Dwellings (x10)			5.12x10^{4+}	1.27x10^{4}				
Multi-Family Dwellings (x10)			6.66x10^{5+}	1.18x10^{5}				
Conventional Dwellings (x10)			8.14x10^{4+}	2.73x10^{4}				
Other Dwellings			4.44x10^{4+}	796				
Built in 1960 or earlier					4218^{+}	435		
Built 1961-1980					2560^{+}	169		
Built 1981-1990					2067^{+}	323		
Built 1991-2000					2897^{+}	235		
Built 2001-2005					1130^{+}	393		
Built 2006 or later					3928^{+}	420		
4 Rooms or Fewer							-512	532
5 Rooms							9586^{+}	2998
6 Rooms							1.06x10^{4+}	3524
7 Rooms							2021	4072
8 Rooms or More							1.14x10^{4+}	972
Spatial Autocorrelation (rho)	0.114^{+}	0.048	0.079^{+}	0.024	0.139^{+}	0.033	0.083^{+}	0.028
R-Squared	0.724		0.920		0.837		0.888	

$^{+}$ Sig 95% CI.

In addition to the analysis summarized in Table 3, analysis was performed for the effects of income and ethnic composition for each community. Results confirm the findings of previous studies that income plays an important role in the energy consumption of households. An increase in the median income of a community by \$5,000 was found to produce a 5.07x10^{5} kWh increase in residential electricity consumption for the community. In terms of ethnic composition, it was found that communities with higher proportions of African, Latin American, and west Asian populations tended to have lower rates of consumption than those dominated by European and East Asian populations. Income is likely the dominant factor in this difference. Median income was found to be roughly \$65,000 in communities with the highest proportions of Latin American and west Asian populations, whereas communities with predominantly European and east Asian populations had a median income of \$89,000.

3.3. *Commercial Electricity Consumption*

A distinction should first be made between the classification of electricity as commercial and the definition of the commercial sector in this research. Electricity is classified as either residential, commercial, or industrial by the land-use classification provided by the City of Calgary. For residential classification, this is relatively straight-forward as there is a single definition of *residential* in this study. In the case of commercial and industrial land, there are a variety of employment sectors that could occupy a parcel and be classified as representing either of these consumption profiles. Commercial establishments are defined by their NAICS code to include professional services, banking, and media. These types of establishments mostly utilize commercial land, but some establishments may exist on industrial land. Within land-use definitions, government and retail establishments would also exist on commercial land parcels. It was found that wholesale/retail, institutional, and government establishments have the most significant negative influence on consumption. Institutions and government establishments typically have greater financial constraints on their operations than commercial establishments, which would explain their lower contribution to consumption relative to the commercial sector. In addition, these establishments are more likely to be constructed according to LEED standards for low building energy requirements. Manufacturing, commercial, and miscellaneous establishments have the greatest influence on consumption in this category. Industrial establishments have a positive parameter, but do not contribute as strongly to commercial electricity consumption. These establishments are typically segregated into their own community boundaries and therefore will have less influence in communities containing other establishment types (i.e. residential and commercial).

Table 4: SAR Regression Results for Commercial 2014 Electricity Consumption

	Model 9		**Model 10**	
Parameter	**Estimate**	**SD**	**Estimate**	**SD**
Employment Areal Density (100s per ha)	$7.14\text{x}10^{6+}$	$6.54\text{x}10^{5}$		
Agriculture Establishments (x10)			$-2.85\text{x}10^{4}$	$5.59\text{x}10^{5}$
Forestry Establishments (x10)			$-8.64\text{x}10^{5+}$	$1.72\text{x}10^{5}$
Industrial Establishments (x10)			$1.23\text{x}10^{4}$	$2.33\text{x}10^{4}$
Construction Establishments (x10)			$-2.79\text{x}10^{4}$	$1.97\text{x}10^{4}$
Manufacturing Establishments (x10)			$1.73\text{x}10^{4}$	9709
Wholesale/Retail Establishments (x10)			$-4.45\text{x}10^{4+}$	9500
Commercial Establishments (x10)			$3{,}97\text{x}10^{4+}$	$1.62\text{x}10^{4}$
Institutional Establishments (x10)			$-3.41\text{x}10^{4+}$	$1.40\text{x}10^{4}$
Arts and Recreational Establishments (x10)			$-4.22\text{x}10^{4}$	$8.55\text{x}10^{4}$
Miscellaneous Establishments (x10)			$2.19\text{x}10^{5+}$	$1.11\text{x}10^{5}$
Government Establishments (x10)			$-5.74\text{x}10^{5}$	$5.29\text{x}10^{5}$
Spatial Autocorrelation (rho)	0.215^{+}	0.078	0.204^{+}	0.060
R-Squared	0.324		0.684	

$^{+}$ Sig 95% CI.

3.4. *Industrial Electricity Consumption*

Institutional and manufacturing establishments comprise the major statistically significant indicators for electricity consumption of land classified as industrial. The contribution of industrial establishments is also significant. In the case of institutional establishments, they are typically located on land classified with a special designation, but the results of the regression suggest the presence of an institutional establishment in a community is a strong indication of high industrial electricity consumption. Manufacturing establishments will typically be located on land classified as industrial and their large contribution relative to industrial sector establishments suggests they have higher electricity demands on a per establishment basis. Agriculture has a larger influence on industrial consumption than was found for commercial consumption. The regression results suggest agriculture is more prevalent in industrial areas than those characterized by commercial activities. This fits with an expectation that the larger land requirements for industrial and manufacturing facilities will locate them in the periphery of the built-up area of the city, and therefore closer to agriculture establishments. In the case of commercial consumption, a negative parameter is associated with agricultural establishments, which suggests that the presence of agriculture signals a lower level of commercial activity in the community.

Table 5: SAR Regression Results for Industrial 2014 Electricity Consumption

	Model 11		**Model 12**	
Parameter	**Estimate**	**SD**	**Estimate**	**SD**
Employment Areal Density (100s per ha)	1.63x10^{6+}	5.46x10^{5}		
Agriculture Establishments (x10)			3.42x10^{5}	3.22x10^{5}
Forestry Establishments (x10)			-2.17x10^{4}	9.53x10^{4}
Industrial Establishments (x10)			1.08x10^{4}	1.33x10^{4}
Construction Establishments (x10)			-6972	1.12x10^{4}
Manufacturing Establishments (x10)			6.56x10^{4+}	5502
Wholesale/Retail Establishments (x10)			-1.08x10^{4+}	5417
Commercial Establishments (x10)			-1.92x10^{4+}	9078
Institutional Establishments (x10)			1.61x10^{4+}	7705
Arts and Recreational Establishments (x10)			7.87x10^{4+}	4.92x10^{4}
Miscellaneous Establishments (x10)			2.58x10^{4}	6.42x10^{4}
Government Establishments (x10)			-1.71x10^{5}	3.03x10^{5}
Spatial Autocorrelation (rho)	0.497^{+}	0.071	0.139^{+}	0.038
R-Squared	0.045		0.835	

$^{+}$ Sig 95% CI.

4. Conclusions and Future Work

A data framework to link electricity consumption with socioeconomic and industrial patterns in the Calgary CMA was developed in this research. A spatial analysis of total consumption throughout the region clearly identifies the higher density of development in the central city as decreasing the consumption per hectare of land area. This study examined relationships between the total electricity consumption of communities and contributing factors using a spatially-sensitive regression formulation. This provides a more accurate fit with the data and suggests spatial correlations exist that introduce proximity effects between communities. Consumption was characterized by the stated land-use of each parcel to differentiate between consumptive activities. This was a novel approach to the analysis that provided key benefits over previous efforts in this regard. It provides a means of quantifying the influence of mixing different types of land-use on electricity consumption. An illustrative example of these effects can be found in the relative parameter values of single-family and apartment dwellings between model instances. When accounting for all consumption in a community, the presence of an apartment dwelling indicates a higher total consumption total with respect to the presence of a single-family dwelling. Taken in isolation, this would suggest that apartments consume more electricity than single-family dwellings. By isolating consumption occurring in parcels designated as residential, a different picture emerges as to the relative contributing of each residence class. In this instance, apartment dwellings drop in their contribution to community consumption of electricity to a fraction of the single-family dwelling parameter value. Examining the composition of land-use across communities, it can be said that communities dominated by apartment dwellings are also characterized by a higher heterogeneity of land-uses. Rather than contributing a higher consumption per dwelling unit, the presence of apartment dwellings indicates a higher community consumption of electricity due to the presence of highly consuming commercial and manufacturing establishments.

The system of analysis developed in this study will be applied to other forms of infrastructure utilization (water consumption, waste production, and transportation patterns) for the Calgary CMA. Previous research in this regard has focused on a single form of infrastructure and examined its underlying drivers, but scarce work has been completed on the relationships between each infrastructure. Future work will examine the relative contributions of factors of consumption to determine their relationship between infrastructures. The types of residences in a community was found to have a significant impact on residential consumption of electricity, but is this impact similar for water consumption and waste production.

References

[1] Pollutant Inventories and Reporting Division, National Inventory Report 1990-2014: Greenhouse Gas Sources and Sinks in Canada, Tech. rep., Environment and Climate Change Canada (2016).

[2] Government of Alberta, Phase-out of coal-fired emissions in Alberta (2015).
URL `http://www.energy.alberta.ca/Org/pdfs/FSCoalPhaseOut.pdf`

[3] M. Lenzen, M. Wier, C. Cohen, H. Hayami, S. Pachauri, R. Schaeffer, A comparative multivariate analysis of household energy requirements in Australia, Brazil, Denmark, India and Japan, Energydoi:10.1016/j.energy.2005.01.009.

[4] I. Lariviere, G. Lafran, Modelling the electricity consumption of cities: effect of urban density.

[5] B. Howard, L. Parshall, J. Thompson, S. Hammer, J. Dickinson, V. Modi, Spatial distribution of urban building energy consumption by end use, Energy and Buildingsdoi:10.1016/j.enbuild.2011.10.061.

[6] H. C. Moll, K. Jan Noorman, R. Kok, R. Engström, H. Throne-Holst, C. Clark, H. C. Moll, Pursuing More Sustainable Consumption by Analyzing Household Metabolism in European Countries and Cities 9 1–2.
URL `http://mitpress.mit.edu/jie`

[7] A. H. M. E. Reinders, K. Vringer, K. Blok, The direct and indirect energy requirement of households in the European Union, Energy Policydoi:10.1016/S0301-4215(02)00019-8.

[8] L. G. Swan, V. I. Ugursal, Modeling of end-use energy consumption in the residential sector: A review of modeling techniques (2009). doi:10.1016/j.rser.2008.09.033.

[9] H. Chang, G. Hossein Parandvash, V. A. Shandas Nohad Toulan, Spatial Variations of Single-Family Residential Water Consumption, Urban Geography 31 (7) (2010) 953–972. doi:10.2747/0272-3638.31.7.953.

[10] D. de Maria André, J. R. Carvalho, Spatial Determinants of Urban Residential Water Demand in Fortaleza, Brazil, Water Resources Managementdoi:10.1007/s11269-014-0551-0.

[11] J. P. Lesage, The Theory and Practice of Spatial Econometrics.

[12] J. P. Lesage, Lecture 2: Mapping in Matlab.

[13] A. Cliff, J. Ord, The problem of spatial autocorrelation, London Papers in Regional Science 1 (1973) 25–55.

[14] A. Cliff, J. Ord, Spatial Processes, Models and Applications, Pion, London.