SPATIAL ANALYSIS OF LEED PROJECTS IN THE TORONTO AND VANCOUVER CENSUS METROPOLITAN AREAS FROM 2001 to 2013

by

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Abstract

The spatial distribution of Leadership in Energy and Environmental Design (LEED) projects was examined for the Toronto and Vancouver Census Metropolitan Areas (CMAs). The projects were analyzed over three time frames between 2001 and 2013. Global and local spatial autocorrelation measures were used to determine if statistically significant clustering of projects exists, and if they are becoming more clustered over time. Pearson's correlation analysis was used to determine if any relationships exist between socio-demographic variables and LEED project presence. Cross-tabulated comparisons were also made between LEED project growth numbers and policy presence in an attempt to discover any patterns. Results showed that LEED projects are mostly clustered in downtown areas, specifically financial districts where there are many commercial buildings. Both study areas for all three time frames showed statistically significant clustering. The global measure results showed that LEED projects are becoming more clustered over time in the Vancouver CMA, but less clustered in the Toronto CMA. However, the local measure results show more intense clustering over time in both CMAs. Statistically significant associations were found between the selected socio-economic variables and LEED presence, however only weak relationships were found. Policy presence was found in most of the top cities for LEED projects and LEED project growth, suggesting that policy which references the LEED system is making an effective contribution to sustainable building practices.

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List of Acronyms

ANOVA – Analysis of Variance

AP – Accredited Professionals

CaGBC – Canada Green Building Council

CHASS – Computing in the Humanities and Social Sciences

CMA – Census Metropolitan Area

CSD – Census Subdivision

ESDA – Exploratory Spatial Data Analysis

GIS – Geographic Information Systems

GIScience – Geographic Information Science

HVAC – Heating, ventilation, and air conditioning

LEED – Leadership in Energy and Environmental Design

LISA – Local Indicators of Spatial Association

MAUP – Modifiable Areal Unit Problem

ND – Neighbourhood Development

NHS – National Household Survey

USGBC – U.S. Green Building Council

CHAPTER 1: INTRODUCTION

1.1 Introduction

Leadership in Energy and Environmental Design (LEED) is a rating system that sets a standard for green buildings in more than 132 countries. Roughly 1500 buildings have been certified and over 4000 have been registered by the Canada Green Building Council (Canada Green Building Council, 2014a). The energy efficiency of green buildings is one way to try and reduce the environmental impact of urban growth. Investing in sustainable buildings also represents an opportunity for energy savings in private and public organizations. However, building green is not only about energy efficiency. It involves sustainability in regards to material selection, design, indoor air quality, site development and water efficiency. The LEED rating system includes all of these elements in its certification process, and is continuously being modified to represent the highest standard of contemporary building practice. Therefore, understanding the geography of LEED projects over time is a key component to increasing implementation of green building, and to the improvement of the green building process in general.

Geographic information science (GIScience) can be defined as the "development and use of theories, methods, technology, and data for understanding geographic processes, relationships, and patterns" (Mark, 2003). It is the study of the fundamental issues that arise from geographic information (Goodchild, 2010). GIScience is adopted widely across many different disciplines, such as retail analysis, urban or municipal planning, environmental planning, and health research (Yang and Lin, 2011; Pamuk, 2006). The analysis of the green building industry can benefit greatly from the tools available in GIScience. Every building project is constrained by its site and situation;

therefore geography plays a role in what is possible in terms of locating new construction or retrofitting (Cidell and Beata, 2009). By using geographic information systems (GIS) and spatial statistics, different elements of the industry can be critically examined and this can lead to better investment. More specifically, these tools can be used to make more informed decisions related to program improvement, education, advertising and incentives (Al-Kodmany, 2012; Coutinho-Rodrigues et al., 2011).

1.2 Research Objectives

The purpose of this paper is to contribute to a better understanding of the emergence of LEED in the Toronto and Vancouver Census Metropolitan Areas since its adoption. The objectives are broken into three parts; primary, secondary and tertiary.

1.2.1 Primary Objectives

1. Determine the spatial distribution of LEED project locations for three time periods, including 2004 to 2007, 2004 to 2010, and 2004 to 2013 for the Toronto Census Metropolitan Area (CMA) and 2001 to 2007, 2001 to 2010, and 2001 to 2013 for the Vancouver CMA. The time frames begin with 2004 for the Toronto CMA and 2001 for the Vancouver CMA, because these dates mark the first year of LEED in each area. The time breaks were chosen based on the number of registrations each year to allow for a meaningful comparison, while trying to keep the breaks roughly the same number of years apart.
2. Determine if LEED projects are concentrated over geographic space.
3. If they are concentrated, quantify the differences in the concentrations over the three time periods.

1.2.2 Secondary Objectives

1. Analyze possible socio-demographic variables that may be associated with the presence of LEED projects from previous studies.
2. Calculate the statistical association of socio-demographic variables and the presence of LEED projects.

1.2.3 Tertiary Objectives

1. Determine the growth rates of LEED projects.
2. Compare the growth rates to LEED policy presence.

By accomplishing the primary objectives, the possibility of a ‘contagion’ effect can be explored by finding out the statistical likelihood that an increase in LEED registrations in one area influences LEED registrations in neighbouring areas. Adding the element of time to the analysis allows the changes in concentrations to be quantified, and also allows for growth areas to be identified. Analyzing the geographic distribution of green buildings over time is important because in doing so; the Canada Green Building Council (CaGBC), public and private developers, urban planners, and policy makers can make more informed-decisions regarding sustainable building. Thematic mapping, and measures of global and local spatial autocorrelation will be used and compared to accomplish these objectives.

To accomplish the secondary objectives, Pearson’s correlation analysis will be used to test for statistical association between LEED presence and socio-demographic variables. Exploring the types of people that live in areas of LEED growth could suggest the demographic that a developer of a LEED project would want to locate close to. Results could also assist the CaGBC from a marketing perspective, allowing them to know what sorts of people buy into LEED development. Previous literature (Cidell, 2009; Cidell and Beata, 2009; Kahn and Vaughn, 2009; Ward, 2012) has provided mixed results for any socio-demographic influence, therefore this paper will contribute to a better understanding of any association.

The tertiary objectives will attempt to contribute to a better understanding of policy implementation and its effectiveness. The comparison of the number of projects as well as the growth rate of projects will provide a generalized indication of the impact that policy has on LEED participation. Cross-tabulations will be created to accomplish these objectives.

1.3 Study Area

The study areas for the major research paper are the Toronto CMA and the Vancouver CMA. Figure 1.1 shows the boundaries of the two areas by census tract. These two major metropolitan areas were chosen because of their substantial growth in LEED registrations compared to the rest of Canada. Figure 1.2 is a bar chart showing the number of LEED registrations by major city. The City of Toronto has the most registrations, with 382. Vancouver has 250, Calgary has 248, Ottawa has 155 and Edmonton has 125. The CMA was used as the study area instead of the city boundaries because there are many suburban areas that have a substantial amount of LEED registrations, which make for an interesting comparison to the Toronto census subdivision (CSD).

There are approximately 682 registrations in the Toronto CMA, and approximately 472 in the Vancouver CMA. The areas with the highest penetration were chosen for this paper because their registration counts are high enough to see meaningful change over time. A second reason that the Toronto and Vancouver CMAs were chosen is because they are growing and expanding at a rapid rate. Toronto and Vancouver both have large growing suburbs (Lewyn, 2012), and booming construction. For two cities that are undergoing so much change to their built environment, it is important to know where opportunity exists to promote environmentally sustainable improvements.

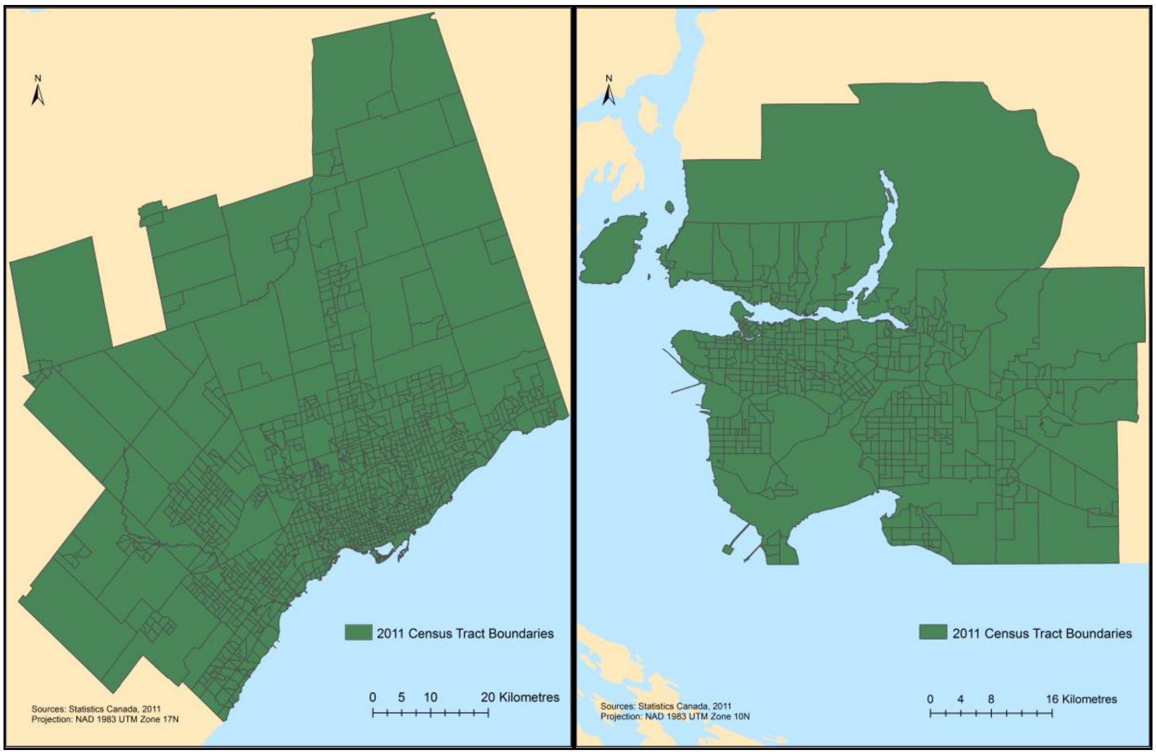

Figure 1.1: The Toronto (left) and Vancouver (right) Census Metropolitan Areas with census tract boundaries.

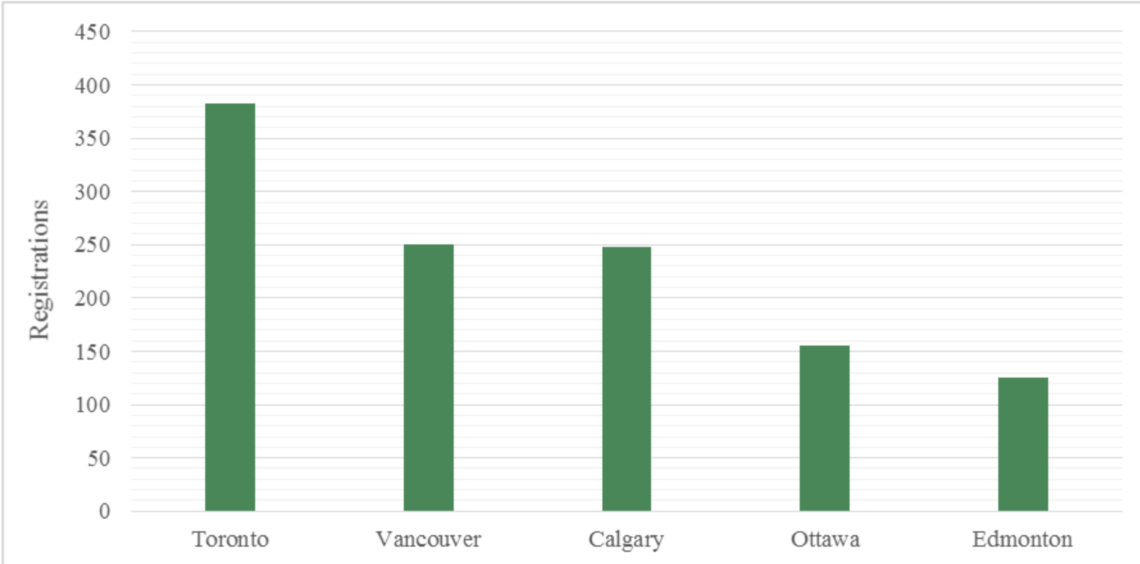

Figure 1.2: LEED project registrations by 2013 by the top five cities. Source: Canada Green Building Council (2014a).

CHAPTER 2: LITERATURE REVIEW

2.1 The Green Building Movement

The term ‘green building’ refers to design and construction practices that ensure buildings last longer, are energy efficient, cost less to operate, and contribute to healthier well-being for occupants (Kubba, 2010). They use energy, water and other materials more efficiently, and use measures for siting, design, construction, operation, maintenance and removal to reduce the building’s impact on the environment (DeLaPaz, 2013). It is important to note that the definition of green building is not constant because it reflects the status of people’s efforts within sustainable construction practices, which change over time (Sinha et al., 2013). Technology and attitudes change over time, therefore, the world’s definition of green changes as well. Sustainability within the building sector is important because a large percentage of the world’s energy goes into it. Buildings account for 33% of all energy consumption in Canada, 50% of natural resources consumed, and approximately 35% of total greenhouse gas emissions (Commission for Environmental Cooperation, 2008), making them an important target for efficiency improvement.

The growing awareness of climate change has stimulated the transformation towards sustainable development, and has created a green building movement throughout the world. The green building movement began in the 1970’s, when many people including lawmakers, architects and engineers channeled their efforts to reduce the negative environmental impacts from building construction. The movement was strongly influenced by the energy crisis during this time, when over-dependence on fossil fuels for building energy consumption became apparent and alternative sources began to be sought out (DeLaPaz, 2013). Since then, the green building movement has matured and has been influenced by many different innovative projects. There is over $10 billion presently invested into green buildings in the United States. The demand is increasing and there is now more pressure on construction companies to adhere to green building practices (Kubba, 2010).

Green building practices have positive implications for the Earth's environment and its resources, but this is not the only benefit. They also have economic benefits. Real estate research has shown that eco-consumers are willing to pay a premium for eco-certified products (Fuerst, 2009; Nyikos et al., 2012; Yau, 2012). Other research has also implied that LEED can increase land value in some cities (Son et al., 2012). The area that the project is located in is important, because many developers create these projects with the assumption that the tenants or people in the area will buy into the idea of an environmentally sustainable building. Additionally, there are social benefits of green buildings, including improved working conditions in offices, which leads to increased productivity, reduced turnover and absenteeism, and overall happier workers (Kubba, 2010).

2.2 Leadership in Energy and Environmental Design (LEED)

The LEED standard was developed by the U.S. Green Building Council (USGBC), a not-for-profit organization, in 1998 as a solution to the challenges facing cities wishing to meet climate change goals through green building. The standard is intended to identify buildings that offer superior environmental performance (Lee and Koski, 2012). The LEED system uses a score-card approach which covers seven main areas: site development, water efficiency, energy efficiency, material selection, indoor air quality, innovation in design, and regional priority (Canada Green Building Council, 2014b). The LEED system was adopted in Canada in 2001, and in 2003 the CaGBC became the primary certifying committee. Before the CaGBC was created, Canadian LEED projects were registered and certified by the USGBC (Canada Green Building Council, 2008). The LEED system is a standard by which people can assess and compare the greenness of buildings within different jurisdictions. The system became widely accepted, mostly because of the variety of stakeholders involved in the USGBC including developers, architects, city planners, and elected officials (Lee and Koski, 2012).

Each category in the certification process has an overarching intent that focuses on the different aspects of what makes a building sustainable. Different projects have advantages and disadvantages based on the geography of the area in which they are located; therefore, if a project is only satisfactory in one area, it can make up the points in another category (Enermodal Engineering, 2009). Cidell and Beata (2009) used GIS and spatial statistics and found that regional differences do exist between the different categories. The sustainable sites category supports aspects of smart growth, favouring building up rather than out. Examples include encouraging alternative transportation such as bikes and public transit, reusing built-up land, and community connectivity. Water efficiency focuses on reducing fresh water use, and reusing "grey water" such as rain fall. Energy and atmosphere aims to reduce the use of electricity and natural gas through efficient heating, ventilation, and air conditioning (HVAC) systems, appliances, insulation, and smart building design. It also promotes the use of renewable energy, either generated on site or imported (Enermodal Engineering, 2009). Materials and resources consider where the construction materials are from and how they are disposed of. Points can be earned in this category through the reusing of building materials, recycling of demolition debris, and through the use of rapidly renewable, local, or eco-harvested materials. Indoor environmental quality measures occupant comfort and health. Air quality, thermal comfort, and lighting drive this category. Innovation in design gives credits for incorporating innovative environmental features not covered in the other areas, and for developing a green education plan. Lastly, regional priority considers if the project targets environmental issues in relation to geographical locations to construct more durable buildings (Enermodal Engineering, 2009).

2.3 Green Building Policy

Policy has an influence on the commitment that people have towards sustainable building practices. Federal, provincial and municipal policies all play a role in the growth of green building practices in Canada. The presence of green buildings can be seen as a result of commitment to reach goals of climate change agreements (Lee and Koski, 2012). According to the Canada Green Building Council (2013) policy database, there are more than one hundred policies, plans and strategies in Canada that reference the LEED system to encourage its implementation. Many policies exist that apply to government buildings. In the City of Burlington, Ontario, all new municipal buildings greater than 500 square metres and major expansions or retrofits must achieve LEED silver certification. There are policies for private buildings as well, but incentive programs are more common. The City of Kitchener, Ontario, offers up to a $5000 subsidy per LEED certified home depending upon level of certification.

The way in which policy is created and targeted can benefit from analysis of previous LEED projects. Cidell and Beata (2009) found that different LEED credits are taken up in various parts of the United States. This finding confirms that incorporating regional differences in the creation of a credit system is justified. It also proves that regional policies encouraging green building are an effective approach, since certain regions excel in different categories. Fuerst et al. (2014) found modest evidence to suggest that policies have an effect on the market penetration of green buildings.

2.4 Analyzing Green Buildings and using GIS and Spatial Statistics

Geographic Information Systems (GIS) are commonly used by the Canadian certifying committee to establish eligibility of LEED projects within the locational credit categories (Canada Green Building Council, 2009). The ability to map the location of the project and the other variables, such as distance to transit stops or flood plains, allows for accurate credit scores. The use of GIS extends further than just credit calculations, as it can be used as an exploratory tool to understand the geographic nature of green buildings. Since the adoption of green buildings, researchers have been increasingly interested in understanding the spread of their development over space, and analyzing their effects (Zuo and Zhao, 2014). Studies across many professional and academic disciplines have attempted to answer questions related to green building, including urban planning, economics, engineering and geography (Eichholtz et al., 2010; Fuerst et al., 2014; Kahn and Vaughn, 2009; Son et al., 2012).

GIS can be used to promote the implementation of LEED, because it can be used as a tool to identify areas that already meet certain criteria in the credit system. Wasserman (2013) used the capabilities of GIS to map the criteria of LEED Neighbourhood Development (ND) linkage and location credits and prerequisite criteria to map site suitability. By identifying areas of suitability, those areas can be targeted for development. In addition, suitability maps can also identify areas where LEED development is not appropriate, due to a lack of prerequisites. Analyzing these unfit areas can reveal development that may be considered unsustainable. Wasserman (2013) found that the LEED system discriminates against small towns and rural areas, and also found that results were less accurate for those areas due to lack of data availability. It is difficult to get credits in rural areas mostly because of the lack of accessibility. Research with spatial findings of this nature can contribute to the further improvement of the LEED system, since new versions are created every few years. GIS and spatial statistics have been used in the past in an attempt to understand the predictors of LEED project development. Exploratory mapping has been used (Cidell and Beata, 2009; Kahn and Vaughn, 2009; Ward, 2012) to identify different factors that influence green building. Ward (2012) used exploratory mapping as well as interviews, and found a lower representation of LEED certified buildings in areas of lower socioeconomic status. Interviews also revealed that the socioeconomic disadvantages appear to be a result of unawareness of the potential benefits of LEED from community residents.

Linear regression has been used in past research to further quantify the statistical significance of certain predictors of green building development. Socioeconomic variables have been explored, and several have been significantly correlated with green building presence, and even with LEED projects specifically. Kahn and Vaughn (2009) used linear regression on multiple variables, and found areas that were "green" based on political choice and areas of high income were statistically significant predictors of the count of LEED buildings at the national level. However, they also found that in California, LEED buildings were located in areas of lower income. Fuerst et al. (2014)

used linear regression and found that market size, educational attainment and economic growth were significant predictors of total LEED certified commercial stock. They also found that a mandatory requirement to get LEED certification for new buildings has a significantly positive effect on market penetration. Cidell (2009) used correlation analysis and found income and education variables to be positive indicators of LEED building presence in the United States. Overall, previous literature has provided mixed results for socio-demographic influence on LEED development, with most findings only showing weak to moderate statistical associations (Cidell and Beata, 2009; Fuerst et al., 2014; Kahn and Vaughn, 2009; Ward, 2012).

Eichholtz et al. (2010) also used linear regression, however, instead of using socioeconomic variables for predictors of green building presence, they analyzed the presence of green buildings and their influence on property rents and values. They found that there is a statistically significant premium in rent and market value for green buildings, and that they have more of an impact in smaller markets and in urban fringe areas of metropolitan centres. Interestingly, they found that beliefs about the benefits of green buildings, such as worker productivity or improved corporate image, statistically increase the value of the buildings as well.

Other statistical techniques have been used by past researchers to analyze green buildings, such as location quotients, analysis of variance (ANOVA) tests and Scheffe post hoc tests (Cidell and Beata, 2009), however there is a gap in research in which spatial clustering of green buildings is analyzed. There is an even deeper gap in research in which the temporal aspect of green buildings is investigated and explained. A study by Kaza et al. (2013) outlined spatio-temporal clusters of green commercial buildings in the continental United States using local Moran's I, nearest neighbour distances, and nearest neighbour indices. This paper will be similar in nature, but will explore the Canadian LEED landscape instead. Research on LEED activity in Canada is still in its early stages. Therefore, this research paper will attempt to identify and explain patterns that have occurred spatially and temporally during the growth of LEED in two major metropolitan areas.

CHAPTER 3: DATA AND METHODOLOGY

3.1 Data

3.1.1 Canada Green Building Council (CaGBC) Data

To analyze the distribution of green building activity, the number of LEED registered and certified projects were used. Registered projects were included even though they have not been approved with the necessary credits yet. This means that the developer has shown an interest in the program, therefore the registered project data contribute to the understanding of the growth of green building practices (Cidell, 2009). For the analysis over time, registration date was used rather than certification date because the registration date is a more natural representation of when the developer's interest was presented. Certification dates are likely to follow a pattern based on the approval process and timing of the certification committee. Certification dates were also not used, because many projects do not have certification dates yet since they are not certified. The data were retrieved from the CaGBC website (Canada Green Building Council, 2014a). The CaGBC has compiled a database on LEED projects including project name, address, ownership, and the certification level. The data were cleaned, and confidential projects were removed, as there were no locational data provided for them. A project is confidential when the developer opts out of providing the locational information of the project to the public through the CaGBC website. There were 357 confidential projects in the Province of Ontario, and 162 in British Columbia. It is uncertain how many of the confidential projects are from the Toronto or Vancouver CMAs, since locational information was not provided in the database.

The project addresses were geocoded by street address using ESRI's ArcGIS Canada Geocoding Service. The number of geocoded locations by level of geography are summarized for both study areas in Table 3.1. Some of the street addresses could not be geocoded by this service, and there are several reasons for this. The first reason is that there is some error in ESRI's address database where not all addresses are listed. The second reason is that some projects did not have an address listed, and only a street intersection or postal code was provided. Thirdly, if the project had more than one building associated with it, only one postal code was geocoded and these records were left geocoded to the postal code level. This paper analyzes LEED on a project basis rather than by each building because the focus is on the growth in registrations, and some projects include more than one building.

Table 3.1: Number of LEED project registrations that were geocoded to each level of geography.

Geography	Vancouver CMA	Toronto CMA
Street Address	425	589
Postal Code	47	93

The Canadian LEED policy database was also downloaded from the CaGBC website (Canada Green Building Council, 2013). The database is a collection of municipal, provincial and federal government policies that reference the LEED rating system in some capacity. It includes policies that are applicable to both public and/or private development.

3.1.2 Temporal Characteristics of CaGBC Data

In order to pick the time frames for the paper, the natural time-series data were explored. This distribution can be seen for the Toronto CMA in Figure 3.1 and for the Vancouver CMA in Figure 3.2. In the Toronto CMA, registrations steadily increased from 2004 and peaked in 2010. In 2011 there was a substantial drop in registrations, and the numbers have been slowly recovering since then. Registrations in Vancouver show a similar trend, however the drop in 2011 was not as steep as the drop in Toronto. The decrease in 2011 was due to the 2008 financial crisis. By 2011, overall construction in the country slowed down and there was not as much willingness to spend money on sustainable building practices (Canada Green Building Council, 2014c). Therefore, the first time frame chosen for the Toronto CMA was 2004 to 2007, the second was 2004 to 2010, and the third was 2004 to 2013. The time frames were the same for Vancouver, except the beginning year was 2001 instead of 2004. 2004 was the first year the Toronto CMA had a registration, and 2001 was the first year the Vancouver CMA had a registration. The years 2007, 2010 and 2013 were chosen as the temporal snapshots because these groupings follow natural breaks in the data. The first time frame covers more years, and this is because during these years LEED was still new in Canada and registrations were quite low.

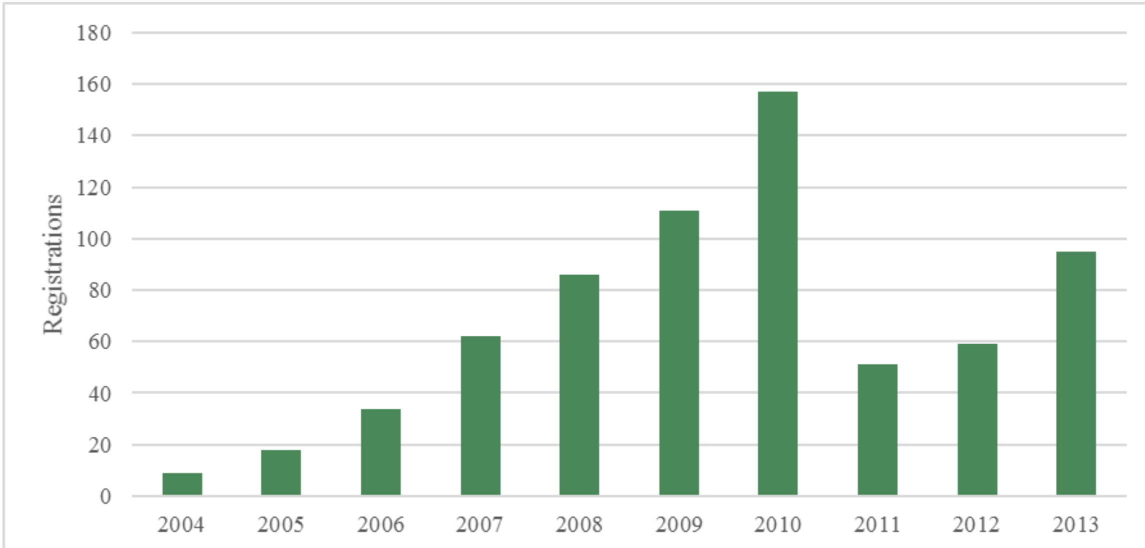

Figure 3.1: LEED project registrations in the Toronto CMA by year of registration.

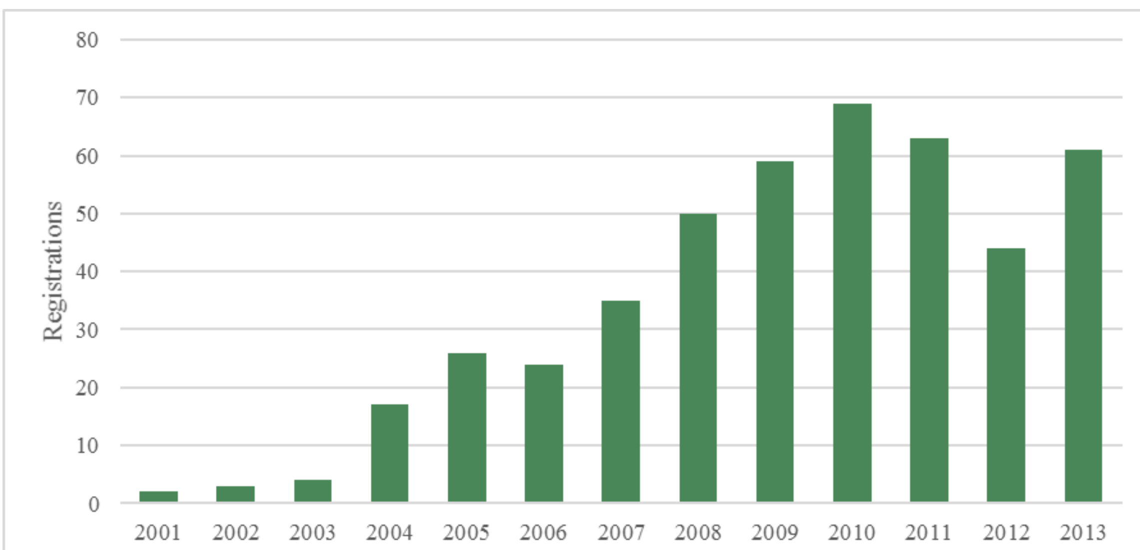

Figure 3.2: LEED project registrations in the Vancouver CMA by year of registration.

3.1.3 Canadian Census and National Household Survey (NHS) Data

The census tract cartographic boundary files for the Toronto and Vancouver CMAs were downloaded from the Statistics Canada website (Statistics Canada, 2011b). Since this project analyzes LEED projects registered by 2007, 2010 and 2013, both the 2006 and 2011 census boundaries were used. The 2006 census boundaries were used for the 2007 time frame, and the 2011 census boundaries were used for the 2010 and 2013 time frames. Census tracts were used as the unit of geography because they follow physical features, population, and socioeconomic characteristics, while staying as compact as possible (Statistics Canada, 2012). Their size is appropriate for identifying patterns in a sample of this size.

Socio-demographic data by census tract were also acquired from Statistics Canada from the National Household Survey (NHS), and were downloaded through the Computing in the Humanities and Social Sciences (CHASS) website (Statistics Canada, 2011a). Data from 2011 were downloaded, since it is the most recent survey. The NHS is a voluntary survey conducted by Statistics Canada. It is a replacement to the long-form census conducted in previous years.

The variables used were; median household income, proportion of the population aged 15 years and over with a bachelor's degree as their highest education attainment, and proportion of the employed population aged 15 years and over who walk as their main mode of transportation to work. These variables were chosen based on findings in the literature (Cidell and Beata, 2009; Kahn and Vaughn, 2009; Ward, 2012), which suggested these socio-demographic indicators contribute to a higher prevalence of LEED participation in an area.

3.1.4 Data Limitations

A data limitation of the project is that not all certified or registered projects are available in the CaGBC public directory and could not be included in the analysis. These omissions are due to collection error and projects listed as confidential. Additionally, the precision is not exact, because the postal code level was the smallest unit available for a small percentage of the projects. However, this limitation does not affect the results to a large extent since the data were aggregated up to the census tract level for analysis, which reduces any small error that may exist.

The CaGBC policy database is limited because only policies that include reference to LEED are included, while excluding others that may promote green building. Due to this, the impact that these omissions may have on LEED presence cannot be accounted for. Using the NHS data has limitations as well. The NHS survey is voluntary, therefore it has a much lower response rate than the traditional census conducted previously. The non-response rate is approximately 30% (Walton et al., 2014), which adds bias to the data.

3.2 Methods

3.2.1 Spatial Distribution of LEED Projects

After the LEED project data were cleaned and geocoded, exploratory spatial data analysis (ESDA) was conducted. ESDA is a class of techniques which focuses on describing spatial distributions, discovering patterns of spatial association, suggesting different forms of spatial instability, and identifying outliers (Anselin, 1996). The ESDA techniques used in this paper are visual inspection of mapped data and spatial autocorrelation analysis using Moran's I and Local Indicators of Spatial Association (LISA).

Before the data were mapped, the geocoded points needed to be separated into the three time frames. For the Toronto CMA, the first time frame was 2004 to 2007, the second was 2004 to 2010, and the third was 2004 to 2013. The time frames were the same for Vancouver, except the beginning year was 2001 instead of 2004. The geocoded points for all three time frames were input into ArcGIS as three separate shapefiles for each CMA. A point map for each study area was created with each time period represented by a different shade of green. Using the Spatial Join tool from the Analysis toolbox, LEED projects were aggregated to the census tract level to create a new count variable. Registrations for the 2007 snapshot were joined to the 2006 census boundaries, while the 2010 and 2013 snapshots were joined to the 2011 census boundaries. Now that the census tracts had the new count variable, it was possible to conduct ESDA with them. Choropleth maps can then be created for the count variable for each time frame by census tract. For both study areas, additional choropleth maps were made showing the total count of projects by 2013 for the census tracts that have more than ten registrations.

3.2.2 Data Transformation

Spatial autocorrelation is a parametric test, meaning that the calculation assumes that the data have a normal distribution. To ensure that the normality sampling assumption is acceptable, the data were further examined. The skewness and kurtosis statistics are one of the most important indicators of the nature of the data distribution (Doric et al., 2009). Skewness describes the degree of asymmetry in the distribution, and kurtosis reflects the extent to which the density of observations is different from the probability densities of the normal curve (Hopkins and Weeks, 1990) Skewness values greater than 0 mean positive skewness is present, and values less than 0 mean that negative skewness is present. When the kurtosis value is a positive number, the distribution is leptokurtic, and when it is a negative number, the distribution is platykurtic. Leptokurtic distributions are peaked, and platykurtic distributions are more flat (McCluskey and Lalkhen, 2007). It is common practice that if skewness is within +/- 1 and kurtosis is within +/- 3, then the assumption of normality can be made (Park, 2008). These two statistics were calculated for the distribution of LEED projects for the three time frames in both study areas. The calculations for the raw data values are shown in Table 3.2. After examination of the statistics, it was found that the natural data distribution is extremely right-skewed and leptokurtic. Therefore, the assumption of a normal distribution was rejected. The non-normal distribution is mostly due to an overabundance of 0 and 1 values in the data.

Transforming data is a way in which non-normal data can approximate a normal curve. The most common transformations include logarithmic, square root and inverse (Manikandan, 2010). The project count data reached their optimal skewness and kurtosis statistics after they were transformed using the inverse transformation. The inverse transformation is calculated using 1/x, and then it is reflected to keep the same numeric direction. Since there are values equal to 0 in the dataset, a constant needed to be added to each of the raw data values to avoid the divide by zero error. Therefore, the transformation became 1/(x+0.5) (Fink, 2009). After the transformation, the data were still moderately skewed and kurtotic. Most values were in the acceptable range, except the Toronto CMA 2004. However, since most of the variables were approaching normal, the data were therefore used for further analysis.

Table 3.2: Skewness and Kurtosis values for LEED project count data before and after inverse transformation.

LEED Project Count Variable	Skewness				Kurtosis			
	Raw Count		Inv. Count		Raw Count		Inv. Count	
	Statistic	Std. Error	Statistic	Std. Error	Statistic	Std. Error	Statistic	Std. Error
Vancouver CMA 2001-2013	6.365	0.114	**-0.612**	0.114	52.134	0.228	**-1.508**	0.228
Vancouver CMA 2001-2010	5.619	0.114	**-0.934**	0.114	43.258	0.228	**-1.01**	0.228
Vancouver CMA 2001-2007	6.272	0.121	**-1.850**	0.121	52.976	0.240	**1.579**	0.228
Toronto CMA 2004-2013	9.023	0.074	**-1.265**	0.074	120.816	0.148	**-0.262**	0.148
Toronto CMA 2004-2010	8.839	0.074	**-1.681**	0.074	116.256	0.148	**0.984**	0.148
Toronto CMA 2004-2007	7.993	0.077	**-3.106**	0.077	99.253	0.154	**7.871**	0.154

3.2.3 Spatial Autocorrelation

Spatial autocorrelation is a statistical method to calculate the correlation within variables across geographic space. It is a result of Tobler's (1979) First Law of Geography, which states that "everything is related to everything else, but near things are more related than distant things". The statistics are made up of two parts; an expression representing a hypothesized causal relationship between specified pairs of observations, and an expression representing the spatial relationship between those specified pairs (Getis, 2008). The term was coined by Cliff and Ord in 1968, but the concept has been traced to the University of Washington in the 1950's primarily by Michael F. Dacey (Getis, 2008). The method identifies if similar or dissimilar values are clustered, rather than being randomly distributed. The calculation tests the null hypothesis that there is no spatial clustering of the values. Researchers became increasingly interested in the method because the spatial dimension of data is not captured well by classical statistics (Griffith, 1992).

There are both global and local tests for spatial dependency, and this paper will include both types. Global tests measure the type and overall degree of spatial association throughout the entire dataset. Local tests, also known as LISA, measure the local variations in the spatial association, which global tests are not as effective at capturing (Malczewski, 2010). The LISA statistic measures the extent of significant spatial clustering of similar values around each observation, and the sum of the LISAs for all observations is proportional to the global test statistic (Anselin, 2010). Therefore, global tests identify if clustering exists, while local tests identify the clusters and outliers.

To test for global spatial autocorrelation, Moran's I was used and run in ESRI's ArcGIS. Moran's I is the most commonly used statistic to measure for spatial autocorrelation (Getis, 2008). It has been used across many disciplines to answer research questions that are spatial in nature. The statistic has been used to identify employment clustering (Chhetri et al., 2013), to identify hot spots for legal offences (Quick and Law, 2013), to detect patterns in vehicle collisions (Matkan et al., 2013), and to analyze other geographic phenomenon (Black and Thomas, 1998; Jephcote et al., 2014; Yang and Wong, 2013). Moran's I indicates the degree of linear association between observed values and a weighted average of the neighbouring values (Anselin, 1996). When the z-score is larger than the significance level, the null hypothesis of no spatial clustering can be rejected. The Moran's I index ranges from +1.0 to -1.0, where +1 is perfect positive correlation, and -1 is perfect negative correlation. Positive correlation indicates clustering and negative correlation indicates dispersion (Wong and Lee, 2005).

To test for local spatial autocorrelation, Anselin Local Moran’s I was used and was also run in ArcGIS. LISA measures are commonly used with Moran’s I, since Moran’s I is not sensitive to local variations in the data (Anselin, 2010). Anselin Local Moran’s I is a measure that finds this local variation, and allows significant clusters and outliers to be identified. The LISA statistic calculates an I index, z-score, p-value and cluster type for each feature in the study area. If the z-score is greater than 1.96 with a p-value lower than 0.05, the null hypothesis is rejected and spatial clustering is occurring. The cluster type indicates whether clustering of high or low values exists, or if an outlier exists (ESRI, 2013).

Moran’s I and LISA both require a spatial weights matrix to be created, in order to define the spatial dependency between features. The spatial weights used for this paper was contiguity edges and corners, which considers any polygon that shares an edge or a corner with a target polygon as a neighbour that exerts influence in the calculation for the target polygon (ESRI, 2013). This spatial weights specification is appropriate because the data are at the census tract level. When census tracts are delineated, population is accounted for, so rural and less populated census tracts tend to cover more area. If a distance weights matrix was used instead, then a large enough distance threshold to allow each census tract to have at least one neighbour may be too large for the smaller census tracts. The k-nearest neighbour specification may fix this issue, but creates another problem where the appropriate number of neighbours is not the same for the large polygons as it is for the small polygons (ESRI, 2009). Therefore, contiguity by edges and corners is most appropriate, because it allows the small census tracts to have enough neighbours without giving the larger census tracts too many neighbours. Row standardization was used, which means each weight is divided by its row sum (ESRI, 2013). It is always important to use row standardization with aggregated data, especially if the data are skewed, because it reduces sample bias.

3.2.4 Pearson's Correlation

Pearson's correlation statistic is a parametric test for bivariate association. It measures the direction and strength of a linear relationship between two continuous variables. The resulting correlation coefficient, also known as 'r', is a value between -1 and +1, with -1 representing a perfect negative relationship, and with +1 representing a perfect positive relationship (Taylor, 1990). Correlation analysis was conducted using SPSS to measure the association between the inverse transformed project count and the proportion of persons with a bachelor's degree, median income, and proportion of persons that walk to work. Correlations were run for both the Toronto and Vancouver CMAs.

Correlations were also run for the City of Toronto and the City of Vancouver to compare any differences. Kahn and Vaughn (2009) followed a similar method when they compared factors influencing California LEED building counts to national counts. Toronto and Vancouver were chosen because they are the most populated cities within their respective CMAs, and because they have the highest proportion of growth in LEED projects in Canada (CaGBC, 2014a). It was hypothesized that the chosen variables would have a different relationship with LEED presence for these two cities since they are the most urbanized. Research has shown that income inequality increases with city size (Baum-Snow and Pavan, 2012), that educational attainment is correlated with city size (O'Hagan and Rutland, 2008), and that percentage of workers walking to work increases with population density (Saelens et al., 2003).

CHAPTER 4: RESULTS AND ANALYSIS

4.1 Spatial Distribution of LEED Projects

Figure 4.1 is a point map showing the location of LEED projects in the Toronto CMA by time period of registration. Projects registered between 2004 and 2007 are shown in light green, between 2008 and 2010 in medium green, and 2011 and 2013 in dark green. There were 123 projects registered between 2004 and 2007, 354 between 2008 and 2010, and 205 between 2011 and 2013. LEED projects are spreading out further into more rural areas over time. Projects registered between 2004 and 2007 are found in more populated areas including downtown Toronto, Markham and Mississauga. The largest clusters of projects are in downtown Toronto, Mississauga, and North York.

Figure 4.2 is a choropleth map of the count of LEED project registrations in the Toronto CMA by 2007. LEED projects were mostly located in downtown Toronto and in highly populated municipalities such as Mississauga, Markham and Vaughan. Figure 4.3 shows the projects by 2010. There was a large growth in registrations between 2007 and 2010, with 123 projects in 2007, and 477 in 2010 - a percentage increase of 287%. Census tracts that had LEED projects within them in 2007 tended to have even more projects by 2010. Overall, LEED participation spread throughout the CMA. Additionally, 52% of the census tracts that did not have any projects in 2007 (but did in 2010) were touching a census tract that had at least one project in 2007. Approximately 69% of those new projects were within one kilometre of a census tract with at least one project in 2007.

In 2011, LEED registrations in the Toronto CMA dropped by 68%. This drop was due to the repercussions of the 2008 recession. Investment in LEED and overall construction decreased (Canada Green Building Council, 2014). Therefore, the resulting choropleth map for 2013 (Figure 4.4) does not show as many new participating census tracts as the 2010 map did. However, even though numbers went down, the map reveals that many census tracts that already had projects in 2010, had more projects by the end of 2013. It is noted that registrations have recovered since the drop in 2011, so this map also includes a small increase. In 2012 there was a 16% increase, and 2013 had a 61% increase. Approximately 75% of the census tracts that did not have any projects in 2010 (but did in 2013) were touching a census tract that had at least one project in 2010. Around 95% of those new projects were within one kilometre of a census tract with at least one project in 2010. By visual inspection of the 2013 map, it can be seen that areas with the most LEED registrations include downtown Toronto, Milton, Mississauga, Markham, Vaughan and Ajax.

Figure 4.5 is a choropleth map showing only census tracts in the Toronto CMA that have greater than ten LEED registrations by 2013. This map allows for the differences in the census tracts with the most LEED activity to be analyzed. The highest count census tract is in the centre of downtown Toronto in the financial district around Bay Street and King Street. There are five census tracts surrounding it that also have greater than ten registrations, making it the most distinct cluster in the CMA. Of the 38 projects within this downtown census tract, 92% of them are commercial, 5% are residential and the other 3% is mixed-use.

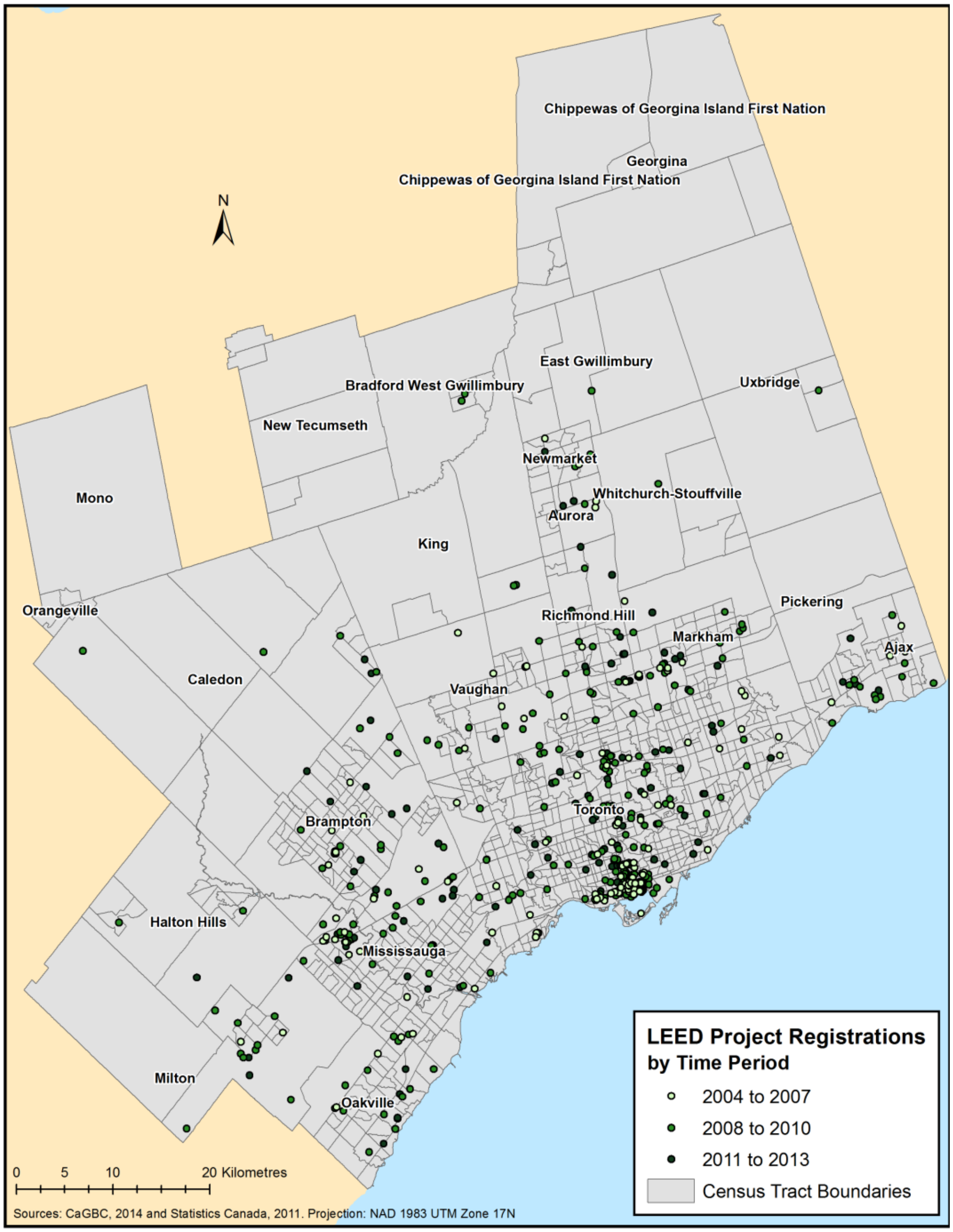

Figure 4.1: LEED projects registered in the Toronto CMA by time period.

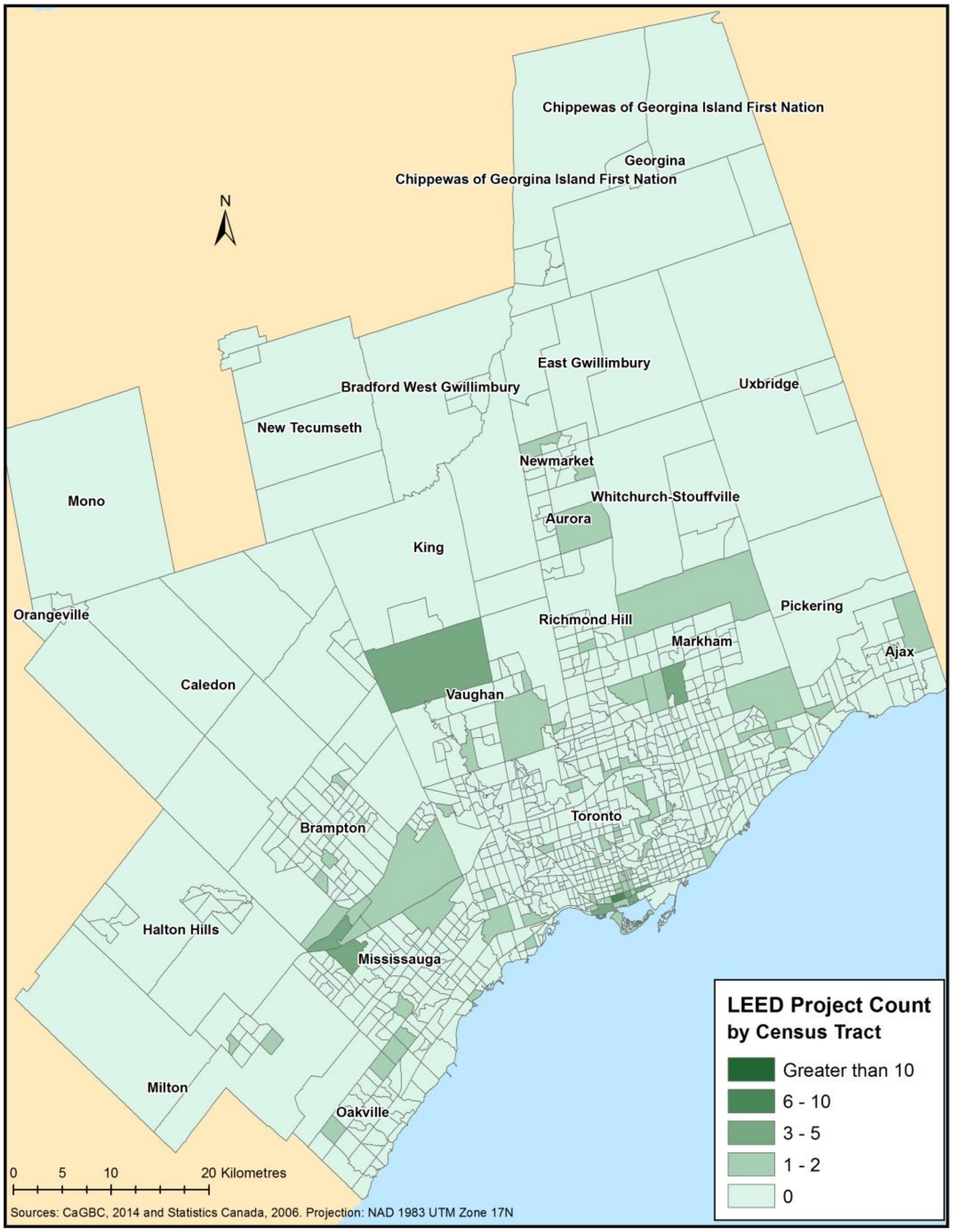

Figure 4.2: LEED projects registered between 2004 and 2007 in the Toronto CMA.

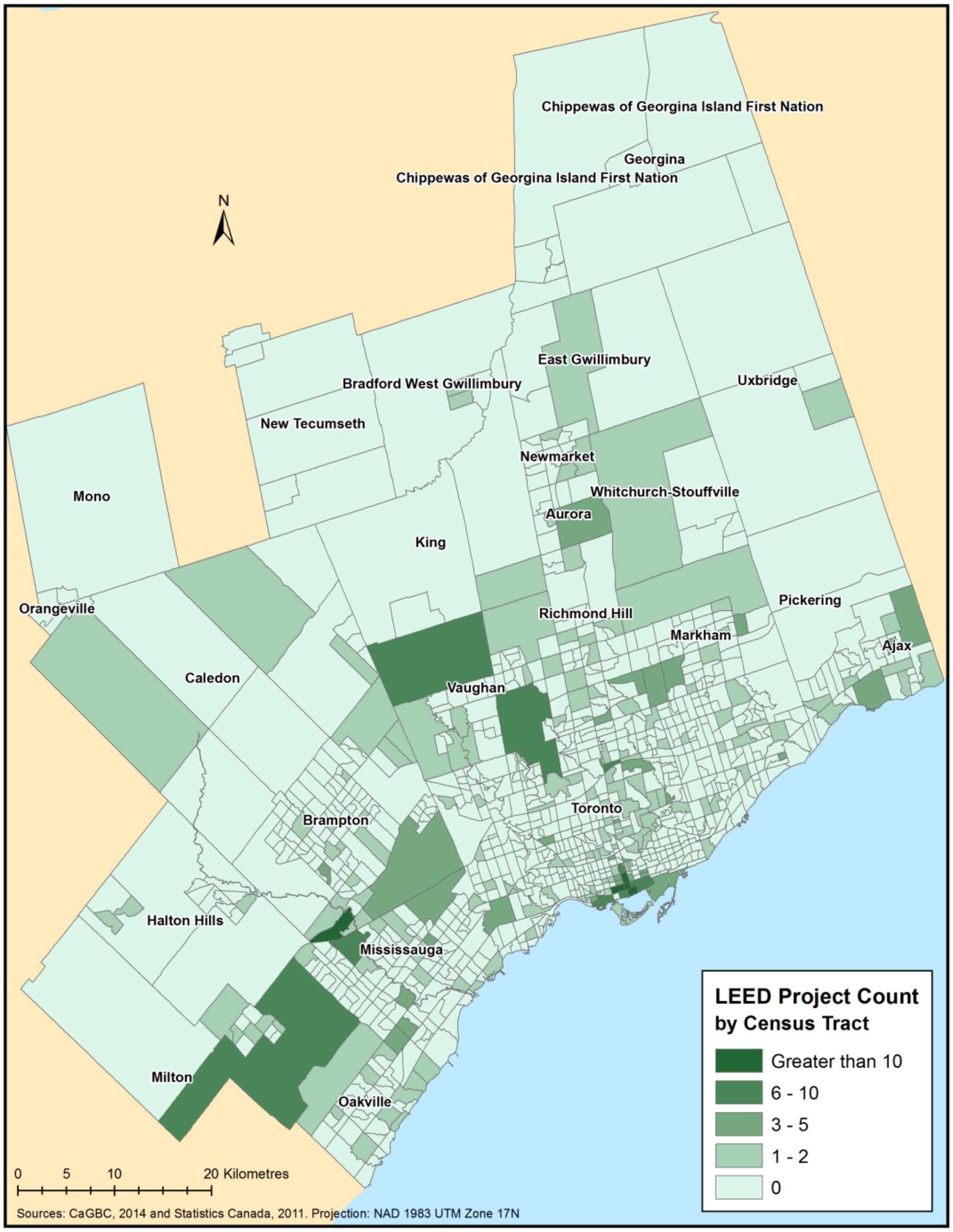

Figure 4.3: LEED projects registered between 2004 and 2010 in the Toronto CMA.

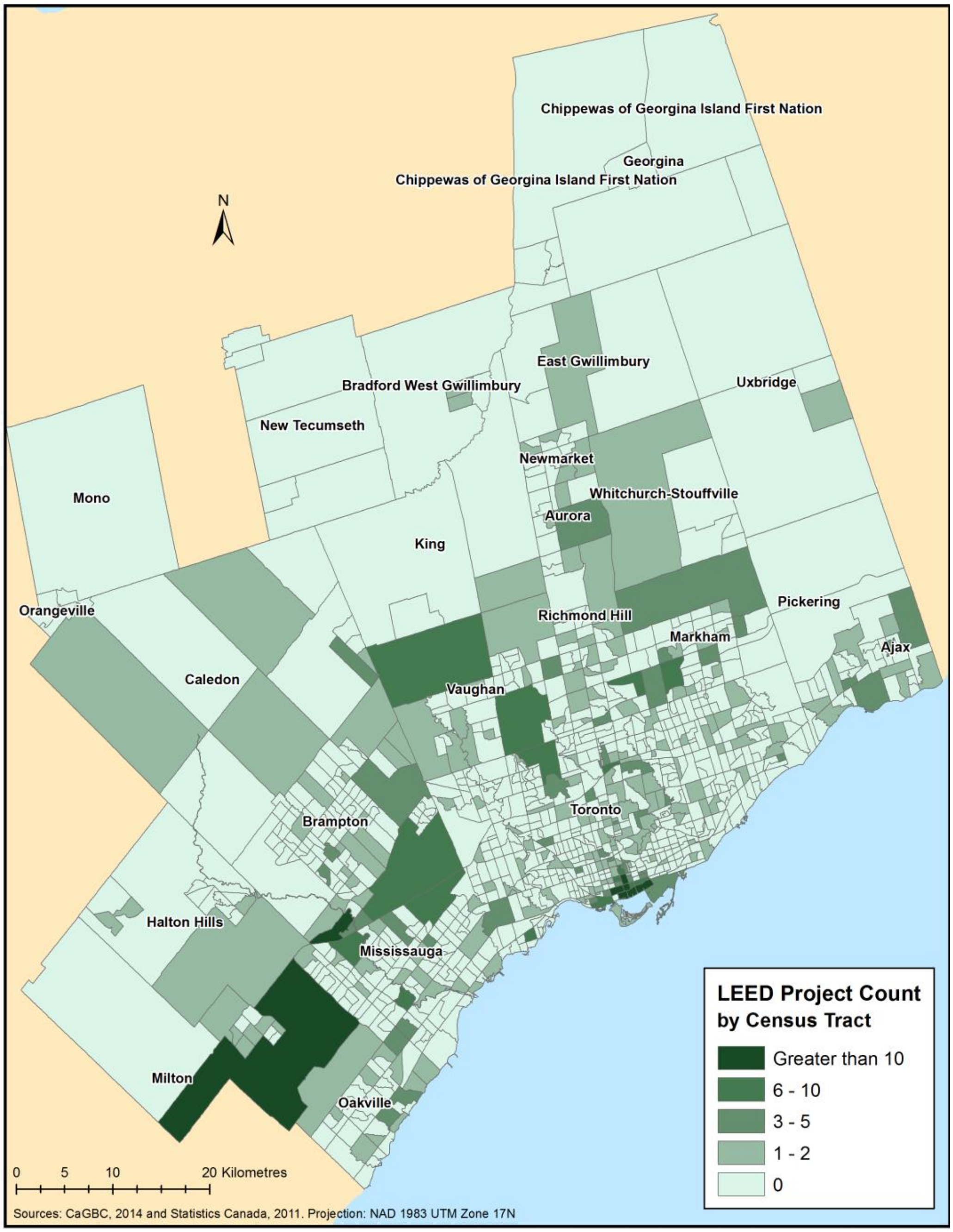

Figure 4.4: LEED projects registered between 2004 and 2013 in the Toronto CMA.

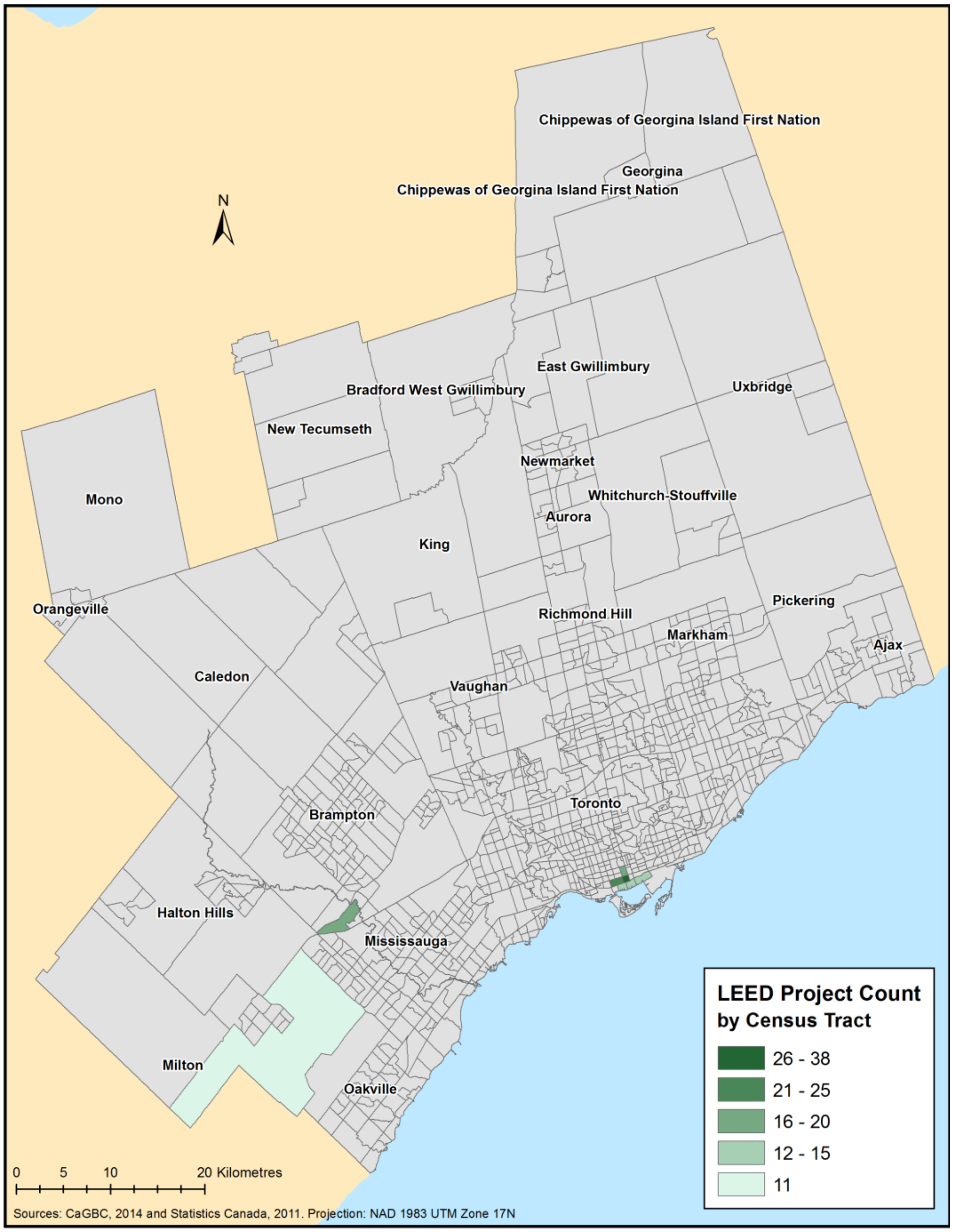

Figure 4.5: Census tracts with more than 10 LEED project registrations in the Toronto CMA by 2013.

Figure 4.6 is a point map showing the location of LEED projects in the Vancouver CMA by time period of registration. Projects registered between 2001 and 2007 are shown in light green, between 2008 and 2010 in medium green, and 2011 and 2013 in dark green. There were 111 projects registered between 2001 and 2007, 178 between 2008 and 2010, and 168 between 2011 and 2013. Similar to the Toronto CMA, LEED projects are spreading out further into more rural areas over time. Projects registered between 2001 and 2007 are mostly found in downtown Vancouver.

Figure 4.7 shows LEED projects in the Vancouver CMA by 2007. Similar to the Toronto CMA, the distribution of projects at this time was mostly in major cities such as Vancouver, Burnaby, and Langley. The project counts were still low at this time. By 2010, project registrations increased up from 2007 by 160%. The resulting map for 2010 is shown in Figure 4.8. Growth in downtown Vancouver was present, as well as in North Vancouver, West Vancouver and Burnaby. There was a large increase in the Delta area. The map shows that projects started to spread further out into the suburban areas. Similar to the Toronto CMA, the “neighbour" effect is occurring, where projects spread to adjacent or near-by census tracts. Approximately 52% of the census tracts that did not have any projects in 2007 (but did in 2010) were touching a census tract that had at least one project in 2007. Around 87% of those new projects were within one kilometre of a census tract with at least project in 2007.

As seen in Figure 4.9, the change from 2010 to 2013 is not as noticeable as the change from 2007 to 2010. Areas that grew were mostly the ones that had LEED projects previously. Approximately 93% of the new LEED census tracts in 2013 were beside census tracts that had existing projects in 2010. Around 98% of those new census tracts were within one kilometre of a census tract with an existing project in 2010. These include the major cities of Vancouver, Richmond, Burnaby, Langley and Surrey. Compared to the Toronto CMA, clusters are not as apparent in the Vancouver CMA for all time periods, with projects more evenly distributed throughout. In both areas, LEED developments are found in downtown areas, and on the fringe of urban suburbs. Rural areas tend to have fewer projects. There are more census tracts with high project counts in the Toronto CMA than there are in the Vancouver CMA.

Figure 4.10 is a choropleth map showing only census tracts in the Vancouver CMA that have more than ten LEED registrations by 2013. The area with the most LEED is in western Vancouver around the University of British Columbia. It has 28 registered projects. The university alone has 26 registrations of the 28. The other two projects are an office building and a high school. The census tract with the second highest LEED count is on the western part of the financial district, with 22 projects. Approximately 91% of those projects are commercial, 2% are residential and 2% are mixed-use. Adjacent to this census tract to the east is the third highest count census tract. The third and fourth highest areas for LEED are not touching this downtown cluster, but are within four kilometres of it.

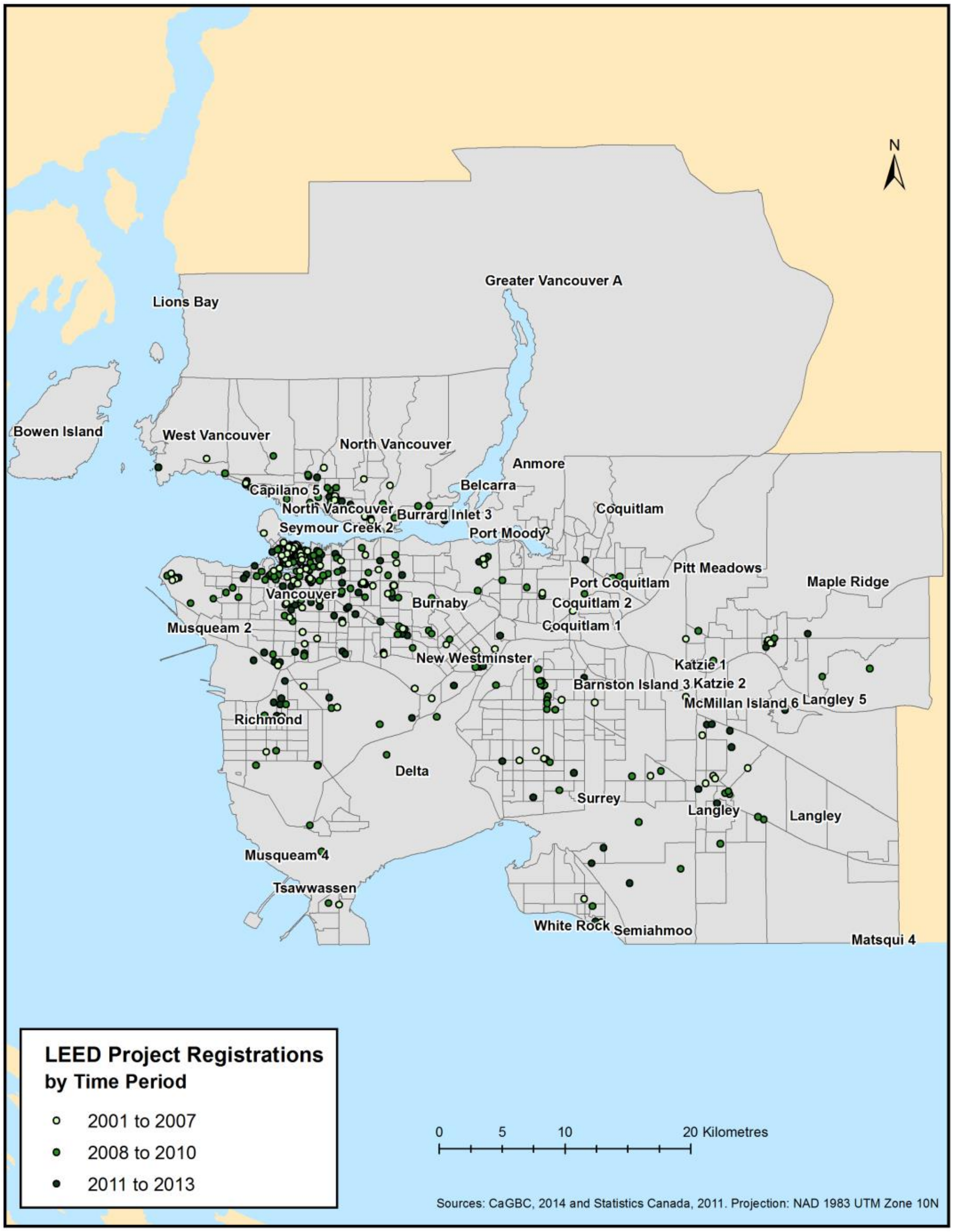

Figure 4.6: LEED projects registered in the Vancouver CMA by time period.

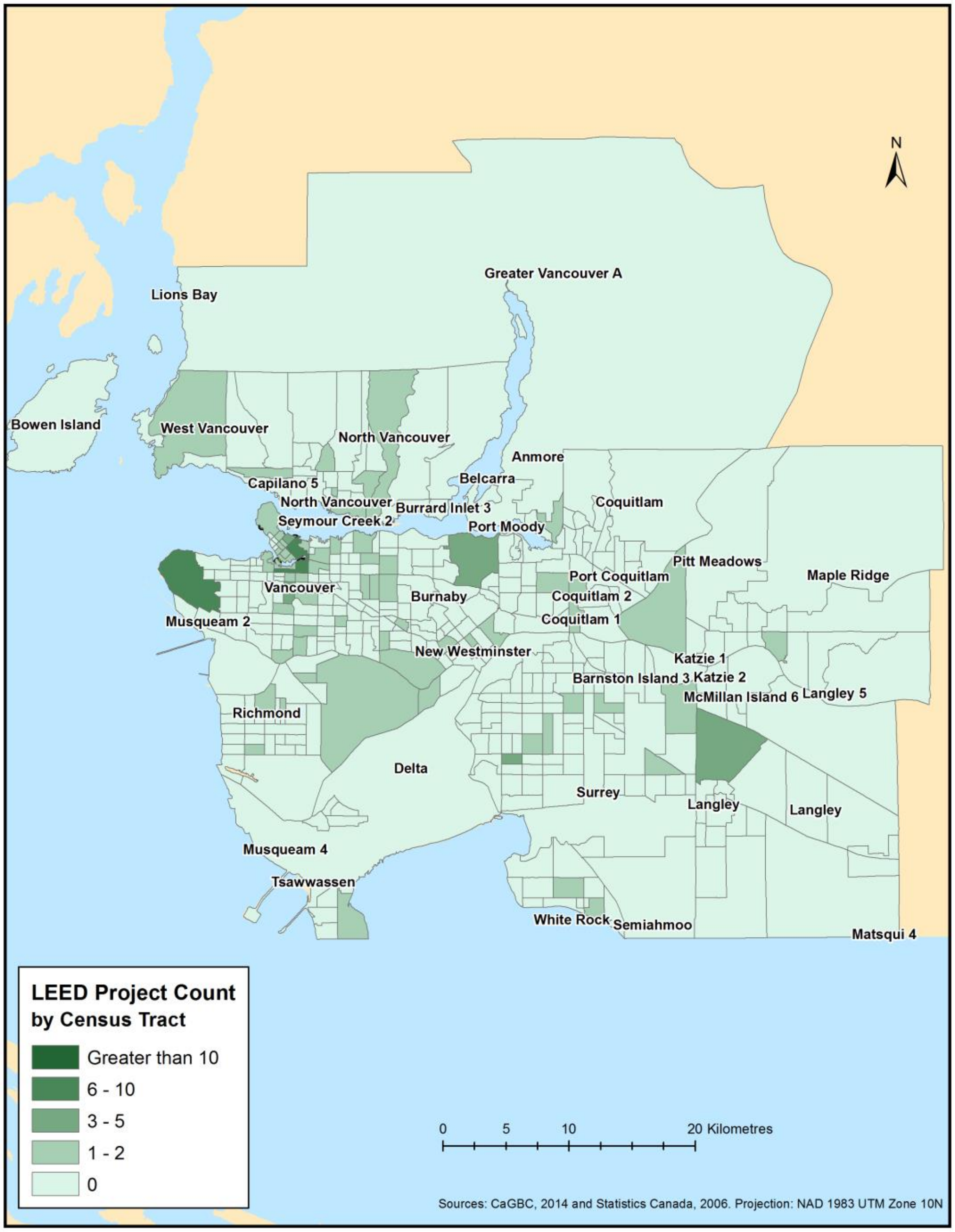

Figure 4.7: LEED projects registered between 2001 and 2007 in the Vancouver CMA.

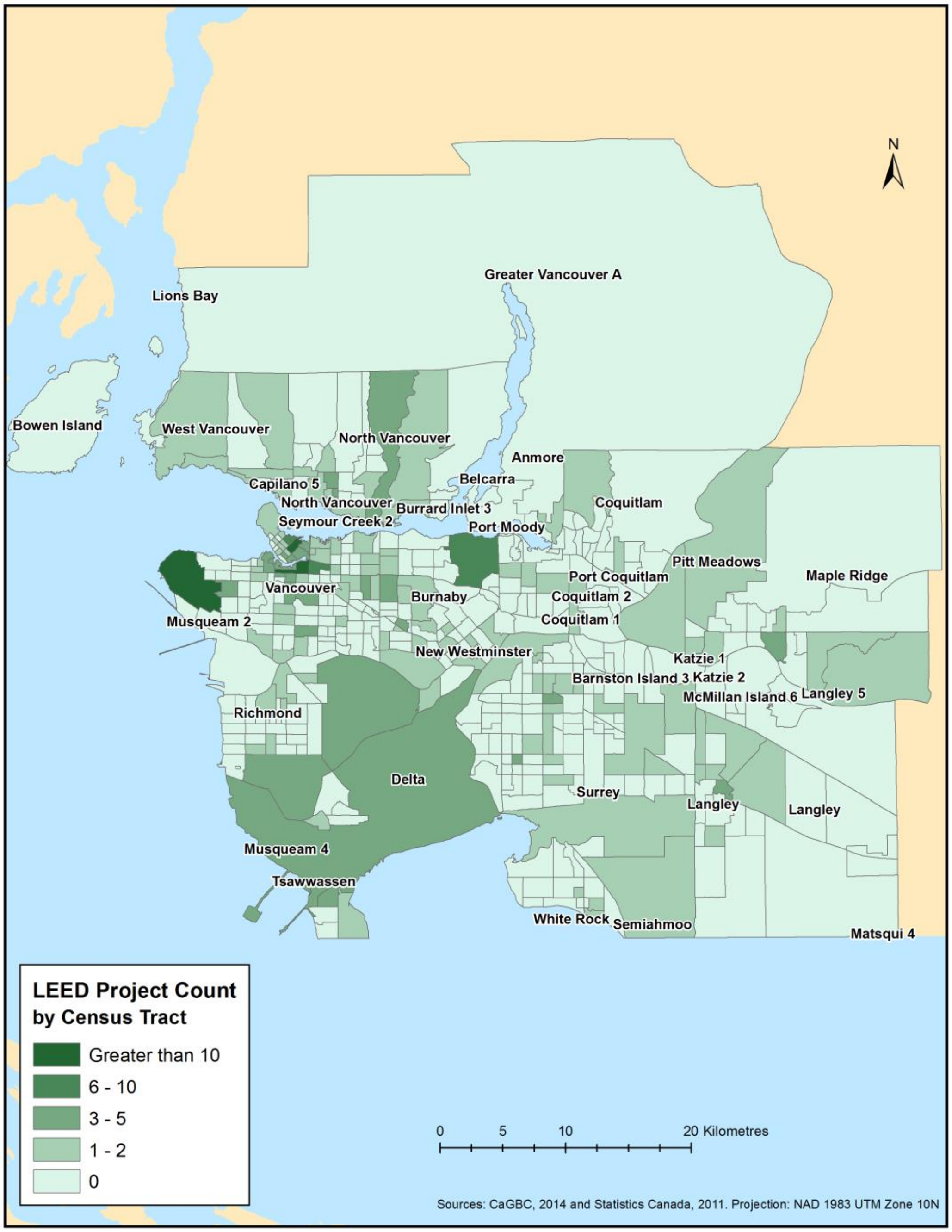

Figure 4.8: LEED projects registered between 2001 and 2010 in the Vancouver CMA.

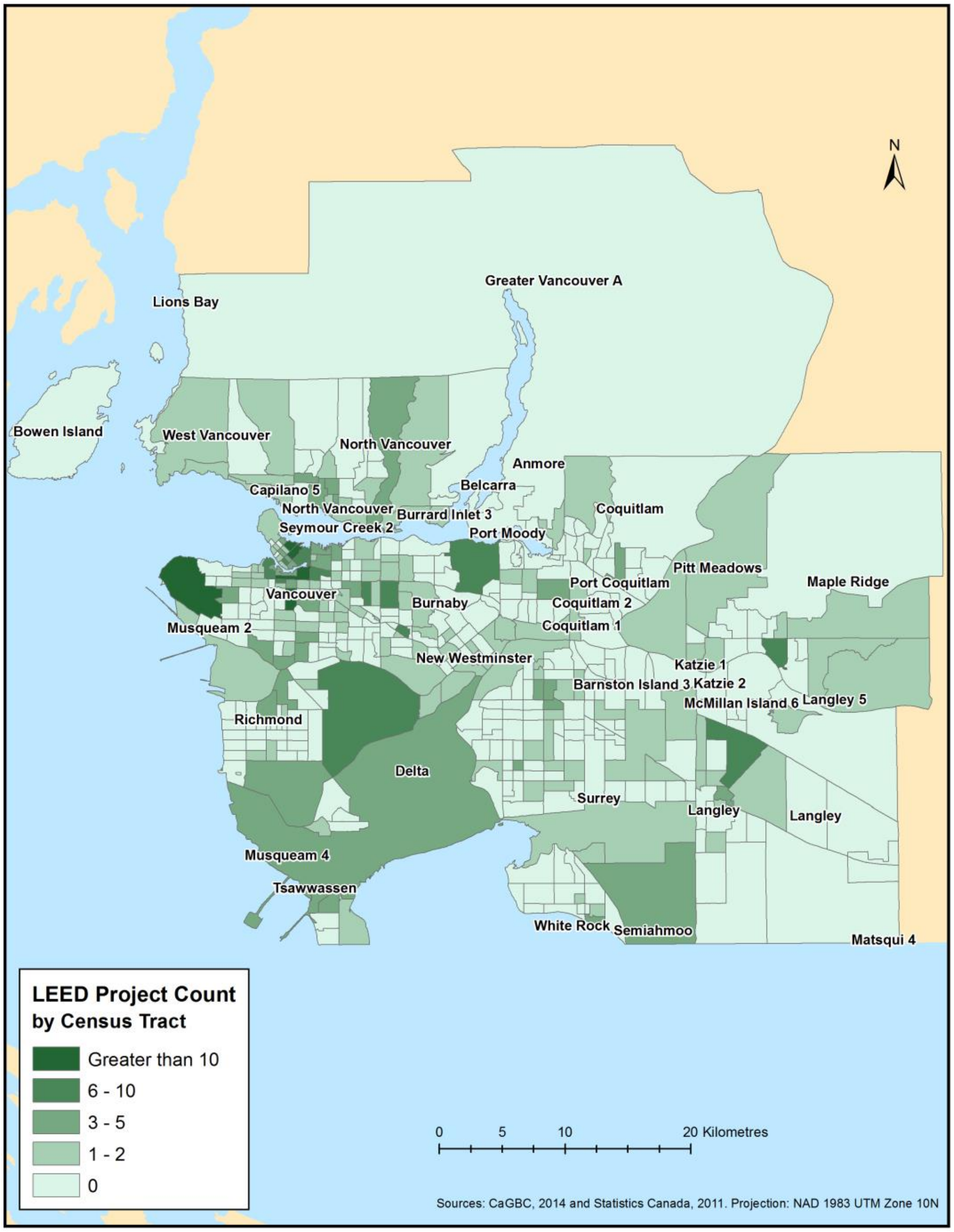

Figure 4.9: LEED projects registered between 2001 and 2013 in the Vancouver CMA.

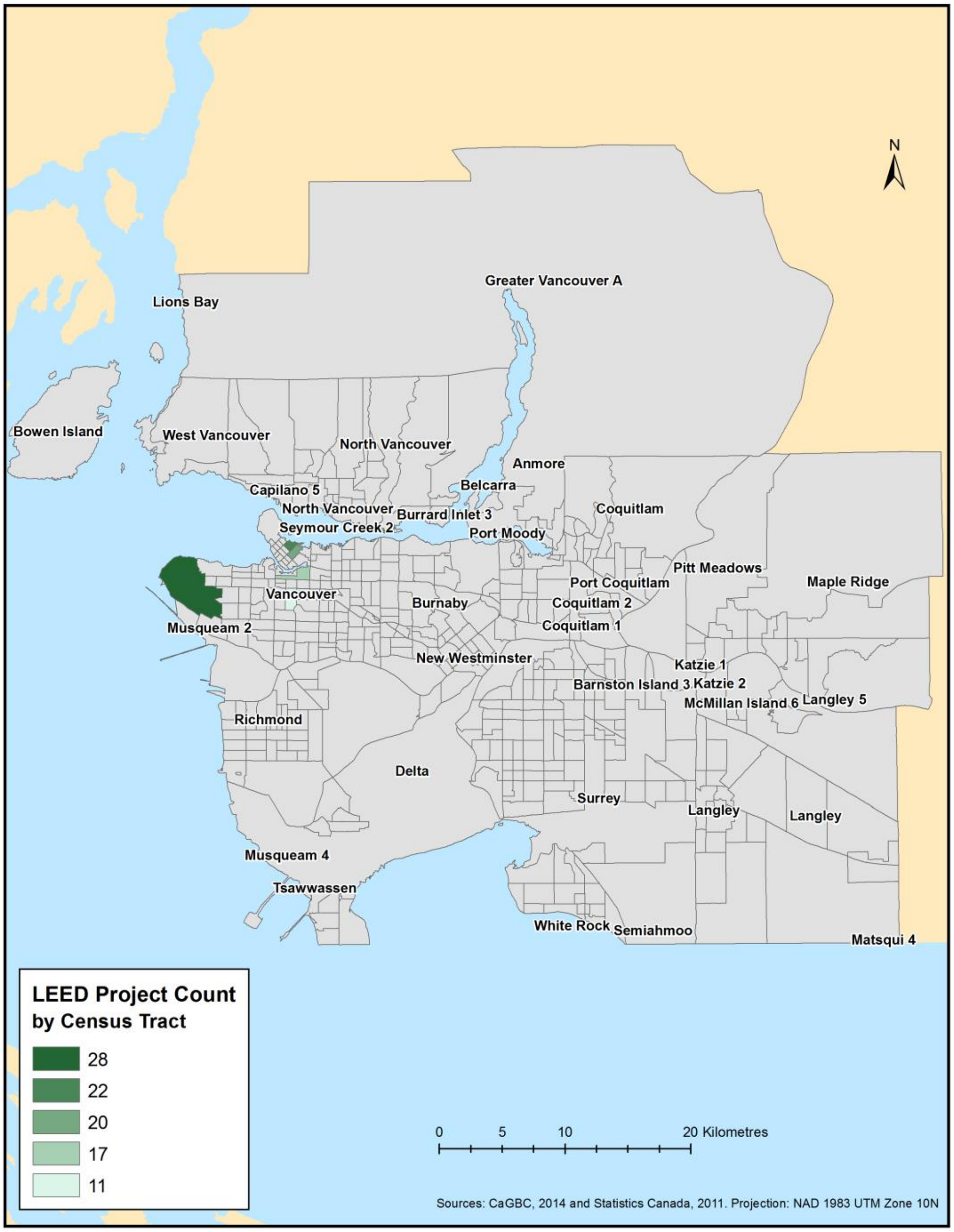

Figure 4.10: Census tracts with more than 10 LEED projects registrations in the Vancouver CMA by 2013.

4.2 Spatial Autocorrelation

4.2.1 Moran's I

The results for Moran's I are summarized by year in Table 4.1. Since all three time periods and both cities have a z-score greater than 2.58, and a p-value of less than 0.01, the null hypothesis of no spatial autocorrelation is rejected (Wong and Lee, 2005). The intensity of clustering can be seen by looking at the value of the z-scores and the Moran Index if the null hypothesis is rejected. The increasing values over time for the Vancouver CMA show that LEED projects are becoming more clustered. However, the decreasing values for the Toronto CMA show that the projects are becoming less clustered.

Previous research has stated that the global Moran's I test might incorrectly show that there is no relationship among the samples, when there may actually be strong correlation in various parts of the study area (Matkan et al., 2013). The global measure is not sensitive enough to smaller-scale clustering, which is important to analyze for this paper. This limitation is why it is valuable to run a LISA test to identify if local clusters exist, and if they are shrinking, or in fact getting larger.

Table 4.1: Moran's I results for LEED projects by census tract in the Vancouver CMA and Toronto CMA by 2007, 2010, and 2013.

	Vancouver CMA			Toronto CMA		
Year	**Moran Index**	**z-score**	**p-value**	**Moran Index**	**z-score**	**p-value**
2007	0.127605	4.622282	0.000	0.144934	8.185515	0.000
2010	0.140085	5.311454	0.000	0.117613	6.902259	0.000
2013	0.153214	5.798272	0.000	0.11507	6.750285	0.000

4.2.2 Anselin Local Moran's I

The LISA results are presented in maps showing cluster types. Features in the high-high and low-low categories represent areas that are surrounded by similar values. The high-low and low-high cluster types indicate spatial outliers, representing polygons with high values that are surrounded by low values, and low values that are surrounded high values, respectively. All the categories require statistically significant clusters at the 0.05 level. The clusters of similar values require z-scores greater than 1.96, while the spatial outliers require less than -1.96 (ESRI, 2013). Features with z-scores between -1.96 and 1.96 are categorized as not significant (Kang et al., 2012).

Figure 4.11 shows a thematic map of the different cluster types resulting from the Anselin Local Moran's I calculation for LEED project registrations in the Toronto CMA by 2007, 2010 and 2013. The green areas represent statistically significant clusters of LEED projects. In 2007, they were generally located in the Toronto downtown core, midtown Toronto, Scarborough, Markham, Oakville, Mississauga and Vaughan. The white census tracts represent areas that had a statistically high number of projects compared to their surrounding areas. These areas are the outliers when it comes to the spread of LEED projects, which likely means that LEED was growing in those areas, but had not grown out to the neighbouring census tracts at that time. These clusters are found in northwest Vaughan, Brampton, Etobicoke, Markham and Aurora.

In 2010 (Figure 4.12), there were substantially more high-high clusters than in 2007. Some areas, especially in Vaughan and Stouffville, went from having clusters of high-low to clusters of high-high. This indicates that high-low census tracts in 2007 were in areas where LEED participation was still new, and therefore had not spread to neighbouring census tracts yet. Clusters that grew by 2010 include those in downtown Toronto, midtown Toronto, Vaughan, Oakville and Mississauga. New clusters were found in Ajax, Stouffville and Milton.

The 2013 map (Figure 4.13) reveals growing clusters. The cluster in Stouffville grew, as did the clusters in Milton, Oakville, downtown and midtown Toronto, Markham, Richmond Hill, and Aurora. Many of the census tracts that were labelled high-low in 2010 were still high-low in 2013, which could imply slowed growth. There are more low-high clusters in the 2013 results, and these areas could be explained as areas that may not be keeping up to speed with their neighbours in LEED participation, or perhaps in new construction or renovation all together. There were no low-low clusters found in any of the time periods.

After visual inspection of the three maps, it can be seen that the clusters of LEED projects that exist are intensifying in the Toronto CMA, showing that LEED projects do tend to locate near each other. These results would not have been found if the Moran's I test was used alone, because the Moran's I test results implied that clustering was becoming weaker. These two tests complement each other to allow differences in global and local clustering to be compared.

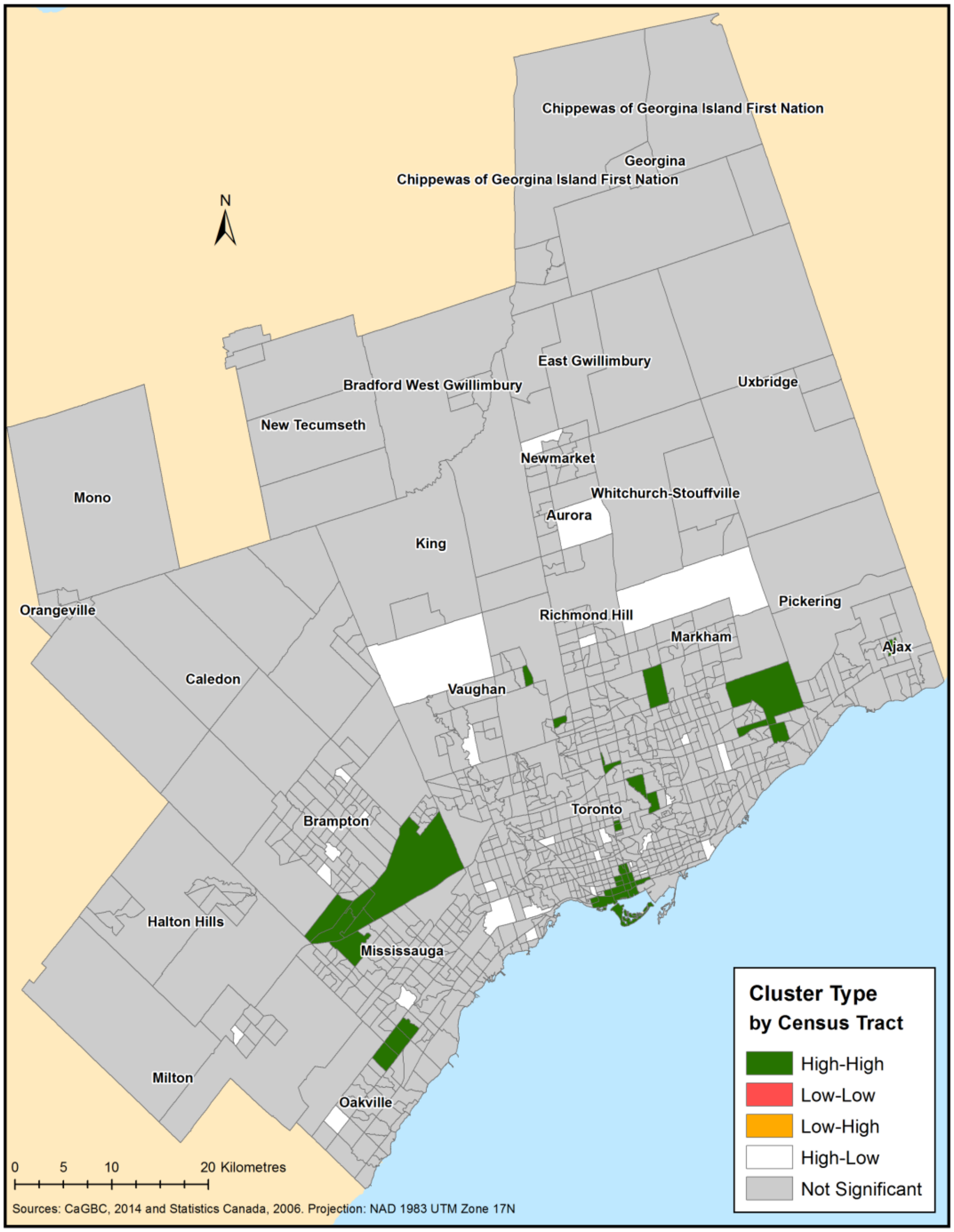

Figure 4.11: Anselin Local Moran's I cluster types for LEED project registrations in the Toronto CMA from 2004 to 2007.

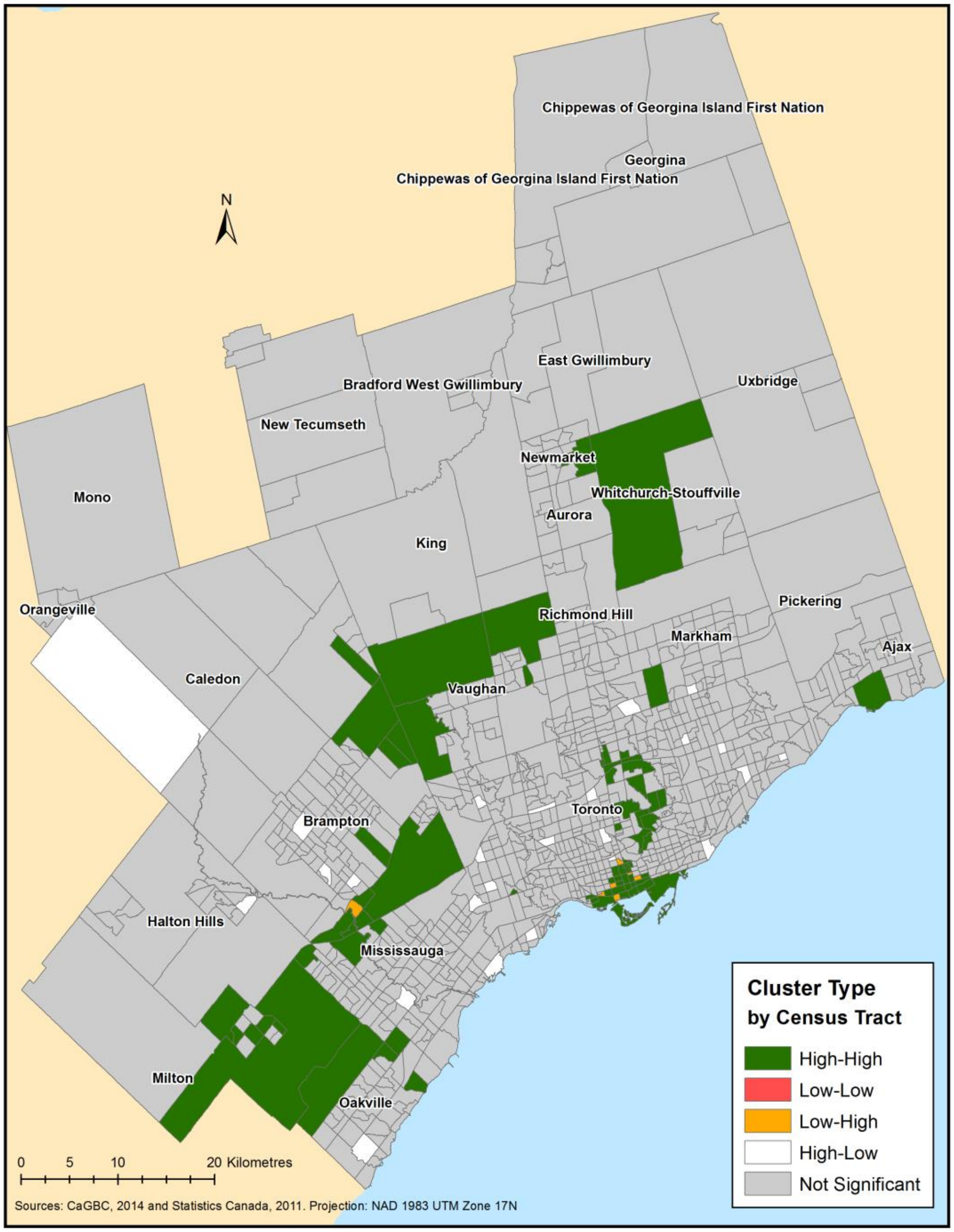

Figure 4.12: Anselin Local Moran's I cluster types for LEED project registrations in the Toronto CMA from 2004 to 2010.

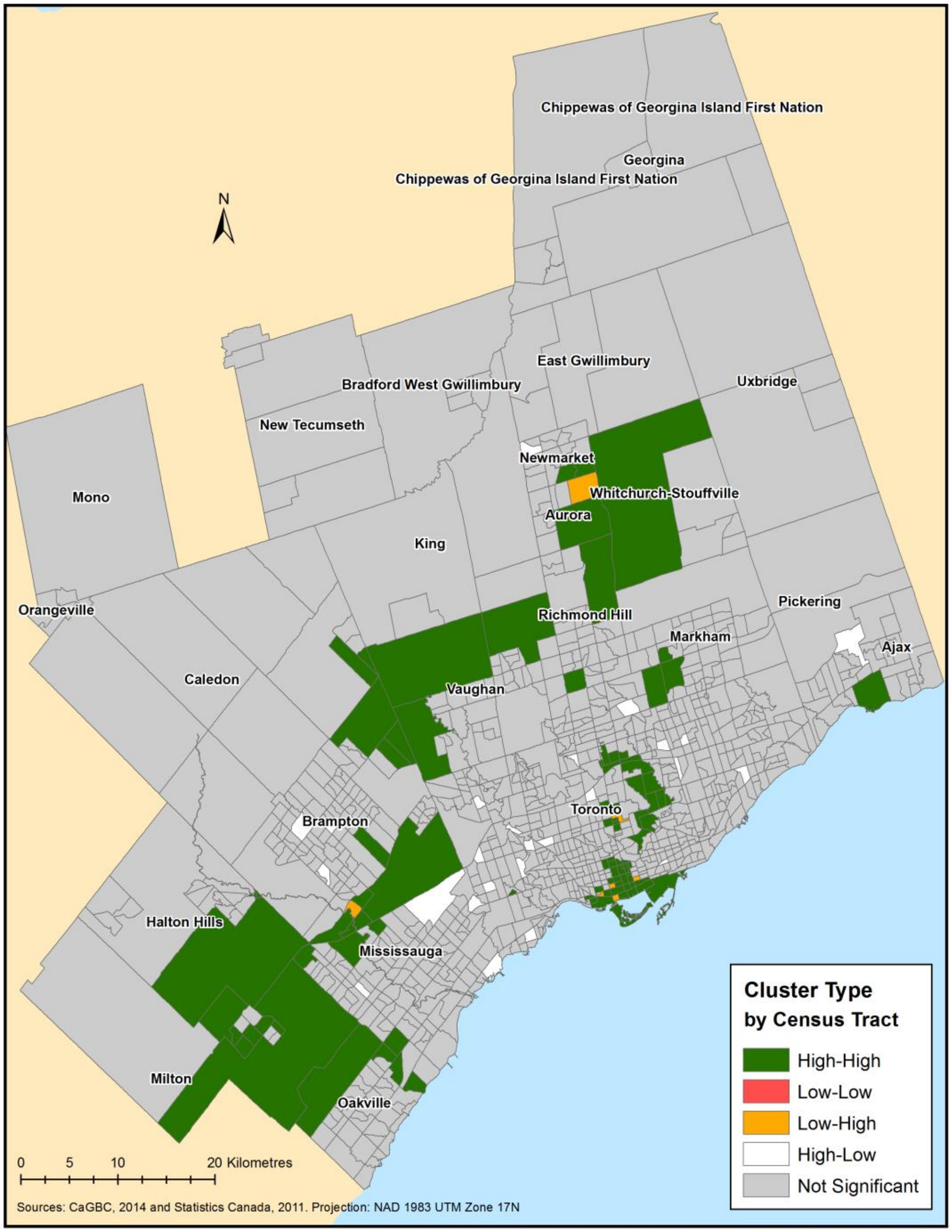

Figure 4.13: Anselin Local Moran's I cluster types for LEED project registrations in the Toronto CMA from 2004 to 2013.

Figure 4.14 shows the LISA results for the Vancouver CMA by 2007. Census tracts with high values surrounded by other highs were located near Vancouver, North Vancouver, New Westminster, northwestern Surrey, and western Burnaby. There were many census tracts that had high values surrounded by low values, including areas around Coquitlam, Richmond, northeastern Burnaby, Langley and White Rock. Figure 4.15 shows the results for 2010. The number of high-low census tracts reduced, and the number of high-high clusters stayed roughly the same, but seemed to become denser around Vancouver and North Vancouver. New Westminster's cluster got smaller, and Richmond's cluster disappeared.

The 2013 map (Figure 4.16) shows less high-low clusters, but more low-high clusters, meaning that these areas have significantly less projects than their neighbours do. The cluster in Vancouver and North Vancouver became even more intense. This pattern was likely the reason that the Moran's I result showed more clustering over time. There were no low-low clusters for any of the time periods.

4.3 Pearson's Correlation

The results for Pearson's correlation for the Toronto CMA and for the City of Toronto are in Table 4.2 and Table 4.3 respectively. A significant correlation of 0.5 or higher is typically considered a moderate relationship, and anything below is considered weak (Taylor, 1990). The tables show that none of the relationships are moderate or higher. For the Toronto CMA, bachelor's degree and LEED project count have a weak positive correlation. Walking and LEED project count also have a weak positive correlation. Both variables are significant at the 99% confidence level because the p-value is less than 0.01.

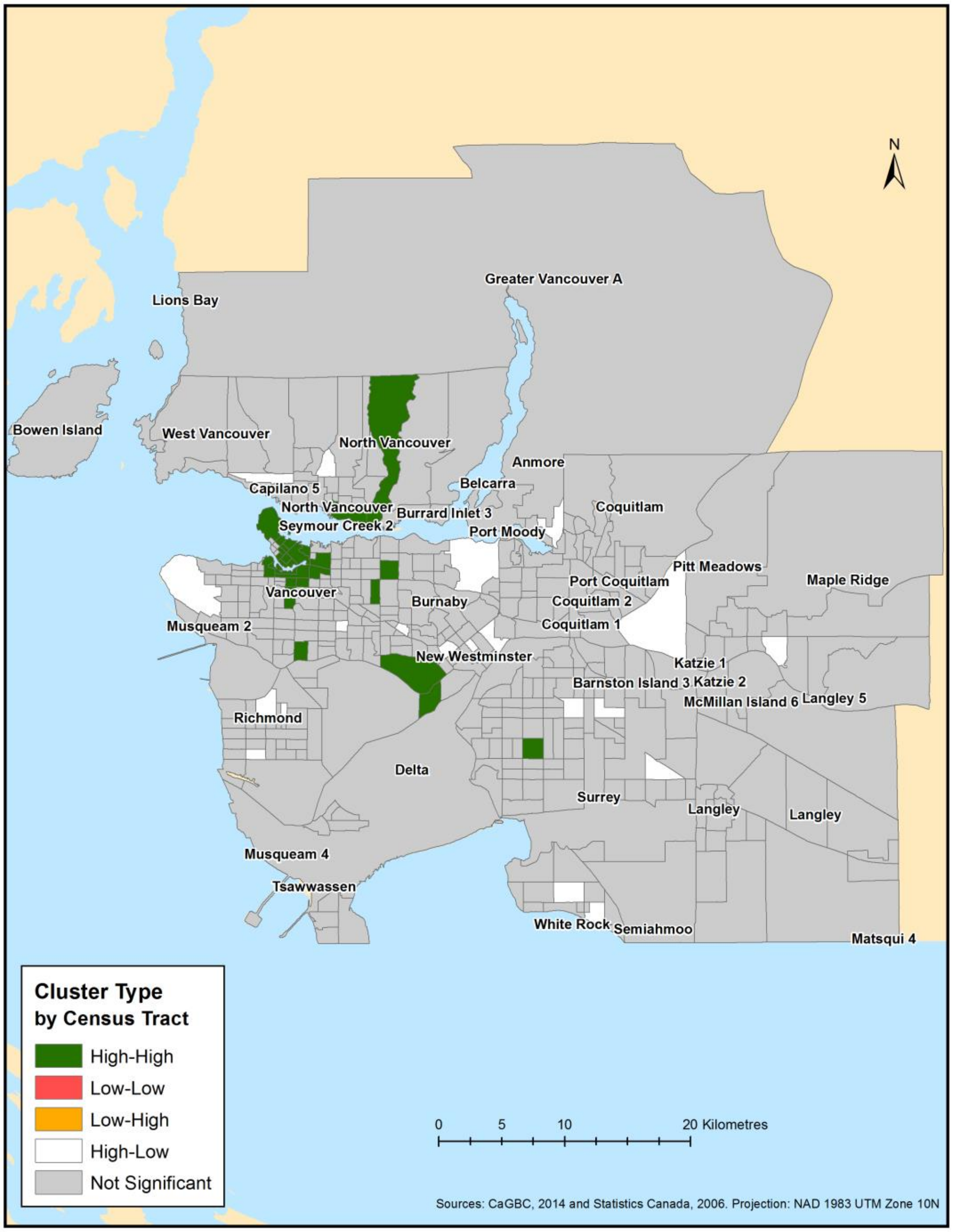

Figure 4.14: Anselin Local Moran's I cluster types for LEED project registrations in the Vancouver CMA from 2001 to 2007.

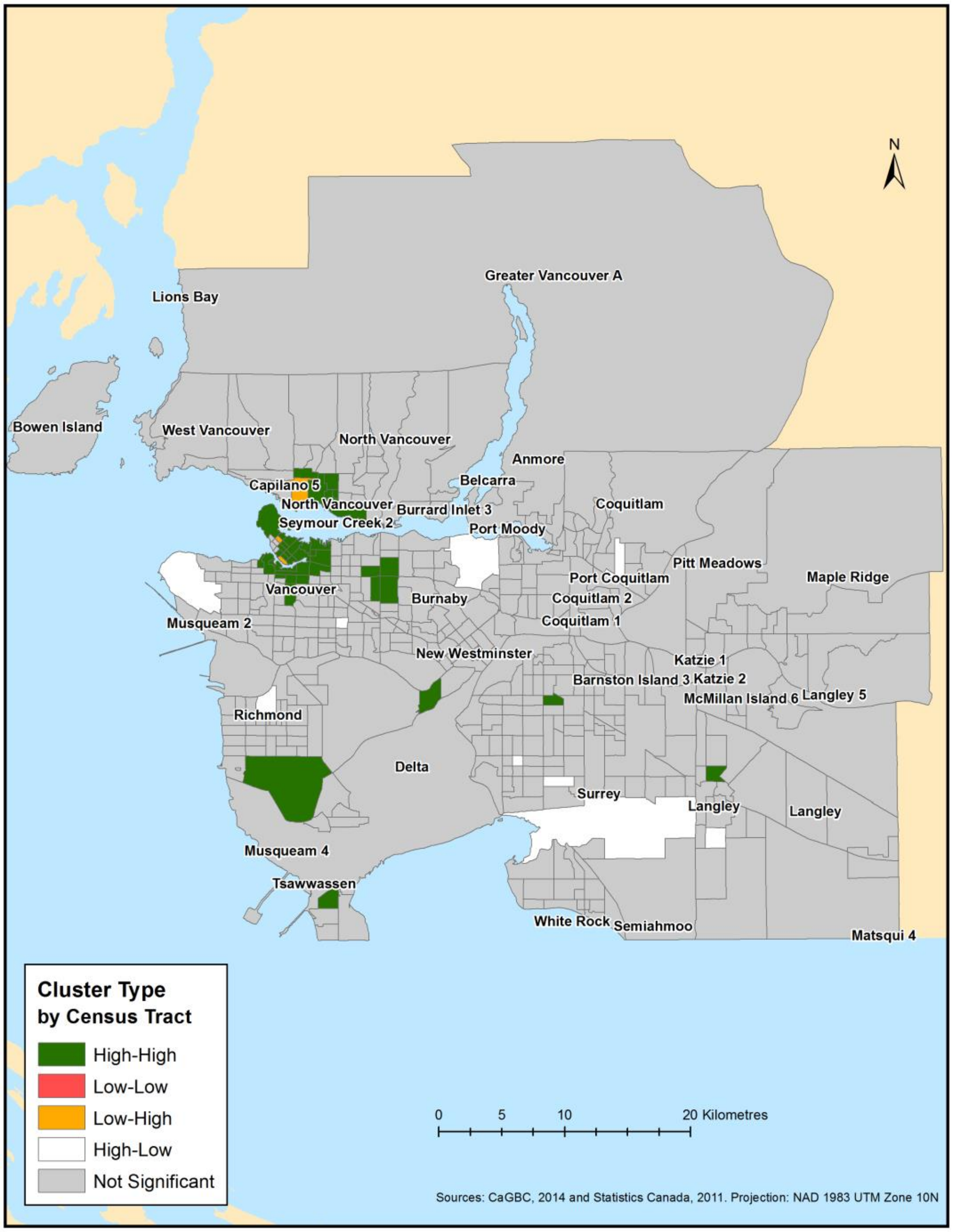

Figure 4.15: Anselin Local Moran's I cluster types for LEED project registrations in the Vancouver CMA from 2001 to 2010.

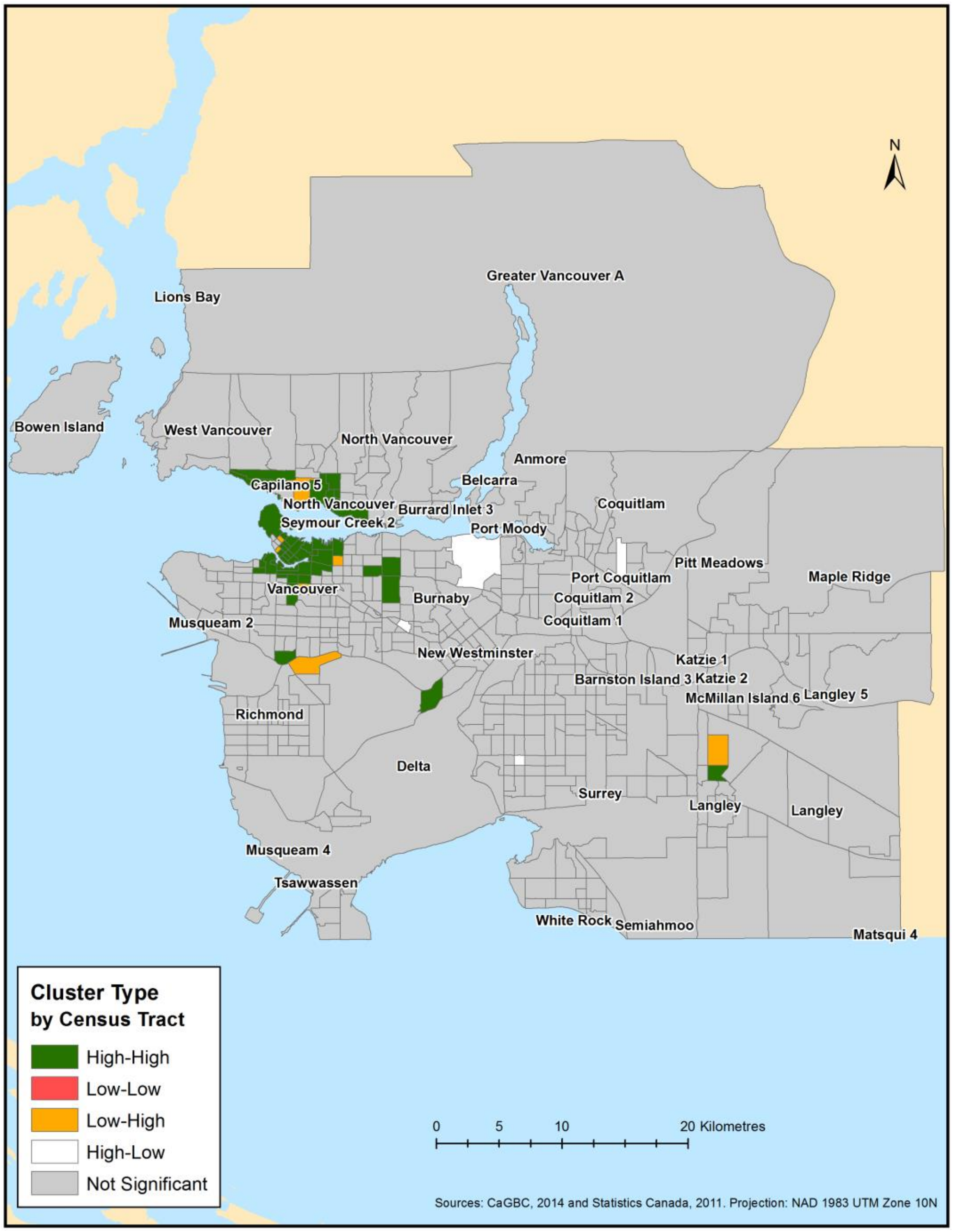

Figure 4.16: Anselin Local Moran's I cluster types for LEED project registrations in the Vancouver CMA from 2001 to 2013.

Median income is not statistically correlated with LEED project count in the Toronto CMA. The City of Toronto had slightly stronger associations, but the results are still only moderately weak. Bachelor's degree and walking are both significant, while median income is not.

Table 4.2: Pearson's correlation results for the Toronto CMA, using 2013 LEED project count (inverse).

Variable	Pearson Statistic	p-value (2-tailed)
Bachelor's Degree	**0.202**	0.000
Walking (Mode of Transport)	**0.266**	0.000
Median Income	**0.040**	0.185

Table 4.3: Pearson's correlation results for the City of Toronto, using 2013 LEED project count (inverse).

Variable	Pearson Statistic	p-value (2-tailed)
Bachelor's Degree	**0.304**	0.000
Walking (Mode of Transport)	**0.407**	0.000
Median Income	**0.032**	0.455

Tables 4.4 and 4.5 show Pearson's r for the Vancouver CMA and the City of Vancouver respectively. In the Vancouver CMA, bachelor's degree had a weak correlation with LEED project count, and walking had a moderately weak correlation. Median income unexpectedly had a significant negative correlation. Some literature has found the same result but other literature has found the opposite, so association varies from place to place. In the City of Vancouver, bachelor's degree was found to have a weak correlation with project count, and walking had a moderate correlation. The correlation of walking for the CSDs was higher than the CMAs for both Vancouver and Toronto. This may be due to more pedestrian presence in larger cities. As with the Vancouver CMA, median income had a significant negative correlation for the

Vancouver CSD. All the variables for both tables are significant at the .01 level. The correlation analysis showed that the selected socio-demographic variables matter more at the CSD level than they do at the CMA level, however only weak associations were found.

Table 4.4: Pearson's correlation results for the Vancouver CMA, using 2013 LEED project count (inverse).

Variable	Pearson Statistic	p-value (2-tailed)
Bachelor's Degree	**0.205**	0.000
Walking (Mode of Transport)	**0.370**	0.000
Median Income	**-0.197**	0.000

Table 4.5: Pearson's correlation results for the City of Vancouver, using 2013 LEED project count (inverse).

Variable	Pearson Statistic	p-value (2-tailed)
Bachelor's Degree	**0.225**	0.000
Walking (Mode of Transport)	**0.428**	0.000
Median Income	**-0.252**	0.006

Figure 4.17 shows pie charts of project land use types in the Toronto and Vancouver CMAs by 2013. In the Toronto CMA, commercial projects are the most dominant, projects of the other category are second, residential projects are third, and mixed-use are fourth. In the Vancouver CMA, projects of the other category are the most dominant, commercial projects are second, residential projects are third, and mixed-use projects are fourth. The other category represents projects that are not residential, commercial or mixed-use, such as public schools, hospitals, churches, conservation centres, public transit stations, industrial projects, and not-for-profit projects. The other projects make up more than the land use types that are typically influenced by profit-

seeking (i.e. residential, commercial or mixed-use). This may explain why the Vancouver CSD and CMA showed a negative correlation between median income and LEED presence. There are proportionately more LEED projects in Vancouver that are government or not-for-profit driven than there are in Toronto, therefore reducing the likelihood of a positive association with income.

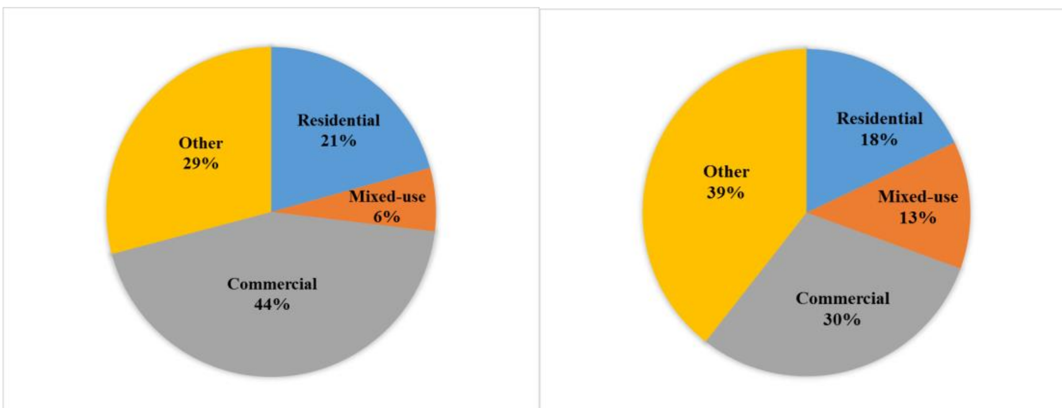

Figure 4.17: Proportion of project types in the Toronto (left) and Vancouver (right) CMAs by 2013

4.4 Trend of LEED Participation by Census Subdivision

In order to gain insight into which cities or towns are growing the fastest in terms of LEED registrations, project count was summed up to the census subdivision (CSD) level to analyze municipal differences in growth patterns. CSDs are levels of census geography, but they are also the boundaries for governing municipalities in which policy is created. Table 4.6 shows a summary of the CSDs in the Toronto CMA with the highest growth in LEED. The table is sorted descending by the final column called '2010 to 2013 Percent Change by Total'. In both time periods, the City of Toronto had the highest percentage of growth when compared to the rest of the CMA. In total, 55.1% of LEED growth in the Toronto CMA was in the City of Toronto in 2010, and 55.6 % was in the City of Toronto in 2013. Mississauga had the second highest percentage growth with 11% in 2010, and 12.2% in 2013. The highly populated cities tended to have the highest growth. The jump from 2007 to 2010, which represents the take-off of LEED in Canada, shows higher rates of growth than between 2010 and 2013. Growing cities such as Vaughan and Milton have an impressive increase in project counts for the size of their cities, and this can be explained by the rapid construction that took place there in the last decade (Ontario Ministry of Finance, 2011).

Table 4.6: Trends of LEED project registrations in the Toronto CMA from 2007 to 2013. (Note: not all CSDs are listed, so the percentages may not sum up to 100%).

Census Subdivision	2007 Project Count	2010 Project Count	2013 Project Count	2007-2010 Difference	2007-2010 Percent Change by Total	2010-2013 Difference	2010-2013 Percent Change by Total
Toronto	73	268	382	195	55.1%	114	55.6%
Mississauga	14	53	78	39	11.0%	25	12.2%
Markham	8	28	45	20	5.6%	17	8.3%
Brampton	6	19	29	13	3.7%	10	4.9%
Richmond Hill	1	6	15	5	1.4%	9	4.4%
Oakville	3	15	21	12	3.4%	6	2.9%
Milton	2	15	20	13	3.7%	5	2.4%
Pickering	1	9	14	8	2.3%	5	2.4%
Vaughan	8	28	32	20	5.6%	4	2.0%
Aurora	2	4	7	2	0.6%	3	1.5%
Caledon	0	4	7	4	1.1%	3	1.5%
Ajax	3	10	11	7	2.0%	1	0.5%
Newmarket	2	6	7	4	1.1%	1	0.5%

Table 4.7 shows a summary of project growth by CSD in the Vancouver CMA. It is also sorted descending by the ‘2010-2013 Percent Change by Total’ field. Vancouver had the highest percentage of total growth in both 2010 and 2013. Surrey surpassed

Langley in 2010, but they were tied for second in 2013. In most cases, for both study areas, the percent increase was steeper from 2007 to 2010 than it was from 2010 to 2013.

Table 4.7: Trends of LEED project registrations in the Vancouver CMA from 2007 to 2013. (Note: not all CSDs are listed, so the percentages may not sum up to 100%).

Census Subdivision	2007	2010	2013	2007-2010 Difference	2007-2010 Percent Change by Total	2010-2013 Difference	2010-2013 Percent Change by Total
Vancouver	53	126	225	73	41.0%	99	54.1%
Surrey	10	29	41	19	10.7%	12	6.6%
Langley	5	8	20	3	1.7%	12	6.6%
Burnaby	10	27	38	17	9.6%	11	6.0%
Greater Vancouver	7	17	28	10	5.6%	11	6.0%
Richmond	6	14	25	8	4.5%	11	6.0%
North Vancouver	8	24	33	16	9.0%	9	4.9%
New Westminster	2	3	9	1	0.6%	6	3.3%
West Vancouver	2	6	10	4	2.2%	4	2.2%
Coquitlam	2	7	10	5	2.8%	3	1.6%
Maple Ridge	2	8	11	6	3.4%	3	1.6%
White Rock	1	2	4	1	0.6%	2	1.1%
Delta	1	10	10	9	5.1%	0	0.0%

Table 4.8 compares percentage of LEED growth with policy presence within CSDs. The table is sorted descending by project count in 2013. A surprising finding is the lack of policies present in the City of Toronto that reference the LEED rating system. The other highly ranked CSDs have at least one policy in place. Toronto has other programs in place, including the Toronto Green Standard, that promotes green building instead of the LEED system specifically (Ontario Green Policy Hub, 2012), which may indirectly increase LEED registrations. Oakville has four existing policies, which is the highest

number in the CMA. Table 4.9 shows the summary for the Vancouver CMA. The two leading cities, Vancouver and Surrey, both have policies in place referencing LEED.

Table 4.8: Number of LEED policies present per CSD in the Toronto CMA compared to the growth trends. (Note: not all CSDs are listed, so the percentages may not sum up to 100%).

Census Subdivision Name	LEED Project Count 2013	Percentage of Total LEED Increase 2004 - 2013	Number of Policies Present
Toronto	382	55.3%	-
Mississauga	78	11.4%	1
Markham	45	6.6%	1
Vaughan	32	4.3%	1
Brampton	29	4.1%	1
Oakville	21	3.2%	4
Milton	20	3.2%	-
Richmond Hill	15	2.5%	2
Pickering	14	2.3%	2
Ajax	11	1.4%	-
Aurora	7	0.9%	2
Newmarket	7	0.9%	-
Caledon	7	1.3%	1
Bradford West Gwillimbury	4	0.7%	-
Halton Hills	3	0.5%	1
King	2	0.4%	-
East Gwillimbury	2	0.4%	3
Whitchurch-Stouffville	2	0.4%	1
Uxbridge	1	0.2%	-
Mono	0	0.0%	-
Georgina	0	0.0%	-
Chippewas of Georgina Island First Nation	0	0.0%	-
Orangeville	0	0.0%	-
New Tecumseth	0	0.0%	-

Table 4.9: Number of LEED policies present per CSD in the Vancouver CMA compared to the growth trends. Note: not all CSDs are listed, so the percentages may not sum up to 100%).

Census Subdivision Name	LEED Project Count 2013	Percentage of Total LEED Increase 2001 - 2013	Number of Policies Present
Vancouver	225	62.3%	1
Surrey	41	11.4%	2
Burnaby	38	10.5%	-
North Vancouver	33	9.1%	-
Greater Vancouver A	28	7.8%	2
Richmond	25	6.9%	1
Langley	20	5.5%	-
Maple Ridge	11	3.0%	3
West Vancouver	10	2.8%	-
Coquitlam	10	2.8%	-
Delta	10	2.8%	-
New Westminster	9	2.5%	1
White Rock	4	1.1%	-
Port Coquitlam	3	0.8%	1
Pitt Meadows	3	0.8%	5
Port Moody	1	0.3%	-
Capilano 5	1	0.3%	-
Coquitlam 2	0	0.0%	-

CHAPTER 5: DISCUSSION AND CONCLUSION

5.1 Discussion

As LEED continues to grow in Canada, this research has confirmed that projects will likely be located where other projects already exist, which may indicate a narrowing of the market. Cidell (2009) found the same pattern in LEED certified buildings across different metropolitan areas in the United States, where nearly all recent projects were located in places that already had at least one green building. The spatial autocorrelation results show statistically significant clustering in both the Toronto and Vancouver Census Metropolitan Areas. The Toronto CMA has more clusters of LEED projects than the Vancouver CMA. Projects within the Vancouver CMA tend to cluster more tightly into downtown Vancouver. LEED had a large jump in registrations from 2007 to 2010, when the program peaked and it was becoming more ingrained into the building science field. However, when the economic downturn occurred, the construction industry suffered, and therefore the LEED industry suffered as well. The LISA cluster maps revealed that even with the decrease in the rate of registrations, existing clusters tended to stay the same or get larger.

The spatial autocorrelation results showed that it is necessary to run Moran's I with a LISA measure in order to realize smaller-scale clusters that may not be caught by the global statistic. The Moran's I results showed that both CMAs had statistically significant clustering for all three time periods. However, they also indicated that the intensity of the clustering increased over time in the Vancouver CMA, but decreased in the Toronto CMA. When analyzing the LISA maps, statistically significant clusters of LEED buildings are getting larger, despite the contradicting Moran's I results.

Pearson's correlation analysis was conducted for three variables; proportion of persons with a bachelor's degree, median income, and proportion of those who walk to work. Statistically significant positive relationships were found in both the Toronto CMA and the City of Toronto between the counts of LEED projects and both bachelor's degree and walking to work. However, the results showed that they both had weak associations. The Vancouver CMA and the City of Vancouver had similar results, but were slightly closer to a moderate relationship. It was found that in the Vancouver CMA and the City of Vancouver, median income had a statistically negative correlation with project count.

Policy is known to be an important step in promoting green building in both the public and private sectors. Additionally, literature has shown that policy presence has found to be associated with more LEED projects (Fuerst et al., 2014). Most of the leading CSDs in LEED project counts in both the Toronto and Vancouver CMAs have at least one policy present. This analysis emphasizes the importance of putting policy in place to encourage LEED or any green building activity.

5.2 Conclusion

The main objective of this paper was to analyze the spatial distribution of LEED projects in the Toronto and Vancouver CMAs from 2001 to 2013 to identify if projects are concentrated over space, and to analyze the differences over time. To do this, thematic mapping and measures of global and local spatial autocorrelation were used. Statistical clustering was found to exist in both study areas, which confirms an industry "spill-over" effect, where LEED projects tend to locate near other LEED projects. The project distributions and clusters were analyzed for three different time periods, which allowed growth areas to be identified. The most LEED projects are located in the financial district in downtown Toronto. The census tract with the highest number of project registrations is situated around the intersection of Bay Street and King Street. In Vancouver, the most LEED projects are in the census tract around the University of British Columbia, which makes up 26 of the 28 projects in the area. The second and third highest counts of LEED are found in the financial district of downtown Vancouver.

In both study areas, nearly all of the projects are commercial, which is valuable information for the CaGBC, urban planners, developers and policy makers. The CaGBC can continue targeting their efforts towards commercial developments, and can actually anticipate more projects if they observe existing projects already in an area. Developers interested in getting involved in LEED would also benefit from these findings because they can use them to find out what kinds of areas LEED is popular in and develop in the same or similar markets. Urban planners and policy makers would find these results helpful because LEED projects are found at all levels of land use types. Understanding where LEED is well received and what kinds of developments cluster together is important for planning and building sustainable cities.

Possible contributing socio-demographic factors were explored to test what previous literature has found. Only weak Pearson correlations were found for bachelor's degree, median income, and walking to work. The results (for education) were similar to research done by Cidell (2009). It was found that in the Vancouver CMA and the City of Vancouver, median income had a statistically significant negative correlation with project count. Kahn and Vaughn (2009) also had this finding in California, while having a positive correlation for the entire United States.

After comparing the LEED project locations to policy data, it was found that most of the top cities for LEED project growth have plans that reference the LEED system. This pattern indicates that policy can be effective in the implementation of green building. However, there are several cases where there is no plan present but a relatively high number of LEED projects exist, including the City of Toronto.

5.3 Limitations

A methodological limitation of the project is that the modifiable areal unit problem (MAUP) is a concern. Spatial autocorrelation is sensitive to surface partitioning (Griffith, 1992). Certain clusters may exist when the census tract boundary is used, but if a different boundary is used for calculation, the results may be different.

There are many different credit categories within the certification process, so patterns are bound to occur across different geographies. For instance, a project downtown will get credits related to accessibility more easily than a project in a rural area. There are also different categories regarding the land use type, such as residential or commercial. Analyzing the different categories is beyond the scope of this paper, however, it is important to note that differences do exist and impact the results.

Some LEED projects are built to the green building standard, but do not go through the certification process. Therefore, all of those projects go unnoticed and are not included in the analysis. LEED is a common program, however, it is likely that there people that are interested in sustainable building practices that do not find the need to be recognized by this organization. Lastly, some projects are registered, but never actually get certified, so they cannot be considered green according to LEED standards.

Since the data were still slightly skewed after the transformation, mostly due to an abundance of zero and one values, zero-inflated binomial regression or negative binomial regression would likely be appropriate for future research. In doing so, socio-demographic indicators may be revealed.

5.4 Future Research

Since correlation analysis results were different at the CMA and CSD levels, future research could analyze relationships at the national level to see what differences exist. The addition of more variables, such as occupation, could also be analyzed for statistical association. It would be beneficial if the spatial distribution of LEED accredited professionals (AP) were analyzed, which would allow interest in the system to be further targeted. In doing so, interest at the individual level could be analyzed and compared to project distributions.

The project credit and land use categories are an important aspect of the emergence of LEED. It is recommended that future research take these types into consideration. Understanding the differences in categories could assist in improvement of the LEED system and its implementation. More specifically, it could be used to target policies towards certain building developments.

Policy and planning are two major influences on development patterns. Further research on statistical significance of the relationship between Canadian policy and LEED development should be researched as more data become available. By seeing where policy is effective and where it could applied would be a proactive step towards increased LEED implementation.

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