ANALYSIS OF CERTIFIED WOOD PRODUCT USE IN COMMERCIAL LEED GREEN BUILDING PROJECTS

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Abstract. There is a growing demand for green building products within the United States. Because of this increased demand and interest in green products, the potential exists for wood product manufacturers to gain additional market share opportunities within the green building sector. The overall objective of this study was to use spatial analysis techniques to evaluate the growth of green building projects and the use of certified wood products (CWPs) within these projects. The focus of this study was on green building projects certified as part of the US Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) that obtained the certified wood credit. Using spatial analysis techniques, this study was able to identify geographic areas in which wood products were used and awarded points toward green building certification. Results indicated a trend of commercial LEED-certified projects that obtained the certified wood credit being geographically concentrated with time. The study also identified various "hot spot" county clusters throughout the United States for commercial LEED-certified projects that obtained certified wood materials. A spatial econometric regression analysis resulted in significant explanatory variables such as population of a county; obtaining LEED credits in material reuse, recycled material content, composite wood and agrifiber products, and regional material; and the density of Forest Stewardship Council (FSC)-certified product manufacturers within 161 km. The results of the study are expected to help improve availability of wood products by indicating potential green building marketing regions for wood product producers.

Keywords: Green building, certified wood, LEED, spatial analysis, spatial econometrics.

INTRODUCTION

The recent and forecasted growth of green building projects in the United States has identified the green building industry as a viable and increasing market for construction materials. A study published by McGraw Hill Construction (2013) indicated that the green market made up 48% of all 2012 building project activity in the United States. In addition, respondents that had 60% or more of their jobs in green building projects expected that more than half of their projects (53%) would be green oriented in 2015, up from 40% in 2012. The top reported sectors in which respondents planned to have green projects were

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new commercial buildings, retrofits of existing buildings, and new institutional buildings. Wood product manufacturers, particularly those providing environmentally certified wood materials, may have additional opportunities to include their products in various green building standards for specific point accumulations. The most recognized green building standard in the United States is the Leadership in Energy and Environmental Design (LEED) program developed by the US Green Building Council (USGBC 2013a) and currently lists 62,525 registered and certified projects (USGBC 2013b) in the United States alone. As a significantly popular standard in the green building industry, building projects pursuing LEED certification represent a large potential market for manufacturers of environmentally low-impact construction materials.

Wood products have low environmental impacts compared with other construction materials such as steel or concrete (Buchanan and Levine 1999; Petersen and Solberg 2002, 2003; Lippke et al 2004; Puettmann and Wilson 2005; Gustavsson et al 2006a, b; Upton et al 2008) and are rewarded by LEED through point-generating categories used to obtain building certification. LEED specifically encourages the use of certified wood products (CWPs) by granting one point for the use of Forest Stewardship Council (FSC)-certified wood, provided that at least 50% (cost based) of all wood-based materials used in the project were FSC certified. Other opportunities for credit accumulation exist, in LEED versions 2009 and earlier, for uncertified wood products in categories such as recycled content, indoor environment quality, locally sourced materials, and rapidly renewable materials. The sales opportunities for wood product producers interested in pursuing green building projects under LEED, therefore, are not limited to those participating in FSC wood product certification.

Recently, the inclusion of CWPs in the green building sector has been a topic of research interest. One study suggested that nonwood products may have an unfair advantage in that green building programs require wood to be accompanied by an environmental certification to comply with particular point-generating categories (Bowyer 2007). However, the singling out of wood products may also provide an opportunity to educate others on the environmental friendliness of the material (Falk 2009). Recommendations have been made to manufacturers who may be interested in diversifying their current market with the green building sector by becoming certified to produce FSC-labeled products and to track new marketplace developments (Tardif and O'Conner 2009). A different study focused in the western United States, however, suggested that design professionals have little incentive to include the use of wood products in the structural material selection of green buildings, although wood was viewed as a more environmentally friendly material when compared with steel and concrete (Knowles et al 2011).

Spatial trends in LEED-certified structures have also been a topic of recent studies. Kahn and Vaughn (2009) investigated the spatial distribution of LEED-certified projects on a state level across the United States. They further investigated zip code level data for the state of California and determined that the explanatory variable "environmental factor," which is a combination of a zip code area's percentage of voters registered with the Green Party, votes in favor of Proposition 12, and votes in favor of Proposition 13, was significant for both the dependent variables "All" LEED ownership types and "Commercial" LEED ownership types within a given zip code. Johansson (2011) determined the temporal and spatial growth of LEED projects in the United States and indicated an expansion diffusion pattern of growth at the regional level. Results from this study also indicate the Pacific coast region as the primary epicenter of green building in the United States followed by a secondary epicenter, New England (Johansson 2011). Cidell (2009) suggested that after the initial dispersion of LEED-certified projects throughout the United States, few new areas obtained LEED certification of projects.

Although the general use of CWPs in green building projects has been explored, there is no known research that explores the spatial and temporal growth of CWP use in the largest green building certifying standard in the United States (LEED). Research in this area could help FSC-certified product manufacturers understand the geographic trends associated with the use of FSC-certified products in the green building sector. Therefore, this research was undertaken to indicate the spatial growth trend of FSC-certified wood product use in the LEED green building program as well as to identify specific geographic regions in which the use is more prominent.

To identify geographic trends of FSC use in the LEED rating system, it is important to explore certified project locations as well as influencing factors that may be associated with that region. By collaborating with USGBC and FSC, the spatial growth of LEED projects using FSC-certified wood to gain points toward building certification may indicate specific areas of market potential for FSC manufacturers. Information obtained through this research may help identify specific market areas for FSC product manufacturers and help to indicate geographic market conditions for future growth trends.

The goal of this project was to assess the spatial growth trends of LEED-certified projects that were awarded the certified wood credit throughout the entire United States. Specific objectives of this research were to identify geographical distribution of LEED-certified projects that were awarded the certified wood credit and to identify particular areas of concentrated use of CWP in LEED-certified projects.

MATERIALS AND METHODS

Spatial Analysis

USGBC, the governing entity for the LEED certification program, was contacted to obtain the most accurate and updated list of LEED-certified projects. This dataset contained all nonconfidential projects up to August 13, 2013, which received LEED certification and were located in the United States. LEED for home projects were not included in this dataset because of confidentiality restrictions. The dataset initially included 13,436 projects that were spread across six different LEED rating program types: LEED for Commercial Interiors (CI), LEED Core and Shell (CS), LEED Existing Building Operation and Maintenance (EBOM), LEED for Schools, LEED for Health care, and LEED for New Construction (NC). The interest of this project is to identify possible markets for wood product producers. Because Alaska and Hawaii are located outside typical sales markets for most wood product producers in the continental United States, the projects located in these states (105) were removed from the list of data as well as further analysis. In addition, 2007 of the projects listed as EBOM were removed from this study because of the lack of a certified wood credit available in the rating program. Therefore, the remaining dataset contained 11,324 LEED-certified projects. Of these certified projects, 3456 projects obtained the certified wood credit and were defined as the working dataset for this study.

The following attributes specific to each project were also obtained: gross square footage of project, owner type, certification date, certification level, latitude and longitude coordinates of the project, industry type, space use type, rating program, and if the project achieved the certified wood credit. Also, specific category achievements were obtained from the USGBC for material reuse recycled content, composite wood and agrifiber products, and regional materials. Although these categories may not be limited to the use of wood products specifically, there are opportunities for non-CWP use to satisfy these categories. Therefore, these data were acquired to explore possible relationships between the achievement of these category credits and that of the certified wood credit.

The individual projects located in the continental United States were geocoded and projected (USA Contiguous Equidistant Conic) and uploaded to geographic information systems (GIS) software for spatial analysis. Individual project locations were grouped for analysis by joining the LEED data with the respective county centroid. Uniform areas (unlike county borders) are preferred when spatially analyzing data; however, county-level analysis was applied because of the availability of complementary data such as electricity rates, income, population, and other census-based data obtainable at the same geographic level.

Spatial analysis was performed on the continental United States as a whole to indicate country-wide growth trends for LEED-certified projects. Also, spatial analysis was individually performed on the four major census regions of the United States to provide greater detail of FSC-certified wood product use in LEED-certified projects for manufacturers and suppliers in these areas. Spatial analysis is inherently tied to the areas of observation. By dividing the continental United States into the four census regions (Fig 1), higher levels of detail are achieved in these regions compared with results obtained when analyzing the entire United States. Therefore, the following five areas were spatially analyzed: Continental, Northeast (NE), South (S), Midwest (MW), and West (W).

As a precursor to the Getis-Ord Gi* test (hot spot analysis) for cluster locations, Moran's I test was initially conducted on the data in all five areas to determine if spatial autocorrelation existed. Results from the Moran's I test indicated that a statistically significant ($p < 0.05$) clustered pattern existed for all five areas. Hot spot analysis was then performed on county-level data to indicate the location of statistically significant clustering and/or dispersion of data points within a determined threshold distance (or neighborhood). Distance thresholds were initially determined by measuring the distance needed to encompass the centroids of the eight largest neighboring counties within each of the five areas of analysis; eight data points have been suggested as a rule of thumb to maintain the reliability of the resulting z score (ESRI 2014a). Each distance was then entered into an incremental spatial autocorrelation analysis tool to determine the highest ranked distance threshold relative to the input distance and based on significance level. The threshold distance calculated for the W was the largest among the four census regions because of the relatively large

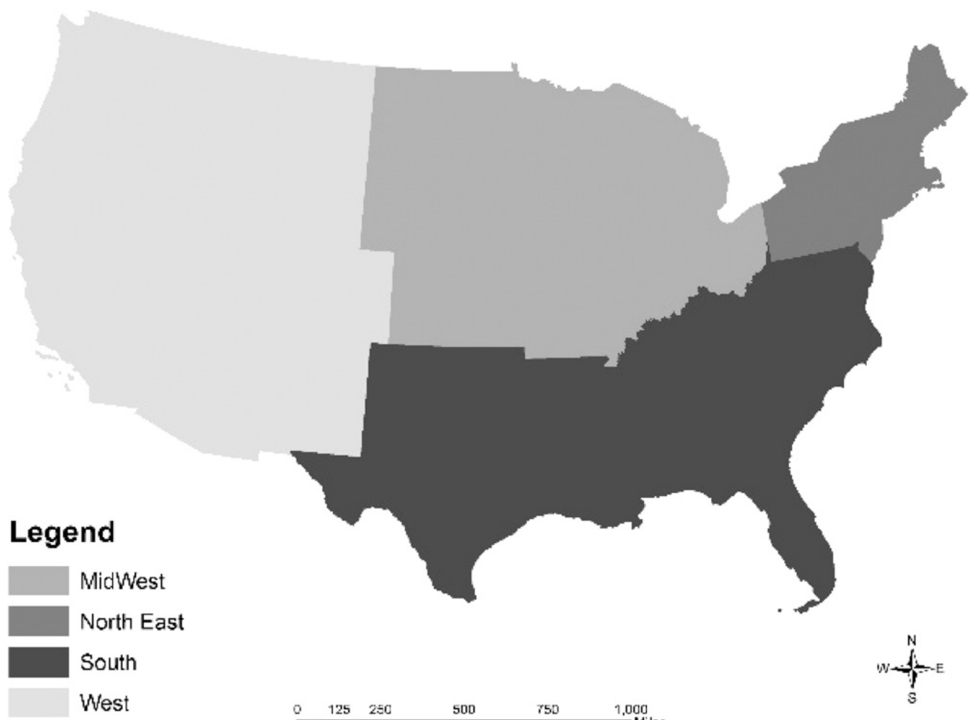

Figure 1. Four census regions of the United States.

Table 1. Threshold distances for the five analysis regions in the United States.

Area of analysis	Threshold distance (m)
Continental	121,856
Northeast	45,411
South	84,888
Midwest	56,723
West	121,856

size of the counties found in this region. This threshold distance, 121,856 m, was also used to analyze data for the continental United States as well to provide county-level precision throughout the country while still encompassing approximately eight neighboring data points for each county centroid. Table 1 shows the resulting threshold distance used for each of the five different areas in the hot spot analysis. As county size increased in an area, the threshold distance also increased to encompass neighboring county centroids.

Spatial analysis was performed on county-level data to indicate geographic trends in certified project locations. LEED-certified projects obtaining the certified wood credit experienced significant spatial growth throughout the country between the years 2000 and 2013 (Fig 2). Moran's I testing was used to indicate the spatial autocorrelation of county centroids based on location and number of LEED-certified projects in that county. In general, results from this test indicate if the spatial distribution of the data are significantly ($p < 0.05$) different from random distribution. Also, if the test results in a significant p value, the z value associated with the test indicates if the pattern of the data are significantly clustered (z score is positive) or significantly dispersed (z score is negative) compared with random distribution of the data (ESRI 2014b). When comparing the Moran's I statistic, negative values indicate a dispersed pattern, zero values indicate a random pattern, and positive values indicate a clustered pattern. To determine growth trends of LEED-certified projects, Moran's I was calculated for each year (2000-2013) in each of the five analysis regions. Increasing Moran's I results indicated higher levels of clustering patterns. Therefore, by comparing the results for each year within each geographic region, building patterns for LEED projects were determined.

Regression

Spatial regression techniques were used to determine the statistical significance of explanatory variables and their influence on the use of FSC-certified wood in LEED projects. Identifying statistically significant explanatory variables may help determine future FSC market areas based on the presence of significant variables in other geographic locations. Also, the use of FSC-certified wood in a LEED project may be affected by its proximity to an FSC-certified product producer. Therefore, a list of all FSC-certified wood product producers and their locations were acquired from the FSC. The list contained 40,092 companies, along with the respective product types and locations. In many cases, a single company was listed multiple times at the same location, each listing containing a different product type. This list was narrowed, however, to only contain those company locations that offered products relative to the building construction market. The following general product categories were selected and determined the final list of FSC product providers

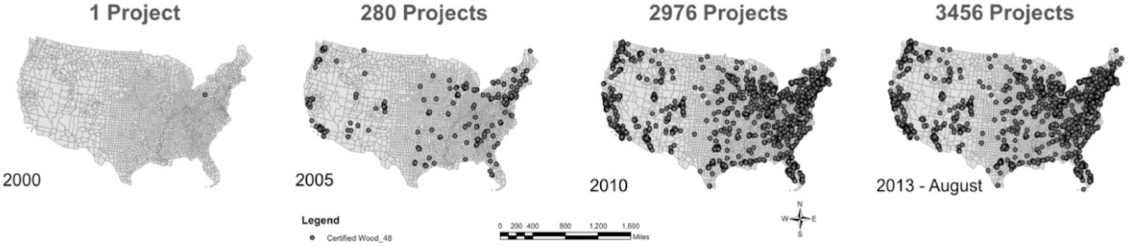

Figure 2. LEED-certified projects that obtained the certified wood credit. Locations in sample data by year 2000, 2005, 2010, and August 2013 (LEED, leadership in energy and environmental design).

for use in the regression analysis: wood for construction, houses and building elements, roofing and trusses, stairs and flooring, cabinetry, boards/planks/beams, plywood and oriented strand board, engineered wood products, and wood–plastic composites. Companies with multiple products available at the same location were decreased to one listing for analysis. The resulting list included 1261 company locations for use in the spatial econometric analysis. These locations were geocoded, projected, and added to the GIS map. The density of FSC product producers was then determined within 161 km, between 162.5 and 322 km, and between 323.5 and 805 km of the county centroids containing LEED-certified projects that obtained the certified wood credit.

The analysis for spatial regression was performed on the county data points through the use of MatLab software (Matlab 2014) and included the following independent factors:

- Latitude
- Longitude
- Percentage of population that has obtained a 4-yr degree or higher (Cidell 2009; USDA 2012a)
- Average electricity rate (EIA 2012)
- Population (USDA 2012b)
- Payroll per building (USCB 2012)
- Median income (USDA 2012c)
- The number of projects that obtained the material reuse credit, the recycled content credit, the wood composite and agrifiber credit, and the regional material credit
- The density of FSC-certified product providers within 161 km, between 162.5 and 322 km, and between 323.5 and 805 km

The dependent factor analyzed was the number of LEED-certified projects that obtained the CWP credit in a county. A procedure determined by Florax et al (2003) and another determined by Elhorst (2010) were used to determine which regression model was suitable to best describe the data found in the analysis regions.

The results of the spatial regression model analysis indicated the regression model that was most suited for the analysis region. For the US region, the Spatial Durbin Model (SDM) was indicated as the best model to use for the data obtained (Eq 1). SDM is unique in that it incorporates the impacts that explanatory variables have not only on the local dependent variable but also on the neighborhood dependent variables. Also, SDM includes feedback loop effects in which neighborhood impacts also affect the local observations (LeSage and Pace 2008).

$$\boldsymbol{y} = \rho \boldsymbol{W}\boldsymbol{y} + \boldsymbol{x}\beta + \boldsymbol{W}\boldsymbol{x}\theta + \varepsilon \quad (1)$$

where $\boldsymbol{y}$ = vector dependent variable, $\boldsymbol{x}$ = matrix of explanatory variables, $\boldsymbol{Wx}$ = matrix of spatially weighted explanatory variables, $\boldsymbol{Wy}$ = vector of spatially weighted dependent variable, β = vector regression coefficients, θ = vector regression coefficients on spatially weighted variables, ρ = scalar spatial autocorrelation parameter, and E = error.

RESULTS AND DISCUSSION

Spatial Analysis

Results for the LEED-certified project data indicated this growth pattern as becoming generally more clustered from 1 yr to the next (Fig 3) when looking at the United States as a whole. When the United States is segmented into the four major census regions, growth patterns generally trended

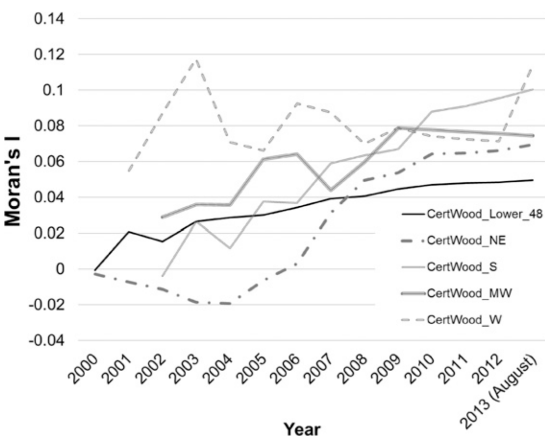

Figure 3. Moran's I for all LEED-certified projects that obtained the certified wood credit in sample data throughout the United States and the four census regions (NE, Northeast; S, South; MW, Midwest; W, West) (LEED, leadership in energy and environmental design).

toward increased cluster patterns between 2000 and 2013. Both the MW and W regions experienced only clustered patterns of LEED projects during this time. In the NE, project locations initially indicated a random distribution with no presence of statistically significant clustering or dispersion. In 2007, however, increased growth in LEED projects in this region led to significantly clustered project locations, and this growth pattern has continued. In the S, growth patterns have shifted steadily during the 13-yr span from neither clustered nor dispersed in 2002 to significantly clustered in 2003. Results from the Moran's I test indicated LEED project locations throughout the United States and that growth in the four census regions has been generally in a clustered pattern. This means that areas that have experienced high volumes of LEED-certified project placement may be likely to continue to see growth of LEED-certified projects and FSC-certified wood use in the future.

Hot spot analysis was performed on the LEED-certified projects throughout the continental United States that obtained certified wood credit. Of the 3109 counties, 718 (23%) contained at least one LEED-certified project that obtained certified wood credit. Hot spot analysis identified statistically significant clustering of counties that contained a large number of certified projects. Several hot spot areas were identified throughout the United States (Fig 4). Groups of adjacent hot spot counties occurred near the large metropolitan areas of Seattle, WA; Portland, OR; San Francisco, CA; Los Angeles, CA; Denver, CO; Houston, TX; Chicago, IL; Washington, DC; Baltimore, MD; Philadelphia, PA; New York, NY; Boston, MA; and Miami, FL. In all hot spot counties, there was a significantly high concentration of LEED-certified projects that obtained the certified wood credit within the neighborhood analysis distance (121,856 m). Based on the significantly clustered growth pattern of these

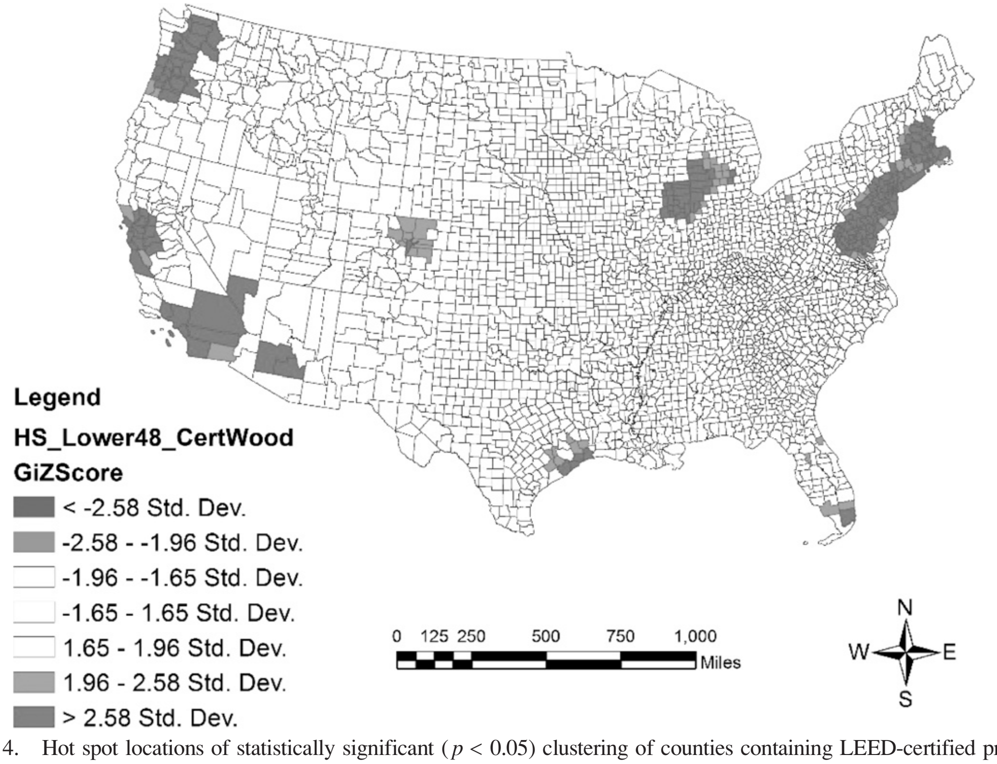

Figure 4. Hot spot locations of statistically significant ($p < 0.05$) clustering of counties containing LEED-certified projects that obtained the certified wood credit in the continental Unites States (LEED, leadership in energy and environmental design).

projects, these geographic areas may be likely potential locations for future development for FSC-certified wood material providers.

Hot spot analysis was performed on the four census regions to determine areas of concentrated LEED-certified projects using and obtaining credit for use of CWPs. Results from census region analyses differ from those on the national level because of decreased neighborhood analysis areas and the total area included in the analysis. For each of the four regions, a smaller neighborhood analysis distance (except W), coupled with a smaller area analyzed, resulted in more geographically specific hot spot counties.

Results from the hot spot analysis (Fig 5) indicated counties containing significantly large numbers of LEED-certified projects that have obtained the certified wood credit. These included the following regions or cities:

- MW—Minneapolis, MN; Chicago, IL; Grand Rapids, MI; Detroit, MI; Cleveland, OH; Cincinnati, OH; and Saint Louis, MO
- NE—Pittsburgh, PA; Philadelphia, PA; New York, NY; and Boston, MA
- S—Washington, DC and surrounding cites; Raleigh, NC; Lexington, NC; Rock Hill, NC; Atlanta, SC; Orlando, FL; Tampa, FL; Miami, FL; Dallas, TX; Houston, TX; and Austin, TX
- W—Seattle, WA; San Francisco, CA; Los Angeles, CA; Phoenix, AZ; and Portland, OR

Findings based on these neighborhood analysis distances revealed more specific areas of interest for green building product manufacturers as well as FSC-certified product suppliers. A more focused target market is indicated than in the county-wide analysis that could help to further minimize manufacturer's efforts in determining potential sales areas. For example, large consecutive areas of hot spot counties were found

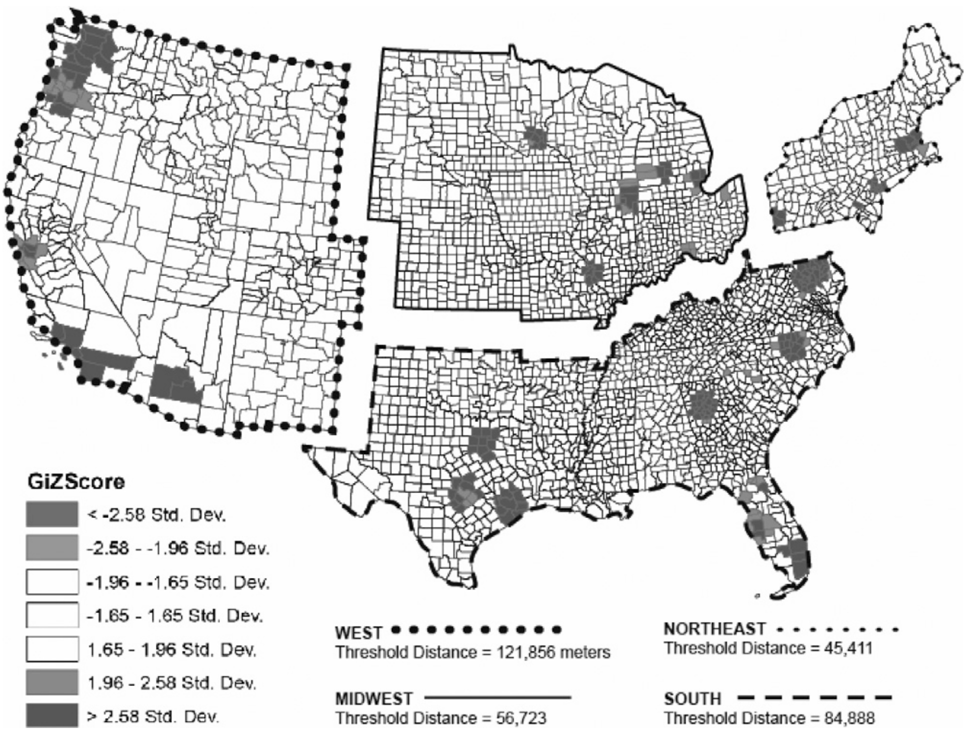

Figure 5. Hot spot locations of statistically significant ($p < 0.05$) clustering of counties containing large numbers of LEED-certified projects that obtained the certified wood credit in the four major US census regions (LEED, leadership in energy and environmental design).

around the Washington, DC; New York, NY; Philadelphia, PA; Boston, MA; and Chicago, IL areas in the country-wide analysis. In the regional analysis, however, these hot spot areas were dissipated to indicate more geographically specific areas of significant CWP use in LEED commercial projects. The areas indicated by the regional analysis may better serve the FSC-certified product manufacturers in pinpointing potential counties to direct.

However, introducing arbitrary boundaries into the geographically connected dataset can have misleading results. Specifically, the analyzed data points near the boundary will not include the influence of other data points within the neighborhood analysis region but will include data points outside the boundary between the census regions. Not accounting for this influential data decreased the significance of hot spot counties near boundaries. For example, the cluster of significant hot spot counties around the Washington DC area (in S) had an effect on the neighboring counties in NE but would not be taken into account when separated by census region boundaries. Because of this factor, future research is suggested to determine the hot spot significance of county locations by including an additional buffer equal to the neighborhood analysis distance to each of the census regions. By adding these buffers, the bordering counties within the analysis region would incorporate influential effects produced by neighboring counties outside the analysis region.

Regression

Results for the SDM country-wide regression analysis indicated direct, indirect, and total effects. In our regression, we used a contiguity-based spatial weight matrix, W. The direct effects provided an indication of the impact a dependent variable would have based on the changes of the explanatory variables at that location. The indirect effects were an estimate of the impact that the dependent variables of neighboring data points would have based on the changes of explanatory variables of the central data point. The total effects were a summation of the direct and indirect effects. According to the results of the SDM regression analysis (Table 2), for all counties in the continental United States containing LEED-certified projects that obtained the certified wood credit ($n = 718$), significant ($p \leq 0.05$) explanatory variables for direct effects were population and obtaining the materials reuse credit, recycled material credit, composite wood and agrifiber products credit, and the regional material credit. The significant explanatory variable for indirect effects

Table 2. Results from Spatial Durbin Model regression analysis for all commercial LEED[a]-certified projects in the continental United States that obtained the certified wood credit.

Explanatory variables	Direct Coefficient	Direct t-statistic	Direct *p* value	Indirect Coefficient	Indirect t-statistic	Indirect *p* value	Total Coefficient	Total t-statistic	Total *p* value
Degree	0.0336	2.2534	0.0245*	−0.0232	−0.6460	0.5185	0.0104	0.2919	0.7704
Electricity	14.3845	1.5147	0.1303	−46.7683	−3.8763	0.0001*	−32.3838	−4.4007	0.0000*
Payroll by number of establishments	0.0009	1.7932	0.0734	−0.0016	−1.4516	0.1471	−0.0007	−0.5732	0.5667
Population	0.0031	10.3492	0.0000*	−0.0007	−1.1481	0.2513	0.0024	4.0874	0.0000*
Reuse	1.3989	3.2049	0.0014*	0.1580	0.1325	0.8946	1.5569	1.1991	0.2309
Recycled materials content	0.2633	4.1926	0.0000*	0.0045	0.0252	0.9799	0.2678	1.2765	0.2022
Composite wood	0.3164	4.8661	0.0000*	0.0861	0.4499	0.6529	0.4025	1.8291	0.0678
Regional	2.6323	36.2355	0.0000*	0.1918	0.9458	0.3446	2.8241	12.9743	0.0000*
FSC 100 miles	−0.0036	−0.1848	0.8535	0.0383	1.6914	0.0912	0.0347	3.0213	0.0026*
FSC 101-200 miles	0.0129	0.8295	0.4071	−0.0178	−0.9333	0.3510	−0.0049	−0.6426	0.5207
FSC 201-500 miles	0.0058	0.8143	0.4158	−0.0082	−1.0894	0.2763	−0.0024	−1.3612	0.1739
Income	−0.0165	−1.4128	0.1581	0.0293	1.2604	0.2079	0.0128	0.5430	0.5873

[a] LEED, leadership in energy and environmental design.

* Statistically significant at $p < 0.05$.

was electricity rate. Significant variables for the total effects for this region included electricity rates, population, obtaining the regional material credit, and the density of FSC material producers within 161 km of the county centroid.

Results showed that the percentage of population with a 4-yr degree or higher had a direct, positive effect on the number of commercial LEED-certified projects that obtained the certified wood credit. Increased population in a county also had a direct, positive effect supporting the results of the spatial analysis in which many of the hot spot counties contained population-dense cities. Furthermore, the presence of each additionally obtained LEED credit (eg material reuse, recycled material content, composite wood and agrifiber products, and regional material) had a direct, positive influence on the number of projects that obtained the certified wood credit in that county. An explanation for this result could be that the material specifiers of projects in these areas favored the use of wood products. The additionally obtained LEED credits could use a wood product to gain the respective credit; however, because it was unknown if wood-based materials were used to gain these credits, further research is needed to determine if a relationship existed between obtaining these credits and the building material used. Another explanation could be that the use of a CWP may have also gained points for one or more of these four credits. In this case, the variables could be confounding and artificially increase the effects of the explanatory variables.

Electricity rate was determined to be a significant, indirect explanatory variable. Furthermore, this variable had a negative coefficient that indicated that high electricity rates were correlated with a decrease in the number of certified projects in the surrounding neighborhood data points. An explanation for this result could be that high electricity rates may be found in population-dense areas with high commercial building density. As the distance from these counties increased to their surrounding county neighbors, the likelihood of LEED-certified project placement decreased.

Electricity rate, population, obtaining the regional material credit, and the density of FSC-certified material manufacturers within 161 km had significant total effects on the number of commercial LEED projects that obtained the certified wood credit. The electricity rate had a significant total effect on the number of commercial LEED-certified buildings that were located in an analyzed county. The direct effect of this variable was insignificant but the indirect effect was significant. Also, the magnitude of the coefficient for indirect effects (−46.77) weighted the total effects to maintain the negative coefficient (−32.38) for the total effects of electricity rates. Results indicate that increasing electricity rates in the analyzed county may result in a lower number of commercial LEED-certified projects that receive the certified wood credit found in neighboring counties. These results indicated that more commercial LEED projects were located in areas of higher electricity rates and less were located in neighboring counties with lower electricity rates. Total effects for the population and obtaining the regional material credit explanatory variables indicated that an increase in either one may increase the total number of commercial LEED-certified projects that obtain the certified wood credit in that county.

The results indicated that a shorter distance to an FSC product provider may be an influential factor in the number of commercial LEED projects that obtained the certified wood credit. Total effects, determined by the SDM regression model, indicated that increased density of FSC manufacturers located within 161 km of the analyzed county centroid may increase the number of commercial LEED projects that obtain the certified wood credit in the neighboring counties.

As previously mentioned, introducing arbitrary boundaries into geographically connected data for spatially weighted regression analysis can have misleading results. However, unlike the hot spot analysis, in which only the counties near the border of the region were affected, the regression analysis returned a singular result indicative of the entire region being analyzed. Consequently, the influential data points outside the analyzed region were not taken into account and ultimately affected the regression results for the entire analysis region, not just the counties near the border. Therefore, regression analysis on each of the four census regions was determined to be inaccurate and omitted from the study.

Also, the results and implications of this research are based on projects certified or applying for LEED certification via versions 2009 or earlier. Changes in LEED version 4 (v4) certification, particularly in the Material and Resource category, continue to reward the use of FSC-certified wood but only as one of six different ways to gain the singular credit point through "Responsible Sourcing Criteria" (LEED 2015). Therefore, specifiers may choose to meet any of the other five responsible sourcing criteria types in place of FSC-certified wood to gain this point. Changes in LEED v4 may influence the use of wood products for point accumulation and should be considered when applying the results of this study to include projects applying for LEED v4 certification.

CONCLUSIONS

This study focused on determining high-use areas for CWPs in commercial LEED-certified projects within the continental United States. Specifically, the results of this study indicated county-level hot spots for CWP use in LEED-certified projects. The projects had high levels of spatial autocorrelation and continued to be constructed near existing LEED-certified projects throughout the country. Given the trend of spatial growth, the hot spot counties may indicate regions of continued growth for both environmentally CWPs and non-CWPs in future LEED projects.

Results indicated approximately nine statistically significant areas of clustered LEED-certified projects that obtained the certified wood credit throughout the United States (Fig 4). These areas indicated a holistic view of the increased use of FSC-certified wood products for LEED projects and may indicate potential markets for providers of such products. These areas may also indicate target markets for non-FSC-certified wood products. Additional points are available in the LEED standards, version 2009 and earlier, for non-FSC-certified wood products in categories such as regional material, indoor environmental quality, recycled content, and material reuse. Therefore, CWP and non-CWP manufacturers searching to supply the LEED green building industry may increase their chances of success by focusing on these areas of concentrated project locations.

Regression results indicated significant explanatory variables that may influence the number of LEED-certified projects that obtain the certified wood credit in a county. Significant explanatory variables include those with direct, indirect, and total effects on the dependent variable. Significant variables with a direct effect include the percentage of population with a 4-yr degree or higher, population in a county, and the presence of each of the additionally obtained LEED credits: material reuse, recycled material content, composite wood and agrifiber products, and regional material. Only one significant variable, electricity rate, was identified to have an indirect effect. Lastly, the significant variables that had an overall, total effect on the dependent variable were electricity rates, population in a county, obtaining the regional material credit, and density of FSC-certified product providers within 161 km.

In general, the spatial econometric regression results indicated that areas of increased population and a higher percentage of individuals with a 4-yr degree or higher were indicators for locations of commercial LEED-certified projects that obtain the certified wood credit. Also, obtaining the LEED credits (material reuse, recycled material content, composite wood and agrifiber products, and regional material) positively influenced the number of commercial LEED projects that obtained the certified wood credit in a county. Lastly, the density of FSC-certified product manufacturers within 161 km had a positive effect on the number of commercial LEED projects that obtained the certified wood credit. This result could be of interest to FSC-certified manufacturers who are looking to locate near high-population areas and market to the green building industry.

However, further research is needed to determine if the location of the existing FSC manufacturers is caused by a demand-driven market such as commercial LEED-certified projects that obtained the certified wood credit or if the location of these manufacturers has helped to drive the market for the location of commercial LEED-certified projects to obtain the certified wood credit.

Although the results of this research are limited to the use of commercial LEED-certified green building projects, certified under LEED version 2009 or earlier, which obtained the CWP credit, they provide a framework for investigating hot spots for other types of green building projects. Future spatial analysis research is needed to identify additional regions of high wood product use in various green building standards as well as in the newest version of LEED, v4. This type of spatial analysis on a variety of green building programs would assist wood product manufacturers in identifying key green building markets and growth trends for wood product use.

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