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Sustainable Electric Vehicle Development in the United States Through Solar Powered Electric Vehicle Charging Station Expansion in Colleges

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Abstract: The transition to electric vehicles is an important strategy to curb climate change and reduce air pollution. However, the adoption of this new technology has been slower than required to reach the goals of the Paris Climate Agreement. This research provides stakeholders with detailed guidance to incentivize electric vehicle adoption at a national level by promoting this new technology through campus colleges, considering that their populations are more receptive to them. This study integrates dispersed and diverse publicly available data, assessing and characterizing colleges in the United States, helping to craft a policy to incentivize investment in solar-powered electric vehicle charging stations based on the best strategies for each particular campus. A novel geospatial concentric buffer feasibility analysis was incorporated into the study to assess not only the campus proper but also its surrounding locations. Locally harvested solar energy was evaluated to power this new infrastructure and the potential to develop vehicle-to-grid (V2G) alternatives. Results provide policymakers and stakeholders with a comprehensive panoramic of the potential to create this new technology in colleges with a national scope. Granular insight into selecting the best technology, the investment level, and the timeframe for each particular campus is generated in this research.

Keywords: electric vehicles (EV); solar powered EV charging stations (EVCS); college campus; concentric buffer analysis; GIS; data analytics; vehicle-to-grid (V2G)

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Citation: Haces-Fernandez, F. Sustainable Electric Vehicle Development in the United States Through Solar Powered Electric Vehicle Charging Station Expansion in Colleges. *Sustainability* **2024**, *16*, 10422. https://doi.org/10.3390/su162310422

Received: 22 October 2024
Revised: 18 November 2024
Accepted: 26 November 2024
Published: 28 November 2024

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1. Introduction

The Lancet Commission on pollution and health indicated that since 2015 air pollution is responsible for nine million yearly premature deaths globally, corresponding to one of every six deaths in the world [1]. The World Health Organization has reported that a high percentage of the world's population breathes unhealthy levels of air pollutants [2]. Vehicles are considered one of the main generators of criteria air pollutants and greenhouse gases [3,4]. It is estimated that between 70–80% of air pollution in megacities in developing countries is generated by mobile sources [5]. Transportation in the US is responsible for 28% of greenhouse gas emissions, while personal passenger vehicles (SUV, passengers, vans, and cars) account for 61% of those emissions [6]. In 2016, the transportation sector in the US overtook the power sector as the main greenhouse gas generator [7]. Therefore, emission reduction from mobile sources is one of the main strategies to reduce air pollution and curb climate change, substituting internal combustion engines with electric vehicles (EV) [8]. Consequently, EVs are expected to be the dominant transportation mode in the near future [9]. It is forecasted that by 2030, half of all new vehicles sold in the United States (US) will be electric [10], resulting in almost 27 million EVs on US roads [11] and 700 million in the world by 2050 [12].

However, providing energy to millions of upcoming EVs all over the world will be challenging. Current electricity generation would need to significantly expand in the near future to satisfy their power requirements [13,14]. If the traditional model of electric grids and nonrenewable fuels continues to be used, the cost and environmental impact will be

vast [15]. The cost of installing thousands of kilometers of new electric lines would be significant [16,17]. Furthermore, these new grids would impact communities and environments in their path, causing social opposition, increased legal regulations, and permitting hurdles [18]. If hydrocarbon fuels continue to be used to generate electricity, the production of additional greenhouse gases and pollutants would cancel environmental benefits from EVs and potentially exacerbate climate change issues [19]. To avoid these potential challenges, diverse strategies have been considered, including the use of renewable energy to power vehicles and novel technologies to build batteries [20,21]. Best practices will be applied in these projects to minimize the impact that may be generated from manufacturing the charging facilities, their operation, and vehicle components [22,23]. Furthermore, proper end-of-life management will be implemented to avoid generating potentially detrimental materials from the life cycle of all these products [24].

Therefore, applying commercially competitive solar renewable energy to power EVs has been explored with great interest [25]. Not only is renewable energy the most inexpensive electricity generation source in many locations, but its local nature also makes it ideal to develop microgrids and avoid the need for national grid expansions [26,27]. On the other hand, the energy storage capacity of EVs and their distributed connection to the electric systems of diverse communities all over the world create extraordinary synergistic opportunities to balance renewable energy generation [13]. Variability is one of the biggest challenges for renewable energy, hindering its potential to replace traditional hydrocarbon fuels completely. It is challenging to control renewable energy generation due to solar and wind power being dependent on exogenous natural phenomena out of human control [28,29]. This causes grid operators to ramp up electric generation using non-green sources to cover energy gaps to satisfy demand when the wind does not blow or clouds block solar radiation [30,31].

A solution, explored with great interest, is the use of energy storage to reserve excess renewable energy during high generation low consumption that may be released during high consumption periods [31,32]. Diverse analysis has indicated that through the use of energy storage, the penetration of renewable energy markets can be significantly increased, replacing a growing proportion of hydrocarbon electricity generation [33,34]. Considering that a large number of EVs spend most of their time parked and connected to a charging station, its use to supply the grid in a vehicle-to-grid (V2G) system provides significant benefits [34–36]. Through smart chargers, EV could receive power at low prices/low consumption periods and sell energy to the grid at high prices/high consumption times. The profit would help owners to offset vehicle costs [37,38].

However, challenges to EV market penetration are reflected in slower-than-expected initial adoption in several locations. Many factors, among them, lack of sufficient public charging stations, range anxiety, and high vehicular prices, have hindered its development [39–42]. Therefore, incentivizing the adoption of this new technology through receptive consumers, such as college populations, would contribute to accelerating EV development. Several factors make universities optimal locations for initial EV adoption. College students have a better disposition and increased interest in EV usage [43]. Higher Environmental awareness, lower fuel and maintenance costs, and university support networks create the opportunity to incentivize EVs in these communities [44,45]. Vehicle manufacturers have announced new generations of lower-price EVs, making a desirable choice of first cars for college students [46,47], considering that almost 60% of students indicated that price and fuel cost are major factors in their buying decision [43]. Additionally, students and Colleges may benefit from charging and V2G opportunities, obtaining fiscal incentives, increased revenue, and improved marketing opportunities through positive community recognition [48–50]. The Federal Government in the US, as well as a considerable number of states, offer tax credits and financial incentives to acquire EV and to install charging infrastructure. This generates additional interest from both students and institutions in promoting this new technology. Direct exposure to this novel technology may increase interest in EVs from local college communities and students' families, promoting

its usage among other consumers in close contact with the colleges [51]. Communities, in turn, would benefit from V2G college microgrids, providing them with cheaper, greener, and more sustainable electricity [44,52]. Many universities all over the world are actively promoting EVs [53,54]. In the United Kingdom, for instance, a government grant aims to grow EV in diverse institutions, among them colleges [55]. Other international colleges have focused on promoting this new technology through Universities [56]. Outreach among students, faculty, and staff plays an important role in the potential development of EV charging station infrastructure and incentive-based infrastructure use [57,58]. Federal and State financial incentives will aid educational intuitions with the cost related to installing, operating, and maintaining the charging equipment. In order to incentivize the use of these facilities, it may be prudent to offer students and the university population preferential rates or discounts, which may be supported by tax incentives and renewable energy [59,60].

This research compiles diverse and dispersed publicly available data to provide policymakers and stakeholders with a comprehensive and granular framework to incentivize EV growth in US colleges. Accelerating EV adoption in college cities across the US will improve sustainability for these urban areas and optimize their logistics in transportation, sustainable energy, and equity. Additionally, the proposed framework incorporates concentric buffer spatial analysis to assess and characterize the potential to grow solar-powered electric vehicle charging stations (EVCS). As diverse data is integrated into a congruent system, with a holistic panoramic of each location, it will provide decision-makers with insight to invest and incentivize EV development. The study evaluates the benefits that students, colleges, and their communities may receive per location. Stakeholders can select the best opportunities to create a seeded college EV investment capable of evolving into renewed accelerated growth for EV technology.

2. Materials and Methods

Figure 1 highlights the overall framework to provide stakeholders with holistic panoramic and granular results to incentivize EV through cities in the nation, growing solar-powered EVCS in college campuses. Incorporating the concentric buffer feasibility analysis allows for a novel holistic panoramic view of the impact this technology may have on colleges, including their neighboring areas, according to their individual characteristics outlined in the study. As shown in Figure 1, in the first activity, college assessment, it is critical to identify, assess, and characterize all campus colleges in the US. Shapefiles and data for all college campuses in the US [61,62] were integrated and overlaid with additional relevant geospatial data. Analysis of the state level for the concentration of colleges and their populations, including students and staff, the vehicles per location, and the existing infrastructure of the campus were identified. Data from the OpenStreetMap database [49,50] and from the US Department of Energy Alternative Fuels Data Center [63] were geo-processed and adapted to be integrated into the system. Under the second research activity, Parking assessment, data analytics, and Geographic Information System (GIS) were integrated to assess the factors that may increase or hinder the use of vehicles around campus. Each campus and its vicinity were assessed according to its National Walkability Index [64], as determined by the US Environmental Protection Agency (EPA), to evaluate the prevalence of vehicle usage.

Under the third research activity, as outlined in Figure 1, campus shapefiles [61] were integrated into the system, and the buffers to adequately identify the impact of campuses on neighboring areas were assessed and characterized. This information, correlated with campus factors and parking infrastructure shapefiles from OSM, provided further characterization of parking in college locations. The fourth activity, indicated in Figure 1, assessed, characterized, and pursued optimization of solar energy in parking locations on campuses at a national level. This provides an adequate panoramic of the potential for each college to install solar-powered EVCS. Installing solar panels on top of parking facilities takes advantage of locations that normally have no other useful function and often sit idle. This concept is currently being incorporated by many local ordinances and regulations, such

as the national law in France, making the use of solar panels covering parking locations mandatory in the next 3 to 5 years. It was reported that when half of the parking lots in France comply with this requirement, their installed capacity would increase between 6.75 and 11.25 GW [65]. The new solar and charging infrastructure can be financed by applying fiscal incentives that are becoming widely available, significantly offsetting the construction and operation costs [66]. Furthermore, locally generated solar energy will reduce the need to expand the electric grid, considering that no new developments will be needed to supply the EV parking directly below the solar panels. This is a significant advantage since grid expansions normally generate significant social opposition; it is one of the highest costs of renewable energy projects and, in many cases, causes these projects to become unfeasible [67,68]. To calculate the power output that a particular parking space may generate, the main parameter to evaluate is solar radiation for each location, assessed on yearly and monthly averages to account for seasonal variability. The second factor to consider is the surface area of the parking location, which is supplemented with the equipment characteristics, which will determine the amount of solar energy that can be harvested, derived from equipment efficiency and its technical specifications.

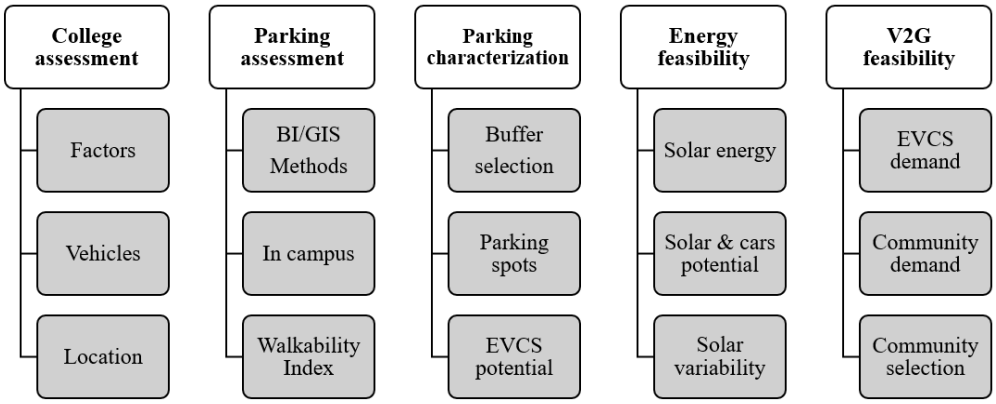


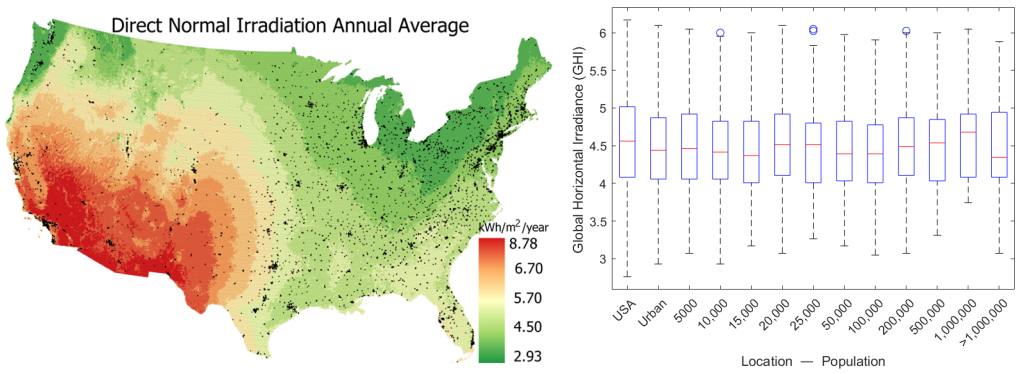
Figure 1. Outline of the methods applied in this study.

The solar radiation for this study was obtained from the National Solar Radiation Database (NSRDB) provided by the National Renewable Energy Laboratory per monthly and annual averages [69,70]. Figure 2a shows a map of the US, which overlays the annual average for direct normal irradiation (DNI) with the locations of the colleges. The diverse distribution across the US is relevant to evaluate the power output that each campus parking location may be able to supply to EVs. Campuses in the southwest US, including California, Arizona, New Mexico, Nevada, Utah, and Colorado, have access to the highest DNI in the nation. On the other hand, locations in the North, including Washington State and the upper Eastern Seaboard, have the lowest DNI exposure. However, to compare solar radiation in diverse urban areas of the US where colleges are normally located, Figure 2b was developed. This box-plot chart indicates that solar radiation at a national level has significantly higher 75% quartile and upper limit values. Although the lowest mean value appears in the largest urban areas, it is only 5% lower than the mean for the entire US. On the other hand, the 75% quartile and the upper limit are remarkably similar for all categories, indicating that urban areas, where most colleges are located, have a good potential for solar-powered EVCS.

To calculate the potential power generated in each parking location in colleges across the US the average yearly and monthly DNI was evaluated by overlaying them, as shown in Figure 2. The surface area of each parking location was calculated by applying GIS, and commercial panels were evaluated for the assessment. System efficiencies and losses for these solar panels were incorporated into the analysis by applying Equation (1),

$$P = DNI * A * S_e * (1 - S_l) \quad (1)$$

where P is the power output generated for each particular parking location, A is the surface area of the parking lot, S_e is the system efficiency for the solar panels, and S_l is the generation and transmission losses suffered by the system. System efficiency (S_e) will be identified as the percentage of DNI that the chosen solar panels can harvest. The system efficiency for non-concentrator solar cell technology may range from 12.5% to 25%, considering emerging PV technologies [71]. This analysis was performed by applying efficiencies and losses evaluated for the most commonly recommended available commercial equipment. S_e was considered at 15.36% and S_l 14.08% [72,73]. The standard technology option considered for this study includes poly or mono-crystalline silicon modules, whose efficiencies could range between 14% and 17%, with a conservative intermediate setting for this analysis pf 15.36% [72]. To assess the potential of V2G in college locations to supply local communities, data from NREL's net electricity, and natural gas consumption [74] was incorporated into the system. It provides additional segmentation into the use and spatial granularity of electricity consumption for residential, industrial, and commercial uses, as well as state and county-level partition. Data for the year 2022 was applied in this research to evaluate the fitness of colleges and their local communities in terms of electricity consumption requirements. Data for this study was obtained from the sources indicated in the corresponding sections. A significant amount of data was provided by US Federal and State government agencies and by National Laboratories, which have a high level of reliability and accuracy, as indicated in their corresponding references. Data from OpenStreetMap was additionally overlaid with other information to generate results from this study. This data source has been evaluated by previous studies and shown to have good accuracy, comparable with other geospatial databases [75,76].

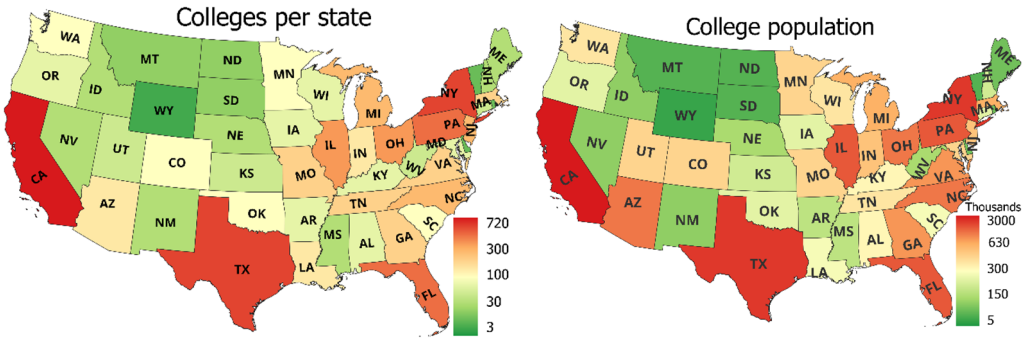


(**a**) (**b**)

Figure 2. Annual average of direct normal irradiation in the US: (**a**) Map, (**b**) Box plot classified for the US and diverse urban areas, according to their population.

3. Results

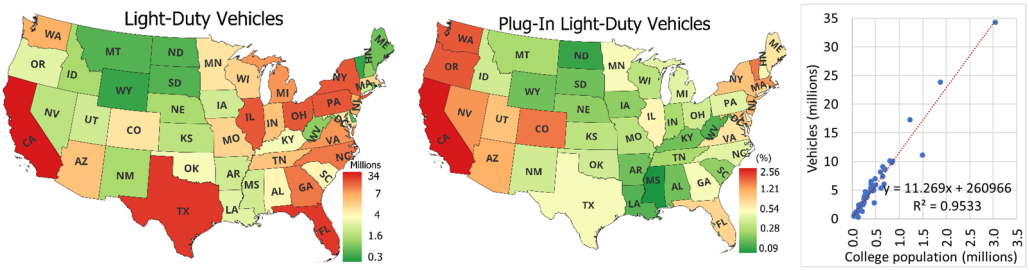
More than 6500 college campuses, with a national college population exceeding 23 million, including more than 19.6 million students and 3.5 million employees, were identified, assessed, and characterized in the first research activity in this study [61,62]. Their spatial distribution per state, applying Jenks natural breaks, as shown in Figure 3, indicates a significant concentration of colleges and their populations. Four states, California, New York, Texas, and Florida, comprise almost one-third of all college campuses and their population in the US. Furthermore, ten states contain more than half of all the colleges and their student and employee population. On the other hand, the last twenty states in the ranking contain less than 10% of colleges or their populations. Therefore, performing a geospatial analysis on the correlation between colleges and their populations and their potential to grow for EV and its charging potential would be necessary for this study. It will allow the identification of specific locations and colleges that can potentialize EV growth through its promotion with their college populations.



(**a**) (**b**)

Figure 3. Spatial distribution of college campus per state, applying Jenks natural breaks (**a**) number of campuses, and (**b**) college population, including students and employees.

Comparing results from the number of colleges and their populations with the number of light-duty vehicles per state, as presented in Figure 4, showcases relevant correlations for the study. This data was obtained from the US Department of Energy Alternative Fuels Data Center [77]. The four states with the highest rank in colleges also top the ranking of the locations with more light-duty vehicles. Furthermore, these four states (California, Texas, Florida, and New York) have almost one-third of all registered vehicles in the nation, while the ten top-ranked states have more than half of all vehicles. Comparing the ten top-ranked states for colleges and vehicles, nine are shared by both lists. Results indicate a high correlation coefficient of 0.976392 when comparing the college population with the number of vehicles per state. Furthermore, a linear regression of this data indicates an equation of 11.269x + 260,966 with a very high R^2 fitness of 0.9533. This showcases the relevance of the study, indicating that promoting EVs in colleges will impact geographical locations with a high number of vehicles. This is relevant, considering that Figure 4b highlights that some states with high college populations show slower adoption of plug-in EV. For instance, five of the ten ranked states for both colleges and vehicles have EV participation of less than 0.5% of the total number of light-duty vehicles. Promoting EVs among college populations would, therefore, have a significant impact on accelerating their adoption.

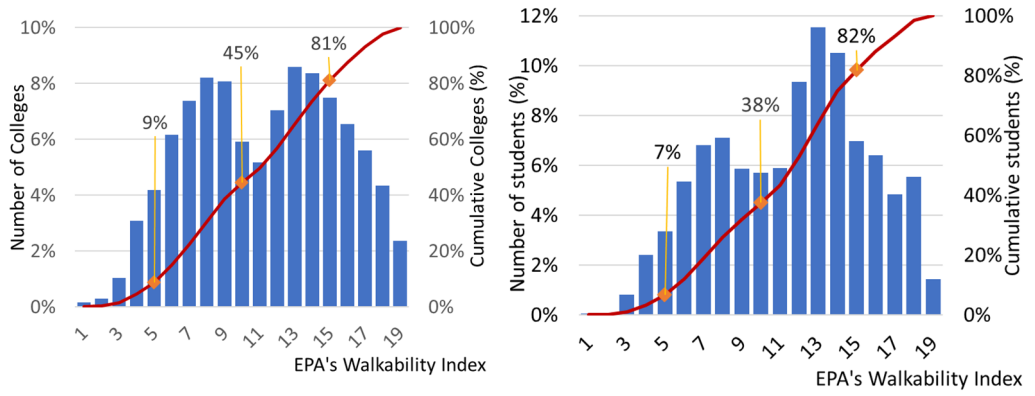


(**a**) (**b**) (**c**)

Figure 4. Light-duty vehicles registered per state, applying Jenks natural breaks (**a**) total number of vehicles, (**b**) plug-in light-duty vehicles, and (**c**) regression analysis of college population with the number of vehicles per state in US.

The second research activity, parking assessment in colleges, evaluates the number of vehicles that are expected to park on college campuses or their vicinity. It provides a good indicator of the potential for each location to grow the EV inventory. This will help stakeholders ascertain the resources needed to improve infrastructure, promote EV vehicles, and provide the college population with the resources and information required for these investments. There is no general publicly available data related to vehicles on college campuses. However, assessments on campus vehicle usage can be performed by applying data provided by diverse government agencies, generating better understatement of each

location. The Environmental Protection Agency (EPA) provides the US National Walkability Index, ranking blocks or block groups. The ranking goes from 1 (least walkable) to 20 (most walkable). Figure 5 presents the number of colleges and number of students under each category of the EPA's National Walkability Index [64]. The brackets categorized as most walkable represent college campuses where students would have minimal requirements to use vehicles inside campus and in its vicinity. On the other hand, lower brackets would indicate a higher need for personal vehicles for college populations. Less than 20% of campuses and students in the US are on locations considered most walkable, with all the other locations requiring significant use of vehicles.



1–5.75	Least walkable	10.51–15.25	Above average walkable
5.76–10.5	Below average walkable	15.26–20	Most walkable

Figure 5. EPA's National Walkability Index of each college campus in the US; (**a**) number of colleges on each index category, and (**b**) how many students included in each index category. Red line indicates the cumulative percentage of students.

Figure 6 presents the EPA's National Walkability Index per state weighted average considering the college student population of each college campus in the US. The total college population of each state is calculated, and the percentual participation of each campus is evaluated to be used as a weight to calculate each state's Walkability Index. The geographic distribution of this index and its performance according to each campus's number of students allows stakeholders to gain additional insight into the requirements for vehicles. Results indicate that, from a geographical perspective, only the District of Columbia has a weighted average in the most walkable range for the Walkability Index. Almost 70% of the states are in the above-average walkable. However, most of the states in this category are ranked lower than 13, indicating a significant need to use vehicles on these campuses.

An additional parameter that can provide clarity on the inventory of vehicles at colleges in the US is the parking lots and garages inside and in the vicinity of campuses. Data from parking facilities in the US was obtained from the OpenStreetMap database [78,79]. Parking lots and parking garages were segmented from the general database, reprojected, and its area was calculated, considering surface for one level. These facilities were overlaid with data for colleges and universities in the United States, which was provided by the Homeland Infrastructure Foundation-Level Data (HIFLD) [61,62]. Figure 7a indicates the area covered by parking facilities per state in the US, providing an assessment of the vehicular inventory that may be normally available in diverse locations. Ten states have almost half of the area of national parking facilities, which correlates well with the number of registered vehicles and colleges per state. Figure 7b indicates the percentage of surface area for parking facilities located inside college campuses in the US in each state. The parking space inside each campus correlates with the student population proportion using vehicles and the walkability index. For almost half of the US states, between 5–6% of their state's

parking surface area is inside college campuses. Furthermore, for 18% of the states, 7–10% of the total state's parking area is on college campuses. This is relevant, indicating a strong connection between vehicle parking and colleges, strengthening the premise of the study, and incentivizing EVs through universities in the US.

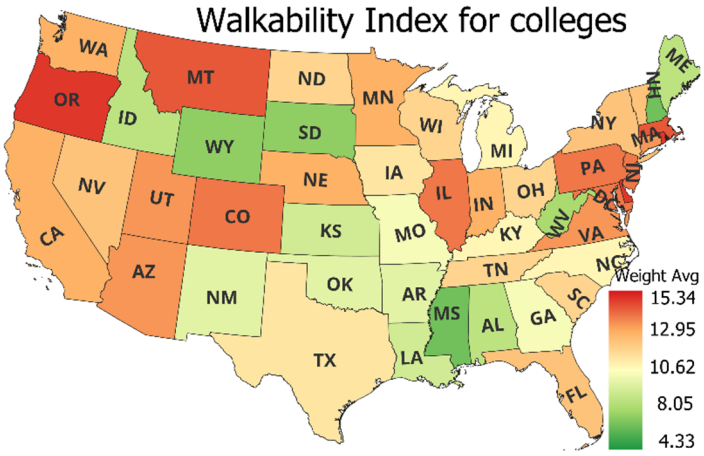
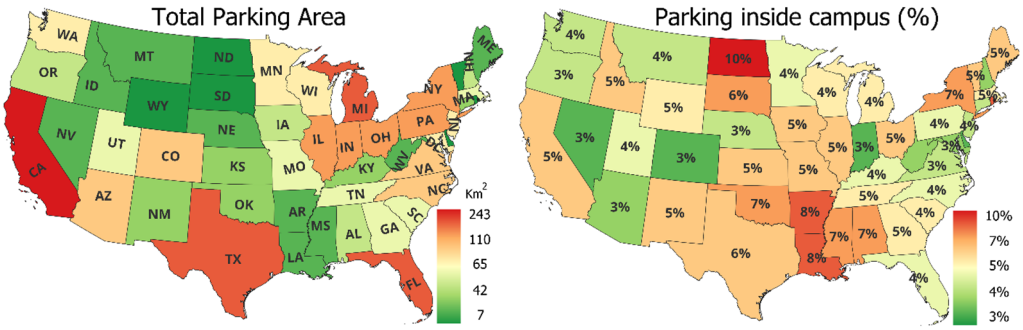


Figure 6. EPA's National Walkability Index per state weighted average, applying Jenks natural breaks, considering the college student population of each college campus in the US.

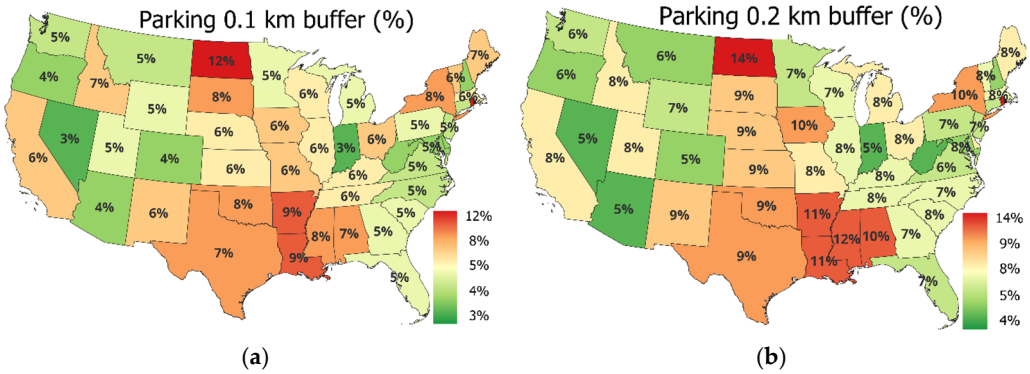


(**a**) (**b**)

Figure 7. Area covered by parking lots and garages obtained from the OpenStreetMap database applying Jenks natural breaks (**a**) total parking areas, and (**b**) percentage of parking inside the campus.

For many college campuses, particularly in larger urban areas or higher walkability index locations, students or employees park their vehicles in garages outside the campus but within walking distance. College campuses are considered by stakeholders as focal points of urban development, spurring, among other amenities, the creation of additional parking spaces [80,81]. Therefore, under the scope of research activity number three, parking characterization, a spatial analysis was performed to select each US college campus and develop GIS concentric rectangular buffers around them. Two initials near buffers were selected considering the distance from one and two blocks from the university, assuming regular square blocks of side 100 m. Figure 8a shows the proportion of parking area per state located inside the campus and in a first selected buffer of 100 m. In this case, for more than 55% of the states, the parking surface in the campus and the first buffer corresponds to 5–6% of the total state's parking surface, while in 30% is between 6–10%, with two states reaching as high as 12%. Contrasting this analysis with the parking area only inside campuses indicates an adequate initial near buffer parameter. Increasing the buffer to 200 m, as shown in Figure 8b, provides a better characterization of near parking options for campus populations, walking two blocks to arrive at college. The area of parking spaces increases in this new analysis, with more than 60% of the states having between 7–9% of their parking area in this buffer and almost 15% between 10–12%. Therefore, this

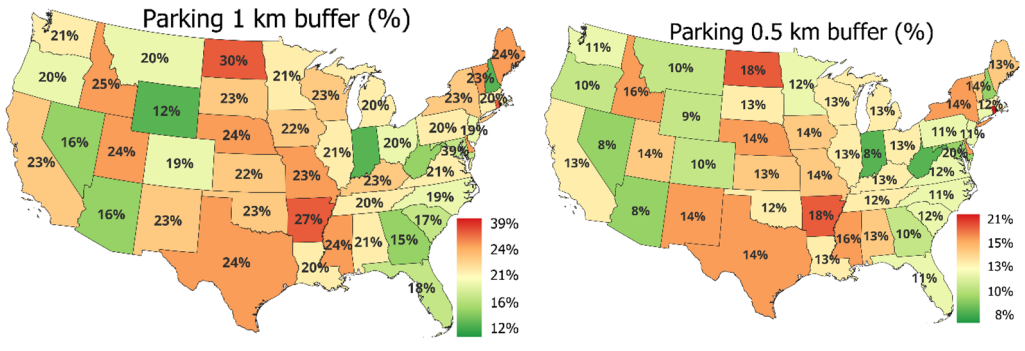
characterization reinforces that neighboring college areas are additional fit locations to incentivize EV development.



(**a**) (**b**)

Figure 8. Area covered by parking lots and garages obtained from the OpenStreetMap database, applying Jenks natural breaks (**a**) buffer of 100 m around campus, and (**b**) buffer of 200 m.

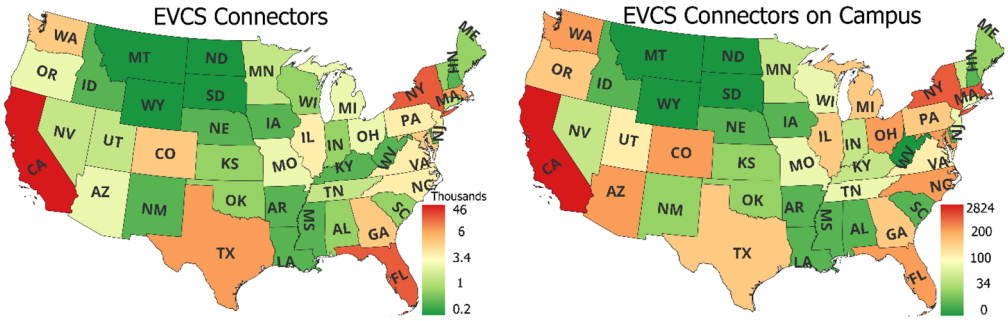
Under the parking characterization research activity, two additional extended buffers were assessed, considering five blocks and ten blocks (0.5 km and 1 km). Extended locations were evaluated, considering that the university population may use shuttles or public transportation to cover the last-mile commute. Additional remote parking may be feasible in higher walkability locations, and the proposed extended buffers aim to capture and characterize them. Figure 9 showcases the impact of college campuses in extended buffers, highlighting the higher concentration of parking facilities in these focal locations. The results for the 1 km buffer, which would imply approximately a 10-block radius, are presented in Figure 9a. It highlights a significant increase in the proportion of parking facilities. This increase is notable in certain states with high overall vehicular registration. More than twelve states have more than one-quarter of their parking surface inside the 1 km buffer. Furthermore, 76% of all states have more than 20% of their parking surface in this buffer, which clearly indicates the strength of the potential clusters that universities can provide to incentivize EVs. A smaller buffer, half a kilometer, as shown in Figure 9b, continues, reflecting a strong connection between vehicles and universities. In this case, 77% of all states showed between 11–17% of all their parking spaces in this 500 m buffer. The two proposed remote buffer locations capture significant parking areas around colleges, showing that in some locations, up to one-quarter of public parking would be in the vicinity of colleges. Furthermore, these parking locations could potentially serve businesses located in the vicinity of the university as well as the college population that may be able to walk this five-block distance. Results from this analysis indicate a strong connection between universities, vehicles, and the potential to incentivize EVs in these locations.



(**a**) (**b**)

Figure 9. Area covered by parking lots and garages obtained from the OpenStreetMap database applying Jenks natural breaks (**a**) buffer of 1 km around campus, and (**b**) buffer of 0.5 km.

As previously indicated, one of the main challenges for EV adoption is the lack of public EVCS [82,83]. This would be even more relevant for the college population, considering that most of the at-home charging options would be limited. US college students mostly live on campus residency or in departments where EVCS may be scarce. Furthermore, a significant number of college students face challenges related to public transportation [84,85], incentivizing vehicle ownership and residency close to campus. Therefore, public charging stations in parking locations would be the best option. To ascertain the availability of EVCS in these locations a geospatial analysis was performed, overlaying the college campus incorporated data with the location of the more than 60,000 EVCS provided by the US Department of Energy [63]. These stations provide almost 157,000 connectors, 78% of which are level 2 and 20% Fast DC chargers. Results presented in Figure 10 showcase a significant geographical disparity in the availability of EVCS connectors. California has more than one-quarter of all EVCS in the nation, with almost 30% of all Level 2 and Fast DC chargers. Furthermore, five states (California, New York, Florida, Texas, and Massachusetts) have almost half of all the EVCS connectors in the nation. Results concerning EVCS connectors installed on college campuses indicate an even larger disparity. California alone has almost one-third of all connectors, with more than half of the Fast DC chargers on the nation's campuses. Five states concentrate more than 55% of all EVCS connectors and more than 60% of all Fast DC on college campuses across the US.



(**a**) (**b**)

Figure 10. EVCS connectors per state applying Jenks natural breaks (**a**) overall EVCS connectors, and (**b**) inside college campuses.

Results presented in Figure 11 indicate that there is limited availability of public EVCS and connectors in college campus areas. Less than 20% of EVCSs are near college campuses, while only 5% are inside the campus. Furthermore, analyzing the types of chargers available, the most abundant for campus locations is level 2 chargers, which require longer periods to charge (80% of EV battery charges take 4–10 h). The DC fast chargers, which would provide about 80% of EV battery charge in 20 min to an hour [86], are scarce in universities. In the extended buffers of half and one kilometer, only 8% of these chargers are in these locations. However, less than half of one percent of DC Chargers is actually inside of the campus, and when expanded to the 200 m buffer, the number is smaller than 2%. Considering that commuting students would visit campus to take a limited number of classes, providing fast charging options would be relevant to incentivize the use of EVs. Slower chargers are, in many cases, disregarded by users for short parking stays [82,87]. Therefore, an area of opportunity would be to expand the availability of fast charging options. These faster chargers normally have higher usage fees, and if universities could offer these services at reduced costs, they would significantly incentivize the use of EVs in college populations.

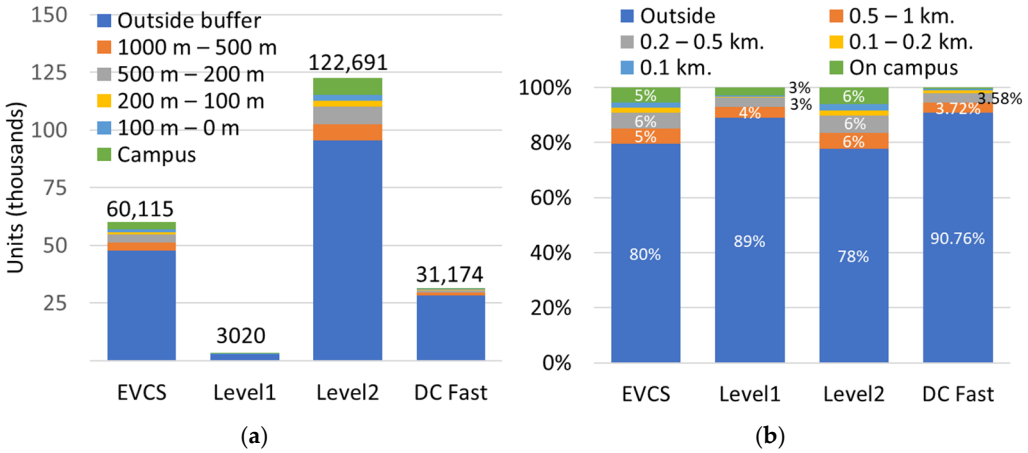


Figure 11. EVCS locations considering college campuses in the US; (**a**) number of EVCS, and (**b**) percentage.

Historical trends on charger installation since 2010, shown in Figure 12, indicate that college campuses have not received significant investment for EVCS infrastructure. Figure 12a reflects an exponential growth on Level 2 chargers until 2021, with 2022 showing a significant decrease in all locations, consistent with the recent EV adoption declining trend. However, the EVCS declining trend is much more significant for the chargers located inside college buffers. The reduction from 2021 to 2022 for all chargers outside the campus buffers is 22%, while EVCS inside the 1 km buffer drops by 36%. Furthermore, the highest drop relates to Level 2 chargers located inside colleges, with a 48% reduction from 2021 to 2022. Results indicated in Figure 12b highlight that there was exponential growth for DC Fast chargers between 2017 and 2021, with a slight stabilization in growth in 2022. In the period from 2021 to 2022, DC fast chargers outside college buffers grew by 18%, while the ones inside college buffers only increased by 1%. However, further analysis indicates that these DC Fast chargers suffered the largest drop inside the colleges (no buffers considered), with a 30% reduction. These results reveal that without proactive incentives, there is a strong potential for lagging growth in the EVCS at campus locations. Furthermore, the number of DC Fast chargers and their trend indicates that campus populations will have limited access to this infrastructure, hindering the growth of EVs in colleges.

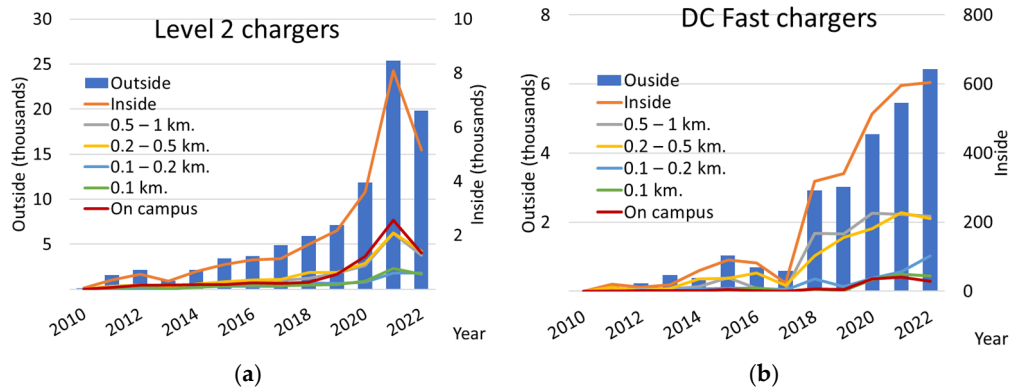
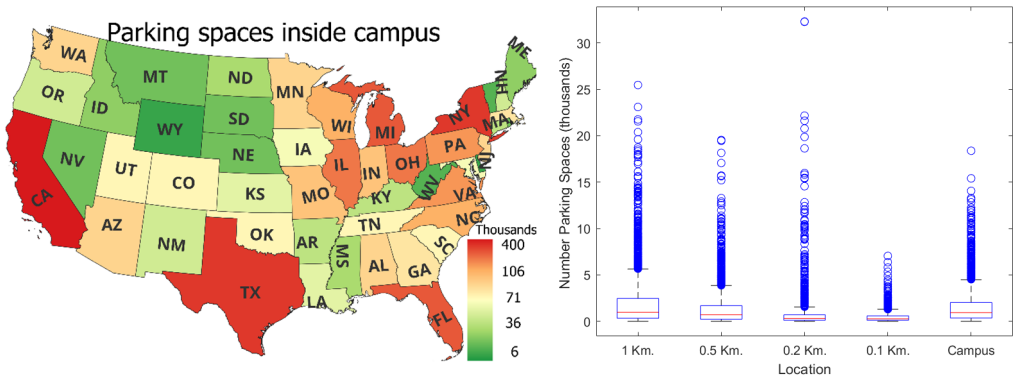


Figure 12. Historical trends on EVCS installation considering college campuses in the US; (**a**) level 2 chargers, and (**b**) DC fast chargers.

4. Discussion

A geospatial analysis was performed to evaluate the potential to grow EVCS in college locations, assessing the number of potential parking spaces on each previously defined buffer area. The GIS analysis reprojected and assessed parking surface areas, considering that optimal parking facilities require an average of 325 square feet (30.20 m) per vehicle,

including areas for parking, maneuvering, and circulation [88,89]. This analysis evaluates the minimal number of parking spaces that may be available, considering that it only assesses one parking level. Other adjacent areas or roof surfaces on campus may be additionally applied to install solar panels to account for potential shading effects from diverse structures or vegetation. Therefore, the opportunity to grow EVCS may be even larger in many locations. The parking space availability for colleges, as shown in Figure 13, corresponds well with the number of students and the walkability index of the location. Figure 13a shows a high concentration of parking spots in some states. Five states have one-third of all the parking spaces inside the campus, ten states comprise more than half of all these parking locations, while 16 states (30% of the states) contain almost two-thirds of all college parking locations. On the other hand, 12 states have only 5% of all these parking spaces, and more than 45% of the states only have less than 20% of the college parking spots. On the other hand, Figure 13b highlights the great potential to grow EVCS in many college locations across the US. The median for college locations is almost 930 parking spaces, while the 75% percentile reaches out to more than 2020 vehicles. Furthermore, the upper limit is nearly 4500 vehicles, with a very large number of outliers between 5000 and 12,000 vehicles inside campus, some of them reaching up to 18,000 vehicles. When these results are supplemented with the diverse buffers around campus, the number of vehicles increases significantly. In the 0.2 km buffer, the outliers increase significantly, while the further (0.5–1 km) has 75 percentiles above 2500 parking spaces and the upper limit beyond 5600 spaces, with a significant number of outliers for all categories.

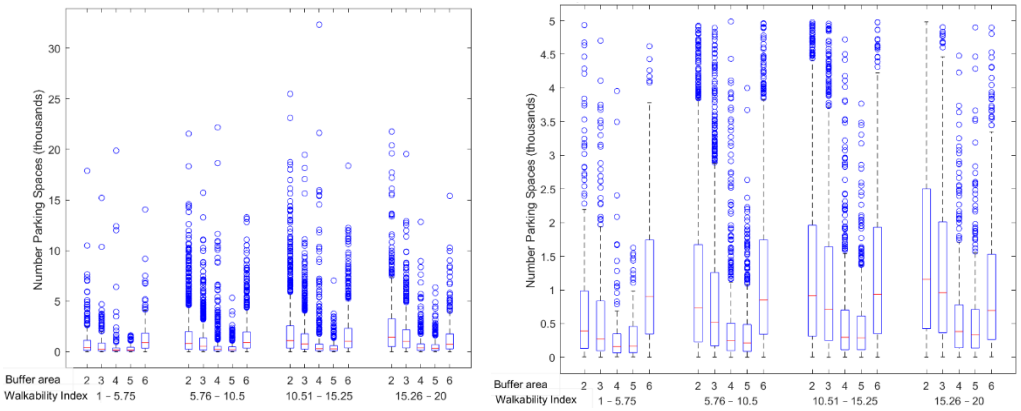


(**a**) (**b**)

Figure 13. Parking spaces inside 1 km buffer around colleges (**a**) per state applying Jenks natural breaks, and (**b**) segmentation per campus buffer category.

Figure 14 provides additional insight into the availability of parking spots across colleges in the US segmented according to their buffer zone and Walkability Index. The label table in the figure identifies each buffer area in the first three columns the walkability areas in the last two columns. These figures show a general assessment on the availability of parking spots in colleges to evaluate the opportunity to install additional EVCS. In this general assessment, the comparison between the least walkable area (1–5.75) and the most walkable area (15.26–20) offers relevant insight to be considered in the planning for new EVCS. Parking spots inside the campus (category 6) experience a significant reduction in the most walkable locations, considering that students and employees do not require a vehicle in these high-walkable areas. However, unless this population resides within walking distance of the campus, they will eventually require a vehicle to commute. This is reflected in the outer buffer area (category 2), where parking availability is significantly increased in the buffer, expanding from 0.5 to 1 km from the college campus. Furthermore, there are a significant number of parking locations that are outliers, showing a very large capacity to park at longer distances from campus in the most walkable locations. This indicates that it is possible to park further away from campus and then complete the commute either walking or on local shuttles. Therefore, stakeholders considering installing

EVCS in college locations should evaluate the walkability of the area to decide where to place the new chargers.



1	Outside	3	0.2–0.5 km	5	0.1 km	1–5.75	Least walkable	10.51–15.25	Above average
2	0.5–1 km	4	0.1–0.2 km	6	Campus	5.76–10.5	Below average	15.26–20	Most walkable

Figure 14. Parking spaces inside different buffers from colleges according to the Walkability Index (**a**) unrestricted values in the *y*-axis, and (**b**) restricted values in the *y*-axis for improved visualization.

Figure 15 provides additional information about the box-plot analysis performed for parking spots in college locations. Figure 15a shows the results for the median in the percentile analysis. It indicates that parking inside campus locations does not change for the three lower walkability categories. However, there is a significant reduction in parking availability inside campus for the most walkable areas. The increase across walkability areas for buffers categories 2 and 3 reflects a linear trend, significantly increasing from the least to the most walkable locations. This indicates that the deficit in parking spots inside the campus for the most walkable area is supplemented by the increased parking locations in the two most remote buffers. This analysis is confirmed by Figure 15b with results for the 75% quartile assessment. Most walkable campuses show a decreasing number of parking spots inside the campus and a very significant increase for buffers 2 and 3 (between 0.2–1 km). The increase in capacity for buffer 3 is similar to the decrease inside campus for the most walkable areas, while buffer 2 showcases a high linear growth trend. These results confirm that stakeholders will need to consider each campus's Walkability Index when planning to expand the EVCS network for college campuses in the US.

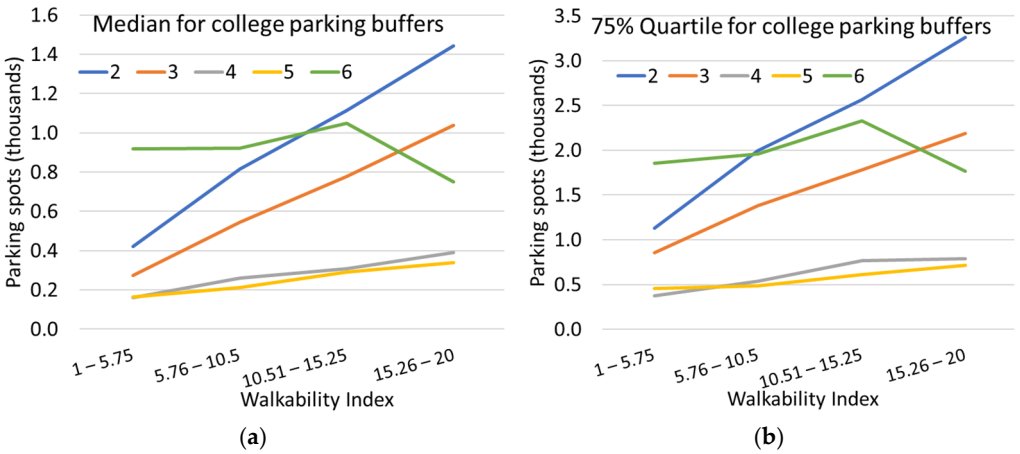


Figure 15. Parking spaces for different college buffers classified by the Walkability Index; (**a**) median in percentile analysis, and (**b**) 75% percentile.

Each US state presents a different perspective on the development of additional EVCS infrastructure when considering college campus locations. Figure 16 shows the different behaviors for each campus buffer applied in this assessment. As previously indicated, some of the driving factors related to parking distribution relate to the Walkability Index of each location and the campus population. States with the highest Walkability Index have the lowest number of parking spots inside campus and a significant number of available spaces in buffers 2 and 3. For instance, the District of Columbia has one of the nation's highest weighted average campus Walkability Indexes, with 15.11, and its parking space availability in college buffers concentrates on buffer 2 at 40% and buffer 3 at 32%. On the other hand, with a weighted average Walkability Index of 8.8 for Wyoming, the inside campus represents 37% of all buffer parking spots, and buffer 2 only accounts for 20%. The spatial analysis at the state level guides stakeholders on the expectation for each location. However, considering that the campus parking availability will depend on the characteristics of each university, it is important to highlight that significant variability may exist inside each state. For instance, Mississippi, with the lowest weighted average college Walkability Index of 8.39, has a 30% parking availability inside the campus and 34% in the buffer 2 category. Therefore, a more granular county or college-level analysis may be required to assess individual new EVCS projects accurately.

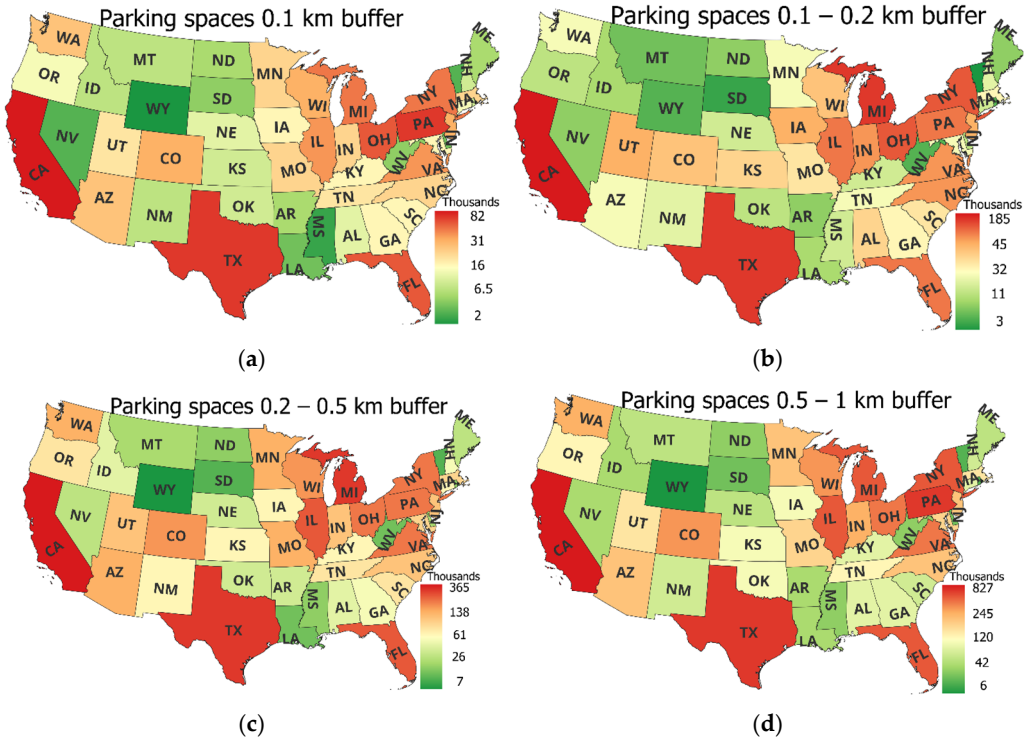
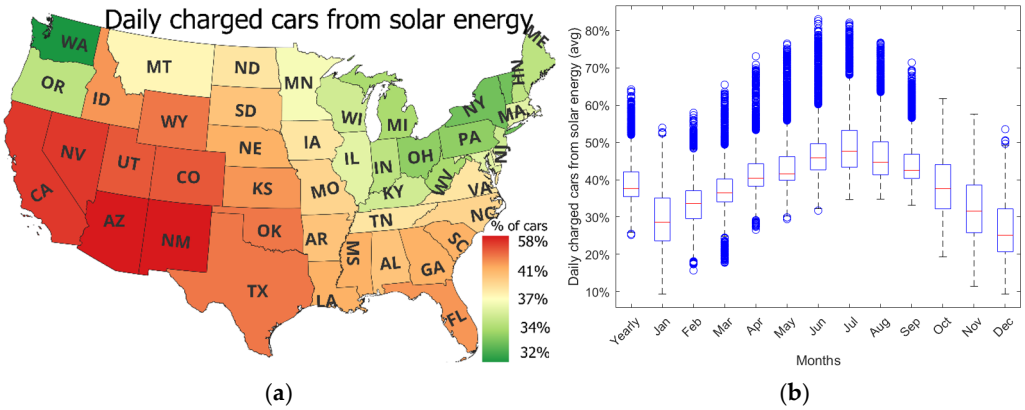


Figure 16. Parking spaces around colleges applying Jenks natural breaks (**a**) 0.1 km buffer, (**b**) 0.1–0.2 km buffer, (**c**) 0.2–0.5 km buffer, and (**d**) 0.5–1 km buffer.

The assessment of potential energy harvesting for each campus parking location was performed by applying solar radiation, parking surface areas, and equipment parameters. Additionally, the study assessed and characterized the average daily vehicle proportion that can be charged from solar energy, considering the spaces contained at one surface level for each campus parking facility. EV battery size of 50 kwh was considered for this analysis. Figure 17a shows the state's average of the percentage of potential EVs inside campus that can be charged. Several states with the largest campus populations have access to some of the best proportion of EVs that can be charged from solar energy. For instance, Arizona, with the highest number of potential EVs to be charged (58% of the vehicles), ranks 9 in campus population, while California, the state with the largest campus

population rank 4, with a 52% daily average of EVs to be fully charged. Furthermore, Texas (second highest population in college) ranks 9 in EV charging from solar energy (44%), and Florida, the state with the fourth largest campus population, ranks 10 in in EV solar charging availability. On the other hand, northern states with a significant number of large college campuses have lower yearly average solar EV charging potential. New York, Pennsylvania, and Ohio (ranked 3, 5, and 7, respectively, on-campus population) are in the lowest positions of access to solar EV charging (33% of daily parked vehicles each, on average). Figure 17b showcases the seasonal variability of the potential to charge EVs from solar energy. The national yearly median is 38%, with 25% and 29% minimums in December and January, respectively. However, the average mean shows a maximum of 48% and 46% in July and June, respectively. Considering the 75% percentile, the yearly average is reported as 42%, with minimums of 32% and 35% in December and January, respectively, and a maximum of 53% in July. For all months, there is a significant number of outliers ranging from 60% to 85%, resulting in many locations capable of providing a high level of charging to EVs parked in these parking facilities. This tool will provide stakeholders with useful assessments to determine the optimal locations to install the new EVCS solar-powered infrastructure to maximize both cost reduction and utilization. This geospatial analysis will provide policymakers with a clear panoramic of the locations that will benefit the most from solar radiation harvesting to supply EVs. As more advanced and efficient solar panels enter retail markets and are considered for the assessment, the potential number of vehicles that can be charged will significantly increase.



(**a**) (**b**)

Figure 17. Percentage of EVs that can be charged per day on yearly average; (**a**) classification per state using US map applying Jenks natural breaks, and (**b**) classification per months using box plot.

To complete the proposed assessment of the potential integration of EVCS in colleges to incentivize EV adoption, the fifth research activity, V2G feasibility, was developed. Results from Figure 17 show that the best season to provide solar energy to campus is during the summer months. However, this period corresponds with the summer vacation, when the college population may significantly decrease. Supplemental uses for this new infrastructure acquire additional relevance, contributing to maximizing utilization and economic benefits for colleges and local communities. As previously indicated, one of the complementary applications for EVCS is supplying local communities with electricity from storage capacity through vehicle-to-grid (V2G) schemes. Data from State and Local Planning for Energy (SLOPE) provided by the NREL for Net Electricity and Natural Gas Consumption [74] at the state level was assessed to evaluate the adequacy of applying V2G for college parking locations using solar energy. Figure 18 shows the electricity consumption for each state for the year 2022 in three categories and total consumption. Results indicate a strong correlation between the number of college parking spots and the general electricity consumption for each state. Some states in northern areas, with low overall solar energy harvesting, may have lower contributions to the grid, but in the southern states, with large college populations, the potential to contribute is significant. The top eleven states

that have more electricity consumption constituting half of the national demand, are the same states with the highest percentage of the college population. Furthermore, the three states with the highest consumption (Texas, California, and Florida), representing 25% of national use, are included in the top ten ranking states with the highest solar radiation. The breakdown of the diverse applications of electricity provides additional insights for stakeholders planning to install solar-powered EVCS in college locations. Residential, commercial, and industrial energy uses differ in the schedule. Residential has its peak usage between 5 PM and midnight. Commercial use has the highest utilization during the workday, while industrial use has uniform usage, considering that many facilities operate 24/7. Therefore, the availability of EV batteries parked in colleges will help supply each segment of electricity consumption. Commuting students and staff, parking during class time, may supply commercial and industrial usage. For residential students, parking overnight would supply residential and industrial consumption. Furthermore, colleges may decide to install large-scale energy storage systems to capture energy to provide to the grid at high consumption and high price times. This would help alleviate the need to increase energy generation for grid operators to provide communities with local, sustainable energy while the educational institutions may profit by selling this energy at high price periods. Figure 18b,c showcases that the same top states with the highest college population have the biggest energy consumption. However, for industrial consumption, Figure 18d indicates that some states have significant industrial electricity consumption with lower college populations, such as Indiana, Alabama, and Michigan. With significant industrial energy consumption, policymakers in these states may incentivize more constant charging and energy storage in their college campus to supply their local industry.

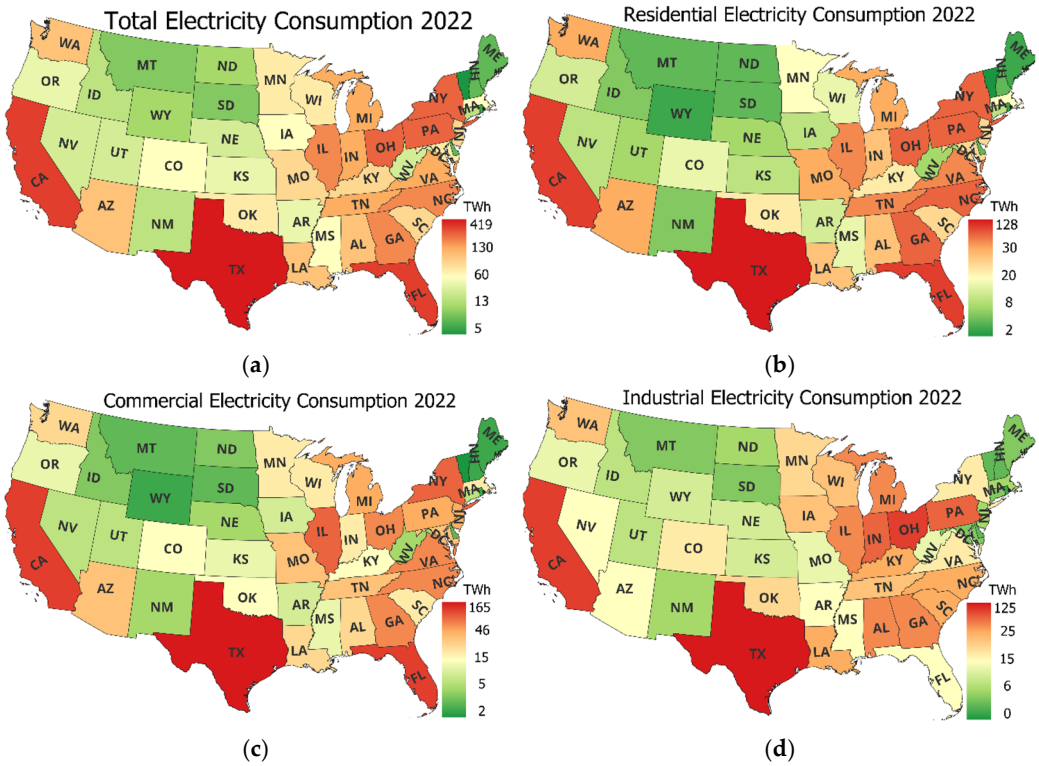


Figure 18. Electric energy consumption per US State for 2022 from the State and Local Planning for Energy (SLOPE) platform; (**a**) total consumption, (**b**) residential, (**c**) commercial, and (**d**) industrial.

Assessing the adequacy of V2G from EVCS in college locations is very important to understand the feasibility of these systems better, advising policymakers on potential benefits to local communities from sustainable energy and the financial benefits that educational institutions may receive. Data for electricity consumption at the county level was obtained

from the Data from State and Local Planning for Energy (SLOPE), provided by the NREL for Net Electricity and Natural Gas Consumption [74]. The number of students per county was assessed to develop the analysis shown in Figure 19 for total electricity consumption (a) and its segmentation into commercial (b), residential (c), and industrial (d). Results from this analysis indicate that there is a strong positive trend in the regression study between the number of students per county and the total electricity consumed in these areas. The highest concentration is in the ranges of less than 20,000 students and less than 4 TWH per county. However, as the consumption increases, so does the student population, creating a strong positive trend that EVCS developers may utilize in college locations. Furthermore, this strong positive trend increases commercial consumption, with an R^2 of almost 0.75, opening opportunities in locations with higher commercial activities and college students. For residential consumption, as shown in Figure 19c, the positive trend between the two factors, indicated by R^2 of 0.68 in the linear regression, is lower than for total consumption, but still showing that in a significant number of counties with high domestic electricity consumption and college campus, there is high potential to develop V2G. For industrial electricity consumption, as indicated in Figure 19d, the overall regression trend between these factors is much smaller. This suggests that many counties with electricity industrial consumption may not have college campuses in their territories. However, as results from Figure 18 indicate, there are several locations that represent a good fit for this scheme, and policymakers can use the methods developed by this research to identify these locations and incentivize V2G solar-powered college EVCS to successfully supply industrial activities.

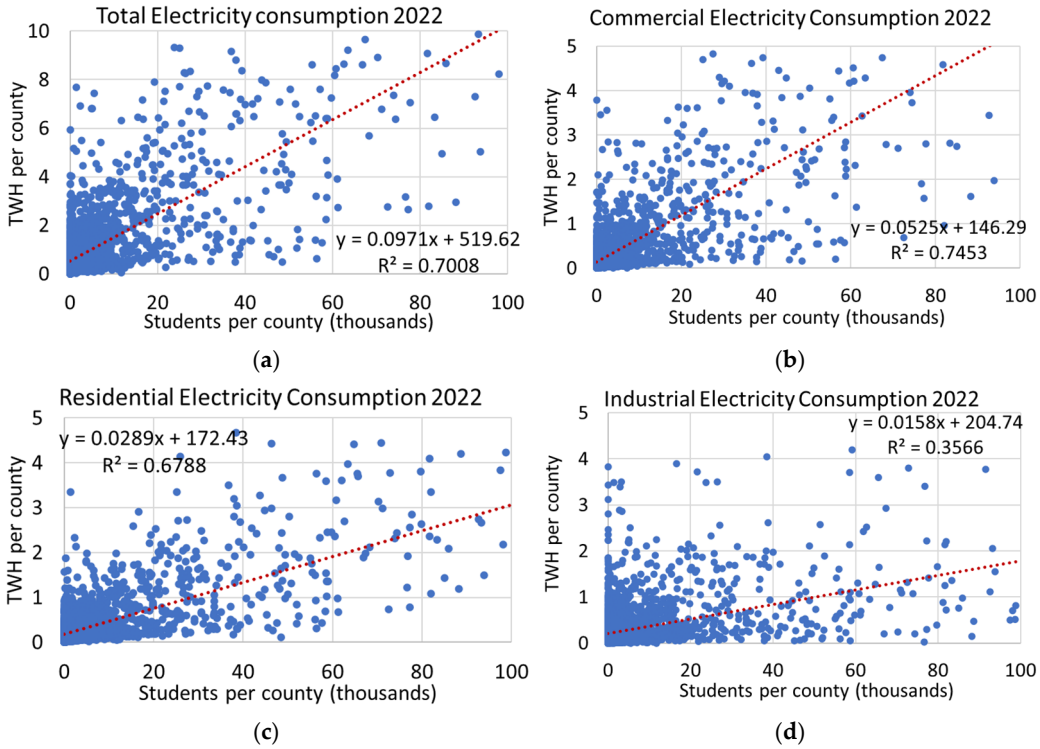


Figure 19. Analysis of the electricity consumption and number of students per county for 2022 in the US; (**a**) total electric consumption, (**b**) commercial, (**c**) residential, and (**d**) industrial.

5. Conclusions

Electric vehicles provide significant benefits to users and their cities, among them preventing the emission of air pollutants and greenhouse gases. However, there has been a recent trend reduction in their adoption. Several factors have caused this decline, chief among them the lack of public charging stations. The main objective of this research is to provide policymakers with a holistic approach and data frame to incentivize EV

adoption through college campus infrastructure investment across the US to improve cities' sustainability.

The research identifies factors impacting EV development and the most promising cities to incentivize its adoption, such as installing additional solar-powered EVCS. Dispersed and diverse publicly available data related to colleges, vehicles, and power supply were integrated, through the proposed framework, into a geospatial system capable of providing stakeholders with granular results to select colleges to promote EV adoption. A novel approach to this analysis is the integration of concentric buffer feasibility analysis to evaluate not just the college campus but its neighboring areas. This approach will provide a comprehensive perspective for policymakers on the potential of transitioning to EV technology, depending on the parking locations for each campus. The application of locally harvested solar energy in cities across the nation was integrated into the proposed method to provide college populations with sustainable and lower-cost power to supply the new EVCS. Additionally, the system integrates the analysis of V2G potential to supply electricity to cities where colleges are located, segmented for residential, commercial, and industrial uses.

Results from the analysis indicated that there are significant benefits to incentivizing EV adoption through colleges. A strong correlation exists between the number of vehicles per location and the college population, indicating that this is a good consumer group to select for EV promotion. Vehicular inventory per campus is not publicly available, but a good approximation was developed by applying EPA's Walkability Index, vehicle inventory per location, and public parking polygon shapefiles from the OpenStreet Map. With this analysis, applying a concentric buffer feasibility analysis approach, five buffers were developed: one for the campus proper, two for near parking in surrounding areas, and two for far parking, up to 1 km. Results indicated that a high Walkability Index campus has the lowest number of public parking spaces on campus, and as the index decreases, the number of on-campus parking increases. However, the buffer analysis indicated that colleges with higher Walkability Index parking locations are displaced to the near and far buffers, with a higher proportion of their parking spaces in the far buffers. This is useful for stakeholders in identifying which parking locations should be evaluated to develop solar-powered EVCS.

The energy supply analysis provided additional relevant assessments. It showed the importance of accelerating the development of DC Fast chargers in colleges, identified the best locations to integrate solar power into the EVCS, providing a monthly analysis for charging optimization. Furthermore, a strong correlation was shown between colleges and electricity consumption per county, indicating good potential for the development of V2G in may college campuses. Furthermore, the electricity consumption segmentation analysis provides policymakers and stakeholders with further insight into the energy consumption that each campus could select. For some locations, domestic or commercial parking would better match normal parking schedules, while others may select industrial parking, considering longer-term parking behaviors. The proposed framework provides stakeholders with reliable and granular information to develop on-campus projects better and incentivize EV development. Future research will explore the financial incentives and tax credits for EV in more detail and their impact on diverse consumer groups, including the university population. This analysis will explore the costs related to the installation, operation, and maintenance of these charging facilities and the incentives that users may be offered.

Funding: This research was funded by the College of Business Administration Summer Research Grant at Texas A&M University, Kingsville.

Data Availability Statement: All data used in this research is publicly available. It is available as indicated in the referenced databases.

Acknowledgments: I would like to gratefully acknowledge the support of the College of Business Administration at Texas A&M University, Kingsville.

Conflicts of Interest: The author declares no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Abbreviations

EIA	United States Energy Information Administration
EV	electric vehicle
EVCS	electric vehicle charging station
GIS	Geographic Information Systems
GWH	gigawatt-hour
HIFLD	homeland infrastructure foundation-level data
NREL	National Renewable Energy Laboratory
OSM	OpenStreetMap database
SLOPE	state and local planning for energy
TWH	terawatt-hour
USCB	United States Census Bureau
USDOE	United States Department of Energy
US DOT	United States Department of Transportation
US EPA	United States Environmental Protection Agency
V2G	vehicle-to-grid

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