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Sustainable Design of Electric Vehicle Charging Station: "Solar District"

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With the shift from gasoline-powered to electric vehicles, the automobile industry faces a critical challenge: the transformation of traditional gas stations into efficient electric vehicle (EV) charging stations. This research introduces the concept of the "Solar District," a novel EV charging paradigm designed to be self-sufficient in energy usage, adhere to sustainable construction ethics, and function as a multifunctional cultural space. The Solar District is envisioned not only as an EV charging station but also as a community support hub, providing essential services such as food, clothing, shelter, and resources during disasters or power outages. Evaluation of the Solar District concept shows a superior performance score, surpassing conventional facilities, and highlights its potential to enhance environmental and energy justice. By reducing greenhouse emissions, preserving local ecosystems, and addressing high charging demands, the Solar District offers a sustainable and community-centered solution. Furthermore, it promotes cultural identity and fosters a sense of community by creating a positive, eco-friendly environment, supporting stakeholders and decision-makers in the pursuit of equitable and sustainable energy solutions.

Keywords: Electric vehicle charging station, Energy efficiency, Sustainability, Design of the charging station

Introduction

The economic development fostered by the automobile industry is evident in the growing number of registered cars each year. In 2022, U.S. consumed approximately 135.73 billion gallons of gasoline, which translates to about 368.63 million gallons per day (EIA, 2023). According to the American Petroleum Institute (API), there are over 145,000 gas stations in the U.S. (API, 2025), serving more than 296 million cars (Hedges & Company, 2025). The International Energy Agency (IEA) reported a 40% increase in EV sales in the U.S. in 2023 compared to 2022, and the trend is expected to continue upward (IEA, 2024). With the government promoting the use of electric vehicles (EVs) to improve air quality, transitioning fuel sources poses a significant challenge under the current overarching plan. Currently, there are more than 3.5 million EV cars (U.S. DOE, 2024) and approximately 11,915 electric vehicle DC fast-charging stations in the U.S. (U.S. DOE, 2025), the majority of which are subsidiaries of gasoline stations. Tesla's Supercharger Network leads the market, accounting for 70.27% of approximately 37,000 DC fast-charging ports, followed by Electrify America (11.62%), EVgo (9.19%), and ChargePoint (8.92%) (Threewitt, 2024). Additionally, fewer than 10,000 fast-charging ports in the U.S. are universally accessible to all EVs, regardless of make or model. To address this, the U.S. Department of Transportation (DOT) has allocated $5 billion for EV infrastructure expansion, requiring states to submit deployment plans to access the funds (FHWA, 2022). In January 2025, the DOT also announced a $635 million grant to further develop EV charging infrastructure (FHWA, 2025). The current expansion plan for EV infrastructure must not only be self-sufficient in terms of power usage but also adhere to green construction codes of ethics to ensure a sustainable future.

As the automobile industry phases out gas-powered vehicles and progressively increases the adoption of electric vehicles, the government faces the enormous task of transitioning gasoline stations into charging stations. The green construction market emphasizes the need for sustainable designs for charging stations. This research aims to present (1) the sustainable design of electric vehicle charging stations, (2) a cultural complex to address consumers' needs, and (3) the multifunctional use of charging stations during disaster situations. The sustainability-based resilience design, Solar District, will generate its own power to charge electric vehicles and provide the community with shelter during power outages and other emergency scenarios.

Background and Related Studies

Renewable energy sources provide an eco-friendly alternative to fossil fuels. They harness naturally occurring processes, such as sunlight, wind, and geothermal heat, to generate electricity. These sources not only reduce greenhouse gas emissions but also offer a viable long-term solution to meet the growing energy demands. Renewable energy systems, such as solar panels and wind turbines, are optimal for powering buildings and charging stations. Table 1 presents studies on renewable energy usage in buildings and electric vehicle stations. Analyzing their economic feasibility and demand strategies reveals that utilizing multiple power sources can enhance performance. Incorporating similar features into the Solar District design could help us better strategize demand characteristics.

Table 1. Use of Renewable Power Source

Authors	Building Type	Power Source	Components Powered	Description
(Huang et al., 2022)	Residential	Solar Panels	Building & EV Cars	Proper charging scheduling and top-down coordinated control was superior in demand performances.
(Seyednezhad & Najafi, 2021)	Office	Solar Panels	Radiant Cooling & Heating system	Optimal operating conditions with economic analysis presented for each condition.
(Ye et al., 2015)	EV Station	Solar Panels	EV Cars	Economic analysis conducted per daily demand of power in kWh.
(Shun & Ahmed, 2008)	Laboratory	Wind & Solar Panels	Ventilation System	Using hybrid power sources resulted in improved operational and performance benefits.

As shown in Table 1, Solar Photovoltaic (PV) panels are currently the most reliable source of renewable energy. The growing popularity of solar-powered equipment in the construction and transportation sectors is remarkable, particularly for mitigating CO_2 emissions. To address demand characteristics, design aspects must include precise specifications rather than relying on conventional

PV panel applications for power generation. Table 2 highlights the current state of PV panel usage and their efficiency in meeting the energy demands of EV stakeholders.

Table 2. Current state of Solar PV Panels uses in EV sector

Authors	Target Market	Components powered	Description
(Shariff et al., 2019)	EV Charging Station	Level 2 EV Charger	Study presents parametric design aspects and implementation of solar-powered chargers.
(Revathi et al., 2018)	EV Charging Station	EV Charger	Presents charger design and use of dc-dc boost converter to boost PV panel voltage.
(Araki et al., 2016)	EV Charging Station	EV Cars	Determined PV panel size to charge 5 EV cars in a day. (6 m x 6 m)
(Khalid et al., 2021)	EV Supply Equipment	EV Charger	Presents PV power specifications, negative impacts with remedies for EV charger use.

As illustrated in Table 2, EV chargers are the primary components powered by PV panels. These chargers are designed to address the growing demand for electric vehicle charging infrastructure. Recent advancements in current technologies, such as NASA's fast charging technology, could enable an EV to be fully charged in just 5 minutes (Collins, 2022). Table 3 outlines the current types of EV charging stations categorized by power level, capacity, connector types, charging speed, and location.

Table 3. Types of EV Charging Stations (Moloughney, 2021)

Level	Capacity (Volt)	Connectors Used	Charging Speed	Location
1	120	J1772, Tesla	3 to 5 Miles Per Hour	Home, Workplace & Public
2	208 to 240	J1772, Tesla	12 to 80 Miles Per Hour	Home, Workplace & Public
3	400 to 900 (DC Fast Charge & Supercharging)	Combined Charging System (Combo), CHAdeMO & Tesla	3 to 20 Miles Per Minute	Public

As shown in Table 3, this study considers the current technologies and market availability of charging components. At present, DC fast charging technology with Level 3 capacity is the best publicly accessible option. Although, home EV charging offers convenient overnight solutions for single-family homeowners but is often inaccessible to residents in multi-family housing due to limited infrastructure whereas public EV charging stations, located at workplaces, malls, and highways, serve as essential alternatives for long-distance travel and urban users without home charging (Varghese et al., 2024). However, disparities in public charging availability and affordability highlight the need for equitable infrastructure development to support widespread EV adoption.

Methodology

The main objective of this study is to design an EV charging station with a cultural complex, called the “Solar District,” which aims to create market opportunities and promote energy justice by making clean energy more affordable and accessible. The proposed methodology consists of four phases: (1) designing the Solar District, (2) selecting its location, (3) conducting energy simulation, and (4) integrating energy justice principles. The Solar District focuses on sustainable design for EV charging stations, incorporating an energy justice-based galleria that can also serve as a shelter during disaster situations. The Solar District includes (1) EV charging stations, (2) galleria, (3) a strip plaza, (4) an amphitheater, and (5) a parking lot, all integrated into a cohesive spatial configuration. The EV charging stations will feature two options: express charging and standard charging. The Solar District can accommodate various electric vehicles with a total of 92 charging ports of different capacities, a large parking area, and a hub for entertainment and relaxation.

Phase 1: Design of Solar District

The versatile design of the Solar District spans an area of 210,040 SF (square feet), including a galleria covering 18,118 SF with two floors, each 18 feet high. The galleria features retail shops, dry storage, a quick-service kitchen, restrooms, and a dining area. The design also incorporates a strip plaza extending over 15,344 SF. The Solar District accommodates 72 Level-2 charging ports distributed throughout the design for regular use and 20 Level-3 ports across five charging hubs for quick charging. Although DC fast charging technology (Level-3) is considered the best available for public use, the Level-2 charging ports are strategically located to serve daily users, while the Level-3 ports are intended for high-speed, public-use charging to meet peak demand. This approach ensures both convenience and efficiency for different user needs. EV trucks can easily access the charging hubs without inconvenience and exit the station seamlessly. Additionally, the site includes an amphitheater with a central garden space for entertainment and a parking lot with a capacity of 61 cars.

The Solar District is powered by an extensive array of Solar Photovoltaic (PV) panels installed over the galleria, strip plaza, and charging hubs. Ventilation throughout the building is managed using dual-bearing roof turbines, ensuring enhanced indoor air quality without relying on non-renewable energy. The sustainable design also allows the galleria to function as an emergency community shelter, equipped with all essential amenities for disaster situations. Figure 1 provides a complete overview of the charging station, including detailed renders of the design.

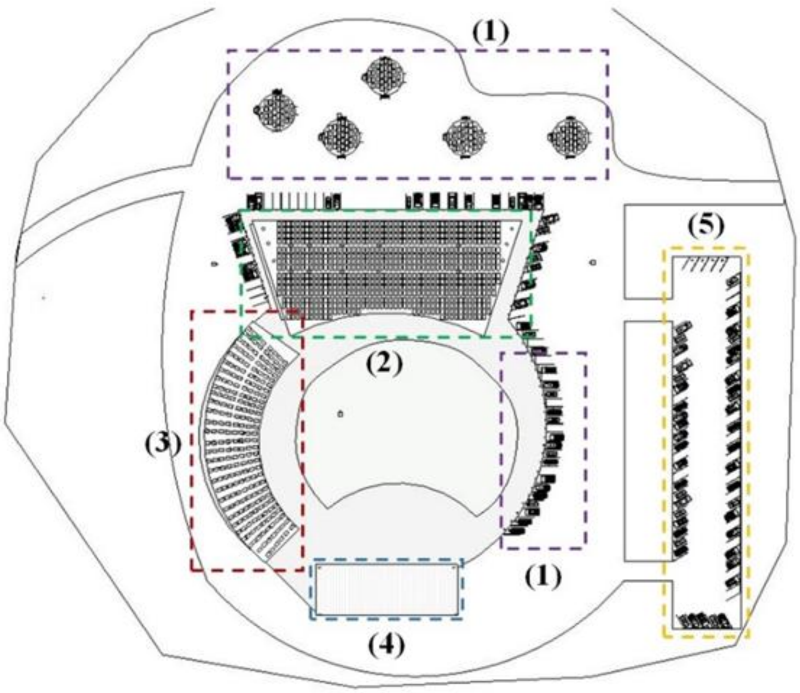

Figure 1. Solar District Overview: (1) EV charging stations, (2) Galleria, (3) Strip Plaza, (4) Amphitheatre, and (5) Parking lot

Phase 2: Location of Solar District

This research selected the best locations for the Solar District in Stillwater, OK. Since the location has more diversity, including 115 residential districts, local businesses, and a college town with students at Oklahoma State University, a modern and versatile rest area is necessary. The two locations were selected based on (1) accessibility to the airport, plenty of open space, and (2) accessibility to hotels, a nearby hospital, the university, and local communities. Figure 2 shows the suitable locations for the EV charging station.

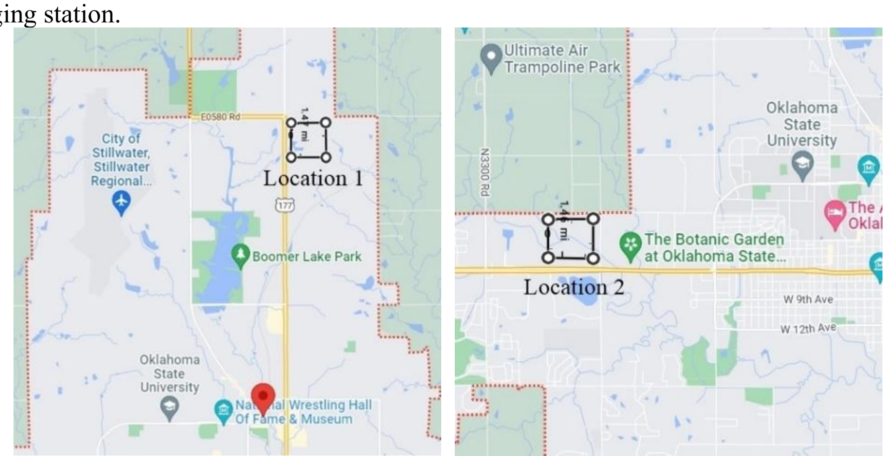

Figure 2. Tentative Solar District Locations at Stillwater, OK

The locations were selected for the best use of amenities and proximity to the community. The available areas in both locations are 3,788,271 SF and 3,714,298 SF, which are ample for designing roadways around the Solar District, as shown in Figure 2.

Phase 3: Energy Simulation

In this phase, energy consumption of the 'Solar District – Galleria' is calculated using OpenStudio and SketchUp. The considerations for the designed envelope include strip mall building types, ANSI/ASHRAE/IES Standard 90.1-2010 template, ASHRAE 169-2006-3A climate zone, and Variable Refrigerant Flow (VRF) as the HVAC system. Wind turbine ventilators are assumed to provide outdoor air as ventilation. The space types used for the designed envelope include a combination of a lobby, public restrooms, retail shops, supermarket sales/produce, dry storage, and a quick-service kitchen/dining area. Eighteen different thermal zones are assigned to the design. Figures 3 and 4 show the different space types and thermal zones considered for the design, respectively.

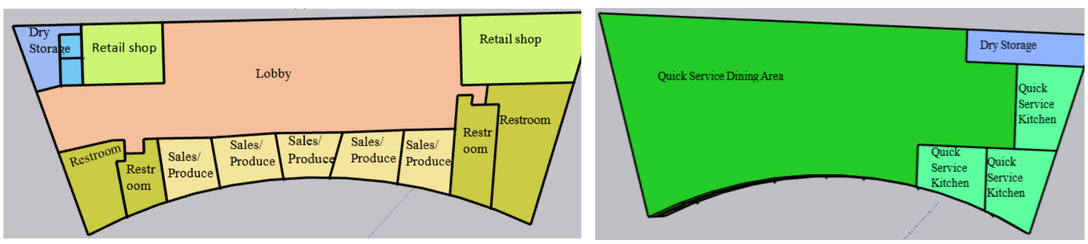

Figure 3. Galleria Render by Space Type

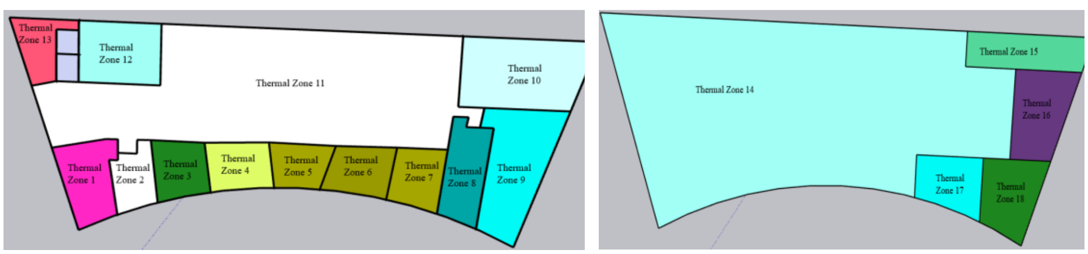

Figure 4. Galleria Render by Thermal Zone

The report from OpenStudio provides the Energy Use Intensity (EUI) of the design, which is the energy consumption of the building per total floor area per year. The reported EUI of the design is compared with the benchmark EUI approved by the ASHRAE Standards Committee to verify that its energy consumption is below the permissible limit. We set the fast-food restaurant as the benchmark EUI, as most of the space in the 'Solar District – Galleria' is occupied by quick-service kitchen and dining areas. Table 4 shows the comparison of the Site EUI and Source EUI of the design with the benchmark EUI. The design resulted in less energy consumption than targeted.

Table 4. Energy Use Intensity of Solar District Galleria and Benchmark

Site	Site EUI (kBtu/ft^2)	Source EUI (kBtu/ft^2)	Reference
Solar District Galleria	131.26	361.93	Openstudio report
Benchmark (Fast-food)	275	868	(Addendum, 2017)

Phase 4: Energy Justice

The research evaluates the achievability of energy justice for the Solar District by conducting a Choosing by Advantages (CBA) analysis for Multi-Criteria Decision Making (MCDM). The objective of CBA is to reflect the specific reality of the dynamics of each dimension, as well as the clear framework for the trade-offs between these dimensions (Fetanat et al., 2019). The dimensions of energy justice are rights, social aspects, environmental issues, and 2A. Each of these dimensions has its own key parameter index (Fetanat et al., 2019). The 'rights' dimension concerns the equal distribution of energy resources/systems to all people and future generations, the health of individuals, and the consent of those involved. The 'social aspects' dimension deals with providing transparent information to the public and addressing the needs of vulnerable sections of society. 'Environmental issues' dimension encompasses the use of sustainable energy sources to prevent the rapid depletion of natural resources and take responsibility for minimizing energy-related social and environmental issues. '2A' refers to the sufficient availability of energy resources when needed and the affordability of the energy system/resources for all people, including low-income families. Table 5 shows the results of the CBA for the Solar District Galleria and Penn Square Mall. Penn Square Mall, the existing mall in OK, is selected to compare the achievability of energy justice.

Table 5. Choosing by advantages (CBA) based on energy justice achievability

Dimensions	**KPI**	**Solar District Galleria**		**Penn Square Mall**	
		Remarks	**Score**	**Remarks**	**Score**
Rights	Intergenerational equity	Better	60	Weak	40
	Due Process	Better	50	Better	50
	Intragenerational equity	Better	60	Slightly better	50
Social Aspect	Transparency and accountability	Better	70	Better	70
	Intersectionality	Better	60	Slightly better	50
	Resistance	Better	60	Slightly better	50
Environmental Issues	Sustainability	Better	100	Weak	40
	Responsibility	Better	80	Weak	40
2A	Availability	Better	80	Slightly better	60
	Affordability	Better	80	Slightly better	60
	Total		700		510

As shown in Table 5, sustainability is considered a paramount factor, with the Solar District Galleria scoring 100, significantly better than the Penn Square Mall's score of 40. This is because the Solar District is designed with energy-efficient systems, such as wind turbine vents, VRF as an HVAC system, and solar panels that generate the required energy for operation. The remarks reflect the qualitative assessment of each dimension, with "Better" indicating stronger performance and higher scores, while "Weak" or "Slightly Better" suggest less favorable performance, resulting in lower scores. These remarks are directly tied to the numerical scores through the CBA method to quantify the comparison. Overall, the Solar District Galleria achieved a total score of 700, outperforming the Penn Square Mall's score of 510, indicating superior energy justice achievability across all dimensions. The Galleria scored higher in areas such as sustainability, affordability, and intergenerational equity, reflecting its stronger alignment with energy justice principles.

Discussion and Market Readiness

The Solar District is designed to pursue (1) self-sufficiency in terms of power usage, (2) adherence to green construction codes for a sustainable future, and (3) a complex cultural space. Additionally, the self-sufficient Solar District will provide food, clothing, shelter, and other essentials for the local community in disaster or power outage situations. Therefore, the Solar District will play a vital role in preserving values and beliefs, fostering a sense of cultural identity, and stimulating social justice advocacy. Culture has a significant impact on the marketing strategies of a product. The Solar District is a design that provides a multicultural space where business viability and market readiness will be established. Figure 5 shows the market readiness for the Solar District.

Figure 5. Market Readiness Assessment

The market readiness assessment consists of three components: User, Market, and Innovation. In the case of the Solar District, a cultural complex, both the users and the market are clearly defined. The inclusion of an EV charging station with solar panels positions the Solar District within the innovation category, as electric vehicles (EVs) represent emerging technology. Parmar et al. (2020) discusses how EVs can enhance the integration of renewable energy into existing power grids. Specifically, the study highlights technologies like vehicle-to-grid (V2G) systems, which allow EVs to store surplus renewable energy during low-demand periods and return it to the grid during peak demand, thus improving grid stability and maximizing the use of renewable energy sources. Moreover, as culture significantly influences consumer lifestyles, the proposed Solar District aligns with the cultural values of its consumers, aiming to foster the belief that they are investing their time and money in the right place. A future direction for this research is to incorporate specific designs for emergency community shelter requirements, including compliance with FEMA/ICC standards for emergency power systems that are protected at the same level as the structure itself.

Conclusion and Impact

The 'Solar District' is designed to provide a sustainable charging station, as well as an environmentally and energy justice-based building design. The literature review identified Solar Photovoltaic panels as the best renewable energy source and outlined the design aspects of their use for EV charging stations. Additionally, energy efficiency was analyzed using EnergyPlus. The Energy Use Intensity (EUI) of the design was compared with the benchmark EUI approved by the ASHRAE Standards Committee. The Solar District's energy consumption is below the targeted level, indicating that the model's energy consumption is within permissible limits. This study also used the Choosing by Advantages (CBA) approach for Multi-Criteria Decision Making (MCDM) to assess the energy justice achievability of the Solar District Galleria, compared to Penn Square Mall in Oklahoma City. The analysis revealed that Galleria achieved a score of 190, higher than the Mall. Furthermore, it is expected that the Solar District will assist stakeholders and decision-makers in achieving equity in environmental and energy justice by reducing greenhouse gas emissions, preserving ecosystems, and mitigating the challenging charging demand after the transition. The Solar District will also play a vital role in preserving community values and beliefs, fostering a sense of cultural identity, and creating a positive, environmentally friendly atmosphere.

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