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ASSESSING THE FEASIBILITY OF PORTABLE SOLAR CHARGING SYSTEMS FOR ELECTRIC VEHICLES: A SUSTAINABLE APPROACH TO ALLEVIATE GRID LOAD

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Assessing the Feasibility of Portable Solar Charging Systems for Electric Vehicles: A Sustainable Approach to Alleviate Grid Load

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Abstract

The global rise in electric vehicle (EV) adoption is creating significant challenges for existing electricity grids, particularly during peak charging periods. Integrating renewable energy sources, such as portable solar charging systems, offers a promising solution. This research assesses the feasibility of portable solar charging systems for EVs, focusing on solar panel efficiency, energy consumption, and cost analysis. Our findings reveal that although advancements in solar technology have significantly improved efficiency, the current portable solar technology, exemplified by a 200W solar blanket, cannot fully meet the energy demand of EVs on campus. Nonetheless, future improvements in solar efficiency and economies of scale could enhance feasibility. A case study of Houston, Texas, and surrounding counties highlights the rapid increase in EV registrations and underscores the need for sustainable energy solutions. Sensitivity analysis indicates that factors such as capital costs, carbon pricing, and interest rates significantly impact the economic viability of solar-powered EV charging systems. By promoting solar energy integration and optimizing EV charging infrastructure, we can reduce grid dependency and enhance environmental sustainability. This study provides valuable insights into the potential of solar-powered EVs and underscores the importance of continued research and technological advancements in this field.

Keywords: Electric Vehicles (EVs), Solar Charging, Renewable Energy Integration, Solar System Efficiency

Introduction

The global surge in the adoption of electric vehicles (EVs) promises a cleaner, more sustainable future for transportation. However, this transition poses significant challenges to existing electricity grids, particularly during peak charging periods. To address this issue, integrating renewable energy sources into EV charging infrastructure has emerged as a promising solution. Among these, portable solar charging systems offer a compelling avenue for alleviating grid load while promoting sustainability. This research study focuses on assessing the feasibility of such systems, emphasizing three key pillars: Solar Panel Efficiency, Energy Consumption of EVs, and Cost Analysis of solar charging equipment.

Charging EVs at work, particularly on university campuses, presents a strategic advantage. Most employees and students park their vehicles for extended periods during the day, coinciding with peak solar energy generation. According to the U.S. Department of Transportation, the average commuting distance for Americans is approximately 16 miles each way, totaling 32 miles per day (McGuckin & Fucci, 2018). In Texas, the average commute is slightly longer, with an average round trip of around 40 miles per day (Blumenberg & Siddiq, 2023). For an EV, this translates to an energy consumption of approximately 10 kWh per day, assuming an average efficiency of 0.25 kWh per mile.

During an 8-hour workday, vehicles parked outdoors are ideally positioned to harness solar energy. Texas, with its ample sunlight, receives about 5 kWh/m² of solar radiation daily (Baltazar et al., 2023). A portable solar panel system with an output of 200W and an efficiency of 20% can generate around 1 kWh per day in optimal conditions. While this may not fully charge an EV, it can significantly offset the energy drawn from the grid.

The feasibility of deploying portable solar systems for EVs in outdoor parking areas addresses several practical constraints. Unlike fixed solar installations, portable systems offer flexibility and individual ownership, enabling each EV owner to harness solar energy independently. This approach mitigates the need for extensive infrastructure modifications and capital investment in solar parking garages. Given the increasing availability and decreasing costs of portable solar technologies, this solution presents a viable and sustainable option for EV charging on university campuses.

By examining solar panel efficiency, EV energy consumption, and the cost of solar charging equipment, this research aims to provide a comprehensive analysis of the potential for portable solar systems to support sustainable EV charging. This study will contribute to the broader understanding of integrating renewable energy solutions into everyday transportation needs, highlighting the benefits and limitations of portable solar charging for EVs. Figure 1 schematically illustrates the concept of a portable solar charging system, highlighting how it captures energy from direct radiation, reflected radiation from the ground, and diffuse radiation from clouds.

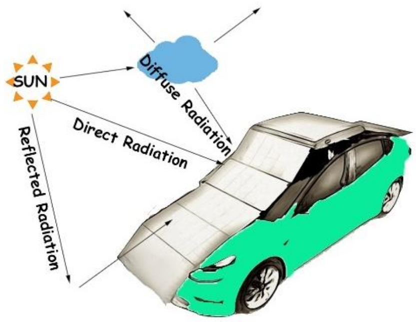


Figure 1: Schematic Diagram of Portable Solar Charging System

Literature Review

The transition to sustainable energy sources in the transportation sector, particularly through the integration of solar power into electric vehicle (EV) charging infrastructure, represents a crucial shift from conventional fossil fuel dependence. Research in this domain primarily focuses on optimizing the design and functionality of solar-powered EV charging stations to cater effectively to the growing demand for EVs (Alrubaie et al., 2023; Yap, Chin, & Klemeš, 2022).

Significant emphasis is placed on the technical specifications required to enhance the operational efficiency of these stations. This includes the capacity of solar panels, compatibility with existing charging infrastructures, and the necessary energy storage solutions to ensure continuous energy supply (Afshar et al., 2021). Additionally, the layout of charging stations is critically analyzed, focusing on maximizing space utilization, positioning solar panels optimally, and ensuring accessibility for EV users (Mohammed et al., 2024).

The durability, efficiency, and sustainability of materials used in constructing these stations are also pivotal, with several studies aiming to explore innovative construction methodologies and rigorous performance evaluations to improve these aspects (Al-Hanahi et al., 2021). These studies often extend into the exploration of construction techniques that highlight modularity, scalability, and ease of maintenance (Ravindran et al., 2023).

Environmental impact is a recurring theme in the literature, with analyses often focusing on the reduction of carbon footprints and enhancing sustainable energy practices within the operational scope of these charging stations (Yang et al., 2021). The feasibility studies typically assess the cost-effectiveness and technical viability of these systems, providing a comprehensive understanding of the economic and environmental sustainability of integrating solar power with EV charging infrastructure (Pradhap et al., 2020).

Emerging studies continue to explore the potential for integration challenges, such as grid connectivity, interoperability, and regulatory hurdles, that may impact the deployment and utilization of solar-powered EV charging stations. This includes a detailed examination of system components like solar panels, inverters, and the overall charging infrastructure, ensuring their compatibility and efficiency (Das et al., 2020).

The broader implications of this research reflect the potential of solar-powered EV charging stations to contribute significantly to the global shift towards renewable energy in transportation systems. This shift is crucial not only in reducing reliance on diminishing fossil fuel resources but also in mitigating the environmental impacts associated with traditional energy sources (Lee et al., 2016). By providing a holistic understanding of the design, implementation, and operational dynamics of these infrastructures, the literature aims to facilitate their effective deployment and utilization, thereby enhancing the adoption of renewable energy practices in the transport sector.

Background: Solar Panel Efficiency

Solar panel efficiency stands as the cornerstone of portable solar charging systems, directly impacting their ability to generate sufficient energy for EV charging. The efficiency of solar panels refers to the percentage of sunlight that can be converted into electricity. Over the past few decades, advancements in solar technology have significantly improved efficiency rates, making solar energy an increasingly viable option for various applications.

In recent years, the average efficiency of solar panels has steadily increased, driven by ongoing research and development efforts within the renewable energy sector. According to data from the National Renewable Energy Laboratory (NREL) and the International Renewable Energy Agency (IRENA), the average efficiency of commercially available solar panels has risen from around 15% to over 20% in the past decade alone. These improvements are attributed to innovations in materials, manufacturing processes, and design enhancements.

Moreover, the trajectory of solar panel efficiency continues to show promise, with projections indicating further gains in the coming years. Emerging technologies such as perovskite solar cells and tandem solar cells hold the potential to push efficiency rates even higher, potentially surpassing the 30% mark in laboratory settings. Such advancements not only enhance the energy-generating capabilities of solar panels but also contribute to reducing the overall cost per watt of solar electricity.

However, while efficiency gains are significant, practical considerations must be addressed when deploying portable solar charging systems for EVs. Factors such as shading, temperature variations, and optimal angles of incidence play crucial roles in maximizing solar energy harvest. Additionally, the intermittent nature of sunlight necessitates effective energy storage solutions to ensure continuous availability for EV charging, especially during periods of low irradiance.

In light of these considerations, this research seeks to evaluate the current state of solar panel efficiency and its implications for portable charging systems. By analyzing data from reputable sources such as NREL, IRENA, and solar industry reports, this study aims to provide insights into the feasibility of harnessing solar energy for sustainable EV charging. Moreover, by forecasting future trends in solar technology, it aims to elucidate the potential of solar-powered EVs in reducing dependency on conventional grid infrastructure while advancing environmental and economic sustainability goals.

Efficiency of Commercially Available Solar Panels:

As of recent years, the average efficiency of commercially available solar panels typically ranges from 18% to 22% for monocrystalline silicon panels and around 15% to 18% for polycrystalline silicon panels. These figures represent the percentage of sunlight converted into electricity under standard test conditions (STC). It's noteworthy that premium-tier solar panels can achieve even higher efficiencies, reaching up to 23% to 25%.

Research has focused on enhancing the efficiency of silicon solar cells, which dominate the market. This includes reducing material defects, improving light trapping techniques, and optimizing cell architecture.

- Thin-Film Technologies: Thin-film solar technologies, such as Cadmium Telluride (CdTe) and Copper Indium Gallium Selenide (CIGS), have seen efficiency improvements through process optimization and material innovations.
- Tandem Solar Cells: Tandem solar cells, which combine multiple materials with complementary absorption spectra, have demonstrated significant efficiency gains. Research in this area has led to new records in tandem cell efficiency.

While the basic principles of solar panel construction remain largely unchanged, there have been notable refinements in manufacturing techniques and materials over the past five years. For instance, improvements in texturization processes have enhanced light capture within the solar cell, while advancements in anti-reflective coatings have minimized energy losses due to reflection. Additionally, the adoption of bifacial solar panels, capable of capturing sunlight from both the front and rear surfaces, has become more widespread, further boosting overall energy yield. Furthermore, there has been a trend towards larger wafer sizes (e.g., moving from 156 mm to 210 mm), enabling manufacturers to produce more efficient panels with higher power outputs. These quantitative insights underscore the dynamic nature of solar panel technology and highlight the ongoing efforts to increase efficiency and drive down the cost of solar electricity. Figure 2 shows the efficiencies for research cells for a range of photovoltaic technologies, plotted from 1976 to the present by NREL.

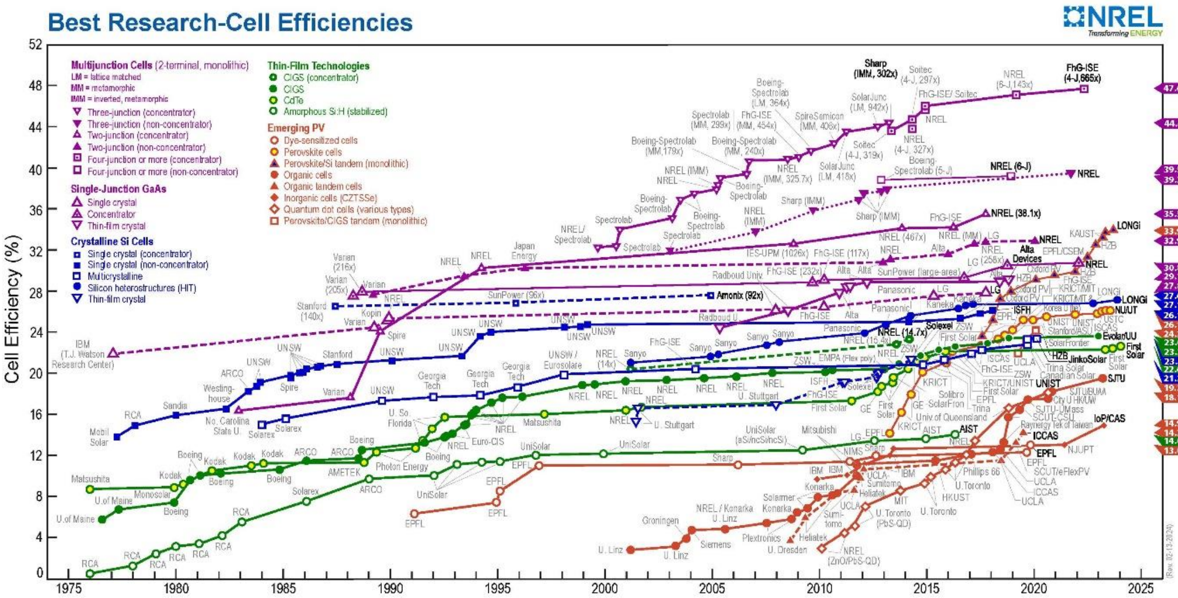


Figure 2: Solar cell efficiencies over time (adopted from NREL)

Cost of Various Solar Panel Technologies/Methods:

Multijunction Cells (2-terminal, monolithic): These cells, especially those with multiple junctions, are typically used in concentrated photovoltaic (CPV) systems, which focus sunlight onto small solar cells. They tend to be more expensive due to their complex manufacturing process and materials.

Crystalline Si Cells: Single crystal (concentrator): While these cells offer high efficiency, they can be costlier due to the expense of producing single-crystal silicon wafers and the additional equipment required for concentration.

Multicrystalline: Multicrystalline silicon cells are generally more cost-effective compared to single-crystal silicon cells. They are widely used in both residential and commercial installations.

Silicon heterostructures (HIT), thin film crustal: HIT cells, also known as heterojunction cells, typically have higher upfront costs but can offer better efficiency and performance in certain conditions.

Thin-Film Technologies: CIGS (Copper Indium Gallium Selenide): CIGS thin-film technology has been gaining traction due to its potential for higher efficiency and lower manufacturing costs compared to traditional crystalline silicon cells.

CdTe (Cadmium Telluride): CdTe thin-film panels are known for their low manufacturing costs, making them one of the most cost-effective solar technologies available.

Amorphous Si:H (stabilized): Amorphous silicon thin-film panels are often used in building-integrated photovoltaics (BIPV) due to their flexibility and relatively low cost.

Emerging PV: Perovskite cells: Perovskite solar cells have garnered significant attention for their high efficiency potential and low-cost manufacturing processes. However, commercialization is still in the early stages, and production costs may vary.

Perovskite/Si tandem (monolithic): Tandem perovskite/silicon solar cells aim to combine the high efficiency of perovskite cells with the stability of silicon cells. Production costs are expected to decrease as the technology matures.

Organic cells: Organic photovoltaic (OPV) cells offer the potential for low-cost, flexible solar panels. However, their efficiency and durability are currently lower compared to traditional silicon-based technologies.

Inorganic cells (CZTSSe): These cells, based on copper zinc tin sulfide/selenide, are being researched for their potential low-cost manufacturing methods. However, commercial availability and cost data may be limited.

Quantum dot cells: Quantum dot solar cells are still in the experimental phase, and cost data may not be readily available due to the early stage of development.

Perovskite/CIGS tandem (monolithic): Tandem perovskite/CIGS solar cells aim to combine the advantages of both technologies. Cost data for this technology may vary depending on the specific manufacturing process and materials used.

Price Comparison:

It's important to note that the cost of solar panels can vary widely depending on factors such as efficiency, manufacturing scale, geographic location, and market conditions. However, here's a general comparison of prices:

Crystalline Si Cells: Typically range from $0.30 to $0.60 per watt, equivalent to approximately $10 to $20 per square foot.

Thin-Film Technologies (CIGS, CdTe, Amorphous Si:H): Generally have lower manufacturing costs compared to crystalline silicon cells and can range from $0.20 to $0.40 per watt, or approximately $6 to $12 per square foot.

Emerging PV (Perovskite, Organic, Inorganic, Quantum Dot): Cost data for these technologies may vary significantly due to their early stage of development, but they are generally expected to be competitive with or potentially lower in cost than traditional solar technologies once commercialized.

Limitations for Portable Use:

The suitability of solar panel technologies for portable applications depends on several factors, including weight, flexibility, durability, and efficiency.

Crystalline Si Cells: While efficient and widely used, they tend to be heavier and less flexible, which may limit their portability for certain applications.

Thin-Film Technologies (CIGS, CdTe, Amorphous Si:H): Thin-film panels are generally lighter and more flexible than crystalline silicon panels, making them suitable for portable use. However, durability and efficiency under varying environmental conditions should be considered.

Emerging PV (Perovskite, Organic, Inorganic, Quantum Dot): These technologies have the potential to offer lightweight and flexible solar panels, but their durability and efficiency in portable applications may vary and require further development.

In summary, while some solar panel technologies are commercially available and well-suited for portable use, others are still in the research and development phase or may have limitations that need to be addressed for portable applications.

Case Study

Houston, Texas (and its surrounding counties), has seen a rapid increase in the number of registered motor vehicles over the past decade, mirroring national growth trends. As of April 2024, the vehicle density in Houston has approached figures comparable to major urban centers, with a notable increase in energy consumption predominantly from petroleum fuels. Gasoline and diesel account for a significant portion of this, with renewable energy sources slowly being integrated.

As an emerging leader in EV promotion within the United States, Texas has made substantial progress. As of May 7, 2024, 275,000 EVs have registered in Texas. In 2022, Texas had 1,386 fast DC chargers, 2,472 EV charging stations, and a fast charger growth year over year 53.5 percent.

Basic Parameters for the Analysis

Solar Radiation

Located in the eastern part of Texas, Huntsville enjoys ample solar radiation, making it an ideal location for solar energy projects. It receives about 2,500 to 2,800 hours of sunshine annually with an average solar radiation of about 5 kWh/m² per day, which is conducive for solar-powered applications.

Electricity Demand

The proposed PV power station in Huntsville is designed to meet the energy demand of 100 fully charged, real-time EVs and one mobile charge truck. Given the typical energy requirements, the total electricity demand for a single PV power station is estimated at 4,500 kWh/day or approximately 1,642,500 kWh/year.

PV Module

The solar PV industry in the United States has seen substantial growth, with costs significantly decreasing over the years. By 2014, the average cost of a PV panel had dropped to around $900/kW. For the purposes of this study, this figure will be used as the cost basis for PV panels, accounting for approximately half the total cost of installing a PV power station in Huntsville. Installation and replacement costs are estimated at $1,800/kW and $1,600/kW, respectively, with annual operation and management costs around $20. The typical lifespan of a PV array is projected at 20 years without a tracking system.

Converter

For the efficient conversion of energy between DC and AC forms, high-quality power converters are essential. In the U.S. market, the retail price for high-capacity converters is approximately $500/kW. These converters typically have a lifespan of 20 years with minimal annual maintenance costs.

Battery

EVs form a crucial component of Huntsville's energy strategy. The EV battery, for instance, plays a pivotal role in this integrated energy system. For this study, we will consider the technical parameters of a widely used EV battery model appropriate for the local market conditions.

Maximum Capacity of Grid Purchase Power

Given the constraints of the existing electrical grid in Huntsville and the potential impact of sudden increases in power load, the grid's maximum purchase and sell power capacities are limited to 1,100 kW to ensure stability and efficiency.

Campus Analysis:

Initial observations revealed that only a fraction of the EVs on campus utilize the existing power station for charging, highlighting the need for broader assessments. To generalize the findings beyond Tesla vehicles, an extrapolation process was initiated. With approximately 11,500 vehicles registered for parking on campus and an estimated 130 being EVs, the ratio of EVs to total vehicles was determined. This ratio serves as a basis for extrapolating the total number of EVs on campus, beyond Tesla models.

County-Level Analysis:

To gain insights into electric vehicle (EV) adoption trends beyond the SHSU campus, data from Harris, Montgomery, and Walker counties were examined. Figures sourced from the Texas Open Data Portal provide a snapshot of EV registrations alongside total vehicle registrations within each county.

Harris County:

- Total Vehicle Registrations: 3,415,702
- EV Registrations: 37,851
- Tesla Registrations: 19,218

Montgomery County:

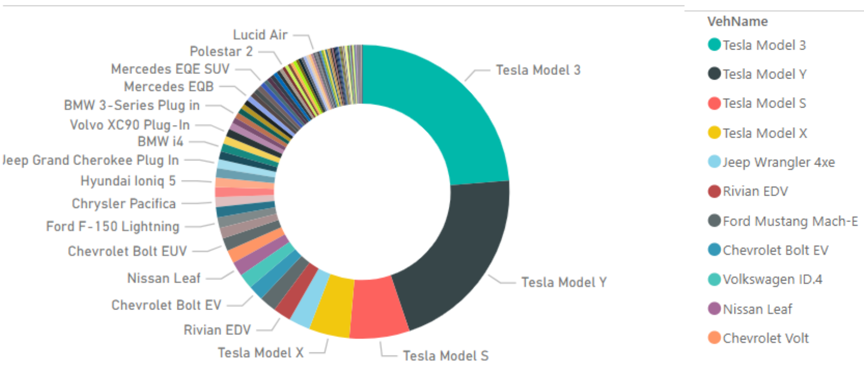
- Total Vehicle Registrations: 575,374
- EV Registrations: 6,535
- Tesla Registrations: 3,639

Walker County:

- Total Vehicle Registrations: 56,176
- EV Registrations: 118
- Tesla Registrations: 41

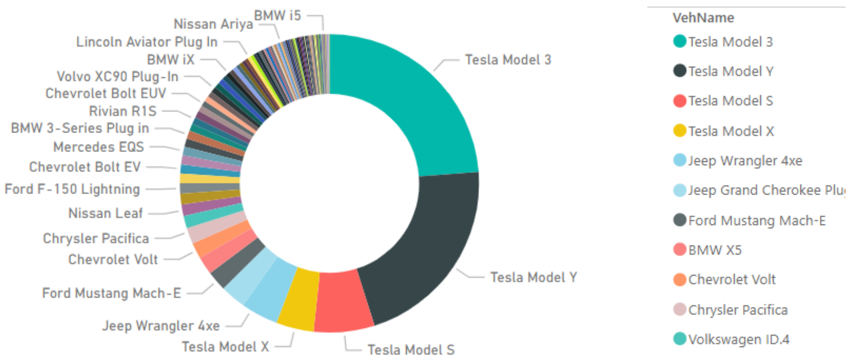
By analyzing the ratio of EV registrations to total vehicle registrations in each county, we can estimate the prevalence of EVs within the broader community. Extrapolating this ratio allows for a better understanding of EV adoption trends and their implications for sustainable transportation initiatives.

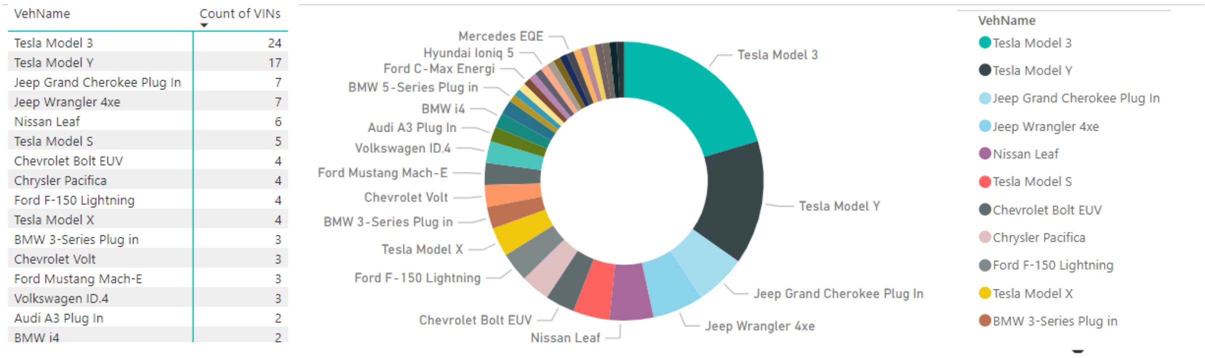
VehName	Count of VINs
Tesla Model 3	8974
Tesla Model Y	7926
Tesla Model S	2498
Tesla Model X	1685
Jeep Wrangler 4xe	883
Rivian EDV	734
Ford Mustang Mach-E	713
Chevrolet Bolt EV	636
Volkswagen ID.4	625
Nissan Leaf	598
Chevrolet Volt	545
Chevrolet Bolt EUV	534
Porsche Taycan	446
Ford F-150 Lightning	445
Rivian R1S	422
Chrysler Pacifica	418
BMW X5	415
Hyundai Ioniq 5	389
Mercedes EQS	387
Jeep Grand Cherokee Plug In	377
Audi e-tron	328



EV REGISTRATION BY MODEL

VehName	Count of VINs
Tesla Model 3	1552
Tesla Model Y	1393
Tesla Model S	429
Tesla Model X	265
Jeep Wrangler 4xe	263
Jeep Grand Cherokee Plug In	179
Ford Mustang Mach-E	142
BMW X5	128
Chevrolet Volt	113
Chrysler Pacifica	113
Volkswagen ID.4	87
Nissan Leaf	82
BMW 5-Series Plug in	76
Ford F-150 Lightning	73
Toyota Prius Prime	68
Chevrolet Bolt EV	65





VehName	Count of VINs
Tesla Model 3	24
Tesla Model Y	17
Jeep Grand Cherokee Plug In	7
Jeep Wrangler 4xe	7
Nissan Leaf	6
Tesla Model S	5
Chevrolet Bolt EUV	4
Chrysler Pacifica	4
Ford F-150 Lightning	4
Tesla Model X	4
BMW 3-Series Plug in	3
Chevrolet Volt	3
Ford Mustang Mach-E	3
Volkswagen ID.4	3
Audi A3 Plug In	2
BMW i4	2

Figure 3: EVs registered in Harris, Montgomery, and Walker counties

The daily power usage for the entire 2023 was collected from ChargePoint charging that shows hourly power usage per day. Also, we know about the number of Tesla vehicles registered on campus. It is obvious that a small portion of the EVs on campus are charging using the existing power station, so the next step is to genialize the number of tesla cars to the total number of EVs. Furthermore, number of EVs and total vehicles registered in Harris, Montgomery, and Walker counties were collected from Texas open data portal. Harris County: 37,851 out of 3,415,702 (19218 are tesla), Montgomery County: 6535 out of 575,374 (3639 are tesla), and Walker County 118 out of 56,176 (41 are tesla). In Harris County, with a significant total vehicle registration of over 3.4 million, the 37,851 registered EVs indicate a notable presence of electric vehicles. Among these, Tesla models constitute a substantial portion, with 19,218 registrations. Similarly, Montgomery County showcases a growing interest in EVs, with 6,535 registrations out of a total of 575,374 vehicles. Tesla vehicles represent a considerable portion, comprising 3,639 of the EV registrations. In Walker County, with a smaller vehicle population compared to the other counties, the 118 EV registrations, including 41 Teslas, reflect a nascent but emerging trend towards electric mobility.

Results and Discussion:

While the integration of portable solar charging systems offers potential benefits in reducing grid load and promoting sustainability, the current solar technology, represented by the 200W solar blanket, is insufficient to meet the energy demand of EVs at SHSU. However, advancements in solar technology and economies of scale may enhance the feasibility of such systems in the future. In the meantime, SHSU can explore complementary strategies such as optimizing EV charging schedules, investing in grid-connected solar infrastructure, and incentivizing energy-efficient EV models to achieve sustainability goals.

Energy Demand of EVs:

- Average Daily Distance Driven per EV: 73 miles
- Number of Days EVs are Driven per Week: 4
- Cost of Charging per kWh: $0.50

Solar Panel Specifications:

- Solar Panel Type: Portable solar blanket
- Power Output: 200W
- Efficiency: 23.5%
- Cost: $1600

Energy Demand per Day:

- Energy Demand per Day (kWh) = Energy Consumption per mile (kWh/mile) × Average Daily Distance Driven (miles) × Number of Days per Week
- Energy Consumption per mile (kWh/mile) = Total Energy Demand per day divided by Average Daily Distance Driven per EV.
- After calculation, assuming an average EV energy consumption of 0.224 kWh/mile, the Energy Demand per Day for EVs at SHSU is approximately 65.6 kWh.

Cost Analysis:

- Total Cost per Day = Energy Demand per Day (kWh) × Cost per kWh
- With a charging cost of $0.50 per kWh, the Total Cost per Day for charging EVs at SHSU is approximately $32.80.

Feasibility of Solar Blanket:

- Energy Generated by Solar Blanket per Day = Solar Panel Power Output (kW) × Efficiency × Hours of Sunlight
- Assuming 5 hours of sunlight per day in Huntsville, TX, the Energy Generated by the Solar Blanket per Day is approximately 9.4 kWh.
- The solar blanket is unable to meet the entire energy demand of EVs at SHSU, as it falls short of the daily demand of 65.6 kWh.

Environmental Aspect

The debate about the role of electric vehicles (EVs) in reducing GHG emissions is ongoing in the United States. According to a study by the American Council for an Energy Efficient Economy, EVs may produce higher GHG emissions than conventional gasoline-powered cars in regions where the majority of grid power is derived from coal-fired plants. In Huntsville, TX, the energy mix includes a significant proportion of fossil fuels, although efforts are being made to incorporate more renewable sources. This suggests that without a shift towards greater renewable energy integration, the environmental benefits of EVs could be limited, simply transferring emission sources from transportation to power generation sectors.

However, adopting solar energy to power EVs could dramatically alter this dynamic, improving air quality in urban environments by reducing reliance on coal power. A comparative study between traditional gasoline-powered cars and a PV-EV system was conducted using popular models produced by a major U.S. EV manufacturer. It was found that a typical gasoline car consumes about 10.6 liters of gasoline per 100 km, while the equivalent EV consumes about 18.2 kWh per 100 km [22]. GHG emission coefficients provided by the Intergovernmental Panel on Climate Change indicate that gasoline has an emission coefficient of 2.44 kg CO2-e/L. The comparative analysis revealed that the PV-EV system could significantly reduce emissions of carbon dioxide, sulfur dioxide, and nitrogen oxides by 232,954, 459,564, and 5,019,833 tons annually, respectively, with reduction percentages of 99.8%, 99.7%, and 100% respectively.

Sensitivity Analysis

A sensitivity analysis was performed to identify the most influential parameters on the system outcomes. The key parameters analyzed included the capital cost of the PV system, carbon pricing, interest rates, and feed-in tariff policies.

Influence of the Capital Cost of the PV System

The relationship between the capital cost of the PV system and the cost of energy (COE) is depicted in Figure 6. The Renewable Energy Fraction (RF) tends to decrease as the price of PV modules increases, indicating a reduced output of PV electricity. The cost of the PV system and the COE of the energy system are non-linearly related, with a clear inflection point observed when the PV price reaches approximately $1,800/kW.

Influence of Carbon Pricing

In the U.S., carbon emission trading is being considered in several states, and Huntsville could benefit from such initiatives to improve the competitiveness of low-carbon renewable energy sources. Figure 7 illustrates how an increase in the price of carbon emission allowances can significantly boost the proportion of renewable energy, suggesting that effective carbon pricing could promote new energy development if set above a threshold of $20/t.

Influence of Interest Rates

Interest rates have a substantial impact on the economic viability of long-term investments like PV power plants. Figure 8 shows that as the interest rate increases from 0% to 6%, the COE rises from $0.027/kWh to $0.097/kWh. The relationship between the COE and interest rates shows a sharp increase at around 6%, indicating that higher borrowing costs can significantly hinder the adoption of PV power plants, which is currently a challenge in Huntsville due to the high costs of financing.

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