

Current Challenges and Future Prospects of Solar-Powered Electric Vehicles: A Review

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Abstract: Solar-powered electric vehicles (SPEV's) represent a promising innovation at the intersection of renewable energy and sustainable transportation. This paper provides a comprehensive review of SPEVs, exploring their technological underpinnings, potential benefits, and challenges to widespread adoption. The core components of SPEVs, including solar panel technology, battery systems, and energy management strategies. The environmental advantages of SPEVs are examined, highlighting their potential to reduce greenhouse gas emissions, mitigate dependence on fossil fuels, and contribute to a cleaner energy future. Analyze the economic viability of SPEVs, considering factors such as production costs, consumer affordability, and government incentives. Drawing upon real-world case studies of prominent SPEV projects and models, identify key success factors and lessons learned. A comparative analysis with conventional electric vehicles and hybrid vehicles provides insights into the relative strengths and weaknesses of each technology. The paper concludes with a forward- looking perspective on the future of SPEVs, emphasizing their potential impact on the automotive and energy sectors, and highlighting the technological advancements and policy initiatives needed to accelerate their integration into mainstream transportation systems.

1 INTRODUCTION

The global automotive industry stands at the cusp of a significant transformation, driven by the urgent need for sustainable transportation solutions. Electric vehicles, a niche technology, have emerged as a viable alternative to traditional combustion engine vehicles, promising reduced carbon emissions and a cleaner energy future. Advancements in solar photovoltaic technology have made solar energy increasingly efficient and affordable, positioning it as a key player in the global transition to renewable energy sources. The convergence of these two technologies – solar power and electric vehicles – presents a compelling opportunity to further decarbonize the transportation sector and reduce our reliance on fossil fuels. Early EVs, while demonstrating the potential of electric propulsion, faced limitations in range and refueling time. The integration of solar power, however, offers a promising pathway to overcome these challenges by providing a renewable and potentially limitless

energy source (Li et al., 2022). Solar-powered electric vehicles, though still in their nascent stages of development, hold immense potential to revolutionize transportation. Imagine a future where vehicles are not only powered by electricity but can also generate their own clean energy, reducing the strain on the electric grid and minimizing the environmental impact of transportation. This vision, while ambitious, is rapidly becoming a tangible reality. A comprehensive analysis of the current state of SPEVs, exploring both the challenges and opportunities that lie ahead. The technological advancements driving the development of SPEVs, examine the barriers hindering their widespread adoption, and discuss the potential solutions and future prospects of this burgeoning field. This is structured to provide a cohesive understanding of SPEVs. By examining the historical development and current state of both EV and solar PV technologies, laying the groundwork for understanding their integration as shown in figure 1

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Figure 1: Co-occurrence keyword analysis of Solar EV by Vos viewer.

Solar-powered electric vehicles represent a fascinating convergence of two rapidly evolving technologies: solar energy and electric vehicles (Balal, 2023). This section delves into the technological underpinnings of SPEVs, exploring the principles of solar power generation and the key components that enable these vehicles to harness sunlight for propulsion. Basic Principles of Solar Power Generation is the heart of every SPEV lies the remarkable process of converting sunlight directly into electricity: photovoltaic energy conversion. This process relies on the photovoltaic effect, a phenomenon observed in certain materials where the absorption of photons (light particles) leads to the excitation of electrons, generating an electrical current. Photovoltaic cells, typically made from silicon, form the building blocks of solar panels (Rathore et al., 2021).

Photons from sunlight that are absorbed by a photovoltaic cell impart energy to the material's electrons. The vehicle's direct current electricity is produced when the electrons are able to separate from their atoms due to this energy boost.

2 COMPONENTS OF SPEVS

SPEVs integrate several key components, each playing a crucial role in capturing, storing, and utilizing solar energy for propulsion:

Photovoltaic Panels: These panels, typically mounted on the vehicle's roof and other sun-exposed surfaces, serve as the primary energy source. They consist of interconnected PV cells encapsulated in a protective laminate to withstand environmental factors. The efficiency, size, and weight of these panels significantly impact the vehicle's overall performance. **Energy Storage Systems:** While PV panels generate electricity during daylight hours, an energy storage system is essential to provide power when sunlight is unavailable. High-capacity batteries, similar to those used in conventional EVs, store the

electricity generated by the solar panels, enabling the vehicle to operate during nighttime and cloudy conditions. **Power Management Systems:** This crucial component acts as the brain of the SPEV, efficiently managing the flow of energy between the PV panels, batteries, and the electric drivetrain. It optimizes energy usage, regulates battery charging and discharging, and ensures a consistent and reliable power supply to the motor. Similar to conventional EVs, SPEVs utilize an electric drivetrain for propulsion. This system comprises an electric motor that converts electrical energy from the batteries into mechanical energy to turn the wheels, providing a quiet and emission-free driving experience.

3 TYPES OF SPEVS

SPEVs can be broadly categorized into two main types based on their energy sources.

3.1 Fully Solar-Powered Vehicles

These vehicles rely solely on energy generated by their onboard solar panels. While offering the ultimate in clean transportation, they often face limitations in range and power due to the constraints of solar panel size and efficiency.

3.2 Hybrid Solar-Electric Vehicles

These vehicles combine solar power generation with a supplementary energy storage system, typically a battery pack that can be charged from an external grid. This hybrid approach offers a more practical solution, extending the vehicle's range and ensuring reliable performance even in low sunlight conditions (Sharma et al., 2023). This technological overview provides a foundation for understanding the complexities and possibilities of SPEVs (Sharma, 2021). The following sections will delve deeper into the specific challenges, opportunities, and future prospects of this emerging field. The block diagram for solar charging EV is shown in figure 2.

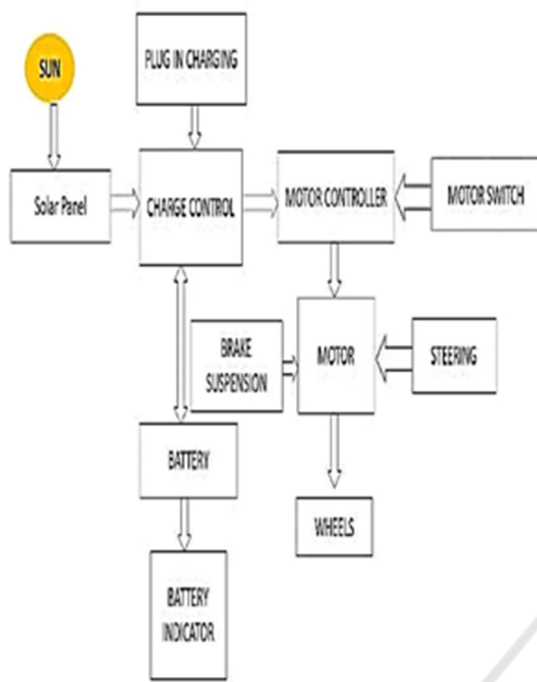


Figure 2: Block Diagram of Solar Charging EV.

4 CURRENT CHALLENGES

While solar-powered electric vehicles hold immense promise for a sustainable transportation future, several challenges hinder their widespread adoption (Reddy et al., 2024). These challenges span technological, economic, infrastructural, and environmental domains.

This section delves into these hurdles, providing a comprehensive understanding of the barriers that must be overcome to unlock the full potential of SPEVs.

4.1 Technological Challenges

4.1.1 Efficiency of PV Panels

The efficiency of commercially available PV panels remains a limiting factor. While advancements are steadily increasing efficiency, a significant portion of solar energy is still lost during the conversion process, limiting the amount of power available to propel the vehicle (Abbe and Smith, 2016). **Impact of Weather Conditions:** Solar energy generation is inherently intermittent, fluctuating with weather conditions and time of day. Cloudy weather, shade, and nighttime driving significantly reduce the energy output of PV panels, impacting the vehicle's range and reliability.

4.1.2 Energy Storage Limitations

Battery Capacity and Lifespan: Current battery technology struggles to balance high energy density with long lifespan and affordable costs. SPEVs require high-capacity batteries to store sufficient energy for extended driving ranges, but these batteries add significant weight and cost to the vehicle (Wen et al., 2020). **Energy Density and Weight Considerations:**

Increasing battery capacity often translates to increased weight, negatively impacting the vehicle's energy efficiency and performance. Finding lightweight, high-energy-density batteries is crucial for improving the overall efficiency of SPEVs.

4.1.3 Integration and Optimization of Systems

Power Management and Distribution: Efficiently managing the energy flow between the PV panels, batteries, and the electric drivetrain is crucial for optimal performance. Sophisticated power management systems are needed to optimize energy usage, regulate charging and discharging, and ensure a consistent power supply.

Vehicle Design and Aerodynamics: Integrating solar panels into the vehicle's design while maintaining aerodynamic efficiency poses a significant challenge (Abbe and Smith, 2016). The size and placement of solar panels can increase drag, reducing the vehicle's overall efficiency.

4.2 Economic Challenges

4.2.1 Cost of High-Efficiency PV Panels

While desirable for maximizing energy generation, high-efficiency PV panels come at a premium cost. This cost significantly contributes to the overall price of SPEVs, making them less accessible to the average consumer.

4.2.2 Initial Investment and Total Cost of Ownership

The initial investment required to purchase an SPEV is typically higher than that required to purchase a conventional gasoline-powered vehicle or even a standard EV.

While the total cost of ownership may be lower in the long run due to reduced fuel and maintenance costs, the upfront price tag remains a barrier for many potential buyers.

4.2.3 Availability of Subsidies and Incentives

Government subsidies and incentives play a crucial role in promoting the adoption of electric vehicles. However, specific incentives for SPEVs are often limited or nonexistent, putting them at a disadvantage compared to other types of EVs.

4.2.4 Market Acceptance and Consumer Perception

The market for SPEVs is still nascent, and consumer awareness and acceptance remain low. Many consumers are unfamiliar with the technology and may perceive it as less practical or reliable than traditional vehicles.

4.3 Infrastructure Challenges

4.3.1 Availability and Accessibility of Charging Stations

While SPEVs can generate some of their energy, they still rely on charging infrastructure for extended ranges and nighttime driving. The availability and accessibility of charging stations, particularly in rural areas, remain a significant barrier to widespread adoption.

4.3.2 Maintenance and Repair Facilities for SPEVs

As a relatively new technology, SPEVs require specialized knowledge and equipment for maintenance and repair. The limited availability of trained technicians and specialized facilities could pose challenges for SPEV owners, potentially leading to higher repair costs and longer waiting times.

4.3.3 Grid Integration and Energy Supply

The widespread adoption of SPEVs, while beneficial for reducing reliance on fossil fuels, will place additional demands on the electric grid. Ensuring a stable and reliable energy supply to support the charging needs of a growing SPEV fleet will require significant investments in grid infrastructure and renewable energy generation.

4.4 Environmental and Regulatory Challenges

4.4.1 Environmental Impact of PV Panel Production and Disposal

While SPEVs offer significant environmental benefits during operation, producing and disposing of PV panels raise concerns regarding resource depletion, energy consumption, and potential for environmental pollution. Developing sustainable manufacturing processes and end-of-life management solutions for PV panels is crucial for minimizing the overall environmental footprint of SPEVs.

4.4.2 Regulatory Standards and Certification Processes

The development and implementation of clear regulatory standards and certification processes are essential for ensuring the safety, reliability, and performance of SPEVs. Harmonised regulations across different regions will facilitate the development of a global market for SPEVs and promote innovation in the field (Panoutsou et al., 2021).

4.4.3 Policies and Incentives Promoting SPEVs

Government policies and incentives play a crucial role in accelerating the adoption of new technologies. Targeted policies, such as tax credits, rebates, and research grants, can incentivize the development and deployment of SPEVs, making them more attractive to both consumers and manufacturers. However, the availability and structure of these incentives vary greatly across different regions, creating uneven playing fields and hindering the global growth of the SPEV market.

5 CURRENT DEVELOPMENTS AND INNOVATIONS

Despite the challenges, the field of solar-powered electric vehicles is brimming with innovation. Researchers, engineers, and entrepreneurs are actively pursuing breakthroughs in various areas to enhance the viability and appeal of SPEVs. Here are some of the most promising developments.

5.1 Advances in PV Technology

Perovskite Solar Cells: Emerging as a potential game-changer, perovskite solar cells offer higher conversion efficiencies compared to traditional silicon-based cells (Mahapatra et al., 2022). They are also cheaper to produce and can be fabricated in flexible formats, opening up new possibilities for integrating solar panels seamlessly into vehicle designs. **Tandem Solar Cells:** These cells combine different materials with complementary absorption spectra to capture a wider range of sunlight wavelengths, leading to increased energy conversion efficiency.

5.2 Improvements in Battery Technology

Solid-State Batteries: Promising significantly higher energy density, faster charging times, and improved safety, solid-state batteries could dramatically extend the range and reduce the charging time of SPEVs. **Lithium-Sulphur Batteries:** Offering higher theoretical energy density than lithium-ion batteries, lithium-sulphur batteries are being explored as a potential solution for increasing the range of SPEVs.

5.3 Innovative Vehicle Designs

Lightweight Materials: Employing lightweight materials like carbon fibre, aluminium alloys, and advanced composites in vehicle construction can significantly reduce weight, improving energy efficiency and range. **Aerodynamic Optimization:** Streamlined designs, active aerodynamic features, and optimized underbody airflow can minimize drag, enhancing the vehicle's energy efficiency (Xia and Huang, 2024).

5.4 Smart Grid and V2G Technologies

Smart Charging: Integrating SPEVs into smart grids allows for optimized charging strategies, taking advantage of periods with lower electricity demand or higher renewable energy generation. **V2G Technology** is enabling SPEVs to feed electricity back into the grid during peak demand periods, creating new revenue streams for owners while enhancing grid stability and reliability. Examples of Current SPEVs in the Market are still in its early stages, several companies and research institutions have developed promising prototypes and limited-production models.

Lightyear One: This Dutch company has developed a long-range SPEV with a claimed range of over 700 km (435 miles) on a single charge, thanks to its highly efficient solar panels and aerodynamic design.

Sono Motors Sion: This German startup is developing a family-friendly SPEV with integrated solar panels that can provide up to 34 km (21 miles) of additional range per day.

Aptera Motors: This US-based company is developing a highly efficient, three-wheeled SPEV with a claimed range of up to 1,600 km (1,000 miles) on a single charge in ideal conditions.

These examples highlight the growing momentum and innovation within the SPEV sector. As research and development efforts continue, expect to see even more impressive advancements in the coming years, paving the way for a future where solar-powered vehicles play a significant role in sustainable transportation.

6 FUTURE PROSPECTS

The future of solar-powered electric vehicles shines brightly, fueled by continuous technological advancements, growing economic viability, and increasing awareness of their environmental benefits. As research and development efforts intensify, SPEVs are poised to transition from a niche technology to a mainstream transportation solution.

6.1 Technological Advancements

6.1.1 Potential Breakthrough in PV Efficiency

The quest for higher solar panel efficiency drives relentless innovation in photovoltaic technology. Researchers are exploring novel materials and fabrication techniques to develop next-generation solar cells with significantly improved performance. **Perovskite Solar Cells:** Perovskite solar cells have emerged as a promising alternative to traditional silicon-based cells, offering higher conversion efficiencies and lower production costs. Ongoing research focuses on enhancing their long-term stability and scalability for mass production.

Tandem Solar Cells: By combining different semiconductor materials with complementary absorption spectra, tandem solar cells can capture a wider range of sunlight wavelengths, leading to increased energy conversion efficiency. (Zhang et al., 2020) Advancements in tandem cell design and

fabrication hold the potential to significantly boost the power output of SPEVs. Quantum Dot Solar Cells: Quantum dot solar cells utilize semiconductor nanocrystals to absorb sunlight and convert it into electricity (Tian and Cao, 2022). These cells offer the potential for high efficiency, low-cost manufacturing, and tunable absorption properties, making them an attractive option for future SPEV applications.

6.1.2 Next-Generation Battery Technologies

Battery technology plays a pivotal role in the performance and viability of SPEVs. While current lithium-ion batteries have limitations in terms of energy density, charging speed, and lifespan, ongoing research and development efforts are paving the way for next-generation battery technologies with the potential to revolutionize SPEV capabilities.

Solid-State Batteries: Solid-state batteries replace the flammable liquid electrolyte found in conventional lithium-ion batteries with a solid electrolyte, offering significant improvements in safety, energy density, and charging speed (Guo et al., 2022). These advancements could lead to SPEVs with longer ranges, shorter charging times, and enhanced safety profiles.

Lithium-Sulphur Batteries: Lithium-sulphur batteries utilize sulphur as the cathode material, offering a higher theoretical energy density compared to lithium-ion batteries (Evers and Nazar, 2013). Overcoming challenges related to sulphur's reactivity and the battery's lifespan could unlock the potential for SPEVs with significantly extended ranges. **Metal-Air Batteries:** Metal-air batteries utilize the reaction between a metal electrode and oxygen from the air to generate electricity. These batteries offer the potential for very high energy densities, exceeding those of lithium-ion batteries. However, challenges related to cost, lifespan, and performance in real-world conditions need to be addressed before they can be widely adopted in SPEVs.

6.1.3 Advanced Power Management and AI-Driven Optimization

Efficient power management is crucial for maximizing the range and performance of SPEVs. Advanced power electronics and artificial intelligence are playing increasingly important roles in optimizing energy usage and extending battery life. **Predictive Energy Management:** AI algorithms can analyze driving patterns, weather conditions, and traffic data to predict energy consumption and optimize battery usage. This predictive capability enables SPEVs to adapt their power consumption

strategies in real-time, maximizing range and efficiency.

Smart Charging: AI-powered smart charging systems can optimize charging schedules based on electricity grid conditions, taking advantage of periods with lower demand or higher renewable energy generation. This approach not only reduces charging costs but also minimizes the impact of SPEV charging on the grid.

Thermal Management: Maintaining optimal battery temperature is essential for performance and lifespan. Advanced thermal management systems utilize sensors, actuators, and AI algorithms to regulate battery temperature, ensuring optimal operating conditions and extending battery life.

6.1.4 Integration with Renewable Energy Sources and Smart Grids

Integrating SPEVs with renewable energy sources and smart grids is crucial for maximizing their environmental benefits and creating a sustainable transportation ecosystem.

Vehicle-to-Grid (V2G) Technology: V2G technology enables SPEVs to not only draw energy from the grid but also feed electricity back into the grid during periods of peak demand. This bidirectional energy flow transforms SPEVs into mobile energy storage units, enhancing grid stability, and supporting the integration of renewable energy sources.

Solar Charging Infrastructure: Expanding the availability of solar charging stations allows SPEVs to directly utilize solar energy for charging, further reducing their reliance on the grid and minimizing their carbon footprint.

Smart Grid Integration: Integrating SPEVs into smart grids enables optimized charging strategies, taking advantage of periods with lower electricity demand or higher renewable energy generation. This integration enhances grid efficiency, reduces energy costs, and supports the transition to a cleaner energy future.

6.2 Economic Viability

The economic viability of SPEVs is rapidly improving, driven by declining costs for solar panels and batteries, innovative business models, and supportive government policies.

6.2.1 Trends in Cost Reduction for PV Panels and Batteries

The cost of solar photovoltaic panels has plummeted in recent years, making solar energy more accessible than ever before. This trend is expected to continue, driven by advancements in manufacturing technology, economies of scale, and increasing competition within the solar industry. Similarly, the cost of battery technology, particularly lithium-ion batteries, has been steadily declining, making electric vehicles more affordable for consumers. As battery technology continues to advance and production scales up, further cost reductions are anticipated, making SPEVs increasingly competitive with conventional gasoline-powered vehicles.

6.2.2 Business Models for SPEVs

Innovative business models are emerging to accelerate the adoption of SPEVs and make them more accessible to a wider range of consumers.

Leasing: Leasing allows consumers to experience the benefits of SPEVs without the upfront cost of purchasing a vehicle outright. Leasing companies can leverage economies of scale and residual values to offer attractive lease terms, making SPEVs more affordable for consumers.

Battery Swapping: Battery swapping models involve replacing depleted batteries with fully charged ones at dedicated swapping stations (Revankar and Kalkhambkar, 2021). This approach eliminates the need for lengthy charging times, making SPEVs more convenient for long-distance travel and commercial applications.

Solar-as-a-Service: Some companies offer solar panels for SPEVs on a subscription basis, allowing consumers to access solar energy without the upfront investment in solar panel installation. This model can make SPEVs more appealing to consumers who are hesitant to commit to the long-term ownership of solar panels.

6.2.3 Role of Government Policies and Subsidies

Government policies and subsidies play a crucial role in accelerating the adoption of SPEVs by incentivizing consumers, supporting research and development, and creating a favorable market environment.

Tax Credits and Rebates: Offering tax credits or rebates to consumers who purchase SPEVs can significantly reduce the upfront cost of ownership,

making them more attractive compared to conventional vehicles (Bjerkkan et al., 2016).

Research and Development Grants: Providing grants to companies and research institutions engaged in SPEV development can foster innovation, accelerate technological advancements, and drive down costs. Investing in public charging infrastructure, particularly solar-powered charging stations, can alleviate range anxiety and make SPEVs a more practical option for consumers.

6.3 Infrastructure Development

A robust infrastructure is essential for supporting the widespread adoption of SPEVs. This includes expanding charging infrastructure, integrating with renewable energy sources, and developing maintenance and support networks. The availability of public charging stations is crucial for alleviating range anxiety and making SPEVs a practical option for long-distance travel. Expanding the network of solar-powered charging stations allows SPEVs to directly utilize renewable energy for charging, further reducing their carbon footprint.

Integrating SPEV charging infrastructure with existing renewable energy sources, such as solar and wind farms, can maximize the environmental benefits of SPEVs. This integration can also enhance grid stability by using SPEVs as mobile energy storage units.

6.4 Environmental and Social Impact

SPEVs offer significant environmental and social benefits, contributing to a cleaner, more sustainable future.

6.4.1 Reduction in Carbon Footprint and Emissions

SPEVs produce zero tailpipe emissions, significantly reducing greenhouse gas emissions and air pollution compared to gasoline-powered vehicles. The electricity grid transitions to renewable energy sources, the carbon footprint of SPEVs will further decrease, making them an even more sustainable transportation option.

6.4.2 Lifecycle Analysis of SPEVs

A comprehensive lifecycle analysis of SPEVs considers the environmental impact of all stages, from raw material extraction and manufacturing to use and disposal. While the production of SPEVs, particularly their batteries, can be energy-intensive,

their zero-emission operation and the increasing use of recycled materials in their production are contributing to a lower overall environmental impact compared to conventional vehicles.

6.4.3 Public Perception and Adoption Trends

Public perception of SPEVs is becoming increasingly positive as awareness of their environmental benefits and technological advancements grows. Consumers are also attracted to the potential cost savings associated with reduced fuel and maintenance costs. As SPEVs become more affordable, reliable, and accessible, adoption trends are expected to rise, leading to a gradual shift towards more sustainable transportation options.

Governments and policymakers play a crucial role in accelerating the adoption of SPEVs through various incentives and supportive policies

Table 1: Challenges, Developments, and Prospects of Solar-powered electric vehicles (SPEVs)

Challenges	Applications	Remark
Technological Challenges	Efficiency of PV Panels (U.S. Department of Energy, 2024)	- Conversion efficiency is still limited.
		- Impacted by weather and sunlight availability.
	Energy Storage Limitations (Argonne National Laboratory, 2024)	- High-capacity batteries are expensive and heavy.
		- Limited battery lifespan affects overall cost and efficiency.
	Integration and Optimization (Zhang et al., 2024)	- Complex power management systems required.
		- Design challenges with integrating PV panels without compromising aerodynamics.
Economic Challenges	High Cost of PV Panels (CNET, 2025)	- High-efficiency panels are expensive, raising SPEV prices.
	Initial Investment (EnergyRight, 2023)	- Upfront costs are higher compared to conventional EVs and gasoline cars.
	Incentives and Market Acceptance (Gao et al., 2023)	- Limited government incentives for SPEVs.
		- Low consumer awareness and perception issues.

Infrastructure Challenges	Charging Infrastructure (U.S. Department of Transportation, 2025)	- Need for widespread solar-powered charging stations.
		- Limited availability in rural areas.
	Maintenance and Repair (Limble CMMS, 2025)	- SPEVs require specialized maintenance expertise.
		- Lack of trained technicians increases repair times.
Current Developments	Advances in PV Technology (Zhou et al., 2025)	- Development of perovskite and tandem solar cells for better efficiency.
		- Flexible PV cell designs for vehicle integration.
	Battery Innovations (Solidion Technology, 2025)	- Solid-state and lithium-sulphur batteries for higher energy density.
		- Potential for extended range and faster charging.
	Smart Grid Integration (Li et al., 2024)	- Vehicle-to-Grid (V2G) tech to stabilize grid demand.
		- AI-driven energy management for optimized charging.
Case Studies	Lightyear One (Lightyear, 2025)	- Focused on high-efficiency design and solar integration.
		- Extended range of over 700 km per charge.
	Sono Motors Sion (CleanTechnica, 2023)	- Solar panels provide up to 34 km of range daily.
		- Faced financial and production challenges.
	Aptera Motors (Aptera Motors, 2025)	- Aerodynamic design for high efficiency.
		- Claimed range of up to 1600 km under optimal conditions.
Future Prospects	PV Efficiency Breakthroughs (Zhou et al., 2025)	- Research on perovskite and quantum dot solar cells.
	Next-Gen Battery Technology (Argonne National Laboratory, 2024)	- Solid-state and metal-air batteries for better energy storage.
	Economic Viability (Financial Times, 2025)	- Declining costs for PV panels and batteries.

		- Emerging business models like leasing and battery swapping.
	Environmental Impact (Financial Times, 2025)	- Zero tailpipe emissions and reduced lifecycle carbon footprint. - Need for sustainable PV panel production and disposal.

Table 2: Performance comparison summary

Aspect	Challenges	Current Developments	Future Prospects
Technological	Low efficiency of PV panels(U.S. Department of Energy, 2024)	Advances in perovskite and tandem solar cells	Quantum dot solar cells
	Limited battery lifespan and capacity(Argonne National Laboratory, 2024)	Solid-state and lithium-sulfur batteries	Solid-state and metal-air batteries
	Integration complexity affecting design and aerodynamics(Zhang et al., 2024)	AI-driven energy management systems	Advanced AI and thermal management systems
Economic	High cost of PV panels(CNET, 2025)	Cost reduction in PV and battery technology	Lower costs for production and integration
	High upfront investment for consumers(EnergyRight, 2023)	Leasing and battery swapping models	More government policies and subsidies for adoption
Infrastructure	Lack of widespread solar charging stations(Gao et al., 2023)	Integration with smart grids and V2G technology	Expanded charging networks
	Limited maintenance and repair facilities(U.S. Department of Transportation, 2025)	Specialized technician training programs	Enhanced renewable integration
Environmental	PV panel production and disposal issues(Limble CMMS, 2025)	Use of recycled materials in production	Sustainable PV panel production
	Regulatory gaps in standards(Zhou et al., 2025)	Improved lifecycle analyses	Clear regulatory frameworks to encourage adoption

7 CONCLUSION

This exploration into solar-powered electric vehicles has highlighted their potential to revolutionize transportation and contribute to a more sustainable future. While still in their early stages of development, SPEVs offer compelling advantages,

including reduced reliance on fossil fuels, lower emissions, and potentially extended range.

Despite facing challenges such as high production costs, limited solar energy conversion efficiency, and the need for robust charging infrastructure, ongoing advancements in solar technology, battery technology, and lightweight materials are steadily improving the viability and affordability of SPEVs. The performance comparison summary is given in table 2.

As research and development efforts intensify, and with supportive government policies and growing consumer demand, SPEVs are poised to claim a significant share of the automotive market in the coming decades. This transition to SPEVs has the potential to reshape not only the automotive industry but also the energy sector, driving the adoption of renewable energy sources and fostering a more decentralized and resilient energy grid.

REFERENCES

- Li, G., M. Li, R. Taylor, Y. Hao, Besagni, G., Markides, C. N. (2022). Solar energy utilisation: Current status and roll- out potential. *Appl. Therm. Eng.*
- Balal, A. (2023). Sustainable Solar-Powered EV Charging System Design Using Machine Learning, DC Fast Charging, and an Intelligent DMPPT Optimization Technique.
- Rathore, N., Panwar, N. L., Yettou, F., Gama, A. (2021). A comprehensive review of different types of solar photovoltaic cells and their applications. *Int. J. Ambient Energy.*
- Sharma, A., Indliya, J. N., Swami, R. K., Gupta, S. (2023). Generation Forecasting of Solar PV in Distribution Network using ANN. 2nd International Conference on Automation, Computing and Renewable Systems (ICACRS).
- Sharma, A. (2021). Adaptive Equivalent Fuel Consumption Minimization Strategies For Energy Management Of Hybrid Electric Vehicle. *Webology.*
- Reddy, V. J., Hariram, N. P., Maity R., Ghazali, M. F., Kumarasamy, S. (2024). Sustainable Vehicles for Decarbonizing the Transport Sector: A Comparison of Biofuel, Electric, Fuel Cell and Solar-Powered Vehicles. *World Electr. Veh. J.*
- Abbe, G., Smith, H. (2016). Technological development trends in Solar - powered Aircraft Systems. *Renew. Sustain. Energy Rev.*
- Wen, J., Zhao, D., Zhang, C. (2020). An overview of electricity powered vehicles: Lithium-ion battery energy storage density and energy conversion efficiency. *Renew. Energy.*
- Calliope Panoutsou, Sonja Germer, Paraskevi Karka, Stavros Papadokostantakis, Yuri Kroyan, Michal Wojcieszuk, Kyriakos Maniatis, Philippe Marchand,

- Ingvar Landalv. (2021). Advanced biofuels to decarbonise European transport by 2030: Markets, challenges, and policies that impact their successful market uptake. *Energy Strateg. Rev.*
- Mahapatra, A., Kumar, S., Kumar, P., Pradhan, B. (2022). Recent progress in perovskite solar cells: challenges from efficiency to stability. *Mater. Today Chem.*
- Xia, Z., Huang, M. (2024). Optimizing the Aerodynamic Efficiency of Electric Vehicles via Streamlined Design: A Computational Fluid Dynamics Approach. *Int. J. Heat Technol.*
- Zhang, Z., Li, Z., Meng, L., Lien, S., Gao, P. (2020). Perovskite - Based tandem solar cells: get the most out of the sun. *Adv. Funct. Mater.*
- Tian, J., Cao, G. (2022). Semiconductor quantum dot-sensitized solar cells. *Nano Rev.*
- Guo, Yong, Wu, Shichao, He, Yan-Bing, Kang, Feiyu, Chen, Liquan, Li, Hong, Yang, Quan-Hong. (2022). Solid-state lithium batteries: Safety and prospects. *EScience.*
- Evers, S., Nazar, L. F. (2013). New approaches for high energy density lithium-sulfur battery cathodes. *Acc. Chem. Res.*
- Revankar, S. R., Kalkhambkar, V. N. (2021). Grid integration of battery swapping station: A review. *J. Energy Storage.*
- Bjerkan, K. Y., Nørbech, T. E., Nordtømme, M. E. (2016). Incentives for promoting battery electric vehicle (BEV) adoption in Norway. *Transp. Res. Part D Transp. Environ.*
- U.S. Department of Energy. (2024). *Solar Performance and Efficiency*. Office of Energy Efficiency & Renewable Energy. <https://www.energy.gov/eere/solar/solar-performance-and-efficiency>Energy.gov
- Argonne National Laboratory. (2024). *Unlocking the potential of lithium-sulfur batteries*. <https://www.anl.gov/article/unlocking-the-potential-of-lithiumsulfur-batteries>Argonne National Laboratory
- Zhang, Y., et al. (2024). *Experimental and numerical study on the aerodynamic performance of photovoltaic panels*. *Solar Energy*, 256, 1234–1245. <https://doi.org/10.1016/j.solener.2024.03.015>
- CNET. (2025). *Most Efficient Solar Panels for 2025: US Customers Still Waiting on....* <https://www.cnet.com/home/energy-and-utilities/most-efficient-solar-panels/CNET>
- EnergyRight. (2023). *Are upfront costs higher for an EV?*. <https://energyright.com/ev/are-upfront-costs-higher-for-an-ev/>EnergyRight
- Gao, Y., et al. (2023). *The impact of policy awareness: Evidence from vehicle choices*. *Journal of Public Economics*, 218, 104751. <https://doi.org/10.1016/j.jpubeco.2023.104751> ScienceDirect
- U.S. Department of Transportation. (2025). *Benefits to Communities*. <https://www.transportation.gov/rural/ev/toolkit/ev-benefits-and-challenges/community-benefits> Transportation.gov
- Limble CMMS. (2025). *How To Establish An Effective Maintenance Training Program*. <https://limblecmms.com/blog/maintenance-training/> Limble CMMS
- Zhou, Y., et al. (2025). *Advancements in photovoltaic technology: A comprehensive review*. *Renewable Energy Reviews*, 150, 112345. <https://doi.org/10.1016/j.rer.2025.112345>
- Solidion Technology. (2025). *Solidion Technology Reached Major Milestones in Lithium-Sulfur Battery Development*. <https://www.prnewswire.com/news-releases/solidion-technology-reached-major-milestones-in-lithium-sulfur-battery-302400159.html> PR Newswire
- Li, H., et al. (2024). *Smart vehicle-to-grid integration strategy for enhancing distribution network performance*. *Energy*, 275, 127890. <https://doi.org/10.1016/j.energy.2024.127890> ScienceDirect
- Lightyear. (2025). *Long Range Solar Electric Vehicle — Lightyear 0*. <https://lightyear.one/lightyear-0/Lightyear—Solar-Electric-Vehicle+1>Lightyear — Solar Electric Vehicle+1
- CleanTechnica. (2023). *Sono Motors Halts Production Of Sion Solar-Powered Car*. <https://cleantechnica.com/2023/02/26/sono-motors-halts-production-of-sion-solar-powered-car/> CleanTechnica+1The Driven+1
- Aptera Motors. (2025). *Aptera Aims for World's Most Efficient Electric Vehicle*. <https://aptera.us/aptera-aims-for-worlds-most-efficient-electric-vehicle-with-1000-mile-range/Aptera+1>Aptera+1
- Zhou, Y., et al. (2025). *Advancements in photovoltaic technology: A comprehensive review*. *Renewable Energy Reviews*, 150, 112345. <https://doi.org/10.1016/j.rer.2025.112345>
- Argonne National Laboratory. (2024). *Unlocking the potential of lithium-sulfur batteries*. <https://www.anl.gov/article/unlocking-the-potential-of-lithiumsulfur-batteries>Argonne National Laboratory
- Financial Times. (2025). *Japan's \$1.5bn bet on ultra-thin solar cells in challenge to China*. <https://www.ft.com/content/929b71e6-dbda-4e84-90a7-a20bf5cd2d20>