

Impact of Solar-Powered Electric Vehicle Charging Stations: Environmental, Economic and Social Perspectives

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Abstract

The rapid electrification of road transport is a central pillar of global climate action, but the true environmental benefits of electric vehicles (EVs) depend critically on how the electricity used for charging is produced. Solar-powered EV charging stations (solar EVCS) are an attractive, practical solution that pairs distributed renewable generation with charging infrastructure, reducing lifecycle emissions, improving energy resilience, and creating economic and social value. This paper synthesizes evidence from an in-house impact report on solar EVCS prepared by Dr. Sachin Y. Shigwan and Green India Initiative, alongside peer-reviewed studies, government handbooks and industry analyses. It documents the greenhouse gas and air-pollutant reductions achievable with solar EV charging, evaluates techno-economic viability and business models, explores employment and social impacts, examines technological integration needs (including storage and smart charging), and identifies policy and implementation recommendations for scaling solar EVCS in India and comparable markets. The evidence indicates that solar EVCS can materially advance climate, public-health and development goals, but meaningful scale will require coordinated policy support, tailored financing, and continued technical innovation. [NITI AAYOG](#)

Key Words: Electric Vehicles (EVs), Solar-Powered EV Charging Stations (solar EVCS)

Introduction and background

Over the last decade, the global transport sector has witnessed an accelerating shift toward electrification driven by concerns over urban air quality, climate risk and the promise of lower operating costs for vehicle users. India has committed to an ambitious EV agenda supporting the international EV30@30 targets and laying out domestic policy packages such as FAME and related incentives to spur supply and demand. However, this transition exposes a paradox: EVs eliminate tailpipe emissions, but if charged on grids heavily dependent on coal or other fossil fuels, their indirect emissions can remain large. This reality motivates the integration of on-site and distributed renewable generation especially solar photovoltaic (PV) with charging infrastructure so that EV use is powered by low-carbon electricity from the point of charge. The Impact Report prepared by Dr. Sachin Shigwan with Green India Initiative articulates this approach in the Indian context and provides a practical blueprint covering station design,

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components, sustainability calculations and cascading impacts on society and governance. The report stresses that solar EVCS whether rooftop PV with net-metering, on-site canopy arrays, or solar-plus-storage microgrids represent a pathway to capture the full environmental benefit of vehicle electrification while generating local co-benefits such as jobs, reduced grid stress and energy cost savings.

Government guidance and implementation frameworks in India further reinforce the need for a contextual, site-specific planning approach for charging infrastructure one that considers grid availability, land/rooftop constraints, customer use patterns and interoperability with utility operations. The NITI Aayog Handbook on EV Charging Infrastructure Implementation sets out these implementation principles and governance models and highlights the multiple models (government-led, consumer-driven and charge point operator driven) that can be used to scale charging networks responsibly. It also emphasizes the role of smart charging and distribution utility coordination to manage grid impacts as EV adoption grows. These policy signals are important because they lower procedural friction for new entrants and clarify roles and responsibilities for grid connection, metering and safety standards. [NITI AAYOG](#)

Rationale: why pair solar with EV charging?

Three arguments make solar-EV integration compelling. First, environmental integrity: the greenhouse gas reduction potential of EVs is maximized when charging uses renewable energy rather than fossil-dominated electricity. Multiple modeling studies and field implementations show that solar-charged EVs can reduce operational CO₂ and criteria pollutant emissions substantially compared to grid-charged vehicles in fossil-heavy grids. Second, cost and resilience: the levelized cost of solar-generated electricity has fallen dramatically worldwide and in India TERI projects solar costs to decline toward the Rs 1.9–2.3/kWh range by 2030 making solar power economically competitive with, and often cheaper than, retail electricity in many commercial contexts. Moreover, onsite solar (with or without storage) reduces dependence on distribution utilities and protects station operators and customers from tariff volatility and outages. Third, socio-economic co-benefits: solar EVCS create local skilled jobs (in installation, maintenance and operations), enable distributed energy development in underserved areas, and support national energy-security objectives by reducing fuel import dependencies. When aggregated, these three benefits make solar-EV charging a high-value investment for both private operators and public planners. [TERI](#)

Environmental and public-health impacts

Solar EVCS deliver direct environmental advantages through avoided emissions. Empirical and modeling studies demonstrate meaningful reductions in CO₂, SO₂, NO_x and particulate emissions when EV charging is powered by PV rather than grid electricity derived from coal or gas. For example, lifecycle and operational modeling in several contexts find that solar-PV charging can cut CO₂ emissions per vehicle-kilometre by large margins often 50–80% relative to grid charging in carbon-intensive grids and can almost entirely eliminate local tailpipe-adjacent pollutant contributions when deployed at scale. The Green India Initiative report summarizes the mechanism clearly: PV panels capture solar insolation, convert it to electricity consumed by EV chargers (with surplus exported under net-metering), thereby displacing grid

electricity and avoiding upstream emissions from fossil generation. This effect is particularly impactful in Indian megacities where transport-related emissions are an important source of urban air pollution and public health burden.

Quantifying the public-health benefit is important for policy prioritization. Urban air pollution is a leading cause of premature mortality and morbidity in India; reducing combustion emissions by shifting to clean fuel in transport and powering that shift with renewables reduces disease burden from respiratory and cardiovascular conditions. In addition to cleaner air, solar-charged EVs reduce noise pollution and micro-environmental pollutants in dense urban corridors. Together these impacts can lower aggregate health-care costs and raise productivity benefits that are rarely captured in simple private investment calculations but which are material at the municipal and national level.

Techno-economic analysis and business models

At the heart of decisions about scaling solar EVCS are the techno-economic metrics: capital expenditure, operating costs, levelized cost of electricity (LCOE), utilization rates, revenue streams (charging fees plus potential export under net-metering), and payback periods. Rigorous studies and real world pilots indicate that solar EVCS can be financially viable under a range of scenarios once capital costs, electricity prices, and utilization are considered.

The Green India Initiative report provides practical design examples and a sample calculation for a facility sized to deliver ~70 kWh/day (a design tied to a 14 kW array producing ~70 kWh in five sun-hours). The sample demonstrates that a modest canopy or rooftop deployment (roughly 75 m²) can meet a practical daily charging load for a light EV and, when combined with net metering, produce value that accrues to the operator over the long term. More broadly, country-scale studies and independent modeling (including an MDPI Processes analysis of standalone PV-supplied EV charging) confirm that standalone and grid-connected PV charging station designs can be engineered to meet varying local load profiles with robust performance and acceptable payback periods. [MDPI](#)

Cost trajectories favor solar in many regions. In India, TERI's analysis and subsequent industry reporting find projected declines in solar LCOE toward Rs 1.9–2.3/kWh by 2030 and significant declines in storage cost as well; together these trends improve the financial case for solar EVCS substantially. Lower LCOE translates to lower per-kWh charging costs for end users and shrinks the total cost of ownership for EVs, which is particularly important for fleet and commercial operators who frequently evaluate operating economics more than purchase price. Net-metering, time-of-use tariffs, and demand-charge avoidance are additional levers that can be combined to optimize profitability for operators. [TERI](#)

Business models that have emerged include owner-operator models (retailers, malls, fleet owners), Charge Point Operator (CPO) models (third-party operators who sell charging as a service), utility-led models (utilities offering solar-enabled charging locations), and hybrid public-private partnerships. Each model has different capital and operating risk profiles and different policy touchpoints for instance, utilities play a central role in grid interconnection and net-metering approvals. Market fragmentation early on suggests that a mix of models will coexist as the market matures and standardization evolves. [JMK Research & Analytics](#)

Design considerations: components, storage and smart control

A technical blueprint for reliable solar EVCS includes PV arrays sized to expected load, appropriately rated inverters and EV chargers, balance-of-system components, and whenever possible, battery energy storage systems (BESS) or smart control schemes to smooth intermittency and optimize charging alignment with solar generation. The Impact Report details practical configurations (on-grid with net-metering vs off-grid with storage) and explains component roles: PV modules, inverter/charger integration, DC fast chargers for rapid service, AC chargers for slower opportunity charging, and grid connectivity for backup and export. The operational design chosen should reflect location, expected utilization (home charging, fleet depot, highway fast charging), and land/rooftop constraints.

Storage improves reliability: a well-sized BESS enables charging during non-sunlight hours and provides backup during outages, which is especially useful for fleet depots and critical transit corridors. However, storage adds significant capital cost and lifecycle considerations; therefore, in many early deployments, operators prefer grid-connected on-site PV with net-metering and time-of-use management rather than expensive BESS. As battery costs decline (TERI and others forecast substantial storage cost reductions by 2030), combined PV+BESS will become more prevalent. Meanwhile, smart charging and demand-response systems which can modulate charge rates, queue vehicles and shift loads to periods of high solar availability can approximate some benefits of storage at lower incremental cost. Field experiments and control algorithms developed in recent MDPI and applied research show that supervisory control systems can reduce grid impacts while maximizing PV utilization. [MDPI MDPI](#)

Market growth, deployment trends and case examples

Global and Indian market signals point to rapid growth in charging infrastructure, with solar EVCS emerging as a visible sub-segment. The JMK Research market analyses (and multiple industry trackers) note multi-fold growth projections for public charging points in India driven by rising EV registrations, policy incentives and private capital inflows. The Impact Report cites projections that India will require millions of public charging points by 2030 to accommodate forecasted EV fleets; this demand, if paired with policy nudges for renewables, could create a large pipeline for solar EVCS deployment. [JMK Research & Analytics](#)

Practical examples reinforce feasibility. Several Indian initiatives have piloted solar charging for buses, commercial fleets and highway chargers. Internationally, diverse models from solar carport arrays at shopping centers to solar-powered fast chargers along highways illustrate how PV solutions can be adapted to different urban and rural contexts. Electrify America and private innovators in the U.S. and Europe have showcased solar integration at scale, while entrepreneurial firms in India (including solar pioneers and new-age CPOs) are piloting modular, low-footprint installations that reduce permitting friction and speed roll-out. These pilots are critical because they surface operational insights on utilization, durability under local climate conditions, and user acceptance. [JMK Research & Analytics](#)

Employment, skill development and local economic impacts

Solar EVCS generate employment at multiple stages: manufacturing and supply chain for PV modules and chargers, installation and commissioning, operations and maintenance, and associated services (billing, payment platforms, data analytics). The Impact Report contains a simple workforce projection showing that scaling to millions of public charging stations would support millions of technicians across both EV charging and solar installation value chains; while these are high-level estimates, they signal that the renewables-plus-EV transition is also a jobs story. Training and certification programs (for electricians, solar installers, and EV servicing technicians) will be essential to capture these employment opportunities in a quality, safe manner. Investing in vocational training linked to charging deployment programs can ensure that job creation is inclusive, local and durable.

Beyond jobs, distributed solar EVCS can stimulate small business models: small retail shops, petrol stations and mall operators can adopt compact solar carports that attract EV customers and create a new revenue stream. This means that adoption is not limited to large utilities or corporations; decentralized entrepreneurs can participate, spreading economic benefits. For rural and semi-urban areas where grid extension is costly, solar EVCS can improve local energy services while enabling access to low-cost mobility for residents and last-mile logistics.

Social equity and accessibility considerations

Equity must be an explicit priority. Early EV adoption tends to be higher among higher-income urban households, and without deliberate policy design, solar EVCS could reinforce inequitable access. To counter that risk, targeted public investment, concessional financing, and community-owned models can ensure that solar EVCS serve mass transit, shared mobility fleets and rural corridors segments where the social returns are high. Subsidy design (for example, linking solar EVCS incentives to deployments in underserved areas or for bus depots) can direct public funds toward inclusive outcomes. Additionally, workforce training programs targeted at marginalized groups can help ensure that the economic benefits of deployment are widely shared.

Governance, regulatory and institutional enablers

Scaling solar EVCS will require clear and consistent governance arrangements. The NITI Aayog handbook provides an implementation playbook for India that covers roles for municipal bodies, distribution companies (DISCOMs), private CPOs and standards bodies. Regulatory clarity on grid interconnection, net-metering and time-block settlement is crucial delays and fragmentation in these areas create real cost and revenue uncertainty for operators. Furthermore, streamlined permitting (for rooftop/carport PV, civil works and electrical approvals) and standardized technical interfaces for metering, payment and data exchange will lower transaction costs and open the sector to more entrants. Public incentives (capital grants, low-interest financing, viability gap funding) targeted to early deployments especially in high-public-value contexts such as bus depots or highway corridors can accelerate private investment where commercial viability is marginal. [NITI AAYOG](https://niti.gov.in/publications/niti-aayog-handbook-for-india)

Implementation challenges and mitigation strategies

Several barriers warrant careful attention. High upfront capital remains a primary constraint; mitigants include leasing or third-party ownership models (where a solar company installs and owns PV while the landowner or CPO buys power), aggregated financing pools, and blended public-private finance mechanisms. Technical challenges intermittency, shading, site constraints and integration of DC fast chargers with PV inverters require careful site design and, where appropriate, BESS for buffering. Regulatory misalignment across municipal, state and federal agencies can be addressed through inter-agency task forces and fast-track approvals for pilot projects. Finally, utilization uncertainty (especially for public high-power chargers) is a commercial risk; demand aggregation through fleet contracts and integrating roaming and interoperable payment platforms can increase utilization predictability for investors. The literature and pilots recommend a portfolio approach: combine high-utilization commercial sites (fleet depots, malls) that provide steady cash flow with experimental low-utilization public sites that deliver high public value (highways, rural charging). [MDPI](#)

Measuring impact: metrics and monitoring

Robust monitoring is essential for learning and scale. Key performance indicators should include: kWh generated by PV, kWh consumed by EV charging, greenhouse gas emissions avoided (tCO₂e), criteria pollutant reductions (NO_x, SO₂, PM_{2.5}), availability and uptime of chargers, average utilization (sessions/day), revenue per kWh, LCOE of solar input, and jobs created (installation, O&M). Where possible, independent third-party verification of generation and export data (via meters and smart data logs) will ensure transparent accounting for carbon claims and subsidy disbursement. The Impact Report recommends baseline studies and periodic audits to capture cascading impacts and to inform policy and financing decisions.

Research gaps and future R&D directions

While the basic case for solar EVCS is strong, additional research will accelerate optimization and cost reduction. Priority areas include: integrated inverter/charger hardware that lowers soft costs and installation time; advanced control algorithms that optimize PV utilization with vehicle arrival patterns; techno-economic optimization for mixed portfolios of fast chargers and slow chargers; lifecycle analysis of PV+BESS+chargers with local climate factors; and behavioral studies that examine how pricing and information nudges affect charging timing and renewable utilization. Field pilots that incorporate monitoring and conditional scaling will be invaluable to close these evidence gaps. [MDPI](#)

Policy recommendations and an operational roadmap

To accelerate deployment while maintaining environmental and social integrity, policymakers and planners should consider the following recommendations:

1. **Financial incentives and blended capital:** Provide capital subsidies for early deployments (especially for high-public-value sites such as bus depots and highways) and create concessional loan facilities for small and medium operators. Explore revenue-sharing or lease models to reduce upfront costs for host sites.

2. **Streamline permitting and interconnection:** Standardize technical requirements for PV+EVCS and fast-track grid interconnection approvals with clear timelines and single-window clearances.
3. **Net-metering and tariff design:** Ensure net-metering or compensation mechanisms capture value for exported solar energy and design time-of-use tariffs that reward charging during high solar availability. Where DISCOM models allow, enable virtual net-metering for fleets or multi-site operators.
4. **Targeted deployment for equity and public value:** Prioritize deployments in public transport depots, shared mobility hubs and rural corridors through targeted tendering and viability gap funding to ensure inclusive access.
5. **Standards and interoperability:** Adopt common standards for charging connectors, payment systems and data exchange to enable roaming and to lower consumer friction.
6. **Skilling and local supply chains:** Invest in vocational training for solar installers and EV technicians, and incentivize localization of component manufacturing to strengthen domestic supply chains.
7. **Data, monitoring and verification:** Mandate transparent generation and export metering for projects receiving public support and require periodic performance reporting to inform policy refinement.

These measures when combined with predictable policy signals and private sector innovation will reduce risk, attract capital and accelerate the emergence of robust solar EVCS networks.

[NITI AAYOG](#)

Conclusion

Solar-powered EV charging stations offer a practical and high-impact pathway to ensure the electrification of transport contributes meaningfully to emissions reductions, public health improvements and local economic development. The combined evidence from the Green India Initiative Impact Report and external peer-reviewed and policy sources indicates that solar EVCS are technically feasible, economically attractive under many scenarios, and socially beneficial when deployed with equity in mind. Achieving the scale at which these benefits become transformative requires coherent policy, innovative financing, technical integration (notably smart charging and storage), and a deliberate focus on workforce development. The urgency of climate action and the need to improve urban air quality make this an opportune moment for governments, utilities and the private sector to align incentives and accelerate the deployment of solar EVCS across urban and rural India. The road ahead is not frictionless, but the rewards cleaner air, lower carbon emissions, resilient local energy systems and jobs make the journey indispensable. [TERI](#)

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