Coupling solar with eMobility: The next frontier in clean transport

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Introduction: The need for integrated solutions

The global transition to cleaner energy and mobility systems is accelerating, but progress remains uneven. Climate goals are becoming more challenging, urban air quality remains a key concern and energy security is once again a threat in many regions. In this fast-changing landscape, the integration of solar energy and electric mobility represents one of the most effective ways to cut emissions at scale – replacing fossil fuels altogether rather than simply relocating them from tailpipes to power stations.

Electric vehicles (EVs) are transforming how we travel, with adoption rising rapidly. Global electric car sales surpassed 17m units in 2024 – a year-on-year increase of more than 25% – and are projected to exceed 20m in 2025, representing over one-quarter of all new cars sold worldwide.[1]

This growth will inevitably increase electricity demand, especially from charging infrastructure that must scale alongside EV adoption. If that electricity is supplied from fossil sources, we risk undermining the environmental benefits of EVs. Solar energy therefore becomes essential: it enables the direct decarbonisation of both power and transport, ensuring that EVs are powered by genuinely clean energy.

Both solar power and EVs are advancing quickly, especially in regions with abundant sunlight and ambitious clean energy strategies. Yet without deliberate integration, new inefficiencies could emerge. For instance, EVs often charge in the evening when solar output is low, increasing reliance on conventional energy sources, and stressing the grid. At the same time, daytime solar generation is frequently underutilised, even as overall electricity and mobility demand rises.

Aligning solar generation with EV charging through smart infrastructure, energy storage and demand-side management can reduce grid emissions, optimise energy use and create more resilient, cost-effective mobility systems.

Integrated systems also enable innovation such as vehicle-to-grid (V2G) technology, decentralised energy networks and smart city applications. But this transition requires purposeful action across sectors, progressive policy frameworks and significant investment in both digital and physical infrastructure.

The next leap in sustainability is not about scaling individual technologies but about weaving them together. Solar-powered e-mobility ecosystems must now move from concept to reality, building smarter, cleaner and more connected systems that serve both people and the planet.

95%

of vehicles remain parked throughout the day - a missed opportunity if charging isn't aligned with solar availability.

2

The synergy between solar energy and electric mobility

02

The synergy between solar energy and electric mobility

2.1. Solar energy: A maturing backbone

Solar energy has rapidly evolved from a supplementary power source to a cornerstone of energy strategies across the region. With some of the world's highest solar irradiance levels, GCC countries are leveraging this natural advantage to diversify their electricity mix, reduce emissions, and expand their economies.

Saudi Arabia:

Saudi Arabia aims to generate 50% of its electricity from renewables by 2030, with solar playing a central role. Under the National Renewable Energy Program, 58.7GW of solar capacity is planned. Major projects include the 300MW Sakaka plant and the 2,060MW Al Shuaibah project – one of the world's largest single-site solar developments. In 2024, three new solar agreements totalling 5.5GW were signed, further advancing the Kingdom's clean energy transition.[2]

United Arab Emirates:

The United Arab Emirates is guided by the UAE Energy Strategy 2050, which targets 30% clean energy in the mix by 2030.[3] The 2GW Al Dhafra Solar PV plant, launched in 2023, sets global records for both scale and cost. The Mohammed bin Rashid Al Maktoum Solar Park continues to grow toward a 5GW capacity, while a US$6bn project is underway to add 5GW of solar with 19GWh of battery storage – the largest integrated solar-storage system.[4]

Qatar:

Qatar is also accelerating its solar ambitions under the National Renewable Energy Strategy, targeting a 30% solar share in electricity generation by 2030. The 800 Al Kharsaah Solar PV Plant, operational since 2022, already supplies up to 10% of national peak demand.[5] Total renewable capacity is expected to reach 4GW this decade.

Together, these initiatives highlight the region's commitment to integrating solar energy into national grids, enhancing energy security and contributing to global sustainability efforts. The transformation is already underway – reshaping economies, driving innovation and laying the foundation for a cleaner, more resilient future.

Saudi Arabia:

58.7 GW renewables by 2030

United Arab Emirates:

World's largest integrated solar + storage system (5 GW + 19 GWh)

Qatar:

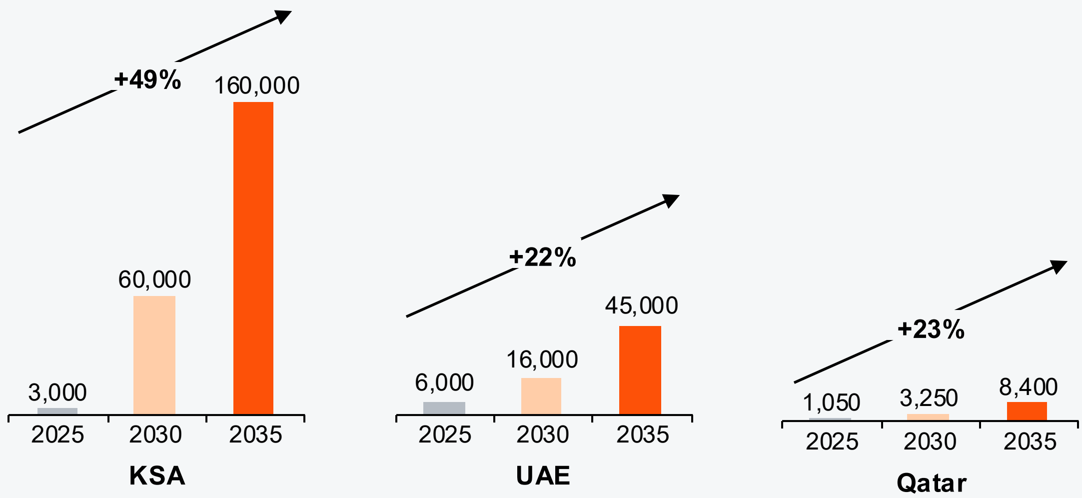
30% solar by 2030

2.2. eMobility: More than just vehicles

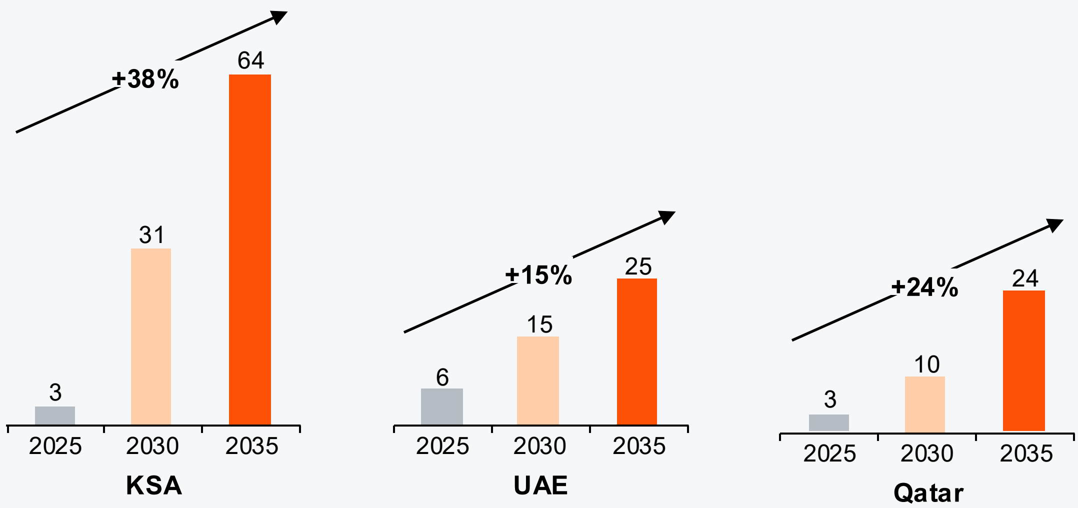
eMobility is now a pillar of national transport strategies across the GCC. The UAE, for example, has seen one of the fastest adoption rates globally, with EV sales rising by more than 260% in 2024 – far outpacing the global average growth of about 14% – as both public and private investment in charging networks accelerates.[6] While EVs are often recognised for their environmental benefits, their growing adoption across the region is equally driven by broader aims: economic diversification, industrial innovation, energy security, and establishing leadership in sustainable technology.

Saudi Arabia is investing around US$39bn through 2030 to establish a domestic EV manufacturing ecosystem, including a new hub in King Abdullah Economic City that will produce 150,000 vehicles by 2026 and 500,000 by 2030.[7] The Kingdom aims to make 30% of all vehicles in Riyadh electric by 2030 as part of its plan to cut citywide emissions by half.[8]

Public charging point demand (units)



Percentage share of electric vehicles of total annual sales in Saudi Arabia,[9] UAE[10] and Qatar[11] (%)

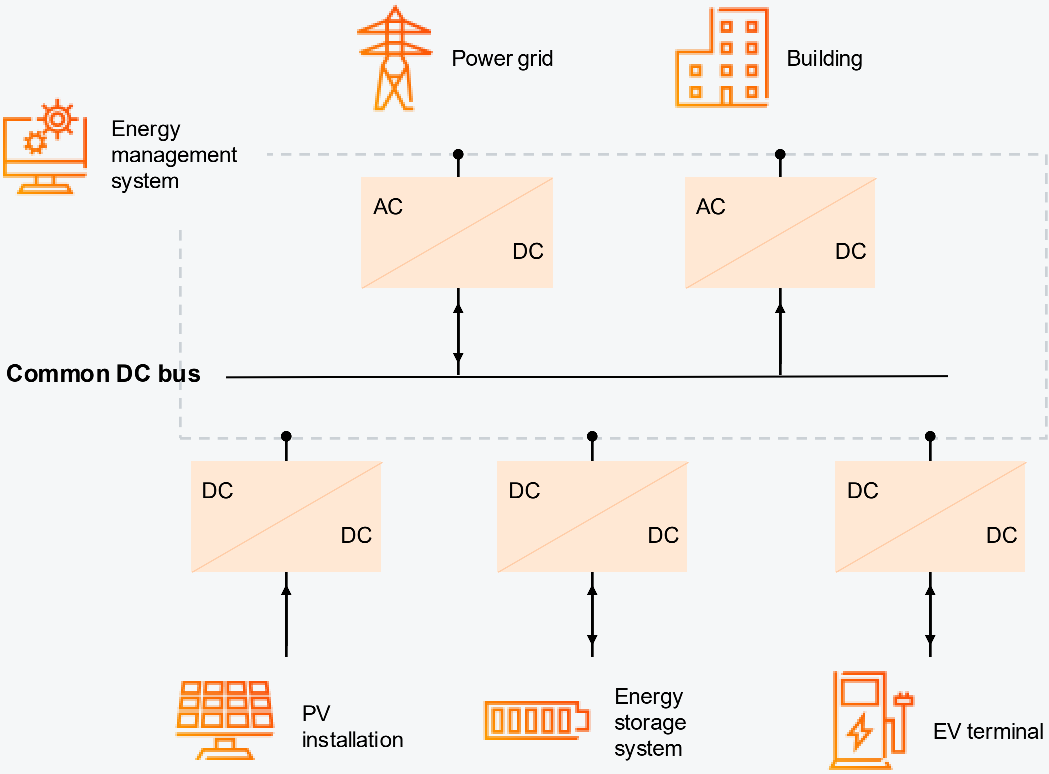


2.3. Coupling solar with eMobility: A win-win situation for all the ecosystem

As eMobility and solar energy expand, their integration presents a unique opportunity to create a cleaner, smarter and more resilient energy ecosystem. Charging EVs with solar power, especially during peak sunlight hours, reduces reliance on fossil fuels, cuts greenhouse gas emissions and eases pressure on electricity grids during high-demand periods. In regions with abundant solar resources and growing EV penetration, this coupling is both environmentally sound and commercially viable.

However, as the EV market matures and battery capacities increase, the impact on power systems becomes more complex. Average battery capacity across the global electric car fleet reached around 80kWh in 2024, largely due to the increasing share of larger vehicles such as SUVs.[12] This growing energy demand underscores the importance of charging alignment with renewable generation. Without coordinated planning, the rising electricity needs of millions of vehicles could significantly shift daily load patterns and increase peak demand, undermining the very sustainability benefits that eMobility and solar integration promise.

Figure 1.1-1 PV powered charging stations



2.3.1. Coupling can occur on several scales: From local to virtual level

Integrating renewable energy with charging infrastructure is emerging as a powerful enabler of the energy transition. As EV adoption and solar deployment scale up, different models of coupling, ranging from local to virtual, offer flexible pathways to decarbonise both mobility and electricity systems.

On-site renewable charging

- At the most local level, on-site coupling allows EV chargers to be directly powered by co-located renewable sources, typically solar PV. These systems, installed at workplaces, homes, or commercial facilities, can be paired with battery storage to shift charging to evening hours, increase self-consumption and reduce grid reliance. This setup is ideal for areas with high solar exposure and predictable parking patterns.

Community-level integration

- At the community or district level, shared renewable installations and EV charging points operate across a local grid. Often referred to as energy communities or collective self-consumption schemes, this model enables coordinated energy use within defined zones, supporting local grid stability and making better use of distributed resources. Its effectiveness depends on regulatory frameworks that define proximity and data-sharing rules.

Virtual coupling

- Virtual coupling allows EV charging to be matched with renewable generation through contractual agreements like power purchase agreements (PPAs). Electricity flows through the broader transmission network, but it is certified green through tracking systems. This model is especially suited to fleet operators and public charging networks seeking to decarbonise at scale without owning physical renewable assets.

2.3.2. Three key use cases for solar-EV integration

One of the most overlooked facts in the eMobility landscape is that vehicles are parked approximately 95% of the day.[13] This presents a massive untapped opportunity as nearly all charging events could, in theory, occur while the sun is out. Smart planning can locate chargers at workplaces, shopping centres and residential areas to match charging demand with solar generation. This not only maximises solar use but also reduces expensive grid upgrades or fossil-fuelled backup during evening peak loads.

1. Home charging with rooftop solar panels

Homes with rooftop solar panels and private EV chargers are ideal for direct integration, especially in regions like Saudi Arabia and the UAE, where most houses can host solar installations. Home Energy Management Systems (HEMS) or cloud-connected controls optimise household electricity consumption and prioritise self-generated solar energy.

2. Workplace charging powered by on-site solar panels

Public institutions and businesses increasingly pair solar carports with EV chargers to cut emissions and lower grid demand. Employees typically leave vehicles parked through the day, allowing for standard or slow charging powered by on-site generation. Visitors may require faster charging options depending on their stay duration, supplemented by power from the grid as required. In corporate settings, energy management systems help balance power flows between buildings and vehicles – enabling companies to cut emissions, optimise operations and future-ready their infrastructure.

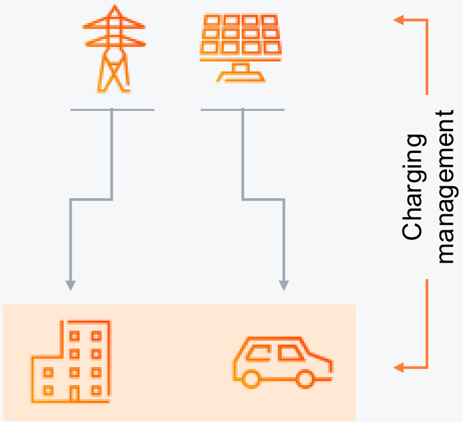
3. Public charging hubs with local renewable supply

Fast-charging stations along highways are increasingly being paired with on-site solar installations, transforming rest areas into hybrid energy hubs. Midday charging aligns naturally with solar peaks, reducing grid stress and enabling partial use of clean energy for long-distance travel. Although high-power charging demand exceeds what solar alone can provide, combining PV with storage or hybrid supply models can significantly lower emissions and improve grid efficiency.

2.3.3. Architectures for solar-powered EV charging

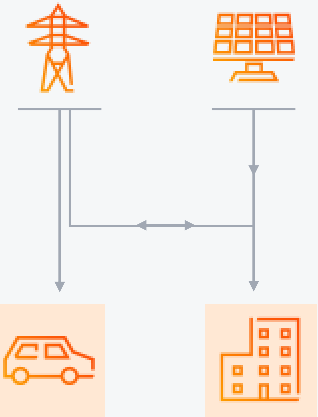
Real-world configurations vary by design, ownership and energy-flow strategy. Four common architectures illustrate the spectrum of integration, from direct self-consumption to virtual coupling.

Case 1



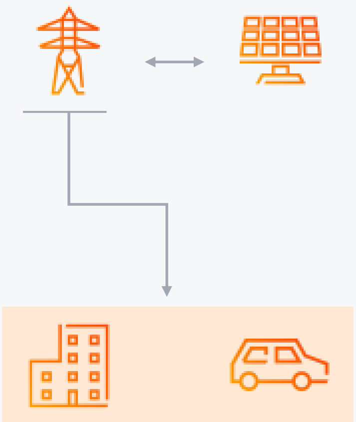
Rooftop solar panels and EV chargers are managed by a smart energy system to optimise on-site usage without selling solar surplus to the grid.

Case 2



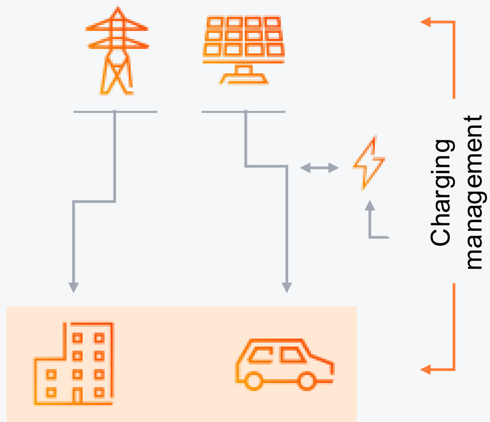
Rooftop solar generation supplies the building first, with excess power sold to the grid. EV chargers draw electricity indirectly through the building's internal system rather than directly from solar.

Case 3



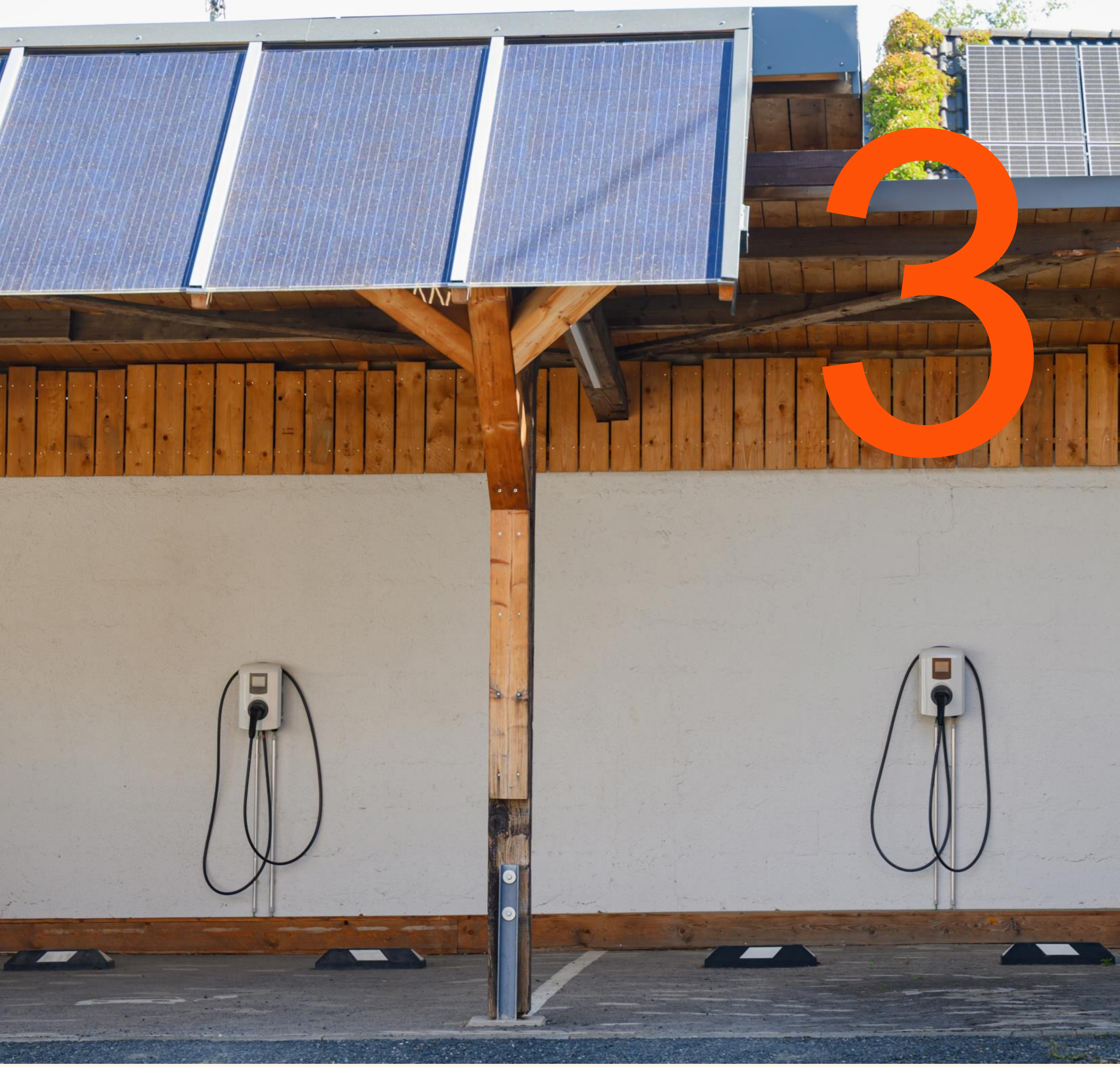
All solar production is exported to the grid. The site and EV chargers consume electricity independently but benefit indirectly from a greener energy mix through certified renewable supply.

Case 4



Solar panels, EV chargers and batteries are integrated under a smart control system that prioritises solar use and relies on the grid only when necessary.

Case studies from[14]



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Maximising the benefits of solar-eMobility coupling

03

Maximising the benefits of solar–eMobility coupling

Fully realising the potential of solar-EV integration requires more than simply linking chargers to panels. The real value lies in managing, storing, and sharing energy intelligently. Several technological solutions can significantly enhance efficiency, flexibility, and cost-effectiveness.[15]

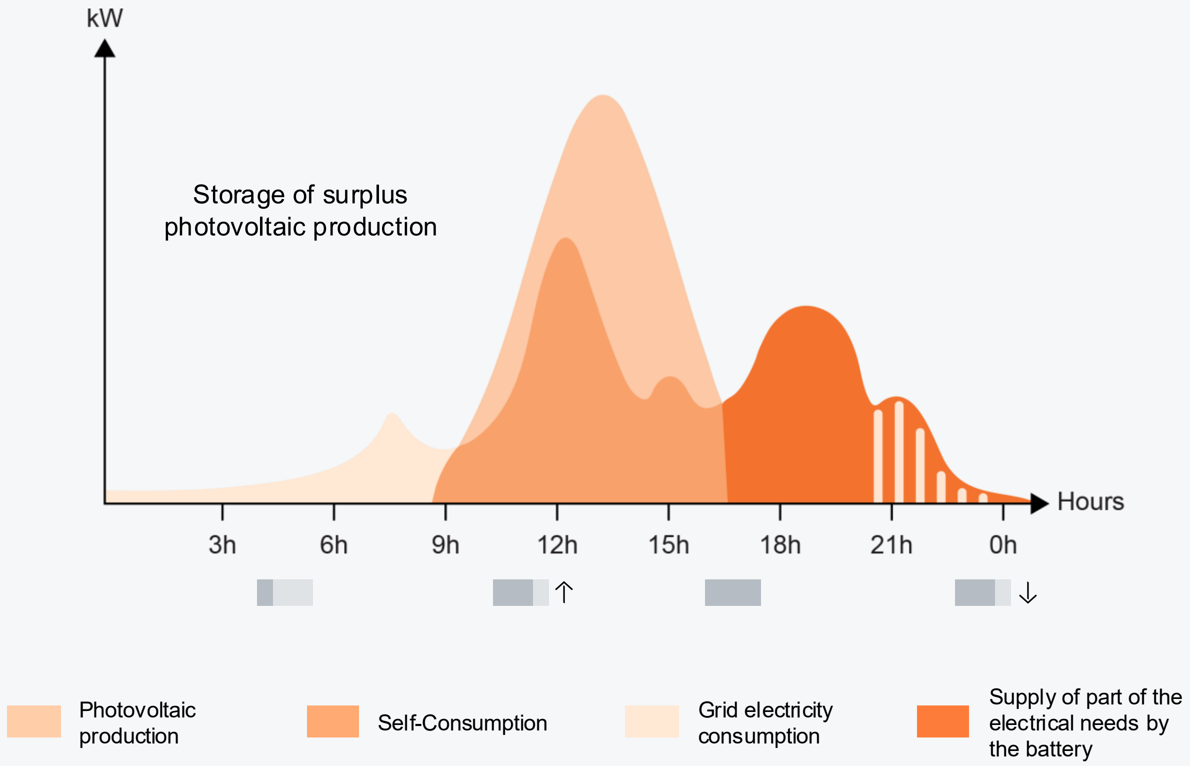
3.1. Smart charging with energy management systems

Smart charging uses digital platforms to align EV charging with solar generation peaks. By timing charging sessions to coincide with daytime solar output, users can reduce grid strain and improve self-sufficiency. This is especially useful in homes and offices where vehicles remain parked for long hours in daylight.

In France, the Crédit d'Impôt pour les Bornes de Recharge Électriques (EV charging tax credit) covers 75% of costs (up to €500 per charger, €1,000 per household) for installing smart EV chargers, which must be internet-connected and controllable to optimise charging based on solar production, electricity prices and peak hours, helping reduce costs and ease grid pressure.[16]

3.2. Battery storage as a balancing tool

Battery storage helps bridge the mismatch between solar generation and charging demand, particularly for evening use or cloudy days. Stationary batteries allow homes and businesses to store excess electricity and draw on it when required, reducing reliance on the grid during peak hours.



Germany's KfW Solar EV charging home subsidy illustrates this synergy. Homeowners can receive up to €10,200 to install rooftop PV, battery storage and an EV charging station under a single scheme. The programme attracted 33,000 applications in one day, fully using its €300m budget. In response, an additional €200m in funding has been allocated for 2024.[17]

3.3. Unlocking bi-directional potential via Vehicle-to-X (V2X)

EVs can also serve as mobile energy assets. Vehicle-to-Home (V2H), Vehicle-to-Building (V2B), or Vehicle-to-Grid (V2G) technologies allow energy to flow from vehicles back to buildings or the grid during peak demand periods. This makes EVs flexible storage units that support energy resilience, lower electricity bills, and contribute to grid stability. As V2X standards mature, this bidirectional model could become a cornerstone of smart, decentralised energy systems.

France's aVEnir project and Germany's Bidirectional Charging Management programme demonstrate this future. The former uses solar-charged EVs to stabilise the grid with €16 m in funding. The latter enables vehicles to feed energy back into homes and the grid, with over €30 m in public and private investment.[18, 19]

4

SWOT analysis

04

SWOT analysis

The following SWOT analysis outlines a strategic overview of the technical, economic and regulatory factors that influence the success of solar eMobility coupling initiatives.

Strengths

- Reduces CO_2 emissions in both transport and power sectors
- On-site solar boosts self-consumption, avoids grid fees and taxes, reducing charging costs and improving EV total cost of ownership.
- Reduces grid stress through local energy use and load shifting
- Ideal synergy: vehicles are parked ~95% of the time, often during solar hours
- Improves energy independence and resilience
- Coupling renewables with EV chargers reduces installation and connection costs.

Weaknesses

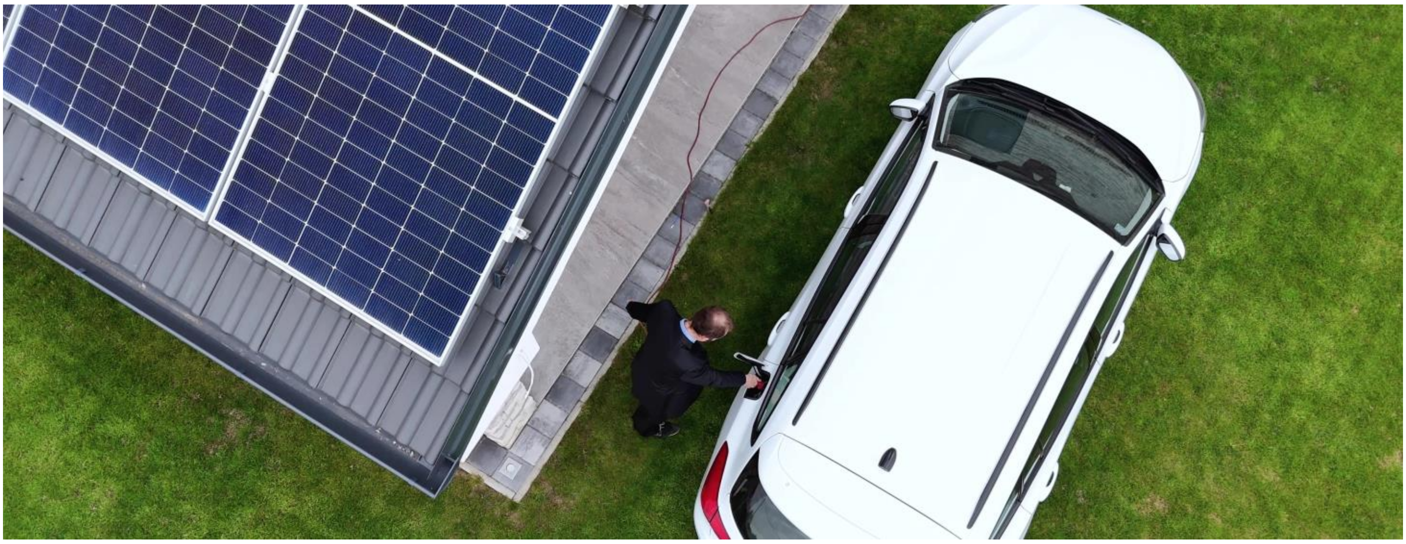
- Mismatch between solar generation (daytime) and charging demand (often evenings)
- High upfront costs for solar PV, storage, and smart charging infrastructure
- Intermittency of solar requires additional balancing/storage solutions
- Open international standards are needed to enable communication between EVs, chargers, EMS, and aggregators
- V2G requires compatible vehicles and chargers, with added costs of up to 50% compared to standard setups
- Limited numbers of PV-EV ready-coupled models

Opportunities

- Expansion of smart charging, V2G, and dynamic pricing models
- Supports net-zero targets and ESG goals for governments and businesses
- Growth in battery storage can enhance reliability and cost-effectiveness
- Potential for digital energy platforms and new business models

Threats

- Lack of a clear regulatory framework
- Lack of financing options or incentives for integrated projects
- Grid connection delays and capacity limits
- Falling battery or solar prices may affect timing of investment returns
- Cybersecurity and data management challenges with connected systems
- Users must consent to battery discharge, and charging must prioritise mobility needs to ensure vehicle availability



Lessons from leading European case studies

05

Lessons from leading European case studies

The GCC's solar advantage positions it well to replicate proven European approaches that link clean energy with eMobility. Germany, the Netherlands and Norway each illustrate how policy, infrastructure and consumer incentives can accelerate this integration.

Germany: Enabling solar-powered EV charging at scale

Germany has aligned energy and transport strategies to encourage residential solar PV paired with EV charging. A 2023 federal grant of up to €10,200 incentivises homeowners to install rooftop solar, battery storage and bi-directional EV chargers.[20] Simplified permitting and feed-in tariffs under the Renewable Energy Act (EEG) have expanded residential solar adoption. EV users can also earn CO_2 credits for solar charging making homes and small businesses self-sufficient energy hubs that support grid flexibility.

The Netherlands: Seamless integration of solar and smart charging

With 24GW of installed solar and a nationwide smart charging network, the Netherlands showcases how distributed solar can power eMobility. The Smart Charging for Everyone initiative ensures new public chargers dynamically respond to grid signals, favouring solar charging during peak production hours. Public-private partnerships have delivered solar canopies at charging stations, while municipal schemes allow residents to request chargers near homes – many powered by local solar energy. [21]

Norway: Linking solar to a hydro-dominant grid

While hydropower dominates Norway's mix, solar integration is rising through the Enova subsidy scheme, which funds rooftop PV, storage and chargers.[22] Municipalities and utilities are testing solar-powered charging in remote areas where grid upgrades are costly. Even with modest sunlight, midday solar charging reduces peak-hour strain and public operators increasingly source renewable electricity through solar-inclusive power purchase agreements.

6

Challenges to solar-eMobility integration

06

Challenges to solar-eMobility integration

While the potential to align solar energy with eMobility is compelling, especially in regions like the GCC, the path to full integration remains uneven. Visible progress has been made, yet several barriers continue to slow deployment.

1

From vision to alignment: policy and regulatory gaps

The journey toward solar-powered eMobility is often hindered by fragmented planning. Energy, transport and urban development strategies typically evolve in isolation, missing opportunities such as co-locating solar with EV charging or enabling vehicle-to-grid (V2G) services. Although regulatory clarity on storage, dynamic tariffs and grid interconnection is improving, greater harmonisation is needed to provide confidence to investors and innovators.

2

Grid and infrastructure readiness

Electricity networks were not originally designed for the dynamic demands of combined solar-EV systems. Utilities are beginning to anticipate new load patterns, but upgrades and flexibility measures – such as smart grid capabilities and localised storage – are still gaining traction. Many charging solutions are not yet optimised to fully leverage solar generation, especially during peak daylight hours when potential synergies are highest.

3

Technology integration and investment gaps

Markets for hybrid systems that combine charging, solar and energy management, remain immature. Interoperability between platforms is limited, making it difficult to scale pilots into commercial solutions. Costs are falling but upfront investment remains a barrier, especially in the absence of bundled financing or incentive mechanisms tailored to hybrid systems.

4

Market awareness and demand behaviour

Awareness of the benefits of solar-powered charging is still limited. Most EV users charge at home during evening hours, missing opportunities to align demand with solar output. Better tools, apps and consumer engagement can help drivers shift habits, reducing costs and emissions while easing pressure on the grid.

5

Execution at the local level

Cities and municipalities are central to delivery but often face competing priorities and limited access to planning tools for solar-EV projects. Embedding this knowledge into zoning, permitting and procurement practices remains a work in progress. Success stories, such as solar carports at transit hubs or solar-powered fleet depots show what's possible but remain the exception rather than the norm.

Policy implications for the solar and eMobility ecosystem stakeholders

07

Policy implications for the solar and eMobility ecosystem stakeholders

The GCC is well-positioned to lead in clean eMobility, combining abundant solar energy and rising interest in EVs. Achieving this requires coordination across all stakeholders – from policymakers to end users. Here's how each group can contribute:

Policymakers and regulators

→

Develop integrated policy frameworks that connect energy, eMobility and urban development under unified national strategies. Ensure policies actively support co-location of EV charging with solar infrastructure

Simplify permitting and grid access procedures, especially for high-impact sites such as public buildings, transport hubs and commercial zones

Establish clear legal frameworks for storage and bidirectional charging to allow EVs to contribute to grid stability

Grid operators and utilities

→

Adopt flexible interconnection standards for hybrid systems and plan upgrades in areas with high solar and EV uptake

Introduce dynamic tariffs to incentivise off-peak and solar-aligned charging, reducing grid stress and supporting renewable integration

Private sector and charging infrastructure providers

→

Invest in solar-ready and smart charging infrastructure, particularly in sites where vehicles remain parked during daylight hours such as offices, malls and logistics centres

Adopt open communication protocols across EV chargers, solar inverters and energy management systems to ensure interoperability and scalability

Public sector and municipalities

→

Lead by example through procurement – installing solar-integrated charging for government buildings and vehicle fleets to build market confidence

Incorporate solar and charging infrastructure into urban planning through zoning and design tools, reserving space for carports, shared storage and integrated stations in new developments

End users and fleet operators

→

Align charging behaviour with solar generation patterns to cut energy costs and emissions

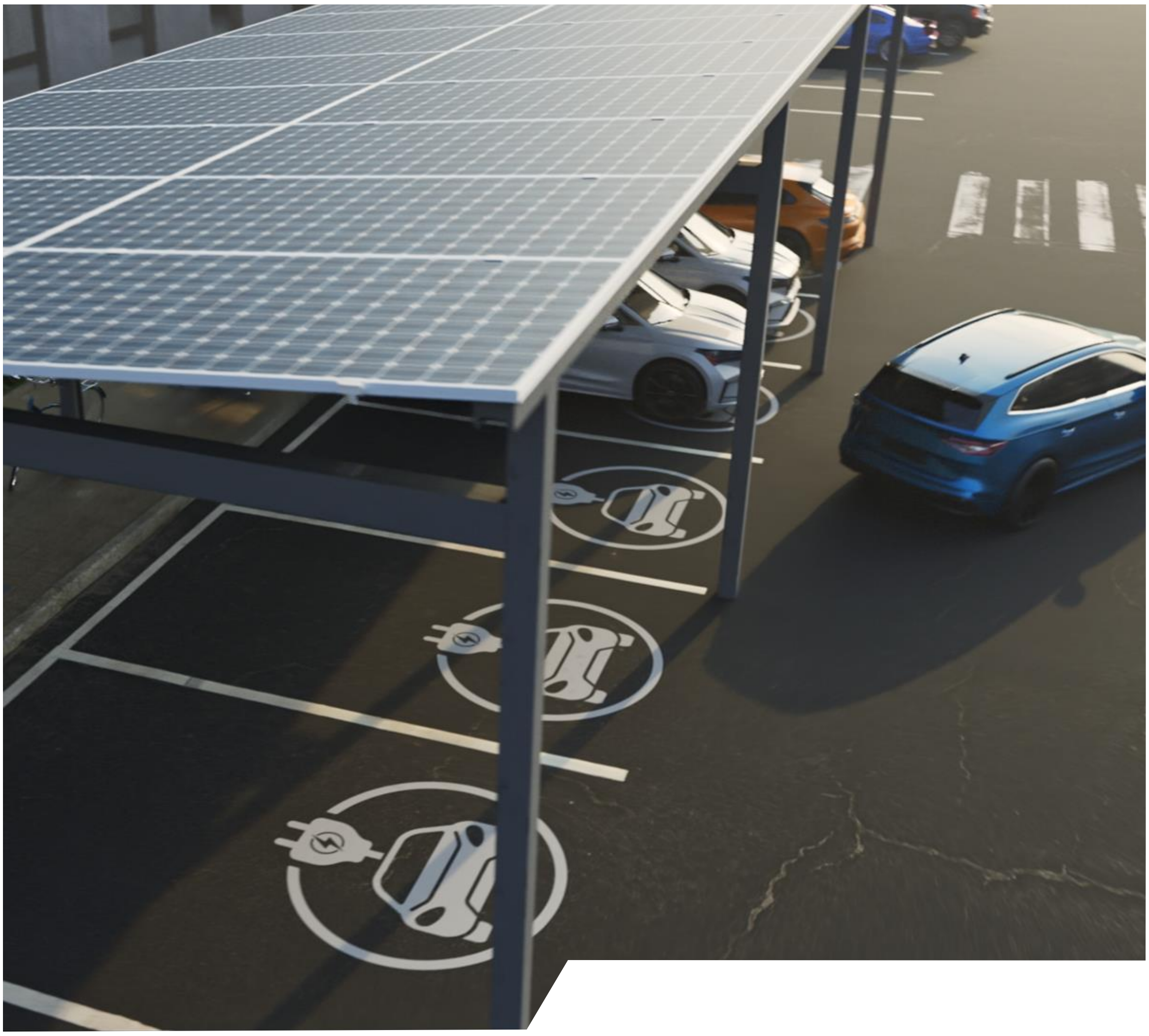
Join pilot projects exploring storage or grid-support applications, helping to advance technology readiness and business model development

Industry associations and NGOs

→

Raise awareness of the cost and environmental benefits of solar-EV integration through targeted campaigns

Collaborate with governments and financiers to promote R&D funding, pilot programmes and innovation scale-up



Why integration matters now

The GCC has a rare opportunity to connect its world-class solar resources with the emerging eMobility revolution. Doing so will not only decarbonise faster and more affordably than elsewhere but also strengthen energy independence and grid resilience. Integration is no longer a technical challenge – it is a strategic choice that will define the region's next decade of sustainable growth.

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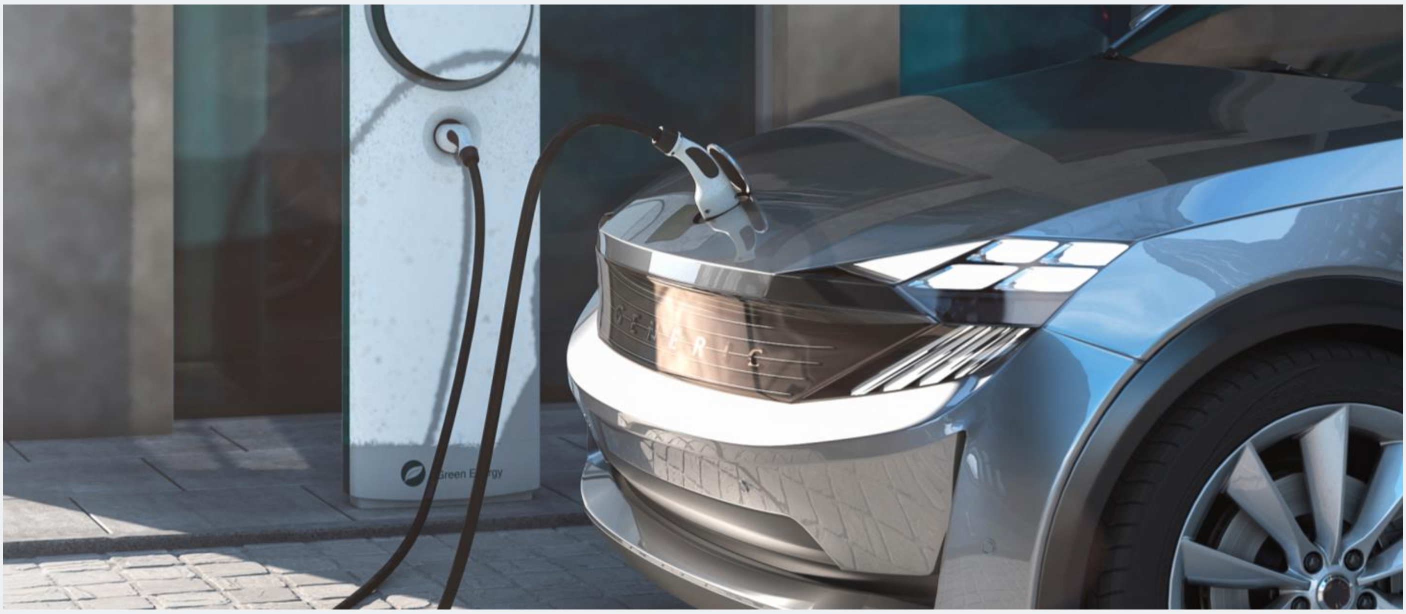

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