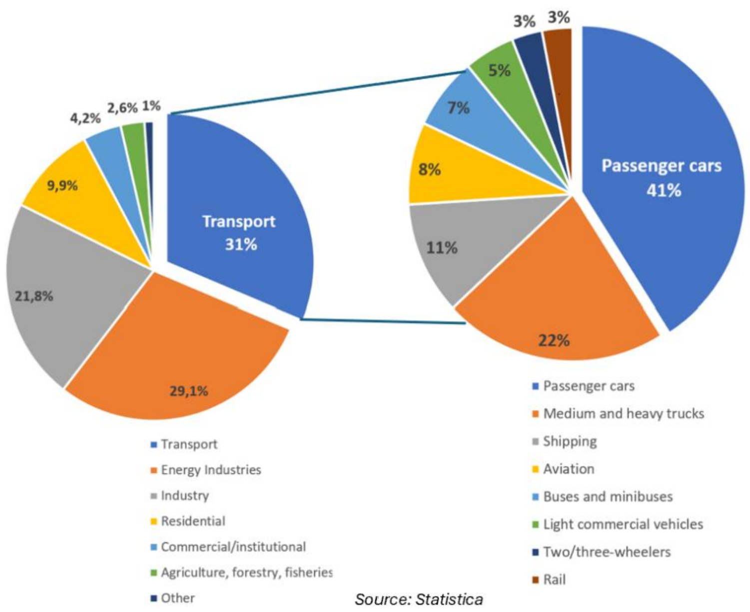
Factsheet Vehicle-Integrated Photovoltaics (VIPV)

Accelerating Clean Mobility Through Embedded Solar Technology

As Europe advances toward climate neutrality, decarbonizing transport is urgent. Electrification is essential, but true sustainability also requires rethinking how energy is supplied, stored, and used on the move. This is where Vehicle-Integrated Photovoltaics (VIPV) comes in. By embedding solar cells directly into vehicle surfaces: roofs, hoods, trunks, and panels allowing cars, vans, buses, and trucks to produce renewable electricity seamlessly. Unlike external solar mounts, VIPV maintains aerodynamics and design while bridging electromobility and renewable energy. It is both a technological innovation and an industrial opportunity supporting Europe's goals for climate neutrality, energy sovereignty, and manufacturing competitiveness.

Why VIPV Matters?

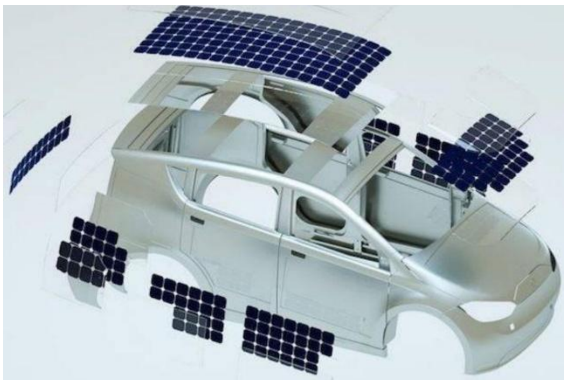


The advantages of VIPV extend well beyond simple energy supply. Technology transforms vehicles into decentralized energy systems that can contribute directly to reducing emissions, enhancing grid resilience, and lowering operational costs.

In moderate European climates, VIPV can add between 1,500 to 3,000 kilometers of solar-powered range per year, equivalent to about 5 to 20 kilometers of extra range per day in good sunlight. For many passenger cars, that represents 15–25% of their total annual driving needs, while for urban fleets and light electric vehicles, the share can be even higher.

According to the International Energy Agency PVPS (2022), each vehicle equipped with VIPV can avoid up to 400–600 kilograms of CO_2 emissions annually, and a fleet of 10,000 such vehicles could collectively cut more than 50,000 tons of CO_2 over a decade.

But the benefits do not end there. By producing electricity directly onboard, VIPV helps relieve pressure on power grids, especially during peak demand periods. This is critical in urban areas or regions where charging infrastructure remains underdeveloped. Furthermore, VIPV contributes to lifecycle efficiency, offsetting embedded emissions and supporting component reuse and recycling. In remote or emergency situations, the system can even provide power for refrigeration, lighting, or communications enhancing energy resilience far beyond conventional vehicle design.



Debunking the Myths

Despite these clear benefits, several myths continue to cloud perceptions of solar mobility.

MYTH 1: "Solar panels on vehicles don't generate enough electricity to make a difference."

FACT: VIPV can add between 1,500 to 3,000 km of solar-powered range per year in moderate climates like central Europe and much more in sunnier regions.

- This is equivalent to 15–25% of the total annual driving distance for many passenger cars and even more for L-category vehicles and urban fleets.
- A study by Fraunhofer ISE (2021) showed that VIPV could provide 20–30% of the daily driving energy needs in Germany for small to mid-sized vehicles.
- For example, Lightyear 0 solar electric vehicle could generate up to 70 km of range per day from its VIPV system under optimal conditions. Sono Motors' Sion model, with full PV surface coverage, achieved nearly 25 km/day in sunny conditions in Munich.

MYTH 2: "VIPV is just a gimmick for niche vehicles."

FACT: VIPV is already being applied in commercial delivery vans, trailers, and light urban transport, where the ROI is measurable.

- Solar trailers (e.g., Sono Motors x CHEREAU) can cut diesel use for refrigeration by up to 50% and 5 to 15% even for non-refrigerated diesel transport.
- A report commissioned by the European Parliament (SolarMoves) calculates that the added direct costs of VIPV systems for passenger cars can be paid back in direct electricity cost savings within 2-5 years (not including OEM markup).
- Urban delivery vans with VIPV reduce charging frequency and improve fleet efficiency, lowering both downtime and total cost of ownership.
- Beyond road transport, marine applications (e.g., electric vessels for lakes and near-shore use) and aeronautics (drones, lightweight aircraft) emerge as promising niches.
- Passenger cars are often overlooked due to multi-story parking concerns, yet Europe has far more open-air parking spaces than covered ones, meaning most vehicles are exposed to sunlight during significant parts of the day. VIPV is therefore relevant far beyond niche applications.

MYTH 3: "Solar mobility isn't relevant to climate targets."

FACT: VIPV contributes to climate goals by reducing real-world operational emissions, even without relying on a decarbonized grid.

- According to the European Commission's Fit for 55 plan, transport must reduce emissions by over 55% by 2030 solar mobility is a near-term enabler.
- GHG emissions from transport remain a major challenge in the EU, as highlighted by the European Environment Agency (2022).
- For fleets, Solar-Moves and Fraunhofer data show 5–15% fuel consumption reduction if all diesel trucks were equipped with PV.

MYTH 4: "Solar panels will make vehicles heavier and less efficient."

FACT: Modern VIPV uses lightweight, high-efficiency solar modules with negligible impact on vehicle weight or aerodynamics.

- VIPV technology typically adds less than 2.5 kg/m², and solutions below 1 kg/m² are already emerging, particularly for aeronautics where weight is critical.
- VIPV is engineered to maintain aerodynamics.
- VIPV is an efficiency multiplier; as cars become more efficient, the impact of solar is greater. When we double a car's efficiency, the solar roof suddenly does 'double duty.' It’s the difference between solar being a nice 'bonus' and solar providing almost everything you need to drive. You aren't just saving energy; you’re making the grid 3x less relevant to your daily commute.

MYTH 5: "There are no standards or policies for VIPV so it's not ready for support."

FACT: International work is already underway to develop VIPV standards, and the EU can lead this frontier with strategic policy inclusion.

- IEC TC82 and CEN/CENELEC are developing frameworks for VIPV testing and certification.
- The IEC TC82 PT 600 initiative, discussed at the PVinMotion conference (March 2025), is a key international effort.
- The Renewable Energy Directive III (Directive EU 2023/2413) includes an amendment to Article 2 (44e) which defines a solar-electric vehicle. Further, the same document Article 27 (1.c.iii) recognizes all energy generated on a solar-electric vehicle is renewable. As a renewable that powers transport, it can be multiplied by a factor of 4 for member states monitoring renewable electricity targets.

MYTH 6: "Solar energy from vehicles can't be measured or credited in emissions reporting."

FACT: Embedded solar yield meters can track energy generation precisely, enabling crediting in fleet CO_2 accounting and potential carbon offset systems.

MYTH 7: "Europe's climate isn't sunny enough for VIPV to work."

FACT: Even in cloudy climates like northern Germany, VIPV adds meaningful range—especially in stop-and-go urban mobility.

- Rooftop solar on vehicles can generate 400–600 Wh/day in cities like Amsterdam, sufficient to power a light electric vehicle (LEV) for typical urban use.
- Stockholm studies show ≥5% solar range contribution for commercial vehicles and up to 35% for vans.
- Efforts are underway to better measure real-world solar irradiance on vehicles under urban and road conditions.
- The Solar-Moves report is based on more than 1.5M km of irradiance data that was collected from all over Europe from April 2024 – October 2025. This database is currently owned by the EU and may become public in the near future.

Technology at a Glance

The performance of today's VIPV systems is already significant. Depending on the vehicle's surface area, integrated panels can deliver 150–600 Wp of power, generating an average of 0.5 to 2.5 kWh per day under European conditions. The technologies used range from conventional crystalline silicon and heterojunction cells to emerging perovskite tandem structures, offering lightweight, curved, and shatterproof integration solutions.

Cars typically feature between 1.5 and 4.5 m² of solar surface, while buses and vans can accommodate up to 10 m² enough to produce meaningful energy for propulsion or auxiliary functions. This integration is already being commercialized by several pioneering companies, including Lightyear in the Netherlands, Sono Motors in Germany, and Toyota in Japan, whose Prius Prime model includes a factory-installed solar roof.

A Policy Moment for Europe

VIPV is fully aligned with major European policy frameworks, including the EU Green Deal, the Fit for 55 Package, the Alternative Fuels Infrastructure Regulation (AFIR), and the Clean Vehicles Directive. Moreover, ongoing research initiatives such as PV2GO, SOLAR-MOVE and SUN-TRANS are already advancing innovation and standardization in this field.

However, despite this alignment, current policy instruments and incentive schemes rarely recognize VIPV explicitly. Most EV subsidies do not differentiate between vehicles with or without integrated solar capacity, and VIPV-generated electricity is not yet credited within vehicle CO_2 reporting or renewable registries. Closing these gaps would create powerful synergies between industrial innovation and climate policy.

Challenges to Scale

Scaling up VIPV will require tackling several technical and market challenges. The limited surface area of vehicles naturally constrains energy yield and integrating PV modules into curved or movable surfaces demands specialized materials and manufacturing processes.

Costs also remain a barrier: VIPV integration can currently add €1,000-€4,000 to a vehicle's sales price (depending on vehicle segment) as it is offered as an option and therefore with large margin. For example, the consumer cost of OEM solar roofs from Toyota/Hyundai is typically €1,500-€2,000. Yet, with continued R&D,

local manufacturing, and economies of scale, this premium is expected to shrink significantly. Safety and testing standards must also evolve to cover aspects unique to mobile solar systems, such as crashworthiness, electromagnetic compatibility, and thermal stability.

Strategic Pathways Forward

Europe has a unique opportunity to lead the global VIPV industry through a coordinated approach that combines innovation, regulation, and industrial strategy.

1. Local Manufacturing for Resilience: Building European VIPV production clusters would strengthen supply chain independence and technological sovereignty. Integrating VIPV into the EU Net-Zero Industry Act would help ensure that Europe retains leadership in clean-tech manufacturing while creating skilled jobs and reducing reliance on imports.

2. R&D and Standards Leadership: Public funding should prioritize advanced materials, flexible PV technologies, and smart integration methods, while supporting European leadership in pre-normative work through IEC and CEN/CENELEC.

3. Urban Fleet Deployment: VIPV should be incentivized in high-mileage and predictable-use fleets such as postal vans, municipal buses, and logistics vehicles. Including VIPV in public procurement and eco-labeling criteria would send a strong market signal.

4. Circular Economy Integration: Policymakers can promote repairable and recyclable VIPV designs, aligning with the EU's battery regulation and digital product passport initiatives to ensure full lifecycle sustainability.

5. Certification, Monitoring, and Credit Systems: Finally, solar yield metering should be incorporated into CO_2 accounting for fleets, enabling companies to quantify and report emission reductions from onboard solar generation.

Research and Innovation Priorities

To achieve widespread adoption, research must continue in several key areas:

- Integration and Durability: Develop flexible, UV-resistant modules and crash-safe mounts.
- Power Electronics and Management: Improve MPPT algorithms, compact converters, and seamless integration with battery and V2X systems.
- Modeling and Simulation: Create region-specific tools that link solar yield with cost and lifecycle metrics.
- Certification and Testing: Establish EU-led standards for curved-surface testing and data security.
- Lifecycle Impact: Promote modular, recyclable designs that support a circular economy model.
- Energy system impact: Investigating the energy system impact of VIPV on electricity demand and adjusted load pattern of VIPV-enabled EVs. An initial, limited study in the Solar-Moves project shows up to a 25% impact on grid congestion at the local neighborhood level.

A Solar Mobility Vision

VIPV represents more than an incremental improvement, it marks a structural shift in how energy and mobility converge. By turning every vehicle into a small-scale renewable power generator, VIPV decentralizes energy supply, strengthens resilience, and enables a cleaner, smarter transport system.

For Europe, supporting VIPV means not just embracing new technology, but redefining industrial leadership in the age of sustainable mobility. The transition to solar-powered vehicles is no longer a question of possibility, but of policy ambition and strategic coordination.

If supported by the right mix of incentives, standards, and local manufacturing, VIPV could become one of Europe's most visible and practical examples of innovation driving climate action, proof that the vehicles of tomorrow can carry both people and power, responsibly and sustainably.

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