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Reallabor für verNETZte E-Mobilität

Sustainable Charging and Discharging of Electric Vehicles

Results and recommendations
from the field tests of the Cluster Harmon-E

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Content

What is Harmon-E?

The Harmon-E cluster is a subproject of the nationwide research project unIT-e². More than 30 partner companies and research institutions have investigated the optimal integration of electric vehicles into the future energy system in unIT-e² and tested smart charging in field trials.

The unIT-e² project ran over 3 ½ years (from mid-2021 to early 2025). It was funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK).

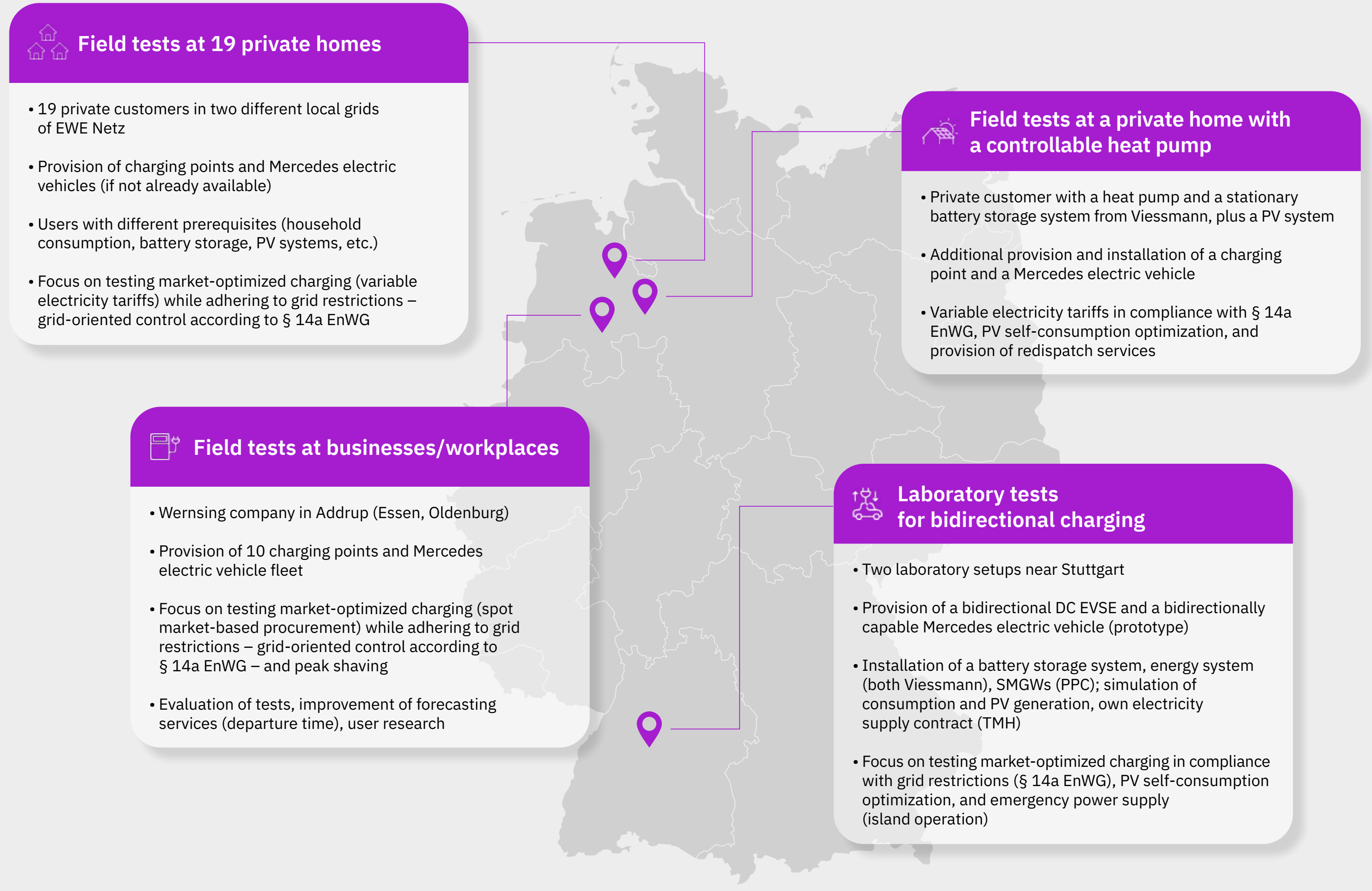
The focus of the project work in the Harmon-E cluster was on testing complex application cases (so-called use cases) of the intelligent charging of electric vehicles in conjunction with other components (PV systems, heat pumps, home storage systems, and smart metering systems (iMSys)) in real environments. To enable the integration of electromobility into the energy system, those use cases that provide additional benefits to the energy system were selected in Harmon-E. These use cases can be beneficial to electricity markets (market-friendly), relieve or protect electricity grids from overload (grid-friendly), or stabilize the overall energy system (system-friendly).

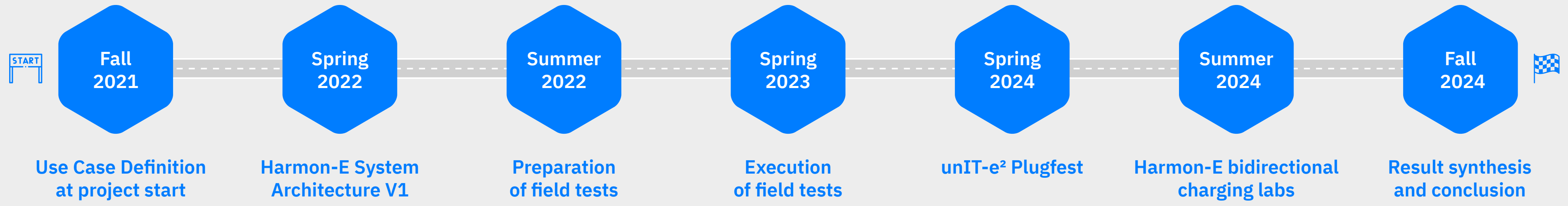
At the same time, for the successful mass implementation of the use cases, economic benefits must be realized for the involved stakeholders. The resulting conflict of objectives between the added value for the energy system and the financial incentives for stakeholders and users was addressed in Harmon-E and supported by accompanying user research during the use case testing.

The goal of the use case testing in field tests was to create blueprints for technically scalable solutions for the use cases. Different process chains based on technical standards were established and tested in three field test regions (see Germany graphic on the next page).

In addition to testing use cases of intelligently controlled charging in three field test regions, use cases of bidirectional charging — i.e. the ability to discharge electricity from the electric vehicle — were technically developed and tested in a laboratory environment.

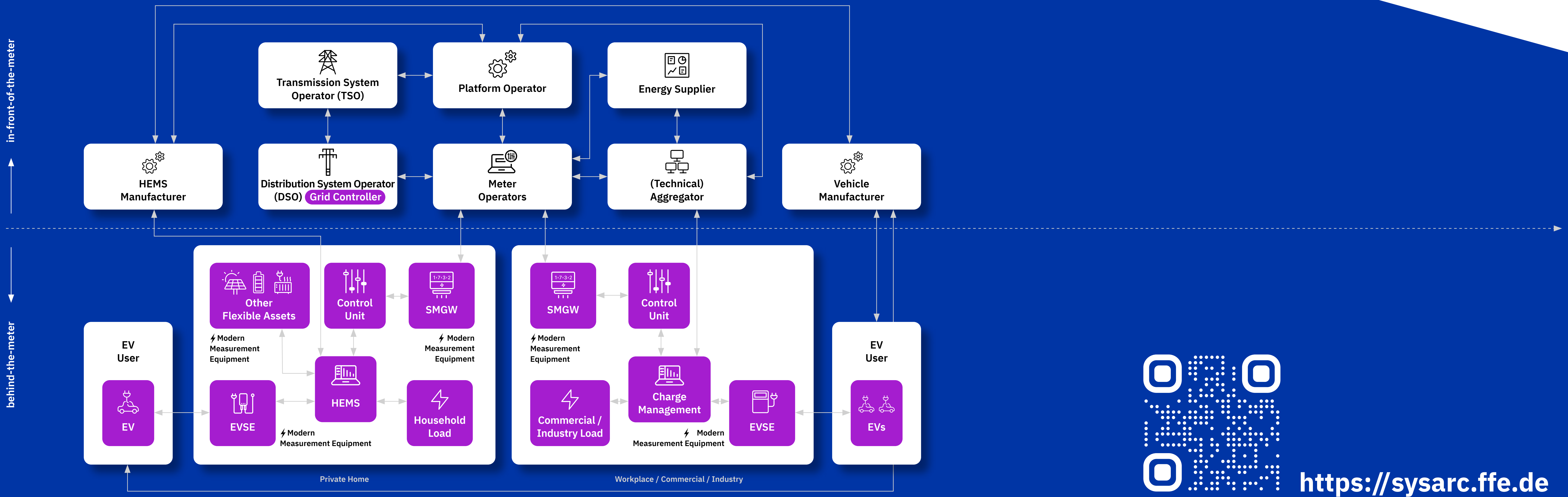
The technical implementation of all use cases tested in Harmon-E and the insights identified during the process are clearly described on the following pages.





The System Architecture

HEMS: Home Energy Management System
EV: Electric Vehicle
EVSE: Electric Vehicle Supply Equipment
SMGW: Smart Meter Gateway



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What was tested in the field?

Field Trial in Low Voltage Grid in the Context of Single-Family Homes

In the Oldenburg region, two selected local networks were digitized as part of the field trial to enable measurement at the local network transformers and cable distribution stations. The field trial focused on the intelligent charging control of electric vehicles and their interaction with the distribution networks. To this end, 19 private electric vehicle users were equipped with intelligent metering systems (iMSys) for measurement and control, which were integrated into the EWE Netz systems.

Grid Congestion Detection and Grid-Friendly Control (EnWG §14a)

- Achieving transparency in low-voltage networks
- Automatic detection of current- and voltage-related congestion situations in the low-voltage grid
- Implementation of grid-oriented control measures to reduce peak loads in the low-voltage network
- Building and validating the technical chain of communication from the distribution system operator, through the intelligent metering system and the operator‘s control unit, to the technical components and the users‘ vehicles

Market-Oriented Control (Dynamic Electricity Prices):

- Communication of stock market electricity prices to the home energy management system (HEMS)
- Automatic identification of optimal charging times
- Parallel operation of both grid-friendly and market-oriented flexibility utilization
- User experience and acceptance surveys

Field Test at Wernsing Feinkost Industrial Facility

At the central location of Wernsing Feinkost in Essen (Oldenburg), various use cases of smart charging were tested during ongoing operations. The focus was on the following use cases: grid-friendly charging, peak-shaving, and market-oriented charging. For this, ten fully electric Mercedes-Benz vehicles were provided to Wernsing participants, primarily charging at the site. The charging infrastructure, including intelligent charging and energy management, was provided by The Mobility House, and PPC supplied the SMGW infrastructure. EWE Netz investigated the grid-friendly charging of electric vehicles. The University of Passau conducted and evaluated several participant surveys during the field tests.

Benefits through Controlled Charging / Smart Charging:

- Automated charging during low electricity prices: Electric vehicles are charged when the power is green.
- Energy costs and CO_2 emissions are reduced while simultaneously stabilizing the power grid.
- Intelligent prediction of planned trips by determining departure times and required battery state of charge.

Tested Use Cases:

- Load shifting in times of peak load
- Price-optimized charging based on energy market prices
- Power limitation at the grid connection point by the grid operator in case of grid congestion
- Optimized charging while considering grid restrictions.

Field Test: Smart Home with Heat Pump

At a newly built single-family home near Bremen, use cases involving multiple components from Viessmann were tested. The Viessmann Energy Management System (EMS) received power limitations from the distribution grid operator via EEBUS. The EMS negotiated charging plans with the electric vehicle using EEBUS and ISO 15118-2. Additionally, the EMS was integrated with other systems into a virtual power plant to provide redispatch services.

Components Installed:

- Viessmann Energy Management System (EMS)
- Viessmann Heat Pump
- Viessmann Battery Storage, including PV system
- Kostal AC Wallbox
- Mercedes-Benz Electric Vehicle
- Intelligent Metering System and Control Unit by PPC

Tested Use Cases:

- PV Self-Consumption Optimization: Maximization of PV self-consumption through intelligent control of consumers.
- Grid-Friendly Flexibility: Limiting consumption and feed-in by the distribution system operator according to EnWG §14a.
- Market-Oriented Flexibility: Cost optimization with dynamic electricity prices.
- System Services: Integrating the EMS into a virtual power plant for redispatch services.
- Peak-Shaving: Reduction of consumer load in case of overload at the grid connection point.

Field Test: Bidirectional Charging Lab at Mercedes-Benz in Stuttgart

At Mercedes-Benz in Stuttgart-Untertürkheim, test activities for bidirectional charging (charging AND discharging of electric vehicles) are taking place. The test activities focused on testing the home charging management system. Selected use cases were tested in a lab environment to ensure a customer-centered future experience. The main focus was on providing the functionality of individual components and achieving a harmonious interaction within the entire process chain. The standardized technical implementation of some use cases has already been successfully tested during the project.

System Components:

- Kostal: DC Bidirectional Wallbox, AC Wallbox
- Viessmann: Vitocharge Battery Storage, Energy Management System
- PPC: Smart Meter Gateway, CLS Gateway
- PV Emulator
- The Mobility House: Charging Station Management System (CSMS), Aggregation and Trading Platform
- Solar Inverter

Tested Use Cases:

Vehicle-to-Home:

- PV Self-Consumption Optimization: Maximizing PV self-consumption through intelligent charging and discharging.
- Backup Power Supply (Island Mode): Providing power to the premises from the electric vehicle.

Vehicle-to-Grid:

- Grid-Friendly Flexibility: Limiting consumption and feed-in by the distribution system operator according to EnWG §14a.
- Market-Oriented Flexibility: Using the vehicle's battery for arbitrage trading.

Implementation Sequence of Use Cases

Key findings and recommendations

Finding

High Charging Simultaneities (multiple electric vehicles charging simultaneously in the same region) can already lead to bottlenecks in the low-voltage network. Even with the small number of unIT-e^2 participants (< 10% in the network area), congestion in the low-voltage grid could be triggered.

Harmon-E Recommendation

Section 14a EnWG provides an essential foundation for secure grid operation with flexibility and the ramp-up of market-based instruments. For efficiency reasons, a minimum standard should be defined at the protocol level (EEBUS LPC, according to VDE AR2829-6, is recommended).

Additionally, further (voluntary) use cases help achieve a forward-looking and data-sparing integration of future flexible generation and consumption devices (e.g., the use of envelopes in the sense of EEBUS PODF and POEN).

Finding

Load-side Flexibilities (e.g., electric vehicles) cannot currently be used for redispatch.

Harmon-E Recommendation

Expanding the regulatory framework for redispatch with a complementary market-based approach is recommended to integrate flexibility potentials in the low-voltage grid into the redispatch, which are not covered by the cost-based redispatch 2.0.

Finding

The standards and technical specifications used in the Harmon-E architecture predominantly provide a high level of security. However, there are still gaps where security against attacks cannot be guaranteed.

Harmon-E Recommendation

Security mechanism requirements must be further supplemented, primarily when proprietary protocols are used. If security mechanisms in a standard or protocol are optional, the architecture specification must mandate their activation.

Finding

The scalable integration of millions of flexible consumption and generation systems (e.g., electric vehicles) requires consistent standardization across the entire technical process chain. The interfaces must be as simple and understandable as possible to ensure the acceptance of the involved stakeholders. Standards simplify the interoperability of the process chain. Still, they must be sufficient for error-free interaction of components with comprehensive and cross-industry integration tests.

Harmon-E Recommendation

Regular conduct of „testivals“ or „plugfests,“ as well as feeding back the findings from field tests into standards and standardized certification procedures, are necessary to eliminate interpretation scopes. The cross-industry events should be open-ended and transparent. Developing a standard test plan in advance and systematically documenting the test results is recommended for structured implementation to ensure comparability.

Finding

The digital control via the intelligent metering system (iMSys) forms the basis for integrating controllable consumption devices (e.g., electric vehicle wall boxes). The local EEBUS interface between the control unit of the meter operator and the customer‘s system (e.g., HEMS, heat pump, wall box) works reliably, is generic, and covers all current and potentially future use cases.

Harmon-E Recommendation

VDE AR 2829-6 (EEBUS) should serve as the standard for digital control within the property, as it enables interoperability between different manufacturers and components for control.

Digital control should always be preferred over analog contacts in future installations.

Finding

The commissioning process and the EEBUS coupling between the control unit and the customer‘s system still require too many manual steps. This makes the process prone to errors and makes it unscalable for mass deployment. In the project, concepts for a scalable evolution of the installation process have already been developed.

Harmon-E Recommendation

The commissioning process, especially between the control unit and downstream devices, should be standardized and simplified, for example, by establishing a nationwide portal for device registration or a technician tool. This would allow role-based, unified access to authorized data (e.g., for system operators, installers, grid operators, and meter operators). See also the unIT-e² guide on the „Integration Process for Energy Infrastructure.“

Finding

The digital communication via ISO 15118-2 between the electric vehicle and the wall box worked well in the field tests for unidirectional charging. The communication via ISO 15118-20 also worked well in the laboratory for bidirectional charging. However, in ISO 15118-2, ad-hoc changes to the charging plan during automated implementation using the energy management system (EMS) are only possible to a limited extent. Therefore, ISO 15118-2 is less suitable for use with an EMS. The ISO 15118-2 communication between the vehicle and the wall box, as well as the communication of the metering operator with the home environment, is sufficiently secured by existing standards (TLS in connection with predefined PKIs) to avoid high attack risks.

Harmon-E Recommendation

Dynamic control via ISO 15118-20 between the electric vehicle and the EVSE should also be used for unidirectional charging. The development and implementation of the standard should be accelerated accordingly.

The following ISO 15118-20 standard should also mandate the SoC (State of Charge) for DC and AC charging, as the ISO 15118-2 standard will no longer be modified.

Finding

Vehicle-to-grid (V2G) (feeding power back into the grid from the vehicle) is a complicated legal situation, but it has high profit potential. Vehicle-to-Home (V2H) (feeding power within the building boundary) has a significantly simpler legal situation and much lower profit potential.

Harmon-E Recommendation

For profitable use of bidirectional charging, the focus should be on V2G, but further clarification of the regulations, simplifying the legal situation, and removing double charges are necessary.

Finding

Understanding all phases of the customer journey (customer experience) in the electromobility ecosystem is crucial for customers. The field trial showed positive user experiences, increased trust, and increased willingness to invest in additional components. An increase in purchase intentions for the various components suggests that when users experience the combined benefits of electric vehicles and supporting technologies firsthand, they are more likely to purchase the entire product package. However, the customer journey analysis still reveals several key problem areas, particularly pre- and post-purchase phases.

Harmon-E Recommendation

To fully leverage this potential and encourage more purchasing and usage behavior, the identified problem areas need to be addressed. In this way, companies can increase overall satisfaction and promote engagement and acceptance of connected e-mobility solutions.

Finding

When there is insufficient information, or it is difficult to process, it becomes harder for customers to decide on various components (EV, EVSE, HEMS, storage, PV system) of the electromobility ecosystem. Providing information to interested parties is inherently beneficial, regardless of the method of presentation.

Harmon-E Recommendation

We recommend the professional production of informational material on the topic of connected electromobility. This could include informational indexes that allow interested parties to further explore individual issues, components, and relationships.

Conclusion from 3 ½ years of research

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The Harmon-E subproject within the framework of unIT-e² has made significant progress in integrating electric vehicles into the energy system in collaboration with other technical components.

By testing complex use cases in real-world field trials, it has been demonstrated that smart charging solutions can be used for grid-friendly and market-oriented purposes and offer economical and sustainable customer incentives.

The field trials demonstrated innovative control options using the intelligent metering system infrastructure and Backend-to-Backend connections. A functional technical solution for grid-friendly charging by §14a EnWG was developed. Energy management systems were used to automate intelligent operation, which was successfully tested.

Our findings show that standardization and simplification of the process chain are essential to enable mass-compatible, scalable, yet secure integration of flexible consumption and generation systems. Furthermore, IT security aspects should be given more focus in the future. From the customers‘ perspective, the developed solutions are viewed mainly positively, with no significant loss of comfort perceived. Use cases for bidirectional charging are technically feasible today; however, coordinated, standard-based processes are also required to integrate into the energy system.

In conclusion, positive customer experiences significantly enhance trust and acceptance of connected electromobility. Customer-centered business models, which highlight the advantages of smart and bidirectional charging, play a crucial role in the success of the mobility transition.

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