ADVANCING GRID INTEGRATION OF ELECTROMOBILITY: INSIGHTS FROM THE PROJECT UNIT-E²

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Abstract

In the project “unIT-e² – Living Lab for Integrated E-Mobility”, over 30 partners worked on integrating electromobility into the energy system. The focus was on practical applications where pilot customers tested electric vehicles and complementary software and hardware. Selected results and recommendations from the tests and research activities, aiming to transfer insights into practice, are presented here. The findings are categorized into four areas: “Grid Integration of Electromobility”, “Scalability and Standardization”, “Information and Incentives for Users”, and “Economic and Ecological Benefits for Users and Energy System”. The report highlights ongoing research and development needs to promote efficient integration of electromobility with a focus on Germany. Grid integration and standardization were dominant topics, yielding the most insights, but also showing the greatest need for further discussion and research. Field tests provided practical insights from electric vehicle users’ perspectives. Research focused on the economic and ecological evaluation of electromobility and its impact on the energy system.

1 Introduction

1.1 The Project unIT-e²

The project “unIT-e² – Living Lab for Integrated E-Mobility” aimed at the secure and intelligent integration of electromobility into existing and future infrastructure to meet the transformation of the energy system. Over 30 partners, ranging from automotive and charging infrastructure manufacturers to grid operators and research institutes, developed interoperable solutions and tested them in field trials across four sub-projects (so-called “clusters”). The clusters focused on different topics: While the Harmon-E cluster focused on the harmonious interaction of the overall system of grid, market, and energy system, Heav-E primarily examined the user perspective and acceptance of intelligent charging. The sun-E cluster focused on the use of photovoltaic power generation in the context of electromobility and grid- and market-friendly charging strategies. Additionally, Cit-E-Life addressed electromobility in urban areas. Furthermore, two accompanying sub-projects “Research” and “Grid” coordinated cross-cluster topics, scientifically analyzed them, and derived recommendations.

Despite the large number of project participants and research topics, the collaboration in unIT-e² was characterized by a trusting and team-oriented approach. The core of the project was the joint development of interoperable and thus future-proof solutions that consider various grid, market, and stakeholder interests, with a particular focus on customer orientation.

1.2 Synthesis of Results

The project results were consolidated in a coordinated synthesis process at the end of the project. The derived findings and recommendations are presented in a results report. This paper is largely based on the report, which is published in German language [1].

To collect the insights gained by over 30 project partners in six clusters as central unIT-e² project results in these fields, a synthesis methodology was developed. Two to four key findings per cluster were discussed and elaborated in a structured format.

Subsequently, these cluster findings were reviewed by FfE and aggregated to deduce general recommendations. The project results were divided into the following fields, which also constitute the structure of the following chapters:

- Grid Integration of Electromobility
- Scalability and Standardization
- Information and Incentives for Users
- Economic and Ecological Benefits for Users and the Energy System

Thus, results from different project partners and in different levels of detail can be summarized in a comprehensive presentation.

2 Grid Integration of Electromobility

2.1 Findings

Increased pressure on grid operations are anticipated as a result of the electrification of the transportation industry and the ensuing rise in consumption of electricity. The regulatory process for grid-oriented control in accordance with § 14a of the German Energy Industry Act (EnWG) influenced discussions during the project. One goal of field trials was to evaluate these regulations' effects and technical execution. In essence, § 14a EnWG offers a feasible means to temporarily incorporate electric cars and other new consumers into low-voltage grids, like heat pumps and home storage systems. In order to prevent delays in the ramp-up of electric vehicles and other new consumers, grid operators are provided with capabilities to handle overloads in the short term. Concepts for future grid integration with high penetration of controllable consumer devices (CCDs) and increasingly digitized distribution grids were also developed.

Grid-Oriented Control of CCDs (§ 14a EnWG) – Experiences from Field Trials:

Distribution network operators (DSOs) are permitted by the German regulator (BNetzA) to reduce controllable loads, such as EV charging stations, in order to maintain grid security during periods of congestion. Grid fees get discounted for CCD operators, and they are guaranteed an immediate grid connection. For quick deployment, DSOs and CCD manufacturers must develop general recommendations for the technical design of interfaces. The technical chain for grid-oriented control was demonstrated in the unIT-e^2 field tests, demonstrating the route from the DSO's system to the electric car. This chain can pose a recommendation to the BNetzA for a standardized, mass-market-compatible setup. The increased simultaneity caused by market-based dynamic electricity prices, which can negatively impact grid load, was safely managed through grid-oriented control according to § 14a EnWG. User surveys indicated no noticeable loss of comfort.

Alternative Grid Fee Structures in Low Voltage Grids Based on Peak Demand – A Concept from the sub-project Grid:

Cost causation fairness, or reflecting the costs end users cause as a result of their behavior, is a key objective of the grid fee system. The current method is designed for private households with moderate peak loads. The customer base is moving from consumers-only to prosumers and flexumers as decentralized generation units and CCDs proliferate, altering grid usage and generating new needs.

The existing energy-based grid fee structure, which includes § 14a EnWG and other special fees for specific customer categories, redistributes grid expenses in a way that raises standard grid fees. This mainly affects consumers without CCD. Since the integration of prosumers and flexumers poses a challenge, higher grid fees for non-flexible consumers appear contradictory.

The developed concept [2] for grid fees is based on the annual peak demand of customers. The objectives are lower complexity, better compatibility with market-oriented CCD use, and a more equitable allocation of grid costs. The approach is based on the fact that demanded power is crucial for grid design and expansion needs. The introduction of demand-based grid fee flat rates in the standard load profile customers segment is proposed. This is expected to encourage efficient use of grid capacities, changing the behavior of consumers and producers. Standard grid fees are divided into tiers based on demand, specific to the grid area. False incentives should be reduced and planning security for grid operators and end users should be reinforced by eliminating exceptions like special fees.

Incentive-Based Grid Usage Control and the European Legal Framework – Concepts from the sub-project Research:

In addition to § 14a EnWG, also § 14c EnWG for market-based procurement of flexibility services in the distribution grid is included in the legal framework and enables DSOs to procure flexibility services for congestion management through transparent, non-discriminatory, and market-based procedures. Alternatively, incentive-based instruments in grid fees are considered. Both approaches are voluntary and aim to control grid usage based on users' willingness to pay. Two concepts for incentive-based grid usage control were developed.

The coordination and allocation algorithm for flexibility (KOALA) is an auction-based mechanism where users bid for grid capacity beyond their basic allocation [3]. Additionally, a "double-optional dynamic grid fee tariff" (dodyNT) was developed, incentivizing load shifting through dynamic grid fee adjustments [4]. Implementing these mechanisms requires sufficient observability of low-voltage grids. Both concepts were evaluated for legal and economic feasibility.

Moreover, the European legal framework for grid fee design was examined. According to the European Court of Justice, national regulators are solely responsible for grid fee design. The EU framework for this design, derived from the regulation on the internal market for electricity and from the Energy Efficiency Directive, was analyzed, revealing a lack of clarity and systematics.

2.2 Recommendations

The BNetzA should set the course for a fundamental reform of the national grid fee system. With a high penetration of decentralized generation and CCDs, such as electric vehicles and heat pumps, the cost causation fairness and incentive effects of grid fees need to be reassessed. In the project unIT-e^2, a concept for an alternative grid fee system based on demand tiers, as well as two different concepts for incentive-based grid usage control, were developed. All concepts are sufficiently elaborated to be brought into discussion with the regulator in the next step.

At the EU level, a consistent and clear structure in EU regulation regarding grid fees should be implemented by the legislator, in order to ensure legally secure application and uniform interpretation of the requirements by national regulatory authorities. Additionally, the European legal framework should support national regulators and enable the implementation of innovative solutions such as the presented concepts.

3 Scalability and Standardization

3.1 Findings

Due to the diverse and numerous roles and components in the ecosystem of intelligent electromobility, information and control commands must be transmitted along a complex process chain with many heterogeneous interfaces and protocols, as also depicted in the unIT-e² system architecture [5]. Established standards (e.g., IEC 61851, ISO 15118, VDE-AR E 2829-6-1, IEC 63380, OCCP, IEC TR 62746-2) already exist for communication between the various actors and technical components, such as the electric vehicle, the charging station, the grid operator, the intelligent metering infrastructure, and the energy management system [6].
The use of standards along the entire process chain allows for interchangeable integration of components, the so-called interoperability. Furthermore, solutions based on international standards enable their transferability and application in international markets.

Minimizing Room for Interpretation:
Standards facilitate communication between components from different manufacturers and reduce implementation effort compared to manufacturer-specific proprietary solutions. However, some standards leave room for interpretation, leading to different behaviors and, thus, impairing system interoperability. Field tests showed that, e.g., ISO 15118-2 and -20 have such definition gaps, causing communication errors or interruptions due to deviations in the implementation by manufacturers, potentially preventing vehicle charging. Clear guidelines are essential to ensure error-free functionality. The project achieved this through close coordination, iterative testing, and software adjustments. Interoperability was tested within and across clusters in a so-called plugfest [7]. Insights from the project are being fed into standardization committees to reduce room for interpretation.

Challenges in Integrating Existing Systems:
While it is now common practice for most manufacturers of components to provide interoperable and digital interfaces, existing systems are often equipped with proprietary solutions. Thus, it is useful to differentiate existing systems regarding digital interfaces:

- Existing systems that will neither be switchable nor controllable today or in the future,
- Existing systems that are not yet switchable or controllable today but will be through retrofitting,
- Existing systems that are already switchable or controllable today and thus offer the possibility of grid-oriented or market-based control.

In older systems, proprietary solutions and interfaces predominate, which do not allow uniform information transfer for grid- or market-side communication. This leads to different optimization potentials for existing and new systems. Interoperable energy management systems can integrate existing systems, but the flexibility potential is still primarily determined by the proprietary interfaces. Field tests have shown that integrating existing systems into the energy management system is possible, thus leveraging flexibility potentials in properties that would otherwise remain unused. Although these are smaller than with new systems, they should still be utilized for energy and resource efficiency. It could also be shown that complex optimizations can only be partially implemented by existing systems. However, existing systems have grandfathering protection under § 14a EnWG, so connection is not mandatory.

Continuous Development of Standards:
In addition to identifying definition gaps, the project identified necessary functional extensions and harmonizations of existing standards. Most controllable systems and especially energy management systems must have digital interfaces in the future. For internal communication in single-family homes, the EEBUS standard is used in the project, which already covers most use cases. For DSO-side control of CCDs, TR 03109-5 for the certification of CLS communication units was recently published. For local measurement data transfer from the Smart Meter Gateway (SMGW) via the HAN interface to the energy management system, the VDE AR 2829-6-1 Use Case “Monitoring of Grid Connection Point” (MGCP) was tested in the project, providing high-resolution and standardized measurement data.
Mapping different standards poses the challenge of harmonization, e.g., regarding ISO 15118-2 and the EEBUS Use Case “Coordinated EV Charging” (CEVC). Certain details still need clarification, such as unifying the optionality of certain data points between the standards.
Furthermore, for the use case frequency containment reserve (FCR), requirements and specifications were collected within the project to implement this use case with existing standards. The EEBUS use case “Power Envelope” (POEN) was initially used as a basis to cover most of the FCR requirements. The insights from the project enable the development of a specific EEBUS use case for FCR.

3.2 Recommendations

For the development of new energy-related use cases, it is necessary to continue interdisciplinary development of new standards and to pass identified requirements from practical implementation to standardization committees.
The local connection between the SMGW and the energy management system for measurement data transfer should be considered in the future standardized installation process. Additionally, interoperable minimum requirements for the interval of measurement data transfer and the necessary data formats must be standardized.
Furthermore, interoperability tests should be conducted to identify inadequately defined or differently interpreted standards, and the findings should be fed back into the committees. These tests can take place either in laboratory environments of the respective companies or as part of test events or so-called plugfests. Such events should be open-ended and held regularly across industries and manufacturers. Additionally, the EEBus Initiative e.V. has created an Implementation Guideline for the “Limitation of Power Consumption” (LPC) use case to reduce interpretation gaps. In the future, implementation guidelines will also be created for other use cases.

4 Information and Incentives for EV Users

4.1 Findings

Information Needs for Purchase Decisions:

Interviews and surveys in the unIT-e² project reveal that users of charging strategies and controllable charging infrastructure components need information and are uncertain about where to find it. A dynamic market and changing conditions, such as regulatory changes, worsen this information deficit, causing significant uncertainty during the information and purchase phase of electric vehicles and related components.

There is a lack of comprehensive contact points to answer questions about integrated electromobility. For the purchase decision, electric vehicle users need simple, understandable information that explains the connections between charging strategies and the components of a controllable charging infrastructure. Therefore, cross-industry and manufacturer-independent information is necessary for potential buyers to understand intelligently controlled electromobility and make informed purchase decisions.

Incentives for Providing Flexibility:

After the purchase decision, users should be incentivized to provide load-side flexibility. In Germany, the retail electricity market mostly uses static tariffs, but integrating electromobility into the grid requires the utilization of user-side flexibility. Different contract designs can facilitate this utilization while also compensating for subjective limitations in usage.

Financial incentives for flexibility can reduce charging costs through dynamic electricity tariffs linked to electricity exchanges. However, adoption barriers and technical limitations mean dynamic tariffs are rarely used now, with some exceptions like The Mobility House, Tibber, or Tado.

The unIT-e² project developed legally valid contracts for variable tariffs, including market-based and grid-based time windows.

Widespread adoption of dynamic tariffs requires overcoming barriers. A field trial in unIT-e² showed most participants did not perceive restrictions in mobility due to shifts of charging processes. Publicizing such results can help reduce adoption barriers.

4.2 Recommendations

Manufacturers should provide potential customers with accessible and comprehensive information for purchasing electric vehicles and related charging and control components to ensure the functionality and compatibility of the systems.

DSOs should focus on creating the technically necessary infrastructure for customer-side provision of flexibility. In particular, the digitalization of the low-voltage grid contributes to creating suitable conditions. Local real-time monitoring of grid load enables the grid-friendly use of customer-side flexibility.

Electricity suppliers and BNetzA can help reduce adoption barriers by implementing incentives for dynamic tariffs. To enable efficient grid management, it is necessary to know the actual grid load. Therefore, grid operators should be incentivized to transition to the target model of grid-oriented control.

5 Economical and Ecological Advantages for Users and the Energy System

5.1 Findings

Electromobility can offer both economic and ecological benefits. This applies to the comparison of electric vehicles with conventional ICE vehicles and to the comparison of intelligently controlled and bidirectional charging with uncontrolled direct charging in the use cases of intelligent electromobility. In the project, both the benefits for vehicle users and the systemic perspective were analyzed.

Benefits from the User's Perspective:

For some vehicle classes, the total costs of electric vehicles are already cheaper than comparable combustion vehicles. However, smaller electric vehicles are often more expensive regarding their total costs. Ecologically, smaller electric vehicles are advantageous due to significantly lower lifecycle greenhouse gas emissions, mainly because of the resource-intensive production phase, especially the battery [8].

Intelligently controlled and bidirectional charging can save electricity costs compared to uncontrolled charging. However, considering additional technology costs, these methods are not always cheaper [9]. Under current conditions (e.g., double taxation in bidirectional charging), the use cases are not always financially viable. Regarding operational greenhouse gas emissions, only some use cases achieve savings compared to uncontrolled charging, as some increase emissions due to cost-optimized rather than emission-optimized charging [9].

Systemic Benefits of Intelligent Electromobility:

The optimized use of charging processes for electric vehicles (uni- and bidirectional) can support the energy system as a cost-effective flexibility option and ensure supply security. Ecologically, it accelerates the integration of renewable energies. High user adoption is crucial to utilize the vehicles' potential. The approach according to § 14a EnWG is less restrictive than reducing charging power, as done in some countries. However, significant incentives for systemically optimized electric vehicles can reduce electricity prices and price volatility long-term, potentially lowering cost savings for individual users. Detailed regional ramp-up of electromobility must consider grid restrictions [10].

Ecologically, widespread bidirectional charging provides systemic value. A lifecycle analysis shows using vehicle batteries as flexible storage can reduce the need for stationary battery storage in Germany by up to 117 GWh, saving emissions and resources. Bidirectional charging can accelerate decarbonization of the energy system by 2030 to 2035 by efficiently integrating renewable energies [11].

5.2 Recommendations

If government incentives for electric vehicles or their systemic use are planned, they should be designed to promote vehicle classes and use cases that are ecologically advantageous and ensure system-friendly charging and discharging.

Since economic benefits do not always correspond to ecological benefits, providers, manufacturers, and policy makers should clearly explain the respective advantages of a use case to users.

6 Summary and Conclusions

The presented project results can be classified in four fields. Grid integration of electromobility and standardization of the required process chain were the two fields which posed most challenges and discussions, leading to valuable insights for future implementation. Due to the project's strong field test focus, insights on information and incentives for users could also be obtained. The economic and ecological evaluation of electromobility and its impact on the energy system was primarily considered from a research perspective.

Discussions on the grid integration of electromobility were largely dominated by developments around § 14a EnWG, whose implementation was successfully tested in field trials. Additionally, the investigation of both market-based and grid-based incentive mechanisms was a priority, leading to the development of an auction-based capacity allocation mechanism and an optional dynamic grid fee tariff. Both proposals aim to efficiently shift loads to low-load times by making customers pay a high price for demanding high grid loads during peak times. Additionally, a concept for fundamentally changing the grid fee system was developed in the sub-project Grid. This concept targets peak demand and includes all customer groups (consumers, prosumers, and flexumers) in the challenges of grid expansion and costs through tiered grid fee flat rates, while also providing incentives for efficient use of the infrastructure.

Various field tests and the unIT-e² plugfest showed that existing standards and protocols leave room for interpretation, identifying a further need for standardization activities. This involves not only new components but also the effective integration of already installed components.

The investigation of the user perspective revealed that a significant hurdle in the purchase decision of electric vehicles and related components, such as charging infrastructure and control systems, is an information deficit among customers. It is essential to provide appropriate information to enable the market ramp-up of electromobility in practice. Once customers have switched to using electric vehicles, it is highly relevant to set incentives for providing flexibility. This can also be seen in the investigation of the economic and ecological benefits of electromobility for users and the energy system: Not all electric vehicles are currently cheaper than comparable ICE vehicles, and not all types of charging are economically and ecologically more sensible than simple direct charging.

The derived recommendations are primarily directed at manufacturers of electric vehicles and related components, as well as legislators. They are essential for providing information to users of electric vehicles and setting incentives for load flexibility. Additionally, standardization committees and regulators are relevant stakeholders to overcome the final hurdles for the mass-market ramp-up of electromobility.

Overall, it can be noted that the unIT-e² project worked on important key topics and made a significant contribution to the current developments around electromobility in Germany through the testing of § 14a EnWG, user surveys, and the testing of technical interfaces in field trials.

However, the path to practical implementation is not yet paved. Further research and development is required, particularly in the areas of grid integration and scalability. After successful grid integration of unidirectional electric vehicles, the next step for the integration of electromobility remains: the market ramp-up of bidirectional charging and comprehensive system integration into the energy system.

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