Deliverable D4.4

Common findings for the interaction between Electric vehicles and electrical networks[1]

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

AC	Alternating Current
ACEA	European Automobile Manufacturers' Association
BEV	Battery Electric Vehicle
CEE	Commission on the Rules for the Approval of the Electrical Equipment
CEN	Comité Européen de Normalisation
CENELEC	Comité Européen de Normalisation Électrotechnique
DC	Directed Current
DSO	Distribution System Operator
EN	European Norm
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
LV	Low Voltage
OEM	Original Equipment Manufacturer
PHEV	Plug-In Hybrid Electric Vehicle
R&D	Research and Development
V2G	Vehicle to Grid
WP	Work Package

1 Executive summary

The aim of this Deliverable is to draw recommendations for facilitating a mass integration of Electric Vehicles (EVs) in the European networks from a DSO perspective. To achieve this, D4.4 summarizes the main results of the entire work package 4, highlighting common findings and recommendations identified in previous WP4 deliverables. The focus is on three main core topics:

- Recharging Infrastructure
- Impact of EVs on the distribution grid
- Grid supporting opportunities

Another subject of the analysis are the hurdles encountered during the project that may hinder the integration of EV. Due to the unique situation in the Green eMotion consortium, which includes partners from many European countries, it became evident during the project that different conditions in each country might give rise to different hurdles (and opportunities) for integrating EVs into the electrical network. For example, there is a huge difference in the capacity of standard household connections (e.g. 16A 1-phase in the Netherlands, 63A 3-phase in Germany). D4.4 summarizes those findings and estimates the impact for the future development of e-Mobility in Europe.

When analysing the main findings regarding charging infrastructure towards the integration of EVs into European electricity networks, several conclusions can be drawn. The uncertainty with respect to different types of socket outlets and plugs, which was a dominant factor especially for manufacturers and operators of charging infrastructure back in 2011, has been resolved in the last few years. As the European directive prescribes the use of Type 2 plugs and socket outlets for AC charging and at least the combined charging system (with Type 2 as the basis) for DC public charging, charging station manufacturers and operators have benefited from a higher security for their investments. This was supported by the evidence from the assessment of the recharging infrastructure recently deployed across Europe (2014). [2]

The extent to which the cost of hardware and installation will drop in the future is uncertain. If cost components are analysed separately, it is likely that the pure hardware costs will drop significantly in a mass-market phase due to learning curves, gained operational knowledge and economies of scale. Installation costs on the other hand, mainly driven by the cost of labour, are likely to remain high.

The work carried out in Deliverables D4.2 and D4.3 analysed how the charging of EV may impact the grids (in terms of both power quality and grid capacity) and showed that in the short term most electricity grids are not going to be affected by the small share of EVs. However, some aspects should be examined in more detail. The effects of harmonic distortions on the grid, although not particularly critical today, could represent a significant aspect of the impact of EVs in the future if no specific regulation is put in place. Following the recommendations regarding harmonics, OEMs (in case of AC charging) and charging station manufacturers (in case of DC charging) should work on common design requirements for inverters in order to reduce harmonics when the inverters are not operated at nominal power (i.e. when load management is applied for reducing the demanded power of the EV).

In addition to modifying hardware, grid planning rules will also need to adapt to EV rollout. As there is no ‘standard’ distribution grid in Europe and the impacts of EVs in the specific regions are likely to vary, a

[2] Internal GeM WP4 survey launched in 2014 addressing the current state of recharging infrastructure

European-wide effort should be made to develop distribution grid planning practices that appropriately consider the additional demand by EVs.

It was also found that new methods may be necessary for estimating load, especially in cases with fewer customers and flexible loads, where averages are a poor estimation. New technologies such as Smart Meters can provide a large statistical base which can facilitate more accurate load estimation and forecasting.

When looking at the current market design and the regulatory regime of the electricity distribution business, it is evident that there is no general 'hub' for matching the energy demand of EVs with local restrictions of DSOs. On a local level, e.g. parking lots, this concept has been tested in the Spanish Demo Region ES01 of Green eMotion. However, in the case of mass market applications, a local management (dispatch) does not incorporate global effects. For the upcoming years one major task for DSOs will be to work on a centralized integration model for coordinating EV charging behaviour.

To summarise, Europe has a good starting position to de-carbonize road transport, but significant work yet remains to be done, especially in linking the currently more or less detached industries of OEMs and utilities. The findings of this deliverable highlight the current capabilities and future challenges and therefore open questions and identify areas for future projects.

2 Introduction

Within the Green eMotion Work Package 4 (Grid Evolution) the effects of Electric Vehicles on the electric grid have been analysed. The aim of this deliverable, Deliverable 4.4, was to develop recommendations for integrating EVs in the European networks from a DSO perspective. The results and recommendations contained in this document are based on the work done during the four years of this WP. The detailed results can be found in different WP4 deliverables[3]:

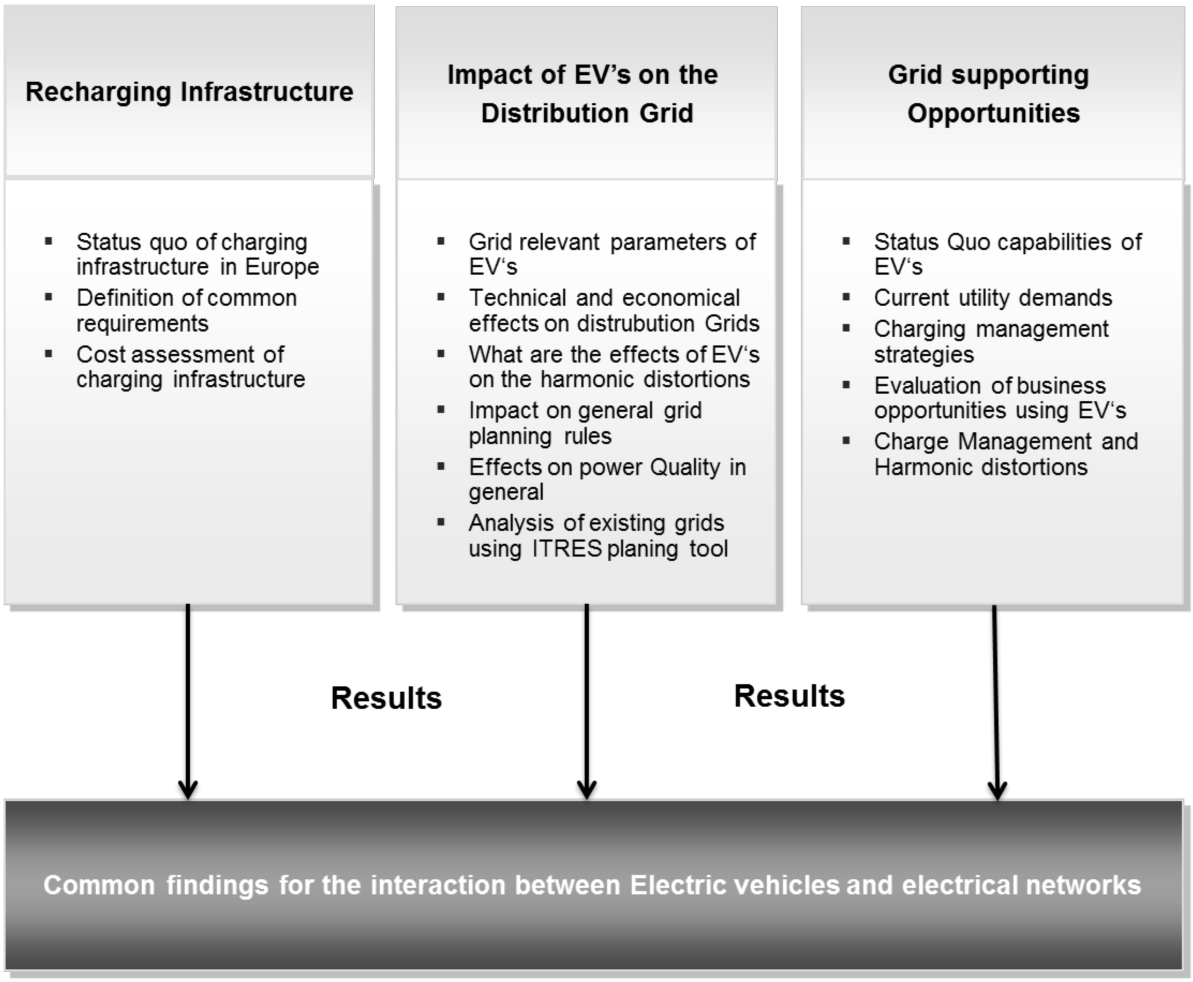
- D4.1 – Specification for minimum requirements for charging spots
- D4.2 – Recommendations on grid-supporting opportunities of EVs
- D4.3 – Tool kit for calculating reinforcement cost for specific grids
- D4.5 – Survey of new functionalities connected to mass rollout of EVs

As shown in Figure 1, D4.4 collects the results of this WP and develops common findings and main observations identified in other WP4 deliverables. The focus lays on three main core topics: 1) recharging infrastructure, 2) impact of EVs on the distribution grid and 3) grid supporting opportunities. D4.4 evaluates whether the outcomes of the different tasks are in line or contradicting.

To achieve that, this report summarizes and explains the main findings in chapter 3. This should enable the reader to understand the key elements of each topic and link those to the broader challenge of integration of EVs into electrical networks.

[3] http://www.greenemotion-project.eu/dissemination/deliverables-infrastructure-solutions.php

Figure 1: Scope and structure of the activities done in Working Package 4



Subsequently an evaluation of those findings is performed. Necessarily this includes a check for common messages out of the deliverables.

Another subject to analyse is encountered hurdles. Due to the special situation in the Green eMotion project, where there are partners involved from many European countries, the specific situations in each country might bring up different hurdles (and opportunities) for different integrating EVs into the electrical network. D4.4 intends to summarize those findings and estimate the impact for the future development of e-Mobility.

Another question to which D4.4 gives answer is about necessary prerequisites for establishing certain schemes or functions, e.g. charging management strategies. This might also include current regulation, which hinders a fruitful and sustainable development of e-Mobility (in the context of "Grid EVolution").

Coming out of the analysis of each deliverable, guidelines for a successful infrastructure deployment are developed. D4.4 achieves this by connecting outputs out of WP4 with the (intermediate) results of the demo regions in Green eMotion, which are contributing by answering two surveys performed in D4.1 and during year four. Thus necessary features of charging infrastructure, grid conditions and charging management strategies are subjects for this best practice part of D4.4. Furthermore the results needs coming out of the deliverables are checked for their economical and technical feasibility.

Combining the evaluation and the best practices, the final outcome of this deliverable is for deploying infrastructure along the e-Mobility value chain for a successful uptake of the EV market.

In Summary D4.4 will provide the reader with:

- Overview and evaluation of the results of the work done in WP4
- Describing encountered best practices
- Giving recommendations for facilitating the integration of EVs in European networks

This document is a standalone deliverable. However, for more technical details and insights to the results which bring to draw the recommendations and conclusions of this report, the reading of the above mentioned deliverables is recommended.

3 Summary of the WP4 Outcomes

3.1 Recharging Infrastructure

Key themes tackled in this section:

- Status quo of charging infrastructure in Europe
- Definition of common requirements
- Cost assessment of charging infrastructure

3.1.1 Introduction

Within task T4.1 the Pan European requirements for recharging infrastructure including design, installation, and associated costs have been surveyed and data has been collected, analysed and presented. The main objective was to have a status quo of the existing charging infrastructure in Europe, as a basis for upcoming common requirements. The survey concentrated on a general overview of installed hardware including communication protocols and costs of hardware and installation. The first survey was circulated and assessed in 2011. The most relevant questions were repeated in a new survey in 2014 in order to check for developments and trends towards a harmonized recharging infrastructure.

3.1.2 Key findings

- Status quo of charging infrastructure in Europe

An important conclusion drawn from the 2011 survey is that according to the data received, the installations being specified by the participants utilities and car manufactures) indicate a trend toward the Mode 3 - Type 2 - variety for the home charging and street/public charging. France in general is installing Mode 3 Type 3. In some parts of Ireland and the UK, Mode 3 with attached cables and Yazaki connectors are being installed for home use.

Also the installations being specified by the survey participants for fast charging were of the 50kW DC CHAdeMO type. Very important is also the description related with utility interface connection and protection requirements including earthing.

At that time a recommendation from Green e Motion was to follow closely the on-going discussions on standardization issues related with EV grid connection.
Analysing the new survey of 2014 it is interesting to check whether there have been new developments regarding charging infrastructure. From a technical perspective there have been some slight, but significant, changes. Compared to the first survey in 2011, the IEC 62196-2 Type2 plug is now the dominant choice of infrastructure providers. Back in 2011 there were several stations in field, which where equipped with the IEC 62196-2 Type3 plug (mainly in France and Italy), but also with an ordinary household socket or CEE industrial connectors. The development towards a harmonized socket outlet / plug solution within Europe in line with national wiring rules is also reflected in the EU directive on recharging infrastructure, which requires as a minimum setup a Type2 outlet.

Additionally there is a development in the area of DC fast charging stations. Whereas in 2011 those stations were using CHAdeMO connectors and charging management schemes, in 2014 the European and US-supported CombinedChargingSystem (CCS) were gaining momentum. Many charging point operators, which would like to give service to more or less all customer are going for a multiple outlet charging station, supporting CHAdeMO and CCS for the DC case.

- Definition of common requirements

The current offer from charge post manufacturers for home charge units are single phase 16A. Early indications are that such design functionality adequately meets customer's expectations while at the same time posing no undue burden on domestic home utility connections. This situation should be consistent across EU jurisdictions. Opportunities exist for utilities that provide a stronger utility grid home connection to allow the rating of the home charge unit to increase to 32A single phase and for some jurisdictions and utilities to increase to 3 phase. This situation will vary considerably across EU but should not impact or restrict roll-out in any serious way. In the various pilot and demonstration projects all cars are single phase 16A but this will change. There are already cars available on the market offering various AC charging means, starting from 16A single phase up to even 63A three phase.

Some conclusions out of the survey performed in Green eMotion might be related to customer preferences. As there is a strong correlation between charging power and charging time, customers in the future might demand solutions for them to charge with such power even at home, in case their EV is capable of doing fast charging at home. To which extend this will be the case, is currently not yet researched.

On street post 16A single phase and 32A three phase service is presently available with a the possibility to increase to 63A three phase.. With this level of design, functionality available and planned it is expected that an adequate range of design options will be available to meet grid requirements and restrictions as well as customers expectations as far as possible.

- Cost assessment of charging infrastructure

The average costs of On Street and Public/Private charging infrastructure vary as follows according to the data of the 2011 survey. The variation in costs for AC posts goes from €5500 to €25000 including installation and ancillary equipment on a per charge post basis. Civil costs drive the costs on the high end of the installation costs/prices.

DC charging units vary in price from €13k to €50k per unit. Installation costs vary from €3500 to €6000. An average package was €48000 due to high civil costs at some installations.

From a cost perspective the 2014 survey indicates that there are only small changes in the field of grid connections costs. As processes and costs for grid connections in the different regions and EU member states are more or less in a mature state it is, according to the survey, unlikely that those costs will vary and decrease in the upcoming years, because they are mainly driven by variable costs for material and workforce and fixed costs for grid connection handling. Moreover, the execution of certain policies (e.g. subsidies) could have some impact on these prices.

What could be observed was a slight decrease of costs for charging infrastructure itself. For AC public charging infrastructure the average costs including installation were approximately €5500, which is a clear improvement compared to the situation back in 2011. This is mainly driven by the fact, that many EVSE manufacturers are building their second generation EVSEs or building more stations to achieve economies of scale. With an upswing in EV sales and an increase of charging stations sold, it is very likely that those costs for the hardware will decrease in the future.

3.2 Impact of EVs on the Distribution Grid

Key topics tackled in this section:

- Grid relevant parameters of EVs
- Technical and economical effects of charging EVs on distribution grids
- What are the effects of EVs regarding harmonic distortions
- Impact on general grid planning rules
- Analysis of existing grids using the ITRES planning tool

3.2.1 Introduction

Within the different tasks of WP4 several questions around the impact of EVs on the distribution grid were tackled. Starting with the expertise from previous EU-funded projects like Grid4Vehicle (G4V) or MERGE, the effects on the grids when applying different control strategies were analysed (both in terms of capacity and quality). A tool for calculating the technical and economical impact (named ITRES) tool, was also developed and tested by different DSOs. The subsequent chapter describes the general outcome and conclusions of the work performed in tasks T4.2 and T4.3 regarding the impact of EVs, with an emphasis on distribution grid operation.

3.2.2 Key findings

- Grid relevant parameters of EVs

The objective of this part of the report was to summarize parameters identified, which are relevant for performing a comprehensive assessment of EVs impact on the low voltage (LV) electricity grid. During the analysis it was assumed that a stochastic approach would be used to derive the charging profiles for the EVs and in this way assess the technical impacts on the LV grids. Three charging profiles were considered within these assessment studies: a) User-dependent charging profiles; b) Timer-based charging profiles; c) Load-dependent charging profiles. Those profiles can also be found in the subsequent chapter of this document (chapter 3.3).

The identification of the parameters is based on the response of several DSOs on a survey regarding assessment of EVs together with knowhow gained in previous R&D projects related to EVs, such as EDISON, G4V and MERGE.

The relevant parameters identified are listed in the table below:

Table 1: Relevant parameters of EVs for the impact analysis on distribution grids

	Parameter
EV	Number of EVs, N_{ev}
	Battery type or size B
	Converter C_{ev}
Charging	Charging power S_{ch}
	Charging time T_{ch}
	Charging profile CP
	Energy Consumption E_{ev}
Charge Management	Charge Management Strategy CMS
	Charger intelligence CI/CAI
	Fast Charger
	Price of electricity
Grid parameters	Consumption S_c
	Production S_p
	Grid Topology
	Capacity
	Power Quality PQ

The analysis of these parameters reveals that for the very short term no significant problems are foreseen in the grid due to the additional demand generated by EVs. An EV charges in general at a power level low enough not to cause particular problems, as long as the EV penetration is low. This will change in case there is significant EV uptake level. The limiting factor for the low-voltage grid will be the capacity of cables and transformers and other critical parameters such as maintaining the frequency and an adequate voltage. Those are most likely to cause critical failures and can be resolved by adding extra capacity in the grid.

In such cases the grid-friendly charging behaviour becomes an attractive option for a DSO. This could be implemented by influencing the user behaviour through campaigns or through a technical solution. The technical approach will mean the interface, i.e. the charger, should support different charging options and many solutions are possible here. One possibility for the user, as implemented in some mode 3 EVSE, is to introduce a “delay charging” icon that shifts the consumption to start at a certain time. Further benefits to grid operation could be achieved by enabling cars and infrastructure to perform smart charging (e.g. using ISO/IEC 15118 as a communication protocol). Thus grid operators could make offers to EVs and EV drivers to charge in certain time periods to avoid peak loads or optimize the integration of renewable energy. On the other hand users know with start of the charging event how the car will charge in the future and might adjust their planning in case they could save some money.

- Technical and economical effects on distribution grids

The scope of this part of D4.2 and D4.3 was to describe the impact of EVs on the reinforcement needs and associated costs of low voltage networks. The focus is on how different EV parameters effect the reinforcement costs. The evaluation has been done by developing and analysing a set of scenarios that assumed a broad range of different input parameters.

The results have shown that the charging profile is the most important parameter of all the investigated parameters. As the charging profile depends on the charge management strategy, it means that the charge management strategy is the most important parameter. With a grid-friendly charge management strategy it is possible to avoid most reinforcements and their associated costs, reducing the significance of all the other parameters.

The results also showed that a simple timer-based charge management strategy with the goal of improved grid friendliness, could end up making the charging process less grid friendly due to a kickback effect since a large number of charge processes may commence at rated power at the same time. This resulted in significantly increased reinforcement costs in many of the networks when using the simple timer-based charge management strategy. More elaborate timer-based charge management strategies, e.g. distributed time slots for charging across LV branches can likely avoid kickback and its negative effects on reinforcement costs, while still providing the benefits of moving EV charging away from the existing load peaks.

Another finding was that the importance of different parameters depended highly on the topology of the networks. Networks with lengths of more than 400m between secondary substation and farthest customer were generally found to be impacted by voltage issues first. Networks with lengths below 300m were generally found to be impacted by thermal issues first. Networks with thermal issues could be divided into two groups – those that required current (line) reinforcement first and those that required transformer reinforcement first. In the evaluated networks the deciding factor appeared to be the number of customers. Networks with few customers were generally supplied by smaller transformers, thus exceeding the thermal limit of the transformer first. Networks with many customers on the other hand were supplied by larger transformers, exceeding the thermal limit of the lines first.

Voltage control and EV location were found to only have a significant impact in networks with voltage issues, while networks with thermal issues were largely unaffected. For networks with voltage issues, EV location is an important parameter.

- What are the effects of EVs regarding harmonic distortions

In D4.2 Harmonic load flow simulations in Power Factory have been performed for three different charging strategies: User-dependent, Timer-based and Load-dependent. Based on a “base-case” simulation on 30 specific low-voltage grids, 6 specific grids have been selected for a more comprehensive assessment.

By adding one EV at a time to the grid, the maximum number of EVs to be connected to the grid was determined in terms of voltage violation, line loading violation and harmonic violation. From the analysis, harmonic emissions from EVs are not expected to create a need for reinforcement of the grid in the nearest future, but could be considered as an issue for communication towards smart meters in the narrowband using e.g. Power Line Communication. The results show, that ensuring a sufficient short-circuit level is the most important requirement to avoid harmonic distortion.

A closer cooperation between manufactures and DSOs in the field of electromagnetic compatibility should be established in order to ensure compatibility between equipment connected to the public electricity grids.

- Impact on general grid planning rules

Current planning and operation paradigms of electrical distribution networks are facing fundamental challenges in view of the envisaged decarbonisation of the power industry, in which large-scale integration of electromobility is expected to play an important role. The key concern is that the widespread integration of electrified transport will lead to increases in peaks that are disproportionately higher than corresponding increases in annual electricity demand. This will potentially require significant reinforcement of distribution network infrastructure, while at the same time the utilization of network capacity will reduce very significantly, increasing the system cost of decarbonising road transport.

Under the current, largely passive management approach to distribution network planning, networks are designed to operate with minimum real-time management, and with an in-built capability to deal with the expected worst-case conditions. Future distribution network planning standards and tools should assist network planners in selecting optimal portfolios of network development strategies, including network reinforcement, use of distributed generation, flexible demand (e.g. EVs), application of energy storage technologies and advanced network technologies so that the costs of these options are balanced against the value they bring to network consumers.

In addition to considering smart non-network solutions, future network planning tools will need to accommodate the improved information on local network conditions provided by advanced network technologies i.e. make use of more precise information on actual network conditions. The management of the EV charging fed from renewable energies (considering their availability in some periods) will be a key feature for future operation of the grid.

In conclusion, the deliverables D4.2 and D4.3 identify the solutions that need be adopted to manage the future distribution grids (resulting from large scale deployment of DER, and not only EVs) and what needs to be incorporated in the planning tools of the future distribution grid. As an example, under the 'Smart' operation paradigm, which optimizes EV charging in real time to minimize the impact on the network, any constraints associated with EV demand flexibility will need to be incorporated in the future distribution network planning framework, including the risk and cost associated with the supporting ICT infrastructure.

- Analysis of existing grids using the ITRES planning tool

During the analysis of the EV impact in distribution grids it was found that new tools are needed that can estimate the economic impact of different solutions and allow more flexibility when it comes to load forecasting. For example an impact analysis of alternative charging strategies and different uptakes of EVs on the reinforcement of a specific LV distribution network is a very interesting research question as very little information or publicly available tools have been available in this area prior to the start of the GeM project. For that reason, a new tool ITRES has been developed in WP4 to quantify the impact of a significant uptake of electric vehicles (EVs) on the need for reinforcements in a specific LV distribution network over the time-horizon of up to 25 years. The key purpose of the tool was to enable the partners in the project to analyse the impact of different EV uptake levels and charging policies on the local LV distribution network, particularly in the demo-regions. Furthermore, this also enabled the evaluation of benefits of alternative smart charging policies for specific LV networks. Unlike the models previously developed in other electromobility projects such as G4V or MERGE, the ITRES tool will be publicly available for download and use, making it the first analytical tool of this kind in the public domain[4].

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[4] http://www.greenemotion-project.eu/dissemination/deliverables.php

Different sets of data are required as input into the ITRES tool: LV network data, cost of network assets, load profiles and EV charging profiles. The tool identifies any violations of thermal and or voltage constraints. If there are constraints that are violated appropriate network reinforcement solutions are presented together with the costs of reinforcements.

It was also found that new methods may be necessary for estimating load, especially in cases with fewer customers and flexible loads, where averages are a poor estimation. New technologies such as Smart Meters can provide a large statistical base which can facilitate more accurate load estimation and forecasting.

ITRES assumes balanced loads across phases, according to the required specifications defined within WP4. Since slow EV charging is mainly single-phase and in many countries also individual household network loads are single-phase, this tool would require further enhancement to include all possible use cases of EV charging. This means that for the countries where the supply is done using single-phase solutions, the results of these studies only provide guidelines regarding the need to reinforce the grid (i.e. individual branches of the network).

3.3 Grid supporting Opportunities

Key topics tackled in this section:

- Status Quo capabilities of EVs
- Current utility demands
- Charging management strategies
- Evaluation of business opportunities using EVs
- Charge Management and Harmonic distortions

3.3.1 Introduction

Much work, also outside of Green eMotion, has been performed to evaluate the opportunities (technically and economically) coming along when Electric Vehicles are connected to the electric grid[5]. Together with the 20/20/20 goals of the EU EVs could play a major role to integrate renewable energy into traffic and therefore drive decarbonisation of mobility. But what kind of charging strategies are required to perform that and are those strategies economically feasible for all players involved in E-Mobility? What are the prerequisites for cars to play an important role for supporting those strategies? Those questions and more are answered in the subsequent chapter.

3.3.2 Key findings

- Status Quo capabilities of EVs

Those EVs which are currently available in the market can be clustered into specific groups regarding their capability in taking part of supporting the grid. Those clusters are mainly not determined by certain manufactures but from their compliance to different international standards for charging. But there are also differences in terms of the type of vehicle (PHEV or BEV) or their charging types (AC or DC). First the subsequent paragraph explains the difference by standard applications.

All vehicles which are available needs to comply to the EN 61851-1 standard, describing the pilot signal between charging stations and vehicles for signalizing different current levels and vehicle states. As this signalling is not digital (e.g. like e-mails) but an analogue signal the kind and amount of information which can be exchanged is limited. However, many applications in the regions are highlighting that even with this limited information cars can be charged with different power levels according to the available power in certain areas. On the other hand this signalling also carries some major weaknesses. If for example one car is charging and the available power decreases there is no means to tell the car (and therefore the user) a duration of that kind of limited service. Additionally the standard is not defining how to deal with certain authentication necessities. One can argue that authentication of users is not a technical parameter which should be defined in such kind of technical standard, but the current field experience shows that at least procedures should be standardized to guarantee a minimum level of service on the one hand (like roaming) and enough flexibility for upcoming business models in the field of E-Mobility (see also parts of the developed NWIP for standardizing the EVSE-Backend communication in D7.7) .

Because of that EVs and charging stations could additionally be equipped with equipment capable of performing digital bi-directional communication. This communication is standardized in the ISO/IEC 15118 standard series and enhances the already existing possibilities by providing means for negotiate charging plans with different power tariffs and prices prior to a charging session. By this, the usage of (forecasted) renewables can easily be maximized in specific areas or even in broader regions. Currently only a small amount of EVs and charging stations is supporting this new standard, but trough the ACEA

[5] One example is the also EU funded project e-DASH [e-DASH (2015), http://edash.eu/]

announcement to have such bi-directional communication in all vehicles starting from 2017 onwards[6], new market opportunities of e.g. energy market aggregators might arise.

Besides these technical limitations due to standards cars also slightly differ trough their types. This means, that for example PHEVs could potentially contribute less in vehicle to grid applications as pure battery electric vehicles, due to their limited battery capacity in case it comes to reverse power flow. As this is the major difference between those two car categories, even an increase of Plug-In Hybrids will increase the potential of E-Mobility for supporting the grid.

A little more controversial is the question about different charging types. Due to the actual range limitation of EVs many OEMs and EVSE manufacturers are promoting DC fast charging scenarios along highways. This model follows the same principle, which follows the well-known gas station principle of conventional cars. The application of this usage is for sure on recharging the car as fast as it is possible to (re-)gain range in a short amount of time. A major effect of EVs compared to other 'loads' in the grid is their potential flexibility paired with high charging powers. This effect is of special importance, if the integration of renewable energy in specific regions is top priority (on charging strategies see the subsequent paragraphs). DC (fast) charging and its special needs of the customers (aim: minimization of waiting time) and operators (aim: maximization of usage) is rather conflicting to this idea.

- Current utility demands

The impact of any load on a network depends on its variability and how this coincides with other existing loads. This is a critical component in any assessment of EVs on the network, yet for EVs there is no information on their variability which will depend on charging patterns and rates as well as on customer usage. Similarly another critical issue is how the customer will respond to Utility tariffs, as transfer of EV charging from peak to off peak would again be critically important in any analysis.

Accordingly it is necessary to assess the pattern of EV charging and develop measure of EV load diversity, while knowing, that most low voltage networks are not equipped with any, or only a few monitoring systems to retrieve the actual status in specific feeders or transformers. As a result, integrated 'smart grid' applications need to integrate information from many different parts of the electric grid like generation, transmission and demand. Depending on their market share, EVs will play an important role in that field. Therefore one single interface to predict and control the charging pattern, ideally a standard, is crucial for shaping the integration of EVs into the smart grid to minimize handling costs and maximize utility for both, the DSO and the EV user.

- Charging management strategies

From a pure grid side, the choice of charge management strategy influences EVs impact on the grid. Deterioration of power quality as a consequence of reducing the charging power by modulating the charging voltage is only one parameter to be considered when assessing grid impact. In Green eMotion it has been tested with 5 different EVs that approached the market in 2012. Among other parameters, such as harmonics in general, voltage drop and overloads also need to be included to perform a comprehensive assessment of EVs impact on low voltage distribution grids. Today grid planning tools are not capable to perform such assessment in a very efficient way as it has so far not been requested by the DSOs.

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[6] ACEA (2012): ACEA position and recommendations for the standardization of the charging of electrically chargeable vehicles
http://www.acea.be/uploads/press_releases_files/ACEA_position_on_EVs_standardisation_May_2012.pdf

EV charge management strategy, penetration and charging power were found to have a profound impact on all networks, both in regard to network reinforcement and reinforcement costs.
The two simple charge management strategies saw a significant impact on network reinforcement and reinforcement costs from both penetration and charging power. Two different charging powers were evaluated – 3.7 kW and 22 kW, corresponding to ordinary home chargers and fast chargers. It was found that use of fast chargers increased network reinforcement and reinforcement costs substantially. EV penetration rates were found to have a high impact on network reinforcement and reinforcement costs as well. With low penetration and home chargers, the majority of the investigated networks required no reinforcement. With high penetration, a significant increase in both network reinforcement and reinforcement costs was found.

The large influence of both charging power and penetration rate show that good forecasts of these parameters are crucial when evaluating the impact of EVs, as both parameters have a significant influence on both network reinforcement and reinforcement costs.

The complex charge management strategy showed a very limited impact from EV penetration and charging power. In the majority of the networks, no reinforcements were seen required regardless of EV penetration and charging power.
This demonstrates that with more complex, i.e. grid friendly, charge management strategies, the other parameters evaluated in this study can become largely insignificant. Of course EV user's needs have to be considered at the same time.

Concluding here are the recommendations regarding charging management strategies:

- to OEMs to improve the design of embedded hardware of EVs in order to sustain ToU tariffs with real time adjustments strategy;
- to Regulatory Bodies to set the incentives framework and suggestions for smart charging business actors depending on the national policies that might be adopted.

- Evaluation of business opportunities using EVs

The evaluation of business opportunities using EVs revealed that depending on the role of the actors (DSO, OEM, EVSE operator etc.) different kinds of vehicle operation or charging management strategies would be more profitable.

The main findings of this evaluation are described below:

- In general, the design of e-parking facilities for EV charging should ensure that all components are perfectly sized and adapted to the real recharging needs to be covered. The application of these functionalities to a non-optimized case study could lead to non-reliable results and conclusions. In this case, the analysis considered the present usage rate of the real e-Parking under study (ES1 Demo Region). An increase in the EV fleet (number of EVs and charging events) using the EVSE could lead to more positive results for the functionalities analysed.
- In the analysed context, the more profitable functionality is the application of DUoS (Distribution Use of System) tariffs depending on the time of use. This functionality involves low investments and allows the EVSE Operator to carry out an optimization of slow charges to adapt them to variable hourly electricity prices. This way, savings both in energy and power terms can be obtained, recovering the investment in about 5 years.
- The investment in second life batteries is not profitable under the assumed conditions: current regulatory framework (in Spain) and kWh battery cost. Moreover, 2nd life batteries could be used to offer regulation services to the grid. These services that would increase the value of installing such a technology have not been taken into account on the analysis. For example, just a reduction of 11% in the considered batteries investment cost would be required to make this functionality recoverable in 10 years, the assumed lifetime of the equipment.

- With regard to Vehicle to grid (V2G), no V2G regulation services to the grid were analyzed. These services would have increased the value of installing such a technology. Only peak reduction and energy arbitrage were taken into account. With such a framework, the investment could be recovered in about 10 years. To this regard, it has to be taken into account that the current cost of the V2G chargers prototypes is expected to be reduced, benefiting the cost-benefit analysis. The current result was obtained applying the current Spanish market conditions (where EVSE Operator does not obtain incomes through electricity sale to the network). The importance of a change in the regulation for facilitating the adoption and penetration of the V2G technology is highlighted.
- On the other hand, under the assumed conditions, the implementation of all the functionalities and the optimization of the e-parking operation would lead to very good payback periods (between 4 and 6 years, depending on the base case used for comparison).
- From the DSO point of view, DSO load management tried to reflect the savings/benefits that could be obtained by the DSO when demand management strategies are implemented instead of extending the existing grid. In order not to penalize the DSO by the implementation of demand response strategies, a minimum benefit has been calculated that should include the payment or incentive to the EVSEO for responding to the request. The best results would be obtained when the amount of controlled kW in a year are the highest possible and the investment cost are the lowest.

- Charge Management and Harmonic distortions

When putting together the results of the charge management studies of Green eMotion and the recommendations on harmonic distortions several recommendations regarding the future combination can be drawn.

First, to really respect the purpose of the IEC 61851-1, the IEC 61851-21 needs to consider the e-cars impact on the network. This could be achieved by, for example, repeating the approach of the IEC 61800-3. In that way, the emission limit will be linked to the network characteristics, so there will be a smaller probability to have an unacceptable impact on the network.
Another way is to facilitate the harmonics compensation on the network. So for each recharge process a random phase should be imposed to each harmonic current by the battery charger.

One specific request from a utility is that if the recharge is uncontrolled, the power factor has to be > 0.95 in order to avoid inefficient reactive power flows.

4 Recommendations and Conclusions for integrating EVs in the European Networks

The work carried out in WP4 has been aimed at drawing conclusions for future grid applications to deal with additional loads in the form of EVs. One cornerstone in this aspect is certainly the direct 'contact point', i.e. the charging infrastructure. When analysing the main findings regarding charging infrastructure towards the integration of EVs into European electricity networks, several conclusions can be drawn.
The uncertainty on the socket outlets and plugs, which was a dominant factor especially for manufacturers and operators of charging infrastructure back in 2011, has been resolved in the meantime. As the European directive requires the use of Type2 plugs and socket outlets for AC charging and at least the combined charging system (with Type2 as the basis) for DC public EVSEs, charging station manufacturers and operators have been provided with a higher security for their investments. This was also evident from the 2014 internal GeM survey addressing the current state of deployed recharging infrastructure. As ACEA, the European Automobile Manufacturer's Association, also harmonize the vehicle Inlets to Type 2/ Type 2 Combo from 2017 onwards[7] it can be expected that prices of components will drop at a later market ramp-up phase.

The second implication is that DC fast charging stations will help to increase market penetration in the early phase of E-Mobility (as they mitigate range anxiety which is one of the key barriers), although they will increase the infrastructure costs significantly, especially in the early stage. To which extent the competition between AC and DC charging will favour one or the other solution will be determined by market forces in the future. From the DSO perspective AC charging has comparative benefit compared to DC fast charging as it opens up possibilities for charging management schemes (given that DC is mainly built to enable fast charging without the intention to facilitate managing the charging process).

When discussing charge management schemes it needs to be acknowledged that there is no common and agreed standard to enforce particular charging behaviours. Communication between EV and EVSE complies with the ISO/IEC 15118 standard, but no means are yet specified nor standardized to bring this information from the DSO to the backend. This is the subject of ongoing work in the E-Mobility Coordination Group of CEN/CENELEC, but no specific standard or procedure has yet been proposed.

Another major part of WP4 was to understand in more detail the impact of EVs on the distribution grid. The work in Deliverables 4.2 and 4.3 has shown that in the short term most electricity grids are not going to be adversely affected by low EV uptake levels. Nevertheless, certain aspects require to be examined in more detail. The effects of harmonic distortions on the grid, although not particularly critical today, could represent a significant aspect of the impact of EVs in the future, if no specific regulation is put in place. Following the recommendations regarding harmonics, OEMs (in case of AC charging) and charging station manufacturers (in case of DC charging) should work on common design requirements for inverters in order to reduce harmonics when the inverters are not operated at nominal power.

Another finding is that a high number of vehicles that are connected to a single feeder or transformer will cause problems due to high likelihood of simultaneous charging events. This is not a new finding, however there are different ways to mitigate this effect. Besides smart charging schemes regulatory measures could also help to cope with increasing EV uptake in distribution grids. Back in 2012 Switzerland discussed about introducing a registration procedure for EVs with the local DSO. Through

[7] Dolejsi (2013): ACEA on alternative fuels infrastructure
http://www.europarl.europa.eu/document/activities/cont/201306/20130625ATT68525/20130625ATT68525EN.pdf

such measures the DSO would be adequately informed about the upcoming extra demand and could improve its grid planning procedures.

This leads to the third recommendation. As there is no ‘standard’ distribution grid in Europe and the impacts of EVs in the specific regions are likely to vary, a European-wide effort should be made to develop distribution grid planning practices that appropriately consider the additional demand by EVs. Green eMotion only started exploring this complex topic, and therefore a parallel FP7 project PlanGridEV was started in 2013 ‘design new planning rules and operational principles for the optimal integration of EV for different network topologies and with different levels of DER penetration such as PV, wind and solar energy and micro CHP’.[8] The results of this project combined with the analysis carried out using the ITRES tool, should lead to the development of a new, comprehensive grid planning and analysis tool for European DSOs.

The third main question besides the capability of charging infrastructure and impact of EVs on the distribution grid focuses on the positive effects of EVs. As the results indicating, EVs have a substantial potential for supporting European distribution grids. This is especially true if the trend towards expanding renewable energy generation continues. An upcoming task for all DSOs will therefore be to incorporate smart charging strategies into their operating practices. The proposition to enable local and regional integration of EVs into decentralised storage systems seems to have significant value.

When looking at the current market design and the regulatory regime of the electricity distribution business, it is evident that there is no general ‘hub‘ for matching the energy demand of EVs with local restrictions of DSOs. On a local level, e.g. parking lots, this concept has been tested in the Spanish Demo Region of Green eMotion. However, in the case of mass market applications, a local management (dispatch) does not incorporate global effects. For the upcoming years one major task for DSOs will be to work on a centralized integration model for coordinating EV charging behaviour. The recently ended EU-funded FP7 project e-DASH already specified the common functionalities for such a ‘Demand Clearing House’.[9]

A real challenge in using EVs to support the grid is the technical limitation of the current EN 61851-1 standard as it does not provide sufficient information about the requested energy demand of the car or its departure time. The control of the charging power is carried out by the charging station, whereas the vehicle (and consequently the user) has no active influence on the charging process. In an ideal world the customer should be able to decide according to his preferences with given information about prices and predicted available power over time. The use of the ISO/IEC 15118 standard is therefore recommended in order to create a win-win situation for the customer and the DSO, as well as the energy retailer. All charging management strategies analysed in D4.3 and D4.5 could be enhanced with the additional information provided by the car due to the more accurate demand forecast.

To summarise, the European distribution grid has a good starting position to support significant EV uptake levels. However, current EV, EVSE and grid technologies need to be upgraded and optimized to enable a smooth integration of those additional loads into existing grids. Additional efforts still need to be made to ensure a more efficient EV integration, especially in linking the currently largely decoupled industries of OEMs and DSOs. The findings of this deliverable highlight current capabilities and future challenges and therefore open questions and identify areas for future projects.

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[8] PlanGridEV (2015): Objectives (http://www.plangridev.eu/project/objectives.html)
[9] e-DASH (2015), http://edash.eu/