Final Publishable Summary Report

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Project acronym: G4V

Project title: Grid for Vehicles – Analysis of the impact and possibilities of a mass introduction of electric and plug-in hybrid vehicles on the electricity networks in Europe

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Name of the scientific representative of the project's co-ordinator[1], Title and Organisation:

Thomas Theisen

Head of New Technologies Department

RWE Deutschland AG

Tel: +49 (0) 201 12 29387

Fax: 49 (0) 0201 12 29749

E-mail: Thomas.Theisen@rwe.com

Project website[2] address: www.g4v.eu

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[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.
[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

4.1 Final publishable summary report

This section must be of suitable quality to enable direct publication by the Commission and should preferably not exceed 40 pages. This report should address a wide audience, including the general public.

The publishable summary has to include ***5 distinct parts*** *described below:*

- *An executive summary (not exceeding 1 page).*
- *A summary description of project context and objectives (not exceeding 4 pages).*
- *A description of the main S&T results/foregrounds (not exceeding 25 pages),*
- *The potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results (not exceeding 10 pages).*
- *The address of the project public website, if applicable as well as relevant contact details.*

Furthermore, project logo, diagrams or photographs illustrating and promoting the work of the project (including videos, etc…), as well as the list of all beneficiaries with the corresponding contact names can be submitted without any restriction.

4.1.1 Executive Summary

The objective of the FP7 funded project "Grid for Vehicles" (G4V) was to develop an analytical framework to analyse the impact of the mass introduction of EV and PHEV on electricity networks (MV and LV grids) and to plan measures facilitating their deployment taking into account the inherent opportunities and challenges for electricity systems. The G4V consortium composed of major European electricity utilities (RWE, Endesa, Enel, EDF, Vattenfall and EDP) and distinguished academic institutions (Imperial, RWTH, TUDo, UPVLC, Chalmers, ECN and TNO) under the lead of RWE achieved the following results and recommendations (project duration: January 2010 – August 2011):

Methodology: The core of the developed methodology is a stochastic load flow simulation to assess the impact of EV on the distribution grid through simulating real grids under the consideration of different charging control strategies and further relevant parameters such as driving data, charging power and charging location

Grid infrastructure (incl. ICT) and operation: The analysis of more than 200 real grids showed that some of the grids already need reinforcements even without EV, while others may integrate 100% EV penetration rate without any problems. This variety appears in all analyzed countries. The implementation of appropriate charging control strategies is of key relevance for a cost efficient integration of EV into electricity grids and can postpone, or even reduce, grid reinforcements. The sophistication of charging control strategies needs to evolve in line with the increasing EV penetration level. Initially, at low EV penetration levels uni-directional /(in terms of energy flow) charging control strategies should be encouraged since bidirectional ones reveal relatively low gains. The ICT infrastructure necessary to enable a mass roll out of EV can be easily developed on the basis of the existing technologies.

System level implications: At a system level benefits of EV integration occur even at low EV penetrations. Optimized charging of EV enhances the system's ability to absorb wind energy. However, additional costs and emissions in the power system due to the introduction of EV strongly depend on the generation mix of the system in question. The additional gains due to battery discharging ("V2G") compared to unidirectional charging are relatively small.

Regulatory and market aspects: Transparency and clarity are necessary for setting up EV charging infrastructure and reinforcing the grid infrastructure. At low EV penetration levels, incentives will be required for establishing the public charging infrastructure by private investors. Alternatively, the infrastructure can be set up by regulated stakeholders. A sufficient availability of public infrastructure is a prerequisite for customers' acceptance of electromobility, even if the customers generally prefer to charge at home. Existing network planning and operation rules should be adapted to embrace efficient charging control strategies and promote non-network solutions. The market should evolve from a centralized to a more distributed one enabling small energy storages such as EV to provide ancillary services for the system. As far as business opportunities are concerned, ICT companies can significantly benefit from the provision of electromobility services due to the synergy effects with their existing business.

Summing up, the G4V project constitutes a crucial cornerstone for the assessment of the impacts of electromobility on electricity systems. It can be concluded that EV deployment is not purely a technical issue, but rather a combination of economic, regulatory and social factors. Therefore a comprehensive approach to enable an EV mass market is required.

The G4V results will be further exploited in the FP7 funded project "Green eMotion" in which most of the G4V project partners are involved. For more information please consult the website www.g4v.eu or the Project Coordinator Thomas Theisen (Thomas.Theisen@rwe.de).

4.1.2 Project context and objectives

Project context

Electric and plug-in hybrid vehicles (EV, PHEV) have the potential to contribute significantly to solving contemporary and future environmental and economic challenges of mobility. In addition, they constitute new possibilities for smart grid management and the integration of Renewable Energy Sources (RES) into electricity networks.

Future mobility faces a number of serious challenges of environmental and economic nature which influence the development of alternatives to the conventional combustion engine and the mix of technologies for mobility.

On the one hand, the concepts and technologies are driven by forces such as the security of energy supply, environmental effects and efforts to reduce CO_2 emissions as well as economic parameters, which in the case of Europe principally includes the dependency on oil imports and volatile oil prices.

On the other hand, the enforcement of alternative mobility concepts requires consumer acceptance, meaning that they have to deliver the same kind of ease-of-use, safety and reliability to the car owners at reasonable prices, and an acceptable level of investment in infrastructure and equipment.

These challenges have led policy makers in Europe and around the globe to adopt policies and strategic approaches to facilitate the development of alternative mobility technologies. In an effort to improve security of energy supply and reduce greenhouse gas emissions, the EU defined the objective of a 20% substitution of traditional automotive fuels by alternative fuels before the year 2020. In 2000, three alternative solutions were seen as promising: bio fuels, natural gas and hydrogen. However, there is uncertainty about the dominating future mobility technology and a strong demand to diversify the portfolio of technologies. A politic paradigm shift was performed by the European Parliament, when paper ITRE / 6 / 58782 was adopted offsetting the focus on bio fuels adhered to in the White Paper for Transport of the EC. Subsequently national actions have been taken to promote the development of electric mobility.

The disadvantages of EV in comparison to other technologies – this holds true only partly for PHEV – were mainly seen in the size and costs of batteries. In addition recharging requirements have made electric vehicles suitable for short-distance motoring only.

These technological and consumer acceptance barriers for the introduction of electric vehicles remain only partly valid until today. Car and battery manufacturers have set up ambitious programmes and technological progress has been achieved in the field of battery technology. One of the major technological challenges which prevail will be to develop a comprehensive and convenient recharging infrastructure.

EV and PHEV are today considered to have persuasive advantages in terms of energy efficiency as well as in a number of environmental aspects such as their contribution to reducing CO_2 and local emissions and other negative external effects of mobility (e.g. noise). In addition, electric mobility has the potential to contribute to increasing penetration of RES and hydrogen in the transport sector as well as to the functioning of innovative future electricity grids.

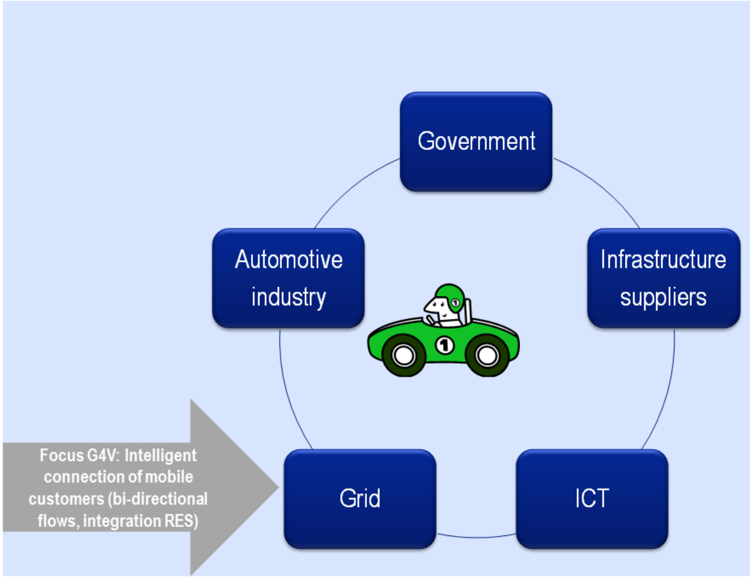
Despite the diverging views on the future mobility technologies among different stakeholders, industry and more precisely all major car manufacturers are in the process of introducing EV and PHEV to the market. In the short term perspective EV are facing a small market due to the relatively short cruising ranges. Accordingly, the efforts of car manufacturers are currently focused on small electric vehicles for city use and PHEV for medium and long distance driving.

In the medium term, however, the achievements and progresses in improving battery performance are expected to lead to the mass introduction of EV. Moreover, a number of governments have adopted measures which will favour the introduction of EV and PHEV in the medium and long term (after 2020).

A mass introduction of EV and PHEV in the medium term will imply both, challenges and opportunities not only for the automotive industry but to a large extent also to the energy sector. A standardised infrastructure solution is needed to facilitate the mass roll out of EV and favour customer acceptance. Major utilities from various EU member states and prestigious academic institutions have joined forces to commonly explore the decisive parameters of the future system.

The graph below shows the context and focus of the G4V project:

Graph 1: Context and focus of G4V project



Source: Consortium

Project objectives

A) Scientific and technologic objectives: analytical method

The objective of the project was to develop an analytical method for the planning of necessary technological developments in the electricity grid infrastructure and the definition of related ICT and policy requirements in order to support and cope with the mass introduction of EV and PHEV until 2020. In particular, the aim was to clearly understand the effects of a mass introduction of EV under physically given parameters and the inherent challenges and opportunities that this will constitute for the electricity grids in Europe.

The active demand and storage options that the vehicles will bring about are considered important opportunities for the operation of networks as they also constitute a possibility to manage the negative impacts a mass introduction could have on the grid. The project focused on delivering analytical results and a guideline to the subject within a project duration of 18 months.

The results of the project will serve as a basis for future RTD activities. Additionally, the influence of policies and user incentives on the further expansion of the technology and consumer acceptance was to be investigated and recommendations for policy makers derived.

B) Focus on electricity grid aspects: system solution

Within the scope of the project, the project partners aimed at exploring for the first time all main parameters influencing a system solution and define the requirements for a smart operation with millions of moving electricity customers which are also potential energy traders. The project specifically addressed the topic from the utility and European perspective with the aim to avoid any potential barrier to the development of alternative mobility solutions. This was ensured through the involvement of major utilities from various EU member states.

The goal of the analysis was further to define necessary changes in the grid structure and its operation and specifically deal with the question to which extent the grids and operational systems will have to be improved in order to satisfy the increased electricity demand and to efficiently absorb the booming “green electricity”. The focus of the project therefore lied on grid oriented innovations

(Grid-for-Vehicles - G4V). Due to the fact that bottlenecks are mainly expected to exist at the distribution level of the grids, localisation aspects in different EU member states were to be carefully considered. In this context, the project intended to analyse all effects of a mass introduction of EV and PHEV on the power system.

To achieve these objectives, a joint European approach to the topic was indispensible. The G4V Consortium intended to provide through the project independent and openly accessible data which can be utilized in further investigations and developmental activities of all stakeholders.

C) European holistic approach

The Consortium and the Scientific Advisory Board aimed at long term cooperation and a holistic approach to the subject. In this context, future projects to commonly address the required technologic development of the system were to be envisaged (i.e. the FP7 funded project “Green eMotion) and shall lead to the elaboration of a European standard.

4.1.3 Description of the main S&T results/foregrounds (not exceeding 25 pages)

The G4V consortium composed of major European electric utilities (RWE Deutschland AG, Endesa, Enel, EDF, Vattenfall and EDP) and distinguished academic institutions (Imperial College, RWTH Aachen, TU Dortmund, University of Valencia, Chalmers, ECN and TNO) under the lead of RWE Deutschland AG achieved in the period from 1 January 2010 until August 2011 the following results / drew the following conclusions:

- **Methodology**: Within the project a methodological approach was developed to assess the impacts of electromobility on electricity systems (with focus on MV and LV grids) and to the design measures enabling seizing of the related opportunities and mitigating the risks. The cornerstone of the approach is the stochastic load flow simulation under the consideration of different charging control strategies. The application of the G4V methodology, if further validated and enhanced, can significantly strengthen the planning practices of the European utilities thus contributing to postponing or reducing grid reinforcement investments through the design and implementation of appropriate load / EV charging control strategies and improving the economic and environmental performance of electricity systems.
- **Key parameters**: All relevant parameters influencing electromobility such as driving behaviour, characteristics of EV, features of electricity systems and electricity customers were identified, thoroughly described and in the case of quantitative parameters their ranges were fixed.
- **Scenario worlds:** To reduce the uncertainty resulting out of the long term time horizon the project was dealing with, three scenarios (“scenario worlds”): conservative, pragmatic and advanced were developed. The main idea behind the scenarios was to show which consequences a mass roll out of EV will have depending on circumstances that cannot be predicted. It was assumed that the conservative world is similar to the today’s situation with the established technological solutions and existing rules. In the pragmatic world moderate advancements are possible. The advanced or visionary world assumes that nearly all thinkable technical innovations are feasible and consequently the situation for EV is nearly optimal. Within each of the scenarios the main parameters can be varied (approach for the simulations) within the fixed ranges.

- **Energy demand due to EV**: To assess the challenges resulting out of the additional energy demand due to EV, detailed distribution grid data for France, Germany, Italy, Portugal, Spain and Sweden were collected (200 grids) and on their basis a stochastic load flow simulation was carried out taking into account different parameters such as the average driving distance and charging behaviour as well different charging control strategies. The simulation showed that some of the analysed grids need reinforcements already now without EV, while others can integrate 100% EV penetration rate without any problems. The variety appears in all analyzed countries.

- **Charging control strategies**: The aforementioned stochastic load flow simulation shows that though the implementation of charging control strategies it is possible to postpone grid reinforcements for considerable EV penetration levels and to reduce the investment volume. Consequently, appropriate charging control strategies are of key relevance for a cost efficient integration of EV into electricity grids. However, the implementation of charging control strategies is not efficient for the grids that are close to their capacity limit even without EV. As a very promising family of charging control strategies revealed those which enable the Distribution System Operator (DSO) to play an active role and to have the possibility of directly influencing the EV charging behavior. To apply these strategies the DSOs shall equip the distribution grids with devices that are able to detect any constraints in the grids. The implementation of these functionalities should be synchronised with the establishment of smart grids.
  To evaluate the effects of more advanced charging control strategies requiring bidirectional communication between the EV and the grid operator and enabling full visibility of the EV status another quantitative analysis was performed using an on purpose developed mathematical model and the extended simulation tool (Power Matcher) describing a decentralised market model. The results show that those strategies might explore the full potential of the use of EV flexibility to support the operation of electricity grids (i.e. energy arbitrage, load shifting). However, their implementation requires sophisticated ICT functionalities and the value of the services is country specific and very sensitive to factors such as charging power, efficiency losses and battery degradation costs.
  In any case, while designing and applying charging control strategies, impacts at distribution network level (MV and LV) must be considered. The sophistication of charging control strategies needs to evolve in line with the increasing EV penetration level. Initially, at low EV penetration levels uni-directional charging control strategies should be encouraged since the bidirectional ones reveal relatively low gains. To capture the complexity of the topic, further development of models evaluating both technical and economic performance of charging control strategies and real life trials are required.

- **Charging infrastructure**: EV charging infrastructure (charging stations) must fulfil multiple requirements of the stakeholders and in particular provide sufficient ICT capabilities to integrate the stations into smart energy grids and fulfil safety requirements. The infrastructure should be formed by a combination of slow AC private (at home) and semi-public (i.e. at shopping malls or office facilities) stations ($P<7kW$), quick AC public (at the streets) and semi-public stations (kW $7 < P < 44$ kW) and fast public DC stations ($P > 44$ kW). Private charging stations are much cheaper than the public ones in particular due to the vandalisms protection necessary in the case of the public infrastructure. From the economic perspective semi-public stations are also a promising alternative. Potential impairments (i.e. harmonics) in the distribution grid should be taken into account while designing EV (i.e. optimized rectifiers, battery management systems). It will be necessary to certify them in this respect.

- **ICT infrastructure**: The analysis of the existing ICT technologies taking into account the requirements of different stakeholders and in particular the preconditions of different charging control strategies and safety aspects revealed that ICT infrastructure necessary to enable mass roll out of EV can be easily developed on the basis of the existing solutions. As the deployment of complex processes such as billing of EV can be very expensive, a sufficient business case is needed. While planning future grids ICT required for charging control strategies should be taken into account already now. To minimize the risk of misinvestment, respective standardization activities should be accelerated.

- **Economic and environmental impacts at system level**: The analysis of the economic and environmental impacts of large scale introduction of EV which was performed within an on purpose developed system level model taking into account factors such as EV penetration level, charging control strategies and generation mix shows that benefits of EV integration occur already at low EV penetrations. Optimized charging of EV enhances the system's ability to absorb wind energy. Additional costs and emissions in the power system due to the introduction of EV strongly depend on the capacity mix of the system in question. Optimized charging leads to lower additional operational costs. The additional gains due to battery discharging ("V2G") compared to unidirectional charging are relatively small. To capture the complexity of the system level analysis further investigations considering a.o. battery lifetime are required.
- **Social challenges:** To investigate customers' attitude towards EV an online survey was conducted in eight countries represented in the consortium (1,900 replies were generated). Its results show in particular that for the mass roll-out of EV it is crucial to mitigate the anxiety/fear of the people living in urban areas of being stranded due to lack of recharging infrastructure (although the average driving distance does not exceed 70 km per day). Consequently, customers expect that appropriate network of public charging stations will be available even if they generally prefer to charge EV at home mainly due to convenience and safety reasons. The survey shows furthermore that price incentives might motivate customers to charge their EV off demand peak hours. The interest in discharging EV (Vehicle to Grid (V2V)) to support the grid is low due to low benefits and the inability to travel for any unforeseen reason.
- **Regulatory aspects and market design:** To facilitate the mass roll out of EV, the crucial areas and challenges for policy and regulatory requirements were pointed out and the market design was analysed. The approach was based on the qualitative analysis including: expert discussions, customer surveys and literature review. One of the main conclusions is that transparency and clarity are inevitable for the development and setting up EV charging infrastructure and the reinforcements of grid infrastructure. This is to be coordinated at pan-European level. Initially, at low EV penetration levels, incentives will be required for establishing the public charging infrastructure by private investors or the infrastructure is to be established by regulated stakeholders who can socialise the costs. Furthermore, to ensure a proper network operation with millions of EV on the streets, existing network planning and operation rules should be modified embracing efficient charging control strategies and promoting non-network solutions. In particular, the regulation has to enable DSO to control EV charge. The market should evolve from a centralized to a more distributed one enabling small energy storages such as EV to provide ancillary services (capacity, energy or balancing) for the electricity systems. To propose concrete solutions for the aforementioned regulatory challenges further investigations are required.
- **Business models**: Starting from the value chain and stakeholder analysis for electromobility (including determination of possible new products such as aggregation of EV demand) a cost-benefit assessment of the products for relevant stakeholders was conducted. It shows that the affinities / knowhow of the stakeholders with relation to the products are crucial for the

profitability of their provision, i.e. for ICT companies it might be very beneficial to offer some ICT functions related to electromobility due to the synergy effects they can achieve with their existing business. As far revenues from ancillary services due to aggregated EV discharging / V2G are concerned, they are nowadays insignificant, but future market development may open new opportunities. Since fees for public parking of EV occur as one of important cost drivers, they should be kept at low level. More in depth insights into economic aspects of electromobility require further research.

For more information on the project results (deliverables) please consult the website www.g4v.eu or the Project Coordinator Thomas Theisen (Thomas.Theisen@rwe.de).

4.1.4 The potential impact

In the long term the results of the G4V project can support facilitating of the mass market of EV and PHEV which have the potential to contribute significantly to increasing energy efficiency, more efficient absorption of RES and to the reduction of CO2 emissions.
These potential impacts will only be achieved if optimal use is made of the opportunities that these vehicles represent for the operation of electricity systems and the related challenges / risks are appropriately mitigated.

Based on the aforementioned potential impacts the results of the G4V project represent a significant contribution to reaching the 20-20-20 goals of the EU and in particular of the SET plan.

As far as the direct impacts of the G4V project are concerned, its results and specifically the developed methodological approach constitute a crucial cornerstone for the assessment of the impacts of electromobility on electricity systems (with focus on MV and LV grids) and for the design of measures enabling seizing of the related opportunities and mitigating the risks.

The application of the G4V methodology, if further validated and enhanced, can significantly strengthen the planning practices of the European utilities thus contributing to

- postponing or reducing grid reinforcement investments through the design and implementation of appropriate load / EV charging control strategies and
- improving the economic and environmental performance of electricity systems.

Furthermore, the project delivered crucial recommendations for the modification of the regulatory and market related policies to enable the mass roll out of EV and their most optimal utilization. In particular important insights into the triggers of customer acceptance for EV were provided.

The conclusions of the project regarding the requirements for the grid infrastructure (in particular regarding charging stations and ICT architecture) are a solid foundation for its design and the related standardisation efforts.

The developed business modelling methodology and the derived conclusions deliver valuable insights into profitability of different electromobility services depending on the affinities of the stakeholders and might become a starting point for new business opportunities, if validated and enhanced in further studies.

The G4V results will be further exploited in the FP7 funded project “Green eMotion” in which most of the G4V project partners are actively involved. The indication of further necessary investigations and important research questions is another crucial outcome of this eighteen months project.

4.1.5 Main dissemination activities and exploitation of results

The results of the G4V project were disseminated through the following channels / measures:

- Establishment of the project website on the Internet
- Elaboration of a project flyer
- Organisation of workshops with crucial stakeholders of electromobility / members of the Scientific Advisory Board (a.o. OEMs, equipment manufacturers, relevant scientific institutions, public institutions etc.)
- Participation in relevant conferences
- Online survey on customer preferences
- Exchange with standardisation bodies in the area of ICT
- Exchange with the projects MERGE and ADDRESS
- Organisation of a standalone event dedicated to the presentation the key project results

The G4V consortium plans to further spread the achieved results among the relevant target groups. For this purpose contributions to relevant conferences and publication of scientific (peer reviewed) articles are planned.

4.1.6 Project website and list of beneficiaries

The website is accessible at www.g4v.eu.

Project logo

G4V™ Grid for Vehicles

Figure 1: G4V logo

List of all beneficiaries

Beneficiaries	Corresponding contact name
RWE DEUTSCHLAND AG	Thomas Theisen
CHALMERS TEKNISKA HOEGSKOLA AB	Lina Bertling
STICHTING ENERGIEONDERZOEK CENTRUM NEDERLAND	Ingo Bunzeck
EDP INOVACAO SA	Rui Filipe Marques
ELECTRICITE DE FRANCE S.A.	Eric Schultz
ENDESA S.A.	Narcis Tejedor Vidal
ENEL DISTRIBUZIONE S.P.A.	Paola Lucia Petroni
IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE	Goran Strbac

RHEINISCH-WESTFAELISCHE TECHNISCHE HOCHSCHULE AACHEN	Armin Schnettler
TECHNISCHE UNIVERSITAET DORTMUND	Christian Rehtanz
UNIVERSIDAD POLITECNICA DE VALENCIA	Carlos Alvarez
VATTENFALL AB	Johan Söderbom
TNO	Joost Laarakkers