



# **MOBILE ENERGY RESOURCES IN GRIDS OF ELECTRICITY**

**ACRONYM: MERGE**

**GRANT AGREEMENT: 241399**

**WP 1  
TASK 1.1, 1.2 & 1.5  
DELIVERABLE D1.1**

**SPECIFICATIONS FOR EV-GRID INTERFACING, COMMUNICATION AND  
SMART METERING TECHNOLOGIES, INCLUDING TRAFFIC PATTERNS  
AND HUMAN BEHAVIOUR DESCRIPTIONS**

**24 AUGUST 2010**



## CONTENTS

- I Task 1.1 – SPECIFY PLUG-AND-PLAY FOR ELECTRIC VEHICLES**
  
- II Task 1.2 – SPECIFY SMART METERING FOR ELECTRIC VEHICLES**
  
- III Task 1.5 – IDENTIFICATION OF TRAFFIC PATTERNS AND HUMAN BEHAVIOUR**
  
- IV REFERENCES**





# MOBILE ENERGY RESOURCES IN GRIDS OF ELECTRICITY

ACRONYM: MERGE

GRANT AGREEMENT: 241399

WP 1  
TASK 1.1  
DELIVERABLE D1.1

SPECIFICATION FOR AN ENABLING SMART TECHNOLOGY

03 AUGUST 2010



## REVISION HISTORY

---

VER.	DATE	NOTES (including revision author)
01	28/04/2010	First draft. S. Bending (Ricardo), S. Channon (Ricardo), M. Ferdowsi (TU Berlin)
02	03/05/2010	Section 6.2 added by F. Nadolini (TU Berlin), M. Ferdowsi (TU Berlin)
03	10/05/2010	Section 7.1 and 8.2 added by M. Ferdowsi (TU Berlin)
04	14/04/2010	Final version submitted for approval
05	23/07/2010	Revised by M. Ferdowsi (TU Berlin)
06	28/07/2010	Revised by E. Bower and S. Bending (Ricardo)
07	03/08/2010	Revised by M. Ferdowsi (TU Berlin)
08		
09		
10		



## AUTHORS

S. Bending	Shaun.Bending@Ricardo.com
M. Ferdowski	Mohsen.Ferdowski@tu-berlin.de
S. Channon	Stephen.Channon@Ricardo.com
K. Strunz	Kai.Strunz@tu-berlin.de

## CONTRIBUTORS

E. Bower	Ed.Bower@Ricardo.com
A. Walsh	Anthony.Walsh@esb.ie
M. Ellingsen	Marius.Ellingsen@inspireinvest.com
J. Peças Lopes	JPL@fe.up.pt
F. Nadolni	Nadolni.Felix@mailbox.tu-berlin.de

## APPROVAL

			DATE
Project Coordinator	PPC	N. Hatziaargyriou	18/08/2010
Technical Coordinator	INESC Porto	J. Peças Lopes	04/08/2010
Work Package Leader	TU Berlin	K. Strunz	04/08/2010

### Access:

Project Consortium

European Commission

Public

### Status:

Draft Version

Submission for Approval (deliverable)

Final Version (deliverable, approved)





## SUMMARY

The MERGE concept is aimed at the development of a management and control concept to facilitate the large-scale integration of electric vehicles with the electric grid.

This task looked at specifying the technologies required to achieve a plug-and-play capability for the connection of electric vehicles to the electric grid.

Just as mobile phone users are able to 'roam' and use mobile phone networks other than the one they are subscribed to, it should also be possible for Electric Vehicle (EV) users to use any charging point within Europe. In order for this to be possible all charging point owners will need to agree on one common system for user authentication and payment.

A review of the existing charging types, charging connectors and charging infrastructure, as of early 2010, was conducted. This found that the charging types are generally grouped into three different charging levels of increasing electrical power. It found that there were several different charging connectors available each with different functionality, but no single connector was available that contained all the functionality desired.

Of the many different charging posts being installed worldwide the majority use the lowest power level (trickle charging), with others also developing solutions for the highest level (fast charging). The review showed a trend towards the use of Radio Frequency Identification **(RFID) smartcards or key fobs for authentication** and, in some instances, **payment**. There was a less substantial trend towards the use of General Packet Radio Service **(GPRS) for communication from the charging point to the charging point manager**.

The computational intelligence and the data requiring communication between each of the parties involved in the charging process, varies substantially with the payment method used. This implies that the payment method used needs to be standardised to ensure that users can 'roam' within Europe.

It was recommended that **for user authentication at the charging point the observed trend of using RFID was continued**, with Near Field Communication **(NFC) being used in the long-term** if the technology gained wider acceptance. These were recommended because of the ease with which such systems could be used by the user, they are relatively simple to implement, and can also be used for payment in a pay-as-you-go system. A slightly less favourable alternative recommendation was the use of a touch screen whether on the charging post or in the electric vehicle.

It was noted that if a smart grid and the vehicle-to-grid concept are used then **the single wire analogue communications used by current charging connectors would be inadequate for the amount of data communication required**. Thus it was recommended that either **CAN-bus, RS-485 or Power Line Communications were used** for the communications between the electric vehicle and charging point.

**For communications from the charging point to parties within the electricity supply network** (supplier/aggregator, distribution system operator) **both Power Line Communications and GPRS are recommended**.



## TABLE OF CONTENTS

1	INTRODUCTION .....	6
1.1	Definitions .....	7
2	OBJECTIVES AND HOW TO READ THIS REPORT .....	9
3	GLOSSARY .....	10
4	APPROACH .....	11
5	REVIEW OF EXISTING CHARGING TECHNOLOGIES .....	12
5.1	Power Stage.....	12
5.2	ICT Stage.....	23
6	POSSIBLE IMPLEMENTATIONS OF THE POWER STAGE .....	35
6.1	Power Stage Safety.....	35
6.2	Possible Power Stages .....	37
7	POSSIBLE IMPLEMENTATIONS OF THE ICT STAGE .....	38
7.1	Introduction to the ICT Stage.....	38
7.2	Computational Intelligence .....	46
7.3	Control of Charging for Battery Longevity.....	55
7.4	Possible ICT Stages.....	58
8	EVALUATION.....	64
8.1	Evaluation of Possible Power Stages .....	64
8.2	Evaluation of Possible ICT Stages .....	66
9	RECOMMENDATIONS FOR CHARGING INTERFACE .....	75
9.1	ICT Stage.....	75
9.2	Power Stage.....	75
	APPENDIX 1 - MESSAGE SEQUENCE CHART FOR EV CHARGING IN A PRIVATE LOCATION WITH PRIVATE ACCESS, EQUIPPED WITH SMART METER.....	76
	APPENDIX 2 - MESSAGE SEQUENCE CHART FOR EV CHARGING IN A PRIVATE AREA WITH PUBLIC ACCESS.....	78
	APPENDIX 3 - MESSAGE SEQUENCE CHART FOR EV CHARGING IN A PUBLIC AREA WITH PUBLIC ACCESS.....	80



## I SPECIFY PLUG-AND-PLAY FOR ELECTRIC VEHICLES

### 1 INTRODUCTION

It is desirable to achieve a 'plug-and-play' capability for the interface linking electric vehicles (EV) and the electric grid. The user would then simply connect the EV to the network, which would then establish a connection in analogy to the plug-and-play as known from computer engineering.

Recharging the EV would be convenient and quick and – as far as the handling is concerned – comparable to the refuelling of conventional vehicles. The interface must be able to access identical charging points across Europe that can be used by any appropriately equipped vehicle.

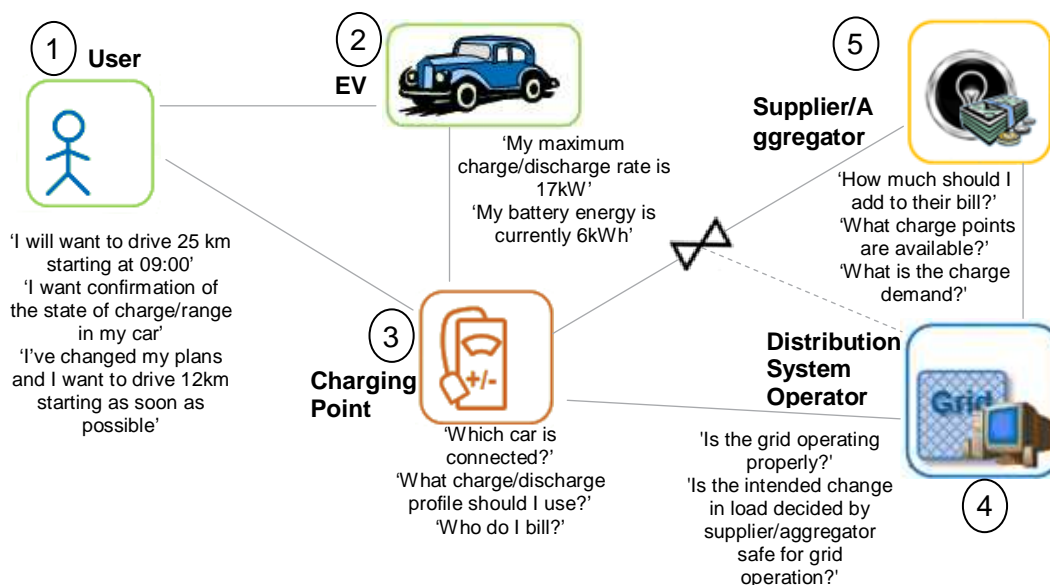
The plug-and-play interface will consist of a **power stage** and an **ICT (information and communication technology) stage**.

- The power stage needs designing to ensure that the EV behaves as a "good citizen" in the sense of network support.
- The ICT stage needs to consider the computational intelligence involved in the communication between the five parties involved in the process of charging an EV; these are:
  - 1) The user
  - 2) The EV itself
  - 3) The charging point
  - 4) The distribution system operator
  - 5) The supplier/aggregator.

In order for these five parties to work together there will need to be some communication between them. Figure 1 shows an example of how the different parties involved may need to communicate with each other.







**Figure 1 – Examples of reasons behind communication between the different parties involved in the charging process**

## 1.1 Definitions

The **ICT stage** encompasses the communication between all of the different parties involved in the charging process, such as the EV, the charging point, the distribution system operator and the supplier/aggregator; and the computation required at each.

The **power stage** encompasses the physical and electrical connections and functionality between the EV and the charging point.

The **user** is the person, or persons, who use the EV.

The term **electric vehicle (EV)** encompasses battery electric vehicles and plug-in electric hybrids.

The **charging post (CP)** is the equipment containing the electrical connection to the electricity grid, any charging electronics (AC-DC converter, AC-AC converter, power electronics etc.) that are not located on the vehicle, the electricity meter, any communications modules that are needed for communicating with the EV or the supplier/aggregator and DSO, any electronics and software needed to facilitate the charging process, a main control board, and a connector for the charging cable to be plugged into.

The **charging point manager (CPM)** is the owner and operator of a number of charging points. Its responsibilities may include providing power for its charging points, managing payment for charging, and dealing with higher entities (supplier/aggregator, distribution system operator,) for the procurement of electricity and other services for their CP collectively.

The **distribution system operator (DSO)** is the operator of the distribution system and is the entity that controls the distribution of electrical power to the CP. It is also



responsible for monitoring proper operation of the distribution system. The **supplier** is the entity that purchases electricity from the power market and sells it to the users. The **aggregator** is the entity which groups charging demand of a number of EV and can offer demand side management of this aggregated group of EV to the market. It is highly envisaged that the aggregator would be owned by the suppliers as it makes it economically a more justifiable business. So, in this report, a **supplier/aggregator (SupAg)** is considered as the responsible entity for both selling electricity to the users and aggregating their charging demand.

Some other useful terms that will be used within this report are:

The **electricity market (market)** is composed of two functional sections:

- 1) The power market. This refers to electricity trade made ahead of time to meet predicted load demand
- 2) The system service market. This addresses the real-time balancing of electricity supply and demand. It is also responsible for procuring enough generation capacity and other system services in advance, to ensure the safe and secure operation of the system

A **Smart Grid** is the electricity delivery system (from point of generation to point of consumption) integrated with communications and information technology for enhanced grid operations, customer services, and environmental benefits. Smart Grid can support **Demand Side Management (DSM)**, which entails actions that influence the quantity or patterns of use of energy consumed by end users, such as actions targeting reduction of peak demand during periods when energy-supply systems are constrained. DSM aims to improve final electricity-using systems, reduce consumption, while preserving the same level of service and comfort. The use of smart meters is preliminary for DSM.

**Vehicle-to-grid (V2G)** is a concept in which electric vehicles are not viewed only as loads but also as distributed energy storage devices. In this view, EV communicate with a smart grid to sell demand response services such as reducing their charge rate or delivering electricity onto the grid. It is believed that the use of such a system could be used for "valley filling" (timing devices to draw power at times of low grid demand) and "peak shaving" (reducing the peak energy demand on the grid) of electricity demand while facilitating a greater inclusion of intermittent electricity from renewable energy sources (providing ancillary regulation services - frequency control, load balance - and spinning reserve services).





## 2 OBJECTIVES AND HOW TO READ THIS REPORT

It is useful for the reader to know where to find relevant information in this report. As defined within the description of work, there are nine objectives in this task. Descriptions of these objectives and where they can be found in this report are given below:

- 1) Review existing ICT stages (Section 0)
- 2) Specify the communication required between the intelligence of the EV and the intelligence of the CP (Sections 7.1 and 0)
- 3) Specify the computational intelligence involved in the communication between the EV and the infrastructure providers (Section 0)
- 4) Specify the steps of a charging procedure that includes a way of charging that supports battery longevity (Section 0)
- 5) Evaluate the relative merits of different potential realisations of the ICT stage (Section 0)
- 6) Review existing power stages (Sections 5.1 and 0)
- 7) Specify a power stage that allows for safe power exchange with the grid, and can be easily handled (Section 6)
- 8) Specify charging systems appropriate for use across Europe (Section 9)
- 9) Evaluate the relative merits of different potential realisations of the power stage (Section 8.1)



### 3 GLOSSARY

TERM	DEFINITION
CP	Charging Post
CPM	Charging Point Manager
DSL	Digital Subscriber Line
DSM	Demand Side Management
DSO	Distribution System Operator
EU	European Union
EV	Electric Vehicle (EV), Battery Electric Vehicle (BEV) or Plug-in Hybrid Electric Vehicle (PHEV)
EV BMS	Electric Vehicle Battery Management System
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
IEC	International Electro technical Commission
IEEE	Institute of Electrical and Electronic Engineers
NFC	Near Field Communication
PLC	Power Line Carrier
PPPoE	Point-to-Point Protocol over Ethernet
RFID	Radio Frequency Identification
SOC	State Of Charge
TOU	Time Of Use
TSO	Transmission System Operator
V2G	Vehicle-to-Grid

All units used in this report are part of the International System of Units (SI) and, as such, are not defined herein.



## 4 APPROACH

Within this report the following approach is taken:

- A review of existing charging technologies is conducted in this report. Information for this review was obtained from both the public domain and technical experts within the MERGE consortium. The review focuses on three different areas:
  - The power stage
  - Current connectors
  - The ICT stage
- The key issues affecting the power stage are discussed; with the focus on a safe exchange of power. Possible implementations of the power stage are then specified.
- The key issues affecting the ICT stage and their effects on the communication requirements were explored and described.
- The different stages needed within the charging process and the computational intelligence required are then specified. Within this, consideration is given to different scenarios of CP location, payment methods, and smart grid usage.
- Next the requirement for control of the charging process and where this should be located are discussed. This discussion focuses heavily on the need to control the charging process to prolong EV battery life.
- Possible implementations of the ICT stage are then specified.
- The possible implementations of the power stage specified are then evaluated relative to each other.
- The possible implementations of the ICT stage are then evaluated relative to each other, for the different communication paths within the charging process.
- Finally the results from the evaluations are drawn together to give recommendations for a plug-and-play charging interface that can be used across Europe.



## 5 REVIEW OF EXISTING CHARGING TECHNOLOGIES

As of early 2010 the USA is the only country to have set a standard for the physical connection between the EV and charging point. However, there are other standards under development and several others in use by different EV. In addition, there are a number of different types of charging infrastructure being installed in different locations worldwide. This section will examine these different connection and network architectures from the point of view of the power stage (Section 5.1), connectors (Section 0) and ICT stage (Section 0).

### 5.1 Power Stage

#### 5.1.1 Classification of Charging Types

##### Conductive Charging

Conductive charging uses physically connecting contacts, similar to methods used by common appliances. It is the method used by most on-board (i.e. part of the EV) chargers, or systems that place the charging circuitry and control on the vehicle.

##### Inductive Charging

Inductive charging systems transfer AC power by magnetically coupling a primary winding on the supply side to a secondary winding on the vehicle side using a two-part transformer. Since the vehicle battery has a DC voltage and can only be charged with DC current, the AC current output of the secondary winding is then rectified before being fed into the battery.

Inductive chargers keep most of the charging circuitry and controls in an off-board (i.e. not part of the EV) charging stand, and communicate with the battery and vehicle electronics via infrared or radio frequencies.



Figure 2 – Inductive charging connectors (paddles)

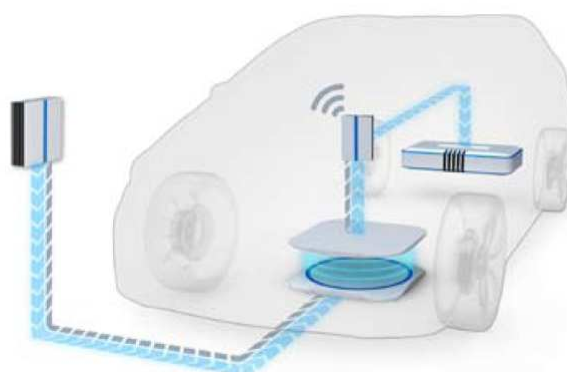


Figure 3 – Overview of the elements involved in the inductive charging of an EV [1]



## Comparison of Inductive and Conductive Charging

A summary of the strengths and weaknesses of inductive and conductive charging schemes are listed in Table 1.

Item	Inductive charging	Conductive charging
Cost	More expensive	Less expensive
Complexity	More complex	Simpler
Safety	Inherently better than conductive charging due to electrical insulation of EV and power supply	Good enough due to highly effective fault detection techniques
Energy efficiency	Not as efficient as conductive charging	More efficient

**Table 1 – Comparison of inductive and conductive charging interfaces**

### Popularity

Both inductive and conductive chargers were popular during late 1990s, but subsequently conductive chargers gained more popularity and were adopted by most manufacturers. The main reason behind this seems to be the simplicity and lower cost of conductive interfaces. Conductive plugs have continued to be the preferred choice by the industry and this has made it unlikely for inductive charging systems to be able to compete with the more mature conductive systems. In early 2010 all the promising charging plugs are of the conductive type.

### 5.1.2 AC Single-phase / Three-phase and DC Charging

Charging the EV batteries can be performed through either AC or DC current fed to the EV inlet.

- **Single-phase AC charging** is usually performed through standard home outlets and provides power levels which are relatively low compared to the battery capacity. However, single-phase charging at considerably higher power levels is also common in charge interfaces which could not be realised using ordinary home outlets. These two charging schemes correspond to what is referred to as Level 1 and Level 2 charging.
- **Three-phase AC charging** requires access to a three-phase power supply and can provide higher charging power levels than single-phase charging. This is because the use of three phases instead of one allows for the transmission of more power without increasing the current or voltage.





- **DC charging** requires a dedicated off-board charger to provide direct current (DC) energy to the EV/PHEV. This method could be applied to provide high levels of charging at public locations.

Due to the short time required for charging the batteries through three-phase AC or high power DC charging methods, they could be the basis for fast or quick charging. Level 3 charging is a term used to describe high power fast charging processes such as the three-phase AC and DC charging.

At present no formal definitions of the different charging levels exists within Europe. Table 2 shows the three different levels referred to throughout this report and their assumed characteristics.

Charging Level	Requirement	Typical charging power	Approximate charging time for a 35 kWh battery
Level 1	Possible through common domestic outlets	3 kW	12 hours
Level 2	Dedicated charging outlet and wiring	10-20 kW	2-4 hours
Level 3	Dedicated charging outlet and wiring – dedicated off-board charger for DC fast charging	40 kW and more	45 minutes or less

**Table 2 – Descriptions of the different charging levels**







### 5.1.3 Connectors

Different manufacturers have produced a large variety of charging connectors for EV. This could be problematic as the EV owners expect to be able to charge their EV at any charging station. On the other hand, from the charge station view point, it would not be acceptable to install several different charging interfaces to accommodate different vehicles. As a result, several joint efforts have been started by vehicle manufacturers, electricity utility companies, and electric equipment producers to reach an agreement on a standard for the charge interface. Some of the most considerable efforts for this charge interface standardisation are described below.

#### Connectors in the USA

##### SAE J1772 standard

The SAE J1772 standard, adopted in January 2010, covers the general physical, electrical, functional and performance requirements of a conductive charging interface. It defines the functional and dimensional requirements for the vehicle inlet and mating connector. It has been supported widely by industry partners in the USA and Japan. This standard is based on a design by Japanese company, Yazaki, and specifies five pins for the connector as listed in Table 3, and shown in Figure 4 and Figure 5. CP, as used in the table below, means 'charging post'.

	Pin name	Description of pin function
1	AC Power 1 (L1)	This is one of the two lines for AC power transfer, with a current rating of 40 A.
2	AC Power (L1,N)	This is one of the two lines for AC power transfer, with a current rating of 40 A.
3	Ground	This pin connects the ground conductor of the CP to the chassis of the EV to enable ground fault protection.
4	Control Pilot	This is responsible for verifying vehicle presence and connection, permitting energisation and de-energisation of the supply, transmitting the supply equipment rating to the vehicle, monitoring the presence of the equipment ground, and establishing vehicle ventilation requirements.
5	Proximity Detection	This pin allows the vehicle to detect the presence of the charging connector, in order to prevent movement of the EV whilst connected to the CP.

**Table 3 – Description of the different pins and their functions in the SAE J1772 charging connector**



The standard (as of early 2010) addresses two charging levels:

- **AC Level 1:** 120 V, 1 phase, maximum current up to 12-16 A, charging from the most common grounded electrical receptacles using an appropriate cord connected to an on-board vehicle charger (1.9 kW).
- **AC Level 2:** 208 – 240 V, 1 phase, maximum current up to 80 A, using dedicated supply equipment through an on-board vehicle charger (19 kW).



Figure 4 – SAE Yazaki plug

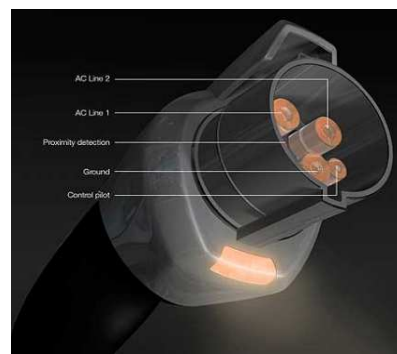


Figure 5 – Pin specification of SAE Yazaki plug

Work on the development of an SAE fast DC charging interface standard has also started. This DC charging system is expected to be an off-board charger which connects directly to vehicle high voltage battery bus. This charger would be controlled by the vehicle, enabling extremely high power transfer (>100 kW) and thus recharge times of minutes instead of hours.

Interfaces in the upcoming SAE DC fast charging system are expected to be the same as the AC standard with the addition of DC contacts and a serial data link between the vehicle and off-board charger. The standardisation is expected to be finalised by the end of 2011.

### Connectors in Europe

In Europe, a common agreement on standardising a single plug has not yet been reached. However, there are currently some promising charging interfaces which are most likely to gain widespread support as the basis of the European standard. These plugs are described below.

### Mennekes plug

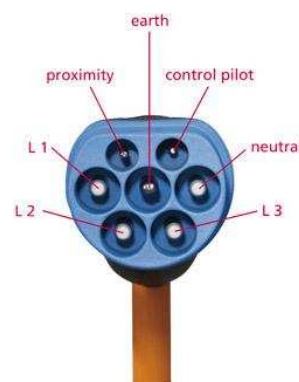
This plug complies with the IEC 69196-1 and 61851-1 standards, and works both for single-phase 230 V connections, the vast majority of European outlets, as well as three-phase 400 V connections, and supports a charging current up to 63 A. Thus, recharging would be possible at 3 kW, the normal single-phase slow charge, or three-phase fast charging at 10, 20, 30, or 43 kW. This plug has seven pins as described in Table 4. CP, as used in the table below, means 'charging post'.

	Pin name	Description of pin function
1	AC Pin 1 (L1)	This is one of the three lines for the three-phase power transfer.
2	AC Pin 2 (L2)	This is one of the three lines for the three-phase power transfer.
3	AC Pin 3 (L3)	This is one of the three lines for the three-phase power transfer.
4	Neutral	This is one of the two pins for conducting the AC current for single-phase power transfer. The other pin may be either of the conductors L1, L2, or L3.
5	Ground	This pin connects the ground conductor of the CP to the chassis of the EV to enable ground fault protection.
6	Control Pilot	This is responsible for verifying vehicle presence, permitting energisation and de-energisation of the supply, communicating the supply equipment rating, monitoring the presence of the equipment ground, and establishing vehicle ventilation requirements
7	Proximity	This pin allows the vehicle to detect the presence of the charging connector, in order to prevent movement of the EV whilst connected to the CP.

**Table 4 – Description of the different pins and their functions in the Mennekes charging connector**



**Figure 6 – Mennekes plug and inlet**



**Figure 7 – Pin specification of Mennekes plug**

The “proximity” contact ensures the activation of the immobilizer, and the “control pilot” contact enables data exchange between the vehicle and the charging point. The current Mennekes charging cable for the connection between the vehicle socket



and the charging station has identical plugs at each end with protection against accidental contact so that the cable can be plugged in either way round.

This plug has gained support among many European energy supply companies and vehicle manufacturers. It has been used in projects by European energy supply companies Vattenfall and RWE and by vehicle manufacturers BMW and Smart.

### Walther plug

The German company Walther produces EV plugs with specifications and pin layouts that are very similar to the Mennekes plug. The Walther plugs also support single-phase 230 V and three-phase 400 V charging. At either of these voltages, current levels of 16 A, 32 A, and 63 A are possible. The resulting charging powers are summarised in Table 5.

		Charging Voltage	
		Single-phase (230 V)	Three-phase (400 V)
Charging Current	16 A	3.7 kW	11.0 kW
	32 A	7.4 kW	22.0 kW
	63 A	14.5 kW	43 kW

**Table 5 – Possible Walther connector charging powers**

The difference between Walther and Mennekes connectors is that the Walther connector is available with two different CP-side connectors for use in different situations. These cables are categorised into two major groups:

- 1) A cable designed for domestic areas with a standard domestic plug on the CP end of the cable (Figure 8). These cables have an "in-cable control box" to provide the required safety features and communication to the vehicle, as this cannot be done through the domestic plug. These cables can potentially be used without the need for a CP, as the EV plugs directly into the domestic mains supply.
- 2) A cable with identical plugs at both ends like the Mennekes plugs (Figure 9). The cable supports direct communication between the EV and the CP.

Based on the vehicle type and its possible charging current limit, different cable cross sections are available to cater for charging currents from 16 A to 63 A.





**Figure 8 – 16 A Walther charging cable with a domestic socket and “in-cable control box”**



**Figure 9 – 16 A Walther charging cable with 2 identical plugs**

### **EDF plug**

French utility company EDF supports a 3-pin industrial plug which conforms to the IEC 60309-2 standard. There is a normal version for 240 V and 16 A (UK 13 A) corresponding to a 3.6 kW charging power, and a high-power version for a 63 A (15 kW) connection. This power interface has no dedicated pins to support the pilot and control signal communication.

The charging cable and the corresponding Elektrobay charging posts used by EDF are produced by the Elektromotive Company.



**Figure 10 – Yellow coiled cable by Elektrobay**

### **Scame-Schneider-Legrand EV plug alliance**

Schneider Electric, Legrand and the Italian company Scame have recently formed the EV Plug Alliance to promote the use of a high safety plug and socket solution for Electric Vehicle charging infrastructure. The plug will safely accept a power load of up to 24 kW on single and three-phase systems.

Three versions of the connector have been introduced by the alliance for different applications:

- Three-phase 500 V AC, maximum current up to 32 A (27.7 kW), 2 pilot contacts (in process of being developed and designed for use by large motor vehicles).
- Single-phase 250 V AC, maximum current up to 32 A (8 kW), 2 pilot contacts (in process of being developed and designed for use by light vehicles).
- Single-phase 250 V AC, maximum current up to 16 A (4 kW), 1 pilot contact (present version).

In addition to the power lines, the connectors are expected to have a pilot contact which enables the following functions:

- Verification that the vehicle is properly connected.
- Continuous protective earth conductor integrity checking.
- Begin energisation of the system.
- De-energisation of the system.

One important feature of this power stage is the presence of an automatically closing lid as a preventive measure against any accidental contact between the user and the live wires on the plugs or the inlets and sockets.



**Figure 11 – EV Plug Alliance prototypes**

### 5.1.4 Work on DC Charging Standardisation

Work to develop and standardise a public DC quick charging system has been led in Japan by the Tokyo Electric Power Company (TEPCO) and Japan Automobile Research Institute (JARI). So far, the Japanese DC charging system has been developed for quick charging of normal passenger cars only. The aim of this quick charging system is mainly for emergency cases and range extending, and it is assumed that EV will normally charge at home or at the workplace.

The TEPCO/JARI charging system has the following specification:

- Input: 3-phase 200 V
- Maximum DC output power: 50 kW
- Maximum DC output Voltage: 500 V
- Maximum DC output current: 125 A



Figure 12 – JARI Level 3 DC connector



Figure 13 – TEPCO DC quick charging station

The TEPCO/JARI DC quick charging plug has 10 pins as shown in Figure 14.

- |                        |                        |                        |
|------------------------|------------------------|------------------------|
| 1) Reference ground    | 2) Control EV relay 1  | 3) Not assigned        |
| 4) Ready to charge     | 5) Negative power line | 6) Positive power line |
| 7) Proximity detection | 8) Communication +     | 9) Communication -     |
| 10) Control EV relay 2 |                        |                        |

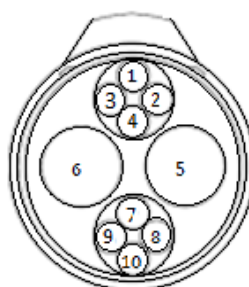


Figure 14 – Pin layout of TEPCO/JARI DC quick charging plug

It should be noted that a Japanese association called CHAdeMO has also been formed to turn the charging system developed by TEPCO/JARI into a global standard for EV.





### 5.1.5 Summary of Connectors

Table 6 shows a comparison of the key features for the above mentioned connectors.

Connector name	Multi-phase charging support	DC charging support	Control signal support	Output power
SAE J1772	✗	✗ (not as of early 2010)	✓	1.9, 19 kW
Mennekes	✓	✗	✓	3, 10, 20, 30, 43 kW
Walther	✓	✗	✓	3.7, 7.4, 11, 14.5, 22, 43 kW
EDF	✗	✗	✗	3.6, 15 kW
Scame-Schneider-Legrand	✓	✗	✓	4, 8, 27.7 kW
TEPCO/JARI	✗	✓	✓	50 kW

**Table 6 – Comparison of the key features for some major charging connectors**

The relative merits of each of these connectors are discussed further in Section 8.1.1.







## 5.2 ICT Stage

### 5.2.1 Main Factors Affecting ICT Stage

There are five main issues that directly affect the design of the ICT stage; these are specified below. Differences in any of these can have a significant effect on the ICT methods used.

- 1) **Charger type.** Faster charging methods come with increased heat and safety risks, requiring careful control. The most logical place for this control to be located is within the battery management system (BMS), thus requiring some means of communication between the BMS and CP.
- 2) **Authentication.** There is a need for the user's identity to be confirmed prior to the start of charging. This is in order to prevent theft of electricity from either domestic or workplace CP, or from users of public CP whose access has been withdrawn. For billing methods involving payment in arrears (payment after charging) user identification data will also need to be recorded for this purpose.
- 3) **Billing.** The billing method employed has a large impact on the communications requirements, especially as the number of parties that need to be involved increases. At the simplest level there is unmetered 'free' charging in which there only needs to be communication between the EV and CP to control the charging process. At the more complicated level is payment in arrears where user data, the time of use and energy usage data need to be communicated to the supplier/aggregator in addition to the communications needed to control the charging process.
- 4) **Location.** The location of the CP will have implications for all three of the previous issues. Those located at users' homes may be able to 'piggy-back' off existing metering, billing and home networking systems. Those located in public areas as standalone units will need to contain all of the functionality they require internally.
- 5) **V2G.** In order to use the V2G concept, the interface between the EV and CP will need to facilitate and measure 2-way flow of energy. The use of V2G will necessitate the communication of real time battery state of charge (SOC) and grid loading data between the CP and utility; and if a financial incentive is offered to users participating, then to take account of the 2-way flow of energy, double the usage data will need to be sent to the supplier/aggregator.

### 5.2.2 ICT Implementations (up to 2010)

Several companies have begun installing charging infrastructure networks in different locations worldwide. Summaries of some of these solutions are given in this section. The key details of the ICT stages used are collated in Table 7 at the end of this section for comparison. The companies producing charging infrastructure that were looked at are:

- Better Place
- Coulomb Technologies





- Elektromotive
- Park and Power
- Aerovironment Inc.
- PEP stations
- POD Point
- Ville de Paris
- CirCarLife
- Mobi.e

### **Better Place**

Better Place [1] is currently installing a network of CP in Israel and Denmark. 220 V Level 1 chargers are being installed at users' homes, as this is expected to be where users primarily charge their EV. CP are also being installed at workplaces, public car parks, and along urban streets. All CP are equipped with a communication system for communicating with the network operators. User authentication is achieved through the use of a contactless RFID (Radio Frequency Identification) smartcard. The connector used is either the Mennekes connector or a non-standard adaptation of the SAE J1772 connector (see Section 0).

The EV has a built-in PC through which the user manages the charging process, can view current battery state of charge and available range, and get directions to the nearest free CP. The user can also interact with the EV via their mobile phone.

Demand side management capabilities are built into the network management software to allow 'intelligent' charging and better utilisation of intermittent renewable energy.

A unique feature of the Better Place model is that fast charging is not offered, but instead battery switch stations are to be introduced. At these, the EV battery is removed automatically from the underside of the EV where it is fitted, and replaced with a fully charged battery. The original battery is then charged by the battery switch station. This battery switch process is completed within a timeframe analogous to current conventional refuelling. One necessity of this method is that the user cannot own the battery as it is frequently changed, thus the user leases the battery from Better Place. A video of this technology in use can be seen at <http://www.betterplace.com/solution/charging/>.





**Figure 15 – A Better Place charging post with charging cable attached** Error!  
Reference source not found.



**Figure 16 – A vehicle on a Better Place battery switch station [2]**

### Coulomb Technologies

Coulomb Technologies [4] have installed a number of CP throughout the USA. They have installed both Level 1 (230 V, 16 A single phase) and Level 2 (230 V, 32 A single or three phase) chargers, and plan to install Level 3 chargers in the future. User authentication at the CP is via a Radio Frequency Identification (RFID) contactless smartcard. The CP are available with either SAE J1772 or Mennekes connectors.

In order to access the CP, the users must swipe their smartcard; upon doing so the door covering the connector will be unlocked. The user then plugs in the charging cable and closes the door, only after which will the CP be energised. To unplug the charging cable, the user must again swipe their smartcard to de-energise the CP and open the door.

The charging network is based around the use of a CDMA (code division multiple access) or GSM (Global System for Mobile communications) module located in certain CP, with up to 127 other CP communicating through this node. The network operating system is built around web based applications to allow web-based mobile phones to communicate and locate free CP. Warnings and notifications are sent to the user via SMS or email.

DSM is included through the sending of usage data to the utility or third party provider. Encryption is achieved through HTTPS and 128 bit AES.

Several different forms of billing can be supported by the system including 'free' charging, pay per use, subscription, and pay per kWh. Roaming is also possible. At present the system supports pay per use by calling a telephone number, and monthly subscriptions. Future capabilities will include payment via RFID smart card and payment via credit or debit cards.



**Figure 17 – A Coulomb Tech charging bollard [5]**



**Figure 18 – The proposed Coulomb Tech Level 3 charging station [6]**

## Elektromotive

Elektromotive [7] have developed a range of Level 1 (240 V, 20 A single phase) CP, called Elektrobay. These have been installed in several locations in the UK (London, Milton Keynes and North East England) [8] and France (by EDF). Authentication is achieved via a RFID key fob. The CP can be fitted with which ever domestic plug socket is used in that country, and uses the EDF industrial plug at the EV.

Safe access is guaranteed in the same way as for the Coulomb Tech CP. To gain access to the CP, the user swipes their key fob which opens a door to allow the charging cable to be connected. Once connected the user closes the door. Only when the user has been authorised, the plug connected and the door closed will the charger be energised. To disconnect from the CP the user must once again swipe their key fob to de-energise the CP and open the protective door.

Payment can either be a 6 or 12 month subscription where user and usage data are stored within the CP until they are downloaded in bulk via a handheld meter. The key fob can also keep track of a users' credit in a cash-less pay-as-you-go (PAYG) scheme. Finally, the CP can be installed with a GPRS module to allow connection to a charging network.



Figure 19 – An Elektrobay charging post with a BS 1363 plug socket [9]

## Park and Power

Park and Power [10] have designed a twin socket, on-street Level 1 (240 V, 13 A single phase) CP. Users subscribe to either a 6 month or 12 month contract and are then issued with a RFID key fob which allows them access to the CP.



Figure 20 – A Park and Power charging post in use [10]

## Aerovironment Inc.

Aerovironment [11] has designed a range of domestic Level 1 chargers (240 V single phase), with installation due to begin in 2010. The chargers will be installed directly into a domestic power supply. The connector used is the SAE J1772.

The company have also designed on-street and public area chargers, and a Level 3 CP compatible with the THINK City using the TEPCO/JARI charging specification.



Figure 21 – An Aerovironment domestic charger [12]



Figure 22 – The Aerovironment Level 3 fast charging station [13]

## PEP stations

PEP stations [12] have developed both a Level 1 (110 V, 13 A single phase) and a Level 2 (240 V, 30 A single phase) on-street CP. Both have an SAE J1772 connector. The user can select the length of time to charge for on an LCD touch screen, and then swipe a credit card to gain access to the CP. The CP can be configured to use an access card instead of a credit card if no payment is required.



Figure 23 – A PEP station on-street charging post [14]

## POD Point

POD Points [15] are the CP being installed by infracharge as a part of their larger charging infrastructure solution. POD points are twin socket, on-street chargers. There are several currently installed throughout central London. These have a standard 3 pin BS 1363 plug.

The user gains access to the CP by swiping an RFID key fob, which then opens up a door giving access to the plug. Upon completion of the charge, the user re-swipes their key fob to close this door.

POD Points contain a communications device (unclear of what form) which allows it to communicate user and usage data back to a central point. This data can then be compiled to give a range of statistics as well as implement many different billing scenarios. The system can support free, pay-as-you-go, pay by SMS and pay monthly payment methods. These can be calculated either as pay per hour or pay per kWh, and can support time-of-use tariffs.





**Figure 24 – An on-street POD Point. Note the protective door and the RFID reader (yellow circle) [16]**



**Figure 25 – POD Point status indication lights and disconnection procedure [16]**

### Ville de Paris

This charging terminal is approved by EDF [17] and can be installed with 2 sockets for EV. The terminal can supply 230 V at up to 63 A. Each of the sockets is covered by an access trapdoor which if opened de-energises the socket beneath. Access to the CP is gained through a contactless RFID card that can also be configured to work with a pay-as-you-go system.



**Figure 26 – A Ville de Paris CP with four sockets [17]**



## CirCarLife

CIRCONTROL [18] have developed a range of CP under the name CirCarLife, for use in public locations such as car parks. This range contains single and double socket charging posts rated at 230 V, 16 A (3.6 kW) for each socket. The range also include a 230 V, 32 A (7.3 kW) single phase fast charger, and a 400 V, 63 A (42 kW) three phase fast charger.

All of the CP use a common RFID card that is pre-loaded with charging credit, which is used to gain access to the plug socket. The plug type used is the industrial IEC 60309-2 compliant type.

The system can be fitted with several different communication modules to allow it to communicate with a main controller. These include Ethernet, ZigBee, PLC, and GPRS. The main controller can be used for metering, load management, and intelligent recharging. The system can also support different price tariffs.



Figure 27 – A CirCarLife on-street CP with 2 IEC 60309-2 sockets [19]

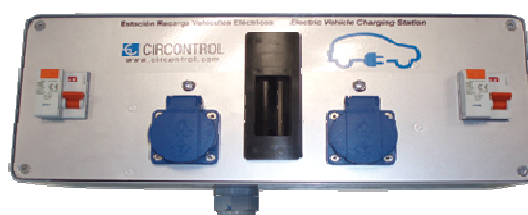


Figure 28 – A CirCarLife CP for use within a car park, with 2 IEC 60309-2 sockets [20]

## Mobi.e

The Mobi.e initiative [21] is a Portugal wide project supported by the Portuguese government that is aimed at the adoption of new energy models for mobility.

An integrated network between several charging points in Portugal, boosted by the management entity Mobi.e, is being created and to allow the supply of electric vehicles by way of a charging card.



Figure 29 – Charge: The Mobi.e pre-paid card [21]

Charging points will be available at many places including shared private garages, public car parks, shopping centre car parks, hotels, airports, petrol stations and on the public highways.



Figure 30 –Mobi.e public charging points [21]

The Mobi.e solution considers two types of charging:

- Standard charging, at 230 V, taking advantage of the energy produced by renewable sources at times of lower consumption.
- Fast charging, taking 20 to 30 minutes, by way of rapid charging during the day in accordance with the needs of the user.

By way of a pre-paid card – Charg.e – the Mobi.e network provides EV owners with access to the charging points, also providing a discounted the charging cost. This charging cost accounts for the electricity consumed and an additional payment for use of the charging service.

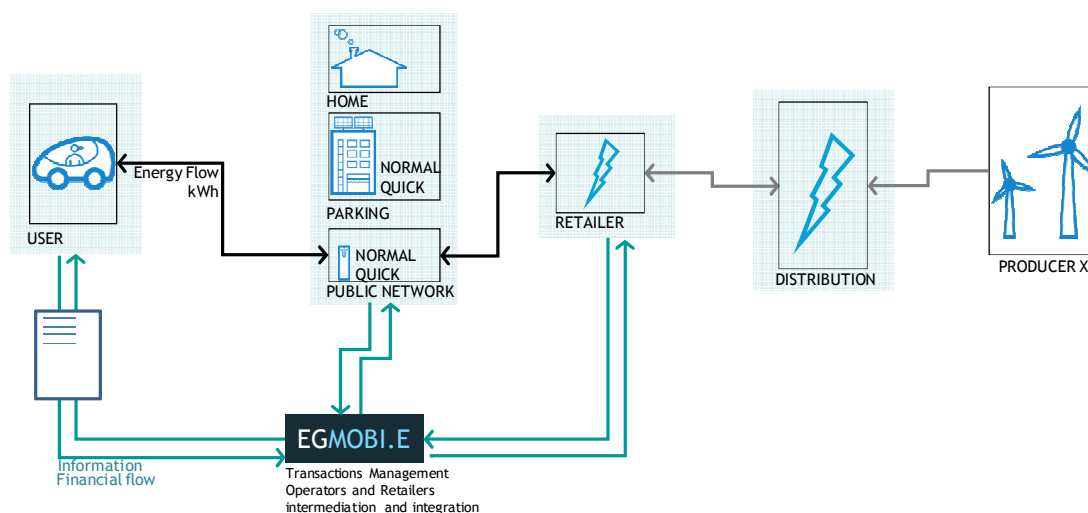


Figure 31 – Mobi.e operational framework [21]



A summary of these different solutions is shown in Table 7.

Company	Charger type(s)	Communication method(s)	Authentication method	Billing method(s)
Better Place	<ul style="list-style-type: none"> <li>• Domestic 220 V</li> <li>• On-street</li> </ul>	<ul style="list-style-type: none"> <li>• On-board PC</li> <li>• Plus mobile to EV</li> </ul>	<ul style="list-style-type: none"> <li>• Smartcard</li> </ul>	<ul style="list-style-type: none"> <li>• Buy miles (or km) on subscription basis</li> </ul>
Coulomb Technologies	<ul style="list-style-type: none"> <li>• 120 V, 16 A</li> <li>• 240 V, 32 A</li> <li>• TEPCO Level III</li> </ul>	<ul style="list-style-type: none"> <li>• CDMA or GSM (1 per local group)</li> <li>• SMS to user</li> <li>• HTTPS and 128 bit AES encryption</li> </ul>	<ul style="list-style-type: none"> <li>• Smartcard</li> </ul>	<ul style="list-style-type: none"> <li>• Free</li> <li>• Pay per use</li> <li>• Subscription</li> <li>• Per kWh</li> </ul>
Elektromotive	<ul style="list-style-type: none"> <li>• 240 V, 13 A</li> </ul>	<ul style="list-style-type: none"> <li>• GPRS (optional)</li> </ul>	<ul style="list-style-type: none"> <li>• RFID key fob</li> </ul>	<ul style="list-style-type: none"> <li>• 6 or 12 month licence</li> <li>• PAYG</li> <li>• Pay-via-mobile</li> </ul>
Park and Power	<ul style="list-style-type: none"> <li>• Twin plug on-street</li> </ul>		<ul style="list-style-type: none"> <li>• RFID fob</li> </ul>	<ul style="list-style-type: none"> <li>• 6 or 12 month licence</li> </ul>
Aerovironment Inc.	<ul style="list-style-type: none"> <li>• Domestic</li> <li>• Either 110 V trickle, or 240 V charge</li> </ul>			
PEP Stations	<ul style="list-style-type: none"> <li>• On-street charger</li> <li>• 110 V, 12 A</li> <li>• 240 V, 30 A</li> </ul>	<ul style="list-style-type: none"> <li>• LCD touch screen</li> </ul>	<ul style="list-style-type: none"> <li>• Access card</li> <li>• Credit card</li> </ul>	<ul style="list-style-type: none"> <li>• Credit card</li> </ul>
POD Point	<ul style="list-style-type: none"> <li>• Twin plug on-street</li> <li>• Level I</li> </ul>	<ul style="list-style-type: none"> <li>• Unclear what method</li> </ul>	<ul style="list-style-type: none"> <li>• RFID key fob</li> </ul>	<ul style="list-style-type: none"> <li>• Free</li> <li>• Pay per hour</li> <li>• Per kWh</li> <li>• Pay by SMS</li> <li>• PAYG</li> <li>• Pay monthly</li> <li>• TOU tariffs</li> </ul>
Ville de Paris	<ul style="list-style-type: none"> <li>• Twin plug on-street</li> <li>• 230 V, 63 A</li> </ul>		<ul style="list-style-type: none"> <li>• Smartcard</li> </ul>	<ul style="list-style-type: none"> <li>• Free</li> <li>• PAYG</li> </ul>

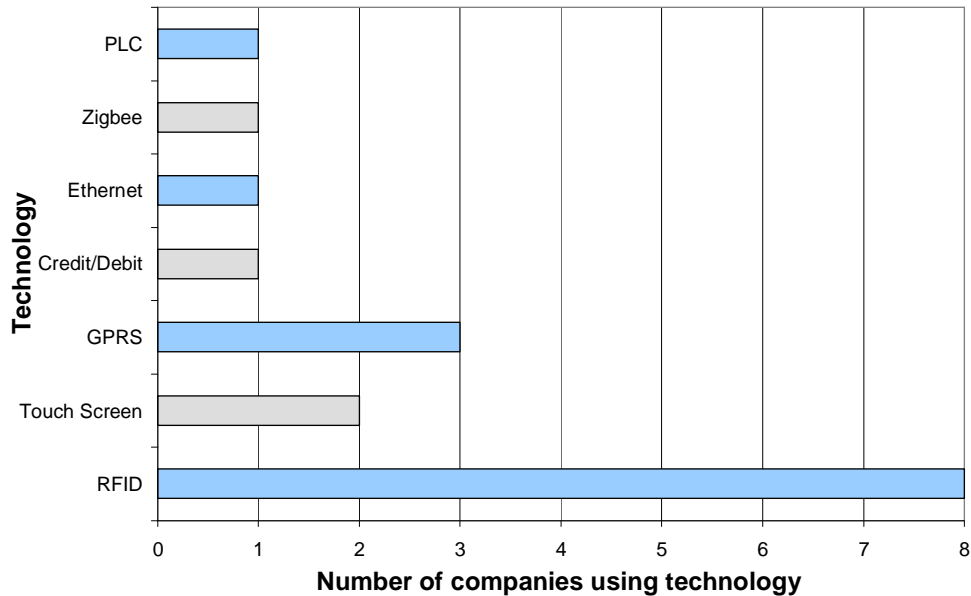




CirCarLife	<ul style="list-style-type: none"> <li>• On-street</li> <li>• Car park</li> <li>• 3.6-42 kW</li> </ul>	<ul style="list-style-type: none"> <li>• (Optional Ethernet, ZigBee, PLC, GPRS)</li> </ul>	<ul style="list-style-type: none"> <li>• Smartcard</li> </ul>	<ul style="list-style-type: none"> <li>• PAYG</li> </ul>
Mobi.e	<ul style="list-style-type: none"> <li>• Domestic 220 V</li> <li>• On-street</li> </ul>	<ul style="list-style-type: none"> <li>• (Optional Ethernet, ZigBee, PLC, GPRS)</li> </ul>	<ul style="list-style-type: none"> <li>• Smartcard</li> </ul>	<ul style="list-style-type: none"> <li>• Pre-paid Card</li> </ul>

**Table 7 – Summary of ICT stage of existing charging infrastructures**

Figure 32 shows the number of these companies using each technology. From this it is clear that at present RFID (smartcards and key fobs) is the dominant communication method in use for authentication and/or payment, and there is a tendency towards GPRS for communication from the CP to the DSO.



**Figure 32 – Number of companies using each technology type**

A safety feature that is common to several of these solutions is the use of a protective “door” and locking mechanism to prevent anything from coming into contact with the CP charging cable socket. The unlocking of this door will need controlling to ensure only authorised users can gain access to the charging socket, and hence charge from the CP.





## 6 POSSIBLE IMPLEMENTATIONS OF THE POWER STAGE

The main function of the power stage as implied by its name is to transfer power from the supply to the vehicle battery and, in the case of Vehicle to Grid (V2G) operation mode, to transfer power from the vehicle battery to the grid. To do so, the AC supply power should be converted to regulated DC as used in the battery through a device which is called a “charger”. This charger may be located either in the vehicle (“on-board” charger) or in the charging post (“off-board” charger).

The charger is often on-board for Level 1 and Level 2 charging. For Level 3 and DC charging off-board chargers are usually required, as the size and weight of the required charger is too large to be carried inside the EV.

The charging cable may either be carried with the EV (with a plug at both ends), or attached to the CP (with only a plug for connection to the EV). If carried with the EV the cable may or may not have similar plugs at both ends. However, it is important that the side for connection to the charging station is compatible with different vehicles, whilst the plug for the vehicle inlet side can be different.

To enable power exchange between the vehicle and the charge station in conductive charge interfaces, a number of pins are required.

- For single-phase charging, one pin for the power transfer and one neutral pin for closing the electrical circuit are needed
- For three-phase charging, three pins are needed for the connection of the three phases
- For DC charging, one positive and one negative supply line are required.

### 6.1 Power Stage Safety

To ensure that the power exchange between the vehicle and the grid is performed properly, a number of safety considerations should also be taken into account. These considerations are explained in the following two sub-sections.

#### 6.1.1 Physical Design for Safety

The power stage connector and interconnections should be designed in a way that minimises the risk of accidental or voluntary contact of the live parts of the plugs, sockets and inlets with the user. Using automatic closing lids can further decrease the chance of any contact between the live parts and slim objects such as screwdrivers or wires.

#### 6.1.2 Electrical Safety Functions

In addition to the physical design consideration, most of the following electrical functions should be performed by the power stage, taking into account different necessities such as ease of use, commercial and manufacturing issues.

- **Ground fault interruption mechanism.** The power stage needs to provide ground fault protection for the safety of the vehicle user in the case of a ground





fault occurrence. This requires using a ground fault interrupting circuit and establishing an electrical connection between the charge station ground and the vehicle chassis. This connection is realised through a dedicated ground (or Earth) pin in the EV plug

- **Immobilisation of the vehicle while charging.** Moving the vehicle during the power exchange with the charging station may result in serious safety hazards to the driver and damage to the vehicle and the charging point. To avoid this, immobilisation of the vehicle when connected to the charge station should be ensured. This is usually done using a “plug present” or “proximity detection” pin in the power stage
- **Proper connection interlock.** Before the charging process can start, it should be ensured that the vehicle is properly connected. This includes connection between the plug and the vehicle inlet, proper function of the plug cable, and connection between the plug and the charge station. Only when the proper connection is ensured can the power stage be energised. This is usually performed through a “control pilot” pin
- **Continuous protective ground conductor checking.** Due to the importance of ground fault protection during the power exchange between the vehicle and charge station, the connection of the ground pin is continuously checked separately from the ground fault interruption mechanism
- **Automatic de-energisation interlock.** This is a mechanism to de-energise the CP if a strain occurs in the cable connection that could result in live parts being exposed. In addition, it de-energises the CP before the plug can be disconnected
- **Ventilation interlock.** In a few battery types, hydrogen may be released during the charging process. The ventilation interlock is to ensure that for vehicles with such batteries, the charging can start only if proper ventilation is possible





## 6.2 Possible Power Stages

EV plugs can be designed in a way that supports both single-phase AC charging and fast charging modes. In Europe, the industry trend is to design plugs which support both single phase and three phase power transfer. The three phase charging mode could provide a fast charging option. This trend can be seen in EV plugs such as those from Mennekes, and Scame-Schneider-Legrand alliance. However, in the USA and Japan DC charging has been the preferred choice for fast charging. The plug specification in the upcoming SAE J1772 standard is expected to have three new pins to support fast DC charging.

The inclusion of both three-phase and DC fast charging in a single plug does not seem to make sense, as they are both aimed to serve the same purpose. According to where the EV is to be used, the fast charging option supported in that region would be enough.





## **7 POSSIBLE IMPLEMENTATIONS OF THE ICT STAGE**

### **7.1 Introduction to the ICT Stage**

The requirements of the CP may differ considerably depending on its location, the level of sophistication desired and the business model into which it is to be integrated. This section will describe these different scenarios and their implications for the ICT stage.

#### **7.1.1 Charger Type**

The rate at which the EV is to be charged will impact both the load on the electric grid and the level of control required to keep the charging process safe. Due to their low power, Level 1 chargers require only minimal control, namely controlling the start and stop of charging under safe conditions.

A typical EV in 2010 has a battery capacity in the range 15 to 25 kWh [22][23], which at a 3 kW Level 1 charging rate would take between 5 and 8 hours to charge. Although this may be acceptable for the charging of an EV overnight, there are other situations in which this is an unacceptably long period to wait to charge the battery. In these cases, higher power charging methods will be needed.

As the rate of charging increases above that of Level 1 the control needed for the charging process will increase. It is likely that at powers greater than 3 kW there may be a need for the charging rate (available and required) to be agreed prior to charging, and the charging rate may need to be varied during charging either for battery longevity or to control the battery temperature.

When Level 3 AC and DC fast chargers are considered, the need for control of the starting and stopping of charging becomes more important; in particular unexpected termination of charging or disconnection needs to be controlled to prevent arcing or electrical damage. In addition for higher charging rates the rate of control communications will need to increase.

#### **7.1.2 CP Location**

Internal combustion engine powered vehicles refuel almost exclusively at dedicated fuel stations. The use of electricity to power EV opens up a much wider range of possible locations in which recharging can take place due to the well developed and wide-spread electricity network. The locations at which CP are believed most likely to be installed can be grouped into three categories:

- Private area with private access (individual and shared domestic garages, fleet)
- Private area with public access (workplaces, large car parks, dedicated charging station)
- Public area with public access (on street)





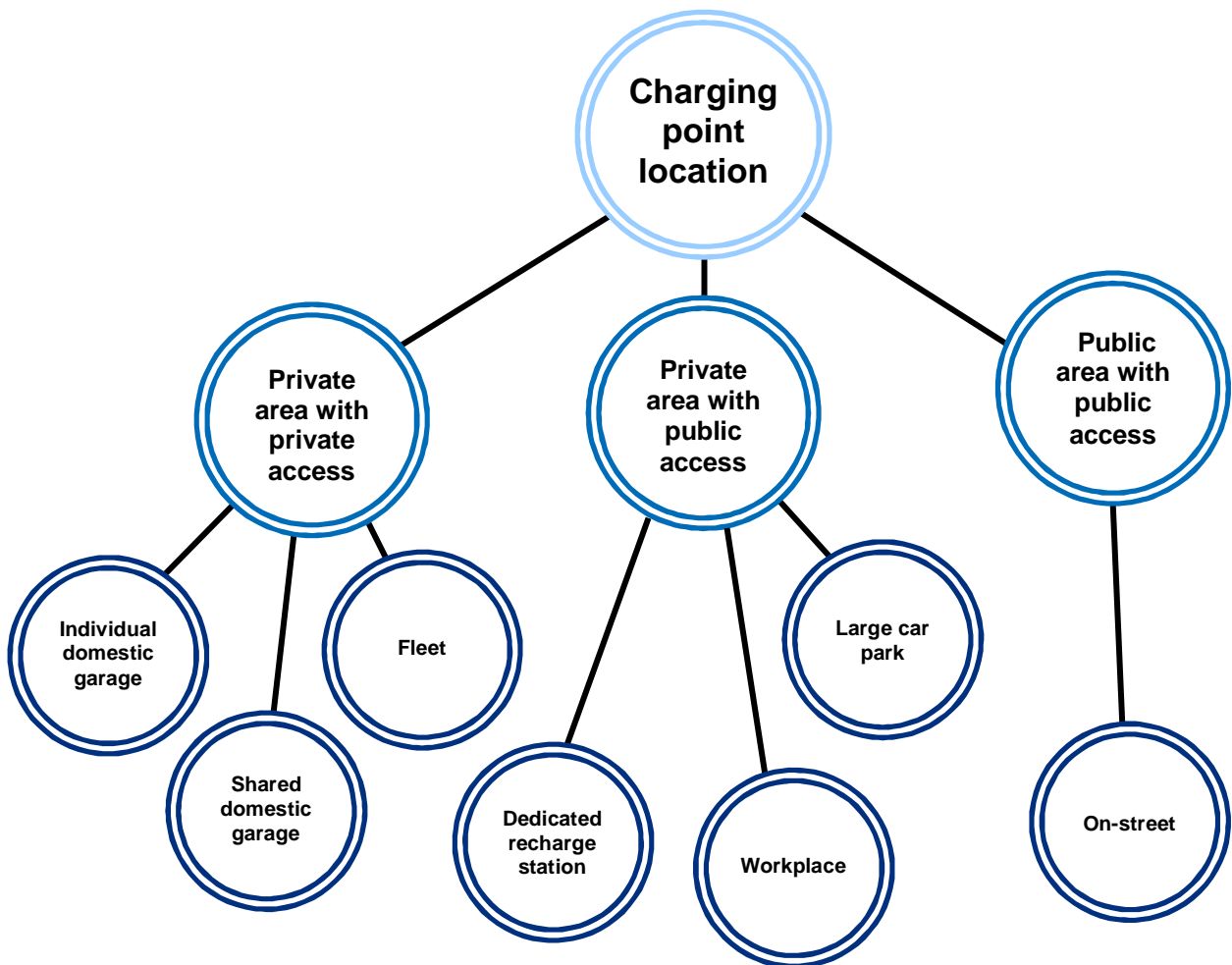


Figure 33 – Breakdown of different charging point locations

These different locations and some of the details relating to their impact on the ICT stage are described in Table 8.

Private area with private access	
Individual domestic garage	It is widely believed that EV users will want to make use of cheap off-peak electricity prices and charge their vehicle overnight at their home when they are not using it. This will require them to have some form of charging equipment at their home (most likely a Level 1 charger), which could range from a simple cable connecting the EV (with an in-built charger) to a domestic plug socket, or a specific domestic CP. Any electricity used to charge an EV at home could be metered and billed through the existing household electricity meter.
Shared	Some users may not have access to their own personal garage but may share one with other residents (e.g. a shared garage for a large



domestic garage	block of flats). In this scenario the individual CP may need to be metered separately in order to allow for different users to pay separately; on top of this there would need to be some way of determining which one of the many residents is using that CP so that the bill can be generated for the correct person.
Fleet	As well as the Level 1 chargers mentioned above companies operating a fleet of vehicles may require Level 2 or possibly Level 3 fast chargers to quickly recharge their EV during the day. These CP would not necessarily require individual metering or payment capabilities. The electricity usage for the location would be measured by one meter and the fleet owner would pay for this bulk electricity usage.
<b>Private Area with public access</b>	
Large car park (e.g. supermarket, railway station)	Large public car parks, in which vehicles are likely to be parked for a couple of hours, present an opportunity for the user to "top-up" the charge in their EV. This would be similar to on-street except payment may be conducted at some central point instead of at the CP; similar to the use of tickets in current car parks. This would demand the communication of user and energy usage data to this central point, which may not be necessary for on-street CP (depending on the payment method). Depending on the likely utilisation and economics the CP in these locations may be a combination of Level 1, Level 2, and Level 3 chargers.
Workplace (e.g. office car park)	Many users' vehicles remain parked for a large portion of the day at their place of work. This provides an opportunity for them to charge their vehicles during the day if desired. The CP used here could be either individually metered or all of the energy usage could be metered through the workplace electricity meter. As the EV is parked for several hours and electricity prices are high during the day it is likely that these will only be Level 1 chargers.
Dedicated Recharge stations / Battery switch stations	<p>Electric vehicles have ranges that are considerably lower than internal combustion engine powered vehicles. In addition, the time it takes to recharge an EV can be considerable. Users may occasionally want to drive their EV over distances that are greater than the EV range from a fully charged battery. This will necessitate the need for recharging stations similar in concept to current fuel stations, in which the EV can be recharged in order to extend its range. It is most likely that EV users using these facilities will want recharge times that are comparable to current refuelling times. This may mean that CP installed at these facilities will need to be Level 3 AC or DC fast chargers.</p> <p>The recharge time achievable with these fast chargers is limited by battery heating. The cooling required to achieve comparable "refuelling" times to internal combustion engine powered vehicles</p>



	<p>would necessitate a large on-board cooling system that would be prohibitively expensive and heavy. Thus in the short term battery switch stations are a more viable option in order to achieve such short recharge times. However, these require EV to have a standard battery size, shape and location; a constraint which vehicle manufacturers will want to avoid. In addition, battery switching requires the purchase and storage of many batteries, representing a very large amount of capital.</p>
<p><b>Public area with public access</b></p>	
<p>On-street (e.g. on residential street near user's home, on high street)</p>	<p>Many vehicle owners, particularly in dense urban areas, do not have their own private driveway in which to store their vehicle. These users would require on-street CP at the point where they park their vehicle in order to charge. These on-street CP will need to be self-contained in terms of metering and control, with some ability to communicate with the supplier/aggregator for payment if this is required. As well as overnight charging for users without a driveway, on-street CP will also be used during the day to "top up" an EV battery. This implies that some on-street CP may be Level 1 whilst others are Level 2, or they may even be capable of operating in both charging modes.</p>

**Table 8 – Descriptions and implications of different CP locations**

### 7.1.3 Payment

Electricity usage is paid for either prior to use at a meter, or in arrears by a bill from the utility company. The meter for this is located in a fixed place and registered to one user. The situation becomes more complex with the use of EV, which are mobile and may charge at many different locations. This leads to several different payment methods being possible. In essence these consist of two types:

- 1) Payment in advance (pre-payment requiring an account to be debited prior to charging), and
- 2) Payment in arrears (requires an account to be debited after charging).

Within these two categories there are several different ways in which payment could be completed.

Figure 34 shows these different options. They are then described in more detail in Table 9.

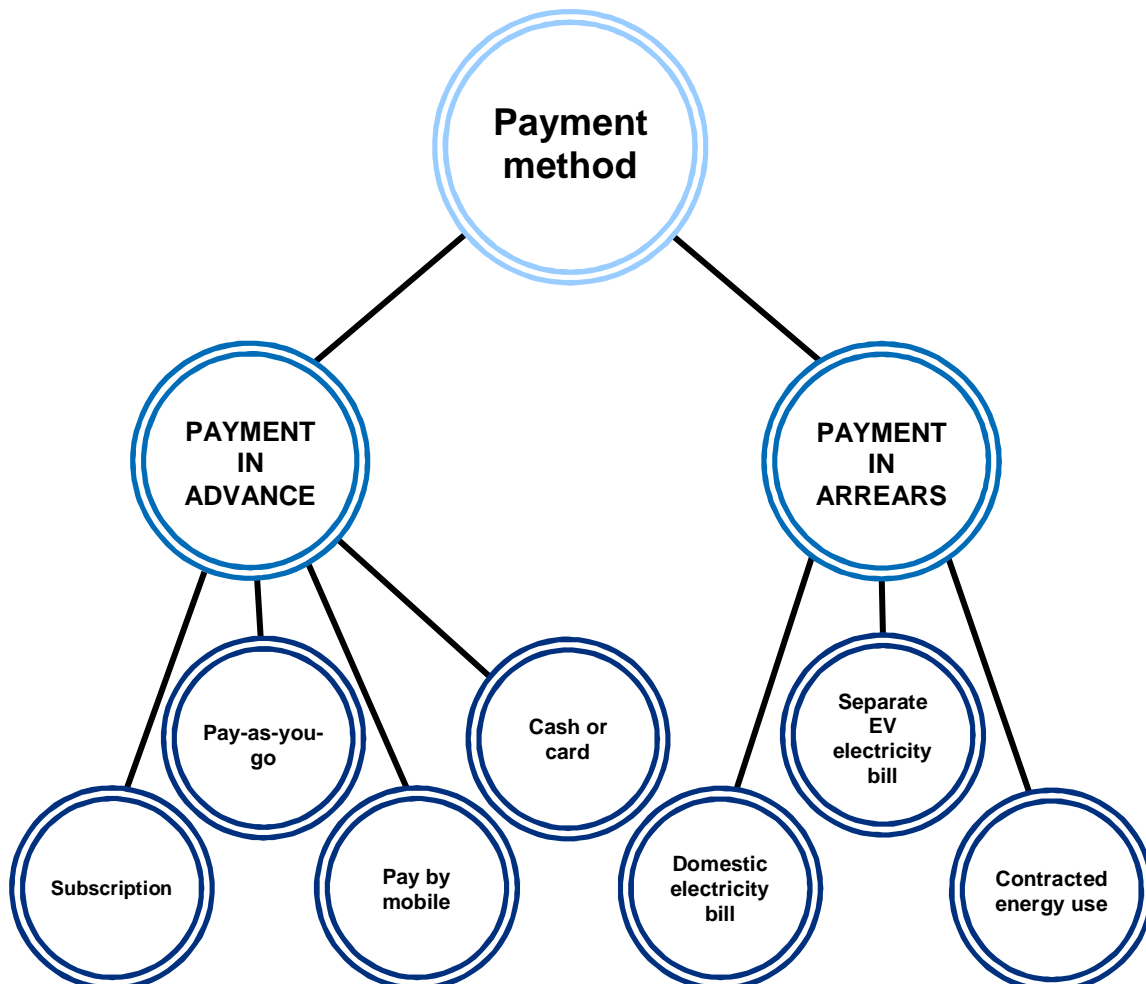


Figure 34 – Breakdown of different payment options



Payment in advance	
Subscription	<p>With this method, individual energy usage is not metered. Instead the user pays a fixed amount in order to be given access to a group of CP for a defined length of time (e.g. six or twelve months). The CP used with this method will not be required to communicate any user or energy usage data with the DSO or supplier/aggregator, but will just need to be able to authenticate users with current subscriptions and communicate with the EV.</p> <p>Although attractive from the point of view of using a simple CP, this method does have drawbacks. Firstly, some users will be paying too much for their energy usage and some too little. Secondly, the user can only buy electricity from the CP owner they are subscribed to. This may create a monopoly for an individual CP owner in the “good” CP locations and violate EU competition rules. Finally, such a system does not allow roaming unless the user is subscribed to several different CP owners. Consequently it is not expected that this method will be used as a long term solution.</p>
Pay-as-you-go (PAYG)	<p>This is analogous to the mobile phone PAYG ‘top-up’ system in which the user pays in advance to obtain a level of credit. This credit is then debited when the user charges their EV. There are two possible ways in which the PAYG credit can be handled:</p> <ol style="list-style-type: none"> <li>1) The CP communicates with the supplier/aggregator at the start of charging to verify the user's identity and the amount of credit they have available. After charging, the user and energy usage data are sent back to the supplier/aggregator where the amount of credit remaining is calculated.</li> <li>2) User details and the amount of credit remaining are stored on the device used for authentication (e.g. mobile phone, RFID smartcard), this device is updated with the new credit level once charging has completed. The user can purchase more credit from a central point (e.g. top-up station). This saves the CP from needing to communicate with the DSO or supplier/aggregator.</li> </ol> <p>This system is currently being used by several different companies (Coulomb Technologies, Elektromotive). It is more complex and costly than a subscription payment method, however it does mean that users are able to roam and use any CP.</p>
Pay by mobile	<p>In this method the user sends an SMS to the CP owner, who then charges the user's mobile phone a fixed amount. The CP owner may also use this system to control access to the CP by sending an authorisation code by SMS for the user to input to the CP.</p> <p>This system is not a plug-and-play system; however it is convenient for the user. It also contributes additional administration to the bill generation as there will need to be a link between both the supplier/aggregator and mobile phone company.</p>





<p>Cash or card payment at point of use</p>	<p>This is akin to payment at current petrol stations. The user may pay for their electricity at point of use using cash or a credit/debit card. The CP used for this method will need to have a communications link to the credit/debit back office for validation and processing. This is on top of any communications required between the CP and DSO or supplier/aggregator, and so is an added complexity. This method places no restrictions on which CP users can use.</p> <p>Due to the low value of the energy used for charging it is unlikely that the exchange of cash will be used. This is simply because the exchange of cash requires some physical mechanism to collect and store the cash and then the employment of somebody to collect this cash, and this is not cost effective.</p>
<p><b>Payment in arrears</b></p>	
<p>Added to domestic electricity bill</p>	<p>Since most EV users will have a domestic electricity account, it may be convenient for users to have their EV electricity usage added to this bill. This would require that for CP not at domestic locations, both the energy used and some user identification were sent to the electricity supplier. In a domestic situation it should be possible to use the existing electricity meter to account for this EV electricity usage. The advantage of this method is that it utilises the existing and sophisticated utility back office infrastructure to generate this bill, thus saving costs. In order for roaming to be accommodated either the user must register their electricity account with several electricity suppliers, or some degree of communication between suppliers must be established (similar to mobile phone roaming). An issue with this system is how to control the access to the CP in order to prevent theft of electricity from unregistered users, and to enable the electricity supplier to remove access to the CP from users who do not pay their bill.</p>
<p>Separate EV electricity bill</p>	<p>This payment method involves the user having a separate electricity account with the utility solely for their EV usage. This may be necessary if a fuel duty (explained below) is applied to EV electricity usage. The implications for this are the same as for having EV electricity usage added to their existing domestic bill, except that a separate meter is required.</p>
<p>Contracted energy use</p>	<p>This method is similar to that used by mobile phones in that the user signs up to contract in which they pay a set amount each month, and receive a certain energy usage in return. Any energy usage they use above this limit will then be charged for on their monthly bill on top of the set payment. This method requires some means of keeping track of how much of their prescribed energy a user has used, and if they have used above this limit then how much extra energy have they used. All of this data will need communicating to the supplier in order for the monthly bill to be generated.</p>

**Table 9 – Description of different payment methods**







In all of the above payment methods, it is possible to either charge the user per kWh used or per unit time:

### **Fuel Duty**

As EV penetration increases the loss of revenue due to the decrease in fuel duty may cause governments to tax electricity usage for EV; this would necessitate having an EV metering and billing system that is completely separate from the existing domestic system. Thus domestic CP would not be able to 'piggy-back' on existing systems; a stand-alone CP would be required. Also it may not be possible for this taxed electricity usage to be added to a user's domestic bill, requiring either a separate EV energy bill or encouraging the use of PAYG systems.

#### **7.1.4 Smart Grid and V2G**

The current small penetration of EV has very little impact on the electricity demand on the grid, but as EV penetration increases this impact will become noticeable. This impact on the grid could be managed in two ways:

- 1) By reinforcing the grid infrastructure to cope with the increased loading (expensive), or
- 2) By controlling the grid loading through DSM.

In addition, EV are particularly attractive if they can source their energy from renewable energy sources, as this will effectively give them zero 'well-to-wheel' CO<sub>2</sub> emissions. Both of these point towards the possible future integration of EV with a smart grid.

Coupled with the use of a smart grid is the concept of V2G. The use of V2G will require the capability for 2-way energy flow between the EV and CP, and the inclusion for both these flows within billing. This increases the amount of data that needs to be metered within the CP and then communicated with the supplier/aggregator, who will act as billing authority. V2G operation also requires extra data exchange for the monitoring of battery states and for controlling when energy is required back on the grid or excess renewable energy is being generated. Behind all of this sophisticated control programs will be needed in the EV, to use V2G whilst still meeting the user's wishes on battery SOC at a certain time; at the supplier/aggregator, to control the energy consumed and the grid services provision according to the market negotiations; and at the DSO, to control the use of this distributed energy storage to smooth the demand profile or even to mitigate eventual congestion or undervoltage problems that might appear in the grid. Within a domestic location a new smart meter will be required in order to take account of the 2-way flow of energy.

If a smart grid is used, the CP will communicate to the supplier/aggregator and to the DSO how much power is being demanded or used. More complex systems may require the communicating of price tariffs that the user will use, or the amount of time the user has given for charging, or willingness to use V2G and current SOC.



## 7.2 Computational Intelligence

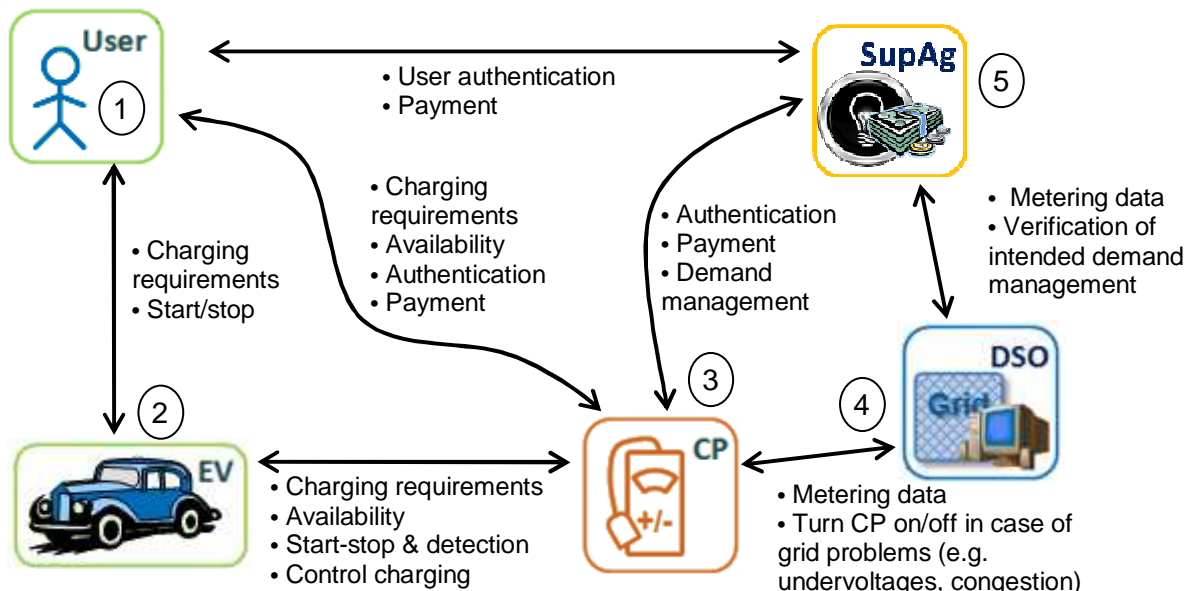
In this section an overview of the computational intelligence between the different entities involved in the charging process is given. The different communication paths and reasons for these are described. These are then expanded on for different charging scenarios. For comparison the interactions between the different entities involved in delivering electricity to customers in today's electricity network is presented. The increased computational intelligence involved in this for different EV charging scenarios is then discussed.

### 7.2.1 Required Communication Paths and Associated Reasons

There are five main elements which, depending on the scenario, may need to communicate with each other. These are:

- 1) The user
- 2) The EV
- 3) The CP
- 4) The DSO
- 5) The supplier/aggregator.

Figure 35 gives an overview of which of these elements may need to communicate with which others and why. In some other scenarios, charging point manager (CPM) or smart home may be also involved which would be responsible for managing several different electrical loads.



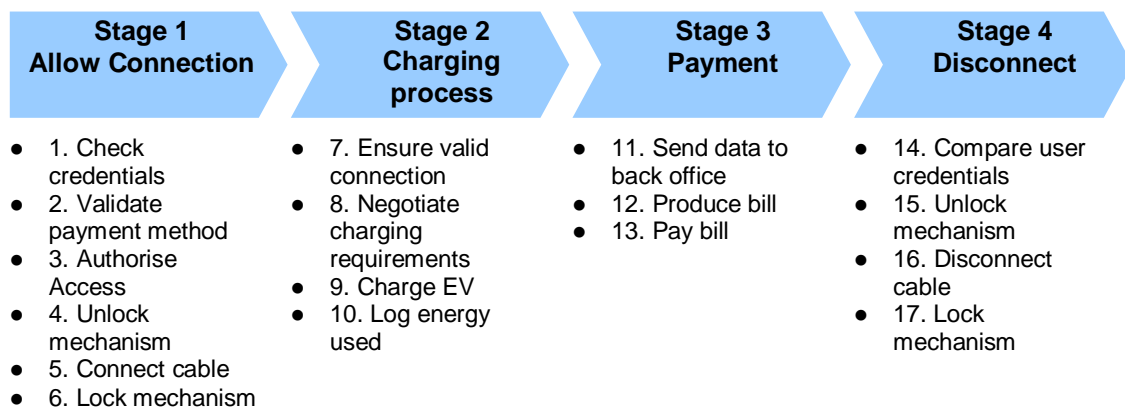
**Figure 35 – Overview of different communication paths and their associated reasons**

One of the elements that is common to all scenarios is the stop-start communications between the EV and CP. The EV battery management system (BMS) is likely to always be in control of the charging process so as to protect and prolong the life of the battery (see Section 0). The other common element is that for



safety reasons there should always be some form of detection that the EV is correctly connected to the CP before the CP will energise.

It is envisaged that the charging process will contain four high level stages regardless of the scenario. Figure 36 shows each of these four stages with the steps of an example charging procedure listed under each stage name. It is worth noting that payment (Stage 3) and disconnection (Stage 4) may occur in the opposite order depending on whether payment is conducted in advance or in arrears, and that step 11 does not have to be performed if payment in advance is used.



**Figure 36 – Example charging procedure - steps organised into four high level stages**

Aside from the essential stop-start feature between the EV and CP, the other elements that are present in some but not all scenarios are described in Table 10.



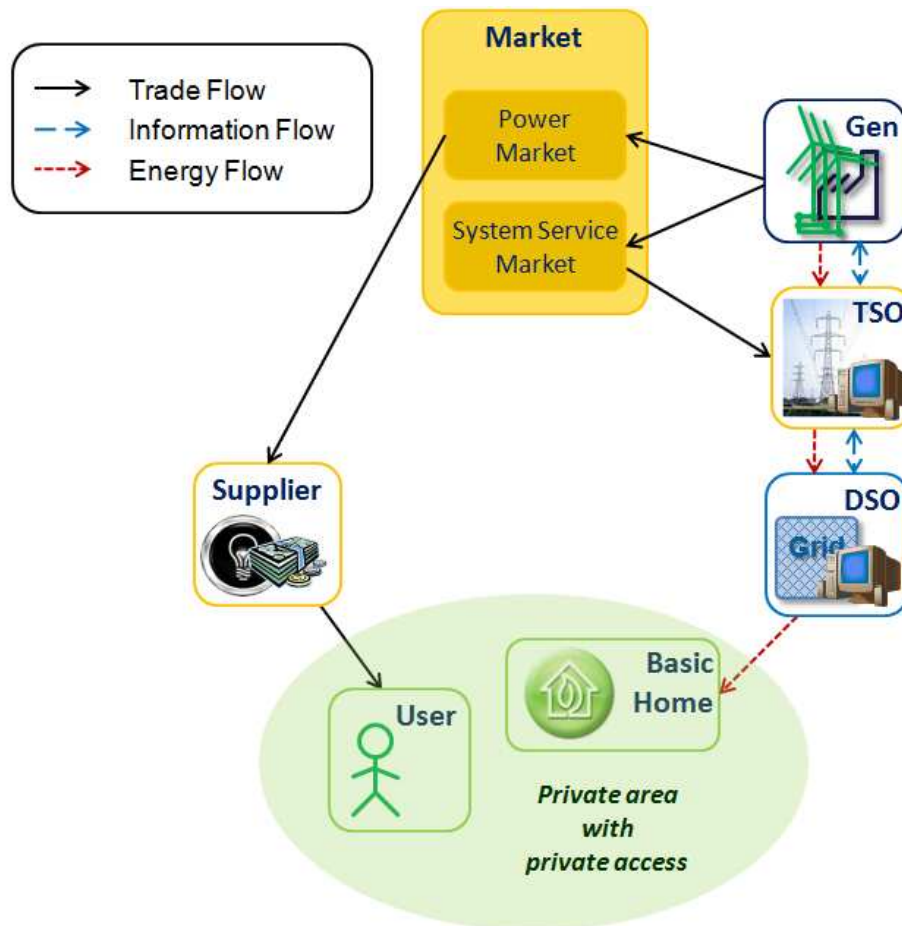
Element	Comments
Authentication	<p>In almost all scenarios the user will need to provide data about their identity or authority to use the CP. This could be for many reasons such as to unlock a protected socket on the CP, to prove that they have credit to pay for their charging, to prove that they are a customer of that company's CP, or so that access can be withdrawn from users who do not pay. It could involve the user authenticating at the CP (e.g. a PIN or access card), or the user communicating with the provider (e.g. obtaining an access code for the CP), or the user communicating direct with their EV (e.g. via an on-board PC or by mobile phone) and the EV then authenticating with the CP.</p>
Charging requirements	<p>There may be users who just want to plug in their EV and not worry about anything else, whilst some might want to carefully control the rates, times of charging and use of V2G, and others some intermediary. The more control required, the more computation involved, and the larger the amount of data to be communicated. This data could be communicated either direct from the user to the CP (e.g. by mobile phone, or via a touch screen on the CP) or from user to CP via the EV, allowing for input from the BMS.</p>
Charge availability	<p>This is likely to be in response to the user's charging requirements. What is communicated may range from simply what power is or is not available to more complex responses such as the charging rate available from the grid, the current energy price, the price incentive for participating in V2G, or the current percentage of energy coming from renewable sources.</p>
Charging control	<p>Aside from the start-stop commands between the EV and CP, charging control is any other element of control during the charging process (e.g. decreasing the charge rate to prevent battery overheating). This will involve communication between the EV and the CP. Within this there will also need to be some element of control within the CP to ensure that the EV demands match with the grid capabilities. For example if the EV demands a charging rate that is higher than the CP limit the CP will need to react to this; it may cap the maximum power output, terminate charging and isolate the CP, or supply a higher rate up to a fixed limit.</p>
Payment	<p>As mentioned in Section 0 several different payment methods are possible; each having different data requirements.</p>
Demand management	<p>If a smart grid or V2G is to be used, then extra data will need communicating between the supplier/aggregator or DSO and the CP (see Section 7.1.4). Before supplier/aggregator (SupAg) would send its bids to the market, these bids should be verified by the DSO. The DSO should at least be able to allow or block the demand side management decisions made by the SupAg to ensure that the intended changes in DSM do not cause grid operation problems.</p>

**Table 10 – Descriptions of data that may need to be communicated**



## 7.2.2 Current Electricity Market

Figure 37 shows the current interaction between the entities involved in delivering electricity to a typical residential customer who does not have a smart meter.

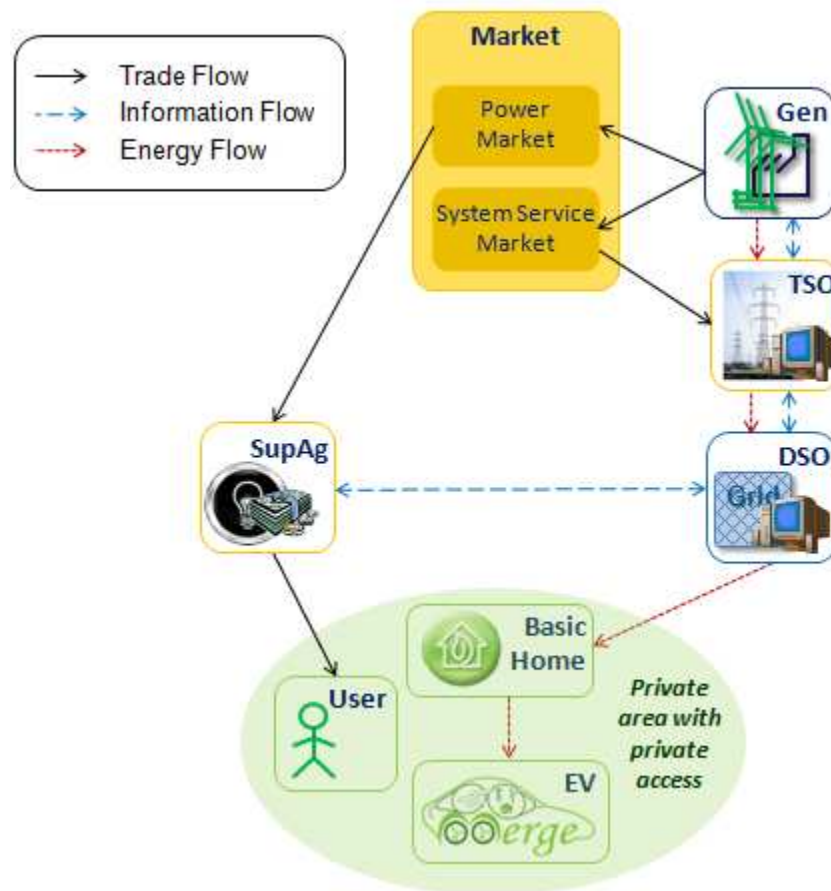


**Figure 37 – Interaction between the entities involved in delivering electricity to the customer in a private area**

The supplier supplies the user in private area (Basic Home) with electricity that it buys from the power market. This power is offered by the generation companies to the market and is transmitted from the generation point by the transmission system to consumption areas and then delivered through distribution networks to the customers.

## 7.2.3 Dumb Charging in a Private Area with Private Access

This scenario represents the charging of an EV plugged directly into the current infrastructure at a private area with private access like a home garage. It is assumed that the private area is not equipped with smart meters and the EV is charged in a 'dumb charging' mode where no control over charging rate is available. As shown in Figure 38, the power flows from the distribution network through the private area (termed Basic Home in this example) to the EV. Neither the DSO nor the supplier/aggregator has any control over the EV charging process, which would start when the EV is plugged in.



**Figure 38 – Interactions between the entities involved in the dumb charging of an EV in private location with the current grid setup**

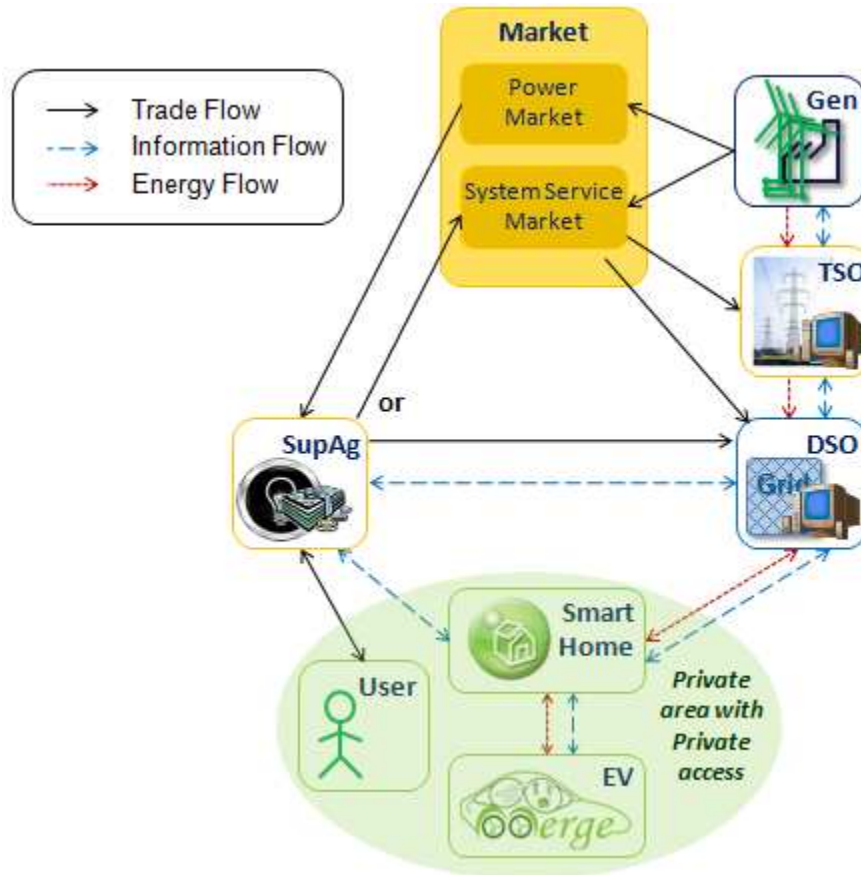
#### 7.2.4 Smart Charging in a Private Location with Private Access

This is an envisaged future scenario in which the EV is integrated into a smart grid using a local control network (e.g. Home Area Network). The use of a smart grid enables the intelligent exchange of electricity between the EV and the supplier/aggregator and DSO, and thus charging could be shifted to time intervals when demand on the grid is low. The private location (here termed a Smart Home) would need to include an advanced electricity meter (e.g. a smart meter) and communications with other parties.

The supplier/aggregator (SupAg) communicates with the Smart Home to request services such as load management and V2G operation as and when required. Such services by the SupAg may be offered to the market directly or agreed upon through bilateral contract with DSO for helping them manage their distribution grid. It should be noted that any bid from the SupAg to the market should be first verified by the DSO to ensure that they do not violate normal system operation. In other words, the DSO should be able to allow or block DSM or V2G decisions made by SupAg if they endanger safe system operation.

The metering data is sent from the Smart Home to the DSO and then to supplier/aggregator for billing issues. Since the house is equipped with a smart

meter, the DSO is also able to control the EV loads by turning them on/off if grid problems are detected. These interactions are shown in Figure 39.



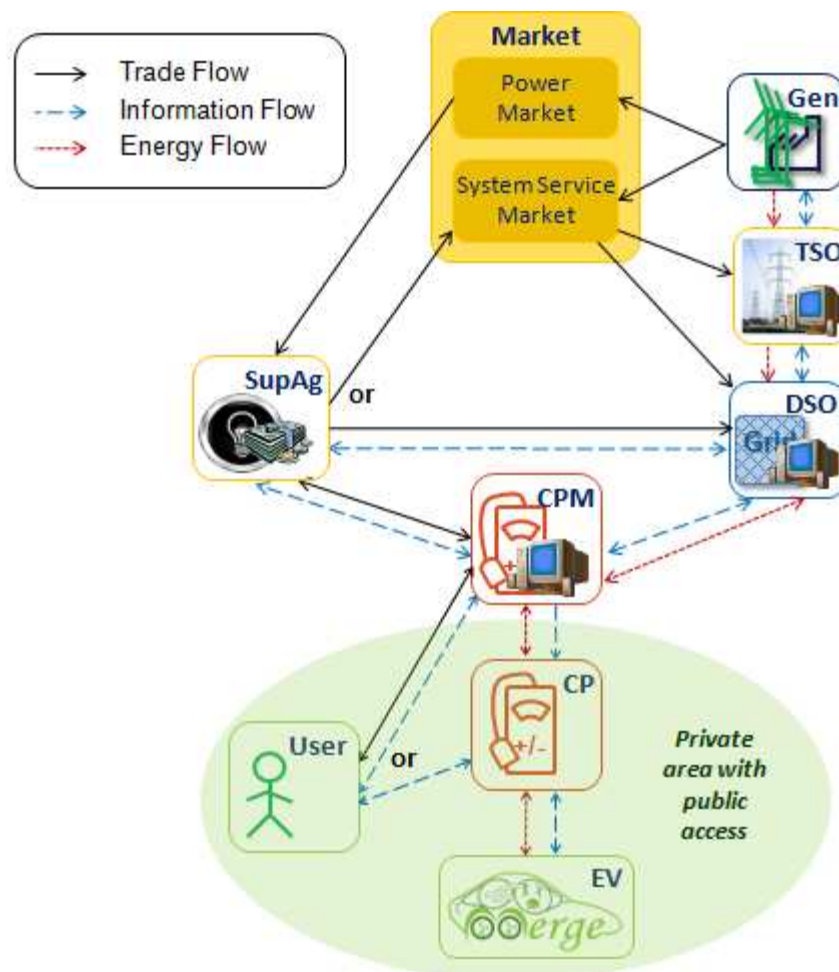
**Figure 39 – Interactions between involved parties in the smart charging of an EV in a private location with private access**

More information on the interaction between these entities, details of the data communicated, and the tasks performed during each phase of EV charging for this case can be found in Appendix 1.

### 7.2.5 Charging in a Private Area with Public Access

The scenario shown in Figure 40 describes EV charging in private area with public access like a large supermarket car park. The charging point manager (CPM) who is the owner and operator of a number of charging points (CP) in the area is assumed to have one smart meter for all of its CP and all the users who use the parking for charging their EV agree with how the CPM would charge their vehicles. The CPM buys its electricity demand from the supplier/aggregator (SupAg) and responds to DSM and V2G requests by the SupAg. So, the energy flow can be in both directions from the CPM to the distribution system. As the CPM has a smart meter, it is also incentivised to implement smart charging to reduce its EV charging energy costs.





**Figure 40 – Interactions between involved parties in charging an EV in a private area with public access**

The EV user communicates either with the CPM (i.e. by SMS from their mobile phone, or getting tickets) or with the CP directly, for the purposes of authentication and payment (i.e. pay-by-mobile, PAYG or subscription).

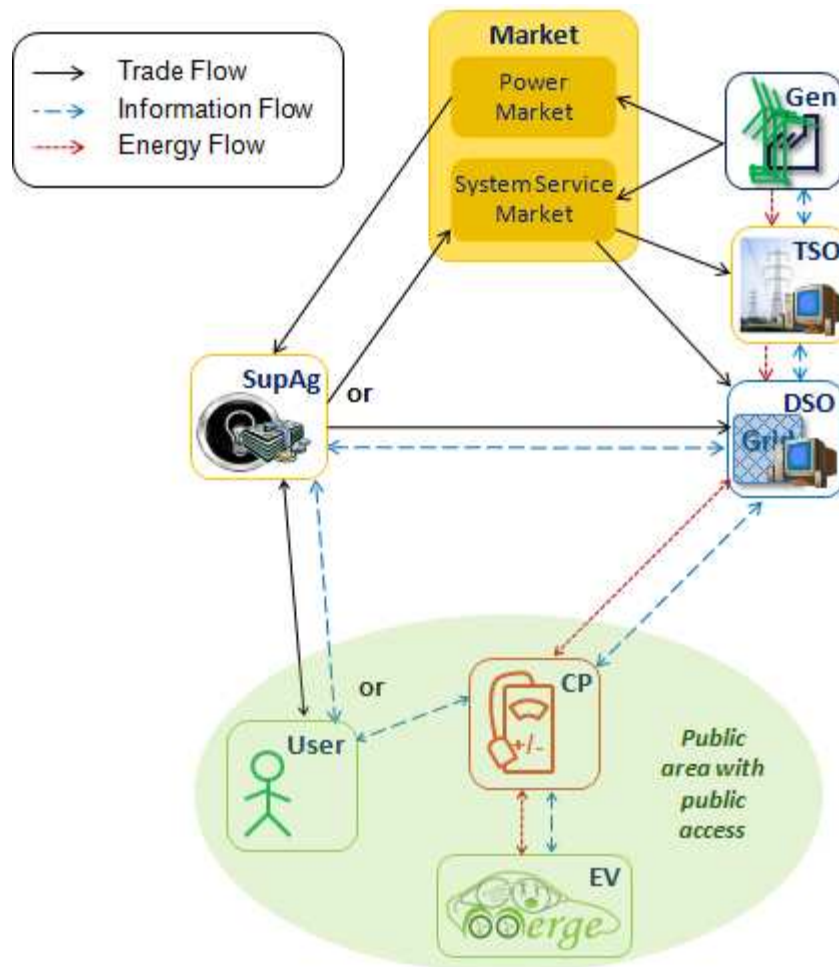
More information on the interaction of the entities detailing the data communicated and the tasks performed during each phase of EV charging for this case can be found in 0.

### 7.2.6 Charging in a Public Area with Public Access

This section describes an envisaged scenario for charging an EV in a public area with public access. The CP is equipped with a smart meter, thus DSM, V2G operation and smart charging are possible. Figure 41 illustrates the interaction between all the involved entities in this scenario.

The EV communicates control and usage data with the CP. The supplier/aggregator collates the energy usage from the CP that it aggregates. This will also include load management and V2G opportunities. These services can be offered to the market or offered via bidirectional contract to the DSO to help them manage their grid. The

DSO can also communicate directly with the CP through the smart meter to turn the CP off/on in order to relieve problems in its grid.



**Figure 41 – Interactions between involved entities in smart charging an EV in a public location**

More information for this case on the interaction between these entities, the data communicated, and the tasks performed during each phase of EV charging can be found in Appendix 3.

### 7.2.7 Communication Paths Not Mentioned

There are some communication paths that have not been mentioned in the above discussion. These, and the reasons for their omission, are described below.

#### EV to Supplier/Aggregator or DSO

So far in this report it has been assumed that billing and DSM data will be sent from the CP to the supplier/aggregator or DSO. This does not however have to be the case. It could be that billing or DSM data, or both, could be sent direct from the EV to the supplier/aggregator or DSO via a wireless communication method built into the EV. This would reduce, if not remove, the need for a communication path from the CP upwards, but would place the control of such communications in the hand of



the user. This is undesirable as it puts the user in control of both payment and DSM, neither of which are in the user's best interests. For example with DSM the communication path would need to be initiated by the user before the EV 'grid load' could be controlled.

Another reason against this direct EV to supplier/aggregator or DSO communication is that it would require the supplier/aggregator or DSO specifying to the EV manufacturer the functionality that would need to be included in the vehicle. This would be at cost to the manufacturer to develop and include it in the EV, but would provide the manufacturer with no real benefit.

### **User to DSO**

The role of the DSO in the electricity network is to monitor the grid operating conditions and, when such actions are needed, control grid loads and V2G use. This requires them to exert some control over the CP and the EV (the loads). As the user is not directly connected to the electricity network, it would be inefficient for the DSO to communicate with the user, as opposed to communicating with the CP or EV directly (see point above on EV to supplier/aggregator or DSO).







### 7.3 Control of Charging for Battery Longevity

The cost of the battery in an EV is a large proportion of the cost of the vehicle. With the battery being so expensive it is important that its life is prolonged for as long as possible. There are several characteristics that can affect the battery life; these are given in Table 11.

Characteristic	Effect on battery longevity
Battery type	The battery chemistry and battery pack construction have a significant effect on not only the possible maximum life of the battery, but also on the effect of the other characteristics listed below.
Temperature	Different battery chemistries have different temperature ranges under which they operate optimally, e.g. Lithium-ion batteries optimum range is 15-35°C whereas Zebra batteries optimum range is 270-350°C. The charging and discharging of these batteries outside of their optimal temperature range can cause the build-up of impurities within the battery cell, that decrease the battery life. In some instances heaters and cooling packs are fitted to maintain the temperature of the battery within this range when charging or discharging, so as to prolong life.
Rate of charge	Increasing the rate of charge can increase the rate of decay of the battery capacity. Also, if very high charging rates are used then the heat generated within the battery may be sufficiently large to heat the battery to outside of its optimal temperature range, unless a cooling system is present. For example for a 90% efficient charging process at a charge rate of 100 kW, the heat generated is significant at around 10 kW. Li-ion batteries fitted with SOC monitoring systems also suffer from a phenomenon known as “digital memory”; this is where the battery is charged and discharged at such high rates that the SOC monitoring system cannot accurately keep track of the SOC and so the indicated error begins to differ from the actual battery SOC. This is correctable through fully discharging and charging the battery approximately every 50 cycles.
Charging profile	The charging profile used has an effect on the battery life. As previously mentioned, it is desirable to use as small a charging rate as possible to optimise battery life, but also the voltage at which the cell is charged should be limited. This is because charging the battery at a voltage above the battery rated voltage has a large effect on battery deterioration. It is expected that the EV manufacturer will develop the optimum charging profile and this will be known by the battery management system (BMS).





Characteristic	Effect on battery longevity
Rate of discharge	As with charging, increasing the rate of discharge can decrease battery life. Driving behaviour is likely to be the major influencing factor on the impact of this. The use of the V2G concept could also have an effect.
Storage SOC	The SOC at which a battery is stored at can have a large impact on the battery life. As an EV will spend the majority of its life not in use so too will its battery. Lithium-ion batteries deteriorate most when stored at 100% SOC, they should instead be stored at 40% SOC for best battery life. EV users will however want to keep their battery at 100% SOC wherever possible. Lead acid batteries should not be stored at 0% SOC or electrically insulating sulphates will build up on the electrodes.
Battery calendar age	Batteries naturally deteriorate with age. Many battery chemistries exhibit a deterioration that is roughly proportional to the square root of time, but this ageing mechanism is suppressed by battery cycling. Cycling the battery however introduces another ageing mechanism that is instead roughly proportional to time.

**Table 11 – Factors effecting battery longevity**

### Control of Charging Location

With so many variables affecting the life of the battery, no single charging procedure will be adequate for all battery types. It is in EV manufacturers' interest to develop their battery management system (BMS) to maximise battery life as they have to offer minimum guarantees on battery lifetime. These minimum guarantees currently range from 2 years in the EU to 8-10 years in the USA (depending on the state). As a result, it is expected that in the short term EV manufacturers will develop a bespoke charging procedure and control strategy for each battery, and program this into the BMS. The BMS will then control the charging of the battery. This implies there will be a need for the ICT stage to assist the BMS by facilitating data exchange between the EV and CP, to control the charging process.

Prolonging battery life is a direct concern of the user not the charging infrastructure. However, if V2G is used then the charging infrastructure is now in control of when the battery charges and discharges, the depth of these and their frequency; all of which influence battery life. Thus the charging infrastructure will need to either take on some responsibility for prolonging battery longevity, or provide sufficient financial incentive to those participating in order to cover the cost of decreasing the battery life. For the infrastructure to be involved in controlling charging to prolong battery life there will still need to be some communication between the EV and CP, but the data communicated and the computational intelligence involved may be considerably different from the scenario where the BMS is in full control. This is a difficult challenge which will need to be overcome if V2G is to become widespread.





## Battery Switching

Battery switching is an enabler to the infrastructure supporting battery longevity. This is because the battery is now owned by an infrastructure party and so it is in their interest to get the longest life possible out of each battery. This will be done by charging “off-board” at a rate and profile that best suits the battery, and by swapping high usage batteries with low usage batteries.





## 7.4 Possible ICT Stages

### 7.4.1 Wired vs. Wireless

Many different types of both **wired** and **wireless** communication methods are available for use between the different elements involved in the charging process. Some of the advantages and disadvantages of the use of each within different areas of the ICT stage are shown in Table 12.

	Wired		Wireless	
Authentication	<ul style="list-style-type: none"> <li>• Little risk of unauthorised interference</li> <li>• User needs to input details to EV for communication to CP</li> </ul>	<p>✓</p> <p>✗</p>	<ul style="list-style-type: none"> <li>• Needs small range to prevent snooping and unauthorised interference</li> <li>• No need for direct connection to EV, so can also control access to power socket for safety</li> </ul>	<p>✗</p> <p>✓</p>
EV to CP	<ul style="list-style-type: none"> <li>• Can be used for proximity detection (detecting the presence of the charging connector in order to prevent movement of the EV whilst connected to the CP)</li> <li>• No worry of connection loss</li> </ul>	<p>✓</p> <p>✓</p>	<ul style="list-style-type: none"> <li>• Loss of connection during charging results in no control signal</li> <li>• Open to snooping or interference</li> <li>• Difficulty determining who is talking to who</li> </ul>	<p>✗</p> <p>✗</p> <p>✗</p>
CP to DSO or supplier/aggregator	<ul style="list-style-type: none"> <li>• May require installation of cables, implying high cost for civil works</li> </ul>	<p>✗</p>	<ul style="list-style-type: none"> <li>• Less installation required</li> <li>• Can use a mesh network to increase robustness</li> </ul>	<p>✓</p> <p>✓</p>

✓ Advantage      ✗ Disadvantage

**Table 12 – Advantages and disadvantages of wired and wireless communication for different areas of the ICT stage**

Table 12 suggests that for **authentication** there is no clear favourite.

It is desirable to use a wired communications method for **communications between the EV and CP** to prevent the risk of losing connection during the charging process.

**Between the CP and DSO or supplier/aggregator** a wireless method may be more desirable as the cost of installing a wired network is likely to be prohibitive. However, as power cables are always present if these are used for communications then the need for civil works (and associated costs) is removed.

### 7.4.2 Possible Communication Methods

There is a vast number of different communication methods available for use between the different elements involved in the charging process. Those which have been identified to provide the most relevance and promise for use within the ICT stage are described below.



- **Touch screen.** A mature technology with a vast range of uses. Its use is becoming increasingly more commonplace (as of early 2010).
- **Credit/Debit card reader with PIN pad.** A very mature technology, used by the majority of retailers throughout Europe.
- **Digital subscriber line (DSL).** A collection of different technologies that provide digital data transmission over a wired local telephone network. It works by superimposing a high frequency data signal onto the low frequency phone signal. The most commonly used technology is ADSL, which is currently used to provide broadband internet.
- **RS-485.** A standard for the electrical characteristics used in a linear network. Due to its ability to be implemented over long distances and in noisy environments, RS-485 is most often used within industrial applications.
- **Ethernet.** A collection of standards defining frame-based technologies for local area networking. It was first standardised as IEEE 802.3 in 1984. A standard for data rates of 10 Gbit/s is under development. The useful range is limited to around 100 m, but can be extended to up to 10 km with the use of fibre optic cables. Ethernet is primarily used within domestic and commercial LANs.
- **Controller Area Network bus (CAN-bus).** A vehicle bus standard designed to allow devices to communicate within a vehicle without the need for a central computer. The protocol was released in 1987. CAN-bus is typically used within vehicles at a data rate of 100 Mbit/s, limiting the usable distance to below 40 m. However, it has been used for industrial automation by lowering the data rate to 125 kbit/s and hence increasing the range to around 500 m. It is a mature technology widely used within the automotive industry.
- **Power line communications (PLC).** A system whereby a modulated carrier signal is superimposed onto the standard electrical wiring system. This can be at any level of the electricity grid, from premise wiring to the distribution network wiring. A wide range of frequencies and data rates are possible depending on the application. Electricity utilities use frequencies in the range 10-490 kHz, which can support distances in excess of 1 km, for Automatic Meter Reading (AMR) and remote switching. A higher frequency band (1.8-80 MHz) is used to provide broadband internet over the power lines. The range of this is similar to standard Ethernet at around 100 m.
- **Wi-Fi.** A set of standards (IEEE 802.11) for wireless local area network communications. Modern versions of the standard use the 2.4 GHz band of frequencies and can have ranges of up to 70 m indoors, and 250 m outdoors. This technology is predominantly used in home and commercial LANs.
- **General Packet Radio Service (GPRS).** A packet oriented mobile data service that extends the Global Standard for Mobile communications (GSM). GPRS is predominantly used for large meshed mobile phone networks; however a range of other products can be fitted with GPRS modules including some electricity smart meters.
- **Bluetooth.** An open wireless protocol for short distance data exchange. The specification was developed by the Bluetooth Special Interest Group. Its range is highly dependent on the device power consumption and varies from around 1 m to 100 m, with 30 m a typical range. Current uses include: mobile phone hands-free kit, wireless networking between PCs, PC input and output devices,





replacement of wired serial communications in test equipment, wireless bridging, wireless games console controllers and advertising.

- **Radio Frequency Identification (RFID).** A radio frequency technology primarily used for the identification or tracking of an object, animal or person. An RFID system typically consists of a powerless device, a tag, and a powered device, a reader. Contactless smartcards (IEC 14443) are a common use of RFID. Range is directly related to the size of the tag; in smartcard technologies this is typically up to 10 cm. Current uses for the technology include: payment by mobile phones, public transportation payments, toll road identification, product tracking, animal identification and tracking, inventory systems and human identification.
- **Near field communication (NFC).** A short-range wireless communication technology. NFC is an extension of the contactless smartcard standard, which combines both the smartcard and reader interfaces into one device. It is primarily aimed at uses within mobile phones. As it is an extension of smartcard technology it is fully compatible with standard RFID and smartcard infrastructure. Use of NFC within mobile phones is large in Japan and some other Asian countries, but has made very little penetration into other markets. Current uses include mobile ticketing in public transport, mobile payment (device acting as a pre-paid card), smart advertising, and facilitating Bluetooth pairing.
- **ZigBee.** An open standard for a suite of communications protocols based on the IEEE 802.15.4-2003 standard, and intended to be simpler and less expensive than Bluetooth. The standard was developed by the ZigBee alliance in 2004. Typical range is less than 100 m, but ranges of up to 1 km line-of-sight have been demonstrated. Its main uses are in applications where low data rate, low power usage, and network security are required. Current uses include home automation, smart metering, healthcare and toys.
- **Z-Wave.** A low-power wireless control, mesh networking solution designed for home automation. It was developed by Zensys and is supported by the Z-Wave Alliance. Z-Wave has a typical range of around 30 m. Current uses for the technology include home control, security systems, home entertainment and remote controls.
- **Wavenis.** Developed by Coronis in 2000, Wavenis is a wireless solution designed for ultra low power and long range capabilities. It is well suited to use within both fixed and mobile wireless networks, in particular those where the device is located in hard to reach places and where there are strict limits on power usage. Its typical range is around 100 m, but higher power devices (e.g. 500 mW range extenders) can have ranges up to 4 km. Current uses include home automation, industrial automation, home access control, medical panic alarms, and electricity AMR.



A summary of the key attributes of each of these methods is shown in Table 13.

	Communication method	Range	Frequency	Bandwidth	Standards
<b>Wired</b>	DSL	>2 km	10 kHz-1.1 MHz	8 Mbit/s 24 Mbit/s	ANSI T1.413 Issue 2
	RS-485	Up to 1.2 km Up to 10 m	-	100 kbit/s 34 Mbit/s	-
	Ethernet	100 m (~10 km possible)	-	10 Mbit/s – 10 Gbit/s	IEEE 802.3
	CAN-bus	<40 m 500 m	-	1 Mbit/s 125 kbit/s	ISO 11898-1 (2003)
	PLC	>1 km ~100 m	Utilities = 10-490 kHz Broadband = 1.6-80 MHz	500 kbit/s – 1.5 Mbit/s	-
<b>Wireless</b>	Wi-Fi	50-250 m	2.4 GHz	54 Mbit/s	IEEE 802.11
	GPRS	Up to ~2 km	900 MHz 1800 MHz	56-114 kbit/s	GSM standard
	Bluetooth	100 m	2.4-2.5 GHz	2.1 Mbit/s	
	RFID (smartcard)	<0.1 m	13.56 MHz	106-848 kbit/s	IEC 14443 IEC 15693
	NFC	<0.2 m	13.56 MHz	424 kbit/s	IEC 14443
	ZigBee	10-75 m	868 MHz 2.4 GHz	20 kbit/s 250 kbit/s	EU EN300- 220
	Z-Wave	30 m	868 MHz	9.6 kbit/s or 40 kbit/s	EU EN300- 220
	Wavenis	~100 m	868 MHz	4.8-100 kbit/s	EU EN300- 220

**Table 13 – Overview of different possible communication methods**





### 7.4.3 Possible Uses for Each Communication Method

Some of the identified communication methods are more suited to certain areas of the ICT stage than others. The areas for which each method could be utilised are described below.

- **Touch screen.** A touch screen could be used either within the EV or on the CP. The user interacts with the touch screen to enter their charging requirements (e.g. "I need to use the car again in X hours and wish to travel Y miles"). If the touch screen is located in the EV then this provides the advantage that the battery management system (BMS) can use the input from the user, and then control the charging to meet these requirements in a way that will also prolong battery life.
- **Credit/Debit card reader.** The use of a credit or debit card can obviously be used for payment, but also for authentication of the user. This does present certain security issues with the CP reading and manipulating credit card details, and also requires a real-time communications link in order to verify the credit card.
- **DSL.** Public telephone network cables connect to most domestic locations and run underneath many urban streets. DSL could be used along these existing cables to communicate data from the CP to the DSO or supplier/aggregator. The main issue with this is that it requires the lease of these services from a telecommunications company, with each CP having its own phone number. This technology is common for the use of Broadband internet where bandwidth is frequently being upgraded, and as a result there may not be room for a large increase in the amount of data flowing through this network without network reinforcements.
- **RS-485.** As a simple wired system RS-485 could be used for either communications from the EV to CP, or for CP to a central provider or node of a larger network.
- **Ethernet.** As a more complicated wired system than RS-485 or CAN-bus, Ethernet lends itself more to communications from many CP (e.g. at a supermarket) to a wider network than from EV to CP. It also has the advantage of being able to integrate easily with existing Ethernet systems, and making use of the secure internet protocols suite.
- **CAN-bus.** As the CAN-bus is widely used in most modern vehicles the use of a CAN-bus to connect the EV to the CP would integrate well with these systems.
- **PLC.** High frequency PLC, as used for home broadband internet, could be used for communication between the EV and CP. Low frequency PLC is more suitable for use by the DSO or supplier/aggregator for communication or control over long distances.
- **Wi-Fi.** This could be used for communication between the EV and CP, or between the CP and a central provider over a limited distance. The major drawback with this system is that of security; with personal data being broadcast over such a large range it is possible for unauthorised parties to intercept this data. To try to prevent this, a protected network may be used but this requires the user to enter a network key for each CP used. With such a large range there is also a problem of determining which EV is communicating with which CP.





- **GPRS.** This is not suitable for the short distance communication between the EV and CP, but would be suitable for long distance communication between the CP and DSO or supplier/aggregator.
- **Bluetooth.** It is assumed that most (if not all) EV users will carry a mobile phone that is Bluetooth compatible. The user could pair this mobile phone with the CP for authentication purposes and to communicate their charging requirements. The security features in Bluetooth make it essential for users to pair devices before they can communicate. This could prove quite clumsy and time consuming if the user has to pair with a CP every time they wish to charge. An alternative could be that the user pairs their phone with their EV which then communicates with the CP to authenticate the user. If a wired communication method is used between the EV and CP this option requires the charging cable to be connected prior to authentication, thus preventing the use of a locked protective cover on the charging socket.
- **RFID.** A contactless RFID smartcard could be used either for simple and secure (due to its limited range) user authorisation, and as a cashless PAYG payment method.
- **NFC.** Due to its compatibility with RFID systems, NFC could be a future development used for authentication and payment on RFID systems. Its advantage over RFID systems is that the user does not need to carry a special card with them, but simply uses their phone which they most likely already carry. In addition, the “topping-up” of credit could be easier through the use of mobile internet and applications. NFC has an advantage over Bluetooth in that it does not involve the ‘clumsy’ pairing of devices.
- **ZigBee.** As a short range wireless solution ZigBee could be used for communication between the EV and CP. The reduced range compared with Wi-Fi reduces the security concern and the problem of identifying the EV or CP being communicated with. An added advantage of ZigBee is that many current Home Area Networks and domestic smart meters are using ZigBee as their communication method, allowing for the EV to be integrated easily into these systems. However, the technology is immature.
- **Z-Wave.** An alternative to ZigBee for use between the EV and CP, but with less penetration into HAN and smart meter markets.
- **Wavenis.** Another alternative to ZigBee for use between EV and CP. It is designed for longer ranges which may make it more suitable for communication between the CP and a local operator or network node, than from EV to CP.



## 8 EVALUATION

### 8.1 Evaluation of Possible Power Stages

#### 8.1.1 CP Connector Plug

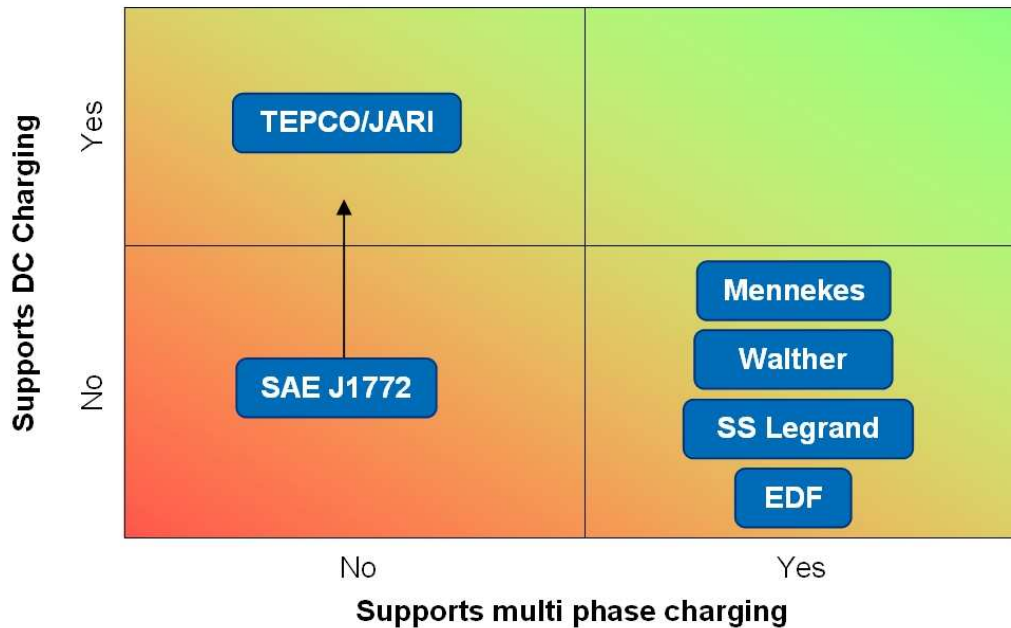
The two main technical considerations for the power stage are the supported power levels and whether the plug can support a control signal. The former is the decisive factor for the charging time of the EV batteries, and the latter determines how well the charging process can be monitored and controlled. The number of phases supported in AC and the possibility of DC charging is also an important issue, which relates to the charging power levels supported. In addition, safety and cost considerations should be taken into account when evaluating different power stage realisations. Figure 42 shows an evaluation matrix comparing the five major AC charging connectors against these criteria.

Supports control signals	Yes	<ul style="list-style-type: none"> <li>Mennekes</li> <li>Walther</li> <li>SAE J1772</li> <li>SS Legrand</li> </ul>	<ul style="list-style-type: none"> <li>Mennekes</li> <li>Walther</li> <li>SAE J1772</li> <li>SS Legrand</li> </ul>	<ul style="list-style-type: none"> <li>Mennekes</li> <li>Walther</li> <li>TEPCO/JARI</li> </ul>
	No	EDF	EDF	
		Level 1	Level 2	Level 3

**Power level(s) supported**

**Figure 42 – Evaluation matrix for different connectors**

Figure 43 shows the different charging types supported by the different connectors. It should be noted that the current version of the SAE J1772 plug does not support DC charging. However, DC charging is expected to be included in the next edition of the standard as mentioned in Section 0.



**Figure 43 – Evaluation matrix for different connectors**

As discussed in Section 0, all the EV power interfaces need to include single-phase AC charging to allow for charging at home and in the workplace. There will also be occasions when the user will want to charge their EV at faster rates. This is the motive for including a fast charging mode in EV connectors. The three-phase and DC fast charging methods are both good options for realising this need as they can both provide sufficiently high power rates. As both of these methods address the same problem, including one of them in any connector would be enough. Within Europe the connectors being developed are capable of three-phase charging (Figure 43 – Mennekes, Walther, SS Legrand, EDF), whereas in the USA and Japan (Figure 43 – SAE J1772 and TEPCO/JARI) DC fast charging is the method being adopted.

The use of DC charging does not require a heavy on-board charger, as rectified DC current can be supplied direct to the EV battery. The use of DC charging in Europe could also help to lead towards a global standard for EV charging connectors.

The use of three-phase AC has the advantage of not requiring dedicated connector pins that are only used for fast charging, as the three-phase pins can be used for charging at much lower charging rates. With a future large EV penetration the electricity grid may suffer from phase balancing problems if all vehicles charge using single-phase AC. This may necessitate a shift to three-phase AC in order to alleviate this problem.



## 8.2 Evaluation of Possible ICT Stages

### 8.2.1 Need for Low Cost, Scalable, Robust Solutions

The effect on the cost of the CP is an important factor to be taken into consideration when evaluating different realisations of the ICT stage.

From the point of view of transportation, electricity is inexpensive when compared to gasoline and diesel fuels. If we assume that a full charge for an EV with a range of 160 km requires 16 kWh, then at conservative 2010 energy prices:

$$\text{Full charge cost} = 16 \text{ kWh} \times \text{€}0.25/\text{kWh} = \text{€}4$$

If we assume that a CP will charge two such vehicles a day (a high utilisation at 6-8 hours per full charge for a Level 1 CP), then the annual total revenue from this CP is:

$$\text{Annual revenue} = \text{€}4 \times 2 \text{ EV/day} \times 365 \text{ days/year} = \text{€}2920 \text{ year}$$

This is before the cost of producing the electricity or any maintenance costs for the CP have been deducted, or the costs of buying and installing the CP have been recouped. For example if a profit margin of 3% is assumed and a return-on-investment (ROI) of 40% desired over a 20 year period then the cost of the CP components and installation must be, at most:

$$\text{Cost of CP \& installation} = \frac{(\text{€}2920/\text{year} \times 0.03 \times 20 \text{ years})}{(1 + 0.4)} = \text{€}1250$$

However, MERGE project partners estimate that the cost of the CP and installation are in the region of €3000 in 2010. This suggests that the CP should be designed to minimise costs where possible. To obtain a ROI large enough to warrant the installation of the CP, the CP will need to be built for a life of many years (15-20 years for the electronics and 40 years for the physical post) with minimal upgrading needed. This implies that the ICT components of the CP should use technologies that are not likely to be obsolete in the near future, and that the CP should be of a modular design so that when components to become obsolete they can be easily and inexpensively replaced without the need to replace the whole CP.

### 8.2.2 Determination of Evaluation Criteria

When considering the implementation of the ICT stage of an EV charging system several different considerations need to be taken into account. These considerations are shown in Table 14, and have been grouped together to form four main criteria to be used in the evaluation of the potential ICT stages.

Consideration	Key issues	Evaluation criteria
Cost	The cost of the solution both to the user and the CP owner. This needs to take account of installation costs, running costs, and the cost of future upgrades.	<b>Cost</b>
Range	The communication method used must obviously have sufficient range to cover the distance asked of it. However, for communication from the EV to another party a range larger than that required is not desirable, as this can lead to confusion about who is communicating with whom.	<b>Suitability</b>
Security	Is the method inherently secure or would some level of encryption be required?	
Bandwidth	Can the method communicate a sufficient amount of data at an acceptable rate?	
Availability	Is the method readily available for wide scale implementation, or is it still under development or only just coming to market? Are protocols for the method available?	
Rate of obsolescence	Is the method outdated or near to being so? Is the method in a rapidly developing area and so likely to be obsolete in a few years?	
Scalability	Are there limits or constraints on the number of elements that can use this method?	
Impact on user & EV	It is desirable if the method integrates with systems used within the EV, or other systems used by the user as this saves on cost and complexity of use.	<b>Compatibility and ease of implementation</b>
Ease of use	For both the user and the provider.	
Impact on infrastructure	Does the method make use of existing infrastructure elements, or does it require the installation of a new communications network? If it does utilise an existing network then will this network require upgrading in order to accommodate it?	

**Table 14 – Considerations for ICT stage and evaluation criteria to be used**

### 8.2.3 Evaluation of Different Communication Methods

Within this section the different stages of the charging process will be considered, and the relative merits evaluated for the different options within each. Where appropriate the variations between different locations will be taken into account.

#### 8.2.3.1 Authentication

As previously mentioned authentication may not be necessary at private locations such as domestic garages or workplace car parks, depending on the payment method used (see section 8.2.3.3 for more discussion on this point). In these situations the communications method for this may be omitted from the CP.

For the situations where authentication is required the two most important factors for considering which method should be used are the suitability of the communication method for use for authentication (one-off communications, need for security), and the ease with which it can be implemented in the CP. Figure 44 shows the evaluation of the different methods identified against these two main drivers.

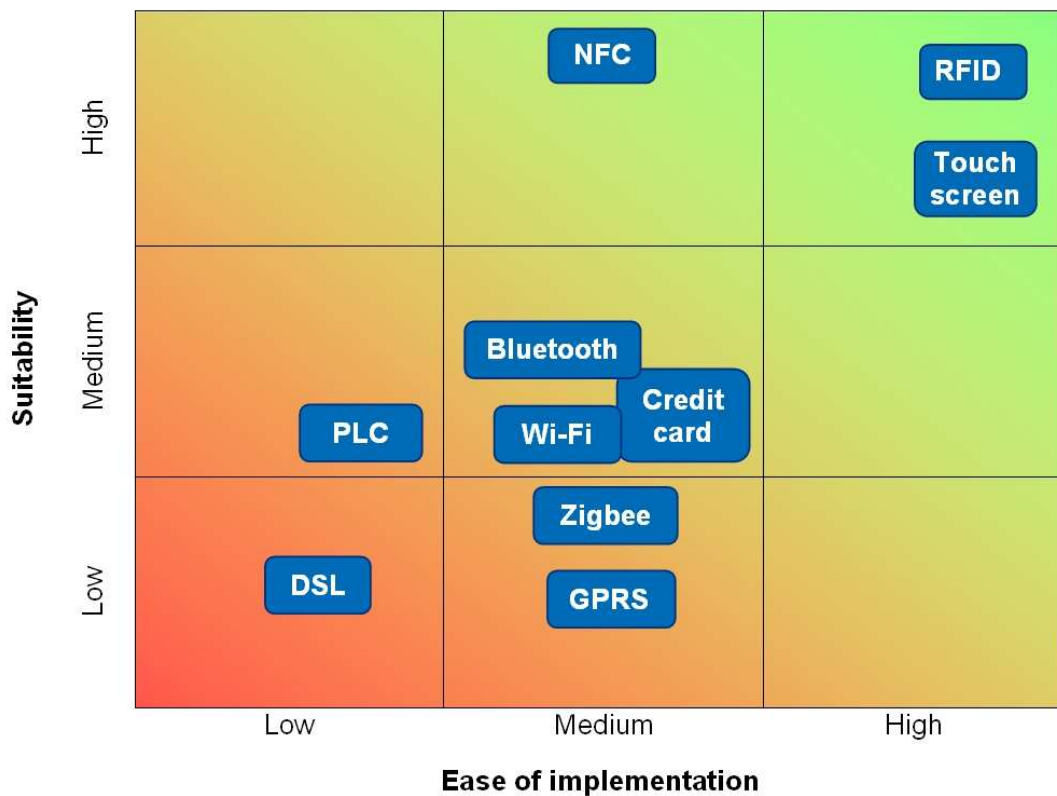


Figure 44 – Evaluation matrix for authentication methods

The simplicity for the user of using RFID, they simply swipe a card before plugging in their EV, and the ease with which the system can be integrated in to the CP, requiring the installation of an RFID reader and some basic electronics to determine the validity of the user's credentials; makes it highly suitable for use for authentication. The simplicity of this is greatly impacted by whether or not all of the information required can be stored on the RFID card in a way that does not require the CP to communicate with the supplier/aggregator to verify the user's identity. The





use of an expiration date on the card, or a list of barred user IDs downloaded to the CP weekly could facilitate this.

NFC could use an existing RFID system but requires users to own compatible phones which are not currently available in Europe (although trials have been conducted [24]). As a result NFC may be introduced in the future if NFC compatible phones become common within Europe, utilising an existing RFID system.

Figure 44 suggests a touch screen to be equally as favourable as an RFID system but it does not take account of the higher cost of a touch screen and the increased likelihood of this screen needing replacing due to fault or vandalism. Depending on whether the touch screen is in the EV or on the CP it may also necessitate the use of another communication method to pass on authentication data from the EV to the CP.

The use of a credit or debit card for authentication is advantageous in that it makes use of an existing, very secure system. This system however requires the card reader to be able to communicate with a back office to verify the user's details. This back office communication would require an additional communication path from the CP to the credit card back office. The use of credit or debit card for authentication should be paired with the use of the same for payment, which is discussed further in Section 8.2.3.3.

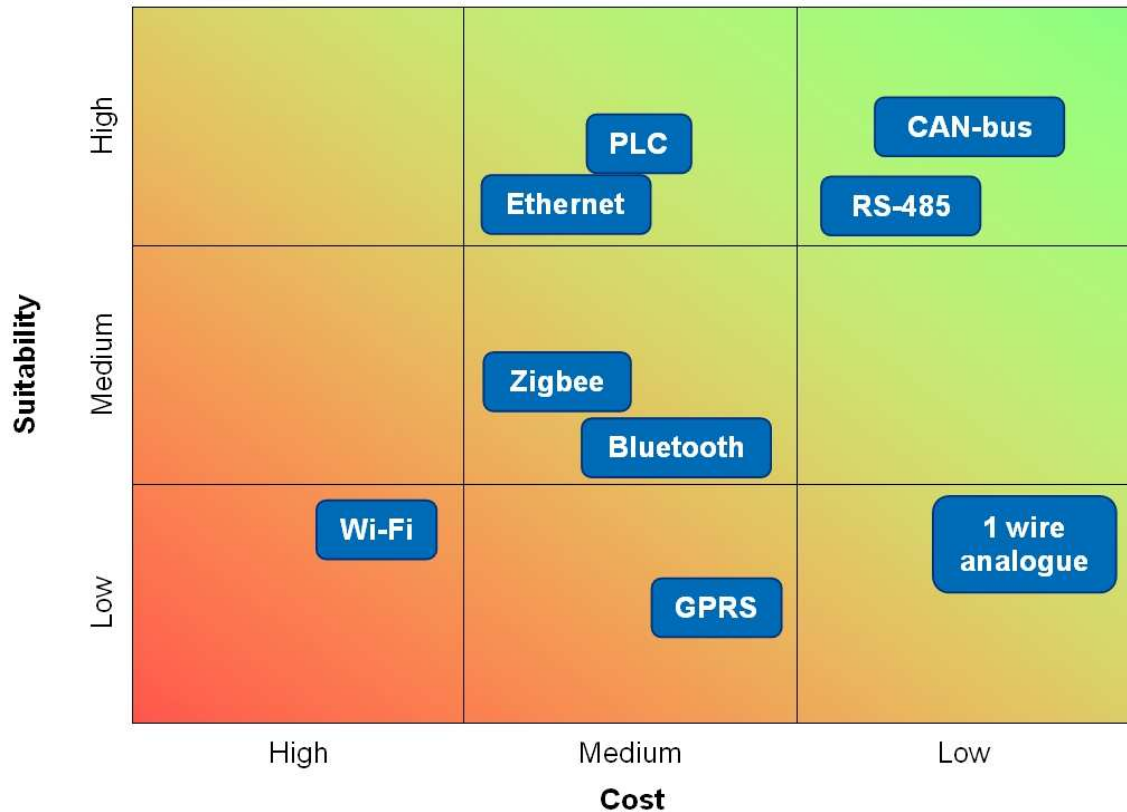
Bluetooth, Wi-Fi and ZigBee all require a connection to be established between the CP and the user/EV. This will require some level of configuration by the user, which is not required for RFID or credit card authentication. Whilst it may be possible to use the Bluetooth or Wi-Fi capabilities of the user's mobile phone, a second device of the same technology will need to be installed in the CP. The use of ZigBee will require both the user/EV and the CP to have a device installed. As all three are wireless there is also the security issue of unauthorised interception of sensitive user data. This is to some degree mitigated by the security features built into Bluetooth and ZigBee.

Technologies such as PLC, DSL and GPRS are scored low because they are best suited to long range continuous data transmission, than the short range one-off communications involved in authentication. Thus they will require the installation of relatively complex components. PLC and DSL are wired technologies which would require the EV to be connected to the CP before authentication could occur, removing the possibility of an authentication controlled access 'door' to the CP socket. If GPRS were used for communication from the CP to DSO or supplier/aggregator then it may be possible for the user to send their details from their mobile phone, and the CP then collect these details from the mobile phone network.

### **8.2.3.2 EV to CP**

The volume of data that will need communicating between the EV and CP still remains unknown, due to uncertainty about the complexity of the services and control to be offered. Current connectors have communications that are limited to start and stop, charging is/is not available, and charge rate required. The use of V2G will necessitate the communication of a larger amount of data, as too may the desire for more control over the charging. In the evaluation of communication

methods for this it has been assumed that this increased amount of data will need to be transferred. Figure 45 shows the evaluation of communication methods against cost and suitability. Note that a single wire analogue signal, as used in the SAE J1772, Mennekes and Scame-Schneider-Legrand connectors, has been included in this evaluation for comparison.



**Figure 45 – Evaluation matrix for communication methods between EV and CP**

CAN-bus and RS-485 are the favourable methods because they can carry sufficient data and due to their simplicity are relatively low cost. CAN-bus also has the advantage of integrating easily with the existing systems on the vehicle. A single wire analogue system is very low cost, but is less sophisticated than CAN-bus or RS-485 because it transmits a limited amount of data (e.g. start and stop, and charge rate required), and thus is unsuitable for applications using V2G.

Wireless systems such as GPRS, Wi-Fi, ZigBee and Bluetooth have a higher cost than the wired methods as they will require the installation of more equipment. They are also less well suited to this communication path due to the risk of connection loss and the inherent security issues of wireless communications.

PLC and Ethernet are just as well suited as CAN-bus and RS-485 but are more complex and so the cost of implementation is higher.

### 8.2.3.3 Payment Method

The payment method used is, in part, linked to the method used for authentication. If the authentication method has been selected to remove the requirement for real-



time communications with the supplier/aggregator, then in order to save cost it may be desirable to do the same with the payment method. However if the CP is already communicating with the supplier/aggregator to verify a user's identity then little extra functionality is required in order for payment details to be sent via the same method.

The two factors driving the decision of which payment method to use are the ease of implementation for the supplier/aggregator, and the ease of use for the user. Figure 46 shows the evaluation of the different payment methods identified in this report, against these driving factors for a domestic location. Figure 47 shows the evaluation for other (non-domestic) locations.

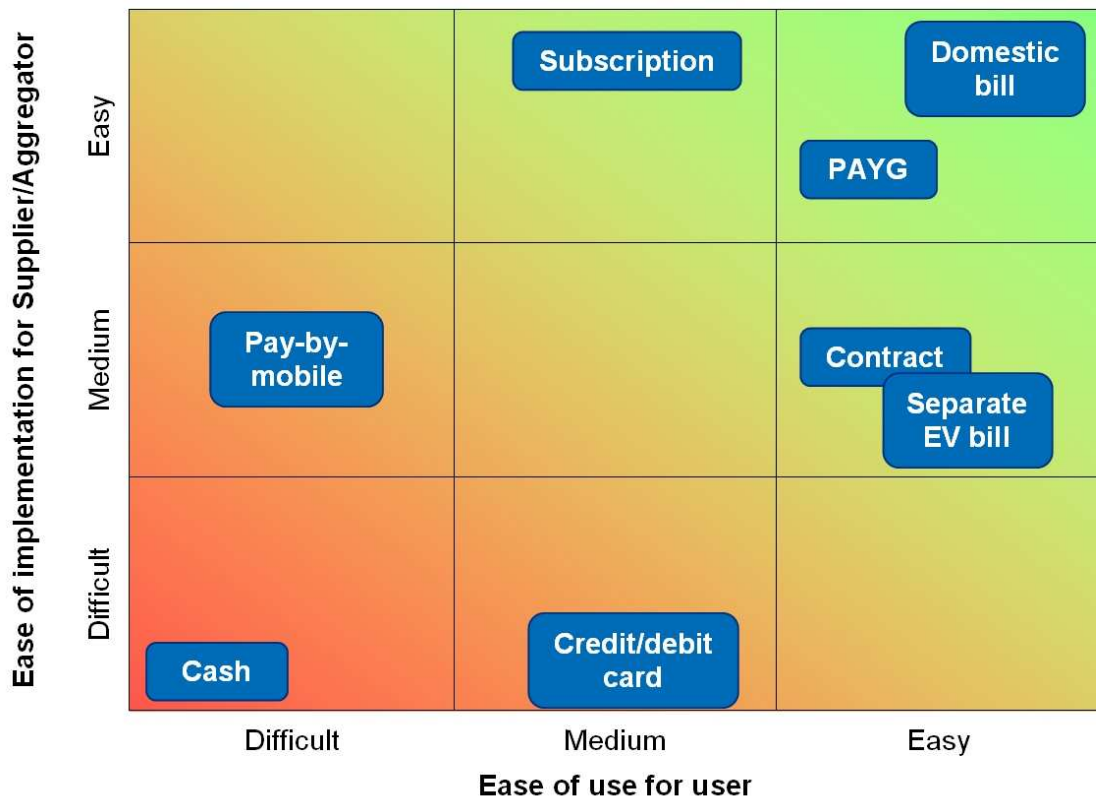
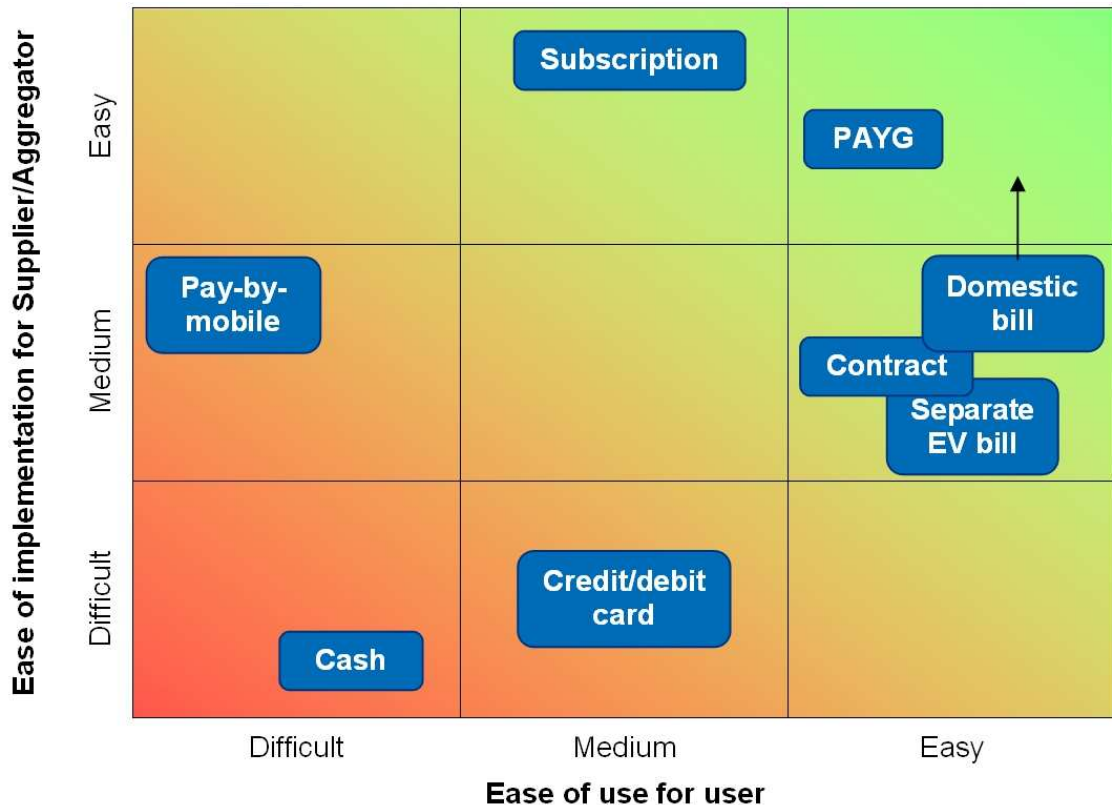


Figure 46 – Evaluation matrix for payment methods in a domestic location



**Figure 47 – Evaluation matrix for payment methods in non-domestic locations**

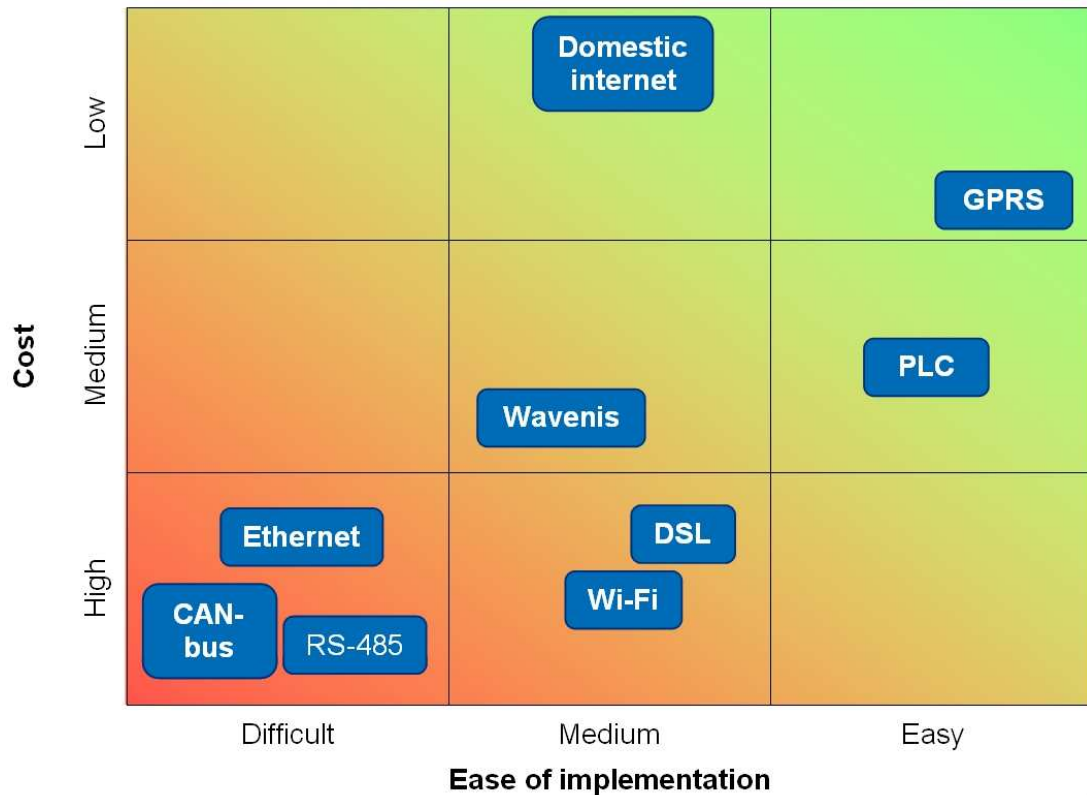
For most locations PAYG is the simplest system to both install and use. However, in all cases the addition of energy usage onto a user’s domestic energy bill is considerably more desirable to the user due to convenience. In a domestic garage this is the easiest method to implement as the metering and billing system is already in place; it is also the easiest system for the user, as it requires nothing new from them. As the penetration of EV increases, it will become more desirable for the supplier/aggregator for energy usage from all locations to be added to a user’s domestic bill, because it will utilise their pre-existing sophisticated billing systems. This is indicated by the arrow in Figure 47.

The use of cash to pay for charging is highly undesirable because of both the inconvenience to the user, and the difficulty in implementing a system to collect and store the cash at the CP and then for the CP owner to collect the cash.

Although easier for the user than cash, the use of a credit or debit card for payment at individual CP may not be attractive to credit card companies. This is because the small turnover may not warrant the installation of the card reader and communications to their back office.

#### 8.2.3.4 CP to Supplier/Aggregator

The main considerations for the communications method between the CP and DSO or supplier/aggregator are the simplicity of implementation and the cost. Figure 48 shows the evaluation matrix for the different communication methods that could be used for this data path.



**Figure 48 – Evaluation matrix for CP to supplier/aggregator communication methods**

Installation of GPRS is the simplest, requiring only the addition of a module within the CP that uses the existing mobile phone GSM network. As there is no need to install the network infrastructure this is also the lowest cost method in terms of implementation. The costs to the user of using this system are relatively high as the cost of sending 1 Mb of data via GPRS is of a similar order to the cost of charging an EV [25]. This will require the amount of data communicated to be minimised to keep costs low.

PLC would require some infrastructure installation to allow communication across transformers, increasing the cost and complexity of installation over GPRS. Other wired communication methods (e.g. RS-485, CAN-bus, and Ethernet) would require the installation of a large scale wired network. This would be both expensive and complex, and so is not desirable. DSL could utilise the existing phone lines in some locations which would reduce some of the complexity and cost.

In areas with a high density of CP a solution combining both PLC and GPRS may be the most suitable. This could use PLC from the CP to a local concentrator (over distances up to 1 km) where data from many CP is collated and then sent on to the supplier/aggregator via GPRS. This could greatly reduce the cost of infrastructure installation as the concentrators could be placed on the same voltage level as the CP, thus negating the need for communications across transformers. In addition the cost of data communication via GPRS could be minimised by the collation of data from several CP.



Both Wi-Fi and Wavenis would require the installation of large scale mesh networks which, although possibly cheaper than the installation of large wired networks, are still prohibitively expensive.

In a domestic location it may be possible for the CP to make use of the user's existing internet connection to communicate with the aggregator. This may present concerns for the aggregator in terms of the security of this data from interference or deletion.



## 9 RECOMMENDATIONS FOR CHARGING INTERFACE

### 9.1 ICT Stage

Table 15 shows the most highly recommended communication methods for the different CP locations and the different communication paths.

	Location		
	Private	Public	Fast Charging
Authentication	If necessary: 1) RFID (becoming NFC) 2) Touch screen	1) RFID (becoming NFC) 2) Touch screen	1) RFID (becoming NFC) 2) Touch screen
EV to CP	1) CAN-bus 2) RS-485 3) PLC	1) CAN-bus 2) RS-485 3) PLC	1) CAN-bus 2) RS-485
CP outwards	1) Domestic internet 2) PLC 3) GPRS	1) GPRS 2) PLC	1) GPRS 2) PLC

**Table 15 – List of most suitable communication methods for the different charging stages and locations**

### 9.2 Power Stage

Adopting a power interface that supports fast charging is essential. Whether DC or three-phase AC should be used for this is still to be decided, however the trend within Europe appears to be towards three-phase AC.

The physical design of plugs and charging points should contribute to both the ease of use and high safety of all involved users. To this end, it is recommended that the power interface should support the following considerations to allow for a safe power exchange between the vehicle and the grid:

- Ground fault interruption mechanism
- Immobilisation of the vehicle while charging
- Proper connection interlock
- Continuous protective ground conductor checking
- Automatic de-energisation interlock
- Ventilation interlock



## **APPENDIX 1 - MESSAGE SEQUENCE CHART FOR EV CHARGING IN A PRIVATE LOCATION WITH PRIVATE ACCESS, EQUIPPED WITH SMART METER**

The EV user defines his personal charging preferences such as the desired range (and thus the SOC required), the drive-away time, and whether V2G can be utilised or not. The presence of a smart meter highly encourages the smart charging of the EV to reduce energy costs. The EV then establishes a link with the home smart meter using network protocols such as DHCP [26]. Next, the smart home identifies the EV and checks the charging preferences of the EV. The electrical parameters of the EV are then negotiated with the smart home and the charging process starts. Concurrently, the supplier/aggregator (SupAg) is informed about the EV connection. Based on the assessment of the demand management and V2G operation capacity of its aggregated EV, the SupAg can offer bids to the system service market. These bids are, however, checked with the DSO before being sent to the market to ensure that they do not violate distribution system constraints. An alternative to ensure that the system will remain in a safe operating mode is to enable the DSO to allow or block the intended changes by the SupAg. The TSO can use such offered services as needed. The DSO can also benefit from such services by market participation or mutual contracts with the SupAg. In case of emergency, the DSO can also directly modify EV loads.

During the operating phase, the charging process is continuously monitored to ensure that it is proceeding normally. In addition, the SupAg may send system service requests to the smart home based on what it has agreed in a contract with the DSO, requests from the TSO as agreed upon in the market. It should be noted that DSO would directly send such signals only in case of grid problems. After confirmation by smart home, the control commands from DSO or SupAg are forwarded to the EV in order to modify the charging rate. During this phase, the smart meter also sends information to the SupAg about any unexpected events or errors.

The log-off phase begins with an end-of-charge indication signal sent by the EV to the smart home. This signal may be generated either as a result of reaching the end of charge time or via user request in the middle of the charge process. This information will also be sent to the SupAg. The smart home will send the metering data to the DSO and this will be sent to the SupAg for billing. This metering data can be also displayed to the user.



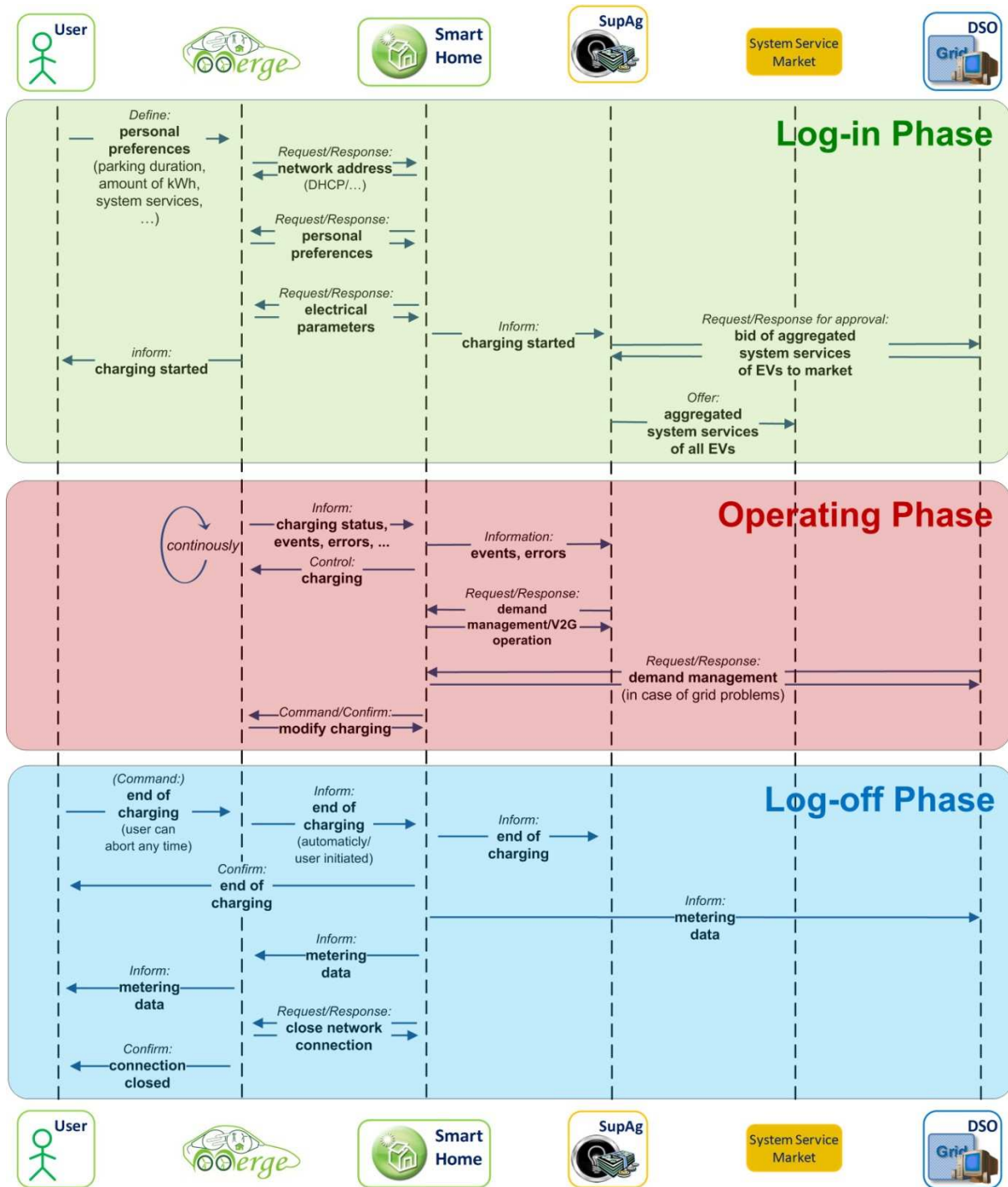


Figure 1A - 1: Message sequence chart for EV charging in a private area with private access equipped with smart meter



## APPENDIX 2 - MESSAGE SEQUENCE CHART FOR EV CHARGING IN A PRIVATE AREA WITH PUBLIC ACCESS

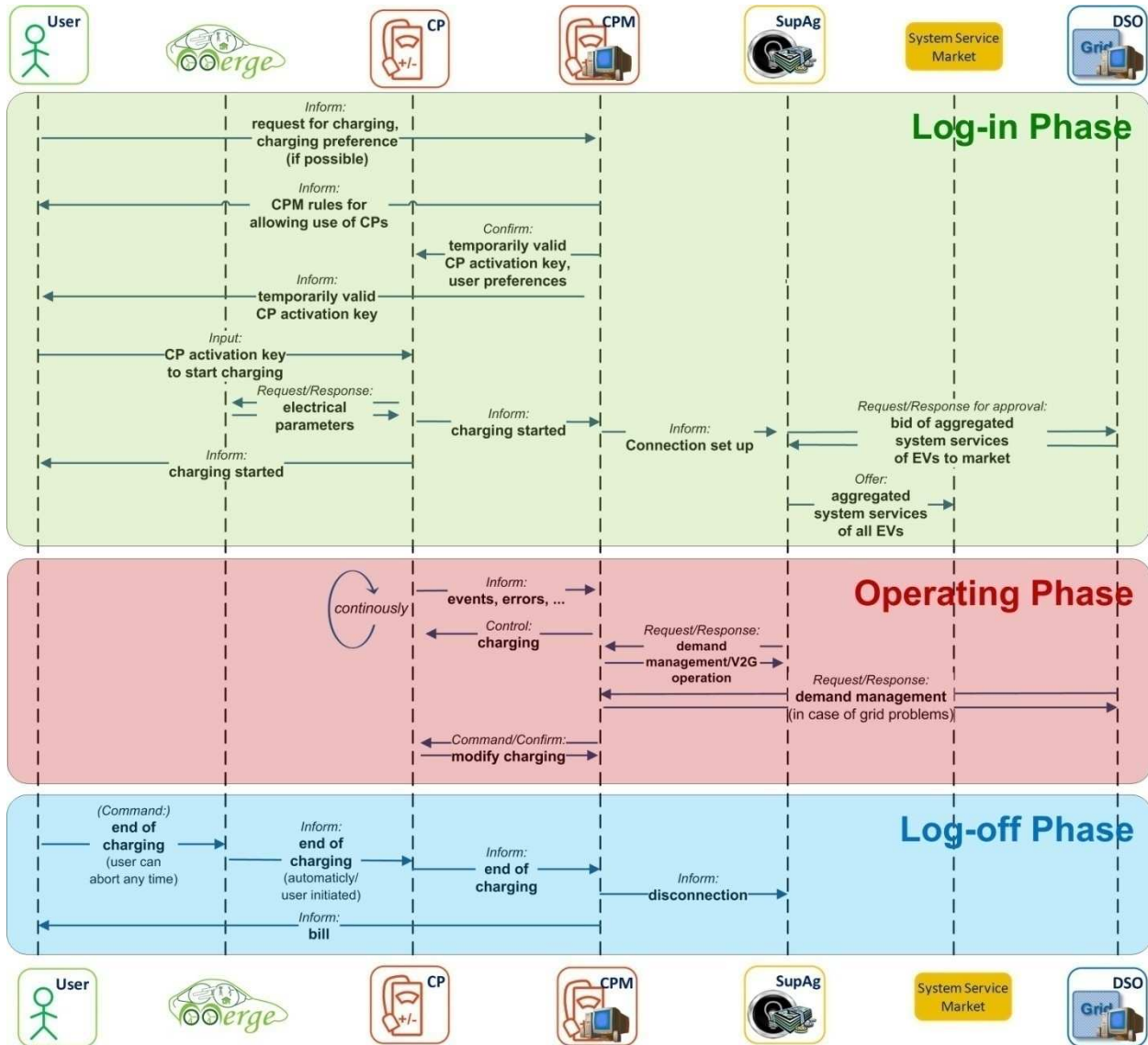


Figure 1B - 1 – Message sequence chart for EV charging in a private charging location with public access

The above figure illustrates the message sequence chart between different entities involved in a possible realisation of EV charging for a private area with public access. The details of charging procedure may be slightly different for different charging locations that can be placed in this category of charging places. For example, the charging process in a dedicated recharge station is not exactly the same as that in a large supermarket car park. So, the sequence message sequence chart in this section focuses on one of these cases, namely recharge points available at a large supermarket car park.

It is assumed that the each single charging point (CP) is not equipped with a smart meter, but the supermarket as a whole or all the CP together have one smart meter. To get the permission to park the EV and connect it to the CP, the user contacts the charging point



manager (CPM) and should agree with the way that the CPM would charge the EV. The CPM gives an activation code to the user to enable the CP and sends a corresponding code to the CP which matches the code given to the user. Using this code, the user can connect his EV to the CP and start the charging process. The CPM can also update the supplier/aggregator (SupAg) on the new load management potential. Based on the assessment of the potential from its aggregation of connected EV, the SupAg can offer bids to the market.

During the charging process (operating phase), the charging process is continuously monitored to ensure that it is proceeding normally. The CPM may receive requests for demand side management or V2G operation from the SupAg. In response to these requests, the CPM can modify the charging rate of the EV or even require them to operate in V2G operating mode according to the conditions for using the car park that the user has accepted. The DSO can also send requests for load management in case of detecting grid problems.

The log-off phase begins with users command to stop the charging process or after the process is finished based on the connection time that may be specified at the start of the charging process or after the EV batteries are fully charged. This request is then informed to the CPM and CPM can update the SupAg with the disconnection information. Finally, the user will be requested to pay the bill.





### **APPENDIX 3 - MESSAGE SEQUENCE CHART FOR EV CHARGING IN A PUBLIC AREA WITH PUBLIC ACCESS**

In this scenario, the EV charges at a charging point (CP) in a public area with public access and the CP is assumed to be equipped with a smart meter. As a result, smart charging is incentivised and is thus considered. The user can specify his charging preferences. When connecting to the CP, the user agrees that his EV is charged as the CP decides. This enables the CP to consider EV as a manageable load. Before the charging process can start, user's credentials are checked and only then the charging is authorised. The electrical parameters of the EV are then negotiated with the CP and the charging process starts. The CP will also inform the supplier/aggregator (SupAg) of connection of a new EV and the new load management potential. Based on the assessment of the potential from its aggregation of connected EV, the SupAg can offer bids to the market.

During the charging process (operating phase), the charging process is continuously monitored to ensure that it is proceeding normally. The CP may receive requests for demand side management or V2G operation from the SupAg. In response to these requests, the CP can modify the charging rate of the EV or even require them to operate in V2G operating mode according to the conditions for using the car park that the user has accepted. The DSO can also send requests for load management in case of detecting grid problems.

The log-off phase begins with users command to stop the charging process or after the process is finished based on the connection time that may be specified at the start of the charging process or after the EV batteries are fully charged. This request is then informed to the SupAg. The user can be informed of the metering data. This information is also sent to the DSO. Finally, the bill is generated and the network connection will be closed.



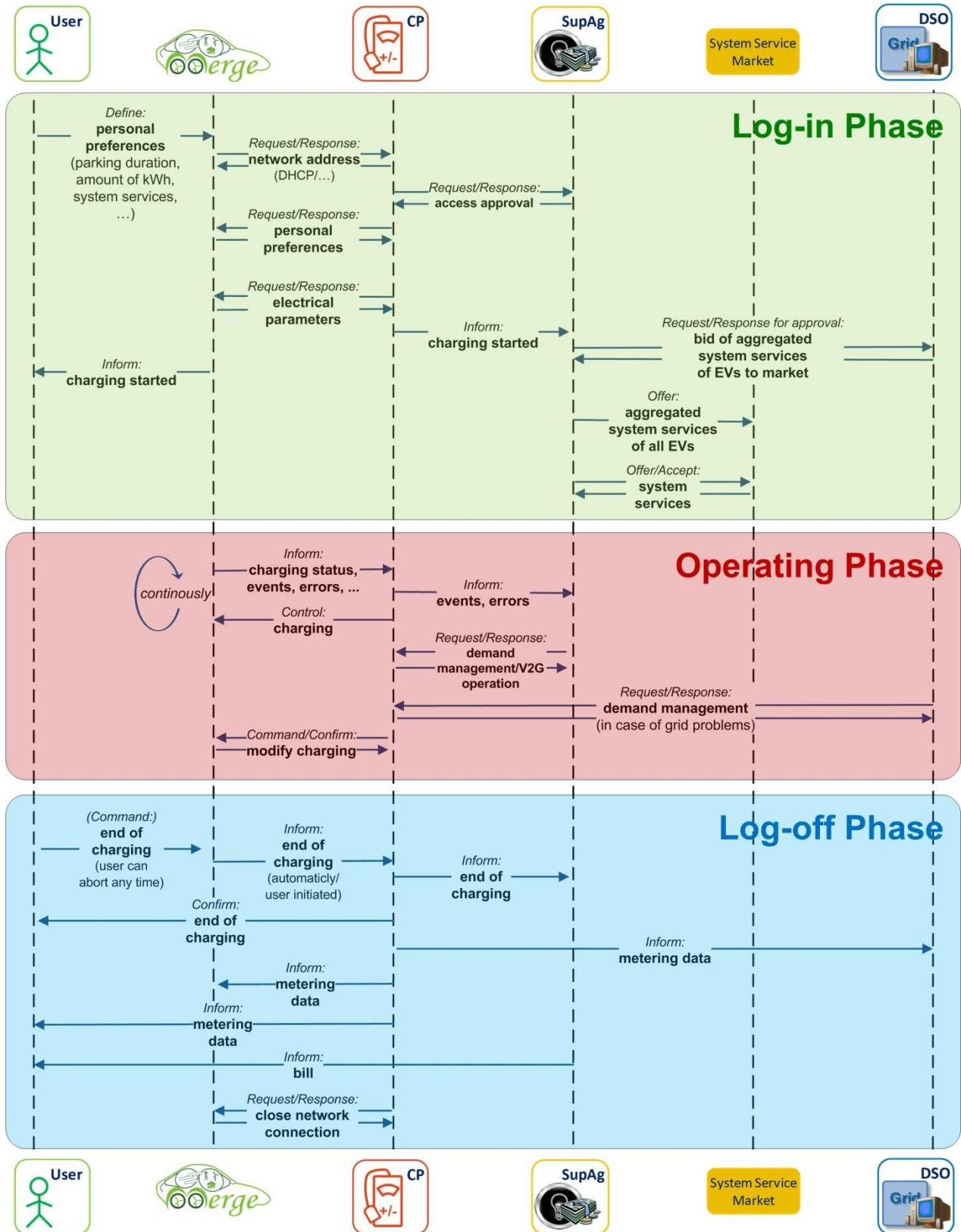


Figure 1C - 1 – Message sequence chart for EV charging at a public area with public access



# **MOBILE ENERGY RESOURCES IN GRIDS OF ELECTRICITY**

**ACRONYM: MERGE**

**GRANT AGREEMENT: 241399**

**WP 1  
TASK 1.2  
DELIVERABLE D1.1**

**SPECIFY SMART METERING FOR EV**

**11 AUGUST 2010**



## REVISION HISTORY

---

VER.	DATE	NOTES (including revision author)
01	14/04/2010	Subtask 1.2.4 by F. J. Soares and P. M. Rocha Almeida
02	14/04/2010	Subtask 1.2.5 by F. J. Soares and P. M. Rocha Almeida
03	21/04/2010	Subtask 1.2.1 by E. Karfopoulos, D.Tsetsis, I.Bourithi
04	21/04/2010	Subtask 1.2.3 by E. Karfopoulos
05	28/04/2010	Subtask 1.2.2 by Erietta Zountouridou
06	04/05/2010	Subtask 1.2.1 by Iñigo Berganza and Iñigo Larumbe
07	10/05/2010	Subtask 1.2.1 by E. Karfopoulos
08	10/05/2010	Subtask 1.2.3 by E. Karfopoulos
09	14/05/2010	Subtask 1.2.6 by Anthony Walsh
10	14/05/2010	WP 1 Task 1.2 by D. Rua, P. M. Rocha Almeida and R. J. Rei
11	09/08/2010	WP 1 Task 1.2 by Mohsen Ferdowsi



## AUTHORS

Anthony Walsh	anthony.walsh@esb.ie
David Rua	drua@inescporto.pt
Diego Issicaba	dissicaba@inescporto.pt
Dimitris Tsetsis	admin@ev-merge.eu
Erietta Zountouridou	eriettaz@power.ece.ntua.gr
Evangelos Karfopoulos	ekarfopoulos@gmail.com
F. J. Soares	filipe.j.soares@inescporto.pt
Iliana Bourithi	merge@ev-merge.eu
P. M. Rocha Almeida	pedro.r.almeida@inescporto.pt
Ana Glz. Bordagaray	ana.gb@iberdrola.es
Nicolas Arcauz Eguren	nico.arcauz@iberdrola.es

## CONTRIBUTORS

Aris Dimeas	adimeas@power.ece.ntua.gr
C. L. Moreira	cmoreira@inescporto.pt
Iñigo Berganza	iberganza@iberdrola.es
Iñigo Larumbe	ilarumbe@iberdrola.es
J. A. Peças Lopes	jpl@fe.up.pt
Kai Strunz	kai.strunz@tu-berlin.de
Luís Seca	luis.seca@inescporto.pt
Mohsen Ferdowsi	mohsen.ferdowsi@tu-berlin.de
Nikos Hatziargyriou	nh@power.ece.ntua.gr
R. J. Rei	rjrei@inescporto.pt
Stavros Papathanasiou	st@power.ece.ntua.gr
Valy Lioliou	v.lioliou@dei.com.gr
Alberto Sendin	asendin@iberdrola.es







<b>APPROVAL</b>			<b>DATE</b>
Project Coordinator	PPC	N. Hatzargyriou	16/08/2010
Technical Coordinator	INESC Porto	J. Pecas Lopes	14/08/2010
Work Package Leader	TU Berlin	Kai Strunz	11/08/2010

- Access:**
- Project Consortium
  - European Commission
  - Public
- Status:**
- Draft Version
  - Submission for Approval (deliverable)
  - Final Version (deliverable, approved)





## SUMMARY

The project MERGE mission is to evaluate the impacts that the integration EVs will have on EU electric power systems regarding planning, operation and market functioning. The focus is placed on the EV and the Smart Grid deployment which along with enabling technologies and advanced control approaches that will have a definite impact on renewable energy increase and on the reduction of CO<sub>2</sub> emissions.

The massive connection of EVs as uncontrolled loads can potentially lead to electric grid problems which can be minimized if proper procedures are implemented. Charging patterns can match some grid requirements, contributing to minimizing the peak load, the renewable energy spillage and branch congestions. If bolder hierarchic management strategies are applied, EV batteries can be used as distributed storage devices and, consequently, some ancillary services can also be provided to the grid. Thus the predictable, large EV deployment can result in future technical and economical benefits, if the electric grids are properly equipped with communicating devices allowing centralized and decentralized levels of control.

Following this path, smart metering solutions seem to be a very effective and adequate gateway to provide universal basic and advanced functionalities from measurement to communication in order to achieve some level of coordinated energy management. Applying those concepts will enable technical and economical management of grid connected EV. Therefore, the main goal of the present task is to establish additional guidelines to be followed on smart meter system design, in order to include EV related functionalities within the scope of the Smart Grids.

The review of the most recent smart metering market solutions in the EU presented in this report, showed a massive regulatory effort and business investment currently underway around the world to upgrade various electrical grids with significant new capabilities, specifically in the areas of increased network communications, remote and automated management of network elements in the field, and new power management functionality. Certainly, a key aspect of this upgrade to a smart grid is the deployment of millions of new smart meters by utilities around the globe, particularly in North America, Europe, and certain countries in the Asia-Pacific region, most notably Australia.

The definition of the smart metering concept presented in this report helps in understanding its benefits and barriers. Smart meter solutions are overviewed along with initiatives towards standardization. Although smart metering is the key for making the European grids smarter, in terms of more economical and efficient grid operation, there is still no integrated solution which can enable a wide implementation of smart metering. Thus, a number of pilot smart metering projects have been initiated across Europe in order to gain experience for the developing of an integrated smart metering solution.

However there are some issues in the massive implementation of smart metering such as the high cost of smart metering technologies, the lack of standardization and the absence of regulatory framework about smart metering. Standardization is an issue that European Union is addressing. Open communication protocols, common functionalities and requirements will enable the interoperability of smart metering technologies resulting to the decrement of their costs.





Without a single standard, manufacturers would be required to offer a number of different solutions incurring additional development expenses. Security concerns are another barrier in the sense that only trusted appliances can share information with the smart meter.

Automatic Meter Reading (AMR) is a technology which automatically collects data from metering devices like water, gas, heat, electricity and transfers these data to a central database for analysis and billing purposes. Many AMR devices can also perform data logging. The logged data can be used for water or energy use profiling, time of use billing, demand forecasting, demand side management (DSM), rate of flow recording, leak detection, flow monitoring, etc. Smart meter goes a step further than simple AMR. It offers additional functionality including a real-time or near real-time indications and power quality monitoring. Standards for smart metering include requirements and test methods to cover data models and protocols for meter data exchange.

Utility metering is undergoing a revolution as long established mechanical and electromechanical meters are replaced by electronic meters. This has the potential to bring hundreds of millions of new meters into use across Europe. Smart metering technology has shown general evidence of product evolution. The lack of adequate common requirements on functionality and open interfaces (interoperability) fractionalizes the market and increases costs. Thus in this document high level requirements for the future smart meters are analysed.

The advent of the smart metering represents a unique opportunity towards a more efficient and detailed approach to DSM. The smart meter can enable consumers to take the initiative with the data that is presented to them. Thus, a smart meter can be seen as a concentrator and manager of information referring to the energy exchange of each consumer, and also a controller of a set of advanced functionalities. It is a tool that provides up-to-date information regarding the energy usage and represents a strong vector to promote DSM.

Smart meters can also be used to support the integration of microgeneration either for billing purposes, since the energy sent to the grid from the microgeneration units is often remunerated differently from the consumed energy, or for managing grid integration of microgeneration. Hence functions of the smart meter as a universal GW for V2G associated with the controlled and uncontrolled charging modes of EVs are explored in this report.

The V2H concept is explored in this document, as particular case of the V2G concept where the domestic/home environment is the main focus. Although V2H is a novel concept, it is envisioned to operate under three realistic use cases depending upon the availability of grid connection and microgeneration.

The specification of technical characteristics of smart metering for EV according to the desired functionalities and based on experience will impact the charging infrastructure. The Electric Vehicle Charging Infrastructure will have a variety of functional requirements. Some of these functional requirements will be met by the smart meter and others by various ancillary electronic systems. Most of the functionalities required for smart meters associated with EV Charging are already available in existing smart meters, including basic DSM. More sophisticated DSM will require extra functionalities along with more demanding communications channel.





## TABLE OF CONTENTS

1	INTRODUCTION .....	8
2	OBJECTIVES .....	10
3	GLOSSARY .....	11
4	REVIEW OF THE MOST RECENT SMART METERING MARKET SOLUTIONS IN THE EU .....	13
4.1	Introduction .....	13
4.2	Smart Metering.....	13
4.3	Benefits of Smart Metering.....	14
4.4	Barriers to Smart Metering .....	15
4.5	Initiatives towards Smart Metering Standards.....	16
4.6	Conclusion .....	18
5	STANDARDS – INTERCONNECTION OF SMART METER WITH OTHER DEVICES..	19
5.1	Introduction .....	19
5.2	Layered Protocols .....	19
5.3	IEC/EN Standards for Data Exchange between Smart Meters and Devices.....	21
6	HIGH LEVEL REQUIREMENTS OF SMART METER .....	23
6.1	Introduction .....	23
6.2	High Level Requirements .....	23
7	FUNCTIONS OF SMART METER AS A UNIVERSAL GATEWAY FOR V2G .....	30
7.1	Introduction .....	30
7.2	Basic Smart Meter Version for Domestic Charging.....	33
7.3	Advanced Smart Meter Version for Domestic Charging.....	35
7.4	Smart Meter Version for Public Charging Points.....	38
8	SPECIFICATION OF USAGE OF SMART METERING IN V2H.....	40
8.1	Introduction .....	40
8.2	Use Case A: EV + Appliances Management .....	40
8.3	Use Case B: EV + Microgeneration + Appliances Management .....	41
8.4	Use Case C: Isolated Management.....	42
9	SPECIFICATION OF TECHNICAL CHARACTERISTICS OF SMART METERING FOR EV .....	44
9.1	Introduction .....	44
9.2	Development of the Functional Requirements for EV Charging Infrastructure ...	44
9.3	Conclusion .....	55
10	FINAL REMARKS.....	57
	APPENDIX 1 - METER TYPES CERTIFIED TO BE DLMS/COSEM COMPLIANT .....	59
	APPENDIX 2 - SMART METERING IN DIFFERENT EUROPEAN COUNTRIES .....	64
	APPENDIX 3 – SMART METER FUNCTIONALITIES .....	72
	APPENDIX 4 – DEVELOPMENT OF SMART METER FUNCTIONALITIES USING PROCESS MAPS.....	76





## II SPECIFY SMART METERING FOR ELECTRIC VEHICLES

### 1 INTRODUCTION

Regarding the overall purposes of the Merge project, eventual electric grid problems resulting from massive connection of EV as uncontrolled loads can be solved and, if proper procedures are implemented, charging patterns can match some grid requirements, minimizing the peak load, the renewable energy spillage or branch congestions. If bolder hierarchic management strategies are applied, EV batteries can be used as distributed storage devices and, consequently, some ancillary services can also be provided to the grid. Thus the predictable, large EV deployment can result in future technical and economical benefits, if the electric grids are properly equipped with communicating devices capable to perform some centralized and decentralized levels of control. Following this path, smart metering solutions seem to be a very effective and adequate gateway to provide universal functions from measurement to communication in order to achieve some level of coordinated energy management. Applying those concepts, technical and economical management of the grid connected EV will be possible. Therefore, the main goal of the present task is to establish additional guidelines to be followed on smart meter system design, in order to include EV related functionalities within the scope of the Smart Grids.

This task is organized in six subtasks (steps). The first subtask includes contributions of Iberdrola and PPC and conveys the state of the art of the European smart metering systems, presenting actual equipment solutions from several manufacturers and describing the implementation of pilot metering projects. The second subtask includes contributions of Iberdrola, PPC, ICCS/NTUA and analyses mainly the standards and technologies towards data exchange between smart meters and other devices, including a survey on protocols applicable to each communication interface envisaged for the smart meters. The third subtask has contributions from Iberdrola, PPC, ICCS/NTUA and states the high level requirements for future smart meters, focusing on features like interoperability, public communication standards, common communication architecture, event support, alarm handling, different business cases combination and participation in different market services. The fourth subtask with contributions of INESC Porto, TU Berlin, InSpire, presents smart meter functionalities in order to cope with EV less demanding charging processes like Dumb Charging or Multiple Price Tariff and functionalities to handle more elaborated EV battery management strategies such as Smart Charging and Vehicle-to-Grid, for both public and domestic appliances. The fifth subtask includes contributions from INESC Porto and analyses the usage of smart metering within the novel concept of vehicle-to-home operation, considering three scenarios depending upon the availability of grid connection and microgeneration: EV plus appliances management, EV plus microgeneration plus appliances management and isolated management. The last subtask with contributions of Iberdrola, PPC and ESB conveys information on smart metering for EV design options, considering the desired functionalities and the collected experience with emphasis on the modularity of solutions, considering a basic DSM as an initial approach, including some functions of the EV Charging Infrastructure that depend on the access and payment method to be provided.





This report follows the structure of the subtasks for Task 1.2 presented in the Description of Work. Table 16 maps the subtasks from the DoW onto the sections of this report.

SUBTASK FROM DoW	DESCRIPTION	SECTION OF THIS REPORT
1.2.1	Review the most recent smart metering market solutions in the EU. Learn from the open meter and smart meter field experience of Iberdrola and PPC	4 page 13
1.2.2	This subtask analyses the standards that enable the connection of smart metering with other devices, regardless of the manufacturer	5 page 19
1.2.3	Define the high level requirements for the future smart meter that will allow access to EV	6 page 23
1.2.4	In this subtask the functions to be performed by the smart metering as a universal gateway for V2G energy management and business are defined	7 page 30
1.2.5	This task specifies the usage of smart metering under V2H scenarios.	8 page 40
1.2.6	This task focused in the specification of the technical characteristics of the smart metering towards EV integration according to the desired functionalities and experience	9 page 44

**Table 16 – Cross-referencing subtasks from the DoW with sections on this report**





## 2 OBJECTIVES

Present a review of the most recent smart metering market solutions in the EU whilst learning from other projects and smart meter field experience of Iberdrola and PPC.

Analyse standards that enable the connection of smart metering with other devices regardless of the manufacturer.

Define high level requirements for the future smart meter that will allow access to EV.

Define functions to be performed by the smart metering as a universal gateway for V2G energy management and business.

Specify usage of smart metering in V2H.

Specify the technical characteristics of the smart metering for EV according to the desired functionalities and experience.





### 3 GLOSSARY

TERM	DEFINITION
<b>AMI</b>	Advanced Metering Infrastructure
<b>AMM</b>	Automatic Meter Management
<b>AMR</b>	Automatic/automated Meter Reading
<b>BOM</b>	Bill Of Materials
<b>BRP</b>	Balance Responsible Party
<b>CAS</b>	Central Access Server
<b>CENELEC</b>	European Committee for Electro technical Standardization
<b>CEN/TC</b>	European Committee for Standardization/ Technical Committee
<b>COSEM</b>	Companion Specification for Energy Metering
<b>CS</b>	Companion Specification
<b>DC</b>	Dumb Charge
<b>DCHP</b>	Dynamic Host Configuration Protocol
<b>DLC</b>	Data Link Control
<b>DLMS</b>	Device Language Message Specification
<b>DoW</b>	Description of Work
<b>DSL</b>	Digital Subscriber Line
<b>DSM</b>	Demand Side Management
<b>DSMR</b>	Dutch Smart Meter Requirements
<b>DSO</b>	Distribution System Operator
<b>DSSS</b>	Direct-Sequence Spread Spectrum
<b>EMF</b>	Electro-Magnetic Fields
<b>ERDF</b>	Electricité Réseau Distribution France
<b>EN</b>	European Standard
<b>ESCO</b>	Energy Supplier Company
<b>EU</b>	European Union
<b>EV</b>	Electric Vehicle. (BEV) Battery Electric vehicle. (PHEV) Plug-in Hybrid Electric Vehicle
<b>EV CI</b>	Electric Vehicle Charging Infrastructure
<b>EV CP</b>	Electric Vehicle Charging Post
<b>FTP</b>	File Transfer Protocol
<b>GPRS</b>	General Packet Radio Service
<b>GSM</b>	Global System for Mobile communications
<b>GW</b>	Gateway
<b>HAN</b>	Home Area Network
<b>HDLC</b>	High-level Data Link Control
<b>HHU</b>	Hand Held Units
<b>HMI</b>	Human Machine Interface
<b>IEC</b>	International Electro technical Commission
<b>IEEE</b>	Institute of Electrical and Electronic Engineers
<b>LAN</b>	Local Area Network



<b>LLAC</b>	Logical Link Access Control
<b>LV</b>	Low Voltage
<b>μG</b>	Micro generator
<b>M-Bus</b>	Meter Bus
<b>MG</b>	MicroGrid
<b>MMG</b>	Multi-MicroGrid
<b>MPRN</b>	Meter Point Registration Number
<b>MPT</b>	Multiple Price Tariff
<b>MRSO</b>	Meter Registration System Operator
<b>MV</b>	Medium Voltage
<b>MV/LV</b>	Medium Voltage to Low Voltage Transformer
<b>NTP</b>	Network Time Protocol
<b>OBIS</b>	Object Identification System
<b>OFDM</b>	Orthogonal Frequency-Division Multiplexing
<b>OSI Model</b>	Open System Interconnection Reference Model
<b>PLC</b>	Power Line Carrier
<b>PPPoE</b>	Point-to-Point Protocol over Ethernet
<b>PSTN</b>	Public Switched Telephone Network
<b>RES</b>	Renewable Energy Sources
<b>RF</b>	Radio Frequency
<b>SBC</b>	Single Board Computer
<b>SC</b>	Smart Charge
<b>SCADA/DMS</b>	Supervisory Control And Data Acquisition/ Distribution Management System
<b>SLM</b>	Service Lifecycle Management Protocol
<b>SOAP</b>	Simple Object Access Protocol
<b>SOC</b>	State Of Charge
<b>TOU</b>	Time Of Use
<b>TSO</b>	Transmission System Operator
<b>UMTS</b>	Universal Mobile Telecommunications System
<b>V2G</b>	Vehicle-to-Grid
<b>V2H</b>	Vehicle-to-Home
<b>VPP</b>	Virtual Power Plant
<b>WAN</b>	Wide Area Network

All units used in this report are part of the International System of Units (SI) and, as such, are not defined herein.





## **4 REVIEW OF THE MOST RECENT SMART METERING MARKET SOLUTIONS IN THE EU**

### **4.1 Introduction**

Massive regulatory effort and business investment are currently underway around the world to upgrade various countries' electrical grids with significant new capabilities, specifically in the areas of increased network communications, remote and automated management of network elements in the field, and new power management functionality, e.g. distributed generation and power storage, including support for (plug-in hybrid) electric vehicles. Certainly, a key aspect of this upgrade to a "smart grid" is the deployment of millions of new "smart meters" by utilities around the globe, particularly in North America, Europe, and certain countries in the Asia-Pacific region, most notably Australia.

The rapid increment of the world population is increasing the energy consumption resulting in high energy demand rise. Environmental, legal and social pressures already constrain where and how fuels are obtained, generation plants are built and transmission lines are located. Without action, any energy shortage will become markedly worse. Key to managing our dwindling energy resources is accurately measuring usage. Measurement is one of the first steps toward effective management and refining consumer behaviour. Thus, several European pilot projects for smart metering have already been initiated.

One of the world's largest smart meter deployments was undertaken by Enel SpA, one of the most important utility in Europe and the dominant utility in Italy with over 27 million customers. Between 2000 and 2005 Enel deployed smart meters to its entire customer base.

These meters are fully electronic and smart, with integrated bi-directional communications, advanced power measurement and management capabilities, an integrated, software-controllable disconnect switch, and an all solid-state design. They communicate over low voltage power line using standards-based power line technology from Echelon Corporation to Echelon data concentrators at which point they communicate via IP to Enel's enterprise servers.

Another example is the deployment made by the company Vattenfall in Sweden, Amrelva. This project is currently in its third phase, which began in 2006 and currently has more than 600,000 smart meters installed and operating and the intention is to operate more than 850,000 meters in Sweden, including both industrial and residential customers through 2017.

In Appendix 2, pilot smart grid and smart metering projects from other European countries are presented. This is the case of Greece, Portugal, Germany, France and Spain.

### **4.2 Smart Metering**

A question that arises is what does the term "smart meters" mean and which are their additional functionalities differentiating them from the existing ones. Smart





metering is designed to provide utility customers information on a real time basis about their domestic energy consumption. This information includes data on how much electricity, gas and water they are consuming, how much they are costing and what impact their consumption has on greenhouse gas emissions. The majority of existing electricity and gas meters are hidden from view and provide little or no information for the customer on energy usage. Customers would be willing to be aware of their consumption and costs. According to an IBM survey, more than 50% of UK households want more than just a figure for energy usage. Meter manufacturers and others have developed smarter metering that offer greater awareness and influence over energy usage than currently existing meters in Europe. These metering systems have been rolled out with considerable success across a number of international marketplaces such as the US, Italy and more recently Australia, Finland and Sweden.

The multiple definitions for smart metering found throughout the literature highlights the lack of consensus, nonetheless it is widely accepted that a smart meter is composed of an electronic box with communication links. The basic version of smart meters measures the amount of energy used and can send present this information to the consumers making them aware of the energy expenditures and associated costs [27].

The distinction of the type of smart meter can be made based on their communication (one or two-way) and the data storage capability. These two characteristics define the level of detail that the metering system has and the potentially available features to customers [27].

Smart metering is also a key element of the Smart Grid, providing a two way link between the grid operators at one end and customers and suitably equipped home appliances at the other. For instance, it is possible for grid operators to remotely adjust thermostats in customers' homes to reduce load on the system. In turn the utility would have to offer their customers an acceptable tariff to accept this arrangement. This also links smart metering into home automation technology.

Smart Metering technologies: i) provide a two-way information and communication channel between the meter and relevant parties and their systems, ii) allow for automated reading and data collection on consumption (including costs and related carbon emission data, iii) enable automated delivery, processing, management and usage of metering data, and iv) facilitate advanced energy services improving energy efficiency and encouraging a more rational use of energy.

### **4.3 Benefits of Smart Metering**

The benefits which are offered by the adaptation of smart metering technologies into the electrical grids are multiple - efficient energy management, reduced operational costs, enhanced and qualitative services – and concern all the involved parties - energy suppliers, system or network operators, consumers.

Smart meters increase the awareness of the consumers informing them how and when the energy is spent. The time cycle between readings is of great importance. Instead of monthly or yearly readings which are the most common now, smart meters can provide more frequent measurements (e.g. hourly) giving a more





accurate understanding of usage patterns. Through web applications consumers can have direct information of their actual energy consumption and thus is more likely to change their behaviour, in order to become more efficient, rather than being informed several months later. Regardless of the billing frequency, smart meters ensure that consumers are billed for their actual energy consumption.

The increased information on low voltage networks provided by smart meters offers potential savings in operation and management of the electrical grid. Problems can be located much easier and the maintenance process is accelerated. This factor enhances the quality of the services provided to the consumers by the system operator. Furthermore, information on low voltage networks offers more accurate analysis of grid operation (load profiles, maximum loads and load distribution) creating the opportunity for better grid planning either concerning new investments in infrastructure or upgrades to the current networks.

Such information for the low level of electrical grids is also beneficial for the suppliers. Smart metering allows suppliers to have a better knowledge of the consumption pattern of individual customers, giving them the opportunity to offer customized contracts. This gives the chance to suppliers to attract new customers by targeting them with different price options and increase the competitiveness between suppliers. The latter is further increased by the fact that the change of supplier is easier since smart meters can be read at any time on request. Moreover, suppliers have more direct information about the quality of the supply. Such information includes failure alarms, statistics on power outages, voltage levels etc. This enables them to improve their services and make their customers more satisfied.

#### **4.4 Barriers to Smart Metering**

Many pilot smart metering projects have been initiated in various European countries. In all these pilot projects a limited number of smart meters have been implemented. There are many barriers that deteriorate the massive implementation of smart metering systems. These barriers are economical, high capital investment, technological, smart metering technologies are still under development, and regulatory, national legislations are still raw or inexistent.

One major barrier for the wide implementation of smart meters is the implementation cost. Not only the cost for the installation of smart metering system is a large investment, but also the depreciation period of such investments is long enough. Of course, further costs such as the maintenance and unexpected quality ones that increase the operational cost of the responsible parties should also be considered. Moreover, the presentation of smart metering data to the customer is another cost which depends on the frequency of the readings.

Smart metering systems are quite recent and they are still evolving rapidly. Various technologies (various types of smart meters-modular or not- with different functionalities) and forms of communication (WAN, ZigBee, LAN and PLC, among others) can be implemented in the smart metering infrastructure. The decision on the best solution is difficult and there is also the inherent risk of being early adopter on a new technology. However, adopting a more traditional and tested system





generates the risk of not being able to live up to the high expectations of tomorrow's smart metering systems.

In Europe, PLC (power line communications) is extensively used for smart metering and is the telecommunication media chosen by major utilities to deploy, such as ERDF, Iberdrola, Endesa and EDP. Clear synergies are expected to be achieved between smart grids and smart metering when using PLC.

Since smart metering systems are a quite new concept it is expected that the regulatory framework for such systems will be inexistent or on an optimistic point of view too weak. The lack of specific and national legislations creates uncertainty to the market actors and makes the process much more difficult. The roles and the responsibilities of each actor should be clearly defined by national regulations. Furthermore, the lack of standardization is another important barrier. There are no specific communication protocols and there is no specification of the minimum requirements and functionalities of smart meter.

Last but not least, customers' concern regarding privacy issues in relation to meter data management was an important issue in some European countries (Holland and Sweden). In Holland small end users refused the installation of smart meters on their premises in relation to confidentiality of metering data. In Sweden, the problem was even worse, consisting of two components. The first one is the fear of increased Electromagnetic Fields (EMF) in the homes. The amount of the generated EMF is influenced by the communication method and the technical platform. This led to increased costs and delay of the installations. However, the largest issue in Sweden was the accuracy of the meter data. There was a public suspicion that the new meter readings were incorrect resulting to higher billings.

Another issue that arises is which grid party that should be responsible for the metering. There are three different ideas for distributing the responsibility of metering: i) the DSO, ii) the supplier or iii) a metering company. According to GEODE report [28], the option of the network operator has been adopted by the majority of the European countries, except from UK and Germany. The meter is part of the electrical grid for which DSO is responsible for. Additionally, the net operator is the only market participant that will always be connected to the customers.

#### **4.5 Initiatives towards Smart Metering Standards**

Key issues for success of smart metering systems are standardization and interoperability. Interoperability can be defined as the ability of information and communication systems to support data flow and to enable the exchange of information and knowledge, both at a technical (linking of systems) and semantic (meaning of data) level. Standardization is the process that enables this interoperability at both levels.

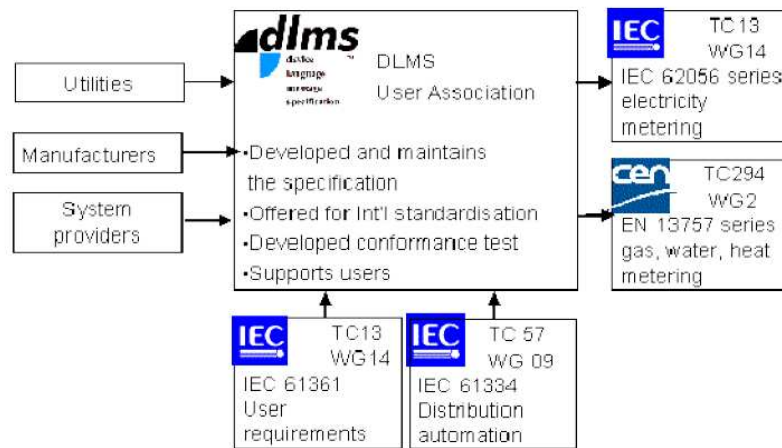
In Germany, the development of a smart metering standard is jointly advanced by the two working groups Figawa and ZVEI, in which the German meter manufacturers are organized. However, further efforts are then necessary in order to come to a European standard for smart metering systems. At the European level, the KEMA14 (by order of the Dutch regulatory authority) and the federation of European meter manufacturers ESMIG are working on the development of a





European smart metering standard. The European Commission is going to issue a mandate to a working group comprising Cenelec15, WELMEC16 and ETSI17 – under leadership of Cenelec, this group assigned the task to develop a European standard for smart metering.

Based on the previous analysis of smart metering solutions offered by different EU vendors, DLMS/COSEM is the most commonly used communication protocol. Device Language Message Specification (DLMS) is a generalised concept for abstract modelling of communication entities. COmpanion Specification for Energy Metering (COSEM) sets the rules, based on existing standards, for data exchange with energy meters.



**Figure 49 – DLMS/COSEM scope**  
 (Source: DLMS)

A great number of different types of smart meters produced by various vendors support DLMS protocol. Most vendors have certified, through laboratory tests, the compatibility of their meters with the DLMS protocol. Annex A presents several meter types certified to be DLMS / COSEM compliant.

There are two European initiatives on Smart Metering standardization, the most important one is Mandate 441 by the European Commission to CEN, CENELEC and ETSI for the definition of an open architecture for smart metering. The solution must be an open architecture that supports secure bidirectional communication upstream and downstream and allows advanced information and management and control systems for consumers and service suppliers, and must be scalable and should ensure full interoperability.

The second initiative is the OPEN meter project, is funded by FP7, which is coordinate by Iberdrola. The main objective of the OPEN meter project is to specify a comprehensive set of open and public standards for AMI, supporting electricity, gas, water and heat metering, based on the agreement of all the relevant stakeholders in this area, and taking into account the real conditions of the utility networks so as to allow for full implementation. The result of the project will be a set of draft standards, include the IEC 61334 series PLC standards, the IEC 62056 DLMS/COSEM standards for electricity metering, the EN 13757 series of standards for utility metering other than electricity using M-Bus and other media. These





existing standards will be complemented with new standards, and must be open to include new agents or actors, like the EV, which should have an important role in the next years. And one of the most important aspects to be into account is that the resulting draft standards will be fed into the European and International standardization process.

#### **4.6 Conclusion**

Smart metering is the key for making the European grids smarter, in terms of more economical and efficient grid operation. Moreover, smart metering will accelerate the efforts of the European Union to reach their policy goals. However, there is still no integrated solution which can enable a wide implementation of smart metering. Thus, a number of pilot smart metering projects have been initiated across all over the Europe in order to gain experience for the developing of an integrated smart metering solution.

The benefits from smart metering are of great importance and concerns all the grid participants. Consumers will have direct information of their actual consumption in a more frequent time base, thus they will be able to efficiently handle their energy consumption and reduce their costs. Suppliers will have better information about their customers' consumption and will be able to offer better services to the customers (e.g. more economical contracts, more accurate billing etc). The system operator will have a more detailed view of the system creating the opportunity for better grid operation and planning (either new investments or upgrades).

However, there are some issues (economical, technological and regulatory) that should be addressed for the massive implementation of smart metering. These issues are the high cost of smart metering technologies, the lack of standardization and the lack of regulatory framework about smart metering. Standardization is an issue that European Union is presently addressing. Open communication protocols, common functionalities and requirements will enable the interoperability of smart metering technologies resulting to the decrement of their cost.





## 5 STANDARDS – INTERCONNECTION OF SMART METER WITH OTHER DEVICES

### 5.1 Introduction

In the ideal world a consumer would purchase a new Smart Meter (SM) and when it is plugged into the home for the first time it would automatically identify itself and register with the home network. There are currently a number of barriers to this ideal vision, most significantly the lack of a global standard for meter networking.

Without a single standard, meter manufacturers would be required to offer a number of different solutions incurring additional development expenses. Security concerns are another barrier in the sense that only trusted appliances can share information with the smart meter.

Automatic Meter Reading (AMR) is a technology which automatically collects data from metering devices like water, gas, heat, electricity and transfers these data to a central database for analysis and billing purposes. Many AMR devices can also do data logging. The logged data can be used for water or energy use profiling, time of use billing, demand forecasting, demand side management (DSM), rate of flow recording, leak detection, flow monitoring, etc.

Smart meter goes a step further than simple AMR. They offer additional functionality including a real-time or near real-time indications and power quality monitoring. Standards for smart metering include requirements and test methods to cover data models and protocols for Meter data exchange.

### 5.2 Layered Protocols

The Open System Interconnection Reference Model (OSI Model) is an abstract description for layered communications and computer network protocol design. It divides network architecture into seven layers which, from top to bottom, are the Application, Presentation, Session, Transport, Network, Data Link, and Physical Layers, as depicted in the following table.

Data Unit	Layer	Function
Data	Application	Network process to application
Data	Presentation	Data representation, encryption/decryption
Data	Session	Inter-host communication
Segments	Transport	End-to-end connection, reliability, Flow control
Packet	Network	Path determination and logical addressing
Frame	Data Link	Physical addressing
Bit	Physical	Media, signal and binary transmission

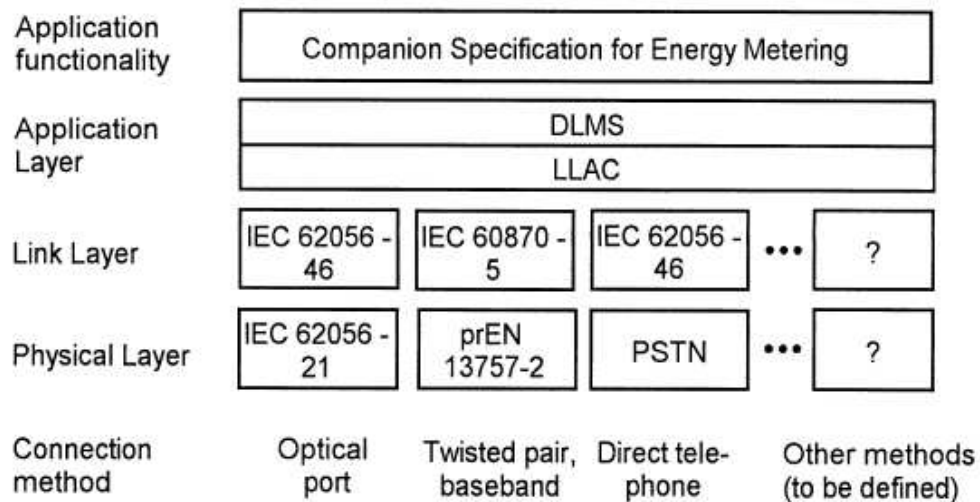
**Table 17 – OSI Model**

In order to perform automatic reading of meters, CEN/TC 294 chose the 3-layer model (EN 61334-4-1), which is derived from ISO - OSI 7- layer model.



The Physical and Link Layers depend on the connection method used (Power Line Carrier-Low Voltage (PLC - LV), Public Switched Telephone Network (PSTN), HF radio, Twisted Pair cable (TP)).

The Application Layer is independent of the connection method used, in order to have a uniform view of all types of meters. As a consequence, the protocol architecture, as shown below is used [29].



**Figure 50 – Protocol Architecture [29]**

The Application Layer specification is sub-divided into two parts: DLMS and LLAC.

DLMS (Distribution Line Message Specification) EN 61334-4-41 is an Application Layer specification. It permits a formal description of the communications system, in terms of its functionalities, in an object-oriented way.

LLAC (Logical Link Access Control) specifies the remainder of the connecting method independent part of communications system. It specifies tasks like security management, handling of multiple applications, and segmentation of large data into multiple packets at lower levels. This corresponds to the Transport, Session and Presentation layers in the ISO-OSI 7-layer model.

A Companion Specification (CS) contains extension to the existing standard, as well as operating rules within the scope of the existing standard. The Companion Specification for Energy Meters (COSEM) specifies the functionality of the meter, as seen through the communication system, defined in terms of the objects contained within them (e.g. Index, ID, meter type, manufacturer, date and time, rate and even communication entities such as a phone number). Meters, support tools and other system components that follow these specifications can communicate with each other in an interoperable way.

### 5.3 IEC/EN Standards for Data Exchange between Smart Meters and Devices

A schematic diagram of a smart meter is shown in Figure 51 [30]. The smart meter infrastructure as an AMI can be divided into three segments [31]:

- The local network segment
- The access network segment
- The backhaul network segment

The local network connects smart meters belonging to the same entity (home, building, facility) as well as end-user applications (HAN) to a node acting as a local data collector and gateway between access and local network.

The access network comprises the networks between house gateway and a Hub /data concentrator or the data management centre in case there is no data concentrator.

The backhaul network is the final segment between Hub/data concentrator and the data & management centre for utility services and customer-related services.

In case that there is no hub/data concentrator, the data is sent directly to data & management centre.

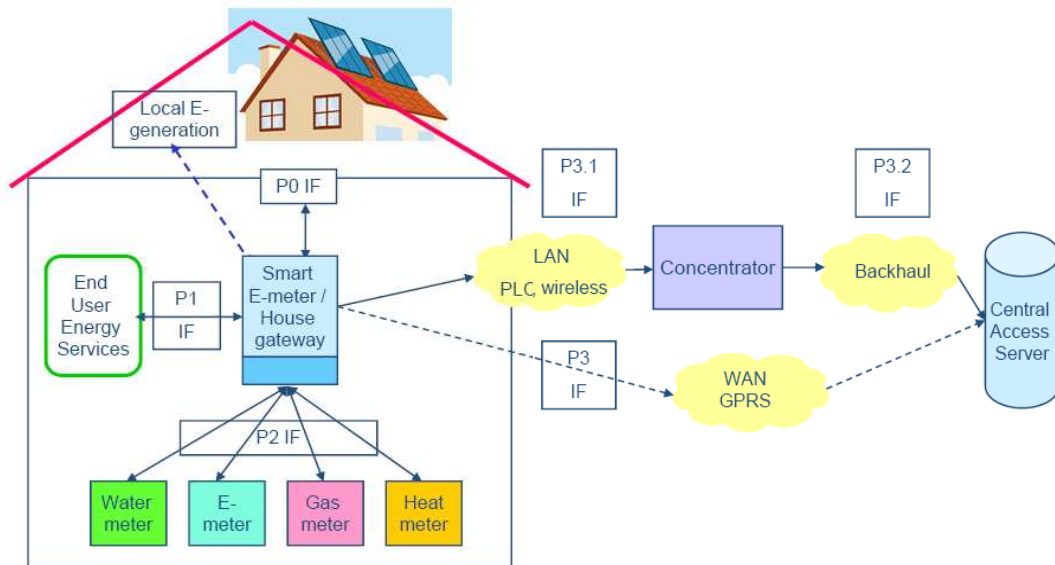


Figure 51 – Smart Meter schematic diagram

There are five interfaces (Ports) that designate the connection of the smart meter with other devices, plus an interface between the Concentrator and the Central Access Server [30].

- **Port 0** Communication with external devices (e.g. hand-held terminal) during installation and on-site maintenance of the metering installation.
- **Port 1** Communication between the metering installation and ISP module or auxiliary equipment.



- **Port 2** Communication between the metering system and one or more metering instruments and/or grid company equipments.
- **Port 3** Communication between the metering installation and the Central Access Server (CAS).
- **Port 3.1** Communication between the metering installation and the Data Concentrator (DC).
- **Port 3.2** Communication between the Data Concentrator (DC) and the Central Access Server (CAS)

One consideration to keep in mind is that although all communication media are being included, PLC is a convenient choice for utilities in Europe. It is convenient in the sense that while the electric vehicle is charging, data exchange is possible between the network and the EV.



## 6 HIGH LEVEL REQUIREMENTS OF SMART METER

### 6.1 Introduction

Smart metering technology has shown general evidence of product evolution. However, the great technological diversity should not generate new obstacles. The lack of adequate common requirements on functionality and open interfaces (interoperability) fractionalizes the market and increases costs both for smart meters and for the applications and services that use metered data.

Figure 52 defines the common high level requirements for the future smart meters. Further analysis of these requirements is following within the next paragraphs.

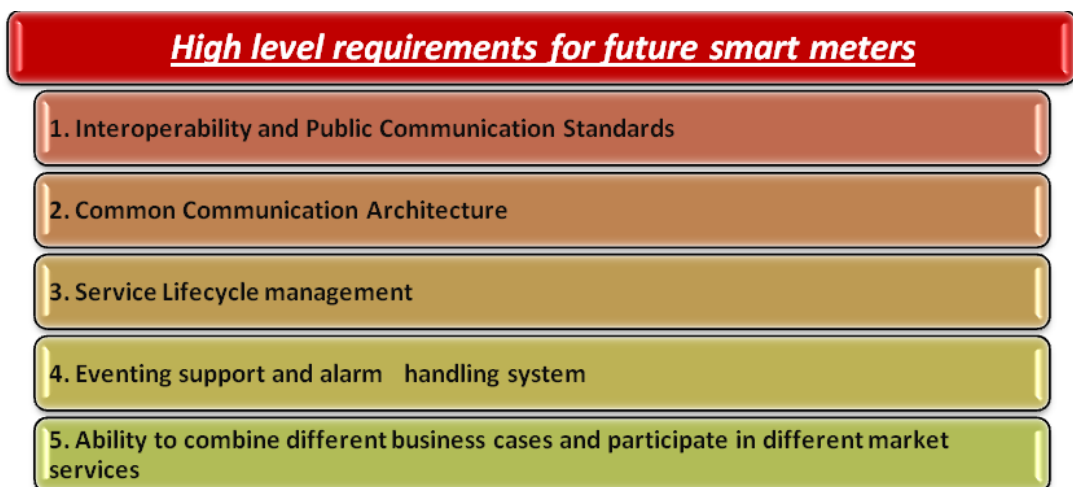


Figure 52 – High level requirements for future smart meters

### 6.2 High Level Requirements

#### 6.2.1 Interoperability and Public Communication Standards

Large, integrated, complex metering systems require different layers of interoperability, from a plug or wireless connection to compatible processes and procedures for participating in distributed business transactions. Very simple functionality—such as the physical equipment layer and software for encoding and transmitting data—might be confined to the lowest layers. Communication protocols and applications reside on higher levels with the top levels reserved for business functionality. As functions and capabilities increase in complexity and sophistication, more layers are required to interoperate to achieve the desired results. Each layer typically depends upon—and is enabled by—the layers below it. Establishing interoperability at one layer can enable flexibility at other layers. The most obvious example of this is seen in the Internet: with a common Network Interoperability layer, the Basic Connectivity Layer can vary from Ethernet to Wi-Fi to optical and microwave links, but the different networks can exchange information in the same common way.



Compatibility and interoperability must be ensured so that the functions of the meters can be effectively used by various parties without any unnecessary technical ramifications. From the end users' scope, it is important to have the freedom to contract with different energy supplier companies (ESCOs), without the need to change the metering infrastructure, and take services from different market parties. For energy retailers competing for final customers, the key issues regarding interoperability is that the smart meter fitted at the property can be adopted by any new energy retailer and connected seamlessly with the new energy retailer's billing system. This would imply that energy retailers will have to find common approaches and agree a minimum level of functionalities related to final customer feedback that all energy retailers provide or risk implementing incompatible schemes with consequent high costs of final customer switching. However, it may be possible that energy retailers choose to avoid interoperability in some areas. For instance, different energy retailers could choose to supply different feedback displays. The display and its functionality would become a differentiation between energy retailer contracts. But even this approach though outside of interoperability, would depend on the different displays being able to access data from the meter LAN in an interoperable fashion.

The issue of interoperability can be identified more as an issue of standards rather than technology. Standards are critical to enabling interoperable systems and components. Mature, robust standards are the foundation of mass markets for millions of components i.e. smart meters. Standards enable innovation where components may be constructed by thousands of companies. They also enable consistency in systems management and maintenance over the life cycles of components. Such standards enable diverse systems and their components to work together and to securely exchange meaningful, actionable information.

There are a number of different physical communication media and associated protocols. It is possible that no single approach will meet all requirements, for instance, wireless based systems may fail to work in circumstances where heavy screening to the signals is required. Thus it is likely that a number of different options will be required even within a single smart metering system. Smart meters will introduce new functions such as local and wide area communications between the meters, local displays, other utility meters and the remote data collector. Smart meters may also introduce new data items, data flows and new business processes, such as dynamic tariffs and multi utility data flows. Smart metering systems will also interface with customers, smart homes applications and smart grids. The meters, display devices, communications and other devices will be produced by many manufacturers to be used by many utilities working under a wide range of market conditions. There will be multiple software applications from those embedded on the meters through to the back office. All of these components must work together correctly and reliably in parallel and series as appropriate. To achieve this, it is essential to develop a comprehensive interoperable environment for smart meters. Thus, it is important to use common standards approach as to facilitate connection to the meters.

There is a danger that the development of incompatible national schemes will lock final customers into their existing energy retailer or restrict market access to local companies that have the necessary knowledge to operate the schemes. The costs for new entrant companies will be lower if they could replicate a common approach in different countries. Such a common approach would have a number of benefits.





By avoiding the need for each member state and national metering stakeholder to investigate and develop their own approach, less regulatory, industry and government cost would be required. Meter and associated equipment would be manufactured in larger volumes resulting in lower costs. Larger markets would also encourage more innovation from hardware and software developers. A common approach would also support European Commission objectives for free market in services.

## 6.2.2 Communication Architecture

A conceptual model of the communication architecture of smart metering is presented in Figure 53. Two layers of smart meter communication can be identified, one with the upstream network and another with the end-user. In the upstream network, the parties that require communication with the smart meters are the energy suppliers, the distribution network operator and the service companies (i.e. metering service companies). Bidirectional information flow and data exchange between the upstream network and the smart meter is mandatory, whereas it is optional for the local communication between smart meter and the customers. In the latter case, the decision depends on the cost of the required communication infrastructure which should be evaluated depending on the added value of the customers' feedback

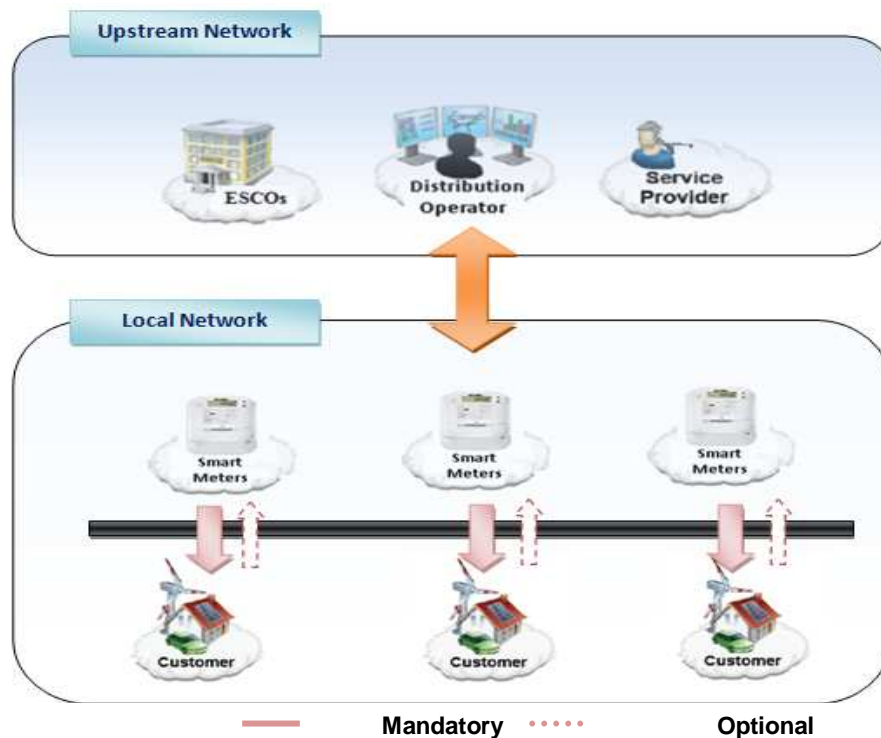


Figure 53 – Conceptual model of the communication architecture

Data exchange between smart meters and the upstream network enables various tasks like readings, connection and disconnection, tariff programming, alarms management, clock synchronization and/or firmware update, which can be done remotely.



Smart meters provide useful information to distribution network operators providing increased levels of voltage and phase monitoring of the distribution system. This information can be further evaluated to manage networks more efficiently minimizing the risk of congestions and reducing the network technical or non-technical losses. Furthermore, the real-time information enables faster identification of the location of a fault and restoration time as with smart meters the DSO automatically knows where the power is out and can dispatch crews to restore it without having to wait for customers complaints.

Smart meters allow the energy supplier a better knowledge of the consumption pattern of individual customers, giving them the opportunity to target them with different prices options. Remote collection of meter data reduces the cost of data collection, eliminates estimated bills and provides accurate data for usage information on bills. In case of bad debts, the energy supplier is allowed to remotely cut off and reconnect the customer. Smart meters can be used to reduce the final customer load when networks or generation capacity is approached, reducing the cost of energy supply and improving its energy efficiency.

Smart meters provide consumers historical and instantaneous information about their energy consumption, the power quality of the supply and the different tariff schemes. Thus customers are able to manage their energy consumption more efficiently resulting in savings on energy bills. Such information is important for the owner of electric vehicle, since he should have knowledge of the state of charge of the batteries, the estimated time of battery charging and the remaining time of charging process.

Energy and other utilities are supplied using independent distribution networks. In most cases, metering of energy as electricity, gas and heat as well as water is based on individual, independent meters. The principle of multi-utility smart metering is to combine all the utility measurements into one device or system. In many circumstances, a smart metering system for more than one utility, for example electricity and gas, could be more effective in influencing energy savings as well as optimizing the metering installation costs and maintenance. Customers can be provided with their utilities by the same energy retailer or by different energy retailers sharing the smart metering system. There are a number of different models for multi-utility metering; the system can be operated by a single energy retailer offering multi-utility services, metering services can be provided by an external independent data acquisition company, or a single utility can offer access to their smart metering system to other utilities. Generally, multi-utility metering offer a significant opportunity for reduction of operational reading costs, especially with regard to shared communications systems and customer displays. Instead of many subsystems only one reliable system is used.

The design of the communication architecture should ensure the communication performance requirements in terms of availability, reliability and speed response. For some services communication availability and response time are much more critical than high data rates and the impact of these on the final customer experience should be considered at the design stage. For example, dynamic tariffs and demand response might need instantaneous communication in order to deal with an imminent peak demand rather than settlement and billing. Reliability is very important as far as the billing process is concerned. Most modern meters store metered values for several weeks or months (depending on how much memory is





specified) thus reducing the risk of losing billing measurements due to WAN reliability problems.

Security of the communication is another major issue that should be addressed. Smart meter systems are vulnerable to hacking attempts as they are widely accessible for extended periods and control large financial values. The security of the system must be managed appropriately to ensure that only approved parties can access the meter data and that final customers and others cannot access data within the meter that they are not approved to view. As the computing power of home computers can be expected to rise considerably over the lifetime of the smart metering system, the meters should be able to remotely accept improved security algorithms during their service lives.

### **6.2.3 Service Lifecycle Management**

Service lifecycle management deals with the administration of functionalities and services during their entire lifecycle. Service lifecycle management (SLM) is a holistic approach which helps service organizations better understand the revenue potential by looking at service opportunities proactively as a lifecycle rather than a single event or series of discrete events. Almost all the different smart meter branches provide customers the same functionalities. What will drive the purchase decision of the customer besides price is the service.

The service lifecycle management should enable the deployment of new services, the update of existing services, the starting and stopping of services and the configuration and parameterization of running services. A sophisticated lifecycle management has the potential to increase the availability of enterprise systems as it extends the possibilities of changing grid operation processes without considerably influencing the efficiency of the entire system.

### **6.2.4 Event Support and Alarm Handling System**

Either in the local network or in the grid, the events that can be generated are numerous even during normal operation. Some of these events can provide an overview of the current status of the network while others can indicate unexpected problems. The event reports may not be only electrical but functional as well. The list below presents examples of event reporting:

- Confirming successful initialization of the smart meter installed in the field
- Confirming data linkages between a smart meter identification number, serial number and customer account
- Confirming that the meter management data has successfully received notification of any changes to customer account information
- Confirming that the metering service operator has successfully made changes to customer account information
- Confirming the successful collection and transmission of meter data or logging all unsuccessful attempts to collect and transmit meter data, identifying the cause, and indicating the status of the unsuccessful attempt(s)
- Confirming whether the meter reads acquired within the daily read period are in compliance with the time accuracy levels
- Confirming time synchronization
- Addressing the functionality of the smart meter communication link





- Identifying suspected instances of tampering, interference and unauthorized access
- Identifying any other instances that impact or could potentially impact the smart meter's ability to collect and transmit meter reads to the responsible parties.

Apart from the event support, smart meters should be equipped with an alerting handling system in case critical events are generated. Critical events are defined to include any operational issue that could adversely impact the collection and transmission of meter information during any daily read period.

- Smart meter operational failure
- Issues related to the storage capacity
- Communication links failures
- Network failures
- Loss of power and restoration of power
- Unauthorized access

Filtering (to select the messages that are of real interest), local processing and evaluation are additional mechanisms that can enhance the performance and scalability of the event support. In a critical situation, messages have to be treated with high priority. Furthermore, the smart meter should get only the necessary decision, critical information and not get overwhelmed with all alerting data from the network. Therefore, support for the exchange of emergency data and a common alerting protocol have to be in place.

### **6.2.5 Ability to Combine Different Business Cases and Participate in Different Market Services**

The power market environment is quite complex since there are several different market sectors where a market player, including EV, can participate. Possible market sectors for EVs to participate depend on their type of management: a) fully controllable storage devices or b) just controllable loads. Smart meter is the mean to the market participation. Thus, they should enable the participation of EVs in different business cases and the selection should be made according to the price offered by the responsible parties (aggregator, ESCO).

Smart meter should enable the market participation of EVs as either individual units or aggregated sets. In the latter case, a commercial aggregator should exercise the task of jointly coordinating the contracted energy use of electric vehicles. The joint management of a collection of electric vehicles can be done in two ways. The aggregator might directly control several electric vehicles (however this would require the end-users to allow direct access to the control of the vehicles). Another way is that an aggregator can only provide incentives to the participating vehicles, so that they will behave in the desired way with a high probability, but not with certainty. The second option leaves the power of control to the end-user. The incentives should not be uniform so that tipping effects due to the sum of similar reactions are avoided.

The aggregated sets of electric vehicles can benefit from a retail portfolio of end user customers using their global load flexibility characteristics. The Balance Responsible Party (BRP) is responsible for balancing the exchanged energy. The





BRP is obliged to make a plan by forecasting the production and consumption of the responsible grid area (control area) and notify this plan to the TSO. The risk of this predictability may cause deviations from this plan and consequently generate increased costs due to the use of reserve and emergency capacity. In order to manage imbalance risk, market participants undertake balancing activities before gate closure occur in the power exchanges as well as in the settlement period itself. In the latter case, the key idea is the utilization of real-time flexibility of their dynamic approach behaving either as flexible distributed generators or as responsive loads/storages.

Another business case is the distribution system congestion management. Non-coordinated control of large fleet of electric vehicles may lead to a sharp rise in required capacity on lines and transformers. The distribution network operator detects overload situations, based on the congestion management system, and excessive voltage drops that requires a local management of the costumers' consumption. The end user (EV owner) should be able to deliver flexibility services to the network operator. By coordinating EV load flexibility, through charging over time, it is possible to comply with grid operational restrictions such that security of operation is assured. .

Variable tariff-based load and generation shifting is the business case where a variable profile is given to the customer day ahead by a retailer. In exchange for an additional financial incentive, customers might be willing to accept adaptations of the price profile during the day of delivery reflecting changes in the retailer's portfolio. Another option could be a "maximum average cost per kWh" guarantee given by the retailer protecting the customer from an increase in his energy cost by errors in the automated management systems or by his personal behaviour.

Distribution grid cell islanding is another important business case in future scenarios of operation. The key idea of this business case is to allow the operation of a grid cell in island mode. This business case considers that the islanding procedure is performed automatically. The scenario has two main steps: the first takes place before the event and the second is the islanded operation after the event. During the first step, the customers declare their availability and forecast the consumption as well as the available power and energy in the next hours. To maximize the longevity of the system operation, a load shedding schedule should be created according to the criticality of the consumers as well as the amount of money they want to pay during the island mode. When balance and stability has been ensured, the aggregator becomes again responsible for managing EV in coordination with the DSO's technical requirements.

It should be noted that it is economically justifiable for aggregator entities to be merged into the already existing supplier companies and form a Supplier/Aggregator (SupAg) company. So, in this report, the term aggregator does not necessarily imply that this entity is separate from a supplier company.





## 7 FUNCTIONS OF SMART METER AS A UNIVERSAL GATEWAY FOR V2G

### 7.1 Introduction

The smart metering is considered as an evolution of an automatic meter management (AMM) system<sup>1</sup>. The advent of the smart metering represents a unique opportunity towards a more efficient and detailed approach to demand side management (DSM). The smart metering concept can incorporate a broader definition that is beyond a simple meter enabling consumers to take the initiative with the data that is presented to them. Thus, a smart meter can be seen as a concentrator and manager of information referring to the energy exchange of each consumer, and also a controller of a set of advanced functionalities. It is a tool that provides up-to-date information regarding the energy usage and represents a strong vector to promote DSM.

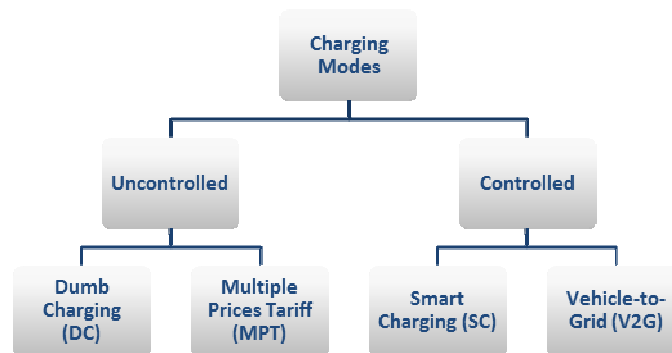
Smart meters can also be used to support the integration of microgeneration either for billing purposes, since the energy sent to the grid from the microgeneration units is often remunerated differently from the consumed energy, or for managing grid integration of microgeneration, as described in the InovGrid project [32].

Three different types of smart meters will be used to deal with the EV charging approaches contemplated in the MERGE Project (Figure 54). The first, a basic version of the smart meter, will include all the necessary functionalities to cope with the less demanding charging approaches, i.e. the Dumb Charging (DC) and the Multiple Prices Tariff (MPT), in domestic environment. The second, an advanced version of the smart meter for home charging, will incorporate enhanced functionalities in order to deal with the more elaborated charging strategies, i.e. Smart Charging (SC) and Vehicle-to-Grid (V2G). The third, an advanced smart meter for public charging points, having the same vehicle management functionalities, but with less complexity as it does not have to control household related appliances or microgeneration units.

In the DC mode EV owners are completely free to charge their vehicles whenever they want. In addition, electricity price is assumed to be constant along the day, what means that no economical incentives are provided to EV owners in order to encourage them to charge their vehicles during valley hours when the grid operating conditions are more favourable to an increment in the energy consumption. Charging starts on the moment each EV plugs-in and lasts until battery full capacity is reached or EV gets disconnected by its owner.

---

<sup>1</sup> The automatic meter management system is an expansion of a remote reading system that includes the possibility of performing technical measurements, functions and carrying out customer-oriented services. This system will interact with the Automated Meter Reading (AMR) that in turn will collect information from domestic meters (electricity, gas, heat, and water).



**Figure 54 – MERGE Project charging modes for EV.**

In the MPT charging mode EV owners are also free to charge their vehicles whenever they want. However, as electricity price is assumed not to be constant during the day, there are periods where its cost is different. This is an indirect incentive based mode of shifting EV energy demand from the peak to the valley hours, aiming to avoid overloading the grid and the generation system during those periods. The electricity prices along the day (prices for each specific tariff period) are fixed by an initial contract established between the client and the trader.

The uncontrolled charging modes do not allow system operators to manage EV charging towards a more efficient operation and so this type of contracts will only allow EV disconnection in case there are severe network problems, namely when voltage levels surpass the defined limits and congestion problems occur. This disconnection of uncontrollable EV will only take place, as it will be explained later, after all the flexibility available on controlled EV is explored. Both DC and MPT customers should have the possibility of choosing between two tariffs: normal and premium. The reason behind the existence of these two tariffs is the fact that some clients may not want to be disconnected at all and so a premium client will, by means of an increase in the tariff, be sure that his EV will not be disconnected unless there is a generalized lack of power.

A SC strategy envisages an active management system where there is an aggregator agent serving as link between the Distribution System Operator (DSO) and the EV owners. In this approach it is assumed that EV batteries' charging is actively managed, adjusting the rate of charging, instead of using an on-off solution. The DSO periodically receives information about all the elements connected to the grid including its state, possibly exploiting and transposing the concepts or similar ones to those used for the management of MicroGrids [33] (MG) and Multi-MicroGrids [34] (MMG). The DSO then may request from the EV, via an aggregator, the services that it may need. In order to guarantee the adherence of EV owners to the SC, the tariffs to be adopted for this strategy should include a bonus on the price of electricity of the clients committed with the SC mode. This way the system will have the flexibility to charge EV during the period they are connected, instead of the charging take place automatically when they plug-in. This type of management provides a more efficient usage of the resources available at each moment, enabling grid congestion prevention and voltage control.

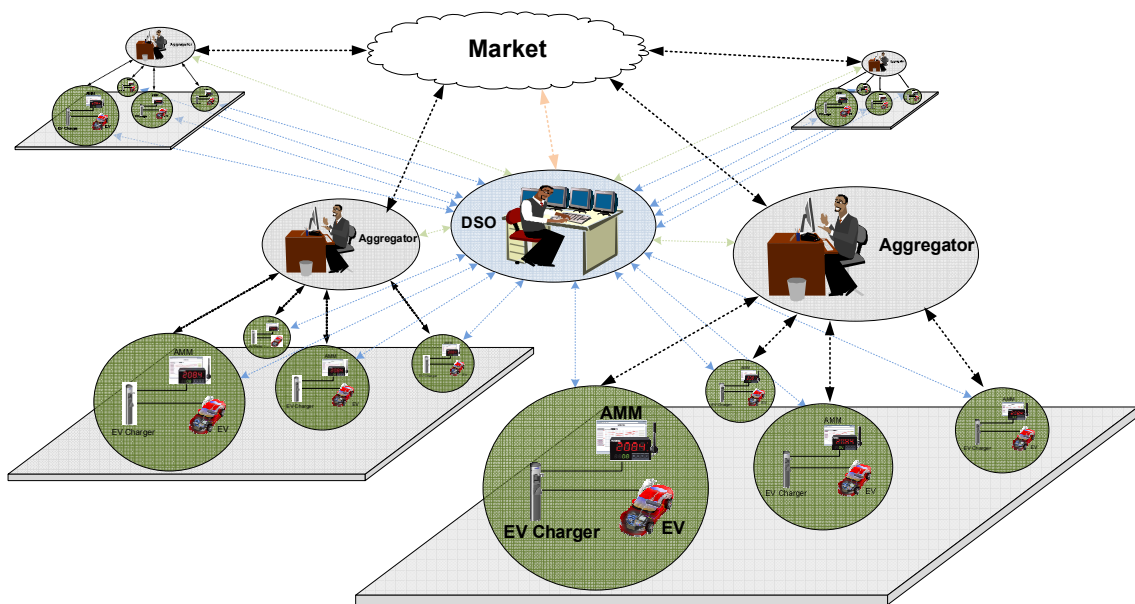
The V2G charging mode is an extension of the previous one, where the aggregator controls not only the charging of the batteries, but also the power that EV might



inject into the grid. From the grid perspective, this is the most interesting way of exploiting EV capabilities given that besides helping managing branches' congestion levels and voltage related problems in some areas of the grid, EV have also the capability of providing peak power in order to make the energy demand more uniform along the day.

A differentiation must exist between the SC and the V2G charging modes due to the more demanding conditions of the V2G option. While the SC only contemplates different charging rates for EV, the V2G approach also involves the injection of power into the network. As this mode of operation is likely to reduce the batteries lifetime expectancy, it is necessary to provide EV owners with economical incentives, like reduced electricity prices as consumer or high selling prices when injecting energy into the grid, in order to foster EV owners' adherence to the V2G charging mode.

Nevertheless, this task does not take into account the economical value of the controlled EV charging modes or the possible electricity market resolutions. Thus, it is only exposed a possible framework for EV charging management and control that enables the technical feasibility of the concept.



**Figure 55 – Framework for EV charging management and control<sup>2</sup>.**

The definition of a smart metering solution for coping with EV energy flux billing and also to help manage the integration of EV in electrical grids does not preclude the discussion on the interest of having additional simple meters installed on board of the vehicles. In fact these meters can be very important for EV charging billing in public areas and would be very helpful in avoiding frauds in home charging.

<sup>2</sup> The interactions DSO – Market, Aggregators – Market and DSO – Aggregators will be thoroughly described in Work Package 5 of MERGE.



## 7.2 Basic Smart Meter Version for Domestic Charging

The basic smart meter version will allow EV owners to charge their vehicles at home, in a slow charging mode, without providing any ancillary services to the system. This version will only support the DC and the MPT charging modes.

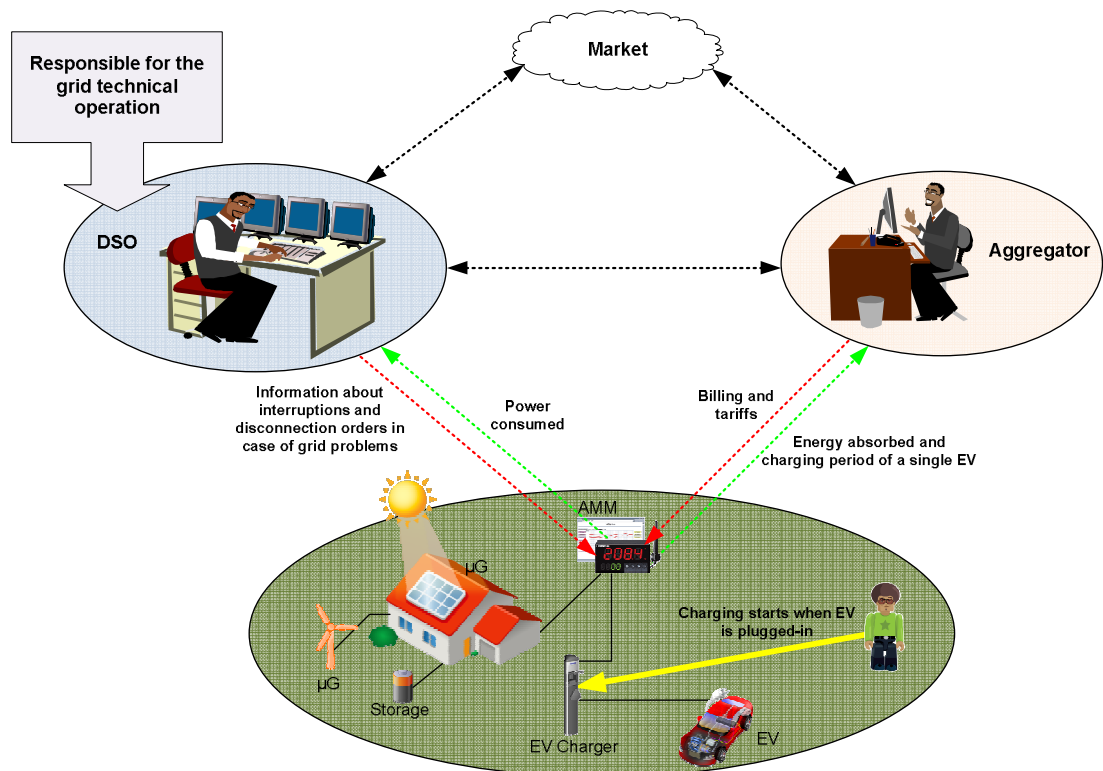
The following functions were deemed as the basic functionalities that the smart meter should provide universally:

- **Basic Human Machine Interface (HMI)** – A simple data display system should be provided in order to allow customers to be aware in real time of their local energy flows, as well as access to billing information and to information related with scheduled maintenance, interruptions and other important events. In addition, this data display should provide information about consumptions and allow the client to compare them with historical data, as well as visualizing the CO<sub>2</sub> emissions related with his energy consumption. Finally, the data display should allow the client to access an application where information on available charging modes is provided, giving the possibility to the client of choosing the more adequate charging mode. As referred previously, the basic smart meter version will only allow clients to choose between the DC and the MPT charging modes.
- **Energy measurement** – Unidirectional (grid to EV) consumed energy must be metered for grid management and billing purposes.
- **Bidirectional communications (Figure 56)** – The smart metering infrastructure is expected to act as a gateway conveying upstream information to the DSO or to an aggregator entity (15 min average power consumed/Injected, charging period, amount of energy absorbed from the grid) and provide relevant downstream information from the DSO/aggregator side to customers (scheduled maintenance, interruptions or other important events, billing information, information on available charging modes and set-points to halt the charging process, in case of problems in the grid).

**Periodic metering report** – Metering data must be reported to the DSO, via aggregator, at least in every 15 min, to allow the evaluation of average power flows and consumption levels, allowing the DSO better assessment of network operating conditions and the aggregator the necessary billing and trading information.

- **Gateway to local system** – The smart meter should interact with other meters such as gas, water and heat meters. It should be designed to promote manufacturer independence and interoperability using standardized protocols and technologies.





**Figure 56 – Information exchange related with the technical aspects of the energy flow: basic smart meter version (for DC and MPT)<sup>3</sup>.**

- Data storage – The smart meter must be able to store the energy consumption values for defined periods of integration (15 min for instance), historical of billing information, data related to regulated quality of service indicators (nr. and duration of interruptions > 3 min, periods where voltage is out of acceptable bounds, nr. of times that the EV was disconnected by the DSO) and logging of other events. The smart meter should have the capability of storing data for prolonged periods without provision of electricity from the grid.
- Seamless connectivity – The EV is able to establish communication with the infrastructure in an autonomous way. The communications are established without having the direct intervention of the user either in the connection process or in the selection of the specific transmission mode or technology.
- Privacy and security – In order to tackle privacy and security issues, the following characteristic should be ensured:
  - Authentication – EV must register when accessing the utility energy services. The network will either authorize or refuse a determined EV connection to the grid. The electric network management will then assign unique ID to each EV user in case of successful registration.
  - Data encryption – The data exchanged between the EV and the aggregator must be encrypted to ensure privacy and resistance to tampering, especially in shared medium communications which are prone to eavesdropping.

<sup>3</sup> The interactions DSO – Market, Aggregators – Market and DSO – Aggregators will be thoroughly described in Work Package 5 of MERGE.



- Logging – In order to account for the quality of service and technical issues, the smart metering must incorporate logging of events which can be classified as:
  - Regular events – Time stamped regular events such as connection/disconnection to the grid, negotiation messages, service requests, service interruption, and others.
  - Unauthorized events – Tampering and other unauthorized activities such as attempts to access the charging infrastructure with a forbidden ID (theft, impersonation, etc.), requesting unauthorized services, illegal energy exchange outside the contracted value and other unauthorized events.
- Clock – Real time clock to support tariff activities. The clock should be synchronised with upstream certified entities.
- Firmware updates – Remote update of smart meter firmware for bug correction or to add new functionalities should be possible. The firmware specifically related with the measurement modules cannot be modified.
- Contract selection – Through the data display, the client should be able to access an application where information on available charging modes is provided. This way it is given the possibility to the client of choosing the more adequate charging mode. The basic smart meter version will only allow clients to choose between the DC and the MPT charging modes.
- Communication fault procedures – In case of communications fault, the proposed framework for EV charging management and control will be compromised, due to its dependency on the communication infrastructure. To overcome this issue, the smart meter must include a mechanism to detect failures in the communications and, when that occurs, it should keep the operating state for the following 30 minutes. After this period, if communications are not re-established, all EV will have their charging rate set to 50% of its rated power. Such mechanism will prevent situations where a high number of EV might be charging simultaneously at their rated power, jeopardising the network normal operation due to the high energy demand. It will also avoid some EV adherents to the SC and V2G schemes to have their charging process halted for long periods of time.

### 7.3 Advanced Smart Meter Version for Domestic Charging

The advanced smart meter is an extension of the basic version and will allow EV charging at home in the SC and V2G charging modes.

In order to cope with the advanced features inherent to the SC and the V2G charging modes, the basic smart meter version has to be enhanced with extra functionalities to face the increased interaction that will exist between the EV owner and the aggregator/DSO, the large amounts of data being exchanged between parties, the remote definitions of the SC and V2G parameters, the load monitoring and management in a V2H perspective and the roaming feature.

The functions associated with the basic version of the smart meter need to be extended in order to satisfy the new features requirements. The following advanced functions are envisioned to be developed:

- Advanced HMI – In addition to the basic HMI, this extended version should allow consumers to be aware in real time of their household and EV energy

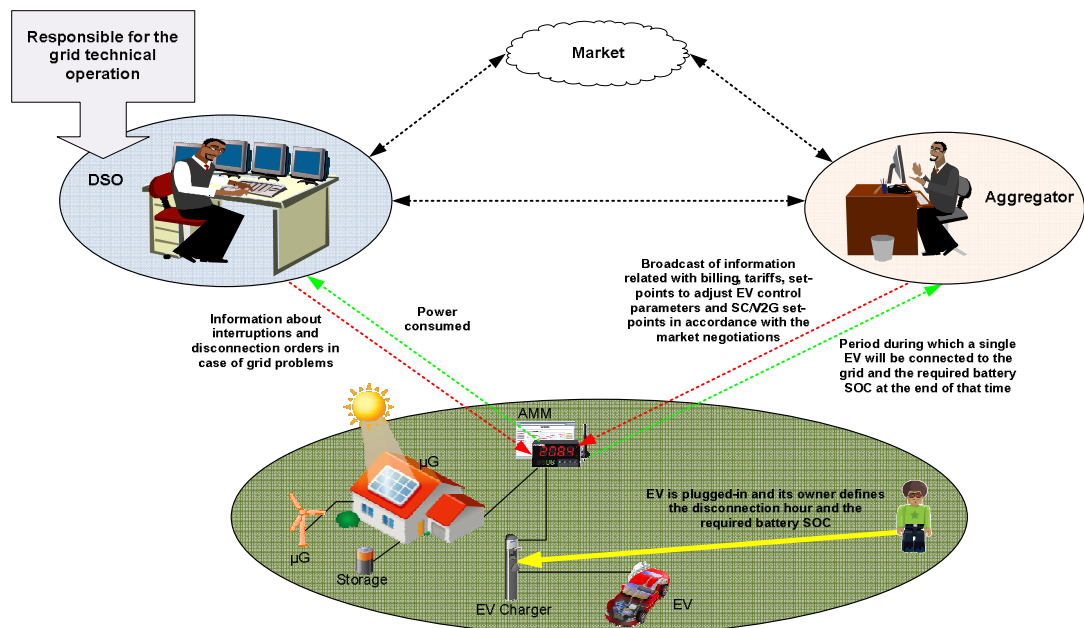




flows, as well as to manage them in a Vehicle-to-Home (V2H) perspective. The data display should allow the consumer to access an application where information on available charging modes is provided. This will provide the consumer the possibility of choosing the more adequate charging mode. The advanced smart meter version will allow consumers to choose between all the existent charging modes: DC, MPT, SC and V2G.

- Bidirectional power measurement – Bidirectional (grid to EV and EV to grid) active power must be metered for grid management and billing purposes.
- Improved bidirectional communications (Figure 57) – The information exchanged in the SC and V2G charging modes is more complex than in the DC and MPT ones. The upstream information sent by the smart meter to the DSO and aggregator entities is the period during which the EV will be connected to the grid and the required battery SOC at the end of that time. The downstream information flowing from the DSO/aggregator side to customers will be scheduled maintenance, interruptions and other important events, billing information, information on available charging modes, set-points to adjust EV control parameters and V2G and smart charging set-points.
- Extended data storage – The smart meter must be able to store the values of the energy absorbed and injected into the grid for defined periods of integration (15 min for instance), historical of billing information, the battery status, data related to regulated quality of service indicators (nr. and duration of interruptions > 3 min, periods where voltage is out of acceptable bounds, nr. of occurrences where EV SOC is lower than 95% of the value required at the specified disconnection moment) and other logging of events. As in the basic version, the smart meter should have the capability of storing data for prolonged periods without provision of electricity from the grid.





**Figure 57 – Information exchange related with the technical aspects of the energy flow: advanced smart meter version (for SC and V2G)<sup>4</sup>**

- Extended logging – In order to account for the quality of service and technical issues, the extended version of the smart metering must incorporate logging of events which can be classified as:
  - Regular events – Time stamped regular events such as connection/disconnection to the grid, negotiation messages, service requests, service interruption and others.
  - Unauthorized events – Tampering and other unauthorized activities such as attempts to access the charging infrastructure with a forbidden ID (theft, impersonation, etc.), requesting unauthorized services, illegal energy exchange outside the contracted value and other unauthorized events.
  - Emergency events – Log of events occurring when the grid is operating in emergency state enabling outage management, islanding operation and other emergency services.
- Improved contract selection feature – The contract selection feature in the extended version should include the possibility of choosing between all the existent charging modes: DC, MPT, SC and V2G.
- Load monitoring and management – The smart metering infrastructure should be able to turn on and off specific appliances or EV according to the established usage profile of each user, in a V2H perspective.
- Communication network management and support – The smart meter should be responsible for the establishment and configuration of a communication network. The metering infrastructure should take care of the normal operation of the local network. It should also ensure the necessary actions towards emergency support by automatically monitoring all the data links. It is also

<sup>4</sup> The interactions DSO – Market, Aggregators – Market and DSO – Aggregators will be thoroughly described in Work Package 5 of MERGE.





envisioned that the smart meter infrastructure will support the integration of sensor networks to enable the control and automation of loads and connected energy resources.

- Remote parameters definition – The advanced smart meter should be prepared to receive every 15 min downstream signals to adjust EV control parameters, as a result of the possible participation of EV in the secondary frequency control, V2G and smart charging set-points.
- Roaming – An advanced smart meter should allow EV to be connected to different electrical network, other than the original one where it is registered. The EV might connect to a visiting network having the same services and features provided as if it was connected to the original/home network.

#### **7.4 Smart Meter Version for Public Charging Points**

The smart meter version for public charging points will need to be prepared to charge EV of all sorts of clients, requiring high flexibility to be able of handling with all existent charging modes.

Therefore, the envisioned public smart meter will have the following functionalities:

- Basic HMI – A simple data display system should be provided in order to allow customers to be aware in real time of their local energy flows, as well as access to billing information and to information related with scheduled maintenance, interruptions and other important events. The data display should allow the consumer to access an application where information on available charging modes is provided. This will provide the consumer the possibility of choosing the more adequate charging mode. The advanced smart meter version will allow consumers to choose between all the existent charging modes: DC, MPT, SC and V2G.
- Bidirectional power measurement – Bidirectional (grid to EV and EV to grid) active power must be metered for grid management and billing purposes.
- Improved bidirectional communications (Figure 57) – The information exchanged in the SC and V2G charging modes is more complex than in the DC and MPT ones. The upstream information sent by the smart meter to the DSO and aggregator entities is the period during which the EV will be connected to the grid and the required battery SOC at the end of that time. The downstream information flowing from the DSO/aggregator side to customers will be scheduled maintenance, interruptions and other important events, billing information, information on available charging modes, set-points to adjust EV control parameters and V2G and smart charging set-points.
- Data storage – The smart meter must be able to store the values of the energy absorbed and injected into the grid for defined periods of integration (15 min for instance).
- Extended logging – In order to account for the quality of service and technical issues, the extended version of the smart metering must incorporate logging of events which can be classified as:





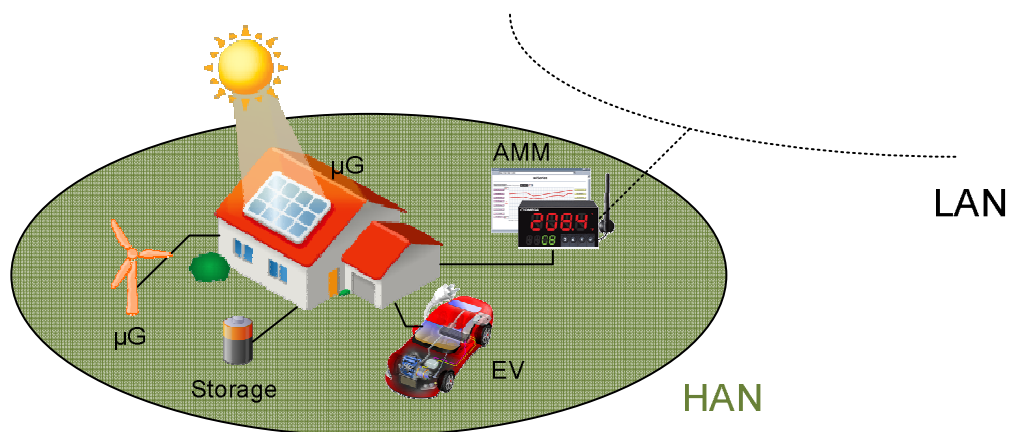
- Regular events – Time stamped regular events such as connection/disconnection to the grid, negotiation messages, service requests, service interruption and others.
- Unauthorized events – Tampering and other unauthorized activities such as attempts to access the charging infrastructure with a forbidden ID (theft, impersonation, etc.), requesting unauthorized services, illegal energy exchange outside the contracted value and other unauthorized events.
- Emergency events – Log of events occurring when the grid is operating in emergency state enabling outage management, islanding operation and other emergency services.
- Improved contract selection feature – The contract selection feature in the extended version should include the possibility of choosing between all the existent charging modes: DC, MPT, SC and V2G. In addition EV owners may opt for a pre-paid service.
- Remote parameters definition – The advanced smart meter should be prepared to receive every 15 min downstream signals to adjust EV control parameters, as a result of the possible participation of EV in the secondary frequency control, V2G and smart charging set-points.
- Roaming – An advanced smart meter should allow EV to be connected to different electrical network, other than the original one where it is registered. The EV might connect to a visiting network having the same services and features provided as if it was connected to the original/home network.



## 8 SPECIFICATION OF USAGE OF SMART METERING IN V2H

### 8.1 Introduction

The Vehicle-To-Home (V2H) idea is a particular case of the Vehicle-To-Grid (V2G) concept where the domestic/home environment is the main focus [35]. In both V2G and V2H, the smart metering is considered as an abstraction of an Automatic Meter Management (AMM) system<sup>5</sup>. Such AMM system is responsible for the establishment of a communication network, setting up a Home Area Network (HAN) that will interconnect Electric Vehicles (EVs), appliances (App), storage devices and microgenerators ( $\mu$ G). In addition, the AMM is responsible for the link between the domestic HAN and the utility Local Area Network (LAN), as illustrated in Figure 58. At last, the AMM will implement a series of control functionalities to deal with EVs usage profiles, technical constraints, and customer-oriented services.



**Figure 58 – AMM establishing a connection between a domestic HAN and a utility LAN.**

Although V2H is a novel concept, it can be envisioned to operate under three realistic use cases depending upon the availability of grid connection and microgeneration. These use cases are:

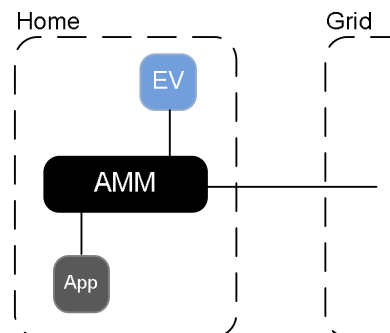
- EV + Appliances Management;
- EV + Microgeneration + Appliances Management;
- Isolated Management.

### 8.2 Use Case A: EV + Appliances Management

In this use case, the home is connected to the electric grid and EVs are available for energy management. The AMM is responsible for managing the EVs

<sup>5</sup> The Automatic Meter Management system is an expansion of a remote reading system that includes the possibility of performing technical measurements, functions and carrying out customer-oriented services. This system will interact with the Automated Meter Reading (AMR) that in turn will collect information from domestic meters (electricity, gas, heat, and water).

charging/discharging along with the home appliances (App), as illustrated in Figure 59.



**Figure 59 – Use case A: EV + Appliances Management.**

The EV battery can be used as a storage device that provides electric energy to the home appliances especially in periods where electricity prices are more expensive. Such approach must be limited by technical and EV profiled usage constraints. In fact, from the technical point of view, the electrical energy that can be supplied by EVs is limited by particular characteristics of the EVs batteries and the domestic electric network ratings. From the usage perspective, the EV might be needed for travelling purposes. Therefore, in order to foster the V2H concept, the AMM might allow users to deal with different EV usage profiles which represent different technical constraints, as well as to decide the most adequate management strategy exploring available tariff schemes. The availability of such a management strategy allows EVs owners to charge their cars in the periods where the electricity cost is lower (typically during valley hours) and use it during the higher price periods (typically in the peak hours), contributing to reduce the EVs owners electricity bill.

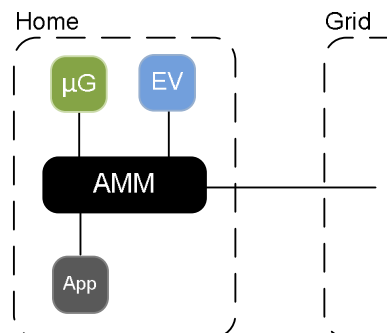
Finally, it should be referred that special contracts with additional economical advantages can be established between the EV owner and the electric utility in order to align the charging strategy with the utility demand side management (DSM). As a matter of fact, EVs charging can be included in the typical on/off strategies deployed by the DSM of the utilities. Besides the on/off approach, utilities might go further and implement a charging management approach based in a droop control [36] for the power absorbed/injected by EVs from/into the grid. The droop control approach provides the utilities with the capability of fine tuning EVs charging according with the grid's needs, conversely to the discrete control provided by the on/off method.

The electrical energy provided by the EVs can be used for peak shaving and other purposes in the DSM strategies as well. Thus the AMM must devise a transparent interface enabling the domestic user to provide DSM services to the utility according to a home usage profile. This profile must contain information regarding the EV profile and the available appliances for remote control.

### **8.3 Use Case B: EV + Microgeneration + Appliances Management**

In this use case, the home is connected to the electric grid with EVs and  $\mu$ Gs available for energy management. The AMM is responsible for managing the EV

charging/discharging along with available microgeneration and home appliances, as illustrated in Figure 60.



**Figure 60 – Use Case B: EV + Microgeneration + Appliances Management**

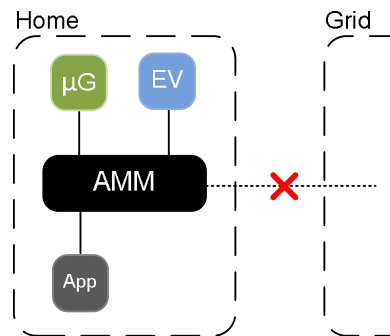
Along with all the functionalities described previously, in this use case the AMM must account for the available microgeneration. The presence of microgeneration will bring additional flexibility for V2H management given that batteries can provide storage for renewable sources. For instance, the AMM must allow communication and control among EVs and  $\mu$ Gs in such a way renewable energy can be stored in the batteries of EVs when this represents an economical advantage. This economical advantage might come from using stored energy to minimize the amount of electricity drawn from the grid when prices are high, typically during peak hours. Another economical advantage might come from selling unneeded stored energy to the utility precisely when prices are also higher.

A different situation where this AMM approach might be exploited is when  $\mu$ Gs are simultaneously producing energy near their higher limits and the energy consumption is low. In such conditions, voltages will probably reach very high values in low voltage networks, as in this type of grids, usually,  $R \gg X$ . Therefore, if required, the DSM might send set-points to the  $\mu$ G units ordering them to reduce the energy production. In these situations, instead of having microgeneration curtailment used to solve the overvoltage problems, EVs might be used to take full advantage of the  $\mu$ G units' potential by storing the energy that would be spilled.

#### **8.4 Use Case C: Isolated Management**

In this use case, the home is isolated from the electric grid in the sense that no energy is exchanged with the grid. This isolation may arise mainly as a result of two reasons.

In the first situation it is considered that enough microgeneration and V2H is available to supply the domestic appliances and as such the AMM intentionally inhibits any energy exchange with the grid. This is only a hypothetical scenario, since the energy produced by the  $\mu$ G units is subsidised, thus making more sense to sell it all to grid operator. In the second an emergency event or fault in the grid force the home to be physically disconnected from the grid. Both cases are illustrated in Figure 61.



**Figure 61 – Use Case C: Isolated Management**

Unlike previous use cases, the domestic network will not be able to provide services to the grid, although the disconnection may represent an advantage to the utility in some situations. In fact the AMM is responsible for performing frequency regulation and energy supply according to a priority list of home appliances. Ultimately if there is enough generation, the AMM will be able to ensure that the entire load is supplied.



## 9 SPECIFICATION OF TECHNICAL CHARACTERISTICS OF SMART METERING FOR EV

### 9.1 Introduction

The Electric Vehicle Charging Infrastructure (EV CI) will have a variety of functional requirements. Some of these functional requirements will be met by the smart meter and others by various ancillary electronic systems.

By detailing the overall functional requirements of the EV CI it should be possible to assign functions to either the smart meter or the ancillary systems.

The following general principals will be assumed:

- 3) The systems described will be modular so that the addition of a module will add extra functionality to the earlier modules – this allows scalability at low cost as not all EV CI need be equipped with full functionality *ab initio*
- 4) It is desirable that the extra costs in providing extra functionality should be capable of being added at any stage in the life cycle of the EVCI as this means that :
  - (a) The total cost does not need to be incurred *ab initio*
  - (b) Technological risk is reduced as extra functions will only be added as required
  - (c) That the risk of providing functionality which may later turn out not to be required is eliminated.
- 5) the solution suggested should be capable of application regardless of the state of development of existing smart meter infrastructure e.g. solution should be feasible in Italy, despite Italy already having installed smart meters which do not cater for EVs.
- 6) Obviously it is also possible to introduce all features described *ab initio* if desired
- 7) The smart meter solution and protocols should be standards due to the interoperability required.

The approach used was to develop Process Maps outlining the implementation of the various functions associated with the EV CI under various regimes, then listing all the functions that were required and common to the various models, and finally ascribing the implementation of these functions to the smart meter or other systems.

### 9.2 Development of the Functional Requirements for EV Charging Infrastructure

#### 9.2.1 Development of EV CI Functional Requirements Using Process Mapping Methodology

The diagrams below enable the charging process to be broken down into a series of smaller processes.



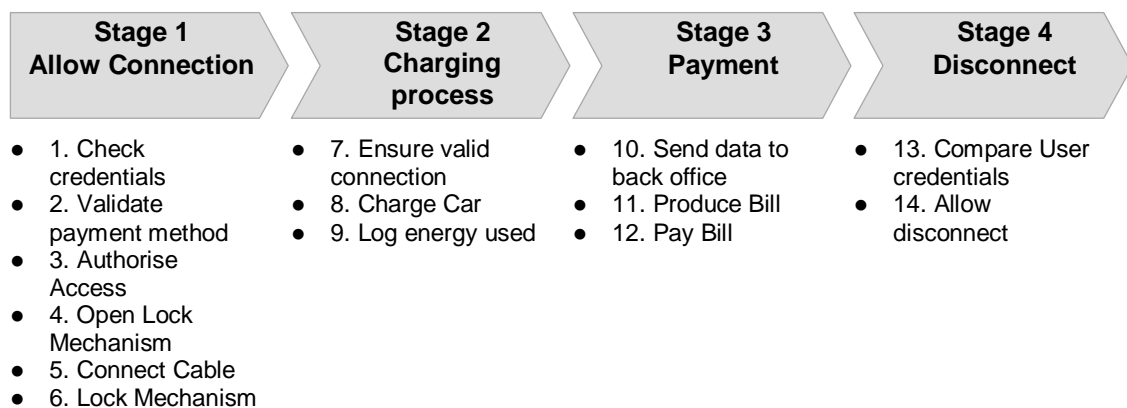


The minimum set of processes required involves access and billing for the EV CI (Electric Vehicle Charging Infrastructure) system, with an additional process involving Demand Side Management functions.

On Street EV CI have potentially the most complex processes as they must cater for a multitude of different users, some of whom may 'roam' from different countries. In contrast, the EV CI at home/work will tend to be used only by the same user. For EV Charging in private areas such as supermarkets, the processes may vary from something very basic, e.g. free charging, to something potentially as complex as the On Street system.

Accordingly, the most onerous requirements will be from On Street EV charging and if this can be catered for correctly, a subset of the functionality provided will also cater for the other scenarios.

A summary of this is available from MERGE Report 1.1 and is shown below:



**Figure 62 – Charge Station charging process**

Note: The function 'Allow Disconnect' is required only where there is a danger that anti-social elements might disconnect EVs during the charging process. In such cases the EV hatch remains locked until opened by the customer whose EV is being charged.

### 9.2.2 Smart Meter Functionality Required for Basic Access/Metering/Billing for On Street EV Charging Post (EV CP)

In more detail, the requirements for access, metering and billing are shown in the table below. The table encapsulates the basic system, without any DSM functionality, and it is clear that the smart meter functionality required is covered by Functions 3.1 and 3.3 which are common to all existing smart meters, i.e. metering the kWh consumption for Billing and then transmitting it to the back office.





Process	Description	Payment Method			
		Free	In Advance (per kWh)	In Advance (per connection)	Payment in Arrears (per kWh)
1.0 Allow connection	1.1 Check credentials		✓	✓	✓
	1.2 Open lock mechanism		✓	✓	✓
	1.3 Connect cable	✓	✓	✓	✓
	1.4 Close lock mechanism		✓	✓	✓
2.0 Payment before charging begins	2.1 Scan Payment Card		✓	✓	
	2.2 Payment is deducted from the card. New credit is written.		✓	✓	
	2.3 Log transaction		✓	✓	
2.0 / 3.0* Charging process	3.1 Ensure valid connection	✓	✓	✓	✓
	3.2 Charge EV	✓	✓	✓	✓
	3.3 Log amount of units consumed		✓	✓	✓
3.0 Payment after charging has been completed	3.1 Send data to back office				✓
	3.2 Bi-monthly bill is produced				✓
	3.3 Customer pays bill				✓
4.0 Disconnect	4.1 Compare user credentials to that used to access the Charge Post		✓	✓	✓
	4.2 Allow unplugging is process 4.1 is satisfied		✓	✓	✓

**Table 18 – Payment method process table**

One additional feature which is not present in any existing smart meter and which is essential to this process is that the kWh consumption data is associated with the Meter Point Registration Number (MPRN) associated with the customer using the EV Charging Post.

So the format of the data transmitted would be along the lines:

***MPRN dd/mm/yyyy 00:15 kWh***

In normal fixed installations the meter is only associated with one MPRN which never changes.

Another feature to note is that the consumption is logged in 15 minute intervals, so that the starting and stopping time recorder are only precise to 15 minutes.



The access controls to the EV Charging Post, the validation of the of the customer's right to use the EV CP would be provided by separate systems to the smart meter, as such functions are not in the smart meter domain.

One particular functionality, which could in theory involve the smart meter, is the validation of the customer's identification. Although it is easy to provide access validation, such validation needs to be kept up to date, so that if it is required to withdraw access e.g. due to non-payment, this should be possible automatically.

To do this requires that at each Charging Post it must be possible to decide whether the identification presented is valid or not.

There are three ways of doing this:

### **1. Co-ordination with Central Site:**

In this method the access identity code provided is sent electronically to a central site which maintains a list of valid identities. It is then compared with the master lists and a decision made as to whether it is valid or invalid. This decision is then communicated to the EV Charging Post.

This is a simple system to operate but has the following disadvantages:

- A separate communications module is required in the EV CP as the dedicated smart meter module will not have the functionality to make this request (- standard smart meters do not require it and it's unlikely that it would be economical to develop a bespoke facility for a small number of smart meters)
- Extra delays may be involved in the communication process
- Extra cost will be involved at the Charging Post in providing the extra communications and at the Central Station also.
- Additional communications cost of the GPRS messaging between the EV CP and the Central Station

### **2. List Method Sent to EV CP:**

- (a) Send the EV CP a daily list of all withdrawn/outdated date identification numbers
- (b) Have the EV CP compare this list with the identification presented

This method requires communication between the utility and every EV CP. This communication channel might have to be via the smart meter unless a second communications channel was installed in the EV CP. However if it is via the smart meter then the complexity of the smart meter increases and it becomes non-standard. As with method 1 mentioned above, there are extra hardware and communications costs involved.

### **3. Code Method with Mobile Phone:**

- (c) Customer uses Mobile Phone local communications facility (e.g. Bluetooth) to beam coded identification number to the EV CP
- (d) EV CP uses 'Public Key' (e.g. the current date) as part of the key to decode the identification number received.





This method has some significant advantages over the first:

- 1) The customer's mobile phone instead of an RFID tag is used for access – this means that no distribution /administration system to issue physical RFID tags is required, and cost savings are achieved
- 2) No special smart meter or other communications facility with the smart meter is required.

Validation is produced by the utility sending an updated code to the customer's mobile phone on a periodic basis e.g. once a month. This code consists of the MPRN number combined with another 'key' in order to form an encrypted number.

The EVCP has an algorithm which uses 'key' (available from the smart meter) to decide the number presented and check its validity – if it can't be decoded it is invalid.

It may also be possible with this method to send the second part of the Public Key to the EV CP via the smart meter as part of a broadcast message from the Central site.

Accordingly, use of the second method avoids any special functionality from the smart meter.

The manner in which the smart meter operates for the Basic Billing and Metering functions is to log the consumption every 15 minutes and then transmit the record at the end of the day – real time communication is not required.

Channels for 'time of day' recording are not relevant as the Supplier will apply the appropriate rates to the 15 min consumptions on receipt of the data – this recording is not actually required at the meter itself.

Other features such as storage of metered data in the event of a loss of power should be no different to that on standard utility smart meters.

Finally, smart meters generally have the capability to measure and log kVARh as well as whether kWh are imported or exported, so if these facilities are required in the future they will be available from virtually any Standard smart meter used.

A list of features currently available from a typical smart meter is shown below:

- Direct connection single and poly phase meter
- Measurement of the active and reactive energy in 4 quadrants
- Single or multi tariff
- Programmable load profile
- Control of maximum demand on active power or intensity
- Button to close the relay and check the information
- Configurable LCD Display
- Historical records
- AMM ready
- Enhanced anti-tamper system
- Load management via built-in relay



- Extended temperature range
- Long life cycle
- Maintenance free
- PLC or GPRS communications with a concentrator or a system directly.



Figure 63 – Typical PRIME PLC smart meter

### 9.2.3 Communications

Remote communication and access to the smart meters are really necessary and can be enabled by a Wide Area Network (WAN). There are a plethora of options for WAN communications for utility meters. WAN area communication equipment tends to be the largest individual source of costs, limitations and risks over the lifetime of a properly functioning smart metering system. Thus a detailed comparison of communication alternatives is important.

All Wide Area Networks must address the following requirements:

- Bandwidth:

A fundamental question for any communications network is how much data is required to be transmitted in each direction. For simple monthly billing of final customers data rates would be typically low in both directions. In the European Smart Metering Guide 2009, it is mentioned that a monthly upload of 4 registers should not require more than 1 kB of data per month. All current communications networks can meet such data rates. This should be compared with the requirements of broadband internet communications streaming multimedia, where the requirement is for more than 1 Mbps. When designing the smart metering system it will also be important to avoid future bottlenecks by allowing sufficient headroom or upgradability in the data bandwidth to cope with growing data communications volumes. This would be especially the case if, in the future, energy retailers developed new offerings for final customers that involved more frequent or longer messages.



- Speed of response:

If data is simply required for billing then there is no need for rapid response. However, where the smart metering system is to be used for demand response, there could be a need for a rapid response in order to deal with an imminent peak demand. In such cases, how the meters are addressed is significant, as this can be done on a one-to-one basis or on a group basis. If a large number of meters are to be sent the same message, a slower communications protocol with multicasting that addresses the meters as one block can be more effective than a faster network that requires all the meters to be addressed individually. A minimum speed of response is also required by low priority alarms that are needed by some possible services based on smart meters.

- Communication Networks:

The WAN design must identify a path for the data from the end-user to the data centre. There are two fundamental options

- Private network, such as Power Line Carrier (PLC) or Wireless Mesh where the meters are connected to a communications network installed by the meter operator or other agent.
- Alternatively they can use a public communications network, such as GSM mobile phone network.

The economics of each choice are quite different. There is a relatively high investment for the private network but operating costs are lower. For the public network capital costs are lower as these are funded by the service provider. These costs though, are recovered by the network operator in their usage charges, either through a flat annual fee or on a message length basis. For private networks it is normal to connect a number of meters to a local data concentrator that provides access to the WAN. The capital costs are affected by the number of meters connected to each data concentrator, as the concentrator represents a fixed cost. An issue for utilities seeking to promote final customer communication will be the relative cost performance of the two choices as communications increase. For the public network, the network operator will provide the additional capacity but the costs of call charges can be expected to rise. For private networks the reinforcement of the communications network will have to be paid for by the network owner.

The most common view of smart metering is that the meter itself has the functionality to make data available to local or remote communications channels. However, meters can be manufactured so that additional components can be added to the meters at a later date. Modules can be chosen based on the local needs and possibilities regarding communication, quantities to be measured and the type of final customer and location in the network. This approach allows meters to be adapted to different communications networks and to be upgraded as the smart metering system evolves. Disadvantages of modular meters are that they are necessarily more expensive and less reliable because of the inclusion of physical connectors. Also, where meters are modified on site, it is less easy to provide the same level of quality control as when they are assembled in a manufacturing plant. Most importantly, probably, is the necessity to visit the site to make any changes as



the cost of the visit is comparable to the meter cost, the savings from this approach are not as great as might be thought.

### 9.2.4 Extra Functionality Required for DSM Functionality for On Street EV Charging Post (EV CP)

Firstly, it should be noted that most standard smart meters are available with a 100 A relay switch which can be remotely addressed by the utility, so that if a particular set of meters needed to be de-energised this is possible. As each EV CP will individually only account for a small load on average (3 kW – 10 kW) it is unlikely that each would be individually measured and controlled. A more likely scenario is that in the event of a load condition on the overall grid or a specific problem locally, the utility might wish to broadcast a ‘message’ to groups of meters. This ‘message’ could be to set the auxiliary relay to ‘Off’, which could then result in a signal to the cars Charging system to ramp down to 10% charging rate until this signal was cleared.

As each meter is currently associated by the utility with each MV/LV transformer, and as association with each LV feeder would be expected in the event of smart meter roll out, such precision would be available at little or no extra cost.

#### Level 1 - Payment in Advance (Pay and Go)

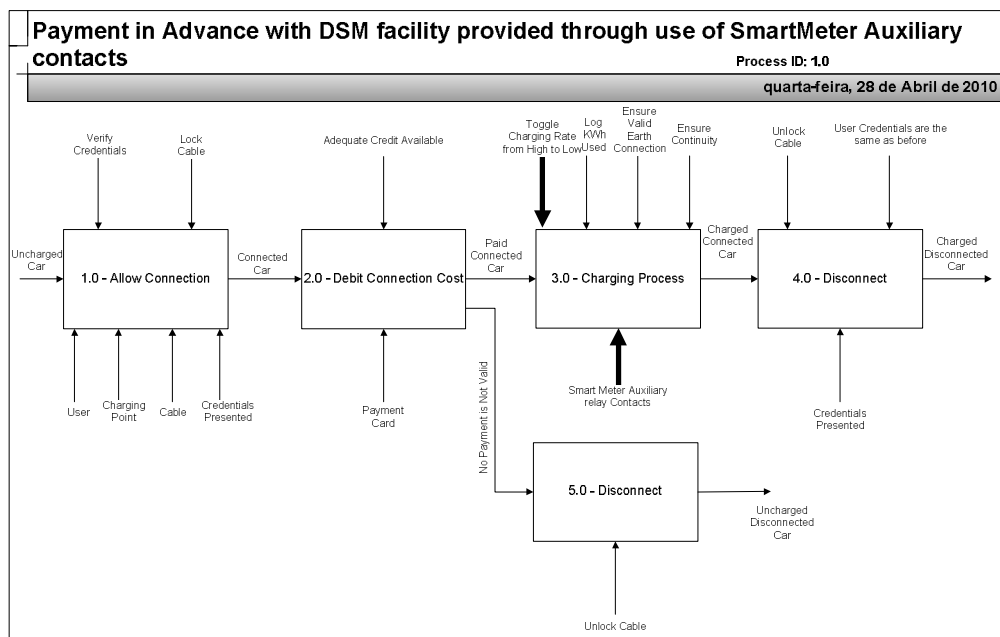


Figure 64 – Payment in Advance

In the case of a ‘triggering event’ a signal is sent by the utility to the smart meter to open or close its auxiliary relay. This in turn applies the appropriate control signal onto the pilot wire of the Mennekes plug and signals the EV Charging system in the car to ramp down to a low charging level. Similarly, when the utility sends out a restore signal the smart meter Auxiliary relay toggles to its previous state and the EV resumes charging.





A 'triggering event' could be any of the following:

- (a) A request from the TSO to reduce load generally, in which case a signal will be broadcast to an appropriate percentage of the smart meters to turn down the EVs.

Note that the Utility does not know whether the EV is actually charging or not as there is no individual metering on the EV itself. However if required it could be arranged that the smart meter Auxiliary relay would only be closed in the event that the EV were actively charging, so knowing the state of the auxiliary would then provide information on whether the EV was drawing load. However for general load reduction a simple broadcast signal would be sufficient.

- (b) reduce load on a particular transformers – down to a particular MV/LV transformer

If there is a system at the transformer e.g. a smart meter which can alarm in the event of certain contingencies such as Low voltage or high load, then this signal when received by the utility gives the identity of the overloaded device. All smart meters associated with this device can then be sent a broadcast message to reduce load by operation of the auxiliary switch. As smart meters will be associated with a particular LV feeder in the utilities' recording system, in theory any signal from the LV feeder would also initiate similar load shedding.

This level of DSM would be quite inexpensive as it is a normal feature of a smart meter.

In the event that the option to have Real time Control of EV CP loads then extra communications and functionality will be required. The difference here is that instead of a single alarm signal being received by a centralized utility control centre and then a broadcast message being sent to large groups of meters, a more sophisticated control strategy is being performed.

E.g. for voltage control reasons it would be more appropriate to reduce power draw on loads furthest from the source so that particular EVs would have their power levels adjusted, or for ensuring that voltage is maintained within an average over a particular time period different EVs are switched on/off for different periods

The question now is whether this extra functionality is provided by the smart meter or by ancillary electronic devices. A feature of this decision is the 'path dependency of the answer – if such features are not required for some time then they will not be available in the original Smart Meter/EV CP roll out, but if required immediately could be incorporated in the smart meter.

Incorporating the extra features in the one smart meter would result in a non-standard product which would have to interface with the existing Billing and other systems. This would be a case of the 'tail wagging the dog' unless all smart meters in every location had the same requirements.

Accordingly it would be more logical that such features would be incorporated in an auxiliary module which fits into the EV CP beside the smart meter. If this 'Auxiliary module' is owned and operated by the utility then is part of the overall utility smart meter system. If the Auxiliary Module is owned and operated by a 3<sup>rd</sup> party e.g. a





Load Aggregator, then it is not part of the utility smart meter system, although the overall system would have the same functionality in either case.

Either way, the issue of real time communications is significant. Operation of DSM in real time with real time communications between EV CPs, EVs and utility will require a considerable increase in the communications channels bandwidth over and above what is required for a simple DSM system. This is not because the control signals per se require any increase in bandwidth, but the data required to assess when control is required is the issue e.g. if voltage were critical the it might need to be continuously measured and then particular loads adjusted. – knowing the voltage and the loads continuously is what will absorb bandwidth. This means that the basic Communications systems suitable for normal smart metering would be unlikely to be appropriate.

This suggests that the communication system used for the ‘Auxiliary Module’ will need to use a higher bandwidth channel. In the event that there is a wider requirement in society for DSM, then, if existing smart meters have already been installed, a separate ‘auxiliary module’ and separate high bandwidth communications system will be more appropriate e.g. original smart meter communications channel may have been Power Line Carrier, but ‘Auxiliary Module’ may require much more capacity and be connected to customers broadband internet connection.

The reason for this is that use of a separate ‘auxiliary module means that:

- (a) Communications from the smart meter to the ‘Auxiliary’ module need only be one way using one communications method. It is the Auxiliary Module which will then use two way communications between the Auxiliary Module and the Appliances, between the Auxiliary Module and the Load Aggregators /Utility.

This means that the data security requirements which would be imposed on the smart meter system by 2 way communications between the smart meter and the Auxiliary Module (e.g. HAN) are eliminated.

Note that the smart meter still has two way communications between the smart meter and the utility, just not outside this loop.

In practical terms this means that the customer will buy a ‘plug in unit’ which goes into a port on the smart meter, and this plug in unit then communicates with the Auxiliary Module. This allows the Market to decide what communications protocols are used between the ‘plug in unit’ and the Auxiliary Module, and between the Auxiliary Module and the Appliances etc. This means that this market can move with the technology available at whatever pace customer’s desire. The only ‘standards’ requirement is the Internet Protocol used to communicate with the ‘Auxiliary Module’

- (b) The smart meter system may only require a limited communications channel, but the DSM module would require a higher bandwidth for real time communications. Such a channel could be shared with other functions such as internet connection.
- (c) The requirement for DSM will depend on two factors, the economical benefits provided and the requirement to use DSM so as to mitigate the impact of EVs on the grid.



If the impact on EVs on the grid is high and occurs soon then DSM will be required earlier – this would correspond to a situation of higher EV loads per vehicle, large scale penetration and little diversity in the pattern of EV Charging is that most of the EVs drew power at the same time.

In contrast, if the penetration is less widespread, the load per EV is smaller and diversity is high (e.g. EVs charged at night) then the impact of EVs on the grid will be far less.

Corresponding to both these scenarios is the scale of EV penetration, which increase with time, so that is reasonable to assume that there will be a gap of some years between the introduction of EVs and the time at which these EVs have a significant impact on the network.

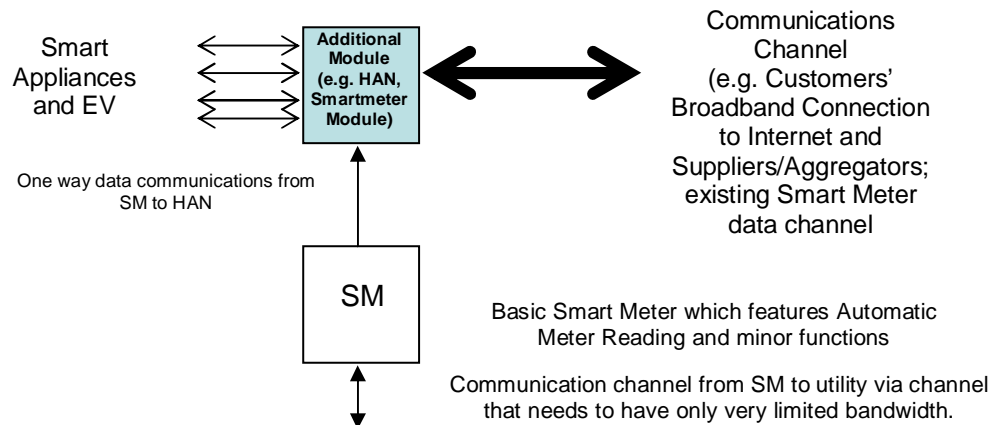
Accordingly, DSM may be required when the impact the impact of EVs on the grid is significant, which could be up to 10 -15 years away. This means that the introduction now of a sophisticated DSM system would result in the system being technologically obsolete before it is required to be used. In contrast, delaying would mean that the DS system finally introduced would utilize the latest technology and have the greatest amount of time actually in use.

Note: Existing smart meters have an Auxiliary Relay which can be switched on/off remotely via a signal from the utility to the smart meter. No extra costs of any significance are involved. Such switches are individually addressable and can be assembled in logical groups by the utility so that all the EVs on a particular Substation or feeder were sent a signal over the normal smart meter communications channels, to switch on/off. This is not a sophisticated DSM facility, but it provides a considerable amount of the DSM benefits required at very low cost, and with no additional upfront investment.

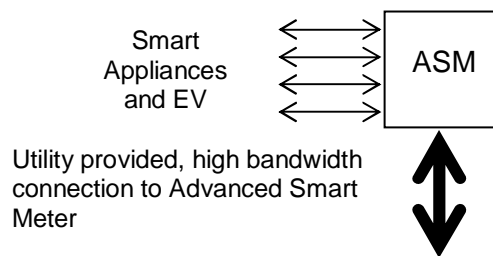
Accordingly the best option is to plan for the ability to retrofit a flexible system which can provide as much sophisticated functionality as will be required, but which does not have to be installed until requirements are clear e.g. EVs are all equipped with Internet communications so direct communication with the EV may be more appropriate than communication with the EV through the Charging Post.

Such a system is shown below and indicates the development of a unit separate to the smart meter to provide advanced DSM Functionality. If it were required to incorporate this functionality in the one smart-meter *ab initio*, it would be a question of incorporating the functionality of both.





**Figure 65 – Generic Smart-Meter System with scope for all advanced functionalities**



**Figure 66 – Specific implementation of Smart-Meter System using Advanced Smart-Meter**

### 9.3 Conclusion

From the above it is apparent that most of the functionalities required for smart meters associated with EV Charging are already available in existing smart meters, including basic DSM.

For sophisticated DSM considerable extra functionality would be required, along with a substantially larger communications channel. It would appear that such requirements would be provided by an 'Auxiliary module', probably using an already available high bandwidth channel. This would allow sophisticated DSM through use of either third party aggregators or via the utility.

As the requirement for sophisticated DSM is likely to be some time away it is important that solutions which will be technologically obsolete by the time that they are required are not developed and installed now. Instead provision should be made in EVCP systems to allow such modules to be retrofitted where necessary as may be required in the future.

Accordingly the functionalities required by the smart meter are:

- Direct connection single phase meter
- Measurement of the active and reactive energy in 4 quadrants
- Control of maximum demand on active power or intensity
- Button to close the relay and check the information



- Historical records
- AMM ready
- Load management via built-in relay
- Long life cycle
- Maintenance free
- PLC or GPRS communications with a concentrator or a system directly.





## 10 FINAL REMARKS

A key issue in electric grids is the predictable massive deployment of EV in Europe in the future. Hence new network functionalities are required to avoid bulky grid reinforcements, facing the related demand rise. Efficient power management can be implemented to support EV grid connection, by applying the principles of the ongoing large-scale effort on upgrading the electric grids functionalities to those inherent to the smart grid. The technical and economic principles behind the smart grid concept imply centralized and decentralized control features, supported by a suitable communication infrastructure. In this sense the first step toward effective management is measurement, however traditional meters cannot cope with some requirements like multi tariff functions to allow demand response or remotely/locally data access for the customers. Data communication, monitoring of microgeneration and grid management, are features that conventional meters also cannot provide to the utilities. As an evolution of Automatic Meter Management system, Smart Metering plays a central role in the aforementioned grid upgrading. As described in this document, European projects in this area are being developed and remarkable know how has been collected by that mean. The state of the art of Smart Meters was presented based on compiled information from device manufacturers, in order to depict which specifications are aligned with the envisaged ones in the smart meter concept and which are not.

The highlighted benefits of Smart Metering for customers and utilities are envisioned under a broad adoption of standardized technologies and solutions. The importance of standardization work related with several functionalities to be implemented is emphasised in this report, in order to achieve interoperability of smart metering technologies and cost decrease. One of the main issues of Smart Metering is the interconnection of smart meters with other devices. In this study, the proposed communication infrastructure consists of five Ports within local, access and backhaul network segments. Regarding the Smart Meter design, a comprehensive analysis of each Port requirements is presented along with the applicable data exchange protocols and technologies.

Under a high level requirement perspective, the communication architecture should rely in suitable availability, reliability, speed and security. Related recurrent issue of interoperability is also mostly a standards subject. The European Commission objectives on free market services offer, implies that State Members' incompatible individual schemes should be avoided, so less government, regulatory and industrial costs will become necessary in Smart Metering context. However, differentiation between Smart Metering offers can be safeguarded by means of distinctive HMI interfaces and software applications, as long as the interoperability concept is present through common definition of basic functionalities. Thus, compatibility between any utility and their customers' metering infrastructures is ensured, despite the chosen manufacturer, guaranteeing also maintenance services over life cycle of components. Through proper life cycle management, the Smart Metering offer should proactively provide the updating of existing services, deployment of new services and configuration of running ones. Basic functions, like event support and alarm handling, should acknowledge and/or properly address several described actions or incidents. Above The Smart Meter emerges also as a pivot element in other market sectors participation. Market parts can aggregate distributed





generation, storage devices and responsive loads in virtual power plants which can sell energy and provide ancillary services to the grid. Business cases like congestion management, variable tariff-based load and generation shifting, distribution grid islanded cell operation, can be handled by Smart Metering. Through these devices, grid connected EV also have the potential to act as responsive loads or storage devices, participating in abovementioned business cases.

Regarding the EV charging approaches contemplated in the MERGE Project, Smart Meter requirements to handle EV grid connection can vary depending on the complexity degree level of the considered charge process. For uncontrolled charging modes, EV owners are free to charge their vehicles whenever they want and charging process ends when the EV are disconnected or battery is full, so DSO cannot directly manage the charging process besides the disconnection actions that take place to react to severe network problems. The basic uncontrolled charge mode defined is Dumb Charge and within this process the electricity price is constant during the day; another uncontrolled process is Multi Tariff which is an energy price based incentive mode of shifting EV energy demand to the valley hours. Controlled methods comprise hierarchical control strategies that can actively manage the battery usage by means of aggregator agents that serve as link elements between adherent grid-connected EV and DSO. Within the controlled modes, Smart Charge comprises the possibility of adjusting charging rates as consequence of DSO services requests to the aggregator. The V2G bolder concept, explores not only the controlled charging of EV batteries, but also its storage device capabilities enabling the power injection into to the grid. For any of the two controlled EV battery management, economical incentives to the adherent owners should be applied. Smart Meters should also have versions that reflect the particularities of EV public and domestic charging points, as described in this document.

In the domestic environment, the usage of Smart Meters is foreseen in this report within the novel concept of V2H. Three operating scenarios are defined, depending on the availability of grid connection and presence of microgeneration: EV plus appliances management, EV plus microgeneration plus appliances management and isolated management.

The final section of this document presents design options for Smart Meters based on experience contributions and previous described work on the state of art characterization, high level requirements and specific requisites. The Electric Vehicle Charging Infrastructures including existing Smart Meters can provide a multiplicity of functionalities regarding EV grid connection, depending on access and payment methods while providing also basic DSM features. Adopting the modularity concept as a design option, more sophisticated management approaches can be tackled considering the possibility of adding further hardware to a basic highly modular system.





## APPENDIX 1 - METER TYPES CERTIFIED TO BE DLMS/COSEM COMPLIANT

Company	Product	Date	Reg. No	Tool Version	Test Laboratory
AEM SA	Enerlux T	16/6/2008	1093	2	AEM_ROMANIA
Actaris Metering Systems	SL7000 Smart V2.34	12/6/2002	1002	1	Actaris Metering Systems
Actaris Metering Systems	ACE SL7000 IEC4	20/7/2004	1013	1.01	Actaris Metering Systems
Actaris Metering Systems	ACE6000 R1	22/8/2005	1017	1.02	Actaris Metering Systems
Actaris Metering Systems	ACE6000R3	16/1/2007	1045	1.02	Actaris Metering Systems
Actaris Metering Systems	ACE SL7000 IEC5	13/2/2007	1046	1.02	Actaris Metering Systems
Actaris Metering Systems	ACE8000 R1	19/3/2007	1052	1.02	Actaris Metering Systems
Actaris Metering Systems	ACE 5000 Type 51	12/9/2003	1010	1.01	Actaris Metering Systems
Advanced Electronic Company	ADDAD-4 DLMS	15/4/2009	1105	2	Advanced Electronics Company Ltd SaudiArabia
Advanced Electronic Company	ADDAD-4 DLMS, Class 0.2, CT, 3P3W	8/1/2010	1135	2	Advanced Electronics Company Ltd SaudiArabia
BlueStar	P2000A2000B1000	7/5/2009	1106	2	Bluestar_Nanjing_China
Bluestar, China	S2000C2000	3/6/2009	1111	2	Bluestar
Cewe Instrument AB	CewePrometer	8/7/2008	1094	2	KEMA
Changsha Weisheng Electronics	DTSD341	10/9/2008	1099	2	WASION
EDMI	ATLAS	23/10/2009	1127	2	EDMI_SINGAPORE
EDMI Ltd.	2000-6EXX	3/12/2007	1071	1.02	EDMI_SINGAPORE
ELGAMA-ELEKTRONIKA	GAMA 300 G3A.xxx	12/1/2009	1101	2	ELGAMA
EMH	LZQJ	20/4/2005	1016	1.01	EMH Wittenburg
EMH	LZQJ-XC (Version 211)	15/4/2009	1104	2	EMH Wittenburg
EMH Wittenburg	DMTZ	20/6/2007	1065	2	EMH
EMH Wittenburg	LZQJ-XC (Version 212)	6/8/2009	1119	2	EMH Wittenburg
EMH Wittenburg	LZQJ-XC (Version 213)	18/8/2009	1120	2	EMH Wittenburg
ENEL d.o.o. Beograd	ENLDB2SV1R0	15/8/2007	1066	1.02	ENEL
ENEL d.o.o. Beograd	ENLDMG2SV1R0	6/9/2007	1068	1.02	ENEL
ENEL d.o.o. Beograd	ENLDMGSV2R0	23/6/2009	1112	2	ENEL
ENEL d.o.o. Beograd	ENLDB2SV2R0	23/6/2009	1113	2	ENEL
ENERMET Oy	E600 v1.00 LN referencing	30/12/2002	1004	1	ENERMET Oy
ENERMET Oy	E600 v1.00 SN	30/12/2002	1005	1	ENERMET Oy
ENERMET Oy	E700 v7.00 LN referencing	23/12/2002	1006	1	ENERMET Oy
ENERMET Oy	E700 v7.00 SN referencing	23/12/2002	1007	1	ENERMET Oy
Elster Electricity LLC	A1800	3/9/2008	1098	2	Elster Electricity







Company	Product	Date	Reg. No	Tool Version	Test Laboratory
Elster GmbH	EK 240	28/1/2008	1078	2	Elster GmbH
Elster GmbH	AS220	23/6/2009	1115	2	Elster GmbH
Elster GmbH	A1440	23/6/2009	1116	2	Elster GmbH
EnergyICT	RTU V2	19/9/2002	1003	1	KEMA
FAP PAFAL S.A.	PAFEC3	24/9/2009	1123	2	FAP_PAFAL_POLAND
FAP PAFAL S.A.	EA5	1/10/2009	1125	2	FAP_PAFAL_POLAND
Genus Power Infrastructures Ltd., Jaipur	FEEE3DP9D	6/11/2007	1073	2	Central Power Research Institute India
Genus Power Infrastructures Ltd., Jaipur	FEEE3DP8D	6/11/2007	1074	2	Central Power Research Institute India
Genus Power Infrastructures Ltd., Jaipur	FEEE2DQ3D	6/11/2007	1075	2	Central Power Research Institute India
Genus Power Infrastructures Ltd., Jaipur	FEEE2DP6D	6/11/2007	1076	2	Central Power Research Institute India
Genus Power Infrastructures Ltd., Jaipur	FEEE1APFD	21/12/2007	1077	2	Central Power Research Institute India
Hangzhou PAX Electronic Technology Co., Ltd.	WS310	5/11/2009	1126	2	Hangzhou PAX Electronic Technology Co., Ltd.
Hangzhou PAX Electronic Technology Co., Ltd.	WD120	16/11/2009	1129	2	Hangzhou PAX Electronic Technology Co., Ltd.
Hexing electric	HXE12v1.00	5/8/2008	1096	2	HEXING Electrical Co. Ltd.
Hexing electric	HXE34	29/7/2008	1097	2	HEXING Electrical Co. Ltd.
Holley Metering Limited	DDSD285	16/3/2010	1138	2.1	Holley_China
ILJIN Electric	IW4T-05	6/11/2007	1070	1.02	KEPCO
ISKRAEMECO d.d.	MT 350	20/4/2004	1012	1.01	ISKRAEMECO d.d.
ISKRAEMECO d.d.	MT372-1010	17/3/2006	1025	1.02	ISKRAEMECO d.d.
ISKRAEMECO d.d.	ME371-2100	6/12/2006	1047	1.02	ISKRAEMECO d.d.
ISKRAEMECO d.d.	ME372-2100	8/1/2007	1048	1.02	ISKRAEMECO d.d.
ISKRAEMECO d.d.	MT371-2200	7/12/2006	1049	1.02	ISKRAEMECO d.d.
ISKRAEMECO d.d.	MT372-3100	16/12/2006	1050	1.02	ISKRAEMECO d.d.
ISKRAEMECO d.d.	MT860-1026-005	13/3/2007	1051	1.02	ISKRAEMECO d.d.
ITRON	ACE781	4/2/2010	1136	1.02	ACTARIS Schlumberger
Iskraemeco d.d.	ME382-1000	3/6/2009	1108	2	ISKRAEMECO d.d.
Iskraemeco d.d.	MT382-1000	3/6/2009	1109	2	ISKRAEMECO d.d.
JilinyongdaGroup	DTSD318	5/3/2009	1102	2	Jilin Yonda Group China
Kamstrup A/S	K351B Electricity Meter	24/9/2009	1122	2	Kamstrup
Kamstrup A/S	K162x	1/10/2009	1124	2	Kamstrup
Kamstrup A/S	K382x Electricity Meter	20/10/2008	1100	2	Kamstrup



Company	Product	Date	Reg. No	Tool Version	Test Laboratory
LS Industrial Systems, South Korea	LSK1210DRA-120	12/10/2005	1018	1.01	Central Power Research Institute India
LS Industrial Systems, South Korea	LK1210CT-005	28/12/2005	1019	1.02	Central Power Research Institute India
LS Industrial Systems, South Korea	LK1210DRa-040	28/12/2005	1020	1.02	Central Power Research Institute India
LS Industrial Systems, South Korea	LK1210DRa-120	28/12/2005	1021	1.02	Central Power Research Institute India
LS Industrial Systems, South Korea	LK3410DRb-040	28/12/2005	1022	1.02	Central Power Research Institute India
LS Industrial Systems, South Korea	LK3410DRb-120	28/12/2005	1023	1.02	Central Power Research Institute India
LS Industrial Systems, South Korea	LK1210DRb-040	10/5/2006	1026	1.02	Central Power Research Institute India
LS Industrial Systems, South Korea	LK1210DRb-120	10/5/2006	1027	1.02	Central Power Research Institute India
LS Industrial Systems, South Korea	LK3410CT-005	10/5/2006	1028	1.02	Central Power Research Institute India
LS Industrial Systems, South Korea	LK1210CTa-005	10/5/2006	1029	1.02	Central Power Research Institute India
Landis+Gyr	Landis+Gyr Dialog ZMD310/400CT/AT. xxxxB21	10/7/2003	1008	1.01	Landis+Gyr
Landis+Gyr	Landis+Gyr Dialog ZMD310/400CR/AR. xxxxB21	10/9/2003	1009	1.01	Landis+Gyr
Landis+Gyr	Landis+Gyr Dialog ZMD 120AR. xxxx.102	15/3/2004	1011	1.01	Landis+Gyr
Landis+Gyr	Landis+Gyr Qualigrid ZxQ200	25/8/2004	1014	1.01	Landis+Gyr
Landis+Gyr	Landis+Gyr Dialog ZMD310/400Cx/Ax. xxxB22	24/11/2004	1015	1.01	Landis+Gyr
Landis+Gyr	Landis+Gyr Dialog ZMD120AR. xxxx.104	9/2/2006	1024	1.02	Landis+Gyr
Landis+Gyr	Landis+Gyr Dialog AD-FGxxxxxx.T20	25/8/2006	1031	1.02	Landis+Gyr
Landis+Gyr	Landis+Gyr Dialog AD-FPxxxxxx.T00	25/8/2006	1032	1.02	Landis+Gyr
Landis+Gyr	Landis+Gyr Dialog ZMD310/400Cx/Ax. xxx.B23	28/8/2006	1033	1.02	Landis+Gyr
Landis+Gyr	Landis+Gyr Dialog ZMD 120AR. xxxx.105	8/9/2006	1038	1.02	Landis+Gyr
Landis+Gyr	Landis+Gyr Dialog ZMG300x/ZMG400x	31/10/2006	1039	1.02	Landis+Gyr
Landis+Gyr	Landis+Gyr Dialog ZMG300x/ZMG400x .P03LN referencing	31/10/2006	1040	1.02	Landis+Gyr
Landis+Gyr	Landis+Gyr Advantis AD-FPxxxxxx.T01	17/9/2007	1069	2	Landis+Gyr
Landis+Gyr	Landis+Gyr Dialog ZMD300/400Cx/Ax. xxx.B24	18/2/2008	1079	2	Landis+Gyr



Company	Product	Date	Reg. No	Tool Version	Test Laboratory
Landis+Gyr	Landis+Gyr Dialog ZMG300x/ZMG400x .P04	10/5/2008	1087	2	Landis+Gyr
Landis+Gyr	Landis+Gyr Qualigrd ZMQ200C.X.H03	18/7/2008	1095	2	Landis+Gyr
Landis+Gyr	Landis+Gyr E35C AD-xG Version 3.0	23/6/2009	1114	2	Landis+Gyr
Landis+Gyr AG	Landis+Gyr E650 ZMD300x/ZMD400x.B30	8/7/2009	1118	2	Landis+Gyr AG
Landis+Gyr AG	Landis+Gyr E850 ZMQ200C.X.H04	8/1/2010	1134	2	Landis+Gyr
Larsen & Toubro Limited, Mysore, India	ER300P-M4CHA0502	25/2/2008	1080	2	Central Power Research Institute India
Larsen & Toubro Limited, Mysore, India	ER300P-M4DLC1010	2/4/2008	1082	2	Central Power Research Institute India
Larsen & Toubro Limited, Mysore, India	ER300P-M4DLC1006	2/4/2008	1083	2	Central Power Research Institute India
Larsen & Toubro Limited, Mysore, India	ER300P-M4CHA0102	2/4/2008	1084	2	Central Power Research Institute India
Larsen & Toubro Limited, Mysore, India	ER300P-M4CHB0502	2/4/2008	1085	2	Central Power Research Institute India
Larsen & Toubro Limited, Mysore, India	ER300P-M4CLC0502	18/8/2009	1121	2	Central Power Research Institute India
MS-M Co., Ltd., South Korea	MSM-104-01	10/8/2006	1030	1.02	MS-M Co., Ltd., South Korea
MS-M Co., Ltd., South Korea	MSM-112-01	15/9/2006	1035	1.02	MS-M Co., Ltd., South Korea
MS-M Co., Ltd., South Korea	MSM-105-01	15/9/2006	1036	1.02	MS-M Co., Ltd., South Korea
MS-M Co., Ltd., South Korea	MSM-304-01	21/12/2006	1042	1.02	MS-M Co., Ltd., South Korea
MS-M Co., Ltd., South Korea	MSM-305-01	20/12/2006	1043	1.02	MS-M Co., Ltd., South Korea
MS-M Co., Ltd., South Korea	MSM-312-01	22/1/2007	1044	1.02	MS-M Co., Ltd., South Korea
Meter&Control	ST100M	24/11/2009	1130	2	METER & CONTROL
Meter&Control	ST300F	24/11/2009	1131	2	METER & CONTROL
Meter&Control	ST300M	24/11/2009	1132	2	METER & CONTROL
Meter&Control	ST100F	24/11/2009	1133	2	METER & CONTROL
Meter&Control, Serbia	ST300	30/5/2009	1110	2	METER & CONTROL
Mikroelektronika	MET400-R1	17/4/2007	1057	1.02	Mikroelektronika
Mikroelektronika	MET410	10/5/2008	1088	2	Mikroelektronika
Mikroelektronika	MEM410	10/5/2008	1089	2	Mikroelektronika
OMNE AGATE SYSTEMS PVT LTD	OMWH34LTA	8/3/2010	1137	2.1	Central Power Research Institute India
OMNISYSTEM Co., Ltd., Korea	OMWH-1205M	5/4/2007	1053	1.02	Central Power Research Institute India
OMNISYSTEM Co., Ltd., Korea	OMWH-1240M	5/4/2007	1058	1.02	Central Power Research Institute India
OMNISYSTEM Co., Ltd., Korea	OMWH-12120M	5/4/2007	1059	1.02	Central Power Research Institute India



Company	Product	Date	Reg. No	Tool Version	Test Laboratory
OMNISYSTEM Co., Ltd., Korea	OMWH-3405M	15/5/2007	1060	1.02	Central Power Research Institute India
OMNISYSTEM Co., Ltd., Korea	OMWH-3440M	24/4/2007	1061	1.02	Central Power Research Institute India
OMNISYSTEM Co., Ltd., Korea	OMWH-34120M	24/4/2007	1062	1.02	Central Power Research Institute India
ORBIS TECNOLOGIA ELECTRICA	DOMOTAX TeLeGeST	13/11/2009	1128	2	ITE Spain
PAFAL Spolka Akcyjna	EC9	11/6/2007	1063	2	EMH
PRI Ltd., Winchester, UK	PRI-P3T000/xxG	16/6/2008	1090	2	Central Power Research Institute India
PSTec Co.,Ltd.	PS12DR040	20/9/2006	1037	1.02	KEPCO
PYUNGIL	PYU-L140	11/12/2006	1041	1.02	KERI
SAGEM	CX2000-7	3/9/2007	1064	1.02	SAGEM
SAGEM	CX1000-5	3/9/2007	1067	1.02	SAGEM
SAGEM	CX3500	3/7/2009	1117	2	SAGEM
SECURE METERS LIMITED	EHL-E3T000/xxG	16/6/2008	1091	2	Central Power Research Institute India
SECURE METERS LIMITED	EHL-E3M000/xxG	16/6/2008	1092	2	Central Power Research Institute India
SITEL D.O.O	MET410-R1	17/3/2009	1103	2	Mikroelektronika
Schneider Electric	ION8800	7/4/2010	1139	2.1	KEMA Consulting (KEMA Connect)
Shanghai Metering	SM3800	15/5/2009	1107	2	Bluestar_Nanjing_China
Siemens Energy Services UK	CM-32	2/4/2008	1086	2	Central Power Research Institute India
Siemens Metering	Landis & Gyr Dialog ZMD310/400CT/AT. xxxx.B14	20/9/2002	1001	1	Siemens Metering
Wasion Electronic Co.,Ltd	WHCi02-1V1.0	3/12/2007	1072	2	WASION
Wasion Electronic Co.,Ltd	DDSD101-5V4.0A	24/4/2008	1081	2	WASION
Wizit Co. Ltd.	WZT-WZ5-10F	11/1/2007	1034	1.02	KERI
Wizit Co. Ltd.	WZT-WZ5-30F	21/3/2007	1054	1.02	KERI
Wizit Co. Ltd.	WZT-WZT-DT40	21/3/2007	1055	1.02	KERI
Wizit Co. Ltd.	WZT-WZT-DT120	21/3/2007	1056	1.02	KERI



## APPENDIX 2 - SMART METERING IN DIFFERENT EUROPEAN COUNTRIES

### Greece

#### I. Smart grid/Smart metering MV pilot project

Siemens together with Amperion prepared for PPC the first Smart Grid system to be installed in Medium Voltage in Greece. Covering more than 100 km of MV network with applications ranging from Load Management to Fault Detection and Automatic Meter Reading, this project is the state of the art in Energy Management and Automation. The Smart Grid network was installed in two Medium Voltage lines starting from the Ultra-High Voltage Substation of PPC just outside the city of Larissa. These two lines named R-240 and R-250 are of mixed use, feeding both agricultural loads and villages in the area.

Larisa is one of the major cities in northern Greece with population of about 250.000 people. Its major role in the Greek society and economy includes the vast agricultural production that characterises this fruitful region. PPC has undertaken the task to electrify this agricultural region in a way that the demand will meet the supply under the harsh Greek summer conditions. This task is not an easy one as it involves the management of a wide spread Medium Voltage network with huge amounts of power delivered peaking at summer, a season most difficult for PPC when temperatures reaching at 40 degrees Celsius bring the air-conditioning loads in Greece at their highest.

Siemens and Amperion designed and implemented for PPC a state of the art Smart Grid network solution featuring embedded telecommunications on the Medium Voltage lines based on the Amperion patented BPL technology and a vast array of end devices including switches and power quality measuring sensors. The previous, coupled with the Siemens Power CC platform gave the utility a 21st century power network.

The network installed is comprised by 105 Amperion BPL units that are installed on the MV network thus creating a backbone of connectivity to the substation. The Units are installed starting at the first pole outside of the Ultra High Voltage substation (KYT) and one is installed every 700 to 800 meters until the end of the MV lines. The first unit, called the Injector unit, is connected to the Substations Control Centre via Wi-Fi and then to the internet / PPC intranet via and HDSL provided by the fiber optics POP in the substation.

Each of the following units, called Repeaters, extend the signal for the next hop and create a wireless hotspot around them for users and devices to connect to the main network. The Wi-Fi is under the IEEE 802.11 a, b and g and the security methods used are both WPA2-PSK and MAC authentication for the network devices. The wireless is also used for backup purposes between units in case of cable failure. In that way a meshed wireless connectivity area of approximately 100 km<sup>2</sup> is created, where load switching units and other installed equipment (sensors, meters etc) can seamlessly connect to any of the units.

As far as switching devices are concerned 200 are connected in customers that PPC indicated and are remotely monitored from the Control Centre via OPC and



over the BPL backbone and Wi-Fi last mile connection. This reduces the cost of installation significantly and reduces that complexity of expanding to more switches (or any other devices) in the area since the coverage and backbone network are already installed.

Apart from the switching equipment 45 remotely operated meters are installed in consumers in the villages of Halki and Mellia in order for PPC to evaluate the AMR opportunity over BPL. They too are connected via the Wi-Fi network on the BPL backbone.

From a telecommunications point of view in the network are also installed two surveillance cameras to secure sensitive parts of the network and 10 VoIP networks are handed out to PPC personnel to use instead of mobile phones while in the area of coverage. Wi-Fi internet connectivity is also available to authorised PPS personnel but not to the public in the villages covered since PPC has decided not to engage in that market as of yet.

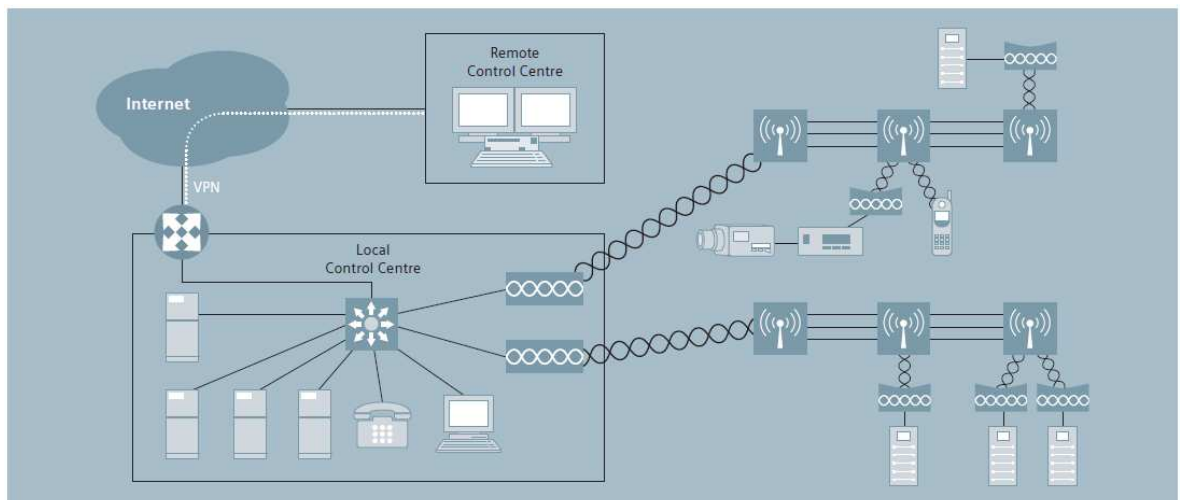
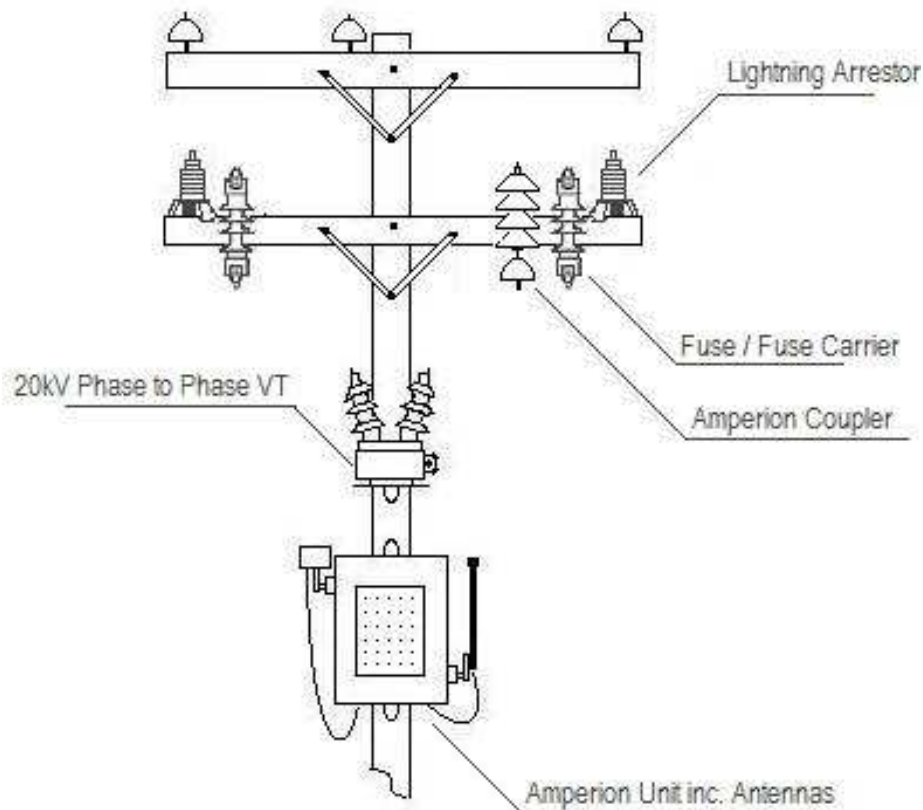


Figure B.1 – Network diagram



**Figure B.2 – Unit installation**

The applications delivered in the context of this project include:

- Load Management (Remote control switches that control the agricultural loads within milliseconds)
- AMI (Automatic Meter Infrastructure)
- RF noise level measurements (Fault Prediction)
- Wireless Cameras Surveillance
- Measurement on the LV grid (Voltage, Current, & Temperature).
- Telecom applications (VoIP, Internet etc)

Within this pilot project a few problems came up concerning the transmission of the data from the meters to the Control Centre. The data was being transferred at lower speed than the nominal one. The nominal data transfer speed for such a BPL communication architecture is 250 MBps. However, such transfer speed was inevitable to be reached in the real field. The real speed of the data transmission was between 100 and 150 MBps. These delays can be explained by the high noise that exists in the MV lines. The increased level of harmonic distortion in the MV lines limits the maximum speed of data transfer. In some other rare occasions, loss of information was noticed due to communication failures. Fuse failures to the BPL





communication resulted in losing the continuity of the communication between the metering devices and the control centre and that was the reason for losing data.

## II. Smart metering LV pilot project

Apart from the experience gained from the smart metering MV pilot project in Larissa, PPC has initiated three smart metering LV pilot projects in different areas within the prefecture of Attiki. In each project, smart meters from different vendors have been implemented. However, the adopted communication architecture was similar for all the projects. The data from meters were gathered by a concentrator located at the respective substation through LV PLC communication (supported by DLMS protocol).

The first pilot project was developed in the area of Neo Faliro and Rentis. The scope of this project was the remote metering of some LV consumers being connected to two different substations. Both single and three phase meters were installed. The single phase meters were ACE 4000 produced by Actaris and the three phase meters were ZMF120 produced by Landis+Gyr. The concentrator that was installed at the substations was the one developed by Landis+Gyr. The communication between the smart meters and the concentrator was PLC (DLMS protocol). The data transfer speed between meter and concentrator is 1200 bits/s. The communication frequency through PLC is SFSK 63 and 74 kHz.

The second pilot project was developed in the area of Karidalos, The scope of this project was the remote metering of some LV consumers, using PLC communication. ISKRAEMECO is the vendor that supplied the smart meters and the concentrator for this project. Both single and three phase meters were installed. The single phase meters were ME371 and the three phase meters were MT371. The concentrator that was installed at the substation was the P2LPC. The data transfer speed between meter and concentrator is 1200 bits/s. The communication frequency through PLC is SFSK 83 & 93 kHz.

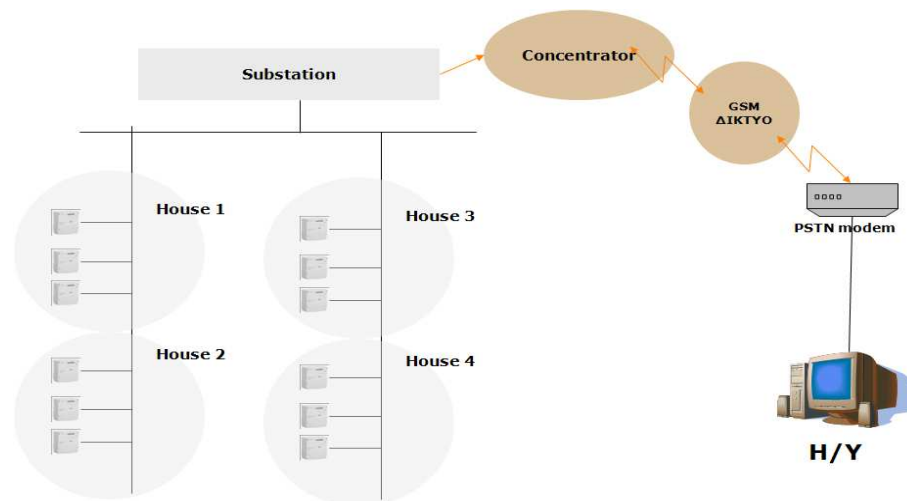
The second pilot project was developed in the area of Kalithea. The scope of this project was the remote metering of some LV consumers using PLC communication (DLMS protocol). SAGEM is the vendor that supplied the smart meters and the concentrator in this project. Twenty two CX-100 single phase smart meters and eight CX2000 three phase smart meters were installed. The concentrator installed at the substation was the XP3000. The data transfer speed between meter and concentrator is 1200 bits/s. The communication frequency through PLC is SFSK 80 & 90 kHz.

A common smart metering architecture was developed for the three pilot projects. Figure B.3 presents the common smart metering concept using PLC communication supported by DLMS protocol. The data signal of each smart meter is transmitted through LV lines to the concentrator located in the substation. The concentrated data is sent via GSM network to the Central Control Room where it is stored in a database for further analysis.

The strength of the data signal from a smart meter is reverse proportional to the distance between the smart meter and the concentrator of the substation. This means that the data signal that is emitted from distant meters may be too weak and not readable by the concentrator. The signal of distant meters should somehow be boosted in order no information to be lost. This signal boost is succeeded by the



adjacent meters. Each meter operates as a repeater for the previous ones in order to amplify the signal.



**Figure B.3 – Common communication architecture for the three PPC LV pilot projects**

The PLC communication requires dense networks since each smart meter acts also as a repeater for the previous ones. This means that the distance between two successive meters should be predefined according to the technical specifications of the meters. This requirement should be considered especially when smart metering pilot projects are being developed due to the limited number of meters that are installed. The average distance between two successive meters in the three pilot projects was about 100 meters in order no data loss to be occurred. However, in case of a massive smart metering application, especially in urban areas, this obstacle can be overcome by the fact that the distance between houses is less than 50 meters.

## **Portugal**

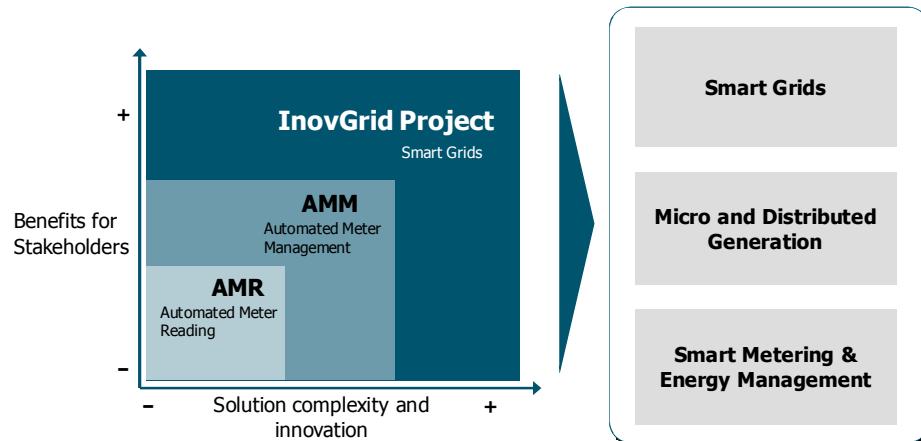
### **InovGrid Project**

The Portuguese distribution network operator EDP Distribuição (EDPD) leads a project entitled InovGrid, with the objective of transforming the distribution network in order to address the emerging challenges that the company and the electric sector are facing.

The project aims at developing a new way of managing and controlling the distribution network. The initiative has three major driving forces (Figure B.4):

- ✓ Energy management – providing smart metering tools for consumers and liberalized market agents, while introducing new mechanisms for network operation and control
- ✓ Micro and distributed generation – creating conditions for larger integration of distributed energy resources, while maintaining network stability, security and quality of supply

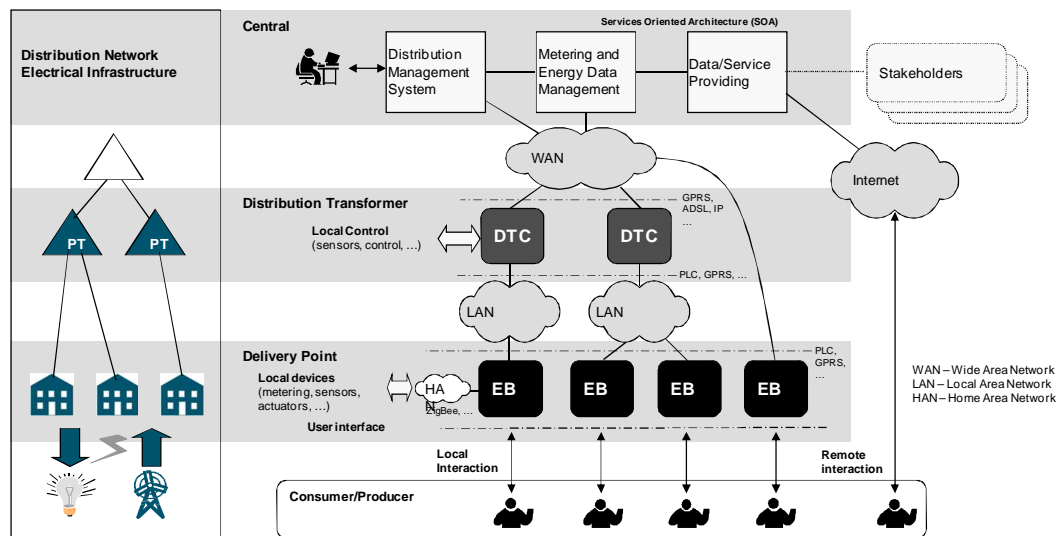
- ✓ Smart grids – increasing the automation level in all network layers, upgrading operational effectiveness and efficiency along with the quality of service.



**Figure B.4 – Project scope**

The technical solution is based on hierarchical management architecture with three main controllers handling both commercial and technical information (Figure B.5):

- ✓ Home energy gateway (Energy Box): The lower level component of the solution, responsible for smart metering and remote power control, will have functionalities related to demand side management, microgeneration control, home automation and other value added services.
- ✓ Distribution Transformer Controller: The intermediate control level, housed at MV/LV substations, is responsible for managing the communication with the energy boxes and will act as an intelligent device for distributed energy management, providing services such as transformer station control and automation or fault detection.
- ✓ Central management, energy data and SCADA/DMS systems: The upper hierarchical level, composed of by the core information systems, will support activities such as operation and energy distribution control, order dispatching, data collection, energy balancing, alarm and network monitoring



**Figure B.5 – Technical reference architecture**

The solution communications will link all the layers and interfaces in the form of WAN, LAN and HAN networks. The main technologies considered for the early stages of the project are narrowband PLC and GPRS/GSM. Other technologies like “intermediate band” PLC, ZigBee, RF and Bluetooth are on the solution radar. To every active control element upgradeability is being conferred.

### Germany

RWE chosen Mülheim city for pilot project. Mülheim, with around 170,000 inhabitants and 100,000 electricity connections, is exactly the right size. Through its mixture of densely and less densely built-up areas, it provides the opportunity to test several data transmission technologies simultaneously.

### France

#### **Linky Project**

ERDF is currently conducting an AMM (Automatic Meter Management) pilot involving 300,000 clients supplied by 7,000 low-voltage transformers. The pilot is located in two distinct geographic areas, the Indre-et-Loire department and the Greater Lyon region. Three different interoperable meter manufacturers have been designated. The focus of the project lies also on the building of a Meter Management System fully integrated with other head-end Information Systems as this project, affecting 1% of low voltage customers, is a precursor to national deployment for 35 million clients in France.

ERDF has also defined an innovative PLC profile, known as 3G, that is based on OFDM and supports IPv6, the new generation of Internet protocol that widely opens the range of potential applications and services.

### Spain

#### **Smart Grid / Smart Metering STAR project**

Since 2007, IBERDROLA has been working on an open and public PLC solution, based on OFDM with proof-of-concept tests in laboratory and controlled pilots in



different environments of low voltage networks in Bilbao, Madrid and Valencia, with outstanding results, both in terms of interoperability and performance. The solution is called PRIME (PowerLine Intelligent Metering Evolution) and the technical specs are mature enough for the industrialization phase.

STAR is an acronym for Sistema de Telegestión y Automatización de la Red (Automation and Smart Metering System). The first massive deployment of PRIME smart meters has just started in the city of Castellon, Spain, comprising 100,000 smart meters awarded to 7 independent meter manufacturers, employing 4 different though interoperable PLC PRIME solutions. The Castellon project also includes advanced monitoring and automation of the LV and MV grid and is the largest smart grid deployment in 2010 in the country. More than 600 secondary substations take part in this innovative project.

PRIME specs are managed by PRIME Alliance, a non-profit organization composed of utilities, semi-conductor manufacturers and vendors that has been created to support and promote open and interoperable advanced PLC standards for the benefit of end-users and all industry stake-holders.

The other company with projects in Spain is Endesa. After the connection of Endesa's first smart meters in Malaga during June, the power company now has 5,000 devices installed at customers' homes in three provinces (Malaga, Seville and Barcelona). Starting from July, the remote management system will be integrated with Endesa's commercial and technical systems, which, combined with the installation of the new meters, will obtain the functions and benefits offered by remote control. The objective of the company is to gradually replace old metering equipment, and the cities that already have the first smart meters will be followed by Badajoz, Zaragoza, Palma de Mallorca, Las Palmas de Gran Canaria and Tenerife, among others. By the end of 2010, there will be 150,000 smart meters in operation.

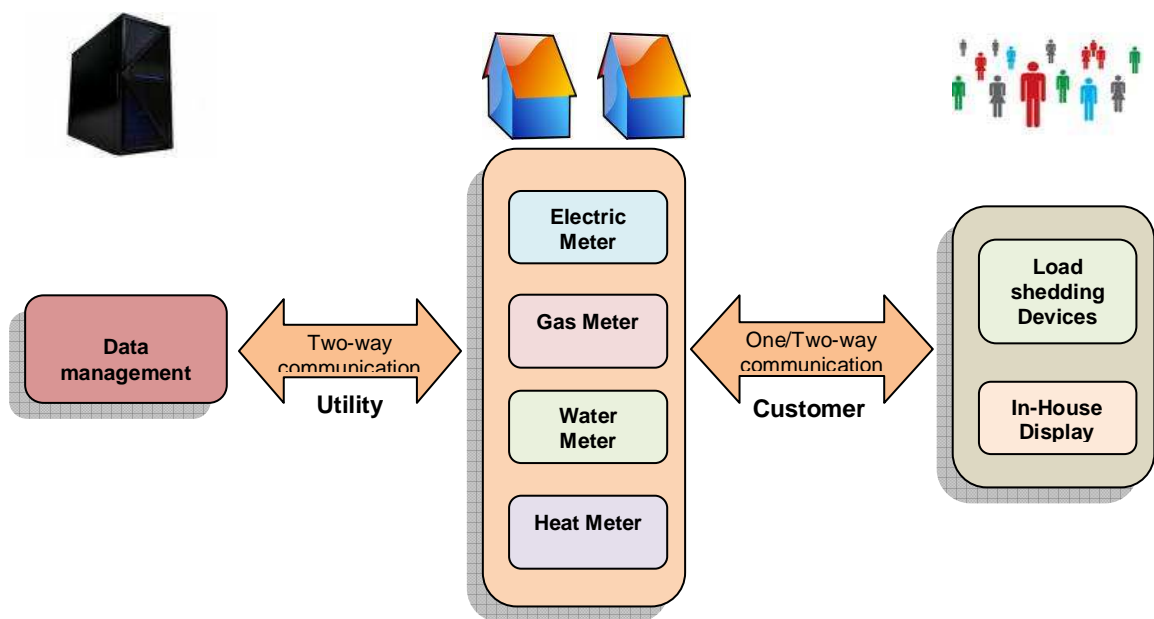


## APPENDIX 3 – SMART METER FUNCTIONALITIES

### 1. SMART METERS

There are numerous technical options facing anyone looking to implement smart metering. It would not be appropriate, though, to promote any given technology over and above others. What is appropriate, however, is to provide an overview of smart metering technology, especially where this impacts on how smart metering can better deliver energy saving improvements. Therefore, this chapter sets out the broad technical options open to everyone implementing a smart metering scheme.

Smart metering systems comprise a number of interconnected elements as shown in Figure 1. Technical options for these elements are described in detail below.



**Figure 1 – Smart metering System**  
(Source: European Smart Metering Industry Group)

### 2. Meter Design Options

#### 2.1. Measured Quantities

All utility meters purchased for billing purposes in Europe must comply with the Measuring Instruments Directive (MID 2004). This specifies the minimum requirements for meters, including their accuracies, divided into a number of different classes, appropriate for different market applications. The MID also specifies the quantities that meters must measure:

- kWh of active energy for electricity
- Reactive energy
- Instantaneous power
- Power factor



- Voltage
- Current
- Maximum demand
- Export energy (active reactive)
- Selected power quality characteristics

It is obvious that adding measured and calculated quantities will tend to increase meter costs, depending on the need for additional hardware. This is not always a simple calculation as, in some cases, additional functionality can be provided with small changes to the design whilst some additions require a step increase in meter memory, processing capacity, or communication bandwidth.

Under rated operating conditions and in the absence of a disturbance, the error of measurement shall not exceed the maximum permissible error (MPE) value as laid down in the appropriate instrument-specific requirements.

Each meter is specified by a class index. The class indices are defined as: Class A, B and C. According to these classes, certain rated operating conditions must be satisfied by the meter as presented in Table 19, where:

- $I$  = the electrical current flowing through the meter
- $I_n$  = the specified reference current for which the transformer operated meter has been designed
- $I_{st}$  = the lowest declared value of  $I$  at which the meter registers active electrical energy at unity power factor (polyphase meters with balanced load)
- $I_{min}$  = the value of  $I$  above which the error lies within maximum permissible errors (MPEs) (polyphase meters with balanced load)
- $I_{tr}$  = the value of  $I$  above which the error lies within the smallest MPE corresponding to the class index of the meter
- $I_{max}$  = the maximum value of  $I$  for which the error lies within the MPEs

	Class A Class B Class C	Class A Class B Class C	Class A Class B Class C
<b>For direct-connected meters</b>			
$I_{st}$	$\leq 0.05 \cdot I_{tr}$	$\leq 0.04 \cdot I_{tr}$	$\leq 0.04 \cdot I_{tr}$
$I_{min}$	$\leq 0.5 \cdot I_{tr}$	$\leq 0.5 \cdot I_{tr}$	$\leq 0.3 \cdot I_{tr}$
$I_{max}$	$\geq 50 \cdot I_{tr}$	$\geq 50 \cdot I_{tr}$	$\geq 50 \cdot I_{tr}$
<b>For transformer-operated meters</b>			
$I_{st}$	$\leq 0.06 \cdot I_{tr}$	$\leq 0.04 \cdot I_{tr}$	$\leq 0.02 \cdot I_{tr}$
$I_{min}$	$\leq 0.4 \cdot I_{tr}$	$\leq 0.2 \cdot I_{tr}$	$\leq 0.2 \cdot I_{tr}$
$I_n$	$= 20 \cdot I_{tr}$	$= 20 \cdot I_{tr}$	$= 20 \cdot I_{tr}$
$I_{max}$	$\geq 1.2 \cdot I_n$	$\geq 1.2 \cdot I_n$	$\geq 1.2 \cdot I_n$

**Table 19 – Current operating conditions a meter must satisfy**  
 (Source: directive 2004/22/EC)





The voltage, frequency and power factor ranges within which the meter shall satisfy the MPE requirements are specified in Table 20. These ranges shall recognise the typical characteristics of electricity supplied by public distribution systems.

The voltage and frequency ranges shall be at least:

$$0,9 \cdot U_n \leq U \leq 1,1 \cdot U_n, \quad \text{where } U = \text{the voltage of the electricity supplied to the meter and } U_n = \text{the specified reference voltage}$$

$$0,98 \cdot f_n \leq f \leq 1,02 \cdot f_n \quad \text{where } f = \text{the frequency of the voltage supplied to the meter}$$

and  $f_n = \text{the specified reference frequency}$

Power factor range at least from  $\cos\phi = 0.5$  inductive to  $\cos\phi = 0.8$  capacitive.

	Operating temperatures			Operating temperatures			Operating temperatures			Operating temperatures		
	+ 5 °C ... + 30 °C			- 10 °C ... + 5 °C or + 30 °C ... + 40 °C			- 25 °C ... - 10 °C or + 40 °C ... + 55 °C			- 40 °C ... - 25 °C or + 55 °C ... + 70 °C		
Meter class	A	B	C	A	B	C	A	B	C	A	B	C
Single phase meter; polyphase meter if operating with balanced loads												
$I_{\min} \leq I < I_{tr}$	3,5	2	1	5	2,5	1,3	7	3,5	1,7	9	4	2
$I_{tr} \leq I \leq I_{\max}$	3,5	2	0,7	4,5	2,5	1	7	3,5	1,3	9	4	1,5
Polyphase meter if operating with single phase load												
$I_{tr} \leq I \leq I_{\max}$ , see exception below	4	2,5	1	5	3	1,3	7	4	1,7	9	4,5	2

For electromechanical polyphase meters the current range for single-phase load is limited to  $5I_{tr} \leq I \leq I_{\max}$

**Table 20 – MPEs in percent at rated operating conditions and defined load current levels and operating temperature**  
 (Source: directive 2004/22/EC)

## 2.2. Time Interval

Different recording schemes can be implemented for the measured quantities. For conventional metering systems there are two options:

- Interval metering, where the consumption is recorded over time periods from 5 minutes up to 60 minutes.
- Non-interval metering, where readings can vary between monthly to annual, (with actual meter read frequency depending on access to the meter).

Electronic meters can, in fact, provide much higher data rates (down to intervals of a second) but such short time intervals are not used for billing because this provides no benefit to the billing process and greatly increases the cost and quantity of data



transmitted. With smart metering it is an option to stream short interval data directly to a local device without feeding it into the billing data network.

For the end-user, shorter periods may be more informative. Especially in cases where feedback is being used to identify the loads of specific appliances, the refresh rate should be fast enough to link the change seen on the display with the operation of the appliance; from which it follows that intervals should be in the order of seconds. The data rate needed depends on two things: i) the time constants of the load dynamics being viewed and ii) the value of energy that can be used in one interval. Where meters rely on battery power, there will be a trade off between higher frequency and lower power consumption. This may have a major impact on the choice of refresh interval for these devices.

### **2.3. Switch**

Meters should be fitted with a switch to interrupt the supply in order various functionalities to be enabled. Firstly a switch can be used to limit the maximum demand of a given final customer - remote load limiting. This can be useful where there is limited supply capacity or where peak loads are growing faster than the network can be reinforced. Another reason is to enable prepayment options. The combination of a switch in the meter with an appropriate payment method defines a prepayment meter. Finally, a switch fitted to the meter can be used for remote meter management and allow the utility to disable supplies to properties that have ended their supply contracts without entering into a new contract with an alternative retailer (energy retailers).

The control of the switch can be either performed locally (by pushing a button on the meter) or from a remote control centre using the meter automatic meter reading communication. Indicators of the switching state (ON-OFF) should be displayed on the meter LCD. They should also be reordered in the meter status registers. The registers are available for remote meter reading and monitoring.

### **2.4. Multiple and Dynamic Tariffs**

Currently residential tariffs are normally limited to one or two tariff rates. This is a result of the difficulty of accurately collecting multiple register data from manual reads. Smart meters with automated data collection can overcome this difficulty and allow multi-rate tariffs to be offered, where the meter records the consumption to different registers at different times of day. Most smart meters support four or six tariff rates. With the ability to communicate with the meter it is also possible to remotely reset the tariff rates, for example if there was a high system demand foreseen. In principle, the tariffs could even be dynamic, varying daily, or even more frequently, to reflect higher or lower availability of renewable energy resources such as wind or wave power.





## APPENDIX 4 – DEVELOPMENT OF SMART METER FUNCTIONALITIES USING PROCESS MAPS

### 1. Payment System

It is clear that in designing a charge post the payment system used is an important consideration as this drives the functional requirements of the EV CI.

#### 1.1. Free Electricity

In the initial stages of roll out, one option is to offer all users of EVs free electricity when parked in the specially designated parking spots. Access to the charge post may be gained by the use of a special key or key fob. This would mean that users would not have to identify themselves to the post they merely have to have the means to open the charge post. This system of payment could mean that the charge post is now nothing more than a weather proof socket on the street. It would not need complicated electronics and it would not need to be monitored by the supplier. The complexity of the unit would be significantly reduced as a consequence.

However there would be no scope for DSM or for Time of Day Billing.

#### 1.2. Payment in Advance

- User will buy a new card or top up an existing card<sup>6</sup> with credit.
- The user will arrive at the Charging Post and scan their card to inform the post that charging should commence.
- The latch will open / or the plug will become usable and the user will plug in.
- The user will then select the amount of charge they want or if they want to fill up completely the charging point should inform the user of how long this will take.<sup>7</sup>
- When the plug is securely in place charging will begin.
- The amount of electricity used should be measured.
- LED's will become illuminated depending on the status of the charging post, for example if the charging post is in the charging mode, a green LED will be illuminated.
- If the parking is paid for<sup>8</sup> a blue LED will be illuminated.
- When the user wants to disconnect they should scan their card to stop charging and release the charging cable.

This could also be achieved by using the prepayment facility on a smart meter system.

#### Advantages of Payment in Advance Method

---

<sup>6</sup> The premise is that these cards will have some sort of chip embedded in them, such as a smart chip or RFID technology

<sup>7</sup> This can only be done if there is some method of displaying the information to the customer, either via mobile phone technology or an LCD screen.

<sup>8</sup> In the beginning of the roll out some of the parking spots may be free for users of EVs. If not we must devise a way of integrating paying for electricity and paying for parking in the one transaction.





- There can be no disputes about bills where customers claim they have not used units of electricity that is on their bill.
- Psychologically this approach may be easier to implement as users may not want to keep tabs on the amount of units they are using so as to validate that their bill is correct.

### **Disadvantages of Payment in Advance Method**

- Putting readers in every single Charging Point will add yet another cost into the implementation of these devices.
- Some people may like the convenience of not having to go to a specialised shop to top up their card.
- The added cost of distributing and managing the dedicated card for payment.

### **1.3. Payment in Arrears**

- Each EV User will have a MPRN number for use at the charging post.
- The user will arrive at the Charging Post and scan their card to inform the post that charging should commence.
- The user's information will need to be communicated to the supplier to ensure that the user is allowed.<sup>9</sup>
- The supplier will send back a yes this is a valid user (allow charging to commence) or no this is not a valid user (do not allow charging to commence).<sup>10</sup>
- The amount of electricity used should be measured.
- LED's will become illuminated depending on the status of the charging post, for example if the charging post is in the charging mode, a green LED will be illuminated.
- If the parking is paid for, a blue LED will be illuminated.
- When the user wants to disconnect they should scan their card to stop charging and release the charging cable.
- The amount of electricity used should be transmitted to the supplier so as they can charge the customer accordingly.

### **Advantages of using the Payment in Arrears Method**

- As there will be communications within the device, it facilitates DSM and Time of Day tariffs
- Convenience– user will not have to repeatedly top up the card with credit.

### **Disadvantages of using the Payment in Arrears Method**

- More communications will be needed, hence increasing the cost of the charging posts.

---

<sup>9</sup> This step needs to be taken to ensure that the user has paid his recent bills.

<sup>10</sup> If a hatch is involved, the hatch will not open for an unauthorised user. If there is no hatch some other prevention method needs to be employed so that the user can not even plug in.





- People may dispute the bill and therefore a record of each transaction needs to be kept.

### **Why have a separate MPRN?**

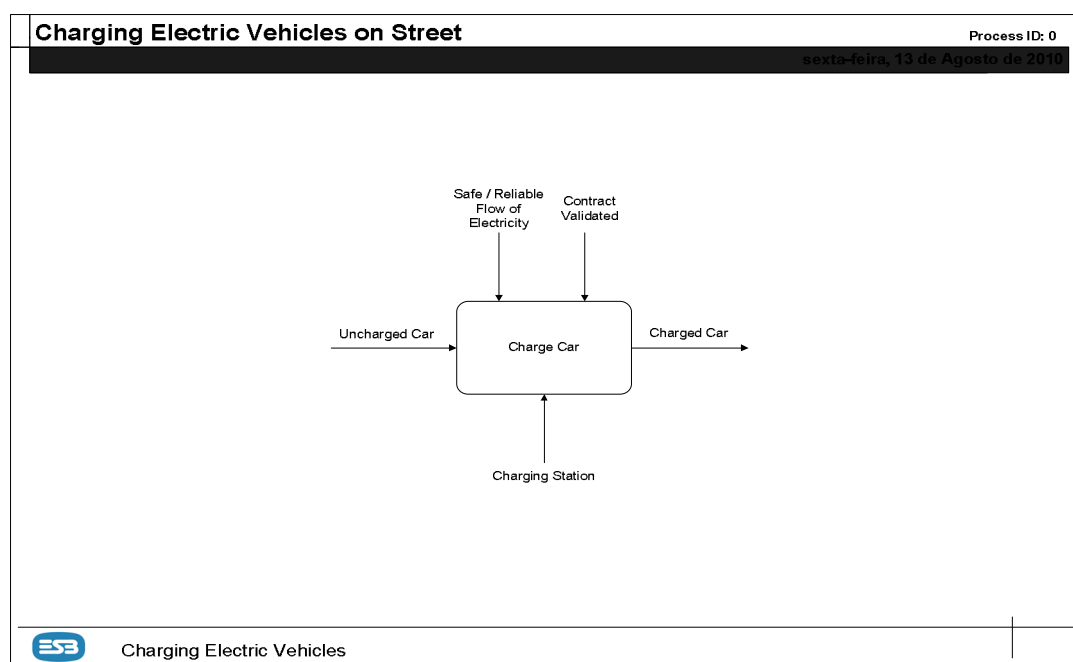
If the Meter Point Registration Number (MPRN) that the user accessed the charge post was the same as the one at their home, it would mean that the electricity that they used at the charge post would be added to the bill for the electricity use in their home. This may lead to a situation where the user disputes the EV charging bill and this in turn could lead to the customer not paying the overall total bill due to the dispute. Another valid reason is that, at some time in the future, parking charges may be added to the charge for using the charge posts and having a separate MPRN would allow this to be implemented much more smoothly. Experience in Holland has shown that customers may try and dispute a small charge on their bill to hold up the payment of the main bill.



## 2. Process Maps for On Street Charging of Electric Vehicles

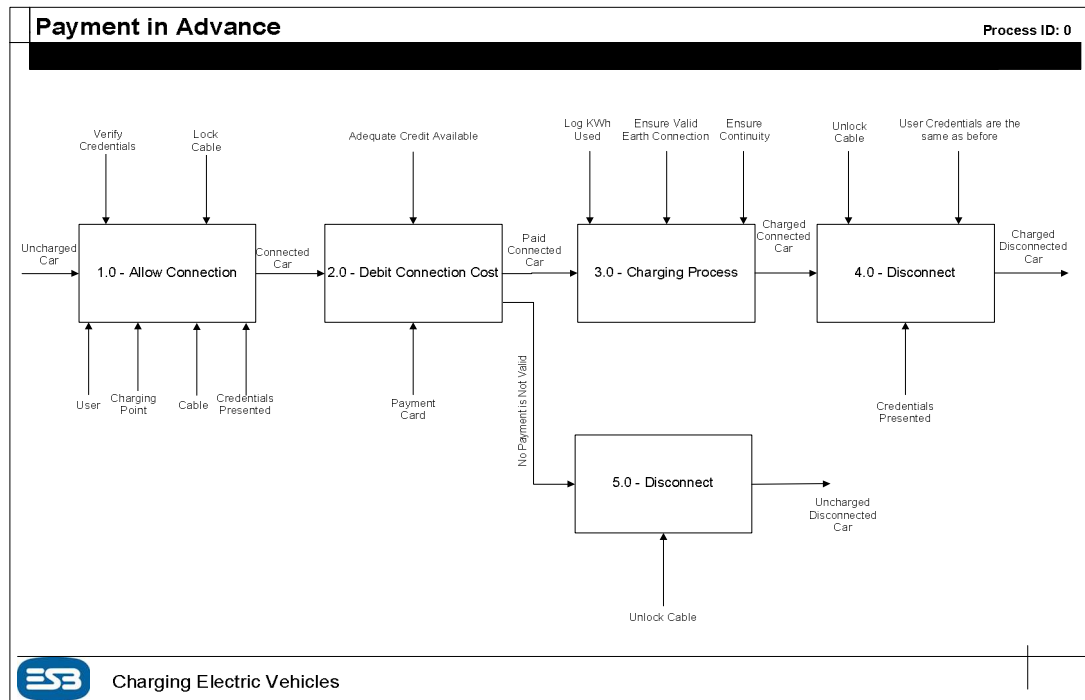
These processes differ in certain essentials according to whether the payment model is based on a 'Payment in Advance' before Charging commences – in which case no back office system is required as the transaction is completed and settled at the EV Charging Post, 'Payment per Occasion' in which case there is a fixed charge per use and the customer is not billed for the exact amount of energy used, or 'kWh Payment in Arrears' where the customer's usage is metered and added to an electricity account which is billed monthly to the customer. Another variation on 'Payment in Arrears' would be 'Pay as you go' which would essentially involve the usage of the utility 'Prepayment' facility which is already commonly available.

### 2.1. Process Maps for Payment in Advance



**Figure 2.1 – Process diagram - Charge Car**

The first process is the highest level process and it shows the essence of the task that is required. This involves connection, charging the EV and then returning to a charged vehicle.

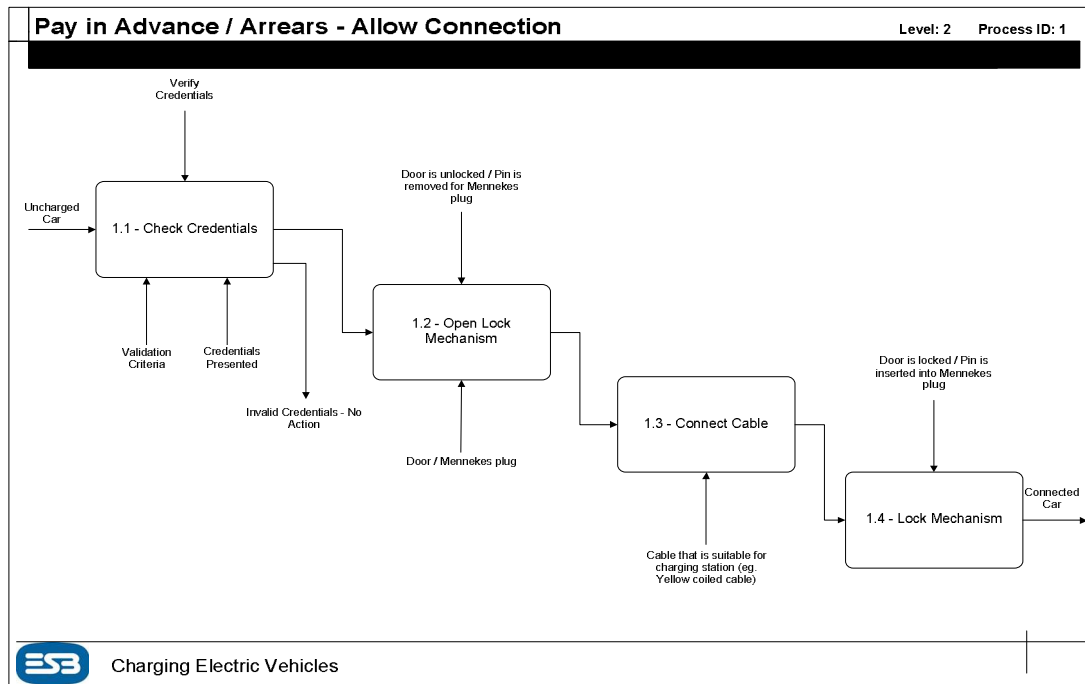


**Figure 2.2 – Process diagram - Payment in advance**

The model for payment in advance is shown in the figure 2.2. The most notable feature of this diagram is that the connection cost is debited before charging begins so as to ensure the user has enough credit to pay the full amount for the charging. Charging will stop when either the battery was fully charged and there are sufficient funds to pay for it or the fund limit is exceeded. If the payment is not valid the vehicle is not authorised to begin charging.

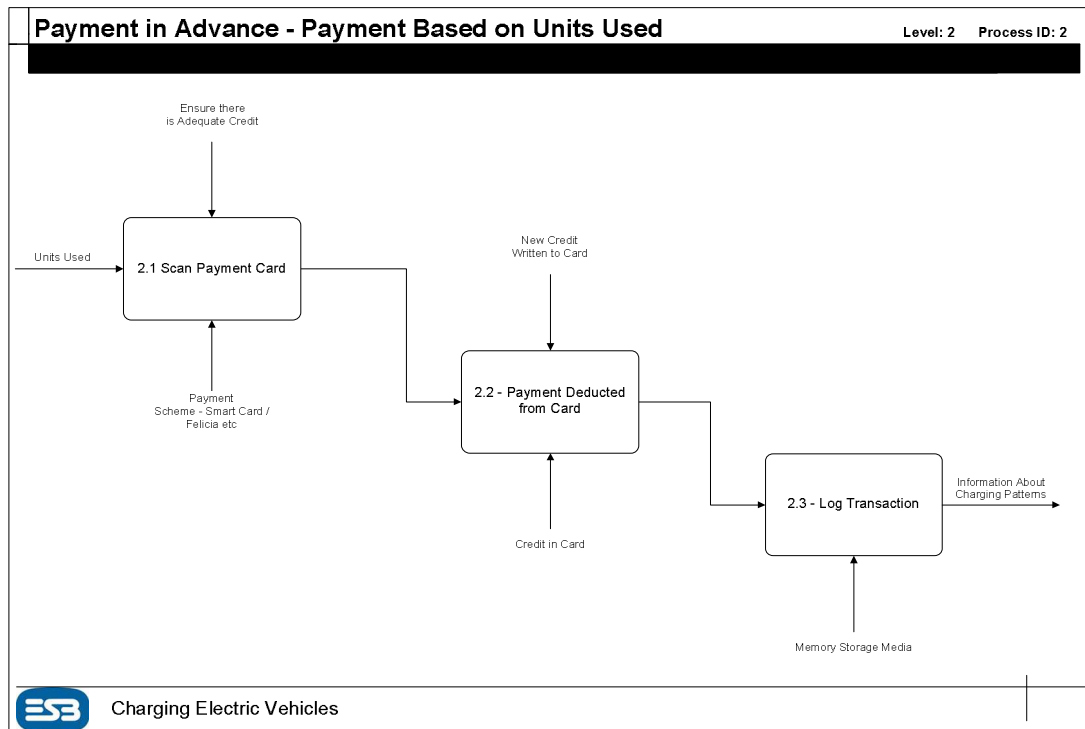




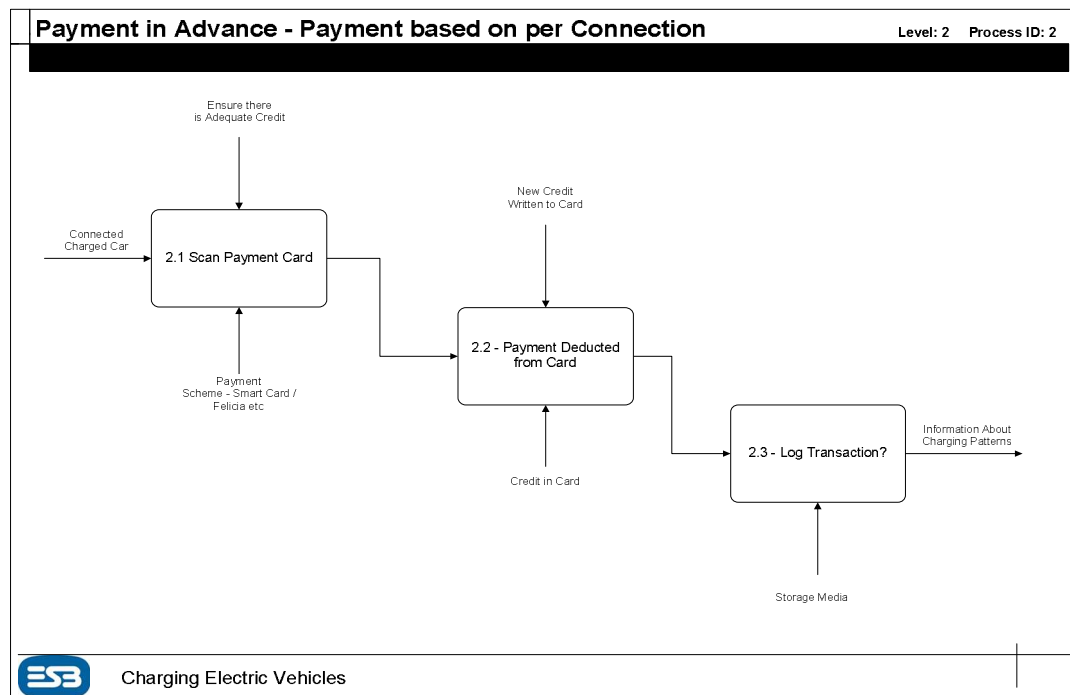


**Figure 2.3 – Process diagram - Allow connection**

The user's credentials must be checked to ensure that the person trying to access the post is an allowed user and although the values of the transaction are small in relation to the cost of the infrastructure it is still an integral part of the system so as to avoid misuse and also to solve any payment disputes that may arise.



**Figure 2.4 – Process diagram - Payment based on units used**



**Figure 2.5 – Process Diagram based on per connection**

The figures 2.4 and 2.5 show two different methods for payment in advance depending on whether a meter is required or not. If a meter is not required then payment in advance based in per connection method will be used and this will deduct a fixed charge from the user's payment card (e.g. €2 per charge), this method will not depend on the time the vehicle has been charging for not how many units of electricity that has been consumed.

If it is decided that a meter will be required then users can be charged for the exact amount of electricity they have used and this should be paid for before charging commences and not afterwards. An input device could be used to allow the user to enter in the amount of units they require; however an input device for the post would add yet another cost the post. One solution is that the charge post could check that the user has enough funds to pay for the transaction before charging begins or that if the user does not have enough funds that a negative amount of money can be left in the card and when the user tops up again the negative amount is deducted from the new top-up. When using the pay in advance method, it is not essential that the transaction be recorded although to allow better planning for future developments it may prove to be a significant advantage having this data.

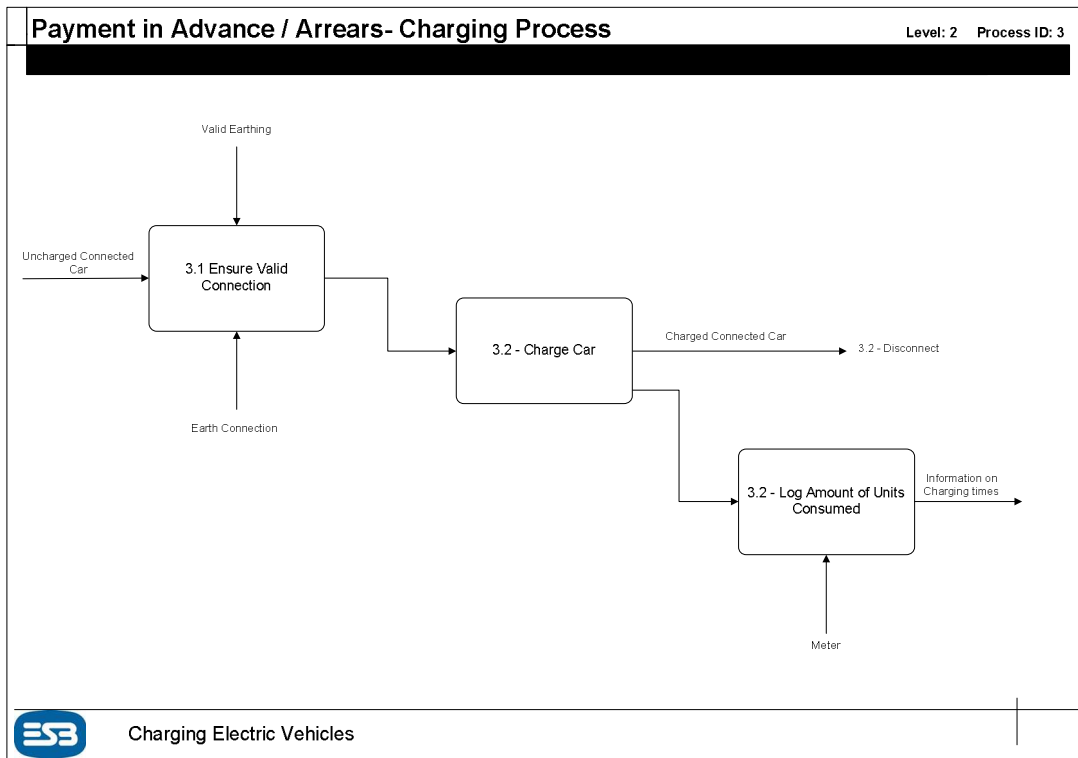


Figure 2.6 – Process diagram - Charging process

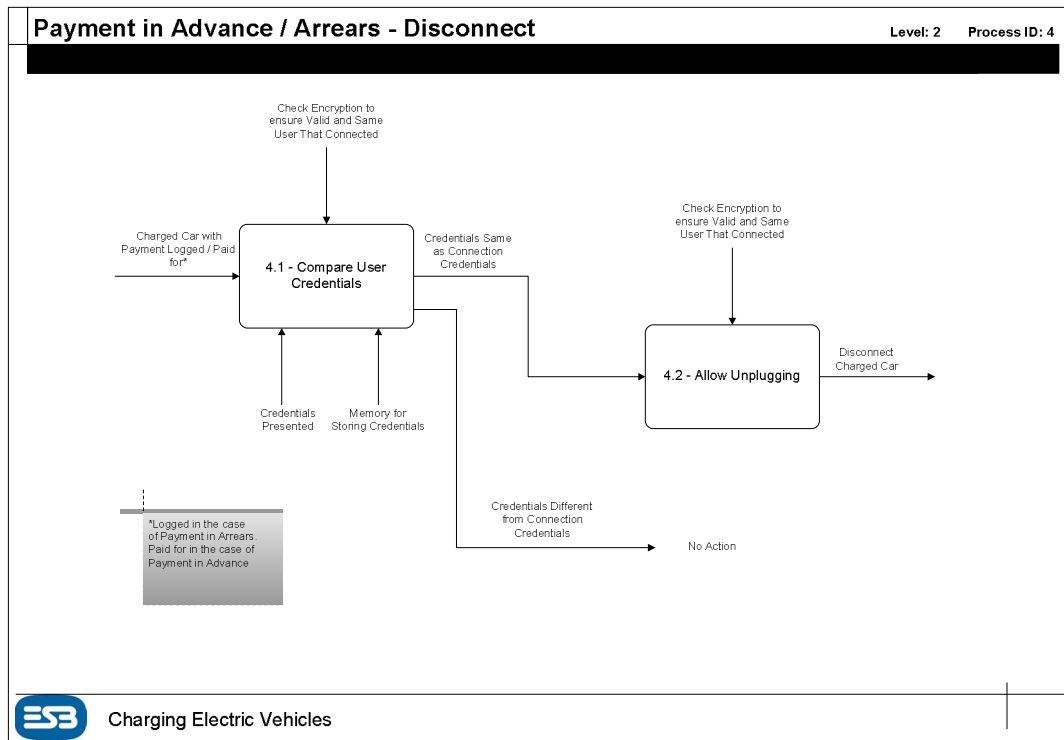
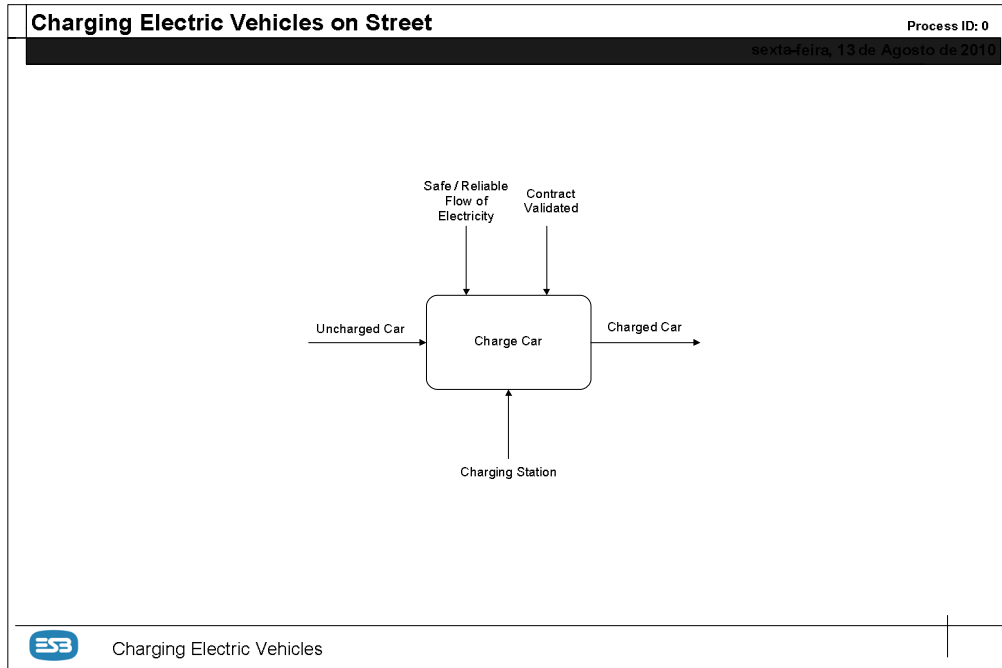


Figure 2.7 – Process diagram - Disconnect

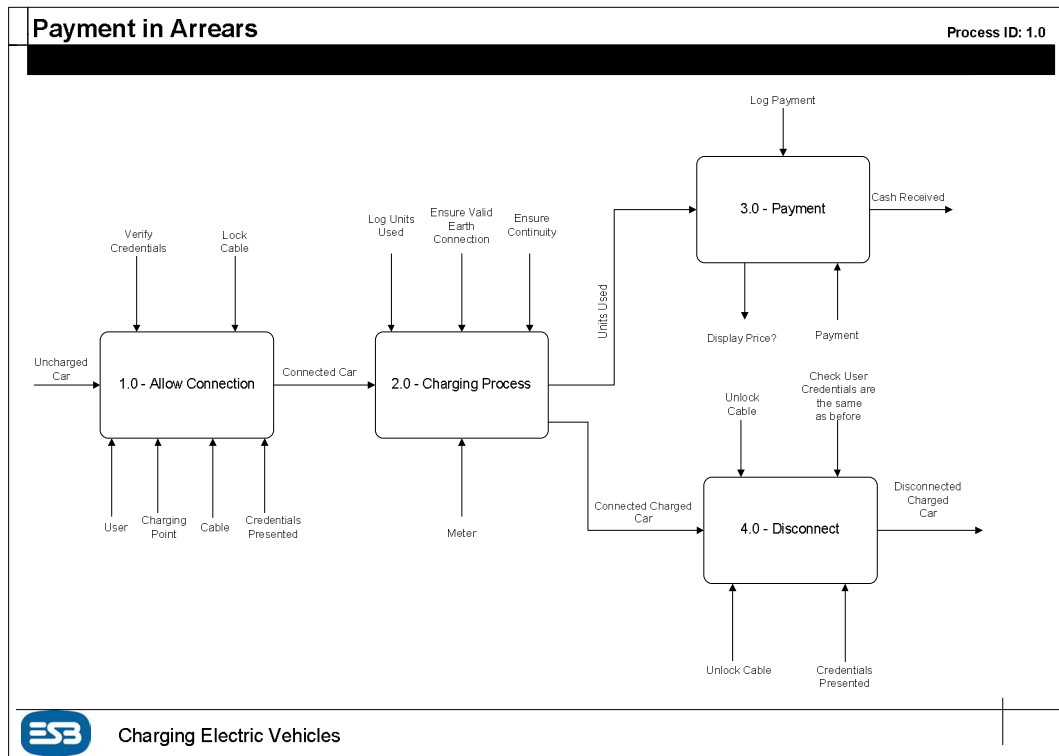


For safety issues and to prevent misuse and vandalism it is important that the credentials of the person who is trying to unplug are the same as the person who connected in the first place.

## 2.2. Process Maps for Payment in Arrears



**Figure 2.8 – Process diagram - Charge Car**



**Figure 2.9 – Process diagram - Payment in arrears**

When the diagram above is compared to figures for payment in advance, one can see the inherent difference between payment in advance and payment in arrears is the payment process. If payment in arrears is used in conjunction with payment in advance, then the best approach seems to include a meter for the amount of electricity use. Although pay per connection simplifies the process of payment in advance, it offers little / no advantage for payment in arrears.

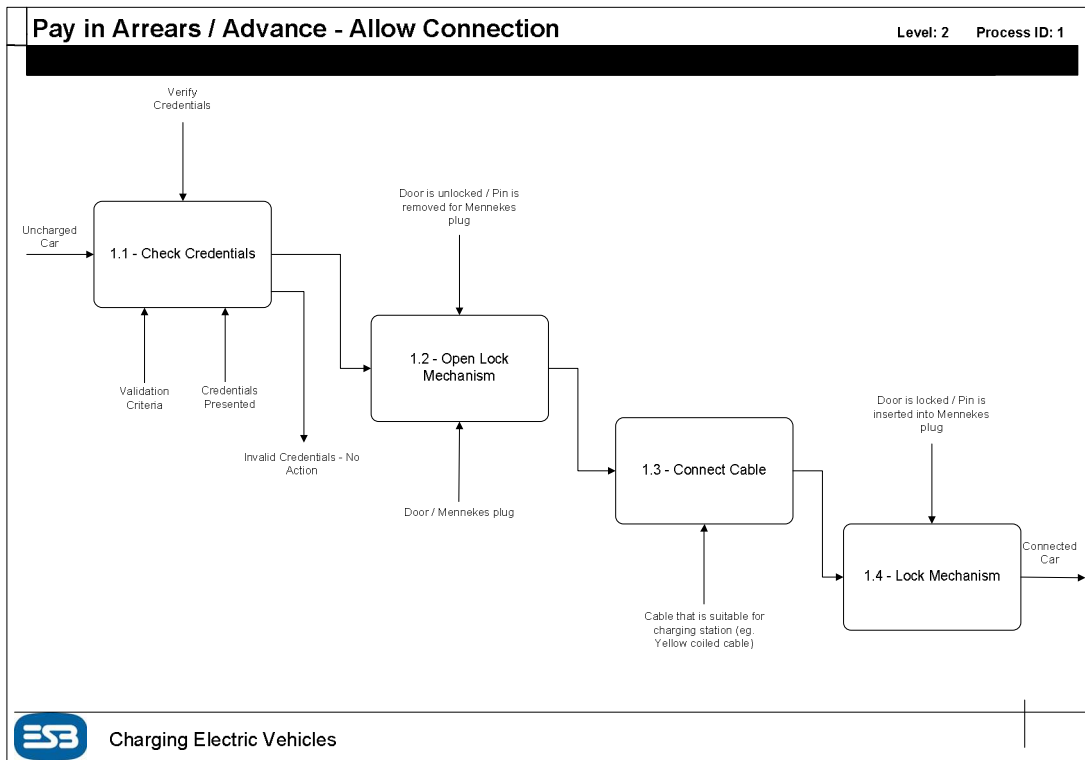


Figure 2.10 – Process diagram - Allow connection

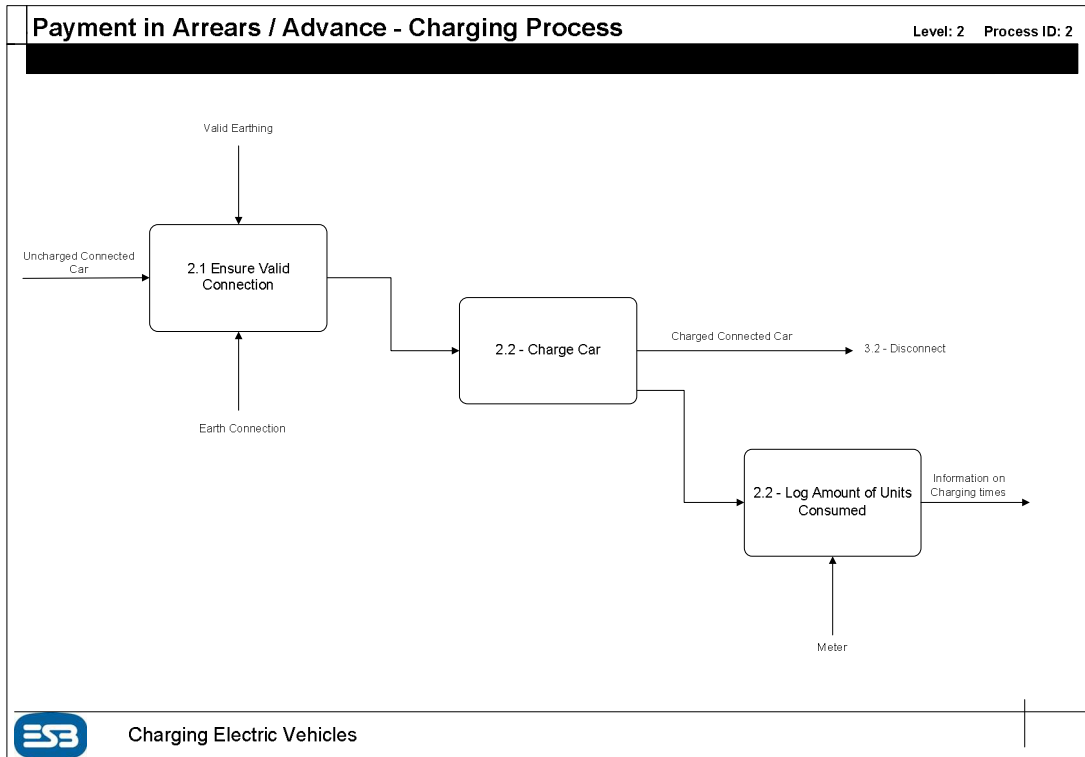
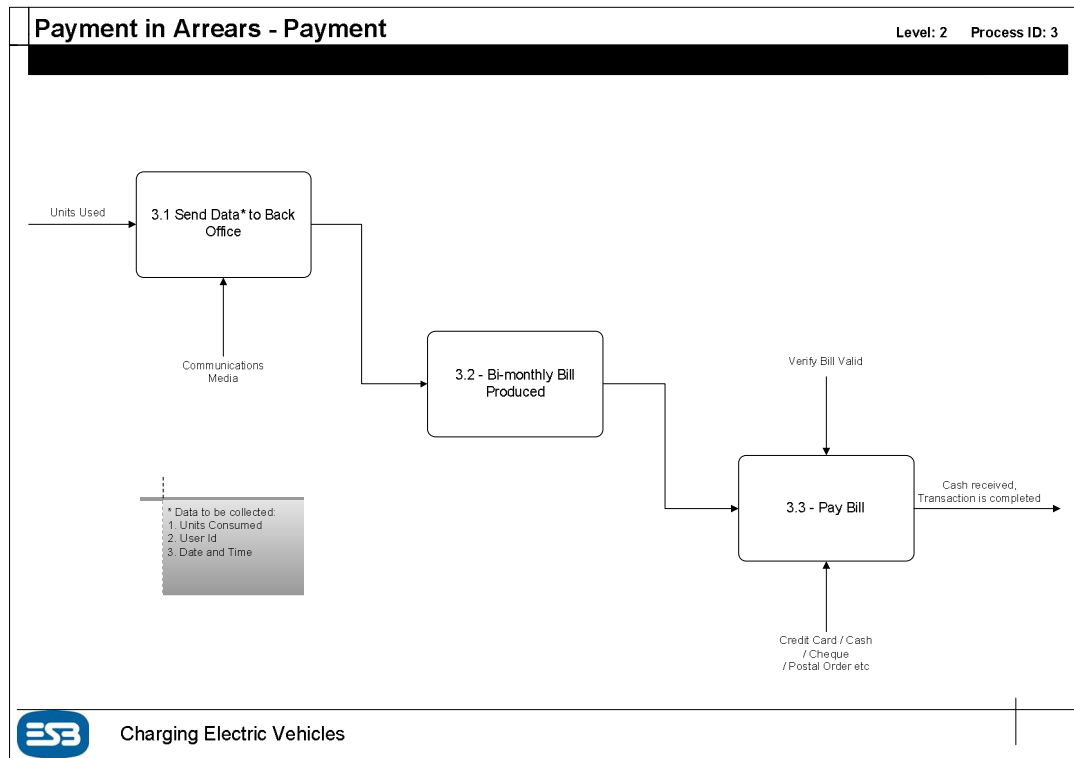


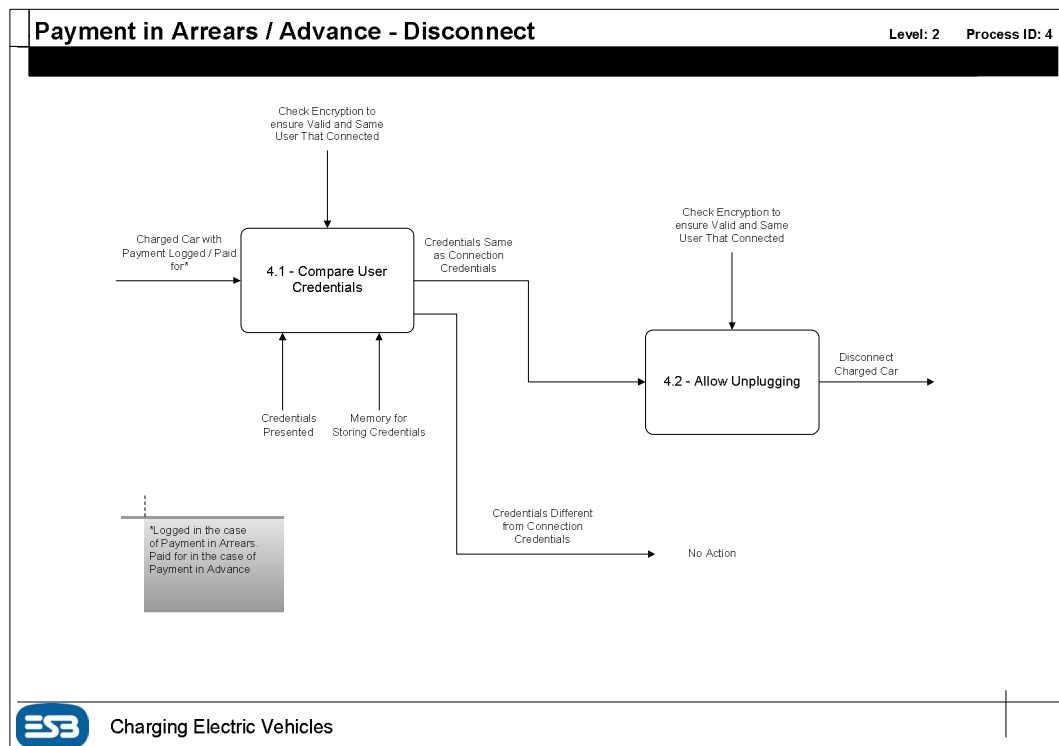
Figure 2.11 – Process diagram - Charging process



**Figure 2.12 – Process diagram - Payment**

Payment in arrears entails more data processing, however, utilities already has well developed Billing systems for charging users for electricity and therefore would be quite a simple system for any utility to operate.





**Figure 2.13 – Process diagram - Disconnect**

From the Diagrams we can see that no matter what charging system or payment system we choose all charging posts will need:

- A 'key' to identify user entitlement to EV CI access e.g. RFID fob
- A system to authenticate 'key' and verify that user is currently entitled to access the EV CI i.e. check and compare credentials
- Locking mechanism - This may be a door that locks when the car is charging so as to prevent an unauthorised user from unplugging the lead, or it may be in the form of a Mennekes plug where a pin keeps the plug in place or maybe both.
- Mode 3 Continuity tester - This will be used to ensure the vehicle is only charging when it is safely connected and will also be used to signal to the public the state of the Charge Post.
- Storage Media - No matter how advanced a system used some storage will be required to compare the user who logged on with the user that is trying to disconnect.
- Communications - Although it is not necessary to have real time communication with the charger for Billing Purposes it will be necessary to update the charge post from time to time and depending on the payment system that will be employed more frequent communication may be required. If Real Time DSM were employed it could be necessary to have a communications channel with wider bandwidth available.
- Display – This need only be an LED system to indicate the Charging Status of the EV CI, as an alphanumeric display could be excessively costly.



### 2.3. Comparison of the Required Processes in a Charging Post for Different Payment Methods

Analysing the processes that take place in the different varieties of charging stations and comparing them to see the commonalities between the different options allows one to understand and identify the features that will have to be modified in the charge post if offering more than one payment system. The choice of payment method will therefore have a significant influence on the design of the Charge Post.

From Table 21 certain commonalities and differences are seen between EV CP systems.

All EV charge posts systems will need to have the functionality to allow the customer to identify themselves as an allowed user. The exception to this is when free electricity is offered to the customer via the Park and Charge scheme. These users do not have to have their credentials verified; they merely have to have a key that will open the charge post. The charge post does not need to “know” or hold any data about the user. If the customer is on a Pre-Pay where the payment is recorded on the card then the user’s identity is not required. If pre-pay is via an account that has already been credited with funds, then identity is required (similar to the scheme that has been implemented in Westminster). Similarly Bill Pay requires identification.

Process	Description	Payment Method			
		Free	In Advance (per kWh)	In Advance (per connection)	Payment in Arrears (per kWh)
1.0 Allow connection	1.1 Check credentials		✓	✓	✓
	1.2 Open lock mechanism		✓	✓	✓
	1.3 Connect cable	✓	✓	✓	✓
	1.4 Close lock mechanism		✓	✓	✓
2.0 Payment before charging begins	2.1 Scan Payment Card		✓	✓	
	2.2 Payment is deducted from the card. New credit is written.		✓	✓	
	2.3 Log transaction		✓	✓	
2.0 / 3.0* Charging process	3.1 Ensure valid connection	✓	✓	✓	✓
	3.2 Charge EV	✓	✓	✓	✓
	3.3 Log amount of units consumed		✓	✓	✓
3.0 Payment after charging has been completed	3.1 Send data to back office				✓
	3.2 Bi-monthly bill is produced				✓
	3.3 Customer pays bill				✓
4.0 Disconnect	4.1 Compare user credentials to that used to access the Charge Post		✓	✓	✓
	4.2 Allow unplugging is process 4.1 is satisfied		✓	✓	✓

**Table 21 – Payment method process table**





For pre-payment another option is a fixed payment per month with the card expiring at the end of the calendar month.

Cards which contain a fixed amount of credit which needs to be debited pose the question of how the customer verifies how much credit they have remaining. This could be via a display device on the EV CP via some other communications media, such as the internet or mobile phone.

The payment system that charges the user according to the amount of units of electricity used requires a meter in the EV CP to record consumption against an MPRN. Communication is required between the EV CP and MRSO (Meter Registration System Operator) so that it can report back the consumption. However, this communication does not need to be in real time, it can actually be performed as little as once every two months.

The pre-paid systems only need to communicate between the pre-payment device and the EV CP but does not need to communicate elsewhere. In this case the EV would be set up with an encryption facility where the encryption would need to be satisfied in order for Charging to start. If for example a system was set up where the user buys a card and it expires at the end of the month a different encryption could be downloaded to the Charge Post every month via radio broadcast making the previous month's encryption invalid.



### 3. Functional Requirements for Charging Posts

Obviously the main function of the charging posts is to provide electricity with the outcome of charging an EV. This needs to be carried out in a safe and economical manner with a simple, easy to use interface at the user end. The charging post needs to be a suitable height above the ground so as all users can access it without posing a safety hazard i.e. if the socket is too high above the ground people in wheelchairs may not be able to access it. A socket approximately 1 m above the ground used in conjunction with a high visibility yellow charging cable (provided by the user in Europe) should be implemented. Another safety feature especially in higher current charging is to provide hatches for the plugs to prevent vandals from unplugging the car in an unsafe manner leaving an exposed socket.

Charging posts should have a life expectancy of about 40 years. As such the posts will need to be made from marine grade stainless steel or other suitable material. They will also need to be water tight to alleviate safety concerns.

Connecting a three phase joint is only a little more expensive than connecting a single phase joint and therefore placing more than one socket on each post could reduce the cost of the post and would also have the added advantage of minimising street furniture. In the initial roll out it may be an option to have one socket on each charge post with the ability to retrofit the installation at a later stage to include a second if required. An installation such as the one on the right could be placed between two parking spaces and two cars could be plugged in simultaneously.



**Figure 3.1 – Garro charging post (2 power outlets)**

LEDs should be incorporated in the design to show the charging status and also to alert the general public to the availability of the charging network. The LEDs will be covered with a transparent material that is scratch proof and will remain transparent over time. The material should also be water tight so as to prevent condensation from building up and obscuring the LEDs.



#### 4. Electronic Requirements for Charging Posts

The electronic unit must perform the following functions:

**Control the LEDs** - A green LED should indicate that the vehicle is charging, a blue LED should indicate that the unit is available for use and a red LED should indicate that a vehicle has finished charging. If incorporating parking charges with this system a combination of these can be used to indicate different status. In areas with home dwellings an extra functionality is needed to disable the LEDs at night if the home owner requests. Control the access hatch.

**Ensure valid earth continuity** of the supply.

**Switch on the power** after safe connection is verified and payment has been deducted (in the case of payment in advance). Switch off the power when earth continuity signal is interrupted or the hatch is in the open position or when a predetermined time has elapsed. The electronics units should be connected in a way that **facilitates future updates** and replacement with a smart meter.

**An RFID key fob** should be provided for all customers. Customers using payment in advance method should have the ability to apply credit to the fob which is deducted when before charging has begun. Customers using payment in arrears should also get a card, the function of this card however is to gain access to the charge post and to give user details to the post so as to compile usage information to give to the MRSO which in turn will lead to a bill being produced.

An option to combine parking and electricity charges should be considered. The customer would pay the charge for parking and electricity combined and then this would be distributed to the local authority for the parking services and to the supplier for the electricity provided.





# **MOBILE ENERGY RESOURCES IN GRIDS OF ELECTRICITY**

**ACRONYM: MERGE**

**GRANT AGREEMENT: 241399**

**WP 1  
TASK 1.5  
DELIVERABLE D1.1**

**IDENTIFICATION OF TRAFFIC PATTERNS AND HUMAN BEHAVIOURS**

**11 MAY 2010**



## REVISION HISTORY

---

VER.	DATE	NOTES (including revision author)
01	11/05/2010	Initial release
02		
03		
04		
05		
06		
07		
08		
09		
10		





## AUTHORS

Neil Downing	Neil.Downing@ricardo.com
Mohsen Ferdowsi	Mohsen.Ferdowsi@tu-berlin.de

## CONTRIBUTORS

Ed Bower	Ed.Bower@ricardo.com
Colum Joyce	Colum@imrworld.org
Kai Strunz	Kai.Strunz@tu-berlin.de
Ehsan Abbasi	Ehsan.Abbasi@tu-berlin.de

## APPROVAL

## DATE

Project Coordinator	PPC	N. Hatziaargyriou	04/08/2010
Technical Coordinator	INESC Porto	J. Peças Lopes	14/07/2010
Work Package Leader	TU Berlin	K. Strunz	14/07/2010

**Access:**  Project Consortium  
 European Commission  
 Public

**Status:**  Draft Version  
 Submission for Approval (deliverable)  
 Final Version (deliverable, approved)





## SUMMARY

This report examines the traffic patterns and human behaviours of drivers from across Europe, to provide a benchmark of current vehicle usage patterns, against which to compare proposed future developments in electric and plug-in hybrid electric vehicle technology. Both battery electric vehicles and plug-in hybrid electric vehicles are hereafter referred to as electric vehicles, or EV.

The data analysed in this survey was collected using a targeted online questionnaire that was filled in by a total of 1,621 people from a number of countries in Europe, from a range of backgrounds, providing a sound basis from which to draw conclusions and perform analysis.

The survey was distributed by all Project MERGE partners to contacts including colleagues, clients, subscribers and friends. Although this distribution perhaps provides a sample population that is more technically-minded and environmentally-aware than the real European population, it certainly provides a sample population that is representative of the likely early adopters of electric vehicle technology, which is appropriate for this study.

Some of the results of this task are statistics taken directly from the survey results, such as the proportion of drivers willing to participate in multiple-tariff electricity schemes, while other results are drawn from analysis carried out using traffic patterns identified by the survey to model the large-scale impacts of transport electrification on Europe's electricity networks.

The survey found that a significant majority of responders would participate in smart control of charging, if multiple-tariff electricity rates were to incentivise it. It also found that most drivers would prefer to recharge an EV at home, although there was no trend as to the regularity with which they would choose to recharge, suggesting the practicalities of limited range and recharging opportunities are difficult to conceive of, without actually owning an EV.

The study found that electric vehicles would serve the needs of 85% of responders, assuming that they could access an electricity supply to recharge the vehicle – only 57% responders said that they could provide electricity to their vehicle where it is parked for the longest period of the day. If recharging a vehicle parked on the street directly outside the owner's home was a viable option, 73% of responders would be able to access electricity.

The analysis showed that a 10% penetration of electric vehicles, with a “dumb” charging strategy with no smart control of charging and all vehicles charging as soon as they return from their last journeys of the day, would cause increases in daily peak demand levels of between 6% and 12% compared to the baseline peak demand and that the peaks would occur at a different time to that of the baseline peak demand.

The analysis further showed that a 10% penetration of electric vehicles, with an ideal “smart” charging strategy with all EV charging load moved to the night-time valley periods, would cause no change to the baseline peak demand levels. In addition, the peak EV charging load is also reduced, unless the charging is already spread over a long period of the day. Our survey of vehicle usages indicates that this might be so in Greece, where there are two main peaks in EV charging load in the evening, while the other countries have one evening peak.

The daily variation from minimum to peak demand was shown to increase significantly for the dumb charging scenario and reduce significantly for the smart charging scenario.



## TABLE OF CONTENTS

1	INTRODUCTION .....	6
2	OBJECTIVES .....	7
2.1	Linking Subtasks from the Description of Work to Sections of This Report .....	8
3	GLOSSARY .....	9
4	APPROACH .....	10
4.1	Data Collection .....	10
4.2	Assumptions .....	11
5	RESULTS .....	12
5.1	Number and Geographical Spread of Responses Received .....	12
5.2	Profile of Questionnaire Responders .....	14
5.3	Data Analysis .....	18
5.4	Suitability of Drive Patterns to BEV and PHEV .....	30
5.5	Impacts of Transport Electrification on the Grid .....	32
6	DISCUSSION .....	51
7	CONCLUSIONS .....	53
7.1	Traffic Patterns and Human Behaviour Analysis .....	53
7.2	Suitability of Drive Patterns to BEV and PHEV .....	54
7.3	Impact of Transport Electrification on Europe's Electricity Grids .....	54
8	RECOMMENDATIONS & FUTURE WORK .....	57
	APPENDIX 1 – AVERAGE RETURN TIMES FROM LAST JOURNEY .....	58
	APPENDIX 2 – EV POWER DRAW FOR DUMB CHARGING SCENARIO .....	61
	APPENDIX 3 – EV POWER DRAW FOR SMART CHARGING SCENARIO .....	64





### III IDENTIFICATION OF TRAFFIC PATTERNS AND HUMAN BEHAVIOUR

#### 1 INTRODUCTION

Traffic patterns are an important input when studying the influence of electric and plug-in hybrid electric vehicles on the grid as they will dictate the total energy requirements of the electrified vehicle network and the vehicles' times of use and disuse, and will define the period in which users must recharge them. It is also important to understand current vehicle users' preferences for refuelling frequency and timing and how they think they may modify these behaviours if they were to replace their current vehicles with electric vehicles.

The impact of transport electrification on the grid differs greatly depending on whether users adopt a "dumb charging" model, whereby they charge their vehicles as soon as they arrive home from their last journeys of the day, or "delayed charging", whereby they choose to recharge their vehicle overnight to take advantage of cheaper electricity tariffs at off-peak times. The specific functions and algorithms of "smart" utility-managed load systems differ greatly depending on users' recharging preferences.

This task was designed to gather data on vehicle usage and human behaviours and to use this data to model the impact of transport electrification on the electricity networks of Europe. This will set the scene for the subsequent work packages in the MERGE project.





## 2 OBJECTIVES

The objectives of this report are:

- To perform an initial overview and analysis of travel patterns, purpose of travel and human behaviour by surveying representative samples of vehicle owners. This phase provides a baseline for demand against the EV integration
- To identify the likely total European, national and regional impacts of transport electrification on the energy system, for predicted levels of EV penetration
- To develop relevant average transport vehicle kilometres driven, driving patterns and journey types for the United Kingdom, Germany, Spain, Greece, Portugal and Ireland; and to create European averages from these data
- To assess the suitability of these driving patterns to full electric vehicles and to estimate the likely proportion of the drive pattern appropriate for electric propulsion for plug-in hybrid electric vehicles
- To develop a time schedule of electric power drawn from the grid for recharging batteries of electric vehicles and plug-in hybrid electric vehicles





## 2.1 Linking Subtasks from the Description of Work to Sections of This Report

The structure of this report does not follow the structure of subtasks for Task 1.5 in the Description of Work (DoW), as a more logical flow of information was developed during the course of the study. Table 22 maps the subtasks from the DoW to the sections of this report.

SUBTASK FROM DoW	DESCRIPTION	SECTION OF THIS REPORT
1.5.1	An initial overview and analysis of travel patterns, purpose of travel and human behaviour will be performed by surveying representative samples of vehicle owners	5.3.1, page 18
1.5.2	The likely total European, national and regional impacts of transport electrification on the energy system will be identified, for predicted levels of EV penetration	5.5.2, page 34
1.5.3	Traffic and transport data will be compiled primarily for Germany, the UK, Spain, Greece, Portugal and Ireland, but a European average driving pattern will also be produced for more extensive, large-scale analyses for the entire continent	5.3.2.1, page 25
1.5.4	Relevant national and European average transport vehicle kilometres driven and driving patterns/journey types and distances will be considered	5.3.1, page 18, 5.3.2, page 25
1.5.5	From the daily drive patterns, assessment on how suitable they are for full electric vehicles will be made. For plug-in hybrid electric vehicles, the share of the drive pattern appropriate for electric propulsion will be found	5.4, page 30
1.5.6	Based on the previous, a time schedule for the charge of batteries and the electric power drawn will be developed. The result will be a charge-of-battery-distribution for each 1/4 hour of the year based on the time of day, weekday, season, weather conditions, and regional particularities	5.5.2, page 34, 5.5.3, page 41
1.5.7	This task will ultimately provide a sensitivity measure to the proportion of EV owners willing to engage in advanced battery charging/discharging management strategies, e.g. smart charging, which is a very important issue to leverage the electric mobility paradigm	5.3.1, page 18

**Table 22 – Cross-referencing the subtasks from the DoW with the sections of this report**



### 3 GLOSSARY

TERM	DEFINITION
BEV	Battery Electric Vehicle
CET	Central European Time (GMT+1)
DoW	Description of Work
EV	Electric Vehicle, Battery Electric Vehicle (BEV) or Plug-in Hybrid Electric Vehicle (PHEV)
GMT	Greenwich Mean Time
UK	United Kingdom

All units used in this study are part of the International System of Units (SI) and, as such, are not defined herein.







## 4 APPROACH

### 4.1 Data Collection

A questionnaire was designed to collect data supporting this task. The questionnaire was made available in eight languages: Dutch, English, French, German, Greek, Norwegian, Portuguese and Spanish. The authors would like to thank the project partners who translated the questions to the various languages, those who helped disseminate the survey and also everyone who gave of their time to fill in the survey.

The questionnaires are still available to view online here:

- Deutsch: <http://www.surveymonkey.com/s/Germany-merge>
- Ελληνικά: [http://www.surveymonkey.com/s/Greece\\_Merge](http://www.surveymonkey.com/s/Greece_Merge)
- English (UK): [http://www.surveymonkey.com/s/UK\\_merge](http://www.surveymonkey.com/s/UK_merge)
- English (Ireland): [http://www.surveymonkey.com/s/Ireland\\_Merge](http://www.surveymonkey.com/s/Ireland_Merge)
- Español: [http://www.surveymonkey.com/s/Spain\\_Merge](http://www.surveymonkey.com/s/Spain_Merge)
- Français: <http://www.surveymonkey.com/s/French-merge>
- Nederlands: <http://www.surveymonkey.com/s/Dutch-merge>
- Norsk: <http://www.surveymonkey.com/s/Norway-merge>
- Português: <http://www.surveymonkey.com/s/Portugal-merge>

#### 4.1.1 Formulation and Translation of Questionnaire

The questions were formulated in English and the precise wording for each was developed by the MERGE partners to ensure that the responses would provide the most appropriate data to complete each of the tasks. The questions were then translated by MERGE partners in the countries where the languages are spoken, to ensure that the meaning of each question would be consistently understood by responders from many different countries.

#### 4.1.2 Questionnaire Dissemination

The questionnaire was made available online in each of the eight languages and the links to each version were circulated to all partners of the MERGE project, who then forwarded the links to a range of distribution lists including friends, family members, colleagues, clients, customers, newsletters and related or associated organisations. The methods of distribution included electronic announcements, emails and inclusion in company newsletters.

The initial data collection period was two weeks, as project partner IMR World reported from experience of other surveys that the vast majority of responses to any survey come within a few days of the survey's





announcement, so leaving the survey open for a longer period represents a law of diminishing returns in terms of likely additional responses.

Although the data to be used in this task was cut at the end of the two-week period, the survey was allowed to remain open for the duration of Project MERGE so that if a significant number of responses are received after the two-week survey period, which alter the results of the analysis, these responses may be included in an updated data set later in the project.

#### **4.1.3 Limitations of Questionnaire**

Obtaining responses to the questionnaire from a perfectly stratified representative sample population would require significant investment and detailed statistical analysis that is outside the scope of Project MERGE. However, the questionnaire contained specific questions regarding the profile of the responder, such as age, sex, occupation and type of vehicle owned, which would allow the project team to assess how representative of Europe's actual population the sample population is. These results are shown in Section 5.2.

It is understood that circulating the questionnaire to colleagues and clients of project partners may produce a sample population that is more aware of, and interested in, alternative transportation technology than "real" populations. However, this may in turn suggest that the sample population is more representative of the real population of early adopters of new technologies, and thus potentially early adopters of electric vehicles, than a more broad population sample.

#### **4.2 Assumptions**

The assumptions used in this study are summarised in Table 23.

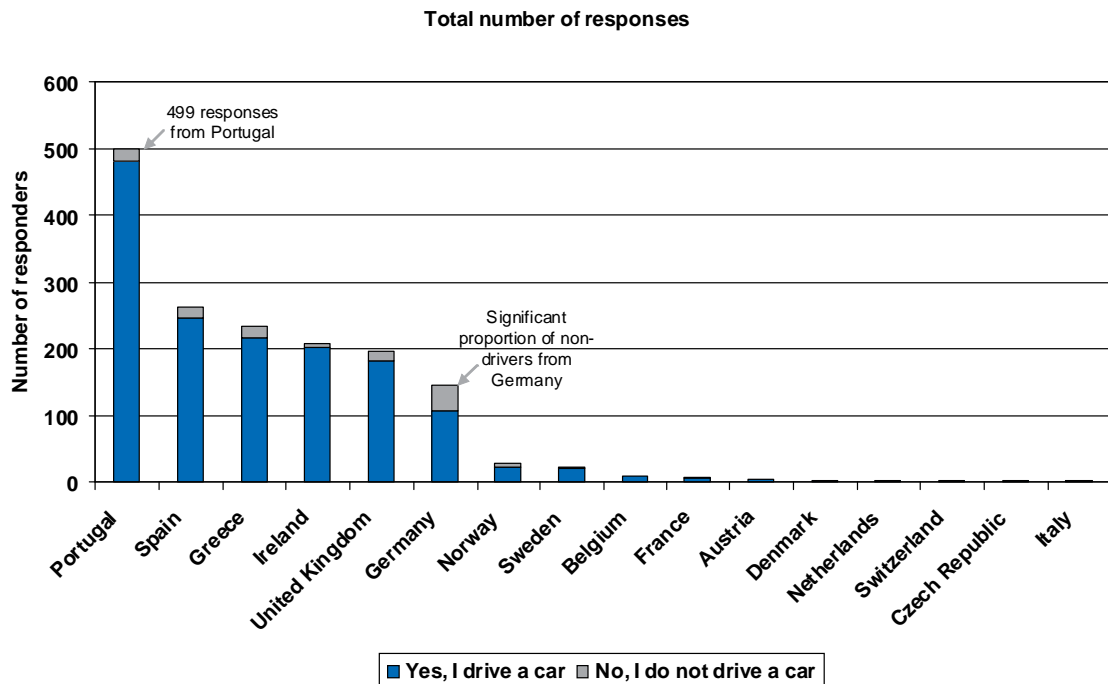
DESCRIPTION	VALUE	SOURCE
Proportion of EV in vehicle fleet	10%	Assumption based on possible medium-term EV penetration, to be verified in later tasks
Regularity of recharging	1 charge per day	Assumption based on a possible scenario driven by range anxiety
Charger power	3 kW	Standard domestic electricity supply, 230 V, 13 A, single phase
Vehicle energy requirement	0.16 kWh/km	Ricardo analysis based on V-SIM simulations
Average distance travelled between charges	40 km	Ricardo analysis based on UK Department for Transport statistics and backup up by survey results
Charger efficiency	90%	Ricardo analysis based on existing charger technology

**Table 23 – Summary of assumptions used in this study**

## 5 RESULTS

### 5.1 Number and Geographical Spread of Responses Received

A total of 1,621 questionnaire responses were received from a range of countries in Europe. Figure 67 shows the total number of responses from each country, and the split between drivers and non-drivers.



**Figure 67 – Number of responses received from each country**

Over one hundred responses were received from drivers from each of the six key countries chosen in the Description of Work, i.e. Germany, United Kingdom, Spain, Greece, Portugal and Ireland.

The study considers the impacts of transport electrification on Europe's electricity grids. As the United Kingdom has two grids, one for Great Britain controlled by National Grid and a separate grid for Northern Ireland controlled by System Operator for Northern Ireland, it was decided that the main Great Britain grid would be chosen for study rather than combining the two grids to form a unified United Kingdom grid, as in practice they are separate systems.

With the exclusion of Northern Ireland, the six countries selected for particular study represent 49% of the total European passenger car fleet. Table 24 shows the passenger car fleets of each of the countries selected for study. These fleet sizes were used as the weighting factor for all analyses that provided European average results in addition to individual country results.

COUNTRY	PASSENGER CAR FLEET
Germany	46,569,657
Great Britain	28,506,867
Spain	20,636,738
Greece	4,446,528
Portugal	4,290,000
Ireland	1,778,861
<b>Total fleet in sample countries</b>	<b>106,228,651</b>
<b>Total fleet in Europe</b>	<b>218,200,626</b>

Table 24 – Vehicle fleet in each of the selected countries [26] [37]

Figure 68 shows the geographical distribution of responders.

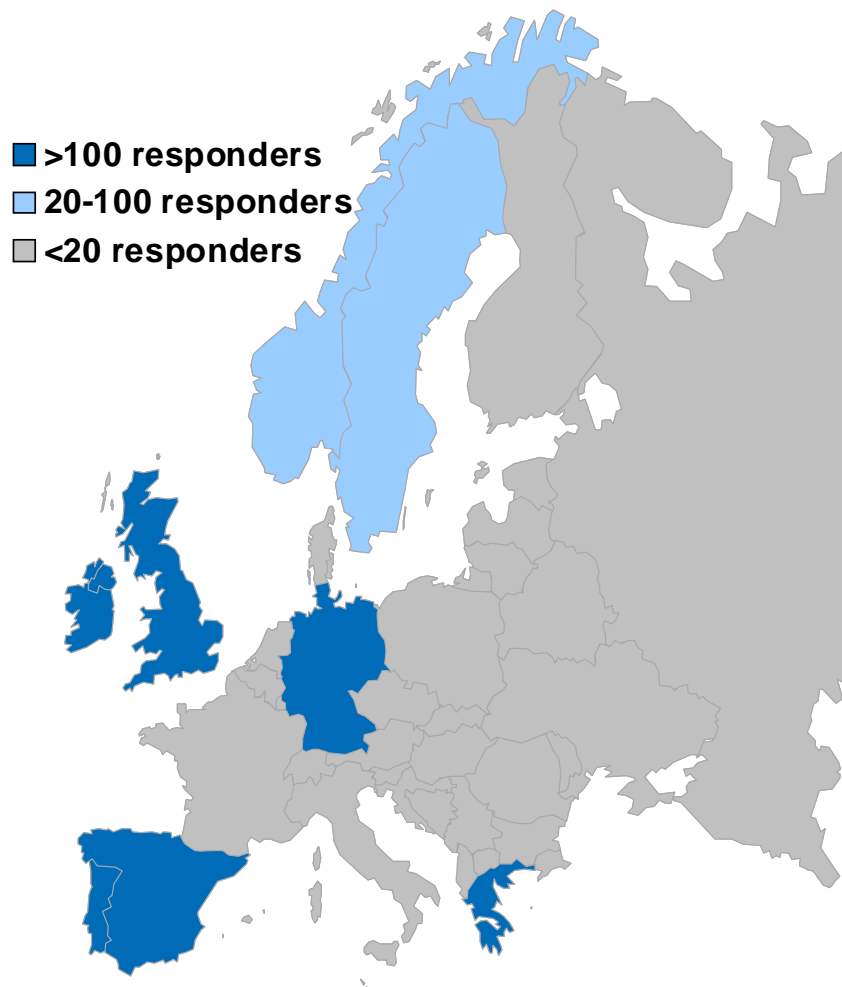
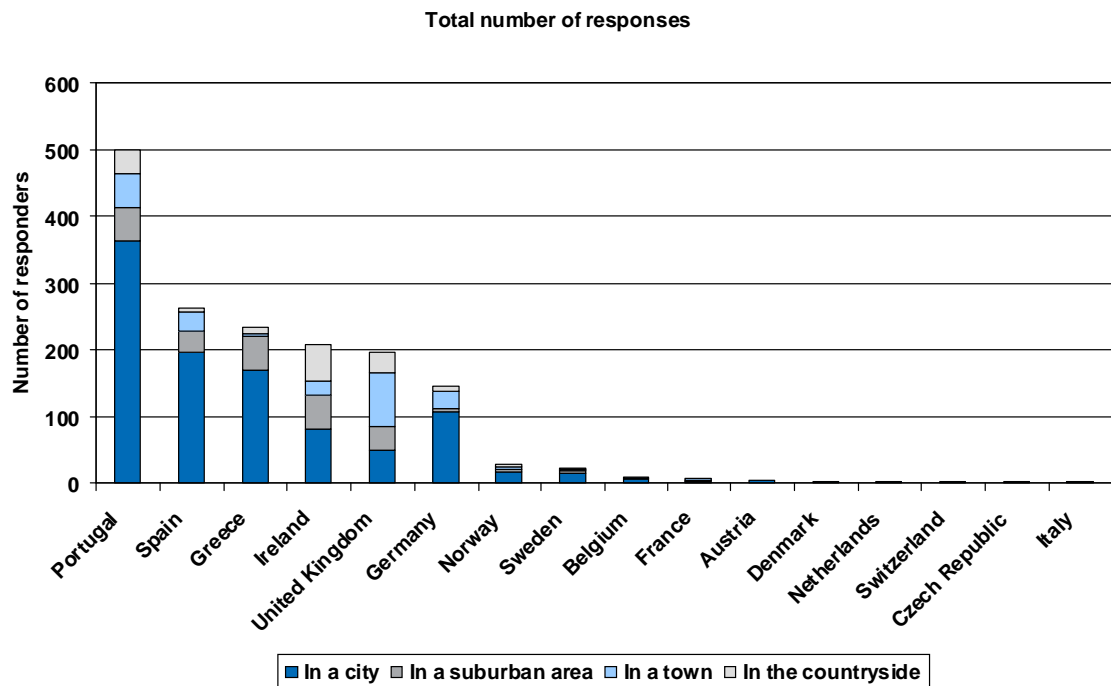


Figure 68 – Geographical distribution of survey responders

## 5.2 Profile of Questionnaire Responders

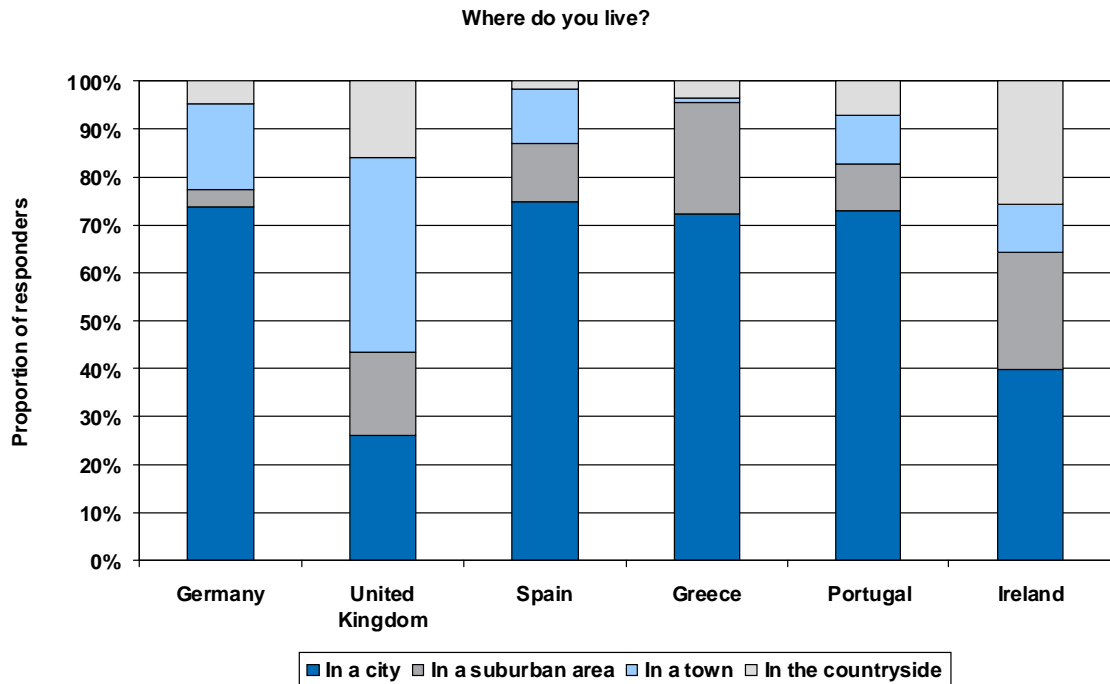
Figure 69 shows the split of responders by where they live. 63% of responders live in a city, 15% live in a suburban area, 14% live in a town and less than 10% live in the countryside.



**Figure 69 – 63% of responders live in a city, 15% live in a suburban area, 14% live in a town and <10% live in the countryside**

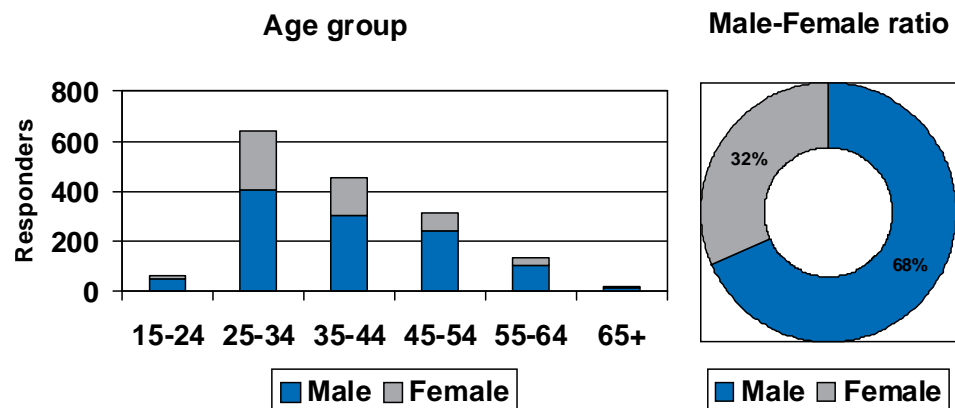
Figure 70 shows that the proportion of responders in each of the six countries selected for study living in each area type varied by country, with more responders from mainland Europe living in cities and fewer responders from the United Kingdom and Ireland that lived in cities.





**Figure 70 – The proportions of responders living in each area type varied by country**

Figure 71 shows the age and sex profile of responders. The age profile is reasonably distributed across groups from 25 to 54 years, with under-25s and over-55s under-represented. The male-female ratio is approximately two-thirds to one-third. These profiles, while not representative of the actual profiles of the European population are sufficiently diverse to ensure that no single group dominates responses. With over 1,600 responses in total, it is assumed that this sample population provides a reasonable base on which to observe patterns in behaviour and thought and on which sound conclusions may be drawn where significant results present themselves.

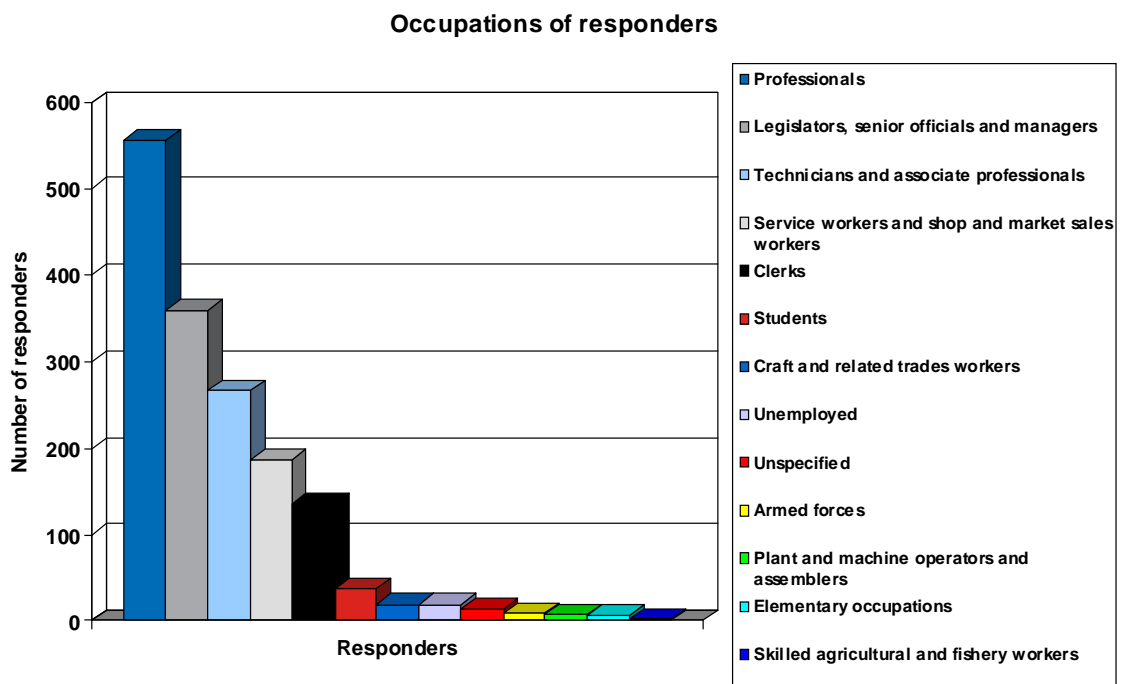


**Figure 71 – Age and sex profile of responders**





Figure 72 shows the occupations of responders, according to the International Labour Organisation’s International Standard Classification of Occupations, with the options “Student” and “Unemployed” added. The sample population was weighted towards technical and professional roles, which is probably due to the questionnaire being circulated by Project MERGE partners. Although this may deviate from the actual spread of occupations in Europe, it is suggested that this sample population may be more representative of the population of potential EV early adopters than the overall actual population of Europe and that their responses are suitable for this analysis.



**Figure 72 – Occupations of responders**

Figure 73 shows the classes of vehicle that questionnaire responders drive. 75% of responders drove cars in the supermini, small family car and large family car segments, which is in line with the real European vehicle fleet.



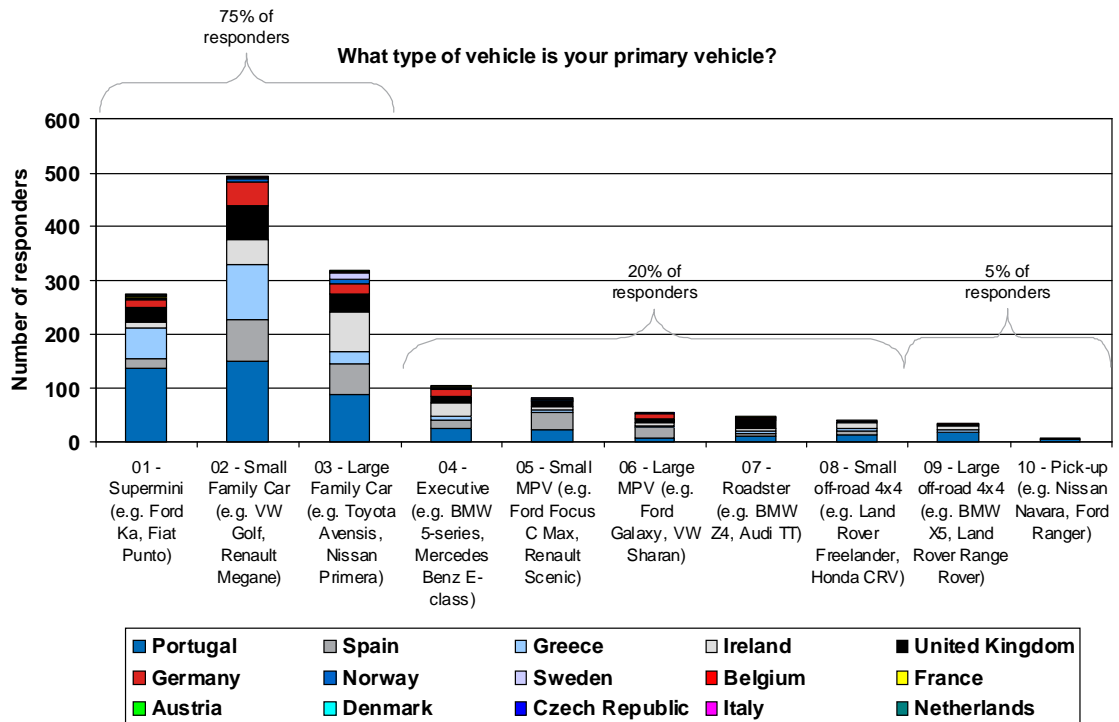


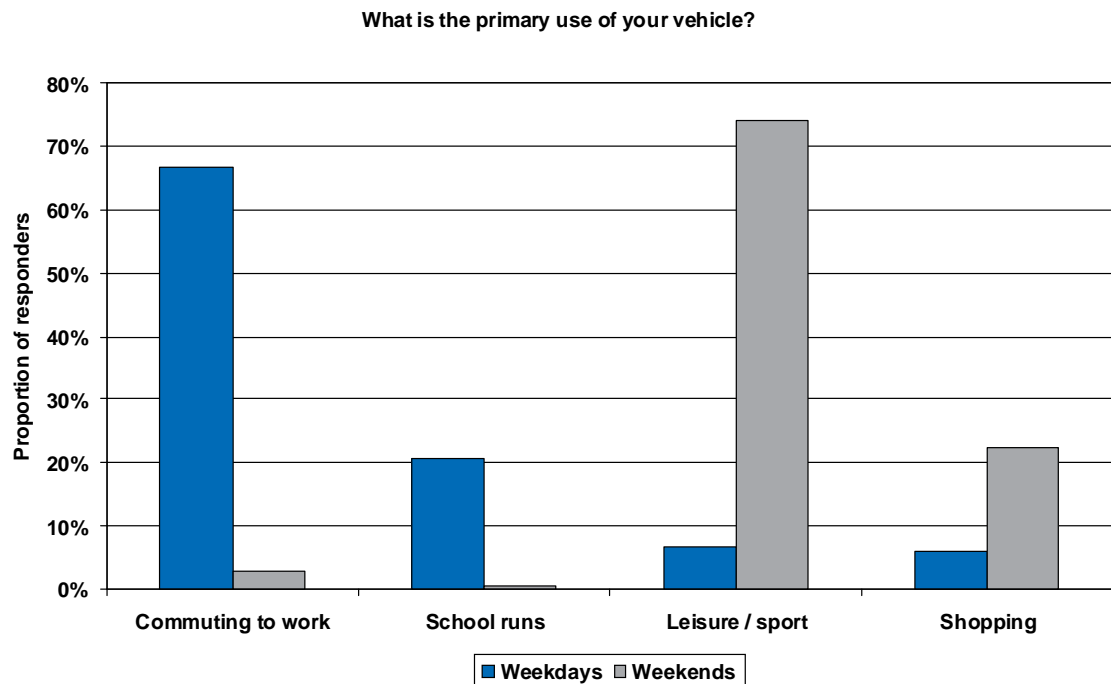
Figure 73 – The types of vehicles driven by questionnaire responders

### 5.3 Data Analysis

#### 5.3.1 Vehicle Usage and User Preferences

Figure 74 shows that the primary use of vehicles in the sample population is for commuting to work during the week and for leisure or sport at the weekend. This is in line with expectations.





**Figure 74 – Primary use of vehicles**

The survey investigated the proportion of journeys undertaken as part of regular cycles. If a vehicle is used to commute to and from work at approximately the same times each weekday, this would be considered part of a regular cycle, while weekend shopping trips may be at different times from week to week and ad-hoc use of vehicles for irregular events vary significantly in distances and timings.

Figure 75 shows that a significant proportion of journeys undertaken by the sample population is comprised of journeys that are not part of a regular cycle. The significance of this result is that the data collected for a “typical” week forms a reasonable baseline for what is likely to happen every week and that irregular use of vehicles should not significantly alter the overall data.

What proportion of your journeys are part of a regular cycle (i.e. same journey on same day each week)?

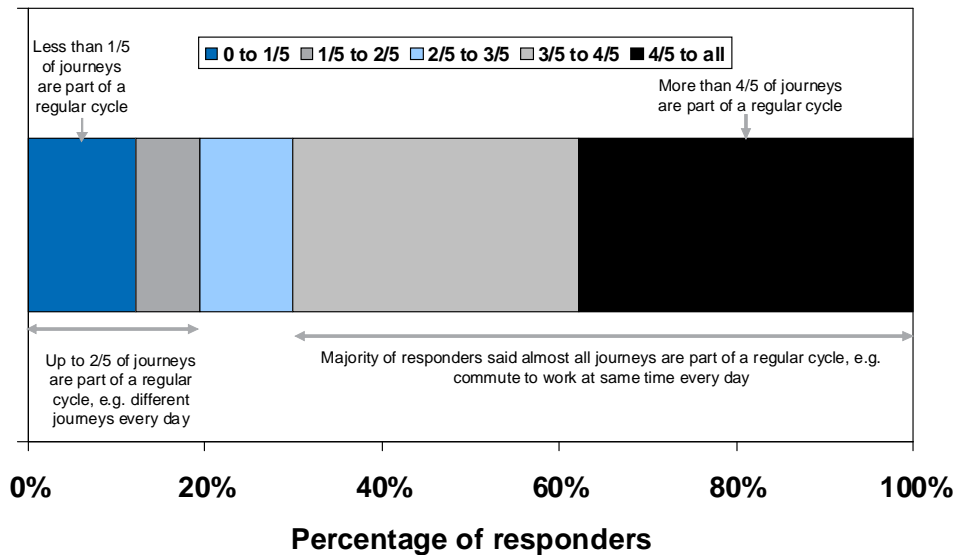
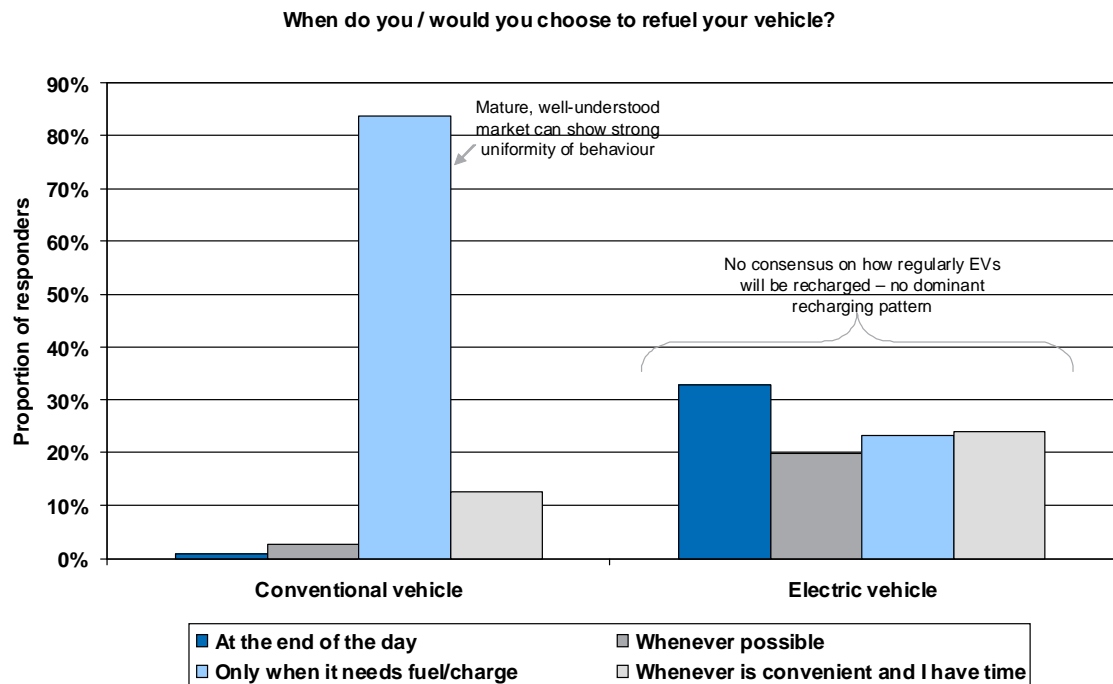


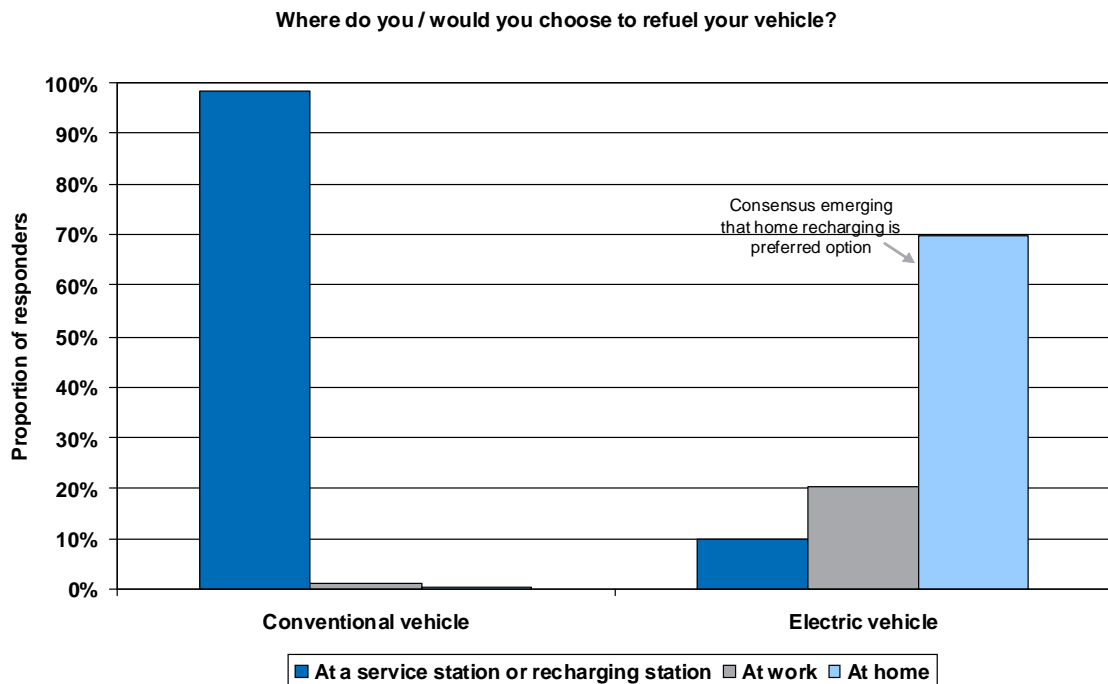
Figure 75 – Proportion of journeys that are part of a regular cycle

The survey investigated drivers' preferences for refuelling. Figure 76 shows that the majority of drivers in the sample population only refuel their vehicles when the fuel tank is nearly empty. However it also shows that this behaviour may not hold true if these drivers were to purchase an electric vehicle, as there was no consensus on the most appropriate strategy for recharging these vehicles. This result underlines the uncertainty in the general public with respect to the use and practicalities of electric vehicles.



**Figure 76 – Refuelling and recharging regularity as well as timing preferences**

Despite the lack of consensus on the timing of recharging electric vehicles, Figure 77 shows that consensus may be emerging that the preferred location of recharging is at home, with 80% of responders choosing that option. This is particularly significant in that it represents a complete change from the current preferred location of refuelling conventional vehicles, which unsurprisingly is at a retail service station.



**Figure 77 – Refuelling and recharging location preferences**

The survey investigated the extent to which drivers may take advantage of multiple tariff electricity rates to reduce the cost of electric vehicle recharging. Figure 78 shows the responses to the four questions fielded in this area. Responses to the first question showed that:

- 94% of drivers would recharge an electric vehicle at night to take advantage of lower electricity prices overnight
- 88% of drivers also said that they would choose to recharge their vehicle during the time of a cheaper tariff, whether overnight or otherwise
- Only 13% of drivers stated that they would not seek savings from multiple tariff electricity rates because electricity is already significantly cheaper than gasoline or diesel fuel
- Only 6% of drivers stated that they would not seek savings from multiple tariff electricity rates because their employer pays for their fuel so they would not personally benefit from the savings

These results provide significant confidence that developing a market and associated smart control system that incentivises charging at particular times would be attractive to the consumer in addition to the transmission system operators, regulators and governments who are proposing and developing such a system.

Where do you / would you choose to refuel your vehicle?

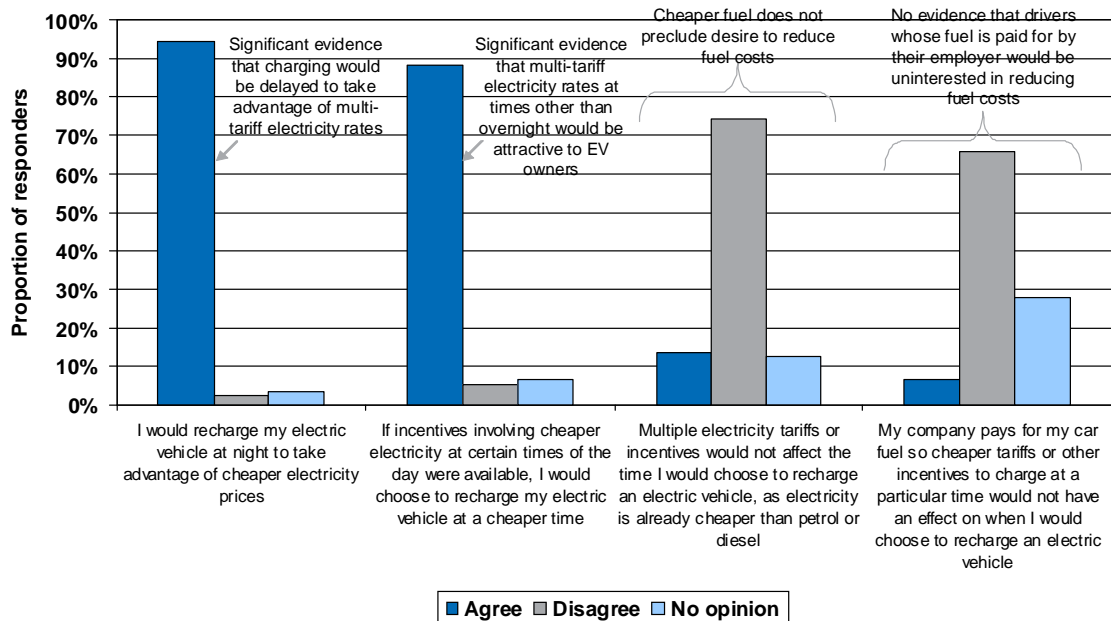
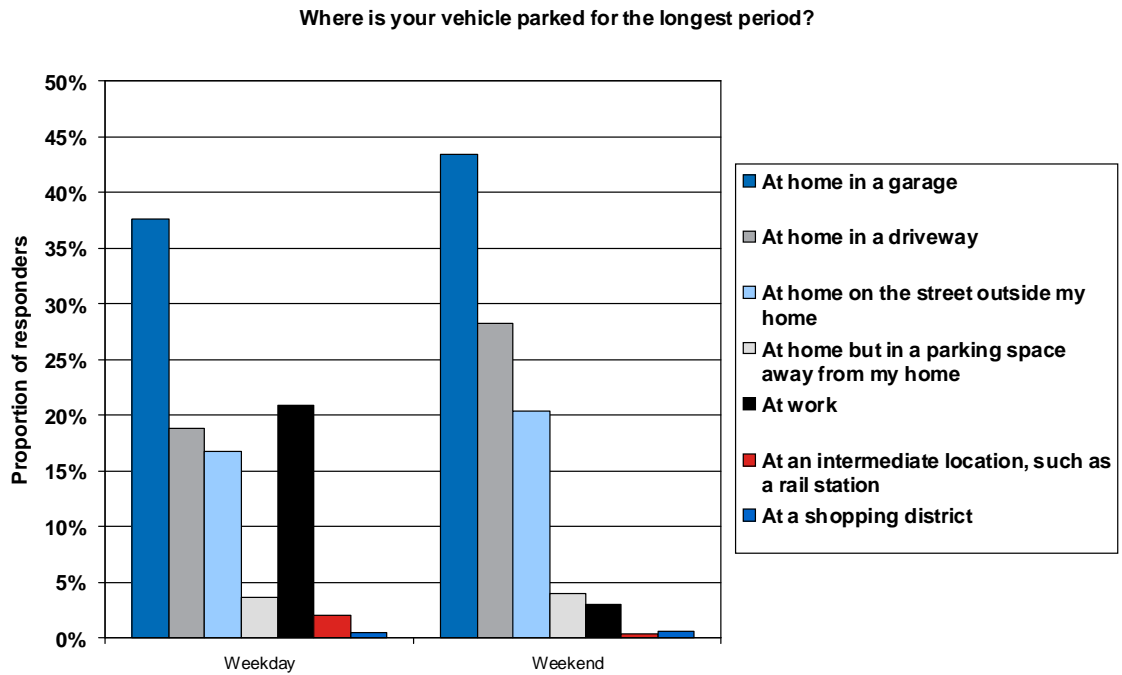


Figure 78 – Responses to questions regarding adaptability to alternative charging times to take advantage of variable tariffs

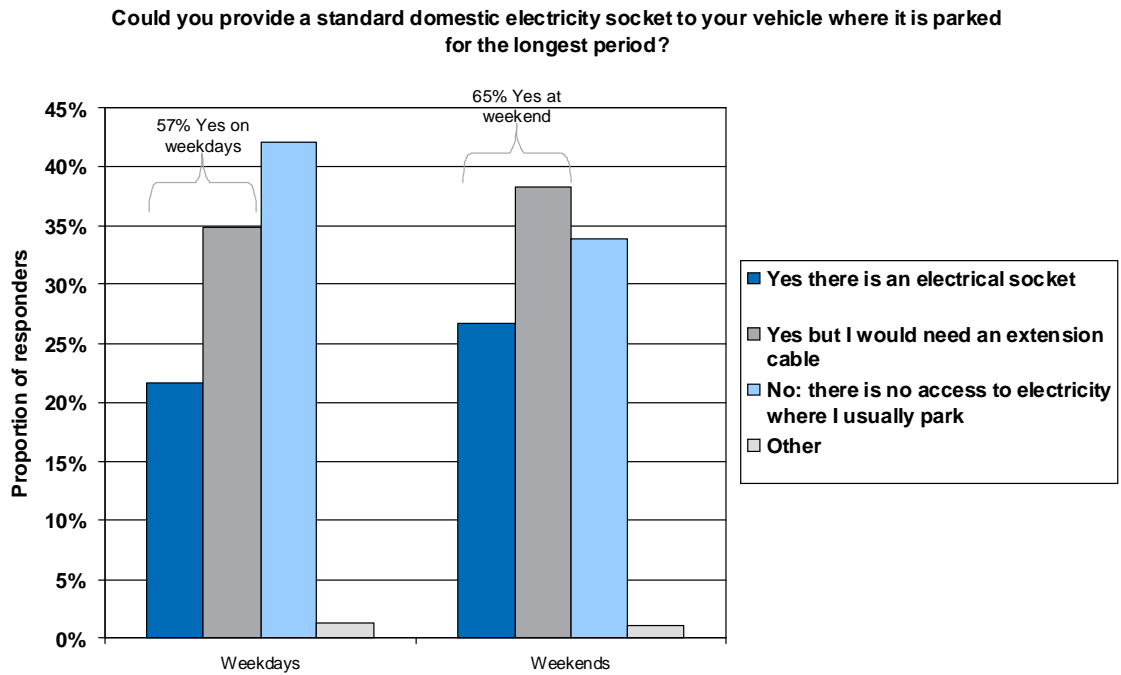
Figure 79 shows the location of survey responders' vehicles when they are parked for the longest period of time in a given day. 56% of vehicles are parked either in a garage or on a driveway on weekdays, rising to 72% on weekends. If cars parked on the street directly outside the owner's house are included, which would require providing an extension cable to the vehicle, the proportions rise to 73% on weekdays and 92% on weekends. This shows that a significant proportion of vehicle users should be capable of recharging electric vehicles at home.





**Figure 79 – Location of vehicle for longest period of inactivity**

Figure 80 shows the results of a more direct question, asking if drivers could provide a standard domestic electricity socket to the place their car is parked for the longest period of the day. 57% of drivers reported that they could provide a supply of electricity to their car where it is parked for the longest period on weekdays, rising to 65% at weekends. These numbers are similar to the proportions reporting that their cars are kept in a garage or on a driveway, but may suggest that the option of providing an extension cable to a car parked on the street directly outside the owner's house is either undesirable from a convenience, security or safety perspective or possibly just not known to be a viable option.



**Figure 80 – Access to electricity at parking space**

### 5.3.2 Average Distances Travelled Per Day

Statistics are often gathered on distances travelled per journey but it is more useful to understand distances travelled per day when modelling the effect of using EV in place of conventional vehicles, given the assumption that the vehicles will be charged once per day, rather than being charged between each journey undertaken. The survey asked drivers to estimate the average distance they travel **per day** on a typical weekday and **per day** on a typical day at the weekend. The following results summarise the data gathered on daily distances travelled, and how this varies from country to country.

#### 5.3.2.1 European Average

Figure 81 shows the proportion of vehicles travelling, on average, up to certain distances per day on weekdays and weekends. For example, 50% of drivers travel up to 30 km on an average weekday and up to 40 km on an average day at the weekend. The data appear to plateau at an average daily distance of up to 110 km, up to which point 85% of vehicles are included.

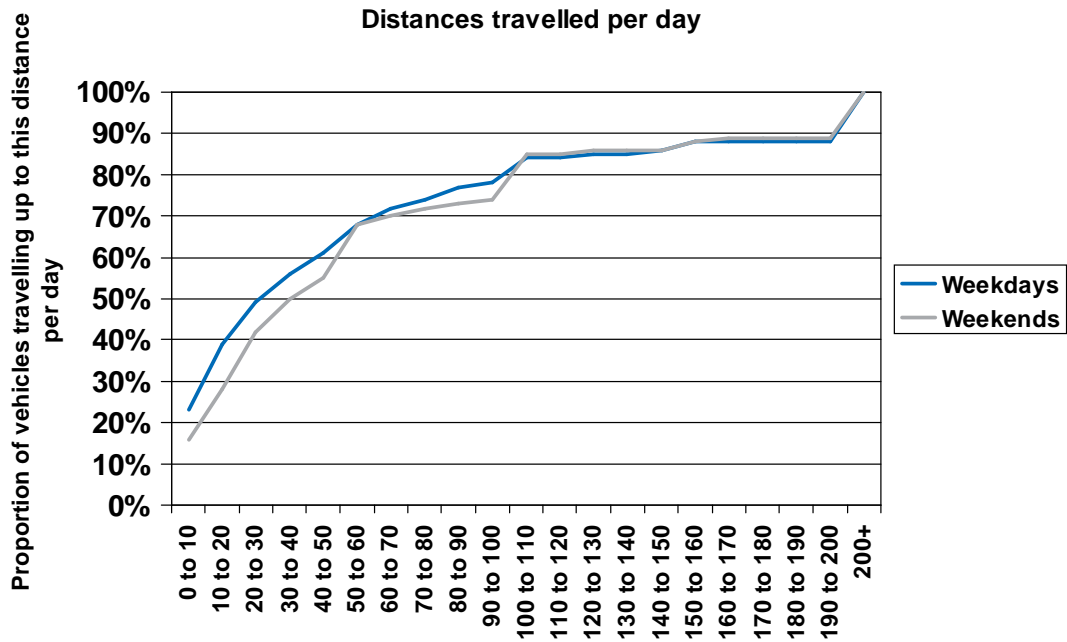


Figure 81 – Distances, in km, travelled per day on weekdays and weekend days, European average

### 5.3.2.2 Variation between Countries in Distance Travelled on Weekdays

Figure 82 shows the variation between countries in distances travelled per day on weekdays. The trends for Germany, the United Kingdom, Greece and Portugal are quite similar, while the data for Spain and Ireland seem to show larger distances being covered in these countries compared to the other four. Between 83% and 91% of drivers in Germany, the United Kingdom, Greece and Portugal travel up to 110 km per day on weekdays, the data point noted in the previous section, while 64% and 68% of drivers in Spain and Ireland, respectively, travelled up to that distance per day on weekdays.

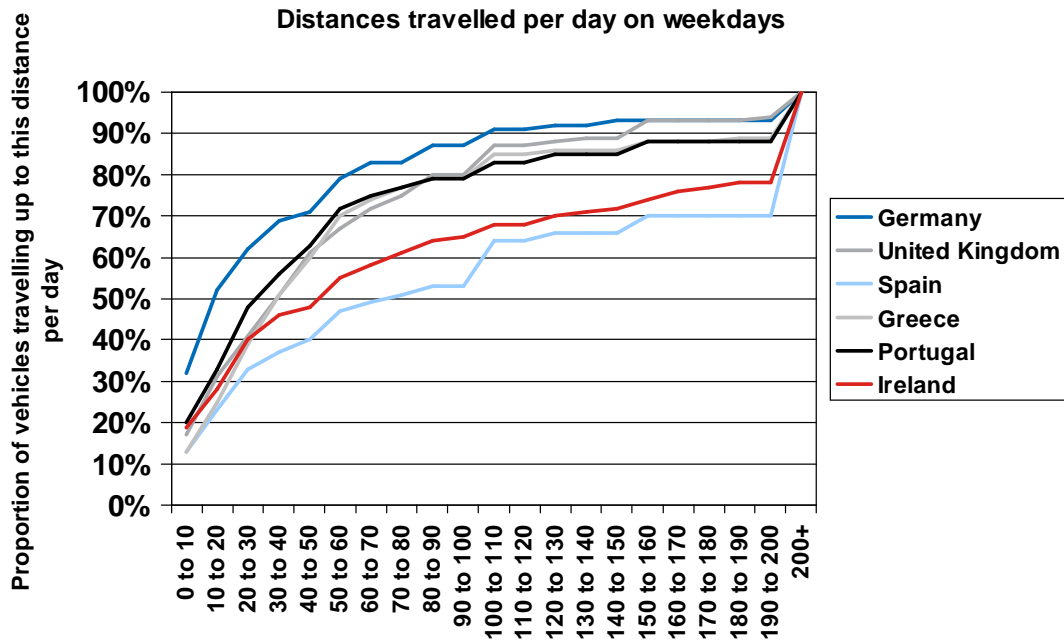


Figure 82 – Variation of distances, in km, travelled per day on weekdays, by country

### 5.3.2.3 Variation between Countries In Distance Travelled on Weekends

Figure 83 shows the variation between countries in distances travelled per day on weekends. The trends for each country are closer to each other than they were for the weekend data, but with Germany and the United Kingdom showing higher proportions of drivers travelling shorter distances per day on weekends than the other four countries. Between 75% and 89% of drivers from all six countries travel up to 110 km per day on weekends.

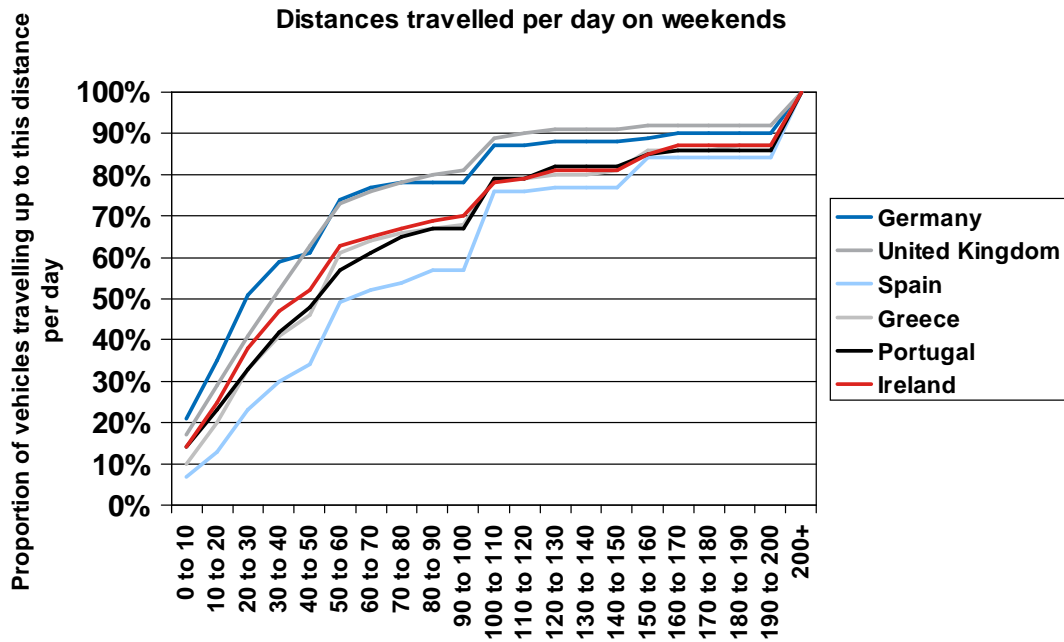
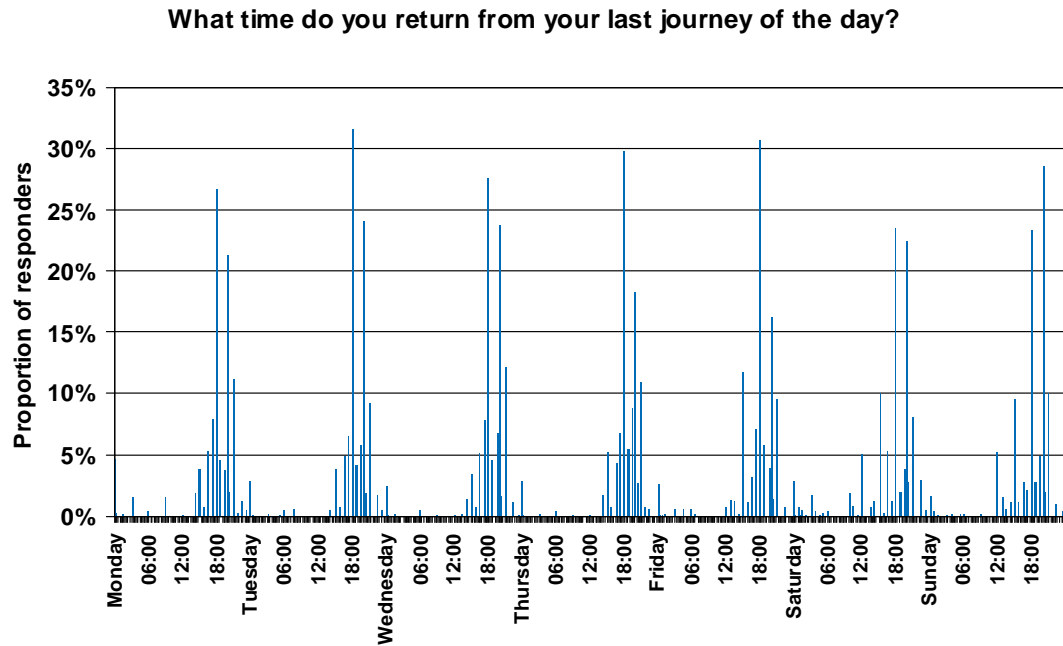


Figure 83 – Variation of distances, in km, travelled per day on weekends, by country

### 5.3.3 Profile of Time of Return from Final Journey of Day

The time that drivers return from their last journey of the day provides a basis for the most straightforward model of electric vehicle charging, whereby drivers plug in as soon as they return from this journey and do not take advantage of multiple tariff electricity prices by delaying charging until a cheaper rate is available. The survey asked responders to input the time that they return from their last journey of each day of the week.

Figure 84, which represents a European average of the survey results weighted by the number of vehicles in each country, shows that there is a regular pattern to the times that drivers return from their last journeys of the day, with the vast majority returning between 17:00 and 21:00, with a significant peak every day at 18:00 and another at 20:00.



**Figure 84 – Profile of time of return from last journey of the day, European average**

There was little variation between the six countries in the profiles of times of return from the last journey of the day, so the individual profiles for each country will not be discussed in detail, but are provided in Appendix 1.



## 5.4 Suitability of Drive Patterns to BEV and PHEV

BEV and PHEV will not be appropriate for all patterns of vehicle use. A usage pattern consisting of long journeys will not be appropriate to a BEV whose range is shorter than total distance covered per day unless it is possible to recharge as quickly and easily as a conventional vehicle can refuel. While PHEV eliminate the range anxiety issues of BEV, it is not appropriate for a usage pattern that consists of significant distances covered at high speeds, such as on motorways, as the additional mass of the battery and electric drive put the vehicle at a disadvantage compared to conventional gasoline or diesel engines, which already operate relatively efficiently at high speeds.

### 5.4.1 Suitability of Drive Patterns to BEV

BEV is suited best to usage patterns with short journey lengths between periods at their base where they can be recharged. The range of a BEV must be larger than a driver's average daily distance to accommodate for journeys longer than the average. Average daily distances were examined in section 5.3.2 and it was found that 85% of drivers travelled up to 110 km per day on average, While 88% travelled up to 200 km per day on average. This shows that there is a law of diminishing returns in terms of the additional proportion of drivers that can be accommodated by additional range.

Many electric vehicle manufacturers aim to produce vehicles whose range is a round number of miles. A range of 100 miles, or 160 km, is becoming a common choice of specification, being selected for the in-production Nissan Leaf [38] and Mitsubishi i-MiEV [39], for example. This particular specification, being 50 km further than the 110 km per day average distance from the survey data seems an appropriate size for the 85% of drivers that fall into that category.

### 5.4.2 Suitability of Drive Patterns to PHEV

Although a BEV needs to have a range longer than the average distance covered between charges, a PHEV does not necessarily need to have an EV range that is longer than the average distance covered between charges. This is because the conventional internal combustion engine drivetrain can provide the necessary range extension to cover distances that are longer than the average distance between charges. A law of diminishing returns will apply if a PHEV is specified with an EV range longer than the average distance covered as the battery will cost proportionally more, but the additional capacity will only be utilised for a small number of outlier longer journeys.

The proportion of vehicle kilometres travelled in EV mode in a PHEV will depend on the EV range of the vehicle and the distribution of journey







lengths that a driver undertakes. If the EV range of a PHEV is 40 km and a driver completes a 40 km journey, then recharges, and then completes an 80 km journey, it is important to understand that the proportion of distance travelled in EV mode is not 33% (i.e. counting the 40 km journey but not the 80 km journey), but 67%, (counting the 40 km journey and the first 40 km of the 80 km journey).

There is a wide variation in EV ranges for near-production and concept PHEV models so, unlike BEV, there is no “typical” EV range specification emerging as a standard. Claimed PHEV EV ranges vary from 22 km for the Toyota Plug-in Prius [40], through 50 km for the Audi A1 e-tron [41], 64 km for the Chevrolet Volt [42] and Chrysler Town and Country EV [43], up to 100 km for the BYD F3DM [44]. It must be noted that EV range is highly dependent on driving style and drive cycle. For this reason, care must be taken when discussing manufacturers’ claimed figures.

Figure 85 shows the estimated proportion of distance travelled in EV mode for PHEV with EV ranges from 5 to 150 km. This was developed by analysing the distribution of different distances travelled per day and assessing the proportion of these distances that could be undertaken in EV mode if a PHEV was to operate in EV mode whenever there is sufficient battery capacity. From the chart, an EV range of approximately 18 km would yield a proportion of vehicle kilometres travelled in EV mode of 50%, while an EV range of 65 km would lead to 85% of distance travelled being completed in EV mode and an EV range of 100 km would lead to 94% of distance travelled being completed in EV mode.

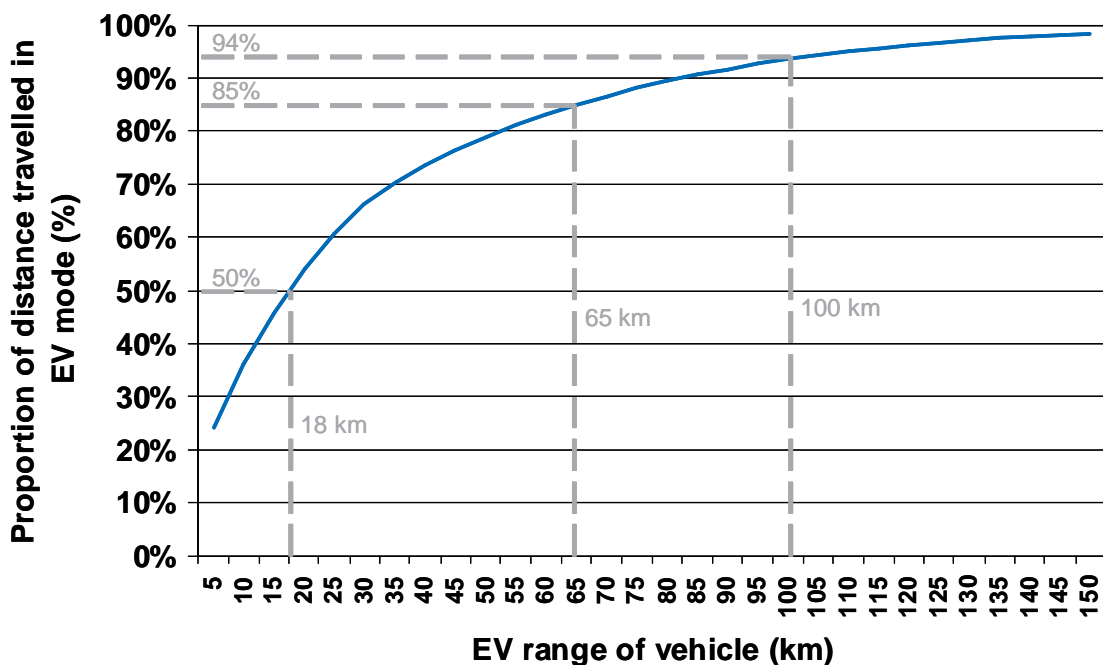


Figure 85 – Proportion of distance travelled in EV mode for varying EV range of a PHEV

## 5.5 Impacts of Transport Electrification on the Grid

### 5.5.1 Baseline Load on the Grid

The capability of electricity grids to incorporate significant levels of electric vehicle charging depends largely on the existing electricity demand, while the capability of transmission system operators to create a market that incentivises load levelling depends on the profile of electricity demand throughout the day. The baseline electricity demand profiles for the six countries of interest were examined for the winter months of 2009, as this season represents the highest daily demand. Figure 86 shows the daily profiles of electricity demand for the six key countries of interest.

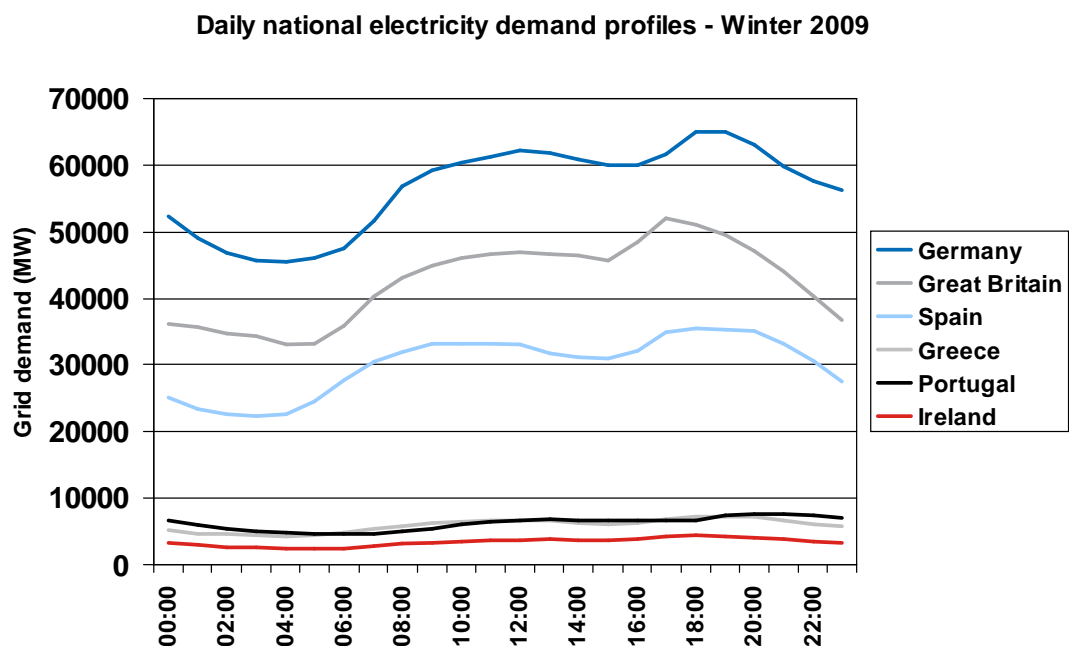


Figure 86 – Daily national electricity demand profiles, Winter 2009 [45] [46] [47]

Figure 87 shows the same data in terms relative to each country's daily peak demand to compare the shape of the profiles. All six countries show significant “valley” periods overnight, relative stability during office hours and significant peaks in the evening around 18:00. It is interesting to note that Portugal's demand profile appears to be shifted to about an hour later than the other five countries, which may be due to the country being in the GMT time zone but is geographically part of mainland Europe, bordering Spain, which is in the CET time zone.

Daily national electricity demand profiles - Winter 2009

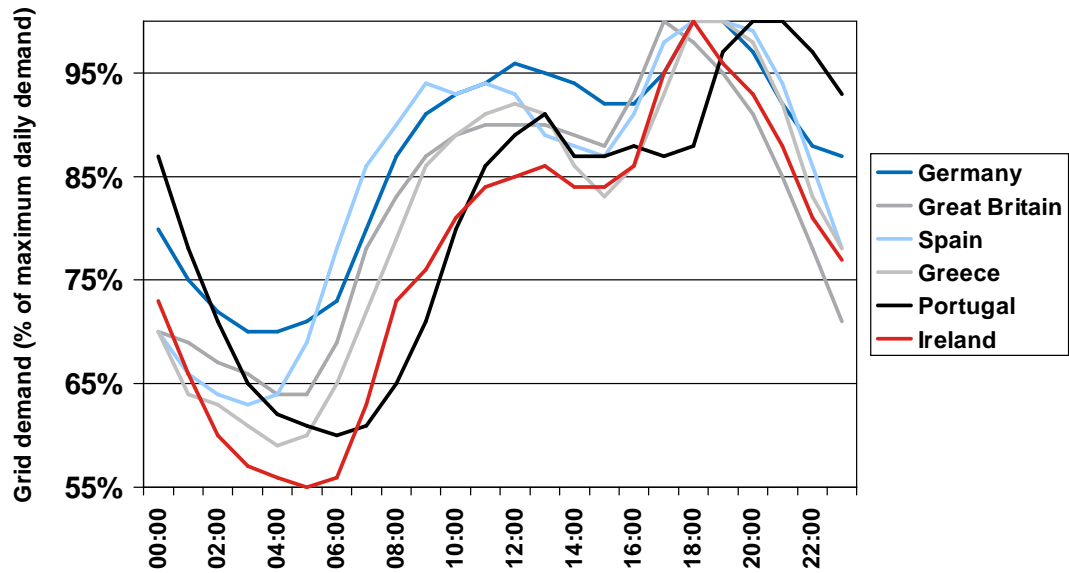


Figure 87 – Daily electricity demand profiles relative to each country's daily peak demand, Winter 2009 [45] [46] [47]. Note Portugal's demand appears to be shifted to the right-hand-side of the other five countries

## 5.5.2 Impact of Dumb Charging Scenario

The dumb charging scenario assumes that all vehicles are plugged in, and begin charging, immediately when they return from their last journey of the day. This is the most straightforward scenario, with no smart control of charging by the utility, and no smart usage of low tariff electricity by the vehicle owner. This provides the baseline for the effect of introducing significant penetrations of electric vehicles, if no action is taken to optimise the effects of the increase in grid demand.

The scenarios were applied to all six countries, using the profiles of times of return from last journeys of the day, assuming a 10% penetration of EV in the total vehicle fleet, an average daily distance travelled of 40 km and a charge rate of 3 kW. The results that follow show the EV charging loads stacked on top of the baseline demands for each country. The EV charging loads are shown in isolation in Appendix 2.

### 5.5.2.1 Germany

Figure 88 shows the impact on Germany's electricity network of introducing a penetration of electric vehicles of 10% of its total vehicle fleet. The peak load of the baseline demand was 65,022 MW at 18:00. The peak EV demand was 8,887 MW at 20:00. The addition of the EV demand to the baseline demand created a new peak of 71,997 MW at 20:00.

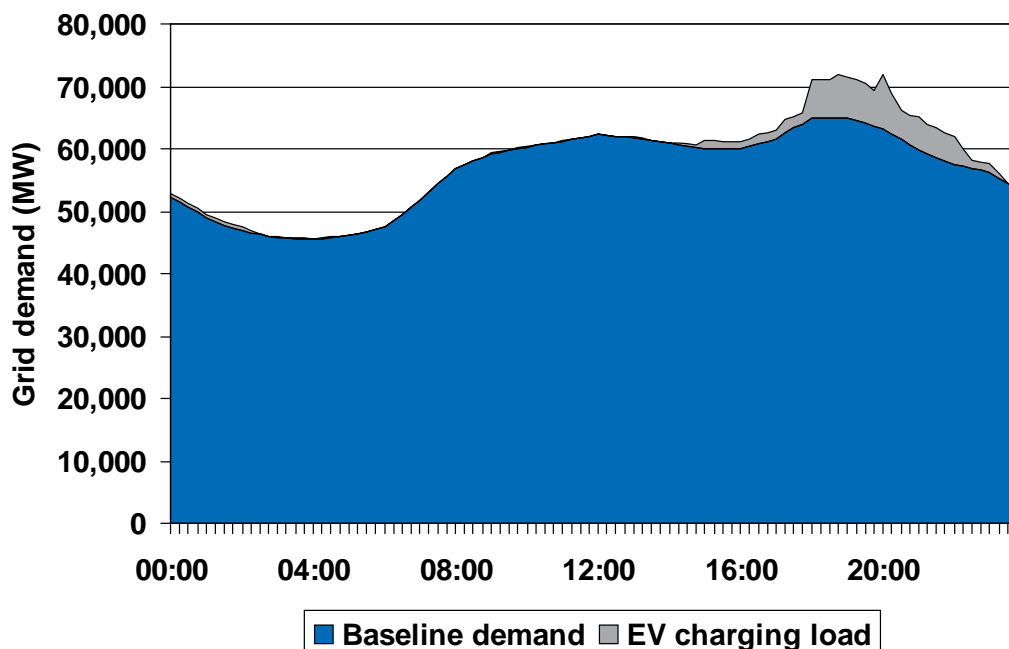


Figure 88 – Effect of dumb charging scenario on Germany's electricity demand

## Great Britain

Figure 89 shows the impact on Great Britain's electricity network of introducing a penetration of electric vehicles of 10% of its total vehicle fleet. The peak load of the baseline demand was 51,970 MW at 17:00. The peak EV demand was 5,596 MW at 20:00. The addition of the EV demand to the baseline demand created a new peak of 56,158 MW at 18:00.

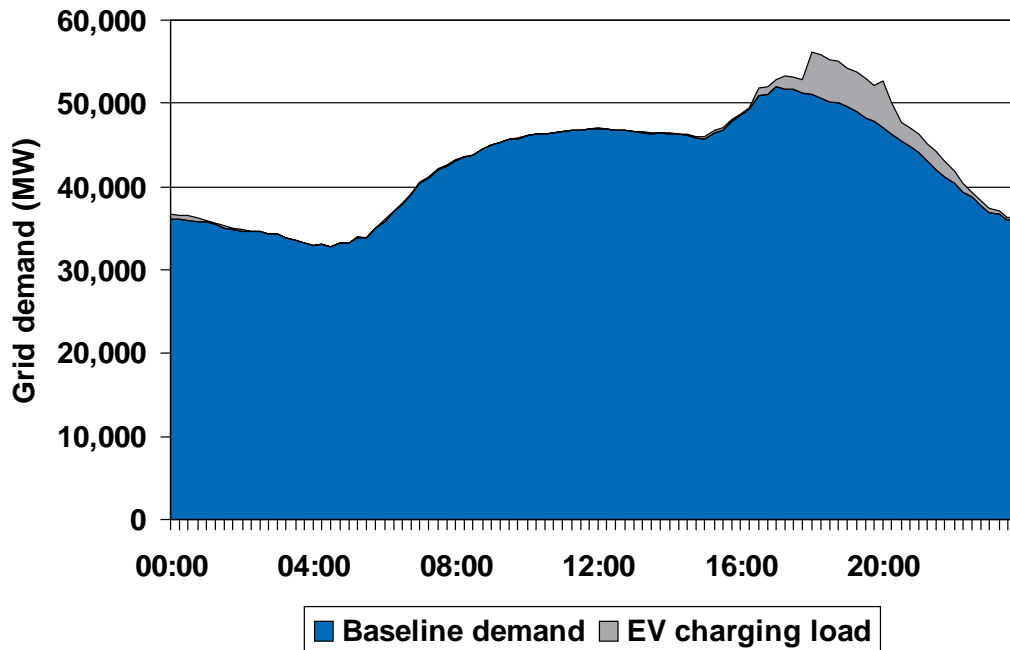


Figure 89 – Effect of dumb charging scenario on Great Britain's electricity demand

### 5.5.2.2 Spain

Figure 90 shows the impact on Spain's electricity network of introducing a penetration of electric vehicles of 10% of its total vehicle fleet. The peak load of the baseline demand was 35,508 MW at 18:00. The peak EV demand was 4,033 MW at 21:00. The addition of the EV demand to the baseline demand created a new peak of 37,912 MW at 20:00.

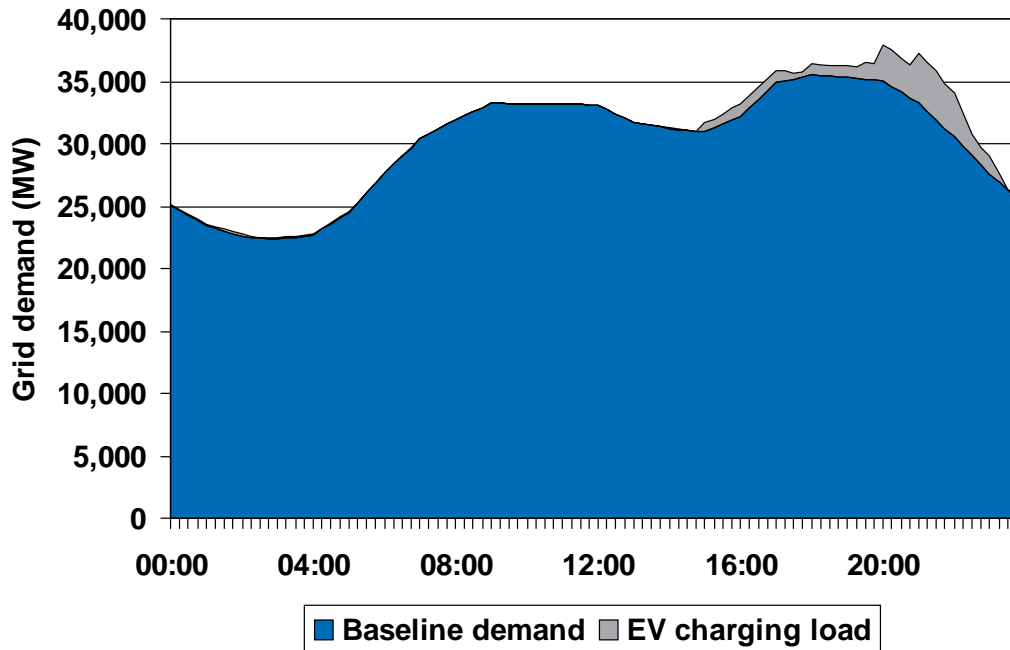


Figure 90 – Effect of dumb charging scenario on Spain's electricity demand

### 5.5.2.3 Greece

Figure 91 shows the impact on Greece's electricity network of introducing a penetration of electric vehicles of 10% of its total vehicle fleet. The peak load of the baseline demand was 7,339 MW at 18:30. The peak EV demand was 687 MW at 20:00. The addition of the EV demand to the baseline demand created a new peak of 7,902 MW at 20:00.

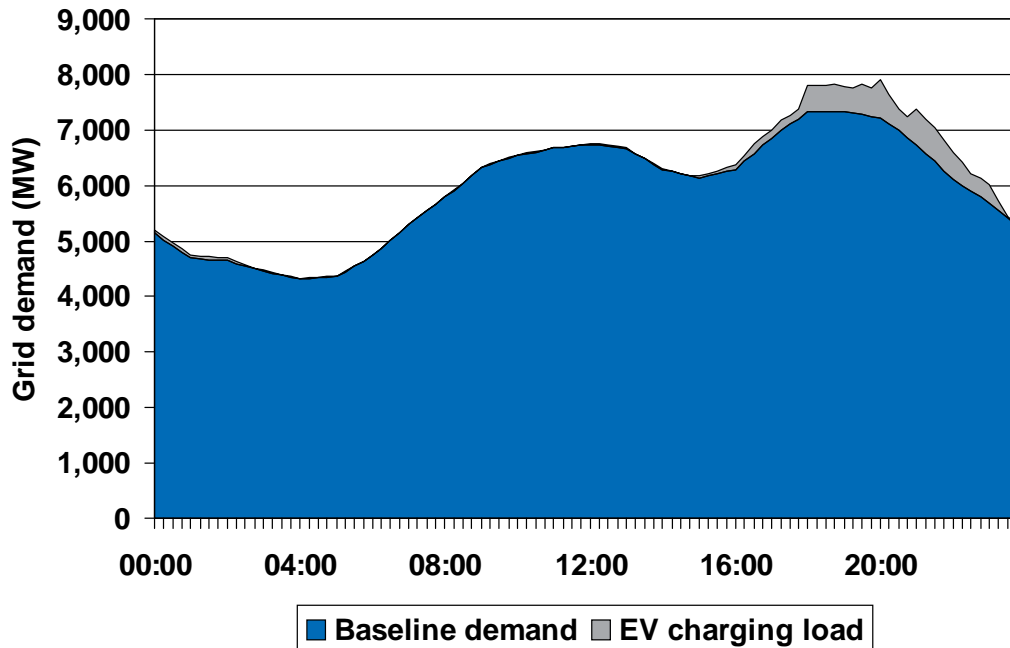


Figure 91 – Effect of dumb charging scenario on Greece's electricity demand

#### 5.5.2.4 Portugal

Figure 92 shows the impact on Portugal's electricity network of introducing a penetration of electric vehicles of 10% of its total vehicle fleet. The peak load of the baseline demand was 7,622 MW at 20:15. The peak EV demand was 948 MW at 20:00. The addition of the EV demand to the baseline demand created a new peak of 8,561 MW at 20:00.

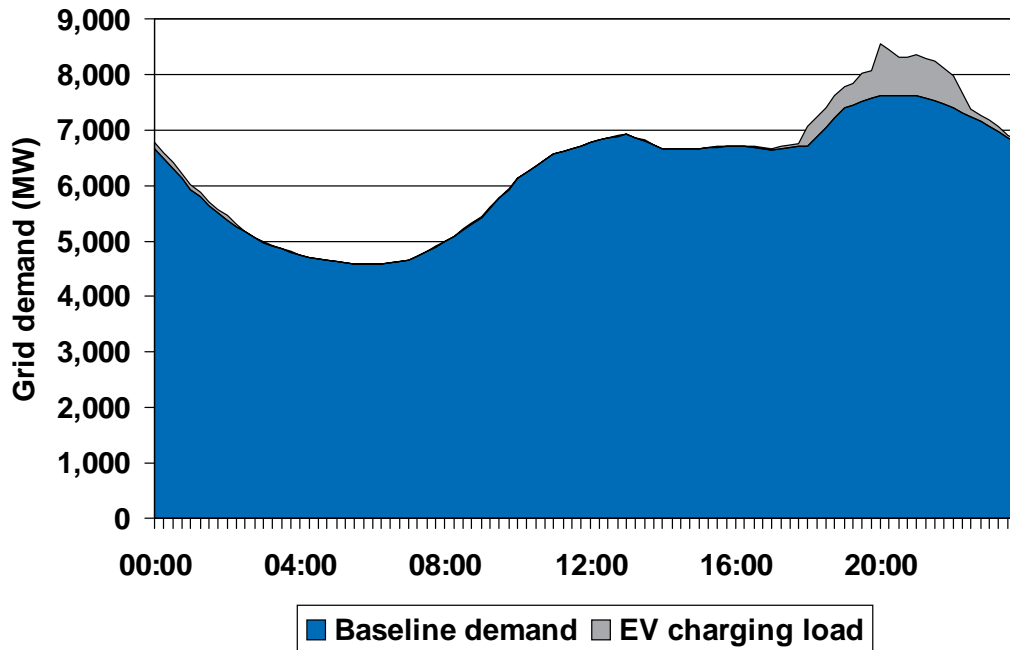


Figure 92 – Effect of dumb charging scenario on Portugal's electricity demand



### 5.5.2.5 Ireland

Figure 93 shows the impact on Ireland's electricity network of introducing a penetration of electric vehicles of 10% of its total vehicle fleet. The peak load of the baseline demand was 4,454 MW at 17:45. The peak EV demand was 368 MW at 20:00. The addition of the EV demand to the baseline demand created a new peak of 4,720 MW at 18:00.

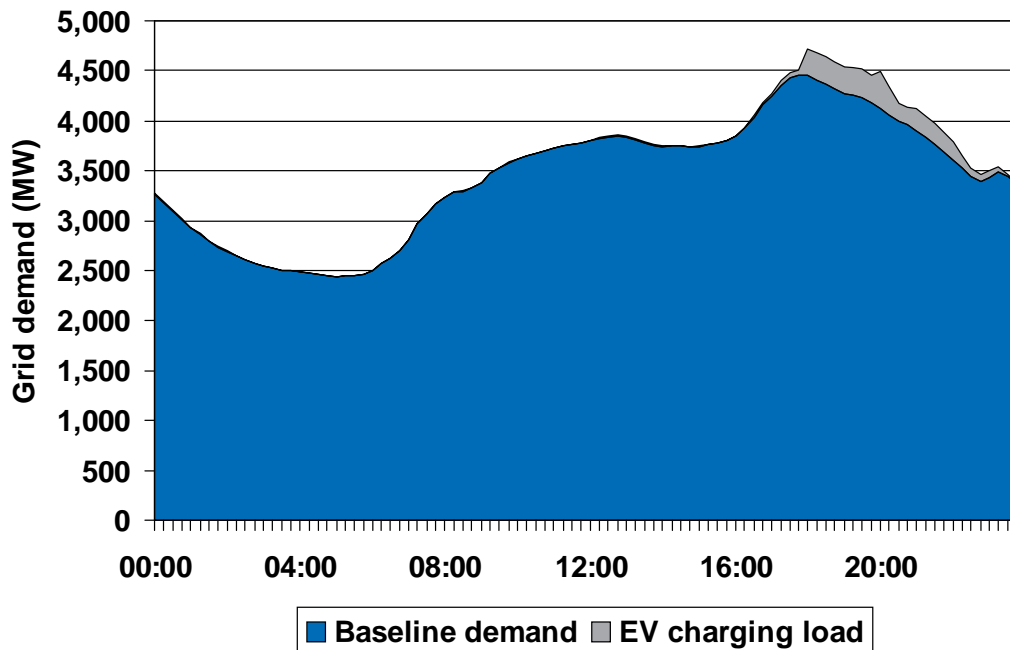


Figure 93 – Effect of dumb charging scenario on Ireland's electricity demand

### 5.5.2.6 Summary of Impacts of Dumb Charging Scenario

Table 25 summarises the impacts of the dumb charging scenario. All six countries had new peak demands created at times different to that of the baseline peak demands.

COUNTRY	BASELINE PEAK	NEW PEAK	INCREASE IN PEAK DEMAND	EV DEMAND PEAK
Germany	65,022 MW at 18:00	71,977 MW at 20:00	11%	8,887 MW at 20:00
Great Britain	51,970 MW at 17:00	56,158 MW at 18:00	8%	5,596 MW at 20:00
Spain	35,508 MW at 18:00	37,912 MW at 20:00	7%	4,033 MW at 21:00
Greece	7,339 MW at 18:30	7,902 MW at 20:00	8%	687 MW at 20:00
Portugal	7,622 MW at 20:15	8,561 MW at 20:00	12%	948 MW at 20:00
Ireland	4,454 MW at 17:45	4,720 MW at 18:00	6%	368 MW at 20:00

Table 25 – Summary of impacts of dumb charging scenario



### 5.5.3 Impact of Smart Charging Scenario

The smart charging scenario assumes that a control system can be put in place that can instruct specific chargers to begin or stop charging, or limit charge rate, so that the total demand for EV charging at a particular time can be dictated by the system. The methods of operation of this system are not considered in this task as further tasks in Project MERGE will specify the systems that can be put in place, so in this task, it is assumed that this type of smart control is implemented. This scenario represents the ideal situation where the overall load on the grids is levelled, so that valleys of demand are filled and existing peaks are not increased.

The scenarios were applied to all six countries, moving all charging to the night-time valley periods, assuming a 10% penetration of EV in the total vehicle fleet, an average daily distance travelled of 40 km and a charge rate of 3 kW. The results that follow show the EV charging loads stacked on top of the baseline demands for each country. The EV charging loads are shown in isolation in Appendix 3.

For all countries except for Greece, the maximum charging load reduces in the smart charging scenario compared to the dumb charging scenario. This is because the dumb charging scenarios constitute significant proportions of vehicles starting to charge in a short timeframe when they return from their last journey of the day, while valley periods overnight allow the charging to be spread over a longer timeframe. In the case of Greece, there was an increase in maximum EV charging demand. This is because profile of times at which vehicles return from their last daily journeys is better distributed in Greece than in the other five countries. Greece has two local maxima in EV charging demand for the dumb charging scenario, at 20:00 and 21:00, which can be seen in Figure 110 on page 62, while the other countries have one local maximum.



### 5.5.3.1 Germany

Figure 94 shows the impact on Germany's electricity network of introducing a penetration of electric vehicles of 10% of its total vehicle fleet using smart control to move charging to the night-time valley period. The peak load of the baseline demand was 65,022 MW at 18:00, which was not altered by the addition of the EV charging load. The peak EV demand was 6,740 MW at 04:00, down 24% from the peak EV demand for the dumb charging scenario of 8,887 MW at 20:00.

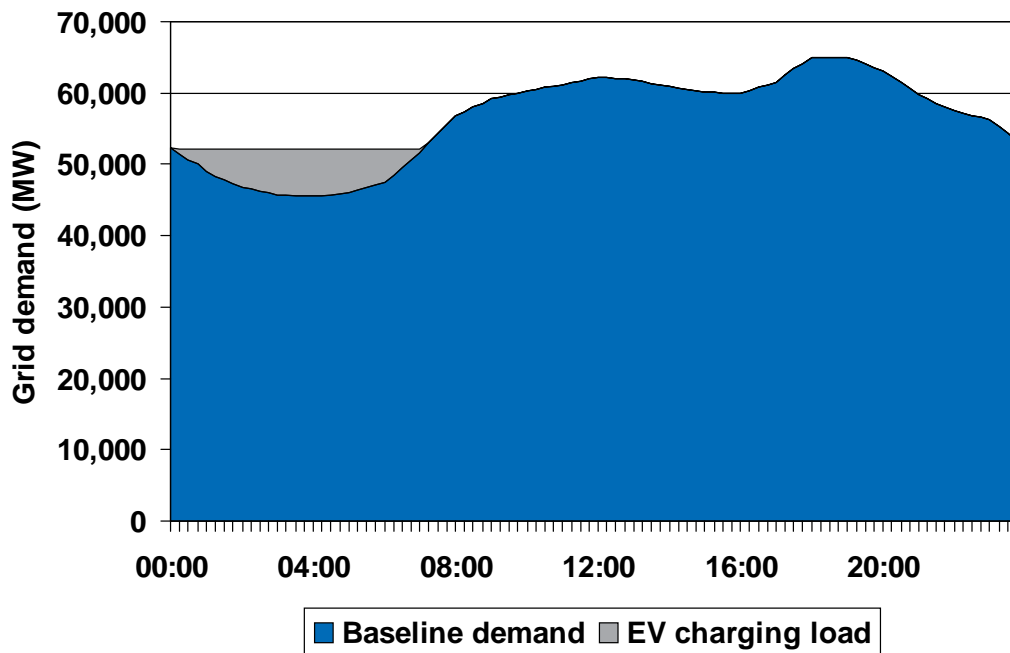


Figure 94 – Effect of smart charging scenario on Germany's electricity demand

### 5.5.3.2 Great Britain

Figure 95 shows the impact on Great Britain's electricity network of introducing a penetration of electric vehicles of 10% of its total vehicle fleet using smart control to move charging to the night-time valley period. The peak load of the baseline demand was 51,970 MW at 17:00, which was not altered by the addition of the EV charging load. The peak EV demand was 4,756 MW at 04:30, down 15% from the peak EV demand for the dumb charging scenario of 5,596 MW at 20:00.

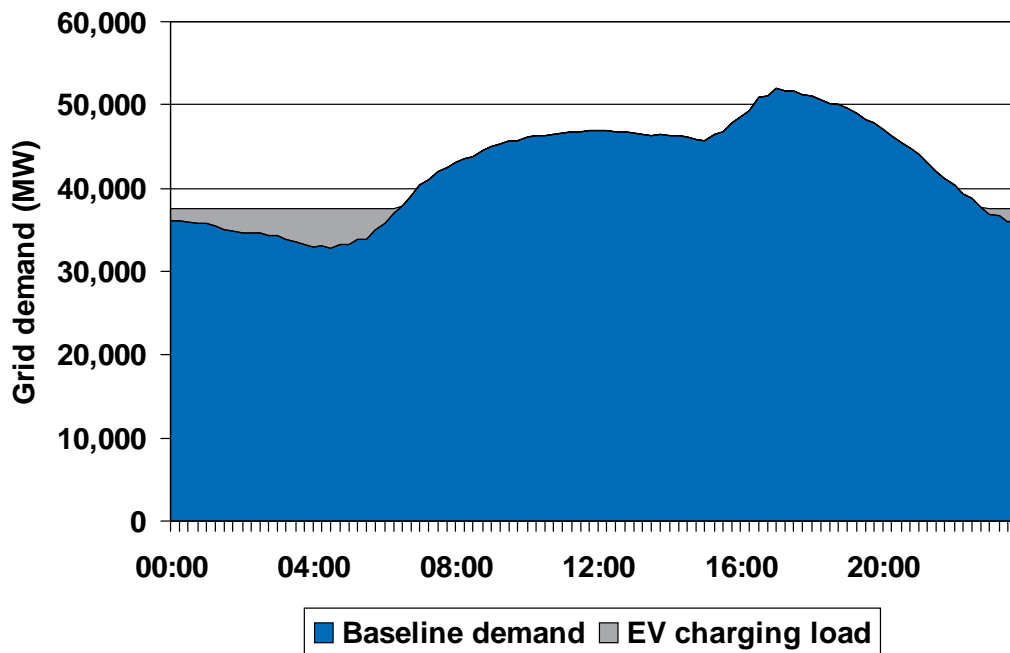


Figure 95 – Effect of smart charging scenario on Great Britain's electricity demand

### 5.5.3.3 Spain

Figure 96 shows the impact on Spain's electricity network of introducing a penetration of electric vehicles of 10% of its total vehicle fleet using smart control to move charging to the night-time valley period. The peak load of the baseline demand was 35,508 MW at 18:00, which was not altered by the addition of the EV charging load. The peak EV demand was 3,616 MW at 03:00, down 10% from the peak EV demand for the dumb charging scenario of 4,033 MW at 21:00.

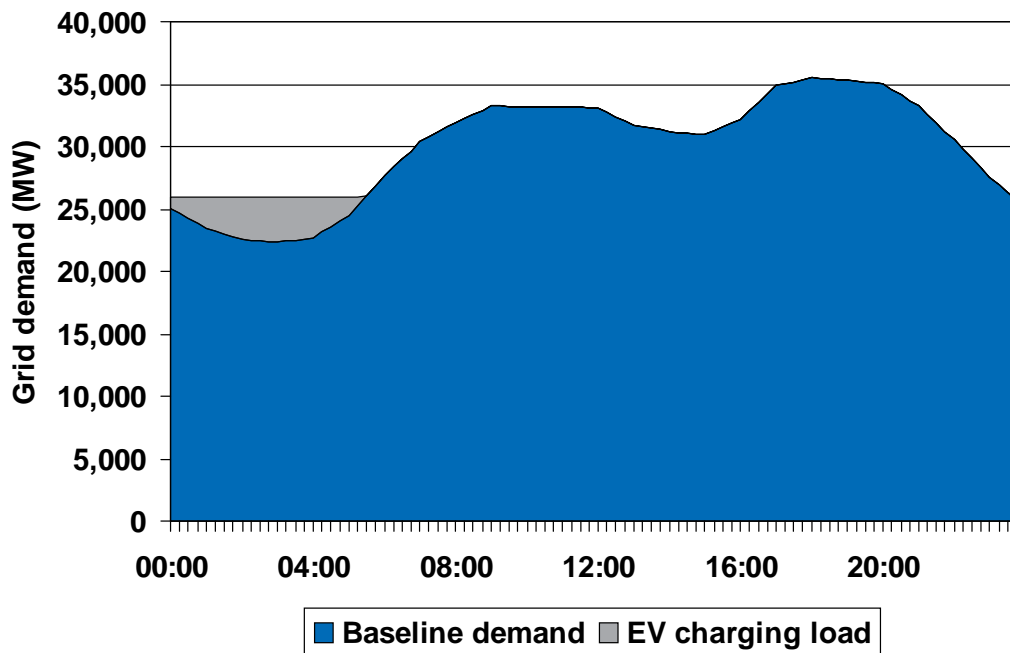


Figure 96 – Effect of smart charging scenario on Spain's electricity demand

#### 5.5.3.4 Greece

Figure 97 shows the impact on Greece's electricity network of introducing a penetration of electric vehicles of 10% of its total vehicle fleet using smart control to move charging to the night-time valley period. The peak load of the baseline demand was 7,339 MW at 18:00, which was not altered by the addition of the EV charging load. The peak EV demand was 745 MW at 04:00, up 8% from the peak EV demand for the dumb charging scenario of 687 MW at 20:00.

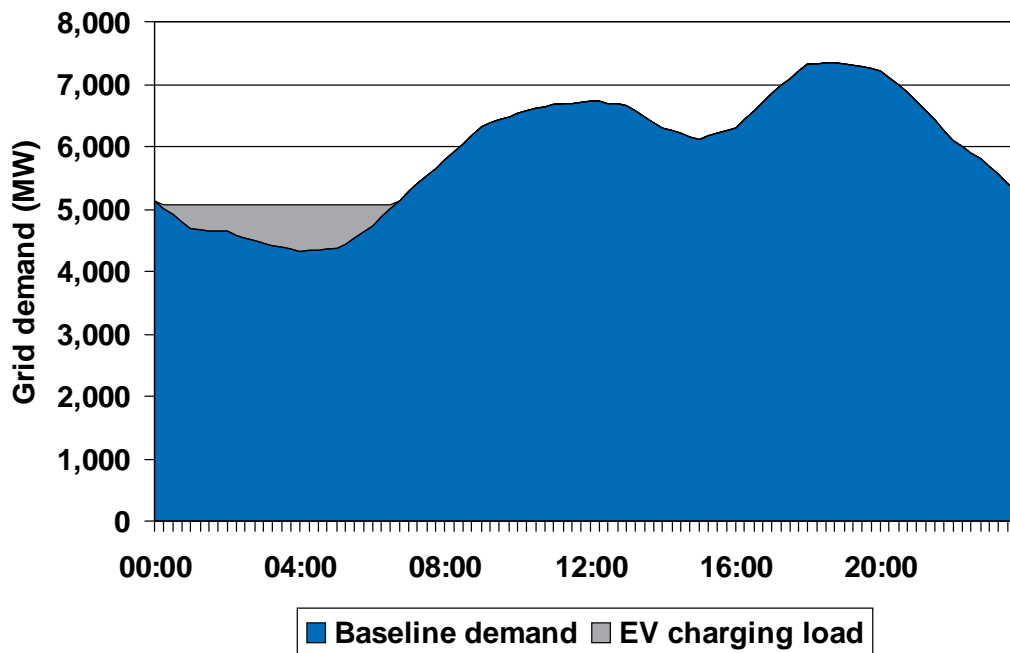


Figure 97 – Effect of smart charging scenario on Greece's electricity demand

### 5.5.3.5 Portugal

Figure 98 shows the impact on Portugal's electricity network of introducing a penetration of electric vehicles of 10% of its total vehicle fleet using smart control to move charging to the night-time valley period. The peak load of the baseline demand was 7,622 MW at 20:15, which was not altered by the addition of the EV charging load. The peak EV demand was 693 MW at 06:00, down 27% from the peak EV demand for the dumb charging scenario of 948 MW at 20:00.

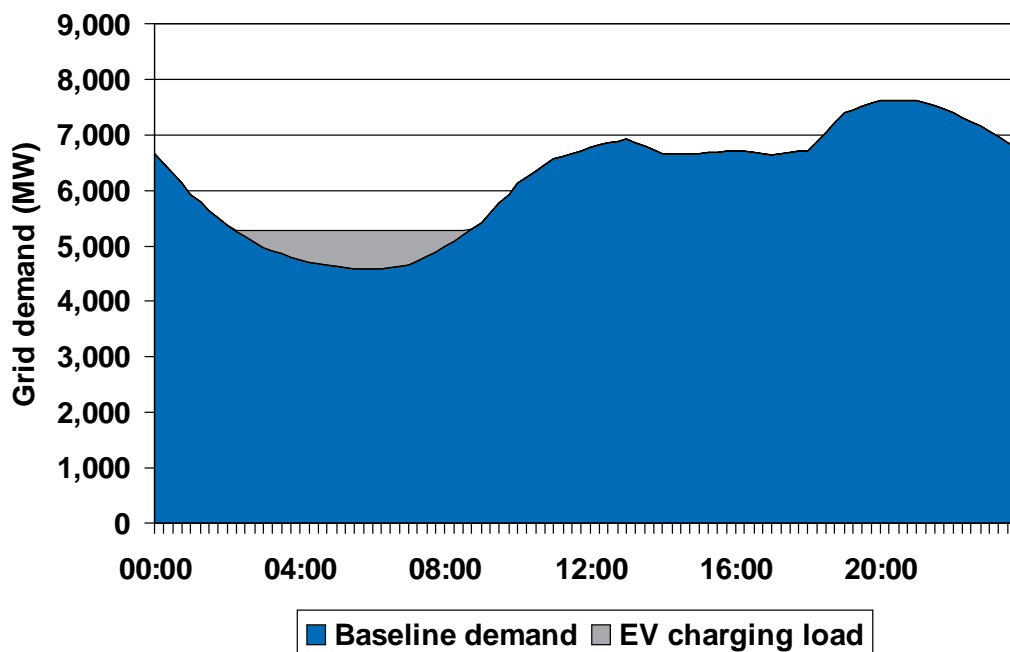


Figure 98 – Effect of smart charging scenario on Portugal's electricity demand



### 5.5.3.6 Ireland

Figure 99 shows the impact on Ireland's electricity network of introducing a penetration of electric vehicles of 10% of its total vehicle fleet using smart control to move charging to the night-time valley period. The peak load of the baseline demand was 4,454 MW at 17:45, which was not altered by the addition of the EV charging load. The peak EV demand was 342 MW at 05:00, down 7% from the peak EV demand for the dumb charging scenario of 368 MW at 20:00.

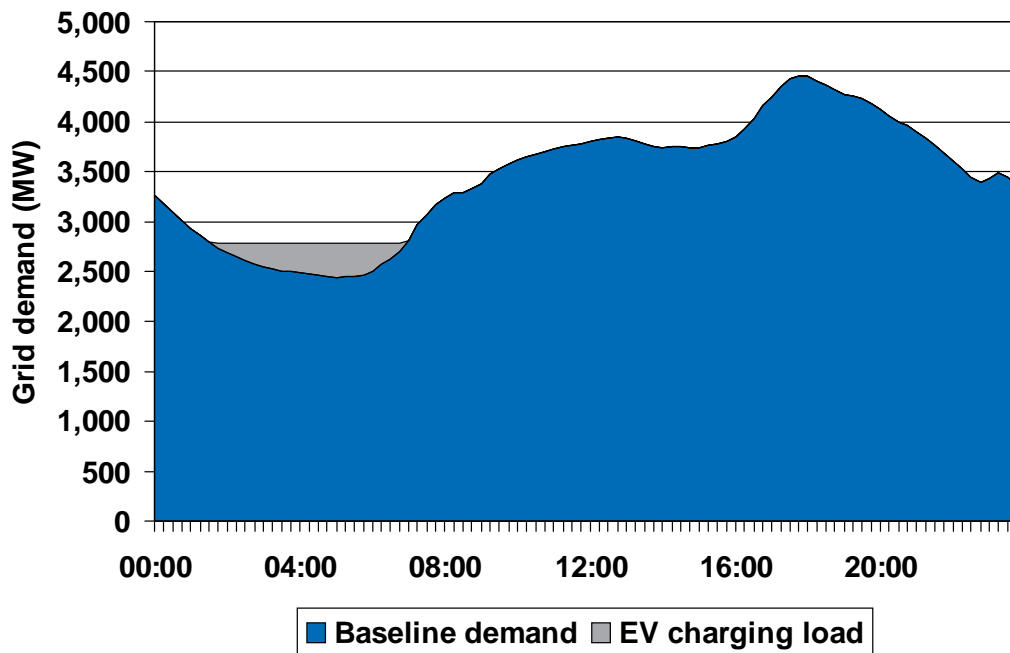


Figure 99 – Effect of smart charging scenario on Ireland's electricity demand



### 5.5.3.7 Summary of Impacts of Smart Charging Scenario

Table 26 summarises the impacts of the smart charging scenario. All six countries showed no change to the baseline peak demand. All countries apart from Greece showed reduced peaks in EV demand of between 7% and 27%, while Greece showed an increase of 8% in peak EV demand.

COUNTRY	EFFECT ON BASELINE PEAK	EV DEMAND PEAK DUMB SCENARIO	EV DEMAND PEAK SMART SCENARIO
Germany	No change	8,887 MW at 20:00	6,740 MW at 04:00
Great Britain	No change	5,596 MW at 20:00	4,756 MW at 04:30
Spain	No change	4,033 MW at 21:00	3,616 MW at 03:00
Greece	No change	687 MW at 20:00	745 MW at 04:00
Portugal	No change	948 MW at 20:00	693 MW at 06:00
Ireland	No change	368 MW at 20:00	342 MW at 05:00

Table 26 – Summary of impacts of smart charging scenario

### 5.5.4 Effect of Dumb and Smart Scenarios on Peak-to-trough Demand Variation

One method of analysing the load levelling capability of the dumb and smart charging scenarios is to look at the variation in electricity demand between the minimum demand overnight and the peak demand in the evening. Figure 100 shows the peak-to-trough variation of Germany's electricity grid for the baseline, dumb charging and smart charging scenarios, to provide an example of how the figures are obtained.

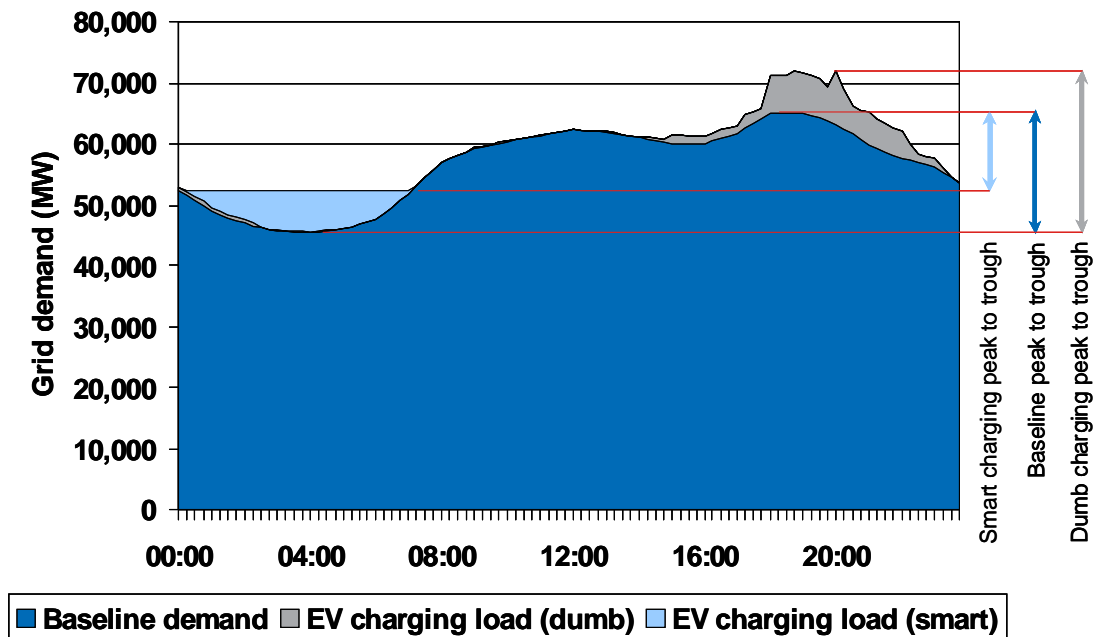


Figure 100 – Diagram showing the peak-to-trough variation of Germany's grid, for the baseline, dumb charging and smart charging scenarios

Table 27 shows the differences between peak and minimum daily demands for each of the six countries being studied. This clearly shows that the dumb charging scenario causes the peak-to-trough variation to increase by between 13% and 35% compared to the baseline demand, while the smart charging scenario causes the peak-to-trough variation to decrease by between 17% and 35% compared to the baseline demand.



COUNTRY	PEAK TO TROUGH DUMB SCENARIO (MW)	PEAK TO TROUGH BASELINE (MW)	PEAK TO TROUGH SMART SCENARIO (MW)
Germany	26,384	19,529	12,789
Great Britain	23,332	19,180	14,423
Spain	15,469	13,143	9,527
Greece	3,570	3,012	2,267
Portugal	3,980	3,042	2,349
Ireland	2,277	2,011	1,669

**Table 27 – Effect of dumb and smart charging scenarios on peak to trough variation of demand**





## 6 DISCUSSION

This task provided a significant quantity of original data, allowing the project partners to develop a strong understanding of current vehicle usage, human preferences related to the uptake of electric and plug-in hybrid electric vehicles. This provides a baseline against which future developments in vehicle technology and infrastructure development may be benchmarked.

A significant number of responses to the vehicle usage survey – 1,621 in total – were received, providing confidence in the results drawn from the data. The sample population was not a perfectly stratified and representative sample of people in Europe, but did represent a cross-section of European countries suitable for this analysis, with a mix of males and females, and a range of ages, occupations and vehicle segments, ensuring that no particular group dominated the results.

The results of the survey confirmed some important assumptions regarding potential future electric vehicle usage patterns. For example, it was confirmed that a significant proportion of journeys undertaken are part of a regular cycle and there is a regular profile of times at which drivers tend to return from their last journey of the day. This provides confidence that forward planning of the demand for vehicle recharging can be undertaken, rather than having to provide for worst case scenarios.

Deliberate questions in the survey examined drivers' desires to reduce the cost of recharging electric vehicles by delaying recharging until cheaper tariffs become available, whether overnight or even at other times of day. This fundamentally confirms that development of smart grid control, whether for load levelling, frequency correction or optimisation of renewable sources, will not be rejected by consumers.

However, some issues remain unresolved, as would be expected with any new technology. There appears to be a consensus emerging that vehicle owners' homes will be the preferred location for recharging, but this is not certain and may be favoured by drivers who are unfamiliar or untrusting of fast chargers or battery swapping systems. Similarly, the regularity at which vehicles are recharged is still an open question – while most drivers refuel their conventional vehicles only when the tank is nearing empty, there was no consensus among survey responders as to whether they would recharge only when their battery was almost depleted or whether they would charge more regularly, even "whenever possible".

The suitability of BEV and PHEV to current driving patterns was examined and seemed to show that significant proportions of the sample population could have their needs served by these vehicles. A typical EV would serve the needs of 85% of the sample population, although this would be tempered by the proportion of these that have access to electricity for recharging. Although only 57% of responders reported having access to electricity where their vehicle is parked for the longest period on a weekday, 73% reported that the vehicle was parked either in a garage, on a driveway or on the road directly outside their home at this period, which perhaps





suggests that the possibility of recharging a vehicle parked on the street, i.e. where it would be possible to provide power, within reach of an extension cable is either unknown or untrusted.

The model of the dumb charging scenario, whereby no smart grid control is used and all vehicles begin to charge as soon as they arrive home from the last journey of the day, showed that, for a 10% penetration of EV in each of the six countries examined, the daily demand peak would move to a later time of the day and would increase in magnitude by 6% to 12%. This shows that the introduction of this proportion of EV into the overall vehicle fleet would cause a significant change to the baseline electricity demand, although not to the extent that existing infrastructure could not cope with the increase.

The model of the smart charging scenario, whereby a control system moved EV charging to the night-time valleys to level the overall load, showed the potential that smart grid control offers. In all cases, the daily peak demand was unaffected by the addition of the EV charging load, and for all countries except for Greece the EV charging load itself showed a reduced peak of between 8% and 27% when considered in isolation. This would also yield significant environmental benefits, not considered as part of this study, as power would be produced by more efficient power plants lower in the merit order, rather than the less efficient peaking plants that deal with demand at the top of the supply window.

The models showed that the variation between daily peak demand and minimum daily demand increased significantly for the dumb charging scenario, due to an increased peak and an unchanged trough, while it reduced significantly for the smart charging scenario, due to the increased trough and unchanged peak. This reduction in demand variation is a target of all transmission system operators and helps to improve planning processes and provide more electricity from efficient baseline plants rather than less-efficient peaking plants.

The data generated as part of this task, and the analysis conducted using the data, provides the baseline against which future models developed as part of the project can be compared. Although only two scenarios were considered, the models generated can be adapted for other scenarios that may be produced by future work packages in Project MERGE.





## **7 CONCLUSIONS**

### **7.1 Traffic Patterns and Human Behaviour Analysis**

#### **7.1.1 Vehicle Use**

- The survey found that 67% of responders primarily used their vehicles for commuting on weekdays, while 74% primarily used their vehicles for leisure or sport at the weekend
- 70% of responders said that at least 60% of the journeys they undertake in a typical week are part of a regular cycle of similar journeys that occur at approximately the same time every week

#### **7.1.2 Refuelling and Recharging**

- 84% of responders currently only refuel their vehicles when their fuel tank is approaching empty, but there is no consensus as to how regularly they would choose to recharge an electric vehicle
- 98% of responders currently refuel at a service station, while 70% would prefer to recharge an electric vehicle at home and 20% at work
- 94% of drivers would recharge an electric vehicle at night to take advantage of lower electricity prices overnight
- 88% of drivers would recharge an electric vehicle during the time of a cheaper tariff, whether overnight or otherwise
- 13% of drivers stated that they would not seek savings from multiple tariff electricity rates because electricity is already significantly cheaper than gasoline or diesel fuel
- 6% of drivers stated that they would not seek savings from multiple tariff electricity rates because their employer pays for their fuel so they would not personally benefit from the savings
- 57% of drivers reported that they could provide a supply of electricity to their car where it is parked for the longest period on weekdays, rising to 65% at weekends
- 56% of vehicles are parked either in a garage or on a driveway on weekdays, rising to 72% on weekends
- 73% of vehicles are parked in a garage, on a driveway or on the street directly outside the owner's house on weekdays, rising to 92% on weekends

#### **7.1.3 Average Distances Travelled Per Day**

- 50% of drivers travel up to 30 km per day during the week, and up to 40 km per day at the weekend
- 85% of drivers travel up to 110 km per day during the week and at the weekend





- Survey responders from Portugal and Ireland reported driving longer than average distances during the week, with only 66% and 68%, respectively, travelling up to 110 km per day during the week
- There was less variation between the countries in the distances travelled per day at the weekend, with between 75% and 89% of drivers in each country travelling up to 110 km per day at the weekend
- There is a regular pattern to the times drivers return from the last journey of the day, which varies little between the countries

## 7.2 Suitability of Drive Patterns to BEV and PHEV

- It was concluded that a typical electric vehicle could serve the primary transport needs to the 85% of survey responders that travel up to 110 km per day on average, but that in practice the proportion would be lower as only 57% of responders reported currently having access to electricity where their vehicle is parked for the longest period of the day during the week. If we consider that all vehicles parked in a garage, on a driveway or on the street immediately outside the owners' houses could potentially provide electricity to their vehicles, this proportion rises to 73% on weekdays and 92% on weekends
- It is not possible to draw a conclusion from the data as to whether certain driving patterns would be unsuitable to PHEV, as these vehicles can provide the same range as conventional vehicles by operating in charge sustaining mode and average speeds were not considered in the survey, which, if high, may suggest that the benefits of PHEV compared to conventional vehicles would be marginal
- It was shown that the proportion of distance travelled in EV mode in a PHEV depends on the EV range of the vehicle and the distribution of journey lengths undertaken by the driver. Using a sample distribution of distances travelled per day from UK Department for Transport statistics, it was shown that an EV range of 18 km would lead to 50% of distance travelled being covered in EV mode, while a range of 65 km would yield 85% of distance travelled in EV mode and a range of 100 km would lead to 94% of distance covered being completed in EV mode

## 7.3 Impact of Transport Electrification on Europe's Electricity Grids

### 7.3.1 Impact of Dumb Charging Scenario

- For the dumb charging scenario with a 10% penetration of electric vehicles in the overall vehicle fleet, all six countries showed increased daily peak demand levels occurring at a time different to time of the baseline peak demand
- Germany showed a new demand peak of 71,977 MW, an 11% increase on the baseline peak of 65,022 MW. The time of the peak moved from 18:00 to 20:00







- Great Britain showed a new demand peak of 56,158 MW, an 8% increase on the baseline peak of 51,970 MW. The time of the peak moved from 17:00 to 18:00
- Spain showed a new demand peak of 37,912 MW, a 7% increase on the baseline peak of 35,508 MW. The time of the peak moved from 18:00 to 20:00
- Greece showed a new demand peak of 7,902 MW, an 8% increase on the baseline peak of 7,339 MW. The time of the peak moved from 18:30 to 20:00
- Portugal showed a new demand peak of 8,561 MW, a 12% increase on the baseline peak of 7,622 MW. The time of the peak moved from 20:15 to 20:00
- Ireland showed a new demand peak of 4,720 MW, a 6% increase on the baseline peak of 4,454 MW. The time of the peak moved from 17:45 to 18:00

### 7.3.2 Impact of Smart Charging Scenario

- For the smart charging scenario with a 10% penetration of electric vehicles in the overall vehicle fleet, the daily peak demand levels remained the same as the baseline after adding the EV charging load as all charging was moved to the night-time valley periods. The peak EV demand levels for all countries except Greece were reduced due to charging being spread over a longer period, rather than all occurring when vehicles return in large numbers from the last journey of the day
- Germany showed a peak EV charging load of 6,740 MW at 04:00, a 24% decrease on the baseline peak EV load of 8,887 MW at 20:00
- Great Britain showed a peak EV charging load of 4,756 MW at 04:30, a 15% decrease on the baseline peak EV load of 5,596 MW at 20:00
- Spain showed a peak EV charging load of 3,616 MW at 03:00, a 10% decrease on the baseline peak EV load of 4,033 MW at 21:00
- Greece showed a peak EV charging load of 745 MW at 04:00, an 8% increase on the baseline peak EV load of 687 MW at 20:00
- Portugal showed a peak EV charging load of 693 MW at 06:00, a 27% decrease on the baseline peak EV load of 948 MW at 20:00
- Ireland showed a peak EV charging load of 342 MW at 05:00, a 7% decrease on the baseline peak EV load of 368 MW at 20:00

### 7.3.3 Effect of Dumb and Smart Scenarios on Peak-to-trough Demand Variation

- The peak-to-trough variation of daily demand was significantly increased for all countries in the dumb charging scenario, while the variation significantly reduced for all countries in the smart charging scenario



- The peak-to-trough variation of Germany's electricity grid increased from a baseline of 19,529 MW to 26,384 MW in the dumb charging scenario and reduced to 12,789 MW in the smart charging scenario
- The peak-to-trough variation of Great Britain's electricity grid increased from a baseline of 19,180 MW to 23,332 MW in the dumb charging scenario and reduced to 14,423 MW in the smart charging scenario
- The peak-to-trough variation of Spain's electricity grid increased from a baseline of 13,143 MW to 15,469 MW in the dumb charging scenario and reduced to 9,527 MW in the smart charging scenario
- The peak-to-trough variation of Greece's electricity grid increased from a baseline of 3,012 MW to 3,570 MW in the dumb charging scenario and reduced to 2,267 MW in the smart charging scenario
- The peak-to-trough variation of Portugal's electricity grid increased from a baseline of 3,042 MW to 3,980 MW in the dumb charging scenario and reduced to 2,349 MW in the smart charging scenario
- The peak-to-trough variation of Ireland's electricity grid increased from a baseline of 2,011 MW to 2,277 MW in the dumb charging scenario and reduced to 1,669 MW in the smart charging scenario





## 8 RECOMMENDATIONS & FUTURE WORK

- Continue to develop the systems that will lead to improved control of Europe's electricity grids as part of Project MERGE
- Refer to the data collected and analysis undertaken as part of this task when benchmarking future scenarios against current vehicle usage
- The data produced for this task can now feed into the remaining work packages of Project MERGE and can be adapted to investigate the large-scale impacts of alternative scenarios developed through the project.



## APPENDIX 1 – AVERAGE RETURN TIMES FROM LAST JOURNEY

The following six figures show the profiles of times drivers return from their last journey of the day. These are included in the appendix as there is little variation between countries.

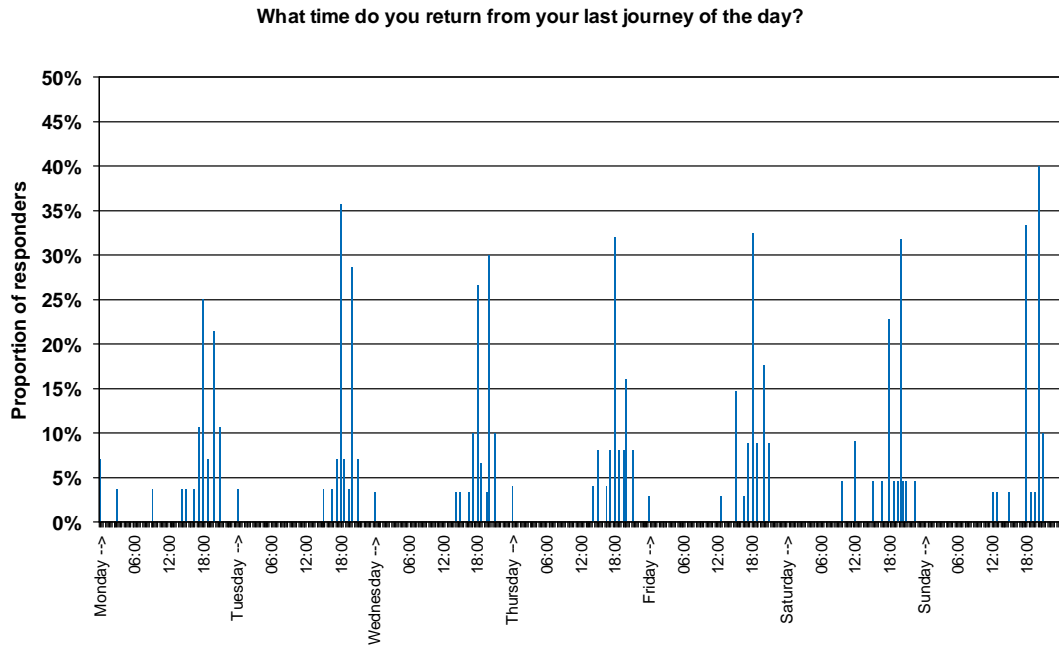


Figure 101 – Profile of time of return from last journey of the day, Germany

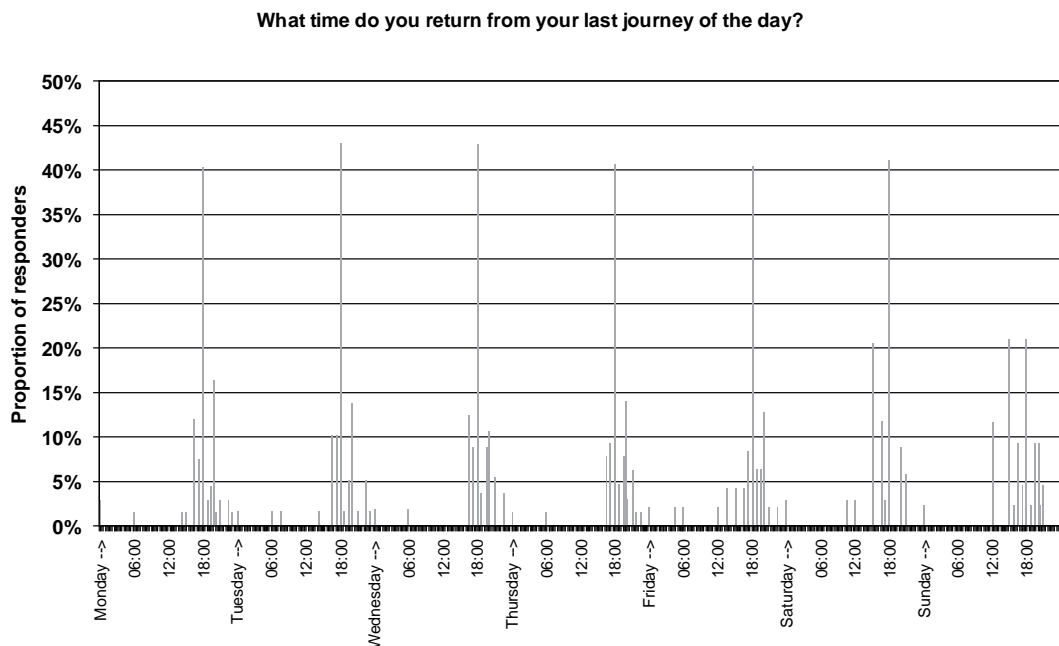


Figure 102 – Profile of time of return from last journey of the day, United Kingdom



What time do you return from your last journey of the day?

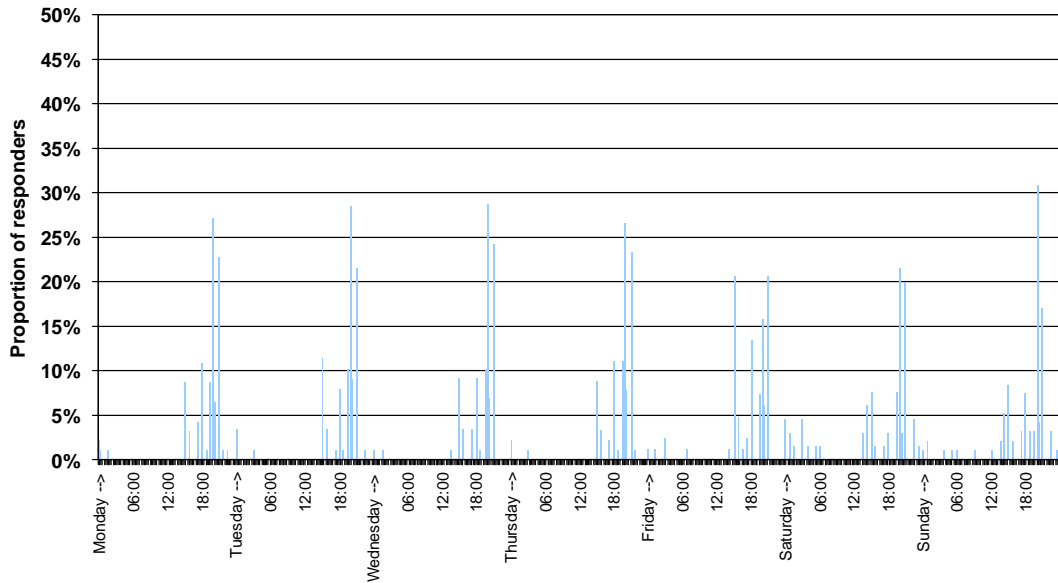


Figure 103 – Profile of time of return from last journey of the day, Spain

What time do you return from your last journey of the day?

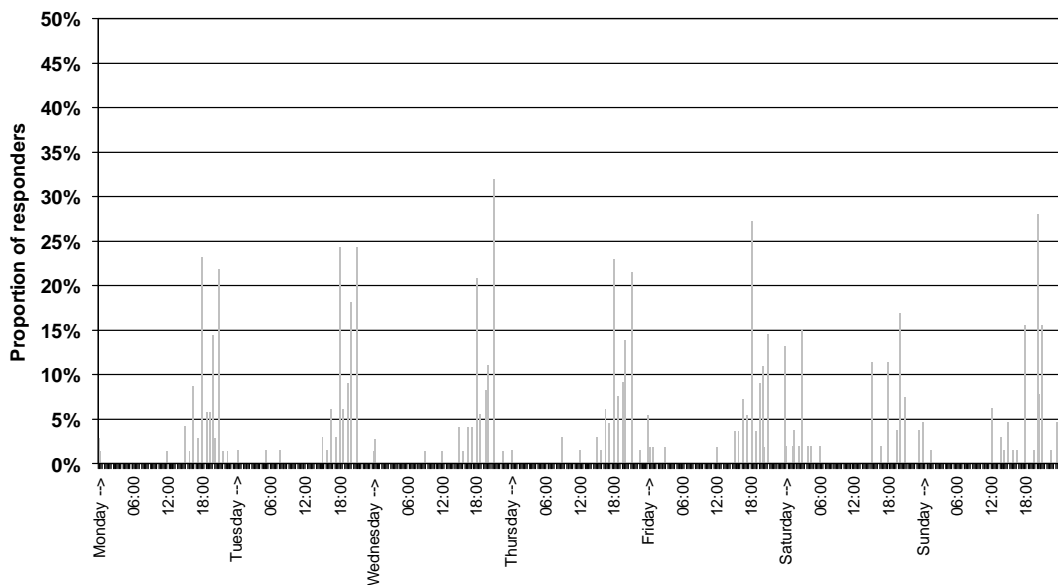


Figure 104 – Profile of time of return from last journey of the day, Greece





What time do you return from your last journey of the day?

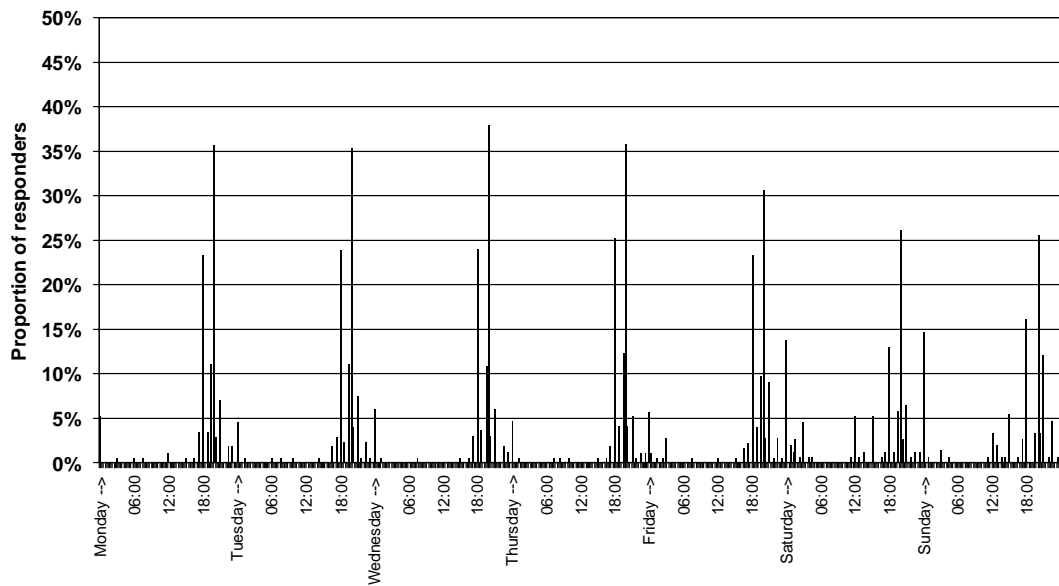


Figure 105 – Profile of time of return from last journey of the day, Portugal

What time do you return from your last journey of the day?

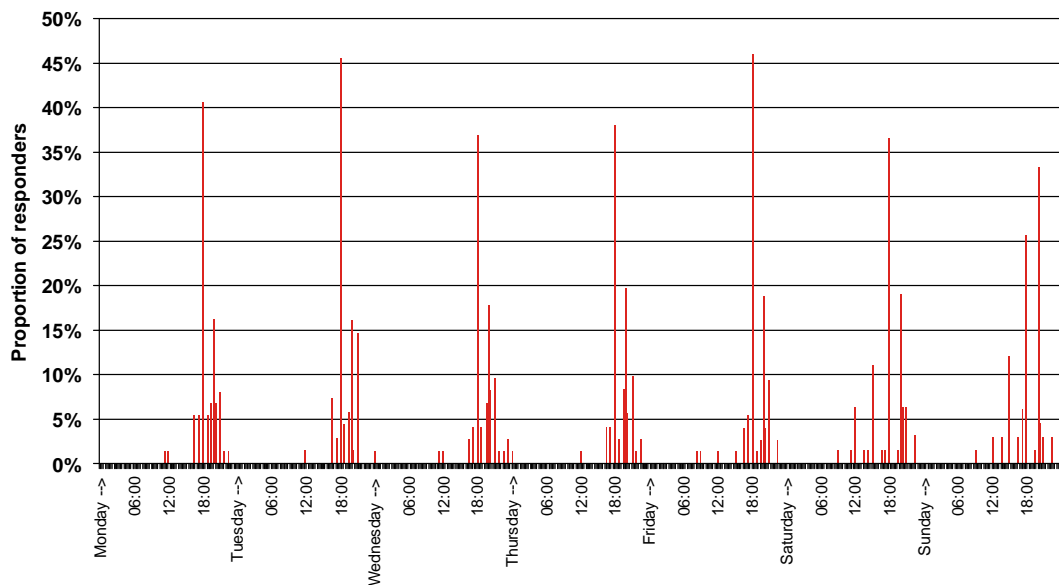


Figure 106 – Profile of time of return from last journey of the day, Ireland



## APPENDIX 2 – EV POWER DRAW FOR DUMB CHARGING SCENARIO

The following six figures show the power drawn from electricity networks to charge electric vehicles in the dumb charging scenario from section 5.5.2. These are included in the appendix as they duplicate the information shown in that section stacked on the baseline grid demands, but their profiles may be interesting when viewed here in isolation.

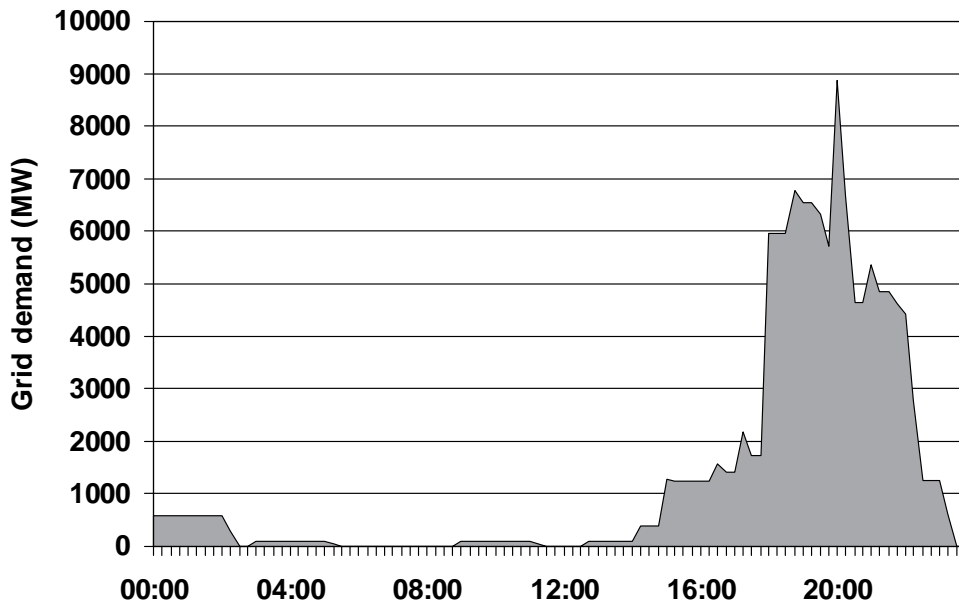


Figure 107 – EV charging load for dumb charging scenario, Germany

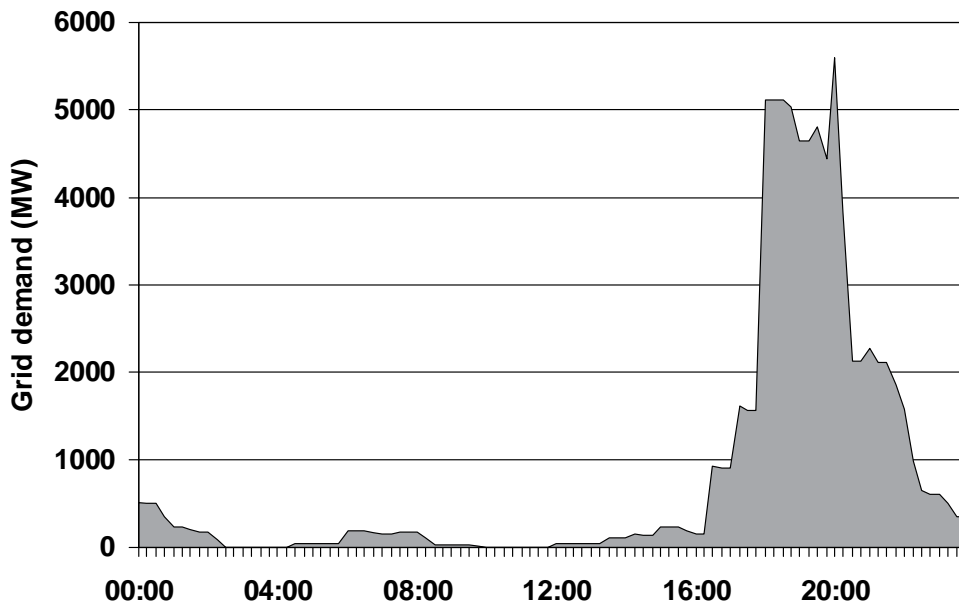


Figure 108 – EV charging load for dumb charging scenario, Great Britain

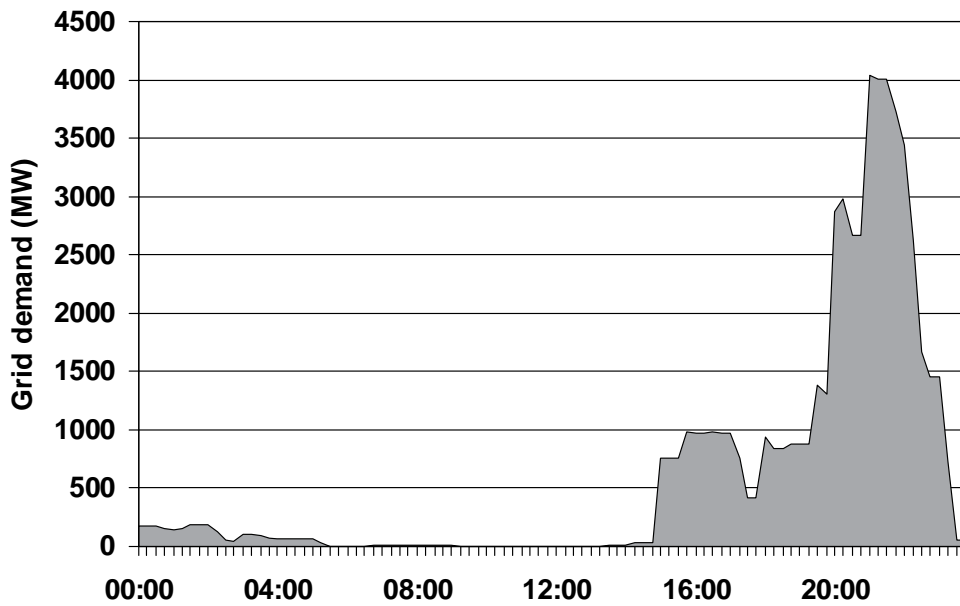


Figure 109 – EV charging load for dumb charging scenario, Spain

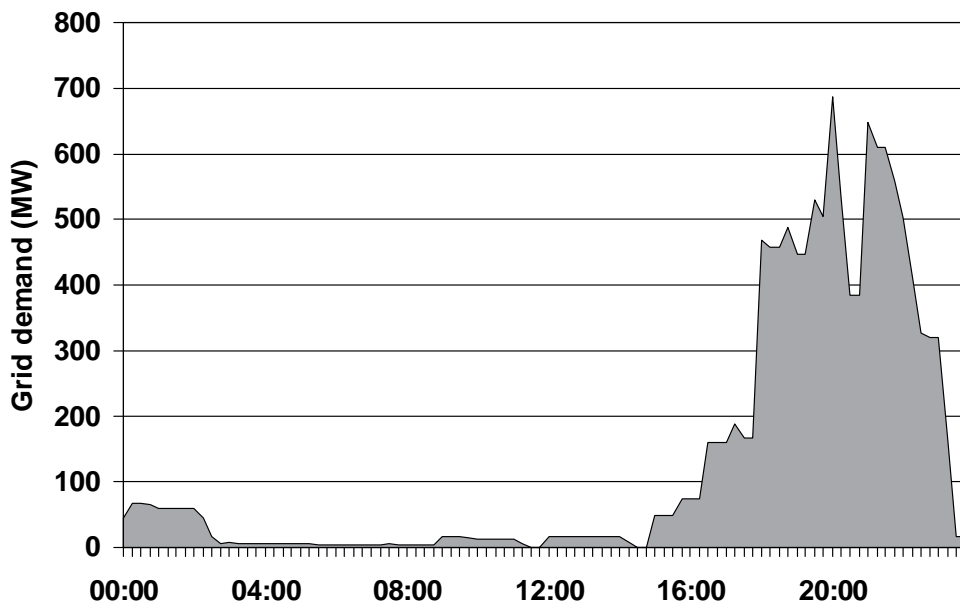


Figure 110 – EV charging load for dumb charging scenario, Greece



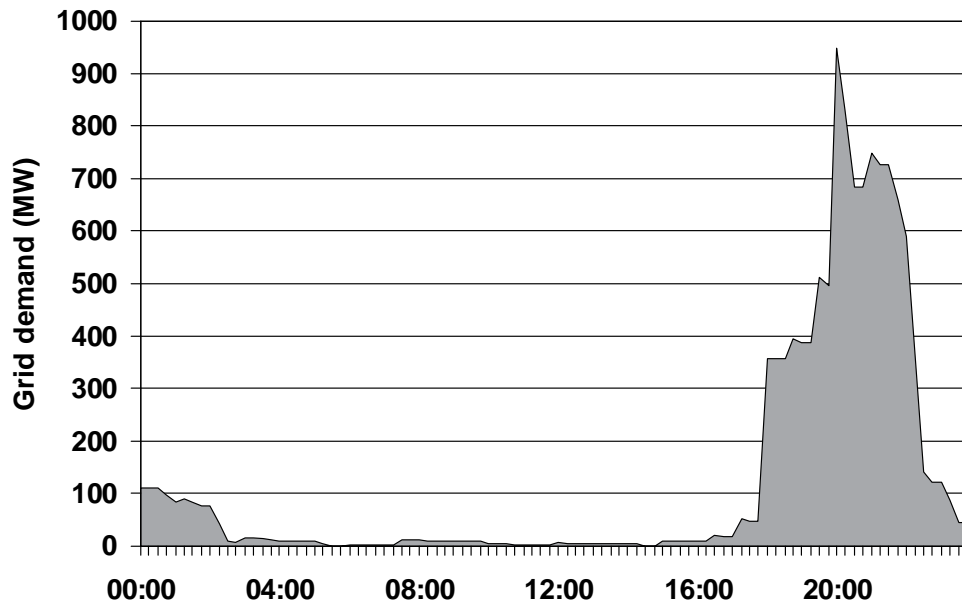


Figure 111 – EV charging load for dumb charging scenario, Portugal

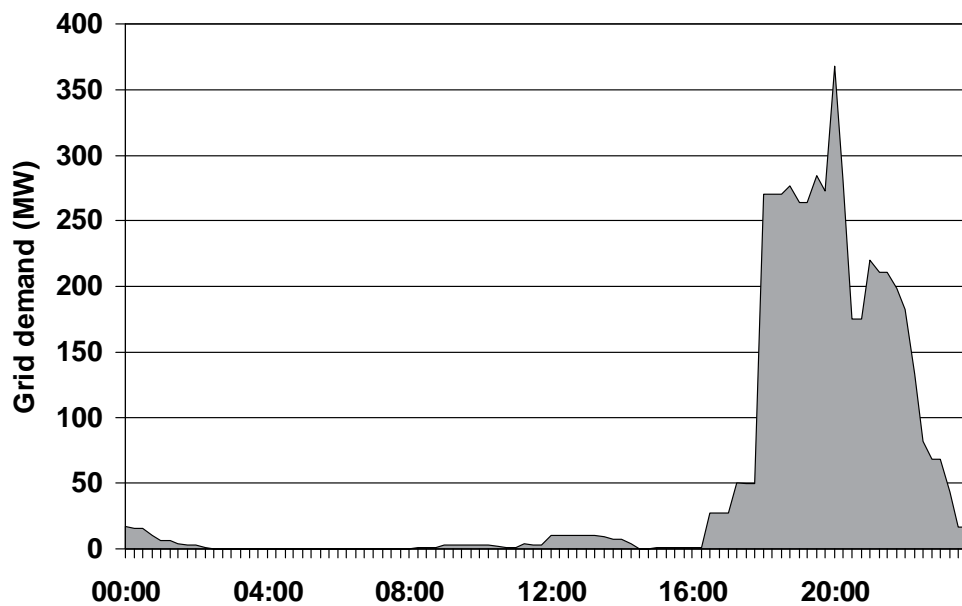


Figure 112 – EV charging load for dumb charging scenario, Ireland

### APPENDIX 3 – EV POWER DRAW FOR SMART CHARGING SCENARIO

The following six figures show the power drawn from electricity networks to charge electric vehicles in the smart charging scenario from section 5.5.3. These are included in the appendix as they duplicate the information shown in that section stacked on the baseline grid demands, but their profiles may be interesting when viewed here in isolation.

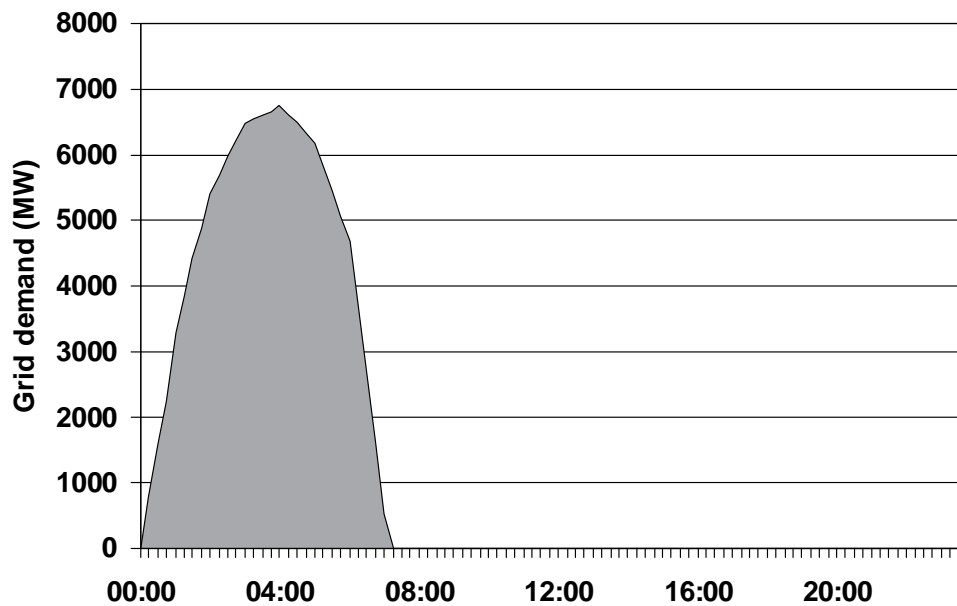


Figure 113 – EV charging load for smart charging scenario, Germany

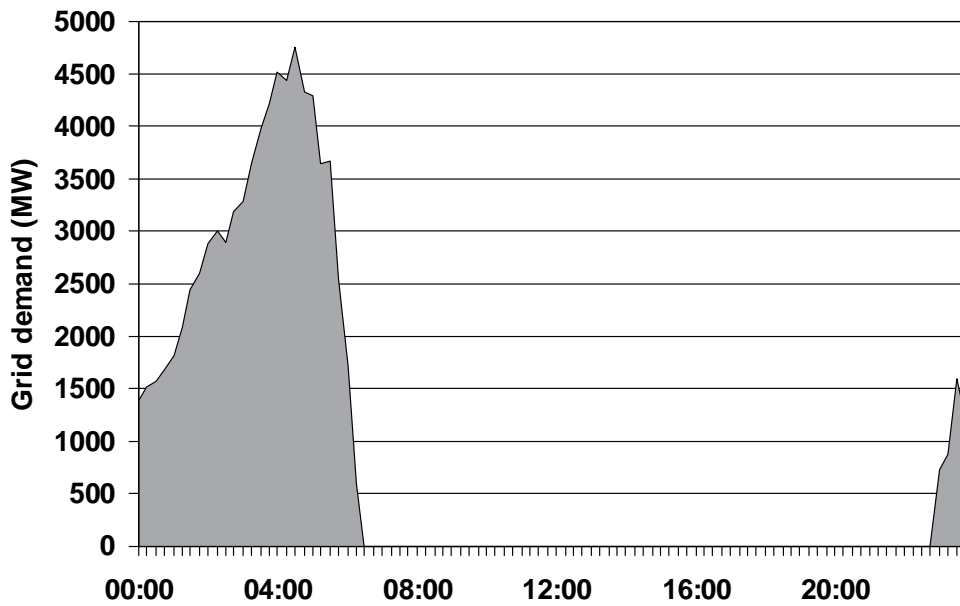


Figure 114 – EV charging load for smart charging scenario, Great Britain

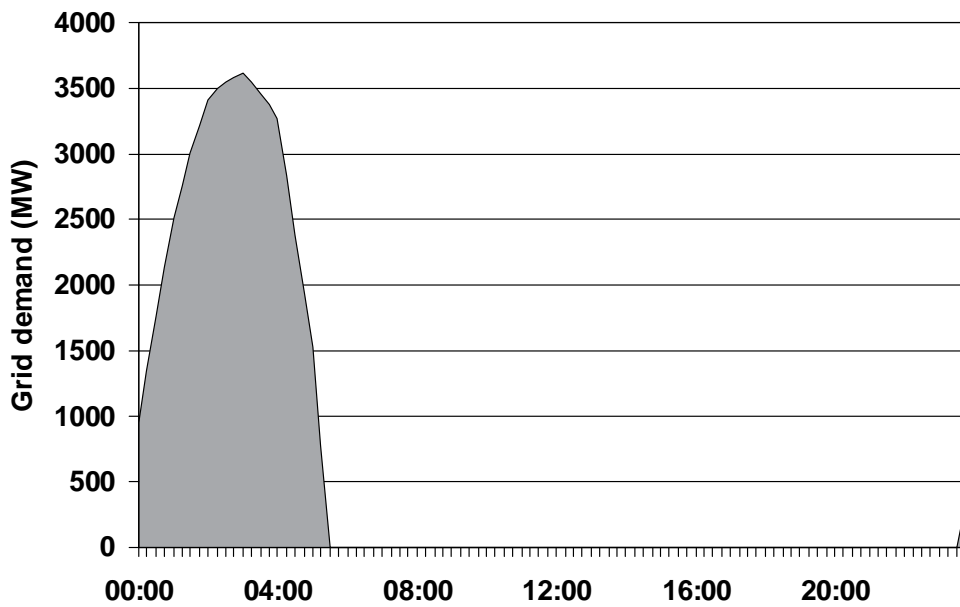


Figure 115 – EV charging load for smart charging scenario, Spain

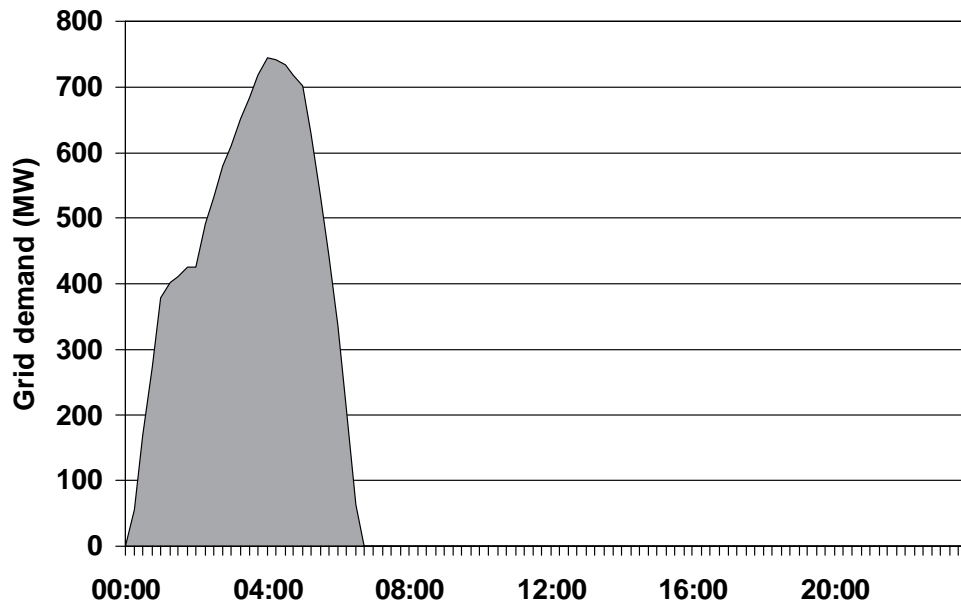


Figure 116 – EV charging load for smart charging scenario, Greece

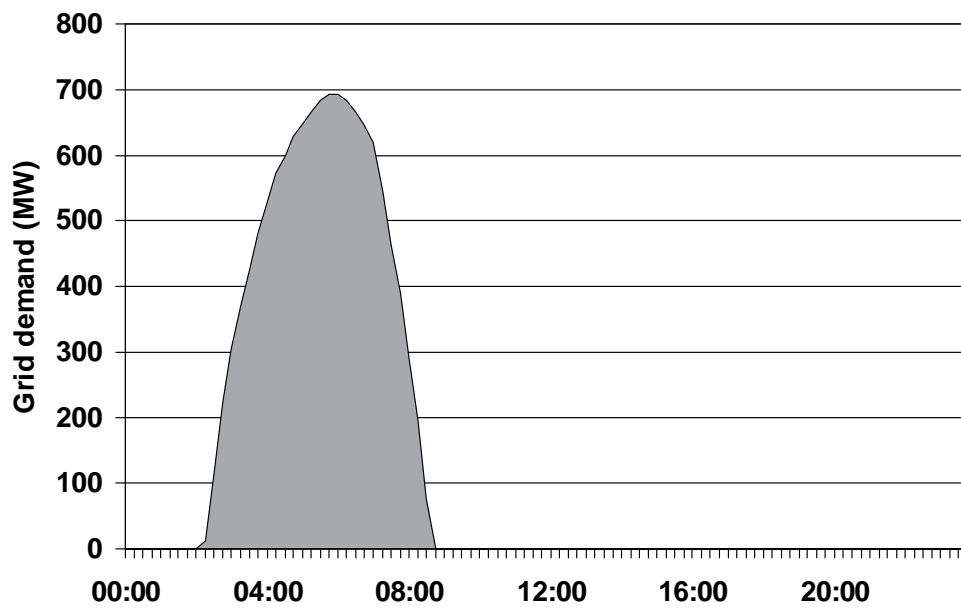


Figure 117 – EV charging load for smart charging scenario, Portugal

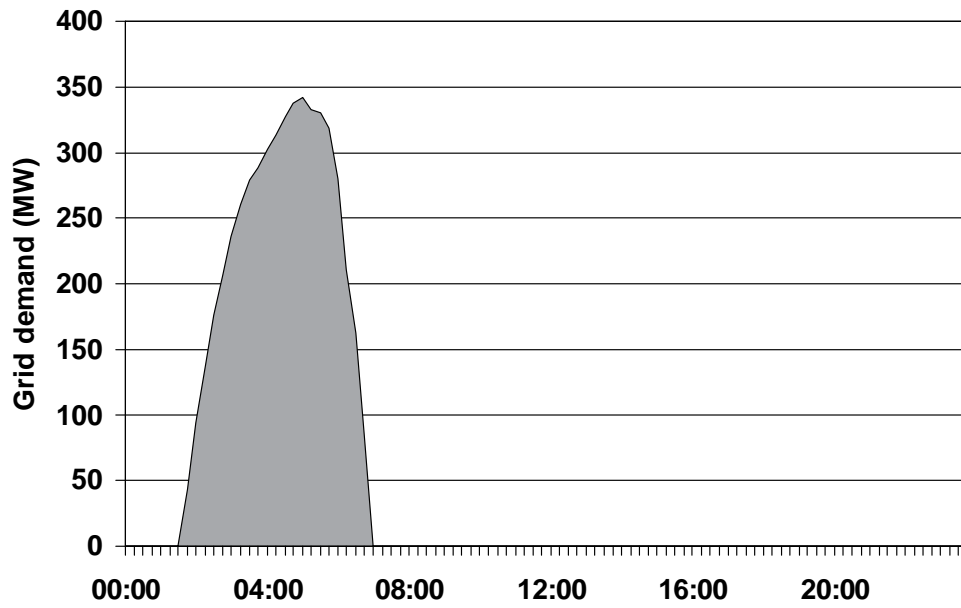


Figure 118 – EV charging load for smart charging scenario, Ireland



## IV REFERENCES

- [1] Thomson, A. "Revolutionary Electric Vehicle Charging System". Available from University of Auckland UniServices website at: <http://www.uniservices.auckland.ac.nz>. Last accessed 28 July 2010.
- [2] Better Place. "Charging Electric Vehicles (EVs)". Available from Better Place website at: <http://www.betterplace.com/the-solution-charging>. Last accessed 27 July 2010.
- [3] The Future is Awesome. "Gas Station of the Future is a Battery Changing station". Available from The Future is Awesome website at: <http://www.thefutureisawesome.com/category/battery/>. Last accessed 27 July 2010.
- [4] Coulomb Technologies. "Coulomb Products Overview". Available from Coulomb Technologies website at: <http://www.coulombtech.com/products.php>. Last accessed 27 July 2010.
- [5] Coulomb Technologies. "Coulomb Charging Stations". Available from Coulomb Technologies website at: <http://www.coulombtech.com/products-charging-stations.php>. Last accessed 27 July 2010.
- [6] Coulomb Technologies. "Canada Charging Stations Fro EV". Available from Coulomb Technologies website at: <http://www.coulombtech.com/blog/tag/canada-charging-stations-ev/>. Last accessed 27 July 2010.
- [7] Elektromotive. "Elektrobay". Available from Elektromotive website at: <http://www.elektromotive.com/html/elektrobay.php>. Last accessed 27 July 2010.
- [8] AutoIndustry.co.uk. Available from Auto Industry archive at: <http://www.autoindustry.co.uk/news/22-03-10>. Last accessed 14 April 2010.
- [9] Environment Times. "Electric car charging network given a nationwide acceleration boost". Available from Environment Times website at: [http://www.environmenttimes.co.uk/news\\_detail.aspx?news\\_id=906](http://www.environmenttimes.co.uk/news_detail.aspx?news_id=906). Last accessed 27 July 2010.
- [10] Park and Power homepage. Available at: <http://test.parkandpower.co.uk/Default.aspx>. Last accessed 27 July 2010.
- [11] Avinc. "EV Solutions: Electric Vehicle Charging Products & Services". Available from Avinc website at: <http://evsolutions.avinc.com/>. Last accessed 27 July 2010.
- [12] Nissan Fan Blog. "Nissan North America selects Aerovironment to install home-charging stations for Nissan Leaf". Available from Nissan Fan Blog website at: <http://www.nissanfanblog.de/nissan-north-america-selects-aerovironment-to-install-home-charging-stations-for-nissan-leaf>. Last accessed 27 July 2010.
- [13] Earth2Tech. "Think Hands EnerDel Exclusive U.S. Battery Deal, Heads for Faster Charging". Available from Earth2Tech website at: <http://earth2tech.com/2010/01/26/think-hands-enerdel-exclusive-u-s-battery-deal-heads-for-faster-charging/>. Last accessed 27 July 2010.
- [14] PEP Stations. "Leading the Charge". Available from PEP Stations website at: <http://www.pepstations.com/min/product/>. Last accessed 27 July 2010.





- [15] Pod Points homepage. Available at: <http://www.pod-point.com/>. Last accessed 27 July 2010.
- [16] Warwick District Council. "Park and Charge". Available from Warwick District Council website at: <http://www.warwickdc.gov.uk/WDC/Roads-parking-and-transport/Parking/Off+street+parking/Park+and+Charge.htm>. Last accessed 27 July 2010.
- [17] La Douaisienne de Basse Tension. "Ville de Paris EV Terminal". Available from DBT website at: <http://www.dbt.fr/spip.php?article95>. Last accessed 27 July 2010.
- [18] CirControl. "CirCarLife | Intelligent recharging system for electric vehicles". Available from CirControl website at: <http://circularlife.circontrol.com/en>. Last accessed 27 July 2010.
- [19] CirControl. "Outdoor recharge posts | CCL-PE2". Available from CirControl website at: <http://circularlife.circontrol.com/en/circularlife/recharging-posts/outdoor-recharge-posts/ccl-pe2>. Last accessed 27 July 2010.
- [20] CirControl. "Intelligent solution for car parks | CCL-CP2-P". Available from CirControl website at: <http://circularlife.circontrol.com/en/circularlife/intelligent-solution-for-car-parks/ccl-cp2-p>. Last accessed 27 July 2010.
- [21] Mobi.e. "Rede Nacional de Mobilidade Electrica. A energia que nos move". Available from Mobi.e website at: <http://www.mobi-e.pt/>. Last accessed 27 July 2010.
- [22] Mitsubishi Motors Japan. "What is iMiEV?". Available from Mitsubishi Motors website at: <http://www.mitsubishi-motors.com/special/ev/whatis/index.html>. Last accessed 27 July 2010.
- [23] Nissan. "Nissan Leaf Specs". Available from Nissan Zero Emission Website at: <http://www.nissan-zeroemission.com/EN/LEAF/specs.html>. Last accessed 28 July 2010.
- [24] Computer Weekly. "NFC trial: Londoners want to use their mobiles to travel and shop". Available from Computer Weekly website at: <http://www.computerweekly.com/Articles/2008/09/03/232115/NFC-trial-Londoners-want-to-use-their-mobiles-to-travel-and.htm>. Last accessed 28 July 2010.
- [25] £3 per Mb on O2 Text and Web PAYG tariff. O2. "Pay monthly tariffs". Available from O2 shop website at: [http://shop.o2.co.uk/tariffs/Pay\\_and\\_Go](http://shop.o2.co.uk/tariffs/Pay_and_Go). Last accessed 14 April 2010.
- [26] IETF, R. Droms, "Dynamic Host Configuration Protocol", RFC 2131, March 1997, Draft Standard ACEA (2009) "The European Vehicle Fleet Composition", *The Automobile Industry Pocket Guide*, Brussels: Association des Constructeurs Européens d'Automobiles
- [27] Venables, M.; , "Smart meters make smart consumers [Analysis]," *Engineering & Technology* , vol.2, no.4, pp.23-23, April 2007
- [28] GEODE ("Groupement Européen des entreprises et Organismes de Distribution d' Energie") Position Paper on Smart Metering (NOVEMBER 2009): [http://www.geode-eu.org/images/stories/GEODE%20Smart%20Metering%20position%2028-10-09\\_12\\_updated.pdf](http://www.geode-eu.org/images/stories/GEODE%20Smart%20Metering%20position%2028-10-09_12_updated.pdf)





- [29] Standard EN 13757-1, "Communication Systems for meters and remote reading of meters - Part 1: Data exchange", 2002
- [30] Considerations for Standardization in the field of Smart Metering, CENELEC TC 13, Smart Meters Co-ordination Group Brussels, 25 May 2009
- [31] Open Meter Deliverable 30.09.2009. Available from Open Meter website at: [www.openmeter.com/.../deliverables/OPEN%20meter%20D2.2\\_v1.0+note.pdf](http://www.openmeter.com/.../deliverables/OPEN%20meter%20D2.2_v1.0+note.pdf). Last accessed 24 August 2010
- [32] L. Cunha, J. A. Pecas Lopes et.al., "InovGrid Project – Distribution network evolution as a decisive answer to new electrical sector challenges", Proc. CIRED seminar 2008, Frankfurt, June 2008
- [33] J. A. Pecas Lopes, C. L. Moreira, F. O. Resende, "MicroGrids Black Start and Islanded Operation", 15th PSCC, Liege, 22-26 August 2005
- [34] N. J. Gil, J. A. Pecas Lopes, "Hierarchical Frequency Control Scheme for Islanded Multi-Microgrids Operation", Proceedings of IEEE Lausanne Power Tech 2007, Lausanne, Switzerland, July, 2007
- [35] G. Haines, A. McGordon, P. Jennings, "The Simulation of Vehicle-to-Home Systems – Using Electric Vehicle Battery Storage to Smooth Domestic Electricity Demand", EVER 2009, Monaco, 2009
- [36] J. A. Pecas Lopes, P. M. Rocha Almeida, F. J. Soares, "Using Vehicle-to-Grid to Maximize the Integration of Intermittent Renewable Energy Resources in Islanded Electric Grids", ICCEP 2009 - International Conference On Clean Electrical Power Renewable Energy Resources Impact, Capri, Italy, June, 2009
- [37] Driver & Vehicle Agency (2009) "Vehicle Licensing Transactions – Business Volumes" *Driver & Vehicle Agency Annual Report and Statement of Accounts for the Year Ended 31 March 2009*, Belfast: The Stationery Office
- [38] Nissan (2010) "Features and Specifications", *Nissan LEAF Electric Car* [online] available: <http://www.nissanusa.com/leaf-electric-car/index#/leaf-electric-car/specs-features/index> [accessed 28 April 2010]
- [39] Mitsubishi Motors Japan (2010) "What is 'i-MiEV'", *Mitsubishi innovative Electric Vehicle* [online] available: <http://www.mitsubishi-motors.com/special/ev/whatis/index.html> [accessed 28 April 2010]
- [40] Darryl McCarthy (2009) "Official switch-on for Toyota's plug-in Prius", *Toyota Today / Tomorrow blog* [online] available: <http://blog.toyota.co.uk/official-switch-on-for-toyotas-plug-in-prius> [accessed 28 April 2010]
- [41] Audi (2010) "Audi A1 e-tron – electric driving in the city", *Audi Experience* [online] available [http://www.audi.com/com/brand/en/experience/audi\\_e-tron/audi\\_a1\\_e-tron.html](http://www.audi.com/com/brand/en/experience/audi_e-tron/audi_a1_e-tron.html) [accessed 28 April 2010]
- [42] Chevrolet (2010) "Introducing Chevrolet Volt", *Chevrolet Future Vehicles* [online] available : <http://www.chevrolet.com/pages/open/default/future/volt.do> [accessed 28 April 2010]







- [43] Chrysler LLC (2009) “Chrysler Envi - Plugged Into The World: Company Broadens its Production-intent Electric-vehicle Portfolio” [press release] available: <http://www.chrysler.co.uk/pressreleases/12-01-09.html> [accessed 28 April 2010]
- [44] BYD Auto (2010) “F3DM Parameteres” *Showroom / F3DM* [online] available: <http://www.byd.com/showroom.php?car=f3dm> [accessed 28 April 2010]
- [45] European Network of Transmission System Operators for Electricity (2010) “Hourly load values of a specific country for a specific month”, *Consumption Data* [online] available: <http://www.entsoe.eu/index.php?id=92> [accessed 21 April 2010]
- [46] National Grid (2010) “Metered half-hourly electricity demands”, *Demand Data* [online] available: <http://www.nationalgrid.com/uk/Electricity/Data/Demand+Data/> [accessed 21 April 2010]
- [47] Eirgrid (2010) “Market and System Data: System Demand”, *Download Centre* [online] available: <http://www.eirgrid.com/operations/systemperformancedata/downloadcentre/> [accessed 21 April 2010]

