Business Opportunities for Interoperability Assessment of EV Integration

COcepts, capacities and methods for Testing EV systems and their interOerability within Smart grids
This White Book targets any reader interested in EV interoperability assessment, its integration in the electric grid and smart charging.

It is mainly addressed to:

• regulators, policy makers and authorities
• standardisation committees and groups
• EMSP, EVSEO
• grid operators: DSO, TSO, aggregators
• manufacturers, mainly EV and EVSE
• investors
• research institutions and test laboratories
Business Opportunities for Interoperability Assessment of EV Integration

White Book
Executive Summary

The main objective of this White Book is to provide insight into the needs and business opportunities for the assessment of interoperability to support Electric Vehicle (EV) integration in the smart grid, as well as to raise the awareness of industry for future EV deployment design. The White Book makes progress from the technologies for EV integration, through the analysis of services and business models, towards needs and recommendations to pave the path for interoperability and its assessment.

The optimum integration of large amounts of EVs, dynamic loads and generators in electric grids remains a challenge. Achieving high levels of interoperability depends on many technical and commercial conditions that make it a complex goal.

To this purpose, it is essential to assess the performance and interoperability of all EV related systems, thus including those dealing with electrical energy transfer and data exchange. Moreover, the smart charging infrastructure has to be considered as a part of the smart grid, increasing the complexity level, but also allowing a market of added value services, as will be required by the expected EV deployment.

In this scenario, several domains have to be evaluated, including stakeholder interactions within the frame of a broad diversity of services, business models and regulatory schemes. It can be concluded that the information exchanged among the different components and actors is crucial for an assessment of interoperability.

There are some standards related to EV integration in the electric grid. Although ISO / IEC 15118 standard permits EVs smart charging, its use is not yet widespread among vehicle and infrastructure manufacturers (OEMs). Moreover, common standards allowing backend functions such as reservation and payment/billing methods are needed, along with cybersecurity features. In order to achieve the requirements for e-mobility interoperability, it becomes clear that international cooperation between standardisation and involved organisations is essential.

With strong alignment to the Smart Grid Architecture Model (SGAM), a basic reference architecture for interoperability assessment has been developed based on a 3-layer approach: the first layer identifies the different actors (business and legal), all the involved physical components and some required standards; the second layer adds services and information exchange as well as some additional communication requirements; and the third layer makes it possible to map these services in different configurations to test laboratories and systems.

To validate the interoperability between the customer, EV, EVSE, grid, and the backend systems in real life, seven test groups have been introduced along with their corresponding testing procedures. More than 250 tests have been performed within the project timeframe, and best practices through practical implementations, explicitly regarding ISO / IEC 61851, ISO / IEC 15118, OCPP and IEC 61850 protocols, have been proposed.

This work leads to the identification of the following business opportunities related to interoperability assessment, which are explained in Chapter 7:

- Testing services for EV interoperability using the COTEVOS unified infrastructure
• Testing services for EV interoperability providing a pan-European Certificate
• Consultancy services for OEM’s concerning interoperability assessment and testing

Though manufacturers, the industry and the rest of stakeholders agree on the interest for implementing functionally compatible systems and apparatus regarding EV charging and ancillary services, nowadays, the market for interoperability assessment is minor, and it is expected to be small in the short-term. However, COTEVOS’ infrastructure is already prepared to give an answer to the foreseeable market needs.

The uncertainty surrounding future e-mobility scenarios and the broad options spectrum make necessary for laboratories to adopt flexible architectures able to adapt to a great variety of use cases linked to different market and business models. This is even more critical when considering interactions between the e-mobility domain and the smart grid, which is crucial for enabling new business opportunities related to the provision of ancillary services to the future energy system.

The services offered by testing facilities are being defined according to business model based strategies. IEC61851-1 for the EV-EVSE interface is the protocol around which most testing facilities have been developed, due mainly to the foreseeable mid-term market. Several partners have created EV and EVSE emulators able to execute conformance tests for the IEC 61851 and ISO / IEC 15118 standards. Test cases for different versions of OCPP have also been developed around the EVSE and EMSP backend communications.

In order to make progress to a global economically sustainable approach for IOP assessment, the concept of a unified testing infrastructure has been developed, which is intended to join together the capabilities of different facilities across Europe, thus enabling harmonised interoperability tests services. It is worth mentioning that such an interoperability testing architecture should be flexible enough to encompass a great variety of future use cases, services and business models and it is also extendable to actors and functions beyond the e-mobility system.

In Chapter 8 several recommendations are addressed to different stakeholders regarding business models, standards development and validation, strategies to achieve a pan-European interoperable testing infrastructure, standard-based control strategies for a cost-efficient grid integration of EVs, etc.
Contents

Executive Summary ...................................................................................................................... 2

Contents ................................................................................................................................... 4

List of figures .............................................................................................................................. 6

List of tables ............................................................................................................................... 7

Terminology ................................................................................................................................ 8

Preface ......................................................................................................................................... 12

Structure of the White Book ........................................................................................................ 12

1. Key stakeholders in EV business ............................................................................................ 14

1.1 Electric Vehicle user ................................................................................................................ 16

1.2 EV and EVSE - Original Equipment Manufacturer (OEM) ..................................................... 17

1.3 EVSE Operator ....................................................................................................................... 17

1.4 E-Mobility Service Provider ..................................................................................................... 18

1.5 Distribution System Operator ................................................................................................... 19

1.6 Energy Supplier ...................................................................................................................... 20

2. Technologies for EV integration ............................................................................................... 21

2.1 EV Charging ............................................................................................................................ 21

2.2 Smart Charging ....................................................................................................................... 24

2.2.1 Needs related to information exchange ............................................................................... 25

2.2.2 Smart charging adoption ..................................................................................................... 26

2.3 Vehicle to grid services .......................................................................................................... 26

2.4 Key technological lessons ....................................................................................................... 28

3. Business models for EV integration ......................................................................................... 29

3.1 The framework: Regulation ..................................................................................................... 29

3.2 Business around EV integration ............................................................................................. 30

3.2.1 Public and semi-public charging ......................................................................................... 31

3.2.2 Private domain charging .................................................................................................... 32

3.2.3 Other ................................................................................................................................... 33

3.3 Services for doing business ..................................................................................................... 34

4. Needs for interoperability between EVs and electric power system ........................................ 39

4.1 Standardisation activities and needs ....................................................................................... 40

4.2 Gap analysis of new tests and conformance testing ................................................................ 46

5. Reference architecture for interoperability assessment ............................................................ 47

5.1 Actor/Interface Layer .............................................................................................................. 47

5.1.1 Actor-based Approach for the Reference Architecture ....................................................... 48

5.1.2 Standard and non-standard Interfaces ............................................................................... 48

5.2 Service/Function Layer ......................................................................................................... 49

5.3 Laboratory/Physical Layer ..................................................................................................... 51

6. Interoperability test cases and test results ............................................................................... 54

6.1 Test cases ............................................................................................................................... 54

6.1.1 EV Charging and Operation – TC1 .................................................................................... 56

6.1.2 EVSE Operation – TC2 ..................................................................................................... 56

6.1.3 EV/EVSE User Services – TC3 .......................................................................................... 56

6.1.4 EMSP-EVSEO Services – TC4 .......................................................................................... 56

6.1.5 Adaptive Charging – TC5 .................................................................................................. 56

6.1.6 V2X and Grid Services – TC6 ........................................................................................... 57

6.1.7 Wireless Charging – TC7 .................................................................................................... 57

6.2 V2G Plugtest Festival ............................................................................................................ 59

6.2.1 Test groups ......................................................................................................................... 59

6.2.2 Test results ......................................................................................................................... 61

6.3 Best practices obtained from practical implementations ....................................................... 62

6.3.1 IEC 61851 ......................................................................................................................... 63
List of figures

Figure 1: Overview of main e-mobility actors and versatile communication interfaces [2] 14
Figure 2: COTEVOS Reference Architecture 15
Figure 3: Structure of the EV design 21
Figure 4: AC EV charging station equipped with versatile communication interfaces 23
Figure 5: Example of HMI for Electric Vehicle [6] 24
Figure 6: Examples of “V2G ready” EVs and V2G at DTU in Roskilde, Denmark 27
Figure 7: V2G at present: Nissan “Leaf to Home” 27
Figure 8: General market model for public charging 32
Figure 9: General market model for private charging 33
Figure 10: Mobile metering model example 34
Figure 11: Fleet management model example 34
Figure 12: Information protocols summary [9] 37
Figure 13: Communications protocols summary [9] 38
Figure 14: Green eMotion Standardisation Roadmap and targets 39
Figure 15: Conceptual Levels of Interoperability [14]) 40
Figure 16: Process from Use Case to Interoperability on SGAM layers 41
Figure 17: eMI3’s overview of its main roles and interfaces 41
Figure 18: OCA architecture and interface view 42
Figure 19: EV overview and context IEC, SAE and GB standards [17] 42
Figure 20: COTEVOS Reference Architecture, Layer Actors/Interfaces 48
Figure 21: COTEVOS Service Layer 50
Figure 22: COTEVOS Service Layer, providing a mapping example on the actor layer 51
Figure 23: COTEVOS Laboratory/Physical Layer 52
Figure 24: Test scenario execution with simulated/real-world components 53
Figure 25: Testing infrastructures hosted by Joint Research Centre (JRC) 59
Figure 26: Test groups for V2G Plugtest™ 60
Figure 27: EVSE tester for ISO / IEC 15118 protocols 61
Figure 28: Structure of the IEC 61850 standard 66
List of tables

Table 1: Matching between actors in CEN-CENELEC and COTEVOS reference architectures 15
Table 2: Standards and differences between EV connectors and inlets 22
Table 3: Sample of the main standardisation activities related to COTEVOS [11] 44
Table 4: Use Cases against Standards and activities for Use Case group 5 Adaptive Charging 45
Table 5: List of test cases and procedures 55
Table 6: Sample template of a test report of TC1-3 (EV Charging using IEC 61851) 58
Table 7: IOP test description based on the manufacturers’ point of view 60
Table 8: Overall test results 61
Table 9 Test results from combining 26 different EVSEs with COTEVOS test cases 62
## Terminology

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>AMI</td>
<td>Advanced Metering Infrastructure</td>
</tr>
<tr>
<td>AMR</td>
<td>Automatic Meter Reading</td>
</tr>
<tr>
<td>AMS</td>
<td>Advanced Maintenance Suite</td>
</tr>
<tr>
<td>ANL</td>
<td>Argonne National Laboratory</td>
</tr>
<tr>
<td>AP</td>
<td>Access Point</td>
</tr>
<tr>
<td>BAIOP</td>
<td>Basic Application Interoperability Profile</td>
</tr>
<tr>
<td>BAP</td>
<td>Basic Application Profile</td>
</tr>
<tr>
<td>BE</td>
<td>Backend</td>
</tr>
<tr>
<td>BEV</td>
<td>Battery Electric Vehicle</td>
</tr>
<tr>
<td>BRP</td>
<td>Balance Responsible Party</td>
</tr>
<tr>
<td>CBA</td>
<td>Cost Benefit Analysis</td>
</tr>
<tr>
<td>CCS</td>
<td>Combined Charging System</td>
</tr>
<tr>
<td>CEN</td>
<td>European Committee for Standardisation</td>
</tr>
<tr>
<td>CENELEC</td>
<td>European Committee for Electrotechnical Standardisation</td>
</tr>
<tr>
<td>CH</td>
<td>Clearing House</td>
</tr>
<tr>
<td>CHAdemo</td>
<td>CHarge de MOve</td>
</tr>
<tr>
<td>CMS</td>
<td>Charging Management System</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>CP</td>
<td>Control Pilot</td>
</tr>
<tr>
<td>CS</td>
<td>Charging Station</td>
</tr>
<tr>
<td>CSO</td>
<td>Charging Station Operator</td>
</tr>
<tr>
<td>CSP</td>
<td>Charging Service Provider</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DER</td>
<td>Distributed Energy Resources</td>
</tr>
<tr>
<td>DIN</td>
<td>Deutsches Institut für Normung</td>
</tr>
<tr>
<td>DNO</td>
<td>Distribution Network Operator</td>
</tr>
<tr>
<td>DNP</td>
<td>Distributed Network Protocol</td>
</tr>
<tr>
<td>DNS</td>
<td>Domain Name System</td>
</tr>
<tr>
<td>DSM</td>
<td>Demand Side Management</td>
</tr>
<tr>
<td>DSO</td>
<td>Distribution System Operator</td>
</tr>
<tr>
<td>DUT</td>
<td>Device Under Test</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
</tr>
<tr>
<td>eMarket</td>
<td>Electricity Market</td>
</tr>
<tr>
<td>EMC</td>
<td>Electromagnetic Compatibility</td>
</tr>
<tr>
<td>EM-CG</td>
<td>E-Mobility Coordination Group</td>
</tr>
<tr>
<td>EMCH</td>
<td>E-Mobility Clearing House</td>
</tr>
<tr>
<td>eMI3</td>
<td>E-mobility ICT Interoperability Innovation Group</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>e-mobility</td>
<td>Electromobility</td>
</tr>
<tr>
<td>EMS</td>
<td>Energy Management System</td>
</tr>
<tr>
<td>EMSP</td>
<td>E-Mobility Service Provider</td>
</tr>
<tr>
<td>ENTSO-E</td>
<td>European Network of Transmission System Operators for Electricity</td>
</tr>
<tr>
<td>eRoaming</td>
<td>E-mobility Roaming</td>
</tr>
<tr>
<td>ES</td>
<td>Energy Supplier</td>
</tr>
<tr>
<td>ETSI</td>
<td>European Telecommunications Standards Institute</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>EV</td>
<td>Electric Vehicle</td>
</tr>
<tr>
<td>EVCC</td>
<td>Electric Vehicle Communication Controller</td>
</tr>
<tr>
<td>EVSE</td>
<td>Electric Vehicle Supply Equipment</td>
</tr>
<tr>
<td>EVSEO</td>
<td>Electric Vehicle Supply Equipment Operator</td>
</tr>
<tr>
<td>EVSEO CC</td>
<td>EVSE Operator’s Control Centre</td>
</tr>
<tr>
<td>FDIS</td>
<td>Final Draft International Standard</td>
</tr>
<tr>
<td>FO</td>
<td>Fleet Operator</td>
</tr>
<tr>
<td>FP7</td>
<td>7th Framework Programme</td>
</tr>
<tr>
<td>FSK</td>
<td>Frequency Shift Keying</td>
</tr>
<tr>
<td>GeM</td>
<td>Green eMotion FP7 project</td>
</tr>
<tr>
<td>GPRS</td>
<td>General Packet Radio Service</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>HAN</td>
<td>Home Area Network</td>
</tr>
<tr>
<td>HEMS</td>
<td>Home Energy Management System</td>
</tr>
<tr>
<td>HEV</td>
<td>Hybrid Electric Vehicle</td>
</tr>
<tr>
<td>HMI</td>
<td>Human Machine Interface</td>
</tr>
<tr>
<td>HSCSD</td>
<td>High-Speed Circuit-Switched Data</td>
</tr>
<tr>
<td>HV</td>
<td>High Voltage</td>
</tr>
<tr>
<td>HVDC</td>
<td>High Voltage Direct Current</td>
</tr>
<tr>
<td>ICE</td>
<td>Internal Combustion Engine</td>
</tr>
<tr>
<td>ICT</td>
<td>Information and Communications Technology</td>
</tr>
<tr>
<td>ID</td>
<td>Identification</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrotechnical Commission</td>
</tr>
<tr>
<td>IED</td>
<td>Intelligent Electronic Device</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IOP</td>
<td>Interoperability</td>
</tr>
<tr>
<td>IP</td>
<td>Internet Protocol</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organisation for Standardisation</td>
</tr>
<tr>
<td>IT</td>
<td>Information Technology</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent Transportation System</td>
</tr>
<tr>
<td>JRC</td>
<td>Joint Research Centre</td>
</tr>
<tr>
<td>LCV</td>
<td>Light Commercial Vehicle</td>
</tr>
<tr>
<td>LV</td>
<td>Low Voltage</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>MV/LV</td>
<td>Medium Voltage / Low Voltage</td>
</tr>
<tr>
<td>MV</td>
<td>Medium Voltage</td>
</tr>
<tr>
<td>OASIS</td>
<td>Organisation for the Advancement of Structured Information Standards</td>
</tr>
<tr>
<td>OCA</td>
<td>Open Charge Alliance</td>
</tr>
<tr>
<td>OCHP</td>
<td>Open Clearing House Protocol</td>
</tr>
<tr>
<td>OCPP</td>
<td>Open Charge Point Protocol</td>
</tr>
<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
</tr>
<tr>
<td>OICP</td>
<td>Open Intercharge Protocol</td>
</tr>
<tr>
<td>OS</td>
<td>Operating System</td>
</tr>
<tr>
<td>OSCP</td>
<td>Open Smart Charging Protocol</td>
</tr>
<tr>
<td>OSI</td>
<td>Open System Interconnection</td>
</tr>
<tr>
<td>PAIOP</td>
<td>Project Application Interoperability Profile</td>
</tr>
<tr>
<td>PAP</td>
<td>Project Application Profile</td>
</tr>
<tr>
<td>PE</td>
<td>Protective Earth</td>
</tr>
<tr>
<td>PEV</td>
<td>Plug-in Electric Vehicle</td>
</tr>
<tr>
<td>PHEV</td>
<td>Plug-in Hybrid Electric Vehicle</td>
</tr>
<tr>
<td>PLC</td>
<td>Power Line Communication</td>
</tr>
<tr>
<td>PU</td>
<td>Paying Unit</td>
</tr>
<tr>
<td>PV</td>
<td>Photovoltaic</td>
</tr>
<tr>
<td>PWM</td>
<td>Pulse With Modulation</td>
</tr>
<tr>
<td>RA</td>
<td>Reference Architecture</td>
</tr>
<tr>
<td>RES</td>
<td>Renewable Energy Sources</td>
</tr>
<tr>
<td>REST</td>
<td>Representational State Transfer</td>
</tr>
<tr>
<td>RF</td>
<td>Radio Frequency</td>
</tr>
<tr>
<td>RFID</td>
<td>Radio Frequency Identification</td>
</tr>
<tr>
<td>SA</td>
<td>Secondary Actor</td>
</tr>
<tr>
<td>SA</td>
<td>SUT Adaptor</td>
</tr>
<tr>
<td>SAE</td>
<td>Society of Automotive Engineers</td>
</tr>
<tr>
<td>SCADA</td>
<td>Supervisory Control and Data Acquisition</td>
</tr>
<tr>
<td>SDR</td>
<td>Service Detail Record</td>
</tr>
<tr>
<td>SE</td>
<td>Secure Element</td>
</tr>
<tr>
<td>SECC</td>
<td>Supply Equipment Communication Controller</td>
</tr>
<tr>
<td>SG</td>
<td>Smart Grid</td>
</tr>
<tr>
<td>SGAM</td>
<td>Smart Grid Architecture Model</td>
</tr>
<tr>
<td>SGCG</td>
<td>Smart Grid Coordination Group</td>
</tr>
<tr>
<td>SG-CG/SP</td>
<td>SG-CG Sustainable Processes</td>
</tr>
<tr>
<td>SNMP</td>
<td>Simple Network Management Protocol</td>
</tr>
<tr>
<td>SO</td>
<td>System Operator</td>
</tr>
<tr>
<td>SOC</td>
<td>State of Charge</td>
</tr>
<tr>
<td>SUT</td>
<td>System Under Test</td>
</tr>
<tr>
<td>TB</td>
<td>Technical Board</td>
</tr>
<tr>
<td>-----</td>
<td>--------------------------</td>
</tr>
<tr>
<td>TC</td>
<td>Test Case</td>
</tr>
<tr>
<td>TC</td>
<td>Technical Committee</td>
</tr>
<tr>
<td>TCO</td>
<td>Total Cost of Ownership</td>
</tr>
<tr>
<td>TCP</td>
<td>Transmission Control Protocol</td>
</tr>
<tr>
<td>TCP/IP</td>
<td>Transmission Control Protocol / Internet Protocol</td>
</tr>
<tr>
<td>TR</td>
<td>Technical Report</td>
</tr>
<tr>
<td>TS</td>
<td>Technical Specification</td>
</tr>
<tr>
<td>TSO</td>
<td>Transmission System Operator</td>
</tr>
<tr>
<td>TTCN-3</td>
<td>Testing and Test Control Notation Version 3</td>
</tr>
<tr>
<td>UC</td>
<td>Use Case</td>
</tr>
<tr>
<td>UI</td>
<td>User Interface</td>
</tr>
<tr>
<td>US</td>
<td>United States</td>
</tr>
<tr>
<td>V2G</td>
<td>Vehicle to Grid</td>
</tr>
<tr>
<td>V2H</td>
<td>Vehicle to Home</td>
</tr>
<tr>
<td>WG</td>
<td>Working Group</td>
</tr>
<tr>
<td>WGI</td>
<td>Working Group Interoperability</td>
</tr>
<tr>
<td>WLAN</td>
<td>Wireless Local Area Network</td>
</tr>
<tr>
<td>WPT</td>
<td>Wireless Power Transfer</td>
</tr>
<tr>
<td>XML</td>
<td>Extensible Markup Language</td>
</tr>
</tbody>
</table>
Preface

Electric Vehicles (EVs) are an important strategic field within the automotive industry. They are closely related to the European Union (EU) policy aimed at energy efficiency and tackling climate change (reduction of CO2 emissions).

Electric Vehicles (EVs) emerge as a great challenge for the electric network infrastructure, but they also offer great business opportunities under the smart grid and future transportation umbrellas. EV deployment can be highly supported by interoperable solutions for vehicle charging and other e-mobility services. A successful interoperability design is expected to result in lower EV charging prices due to lower operation costs for e-mobility actors and extended availability of services [1].

In order to promote the widespread deployment of EVs and to reduce the regulatory, commercial and political barriers, COTEVOS proposes and allows to assess the performance and interoperability of systems for EV integration.

COTEVOS has been working for three years, in the framework of the EU Programme for Research, Technological development and Demonstration, to establish the optimal structure and capacities to test the conformance, interoperability and performance of systems making up the infrastructure for EV charging.

Structure of the White Book

This document summarizes the framework, the needs, the capabilities and the business opportunities around interoperability assessment for EV integration.

Chapter 1 gives an overview of the different EV business-related stakeholders and their interactions, and Chapter 2 focusses on the technologies that make possible the present and provisional services related to EV charging.

Chapter 3 gives an insight on different business models that could motivate and justify interoperability assessment economically. The proposed business models are:

- Public and semi-public charging
- Private domain charging
- Mobile metering
- Fleet management
- Interoperability services

Based on the standardisation activities framework, Chapter 4 identifies the needs for interoperability between EV and the electric power system. The afore-mentioned needs are related to:

- The communication between EV and the electric vehicle supply equipment (EVSE)
- The communication infrastructure integrating EV/EVSE/electric power system/distribution system operators (DSOs)/e-mobility service providers
- Vehicle-to-Grid (V2G) implementation in the market of grid balancing
The identified needs lead to the definition of the reference architecture in Chapter 5, where the interoperability assessment laboratory can be conceived in a rational and flexible way, open to the future, to the market and to collaboration between European test labs.

Chapter 6 illustrates the results of different tests performed by the COTEVOS laboratories. These tests have been performed according to the test procedures developed within the project activities and are meant to give an answer to the interoperability needs of selected use cases and services.

Chapter 7 offers a roadmap for interoperability assessment. The objective of this chapter is to raise the awareness of industry concerning the necessity of interoperability assessment and proposes approaches on how to address this necessity.

To conclude this work Chapter 8 lists emerging recommendations for EV deployment and integration into the smart grid, from the need to facilitate cost-effective business models to the adequate implementation of infrastructures for interoperability assessment.
1 Key stakeholders in EV business

E-mobility is in the interest of many stakeholders:

- Those directly related to EVs such as: EV user, EV and EV Supply Equipment OEMs (EV OEMs and EVSE OEMs), EV Supply Equipment Operator (EVSEO) and E-mobility Service Provider (EMSP)
- Those from associated sectors, e.g.: Energy Suppliers (ES), Distribution System Operators (DSO), Transmission System Operator (TSO), Clearing House (CH) operator, Balance Responsible Party (BRP), etc.

Figure 1 has been chosen as a reference within EU M/468 Mandate to show the interactions among stakeholders in order to allow the functions to provide e-mobility.

Based on this reference starting point and considering the COTEVOS scope and goals, and the evolvement of e-mobility business environment, the COTEVOS Reference Architecture was developed. This architecture, presented in Figure 2, details the interfaces between individual e-mobility actors and introduces the terminology (names of the actors) which is used in standards related to e-mobility and/or is commonly used in e-mobility environment.
For better understanding of COTEVOS Reference Architecture in the light of commonly accepted e-mobility functions and actors (CEN and CENELEC [3]), Table 1 presents a comparison between names of actors used in Figure 1 and Figure 2. The labels of interfaces are the same in both figures, except for interface F, which is represented in COTEVOS architecture by several interfaces (H, J, K and N). In addition, the COTEVOS reference architecture introduces interfaces I, L, and M between actors from associated sectors (DSO, EMSP, Clearing House, Energy Supplier).

Table 1: Matching between actors in CEN-CENELEC and COTEVOS reference architectures

<table>
<thead>
<tr>
<th>CEN-CENELEC (Figure 1)</th>
<th>COTEVOS (Figure 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS Operator / Building Mgt Syst</td>
<td>EVSE Operator / CMS</td>
</tr>
<tr>
<td>Energy Meter</td>
<td>(integrated in EVSE)</td>
</tr>
<tr>
<td>EV Operator</td>
<td>(integrated in OEM)</td>
</tr>
<tr>
<td>E-mobility Operator</td>
<td>EMSP</td>
</tr>
<tr>
<td>Meter Operator</td>
<td>DSO / Smart Grid Management</td>
</tr>
<tr>
<td>Energy Retailer</td>
<td>Energy Supplier</td>
</tr>
<tr>
<td>Transmission System Operator</td>
<td>Transmission Grid</td>
</tr>
<tr>
<td>Distribution System Operator</td>
<td>DSO / Smart Grid management</td>
</tr>
<tr>
<td>Interoperability HUB (clearing House)</td>
<td>Clearing House</td>
</tr>
<tr>
<td>Energy Provider</td>
<td>Bulk / Distributed Generation</td>
</tr>
<tr>
<td>Balance Responsible Party</td>
<td>Energy Supplier &amp; Energy Markets</td>
</tr>
</tbody>
</table>
The COTEVOS Reference Architecture is explained in detail in Section 5, together with corresponding architectures of service and laboratory/physical layers.

A wide range of stakeholders, as presented in Figure 2, requires a set of communication solutions of different levels and types. The main actors affected by interoperability aspects are EV users, OEMs, EVSEOs, EMSPs and DSOs. Their roles and needs are described next.

### 1.1 Electric Vehicle user

EV users are the end customers in the e-mobility field, thus all technological solutions should be suitable for them. In order to meet EV users’ expectations, e-mobility technologies should ensure high reliability, ease of use and proper interoperability levels.

Three main types of EV utilisation can be distinguished: private, corporate and car sharing. Each of them is subjected to different scenarios and requires a commitment (to a different extent) of different actors.

In case of private EVs, the EV user (often is owner) charges his/her vehicle batteries at home by means of an on-board AC charger or in a public place utilising AC or DC charging.

The corporate vehicles are used for business purposes. Here, the EV user is not necessarily the EV owner. Charging at home is rather uncommon, and EVs are usually charged in public or company owned charging spots at car parks. Often, fast charging is favoured (either DC or AC).

Car sharing is a relatively new way of mobility, which is becoming more and more popular, especially in municipalities. In this case, EVs can belong to a car rental company or to a private person, who provides car sharing services to other parties. Dedicated public charging spots can be utilised for this aim.

**Role of EV user:**

- EV and EVSE utilisation
- Potentially, providing services through energy storage resources for other actors (e.g., ancillary services to DSO)

**Needs of EV user:**

- Easy and remote communication with charging infrastructure for comfortable and productive utilisation of EV and EVSE
- Batteries should be fully charged at the time of departure, or battery SOC is sufficient to reach the destination (especially if smart charging or V2G services are employed)
- Range anxiety avoidance
- Interoperability between EV and any EVSE in Europe
1.2 EV and EVSE - Original Equipment Manufacturer (OEM)

The products of EV and EVSE OEMs are developed simultaneously by many manufacturers all over the world. Therefore, the technical solutions that they choose are also diverse, often giving rise to several standards, e.g., for connectors used in EVs and EVSEs: type 1 (IEC 62196 and SAE-J1772), type 2 (IEC 62196-2), type 3, CHAdeMO (IEC 62196-1), Combo (IEC 62196-2) and Combo2 (IEC 62196-3). Such a collection is one of the reasons why conformance with specific standards does not guarantee interoperability and potentially rises anxiety in EV users.

Additionally, the widespread development of EVs requires their smart integration in the electric grid when charging. OEMs must follow and assess the implementation of emerging technologies such as smart charging or V2G.

Role of OEM:

- Provide products or components that:
  - Comply with versatile e-mobility standards
  - Meet end-user expectations (for example: EV range, reliability, ergonomics, etc.)
  - Demonstrate state-of-the-art and potentials of future solutions (smart charging, V2G, autonomous driving, etc.)

Needs of OEM:

- Clear understanding of expectations of end-users and stakeholders regarding aspects such as standards or required functionalities
- Ability to upgrade/diagnose EV and EVSE firmware

1.3 EVSE Operator

The EVSEO is responsible for managing and maintaining the Electric Vehicle Supply Equipment (EVSE).

According to IEC 61851-1 and ISO / IEC 15118-1 standards, the EVSE is composed of conductors, including the phase(s), neutral and protective earth conductors, the vehicle connector and inlet, attachment plugs, and all other accessories, devices, power outlets or apparatuses installed specifically for the purpose of delivering energy from the premises wiring to the EV and allowing communication between them if required.

In colloquial language the term Charging Station is commonly used instead of EVSE. However, these two terms are describing two different technological units. A Charging Station can contain several EVSEs; it is a physical grouping of one or more EVSEs, sharing a common enclosure and usually also other components such as EV user identification interface and communication interface towards EVSEO.
The EVSEO operates at least one EVSE as a service for e-mobility service providers (EMSPs) and their customers (EV users), but has no continuous contractual relation to EV users.

The responsibilities of the EVSEO may include:

- Control and maintenance of EVSE
- Purchase of energy for charging the EVSE
- Management of identification, authorisation and payment for charging
- Dealing with higher entities (energy supplier/aggregator, EMSP, DSO) for the procurement of electricity and provision of other services related to EV charging (such as executing charging service within physical boundaries of EVSE and of connection to grid, or providing smart charging services)

**Role of EVSEO**

- EVSE management
- EV charging process management
- Information exchange with other actors, e.g., DSO, EV, EMSP, Energy Supplier (ES), etc.

**Needs of EVSEO**

The role of the EVSEO may require communication with various stakeholders. For instance the EVSEO interacts with charging stations and EVs on one side and with energy suppliers, DSO and EMSP on the other. Therefore, the EVSEO needs dedicated interfaces ensuring the required interoperability. Principal EVSEO needs are listed below:

- Conformance with smart charging technologies
- Metering and grid parameters measure
- Communication interface to DSO
- Communication interface to EV
- Communication interface to EMSP
- Communication interface to energy supplier

A detailed list of the EVSEO’s tasks is presented in subchapter 2.2.

**1.4E-Mobility Service Provider**

According to the COTEVOS EMSP definition:

*The e-mobility service provider is a legal entity which holds a contract with the EV user for all services related to charging. The EMSP is the only actor who is able to connect the EV user ID number (and/or EV user identifier) with EV user’s personal data (name, address, bank account, etc.).*

**Role of EMSP:**

- Providing e-mobility services for an EV user
• Verification of EV user’s contract validity and authorisation of charging
• Information exchange with other actors such as DSO, EVSEO, ES or E-Mobility Clearing House (EMCH) in order to provide the service for EV user
• EV user range anxiety avoidance support
• Smart logistics management support, especially related to Electric LCV fleets: EMSPs have to provide, to smart logistic management system or to fleet management, information and data related to EV delivery route optimisation, according to vehicle range, vehicle SOC, battery lifetime optimisation, EVSE availability, charging cost, grid balancing, etc.

Needs of EMSP:

• Communication with high amount of third party actors
• ID information from actors involved in the service
• Trading information (what product or service is received/delivered)
• Localisation data

Being one of the key players in smart EV integration and in charge of the relation with EV Users, products and systems used by the EMSP to interface other stakeholders must be highly interoperable.

1.5 Distribution System Operator

A DSO is an entity responsible for operating, developing and ensuring the maintenance of the distribution grid. In the future, the DSO is expected to be responsible for regional grid stability, integration of loads and renewables at the distribution level or regional load balancing.

Reliability of supply is crucial for a DSO, thus, any tool improving grid stability and controllability, such as Demand Side Management (DSM), smart charging and Vehicle to Grid (V2G) services are important and potentially very useful, since still most of the devices in distribution systems are passive (uncontrolled). Communication standards intended to meet requirements for DSO-EVSEO communication are ISO / IEC 61850 (under continuous development) and Open Smart Charging Protocol (OSCP).

Role of DSO

• Delivery of electricity to end users or other DSOs
• Overtaking the electricity from distributed generation
• Power flow management
• Ensuring reliability and high quality of supply

Needs of DSO

• Congestion management
• Power quality maintenance
• Ancillary services (e.g., voltage control, active and reactive power control, phase balancing)
- Blackout recovery
- Bidirectional communication with other actors
- Costs reduction of grid investment

1.6 Energy Supplier

The energy supplier is an entity on the market selling electrical energy to consumers in compliance with the regulations for market organisation. The consumer can purchase the electricity for EV charging directly from the energy supplier or indirectly by buying the charging service from the EMSP who purchases the electricity on behalf of the EV user.

Role of energy supplier

- Trading electricity
- Acting as a balance responsible party

Needs of energy supplier

- Load management
- Communication interface to EMSP
- Communication interface to EVSEO (possibly via EMSP)
- Clarification of whom the energy is sold to (EV user / EVSEO)
2. Technologies for EV integration

The increasing penetration of the EVs in the market is expected to change the way in which distribution systems are operated and planned. The EV user could manage the charge of his/her own EV for providing ancillary services to the DSO, if adequately rewarded. For example, an EV could be charged according to dynamic scheduling, to support network operation.

Charging stations are connected to the grid at MV and LV levels, depending on their rated power. Usually, private and small public charging stations are directly connected to LV lines. In case of a centralised group of charging stations, such as fleet car parks or shopping mall car parks, a dedicated secondary substation (MV/LV transformer) is typically used.

2.1 EV Charging

Users can choose between three different types of electric vehicles: Pure Battery Electric Vehicles (BEVs), Hybrid Electric Vehicles (HEVs) and Plug-in Hybrid Electric Vehicles (PHEVs). PHEVs and BEVs can charge their batteries from the grid, while HEVs can be treated as combustion cars [4] [5]. EV batteries can be charged in different ways: 1-phase AC, 3-phase AC and DC (Figure 3).

![Figure 3: Structure of the EV design](image)
Table 2: Standards and differences between EV connectors and inlets

<table>
<thead>
<tr>
<th>Connector / Inlet</th>
<th>Illustration</th>
<th>Standard</th>
<th>Max voltage</th>
<th>Max current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td></td>
<td>SAE J1772-2009</td>
<td>250V AC</td>
<td>32A single-phase</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IEC 62196-2</td>
<td>32A single-phase</td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td></td>
<td>IEC 62196-2</td>
<td>500V AC three-phase</td>
<td>63A three-phase</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>250V AC single-phase</td>
<td>70A single-phase</td>
</tr>
<tr>
<td>Type 3</td>
<td></td>
<td>IEC 62196-2</td>
<td>500V AC three-phase</td>
<td>16/32A single-phase</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>250V AC single-phase</td>
<td>32A three-phase</td>
</tr>
<tr>
<td>CHAdeMo</td>
<td></td>
<td>IEC 62196-1</td>
<td>500V DC</td>
<td>120A DC</td>
</tr>
<tr>
<td>Combo</td>
<td></td>
<td>IEC 62196-2</td>
<td>500V DC</td>
<td>200A DC</td>
</tr>
<tr>
<td>Combo2</td>
<td></td>
<td>IEC 62196-3</td>
<td>500V DC</td>
<td>200A DC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>120V AC</td>
<td></td>
<td>16A AC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>240V AC</td>
<td></td>
<td>80A AC</td>
</tr>
</tbody>
</table>
Technologies for EV charging are developed simultaneously by many manufacturers all over the world and the technical solutions that they put forward are also diverse. As a result, there are several standards of connectors used in EVs and EVSEs (see Table 2), but they seldom look for interoperability of products compliant to them.

Concurrently, EVSEs are usually equipped with a set of hardware, other than the one devoted to power transfer, needed for the provision of e-mobility services, such as RFID terminals, credit card readers, HMI, etc., which should also comply with the applicable standards (see Figure 4 presenting ETREL station for public EV charging). Figure 5 exhibits an EV’s HMI.

Figure 4: AC EV charging station equipped with versatile communication interfaces

Besides the discrepancies in hardware, interoperability issues may also relate to Information and Communication Technology (ICT) aspects. In consequence, an EV user might face problems with the utilisation of e-mobility functions and services, ranging from the most basic aspects (uncontrolled EV charging) to car park and EVSE reservation, smart charging or V2G services, etc.
To enable the EV user to access additional e-mobility services, a connection to an EMSP is expected. This may require communications between the EV and EVSE. However, most of EVs and EVSEs comply currently only with the IEC 61851 standard, which permits limited features for the provision of additional services. Conversely, the ISO / IEC 15118 standard offers the EV user functionalities such as controlled smart charging or charging station reservation among many others.

### 2.2 Smart Charging

Smart charging refers to a controlled charging process that optimises the energy consumption of the EV from the grid. Moreover, the flexibility of EV charging or the availability of electrical energy in the batteries for feeding back the grid (V2G) can also minimise additional investments for grid reinforcement and facilitate the integration of Renewable Energy Sources (RES). Exchanging services requires a proper commercial agreement between EMSP and EV user as well as the communication between EVs and all other involved parties, e.g., DSO, EMSP, energy supplier.

The smart charging process is thereby controlled in such a way that multiple factors, such as grid stability, load flow management and energy pricing, are considered in order to achieve a beneficial result for all parties involved.

The EVSEO is the main actor for smart charging execution. Its role comprises load management activities according to the DSO’s requests, dynamic tariffing
and integration of EVs being charged into balance groups. A detailed list of tasks needed for the EVSEO to enable smart charging is given next:

- Acquisition of technical data from the EV (connectivity properties and technical parameters of min./max. charging load)
- Acquisition of technical data from the EV users about their preferences (required energy, available charging time window and confirmation to include their EV charging into load management schemes)
- Acquisition of relevant technical parameters from the grid
- Processing of requests received from the DSO about the total EV charging load in a certain area
- Processing of requests received from market actors about the total EV charging load of the EVSE included in a certain balance group
- Determination of an initial charging schedule (load profile) for each charging session, taking into account the aforementioned parameters
- Rescheduling of charging load profiles according to real-time requirements of the DSO or market actors
- Acquisition of data from the EVSE about the current status of each charging session
- Execution of preliminary negotiations with the DSO and market actors about technical and financial parameters of the EVSEO services on offer
- Acquisition of final charging session data (actual load pattern) from the EVSE and forwarding it to other actors if necessary

2.2.1 Needs related to information exchange

In order to provide smart charging, the EVSEO requires data from the charging infrastructure, electric network, energy market, the EV and the EV user.

The information on the charging infrastructure consists of the affiliation (EVSE identification and localisation), charging process details (such as charging time or the energy consumption) and electrical connection data (such as wiring schemes or maximum load at the point of common coupling). The information from the electric network includes the grid status and constraints, which can be obtained directly from the measurements. It includes the operational characteristics (e.g., demand profiles) of loads and generators connected in the same area of the charging station. The energy market data refers to the energy prices and all the information required for ancillary services provision.

Finally, the data from the EV and EV user incorporate information about the type of the EV charger, its rated power, as well as user charging preferences, including maximum charging power, the amount of energy required for charging and the duration of EV charging. The user preferences can be retrieved from the EV and the EVSE utilising the ISO / IEC 15118, or via smartphones or other HMIs.
2.2.2 Smart charging adoption

Smart charging is not common yet, but is expected to be widely accepted in the future. The EVSEO will very likely be the main actor who carries out the smart charging. After getting all data, the EVSEO will prepare charging schedules, which will be further negotiated and then executed. The scheduling can be performed in real time (short notice) or day-ahead, based on historical data and forecasts.

In any regime of operation, the EVSEO should be able to react to information on grid constraints received from the DSO. The EVSEO should also consider the DSO’s instructions on required actions that need to be performed to keep the grid operation parameters within the predefined limits. In addition, the EVSEO is also expected to operate the EVSEs in accordance with the needs of the EV user, who provides the resources for smart charging, and it is the main actor to be considered when assessing the value of the service and its business model. Thus, the preferences of the EV user should be prioritised and considered, including charging procedures recommended by the OEM in order to ensure maximum battery lifetime.

Currently Smart Charging is not widely adopted since there are not many allowed viable business opportunities. DSOs are forced to deliver the demand of (consumers having) an EV and cannot reward delayed charging. Flexible tariffs, which would enable more EV integration business models, is still not common yet. Adapted legislation will enable new viable business opportunities and the adoption of smart charging.

2.3 Vehicle to grid services

V2G is a technology that enables the bidirectional sharing of electricity between the EV and the electric power grid. Thus EV could enhance and support power grid operation by providing additional or enhanced services such as power regulation, spinning reserves substitution or peak generation [7].

The V2G service is based on the following assumptions:

- The EV is equipped with a battery of high capacity
- The State of Charge (SOC) will always fulfil the user’s requirements for driving and will never be lower than the recommended minimum value
- The EV should be connected to the grid via a bidirectional power converter, which allows power to flow in both directions
- The EV owner must be conveniently rewarded, also taking into account the cost of battery depreciation

Due to a low availability of EVs that are technically ready for V2G, the potential for these services is currently low. However, in the future, a fleet of, e.g., 100,000 connected EVs, could easily provide about 1000 MW of dispersed power, which could be used by the DSO and the TSO for grid management.
Examples of “V2G ready” vehicles are provided by Scion and Nissan (Figure 6). Additionally some V2G demonstration installations were recently introduced by Enel and Nissan (Figure 6).

![Example of “V2G ready” EVs and V2G at DTU in Roskilde, Denmark](image)

Figure 6: Examples of “V2G ready” EVs and V2G at DTU in Roskilde, Denmark

![V2G at present: Nissan “Leaf to Home”](image)

Figure 7: V2G at present: Nissan “Leaf to Home”  
(courtesy of Nissan Motor Company)

V2G technology provides various types of services for the network. Some examples are listed below:

- LV network balancing
- LV overvoltage management
- MV-LV transformer and lines overloading management
- Islanded micro grid and black start
- LV congestions management
- Power quality improvement (harmonic mitigation etc.)

The following services could also support the TSO in power system management:

- Frequency regulation
- Synthetic inertia
• Adaptive charging

Currently, there is not legal, market or operational framework for a widespread utilisation of V2G services, which is not expected to become a commonly used technology in the following 5-10 years.

2.4 Key technological lessons

Summarizing the conclusions about the technological lessons with relevance for the business of test laboratories:

• Different types of connectors are competing at international level, and the available infrastructure at a laboratory restricts the applicability of the services. In Europe, Type 2 plugs for AC and Combo2 plugs will be most relevant, but other types cannot be neglected. There is a trade-off between investment and maintenance costs for the physical infrastructure and the range of customers to be addressed.

• Whereas the first implementations of smart charging services were mostly based on ad-hoc solutions, ICT standards such as ISO / IEC 15118, OCPP, OCHP, etc. are becoming widely adopted nowadays, and are a good basis for the provision of interoperability and/or conformance testing services. Some of the standards already provide an accompanying test specification. However, there is still a competition between different standards for some of the interfaces.

• Many advanced charging functionalities that are not yet implemented at a commercial level today will be enabled by ISO / IEC 15118 standard. European test facilities will likely need to support the standard, whether they offer conformance testing services for it or not.

• In principle, EVSEOs can offer a wide range of different services to grid operators (either directly, or via an aggregator), including both traditional ancillary services, such as secondary balancing power, and more advanced functionalities, such as price incentives for grid-friendly charging. Depending on the type of service, different requirements with respect to communication and data exchange must be fulfilled. The infrastructure required for testing, but also for research and development, must integrate the two traditionally separated domains grid and vehicle, and hence requires a high-degree of expertise and investments. This can be an opportunity for large laboratories.

• Vehicle to grid services are still in the experimental stage and do not provide valid business opportunities yet. A relevant case for testing laboratories could be the provision of research infrastructure and support for manufacturers during the research and development process.
3. Business models for EV integration

The smart grid integration of EVs is highly dependent on the interoperability of e-mobility solutions and management procedures of the electric network. In addition, it is expected that the interoperability between different e-mobility developments results in lower prices and extended services availability for end users, when viable business models for EV integration are available and usable. EV integration business models and Interoperability are both preconditions for EV smart grid integration. When both are in place, interoperability assessment can become a business on its own.

In order to achieve this, it is necessary to be able to assess interoperability, not only at the level of physical systems but at all domains, including stakeholder interactions within the frame of a broad diversity of services, business models and regulatory schemes.

This chapter presents business models aspects regarding the smart charging of EVs and the grid, in order to define the grounds to weight the need for interoperability and its assessment.

3.1 The framework: Regulation

Regulation sets the highest level framework for the development of activities within a region. It has a direct influence on regulated businesses, such as those related to the distribution and transmission of energy, but it also builds a framework for private business development.

Regulation should not hinder EV market penetration but promote business models and permit their profitability regarding global sustainability concepts. Both, strict rules and the lack of regulatory definition might become a barrier for the development of healthy businesses.

The electricity sector regulation has a direct impact on all businesses developed in this field and, thus, also on those related to EVs. Some of the regulatory aspects that have an impact on EV businesses are the following:

- **Network operation procedures**: define the involvement of small DER, the implementation of mechanisms for the deployment of demand flexibility services, etc.
- **Low voltage and building codes**: define the basic requirements that infrastructure assets and installations should meet when connected to the low voltage network. Currently, many building codes include requirements related to the EV infrastructure in buildings.
- **Electricity tariff**: has an influence on the end users’ behaviour with respect to the use of electricity. Network tariffs remain regulated in most countries and they could be used for demand response shaping.
• **Market requirements**: might hinder the involvement of some actors (small DER, aggregators, etc.) in potential business models. On the other hand, new market structures should be a good way to increase competition.

• **Security and environmental aspects**: have an impact on EVs, the grid infrastructure for their charging and the commercialisation of the corresponding products: electromagnetic compatibility (EMC) assessment, compliance with the applicable directives, etc.

• **Compensation of regulated activity**: system operators’ incomes are based on the eligible costs defined by regulations. Therefore, regulation has a direct influence on DSOs’ strategies, as key players for EV integration.

Other, more general, aspects of regulation, on top of those mentioned above, further influence the development of business options:

• **Competition protection**: is of great importance and allows new stakeholders to access established markets.

• **Administrative requirements and taxes**: might represent a challenge, especially for startup businesses.

• **Support schemes or other benefits for end user**: they are convenient in the beginning in order to help develop a new market.

An essential characteristic of regulation is its area of applicability. At European Union (EU) level, EC directives are common for all countries and they should be transposed to national legislations. Nevertheless, other rules and requirements exist at national, regional and municipal levels. Different rules, needs and requirements for technical or functional aspects, as well different taxation, fees, public charging costs, and request allowing financial support for EV or politic strategies for e-mobility enabling and growing, could affect EV interoperability and development. In a best case scenario, similar or unified strategy for e-mobility grow up and interoperability could allow stronger EV interoperability and e-mobility grow up: for instance, for public charging technical solutions and diffusion and related costs, for common EV traffic restrictions avoidance or EV congestion tax exemption, as well free parking allowance with opportunity charging available, etc. In general, neighbouring countries and regions should observe interoperability carefully. In the best-case scenario, this would lead to a worldwide integration of EVs.

Even if harmonisation is being pursued at EU level, structural differences between countries exist, resulting in diverse market conditions, which are characterised by the different players’ roles, the electricity system operation procedures, small consumer participation in energy markets, low voltage codes, etc. This poses risks for interoperability that should be minimized through harmonization, as discussed in Section 7.2.

### 3.2 Business around EV integration

The importance of the regulatory framework for the development of business models and, in particular, of innovative businesses has already been mentioned.
in the previous section. Even if some areas provide better environments for the
development of e-mobility businesses than others, current and future market
options should be considered.

Consumers’ tendency to value losses higher than gains has already triggered the
search of innovative businesses. In this context, service sale (compared to
product sale) and solutions based on information and communication
technologies (ICT) seem to stand out. Some examples are the following [8]:

- **Alternatives to vehicle purchase**: the high price of batteries and, in
general, the total cost of ownership (TCO) of EVs, make leasing (of the
complete vehicle or only of the batteries), vehicle sharing and rental
especially suitable services
- **Infrastructure**: the charging point location area, be it either private, public
or semi-public, leads to different costs, smartness opportunities and
competition level options
- **Interoperability**: is expected to generate a demand increase for service
providers, higher comfort for the end user and a reduction in costs
- **Sustainable transportation**: EVs are part of a global sustainable approach
and, therefore, solutions offering new mobility concepts are starting to
appear (combined use of private and public transport, vehicle share,
smart logistic, etc.)

Charging remains the main service linked to EVs. The following sections will
analyse some examples according to the location of the charging point.

### 3.2.1 Public and semi-public charging

Public and semi-public charging present the highest range of solutions and
complexity, because more roles might be involved in the business model,
including the EMSP, the EVSEO, the ICT interoperability platform manager, etc.
This has a direct impact on end-to-end communication complexity.

The use of ICT interoperability platforms (e.g., marketplace, roaming) is mostly
under demonstration phase, but some commercial applications already exist in
the market. The next figure represents a general scheme showing possible
business (orange arrows) and communication (black arrows) relationships
between actors/roles (Figure 7).
3.2.2 Private domain charging

The EV charge in the private domain is similar to the one in public and semi-public areas when EMSP and/or EVSEO are involved. However, many EV users might charge their vehicles under conventional residential energy contracts and infrastructure. In this case, the end user would take over the role of the EVSEO and the tasks of the Energy Suppliers. DSOs might perform load management in the frame of residential demand response strategies, using the infrastructure and protocols deployed for that purpose, including Home Energy Management Systems (HEMS), Advanced Metering Infrastructure (AMI), etc. (Figure 9). This approach is common in the USA and Japan, while the focus in Europe seems to be set on more complex schemes as the one in Figure 8.
3.2.3 Other

Mobile metering is a special case related to both public and private domains. This business approach proposes to use smart domestic or industrial sockets for EV charging instead of the more expensive dedicated EVSEs.
**Fleet management** normally requires some specific services such as EV monitoring, which other activities may not need. It is suitable for public transport and new businesses such as EV sharing or flexibility aggregation.

3.3 **Services for doing business**

Services are the basis of business models. They can be described through use cases.
Many services have already been tested in EV-related demo projects, but their feasibility needs to be validated both in real markets and regulatory frameworks since, in many cases, they were developed in a research and pilot project environment.

Coming back to the example of the EV charging service, it requires different characteristics and information features depending on its smartness, interoperability level and market model. Some options are shown below as an example:

- **Open access**: The EV user charges at an EVSE without the need of having a contract with an EMSP. The EVSEO offers the whole charging service to the EV user and therefore has an agreement with one or more EMSPs. The EV user can be offered the possibility to choose from a list of charging services offered by different EMSPs at the EVSE. The EV user pays on the spot.

- **Without roaming**: The EV users are only allowed to charge at the EVSE network provided by their EMSP. In this case, the EVSEO and the EV user have an agreement with the same EMSP.

- **Roaming**: The EV user can charge at the infrastructure of an EVSEO who has no exclusive agreement with his EMSP. Clearance, either financial and/or data, is done through a CH.

- **With roaming through a marketplace**: EMSP and EVSEO (as well as any other stakeholder) can offer, find and select the required services at a single marketplace.

- **Private charging**: In the private domain, smart charging is normally foreseen through a HEMS system, which is able to control the EV load through a dedicated EVSE or a more conventional smart switch, normally allowing for low levels of management (on/off, deferred start, etc.).

Services definition permits to have a closer look into the interactions between components (stakeholders or systems) and the functions that have to be covered. For example, open access needs less information because it involves fewer actors during the charging process (EVSE operator and EV user) and may not require identification beyond established processes (credit card payment, for example). Roaming involves the CH, and the marketplace adds a new actor, but it would simplify operations by centralising exchanges. By adding smartness to the charging process, other actors like system operators (SO) and services (electricity price information, vehicle information, etc.) are included in the procedure.

It should be noted that business models are based on service trading, and that companies use these services to differentiate their product from those of other competitors. Sometimes communication protocols are not able to address all the services that companies want to provide. Hence, some communication protocols are adapted to allow for new data structures permitting new services.
This barrier for interoperability is quite common today, especially in some interfaces such as the EVSE-EVSEO link.

The following Figure 12 and Figure 13 show the components involved in the e-mobility ecosystem and the potential information and communication protocols that could be used for the exchange of information among them.

The implicit complexity of information exchange among components and the existing barriers introduced throughout this section show the need for an assessment of interoperability. COTEVOS has faced this issue as its main goal, building the technical capabilities and developing the business strategies to present an offer focused on the concept of the Unified Laboratory, where the available testing infrastructures aim at giving the required and foreseeable support towards interoperability.
Figure 12: Information protocols summary [9]
Figure 13: Communications protocols summary [9]
4. Needs for interoperability between EVs and electric power system

COTEVOS has carried out its interoperability approach in close relation to standardisation following on-going standardisation activities [10] [11] (COTEVOS_D21, 2015) (COTEVOS_D22, 2015). The EU project Green eMotion published a Standardisation Roadmap [12] that highlights several business cases related to network services provision by EVs (Figure 14):

![Figure 14: Green eMotion Standardisation Roadmap and targets](image)

This roadmap shows the expected and required timeframe for standards and new e-mobility services, such as smart charging, demand response and V2G.

To ensure interoperability for EV integration, a use case approach, like the one considered in COTEVOS, proves very effective. Its advantage is that it can be based on business opportunities (see chapter 6 for more details).

Interoperability means much more than just a set of standards, as the definition by M/490 WGI shows [13]:

*Interoperability is the ability of two or more networks, systems, applications, components, or devices from the same vendor, or different vendors, to exchange and subsequently use that information in order to perform required functions.*

One of the main issues of interoperability is that standards often contain options, which impair interoperability due to different implementations in different system components.

Next Figure 15 shows the conceptual levels of interoperability considered as reference in the project. Currently, most e-mobility standards operate on the syntax level (level 2). COTEVOS aims at higher levels, which involves a common meaning of the data and an approach towards real interoperability.
4.1 Standardisation activities and needs

With respect to standardisation activities and needs, COTEVOS’s first step was to
analyse the standardisation landscape. Several standardisation activities have
been identified and studied, the following being the most important ones:

- M/468: e-mobility Coordination Group and WG Smart Charging
- M/490: Smart Grid Coordination Group
- IEC TC 69 Electric road vehicles and electric industrial trucks
- eMI3: e-Mobility ICT Interoperability Innovation Group
- OCA: Open Charge Alliance
- Other organisations: JRC, ETSI CTI, DERLab partners, etc.
- Other projects: Green eMotion, PlanGridEV, STARGRID, PowerUp, etc.

The second step was the identification and study of several e-mobility related
standards and best practices, which included:

- IEC 62196, CCS / Combo2, CHAdeMO
- IEC 61851, ISO / IEC 15118
- OCPP, OCHP, OICP, and other EVSEO – EMSP interfaces
- DSO related interfaces like IEC 61850 and OSCP

A well-defined architecture and methodology for standards and interoperability
development and design is crucial. It is recommended to use the methods and
architecture described by M/490 work groups, including the SGAM (Smart Grid
Architecture Model) [M/490-MNA], and the COTEVOS reference architecture as
described in Chapter 5 [15].
In addition, the M/490 WGI has developed a methodology to achieve interoperability, which is again based on use cases (Figure 16) [13].

![Figure 16: Process from Use Case to Interoperability on SGAM layers](image)

Regarding standardisation and architecture, eMI3 and OCA are also worth mentioning. eMI3 has formed a work group on architecture and recently published an overview of its main roles and interfaces (see Figure 17) [16].

![Figure 17: eMI3’s overview of its main roles and interfaces](image)

Similarly, OCA created an architecture and interface view. Figure 18 shows the locations of the OSCP and OCPP interfaces.
The final step made in the standardisation analysis was an international comparison of the standardisation scenarios. Figure 19 represents an overview of EV and EVSE standards in Europe, USA, and China.

According to Figure 19, different regions have different standards. However, they can be easily mapped onto each other since the main structures have been assimilated. Thus, it is recommended to extend the current international cooperation between JRC and ANL to other actors, such as IEC TC 57/TC 69, OCA, eMI3, and relevant laboratories like those built by COTEVOS.

A key project result is the complete COTEVOS Standardisation Table (see Table 3) with references to standards and groups. The following are considered to be the most important current and future standards and protocols in the field of e-mobility integration in the grid: IEC 62196, IEC 61851, ISO / IEC 15118, OCPP, OCHP, OICP, IEC 61850, and OSCP.
From the complete COTEVOS Standardisation Table, the following conclusions are drawn:

- Most e-mobility standards available cover the EV-EVSE interface (more than 15 are international and about 10 are from the USA and China)
- From the standards covering other interfaces, about 10 are international and about 10 are from Europe. They are not very mature yet and involve a great number of actors and systems, which makes them good candidates for further alignment, above all, with regard to the information object content and structure

A basic set of e-mobility information objects was identified in the project [10]. These objects are used by multiple actors and in more than one interface, which corroborates the need for standardisation.

The technical report IEC TR 61850-90-8 makes a step in the right direction. This technical report describes how current standardisation for EV and related communication interfaces (IEC 62196, IEC 61851, ISO / IEC 15118) can be linked to IEC 61850-7-420 - standard for DER - in order to secure a high level of safety and interoperability. The basic information in IEC 61850 and IEC 61850-7-420 already covers a lot of needs for the e-mobility domain. However, this technical report defines missing parts, which are modelled as new logical nodes and data objects.

As expected, most information objects fall in one of the following categories: EVSE search, charging session management, EV, EVSE, charge station management, billing, authorisation, identification and roaming. The remaining categories (energy management, grid management, and e-mobility services) only show few use cases and information objects, which might not satisfy the requirements to prevent interoperability issues.

Many of the recommendations on standardisation derived from the analysis that deals with the extension of the current international cooperation. It would be convenient to involve IEC TC 57/69, OCA, and eM3 in the definition of different advanced use cases. However, common architectures and methodologies should be implemented and validated through simulation or testing in order to produce clear interfaces and information objects, which should be exchanged in terms of security issues.

Considering the outcomes of the work performed in the project, there is no need for new standardisation groups at this moment (2015).
Table 3: Sample of the main standardisation activities related to COTEVOS [11]

<table>
<thead>
<tr>
<th>Reference</th>
<th>TC/SC</th>
<th>Title/Standards, regulations and standardisation activities</th>
<th>Source</th>
<th>Status</th>
<th>Release/Timeframe expected</th>
<th>Region/Country</th>
<th>Related to</th>
<th>Interoperability Area/Interface nr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 61851-1</td>
<td>69 - Electric road vehicles and electric industrial trucks</td>
<td>Electric vehicle conductive charging system - Part 1: General requirements</td>
<td><a href="https://webstore.iec.ch/publication/6029">https://webstore.iec.ch/publication/6029</a></td>
<td>Published</td>
<td>25-11-2010</td>
<td>International</td>
<td>IEC 61851-1</td>
<td>EV-EVSE</td>
</tr>
<tr>
<td>ed2.0</td>
<td></td>
<td>Electric vehicle conductive charging system - Part 1: General requirements</td>
<td><a href="https://webstore.iec.ch/publication/6029">https://webstore.iec.ch/publication/6029</a></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ed.3</td>
<td></td>
<td>Electric vehicle conductive charging system - Part 1: General requirements</td>
<td><a href="https://webstore.iec.ch/publication/6029">https://webstore.iec.ch/publication/6029</a></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEC 61851-21</td>
<td>69 - Electric road vehicles and electric industrial trucks</td>
<td>Electric vehicle conductive charging system - Part 21: Electric vehicle requirements for conductive connection to an a.c./d.c. supply</td>
<td><a href="https://webstore.iec.ch/publication/6030">https://webstore.iec.ch/publication/6030</a></td>
<td>Published</td>
<td>2001-05-04</td>
<td>International</td>
<td>IEC 61851-21</td>
<td>EV-EVSE</td>
</tr>
<tr>
<td>IEC 61851-22</td>
<td>69 - Electric road vehicles and electric industrial trucks</td>
<td>Electric vehicle conductive charging system - Part 22: AC electric vehicle charging station</td>
<td><a href="https://webstore.iec.ch/publication/6031">https://webstore.iec.ch/publication/6031</a></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEC 61851-23</td>
<td>69 - Electric road vehicles and electric industrial trucks</td>
<td>Electric vehicle conductive charging system - Part 23: DC electric vehicle charging station</td>
<td><a href="https://webstore.iec.ch/publication/6032">https://webstore.iec.ch/publication/6032</a></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEC 61851-24</td>
<td>69 - Electric road vehicles and electric industrial trucks</td>
<td>Electric vehicle conductive charging system - Part 24: Digital communication between a d.c. EV charging station and an electric vehicle for control of d.c. charging</td>
<td><a href="https://webstore.iec.ch/publication/6033">https://webstore.iec.ch/publication/6033</a></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4: Use Cases against Standards and activities for Use Case group 5 Adaptive Charging

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Controlled Charging</td>
<td>TC5-3</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>-</td>
<td>yes</td>
<td>-</td>
<td>yes</td>
<td>partly</td>
<td>-</td>
<td>see WGSP-1300/1200</td>
<td>use cases available</td>
<td>maybe</td>
<td>yes</td>
<td>under development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real-time (adaptive) charging</td>
<td>TC5-2</td>
<td>partly</td>
<td>yes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>OCPP (2.0)</td>
<td>yes</td>
<td>no</td>
<td>-</td>
<td>see WGSP-1300/1200</td>
<td>use cases under development</td>
<td>maybe</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smart charging</td>
<td>TC5-3</td>
<td>partly</td>
<td>yes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>OCPP (2.0)</td>
<td>maybe OSCP</td>
<td>yes</td>
<td>no</td>
<td>-</td>
<td>use cases available</td>
<td>maybe</td>
<td>Green eMotion EU Project WPx</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.2 Gap analysis of new tests and conformance testing

In order to elaborate priorities for new tests and conformance testing methods, COTEVOS has compared potential test cases with the international standardisation scenario through a gap analysis process. Table 4 gives an example of this result for the use case group dealing with adaptive charging.

Several conclusions were drawn from this gap analysis:

- Communication between EV and EVSE: too many different solutions have been implemented. There is a need for a standard that simplifies the identification for roaming while providing sufficient features (available digits, security, and relevant data format). ISO / IEC 15118 standard is not installed by default in EVs and EVSEs.
- Infrastructure communications:
  - Need to develop backend requirements as well as an interface standard that supports roaming services between EMSPs
  - Need to develop a universal messaging standard to permit EV drivers to locate and reserve a public charging spot, including local list management
  - On Clearing Houses and service exchange market platforms: OCHP and OICP protocols have already been implemented; several custom made, proprietary solutions are also developed and in use
  - The need to guarantee a sufficient and secure communication between EVSE and other actors in the EV system
  - The need of standardised payment methods and of a guaranteed possibility to pay for charging at all public charging stations
  - For the communication between EVSEs and EVSE management systems, a real standard is welcomed at least at an information/business object level. OCA recently selected OASIS as the Standard Development Organization for OCPP
  - A protocol to secure communication between EVSE Backend and DSO should also be agreed

Several gaps have been identified in terms of standardisation.
5. Reference architecture for interoperability assessment

In order to provide a common and unambiguous context, a reference architecture has been proposed for testing the interoperability of EV-charging infrastructure.

The COTEVOS reference architecture is strongly inspired by two well-known state-of-the-art models in the e-mobility and smart grid environment: the CEN/CENELEC/ETSI focus group model [18] and the Smart Grid Architecture Model (SGAM) [13].

The main requirements for this architecture are the following:

1. Providing a common and unambiguous context for COTEVOS in the form of a basic reference architecture; all COTEVOS partners agreed to use it when specifying use cases and test cases.
2. Reflecting the current and future e-mobility system in Europe; the basic reference architecture should not only describe the future system but also fit the current real world situation.
3. Describing the responsibilities of each actor in the system; when the responsibilities of all actors are clear, the interfaces between the actors will be stable while creating a future-proof architecture and e-mobility system.

The requirements imposed on the COTEVOS reference architecture are located in three different domains: the actor/interface domain, the service/function domain and the physical/electrical domain. The COTEVOS reference architecture is based on these domains using a 3-layer approach. This multidimensional approach is similar to the SGAM model but focused on the testing purpose. The first layer of COTEVOS identifies the different (business/legal) actors, all the involved physical components, and some required communication protocols. The second layer adds services and information being exchanged and some additional communication requirements. The third layer enables to map these services onto different configurations in test labs and systems.

5.1 Actor/Interface Layer

Analysing different initiatives, such as M/468 Smart Charging [18], the FP7 Green eMotion project, eMI3, SGAM, PlanGridEV [19], and considering the current European electricity market [20], the relevant EV actors and roles have been identified. Some actors have similar roles in all initiatives, but this is not always the case. Moreover, depending on the country’s regulatory frameworks, the roles of actors also change.
5.1.1  Actor-based Approach for the Reference Architecture

The interfaces defined among actors are depicted in Figure 20, which represents the whole e-mobility system. The interactions between actors (or more accurate, roles) are described by A-to-M interfaces (COTEVOS Interface IDs). Figure 20, compared to Figure 2 (see Chapter 1), gives additional basic information (communication protocols and standards, data exchanged) about interfaces that are of particular importance for interoperability.

5.1.2  Standard and non-standard Interfaces

In some cases, the interfaces depicted are supported by one or more communication protocols. For example, ISO / IEC 61851, ISO / IEC 15118 standards, or other proprietary alliances, such as CHAdeMO, can be used for the EV-EVSE interface (interface A). In other cases, there are no standards but widely adopted communication protocols and information objects are available. This is true for OCPP (interface E), which has already been adopted by many EVSE Operators. Nevertheless, the existence of a standard or of an open protocol...
does not mean that it will be adopted by the industry. For example, OCHP (interfaces K and L) is an open protocol for CHs and EMSP interoperability but has not been widely adopted yet.

Although interactions as well as information exchange between e-mobility actors are necessary, there are cases without any adopted standard and, sometimes, there will never be one. An illustrative example is the way EV users access the services offered by the EMSP. Every EMSP will have its own web page or smartphone application available for their users. Moreover, the services that two EMSPs offer to their customers can be completely different.

5.2 Service/Function Layer

The service layer in Figure 21 allows for a separation of the interests within the e-mobility system and shows which main services, functions and interfaces are required when dealing with the use cases agreed upon in COTEVOS. It is similar to the functional layer of SGAM, which also describes functions and services including its business relationships [13]. Each service provides specific functions and, consequently, describes its requirements. The proposed view allows the use cases to be defined in terms of services instead of actors or physical power infrastructure, which makes a functional specification independent from its deployment(s).
Figure 22 shows an example of mapping of services onto the corresponding actors. Because of the specific usage of the services in this example, we know the responsibilities of each actor. This mapping may be different for other market models, while the services and their interfaces stay the same.

The above-mentioned approach is similar to the one used to develop the EU Smart Grid Conceptual Model within the Methodology report from the M/490 mandate by CEN/CENELEC /ETSI [13]. This conceptual model is based on the Harmonized Energy Market Role Model [20], in which all actors in the EU electricity market are harmonised by using roles.
Figure 22: COTEVOS Service Layer, providing a mapping example on the actor layer

5.3 Laboratory/Physical Layer

Whereas the layers in the previous sections describe the actors and services within the e-mobility system and can be used as a common scheme, the additional laboratory/physical layer provides an architecture approach for conformance and interoperability testing within a laboratory environment.

The approach for black-box-testing is used, where the test operator has no knowledge of the internal structure and functionality of the Device Under Test (DUT). Only the interactions of the DUT with its environment have to be known. Thus, the test operator can only influence the interfaces of the DUT.

The laboratory system, which is based on this architecture, must offer the possibility to test every component of the actors described in section 5.1. In order to test interoperability, the DUT will be connected to simulated or emulated systems within the reference architecture. COTEVOS decided to emulate several system components, since market solutions and standards are still evolving and expected functionalities are often not available in commercial products.
In addition, in order to support test cases development in accordance to the methodology described above, the laboratory reference architecture should be characterised by a modular design, by a fast configuration change capability, and by permitting to scale up tests.

Figure 23 shows the laboratory reference architecture developed within the COTEVOS project [15]. Every actor of the e-mobility system is integrated as an emulated component. In addition, one or more of these implemented components could be replaced by real-world actors. The communication between the actors is performed by means of a message bus working as a software-based router between all the components in the system.

To complete the reference architecture, a graphical user interface for visualisation, logging and control is provided. This allows the test operator to control the tests by an integrated scenario editor and compare test and expected results using visualisation and logging tools.

The message bus simulation can be based on a TCP/IP-based data exchange to provide the best flexibility with the web-based actors of the e-mobility system (e.g., the CH). If necessary, the flexible and modular approach of the architecture allows the simple substitution of the communication media. On the whole, the reference architecture provides a co-simulation environment with hardware integration support, which is not restricted to the e-mobility system.

The substitution possibilities are depicted in Figure 24. In the user interface and control software (e.g., the scenario editor), all components are abstractly implemented as proxies. Each proxy acts as a common interface and can either represent a simulated/emulated or a real world component (e.g., CH system). The information exchange between the proxies and the corresponding devices

---

**The message bus works as a software-based message router between the connected components**

**According to a modular approach, DUTs as real-world actors and emulated components can be dynamically chosen**
uses the message bus simulation as described before. Every hardware component has its own connector, which works as a protocol converter to the common bus system infrastructure. This configuration allows a fast replacement of simulated components by hardware-based ones. It also allows a fast introduction of new communication protocols or components into the test laboratory environment.

Figure 24: Test scenario execution with simulated/real-world components
6. Interoperability test cases and test results

COTEVOS’ laboratories have set up infrastructures for testing the interoperability of relevant functions in the customer-vehicle-EVSE-grid-backend system chain, according to the reference architecture explained in Chapter 5. More information is detailed in Chapter 7.

These infrastructures were used to test the interoperability of a number of selected use cases, which respond to the real situation of charging an EV. In addition, the procedure to carry out and correctly report a test was also developed in detail. The tests form the basis of a roadmap towards interoperability throughout Europe. The implementation of selected parts of the interoperability tests set shows to what extent COTEVOS supports this roadmap and helped reveal future needs.

6.1 Test cases

A number of test cases have been defined and collected in an attempt to cover the full spectrum of interoperability combinations. The test cases have been mapped, condensed and categorised into seven groups (TC1 - TC7) [15].

Table 5 shows the list of test cases, indicating the Group-ID (column 1), a short title of the Test Case (column 2), and an identifier that denotes each particular test case procedure (column 3). Each case represents a working operation of the chain, a customer-vehicle-EVSE-grid-backend system combination. The test cases, together with actual test results, are the final and critical step towards validating the desired interoperability of a particular service implementation involving several components.

The test cases contribute to a roadmap ensuring a Europe-wide interoperability. If all test cases are successfully approved, a seamless customer experience across Europe would be guaranteed.

However, the task of covering the full range of test cases is prohibitive. Thus, the careful definition and grouping of the test cases, together with the meticulous specification of what and how to test, gives the opportunity to any laboratory, within or outside COTEVOS, to explore single test cases, bundles of test cases or even to specialise in a particular group of test cases. The groups represent an attempt to collect test cases similar in nature and with similar test equipment requirements.
<table>
<thead>
<tr>
<th>Group-ID</th>
<th>Test Cases</th>
<th>Test Case Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC1</td>
<td><strong>EV charging and Operation</strong></td>
<td>TC1-1</td>
</tr>
<tr>
<td></td>
<td>Charge the EV</td>
<td>TC1-2</td>
</tr>
<tr>
<td></td>
<td>Voltage and current limit observation</td>
<td>TC1-3</td>
</tr>
<tr>
<td></td>
<td>Time constraints for charging current changes</td>
<td>TC1-4</td>
</tr>
<tr>
<td></td>
<td>Time constraints for charging termination</td>
<td>TC1-5</td>
</tr>
<tr>
<td>TC2</td>
<td><strong>EVSE Operation</strong></td>
<td>TC2-1</td>
</tr>
<tr>
<td></td>
<td>Monitoring</td>
<td>TC2-2</td>
</tr>
<tr>
<td></td>
<td>Firmware and diagnostics</td>
<td>TC2-3</td>
</tr>
<tr>
<td></td>
<td>EVSE operation</td>
<td>TC2-4</td>
</tr>
<tr>
<td></td>
<td>Local list management</td>
<td>TC2-5</td>
</tr>
<tr>
<td>TC3</td>
<td><strong>EV/EVSE User Services</strong></td>
<td>TC3-1</td>
</tr>
<tr>
<td></td>
<td>EV user’s access to EVSE and charging information</td>
<td>TC3-2</td>
</tr>
<tr>
<td></td>
<td>EVSE reservation</td>
<td>TC3-3</td>
</tr>
<tr>
<td></td>
<td>EV user identification and authentication</td>
<td>TC3-4</td>
</tr>
<tr>
<td></td>
<td>Charging authorisation</td>
<td>TC3-5</td>
</tr>
<tr>
<td>TC4</td>
<td><strong>EMSP-EVSEO Services</strong></td>
<td>TC4-1</td>
</tr>
<tr>
<td></td>
<td>EVSE information management</td>
<td>TC4-2</td>
</tr>
<tr>
<td></td>
<td>EVSE reservation</td>
<td>TC4-3</td>
</tr>
<tr>
<td></td>
<td>Charging authorisation</td>
<td>TC4-4</td>
</tr>
<tr>
<td>TC5</td>
<td><strong>Adaptive Charging</strong></td>
<td>TC5-1</td>
</tr>
<tr>
<td></td>
<td>Controlled charging</td>
<td>TC5-2</td>
</tr>
<tr>
<td></td>
<td>Real-time (adaptive) charging</td>
<td>TC5-3</td>
</tr>
<tr>
<td></td>
<td>Smart charging</td>
<td>TC5-5</td>
</tr>
<tr>
<td>TC6</td>
<td><strong>V2X and Grid Services</strong></td>
<td>TC6-1</td>
</tr>
<tr>
<td></td>
<td>Primary frequency regulation</td>
<td>TC6-2</td>
</tr>
<tr>
<td></td>
<td>LV network balancing</td>
<td>TC6-3</td>
</tr>
<tr>
<td></td>
<td>LV over-voltage management</td>
<td>TC6-4</td>
</tr>
<tr>
<td></td>
<td>MV-LV transformer and lines overloading management</td>
<td>TC6-5</td>
</tr>
<tr>
<td></td>
<td>Secondary frequency regulation</td>
<td>TC6-6</td>
</tr>
<tr>
<td></td>
<td>Synthetic inertia</td>
<td>TC6-7</td>
</tr>
<tr>
<td>TC7</td>
<td><strong>Wireless Charging</strong></td>
<td>TC7-1</td>
</tr>
<tr>
<td></td>
<td>Tolerance of the inductive coupling (X/Y-axis)</td>
<td>TC7-2</td>
</tr>
<tr>
<td></td>
<td>Tolerance of the frequency</td>
<td>TC7-3</td>
</tr>
<tr>
<td></td>
<td>EM-field variation with decoupled coils</td>
<td>TC7-4</td>
</tr>
<tr>
<td></td>
<td>Power variation</td>
<td>TC7-5</td>
</tr>
<tr>
<td></td>
<td>Management of on/off-time</td>
<td>TC7-6</td>
</tr>
<tr>
<td></td>
<td>Communication systems</td>
<td></td>
</tr>
</tbody>
</table>
6.1.1 EV Charging and Operation – TC1

The first group of test cases (TC1) [15] relates to the coherent functionality of the EV when charging. The test cases are divided into 5 distinct test cases. The test cases validate if the EVs are compatible with simple charging, the tolerance of charging (voltage/current fluctuations), and time constraints regarding changes in current set points and termination time, as well as charging controlled through the use of the communication standard ISO / IEC 15118.

6.1.2 EVSE Operation – TC2

The second group of test procedures (TC2) [15] is dedicated to validating the functionality of the EVSE with respect to 5 critical aspects: monitoring, control and operation of the charging point/EVSE, the firmware of the EVSE, the status of the EVSE with respect to the current OCPP communication, as well as to what extent the EVSE is able to handle/perform local list management.

6.1.3 EV/EVSE User Services – TC3

The third group of test cases (TC3) [15] highlights user interaction with the charging point when connecting the EV for charging and the interaction between the EVSE and EVSEO backend in the case the charging is executed in the EV user’s “home” network. Test cases cover the EV user’s access to EVSE and charging information, how the user reserves an EVSE, how the EVSE is able to identify and authenticate the EV user and EV, and, finally, after the identification and authentication, how to finalise the hand-shake by authorising actual charging and initiate billing.

6.1.4 EMSP-EVSEO Services – TC4

The fourth group of test cases (TC4) [15] deals with the interaction between EVSEO and EMSP, either directly or via EMCH. Test cases cover how the involved actors perform information management, how they handle a reservation request, all the actions that need to be performed before issuing the charging authorization, and, finally, the follow-up or closing action of generating and managing the service detail reporting (SDR management).

6.1.5 Adaptive Charging – TC5

This group of test cases (TCS) [15] relates to the adaptive charging of an EV, in order to align with grid constraints or market-related information. The three test cases described cover controlled charging, where the charging can be controlled or limited to a certain degree to a set point due to, e.g., capacity constraints of the grid; real-time (adaptive) charging, where the charging level may be altered offhandedly; and smart charging, where the charging can refer and adhere to a predefined schedule with changes in, e.g., charging power set points.
6.1.6 V2X and Grid Services – TC6

This group of test cases (TC6) [15] refers to the situation with potential grid services and bidirectional power flows. Seven different test cases (TC6-1 to TC6-7) are described covering primary and secondary frequency regulation, LV network balancing and over-voltage management, MV and LV transformer and lines overloading management, synthetic inertia, as well as more specialised services, such as islanding of micro grids and black start from a power outage. This group of test cases relates to the interest of system operators and has a high potential for research work. However, these tests also place large demands on costly test equipment.

6.1.7 Wireless Charging – TC7

The interoperability concepts for wireless charging are in many respects difficult to match with conventional wired charging. TC7 Group [15] analyses the alignment and strength of the wireless charging coils with respect to an electromagnetic field variation up to an air gap of 200 mm between the coils. In this regard, it describes how to assess and characterize the tolerance of the inductive coupling and frequency, the electromagnetic field variation with decoupled coils, the power variation, the management of on/off time and the communications.

Table 6 represents, as an example, the test results template referred to test case TC1-3 (EV Charging using ISO / IEC 61851). In a first part, it includes all generic information about the test lab/person, a version number, the date of test, and equipment details and preconditions. The second part specifies a set of actions with corresponding prescribed or anticipated responses. Finally, the actual response and the derived result (pass or not pass) are given, together with practical actions completing and closing the test.
Table 6: Sample template of a test report of TC1-3 (EV Charging using IEC 61851)

<table>
<thead>
<tr>
<th><strong>Author</strong></th>
<th><strong>Version</strong></th>
<th><strong>Date</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>AIT</td>
<td>1.0</td>
<td>04-08-2015</td>
</tr>
</tbody>
</table>

**Test Group**: EV Charging and Operation  
**Test Case**: EV Charging using ISO / IEC 61851 - time limitations  
**Test ID**: TC-1.3-EV-004  
**Description**: Test max time for charging currents changes to take affect  
**Test Objective**: • Test if time constraints for charging current changes are met  
**Information objects (Standards)**: • ISO / IEC 61851, Charging rate, charging state, communication signal

**Equipment Specifications**

**EV**  
• Manufacturer:  
• Model:  
• Charging mode: ISO / IEC 61851-3  
• Charger power:  

**EVSE**  
• Manufacturer: Phoenix Contact  
• Model: ISO / IEC 61851-3  
• Available charging current: 32A, three phases  
• charging mode: ISO / IEC 61851-3

**Cable**  
• Nominal Current: 32A  
• Plug EVSE side: ISO / IEC 62196 Type 2  
• Plug EV side: ISO / IEC 62196 Type 2  
• Length: 3m

**Preconditions**  
• SoC below 50%

**Test Procedure**

<table>
<thead>
<tr>
<th><strong>Step</strong></th>
<th><strong>Action</strong></th>
<th><strong>Prescribed Result</strong></th>
<th><strong>Actual Result</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Enable measurement setup</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Plug cable to EVSE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Plug cable to EV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Enable charging process (pref. 16A)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Set max charging current to 10A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>$\Delta t &lt; 2s$ as according to 61851 (Y/N)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Post Conditions**  
• unplug cable

**Comments**
6.2 V2G Plugtest Festival

ETSI CTI organised the 1st V2G Interoperability Plugtests™ event, which was hosted by the JRC of the EC in Ispra, Italy, from 30th November to 4th December, 2015. COTEVOS provided the technological support of the event.

The Plugtests™ aimed at verifying the interoperability between products for integration of EV to the smart grid. They focused on assessing the interoperability between the systems, considering also the communication protocols, for the interfaces used to integrate EVs into the electric grid.

The test sessions involved the confrontation of, at least, two devices of different vendors (or an emulator and a device) and depended on the test configuration. During the event, the support team tracked the running tests and updated the schedule on demand. A total of 42 two-hour test sessions were conducted during the four-day event. The testing report tools for scheduling and reporting purposes were provided by ETSI CTI, while the testing procedures were conducted based on the interoperability test plan developed by COTEVOS partners. The interoperability test specifications refer to IEC 61851, ISO / IEC 15118, OCPP or IEC 61850.

6.2.1 Test groups

The test description contained a set of test scenarios to be executed by vendors. Furthermore, it provided guidance to participants for executing and assessing the test sessions as described in Table 6. The IOP Plug Test Festival allowed testing IOP according to the products and protocols shown in Table 7.
Table 7: IOP test description based on the manufacturers’ point of view

<table>
<thead>
<tr>
<th>EV manufacturers</th>
<th>Charging Stations Manufacturers Comments</th>
<th>Charging Points Operators</th>
<th>Multiple Actors (EV/EVSE Manufacturers, EVSE Operators, etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a IEC 61851: Infrastructure and test cases for testing EV charging</td>
<td>c IEC 61851: Infrastructure and test cases for testing the charge</td>
<td>h OCPP v2.0: Testing platform (RC1) and test cases</td>
<td>k IEC 61851/OCPP v1.6 based infrastructure for assessing smart-charging capabilities</td>
</tr>
<tr>
<td>b ISO/IEC 15118: Infrastructure for EV interoperability</td>
<td>d ISO/IEC 15118: Infrastructure for EVSE interoperability</td>
<td>i OCPP WS-Addressing compliance testing platform</td>
<td></td>
</tr>
<tr>
<td></td>
<td>e OCPP v2.0: Testing platform (RC1) and test cases</td>
<td>j OCPP v1.2, v1.5, v1.6: Infrastructure for interoperability</td>
<td></td>
</tr>
<tr>
<td></td>
<td>f OCPP WS-Addressing compliance testing platform</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>g OCPP v1.2, v1.5, v1.6: Infrastructure for interoperability</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The tests were grouped in the following main groups from A-E (Figure 26).

- **TG-A.** IEC 61851: Infrastructure and test cases for testing EV charging
- **TG-B.** ISO / IEC 15118: Infrastructure for EV interoperability
- **TG-C.** IEC 61851: Infrastructure and test cases for testing EVSE to charge EVs
- **TG-D.** ISO / IEC 15118: Infrastructure for EVSE interoperability
- **TG-E.** OCPP v2.0 (RC1): Infrastructure and OCPP test cases for testing EVSE

Since there were no commercial DUTs available, the test groups B and D were carried out with ISO / IEC 15118 EV and EVSE emulators (see Figure 27).
6.2.2 Test results

Table 8 exhibits a summary of the test results as reported in the ETSI Test Reporting Tool (TRT).

Because of the duration of each test session (2h) and a limited availability of the participants, 42 sessions with, on the whole, 262 tests were scheduled and executed. 215 of the tests had a pass rate (OK), which results in a success rate of 82.1%. This high level of interoperability at the event can be attributed to the maturity of base specifications.

<table>
<thead>
<tr>
<th>Interoperability</th>
<th>Not Executed</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>OK</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td>215 (82.1%)</td>
<td>47 (17.9%)</td>
<td>262</td>
</tr>
<tr>
<td></td>
<td>120 (31.4%)</td>
<td>382</td>
</tr>
</tbody>
</table>

In order to avoid any IOP failures and improve the interoperability capability from the manufacturers’ and testing infrastructures’ points of view, it is worth analysing the failed test results.
Table 9 shows the results obtained from testing 26 different EVSEs in accordance with COTEVOS test cases. Clearly, the table is not completely green. Hence, there are gaps in individual implementations of the IEC 61851 standard, which shows that interoperability is not always ensured.

<table>
<thead>
<tr>
<th>DUT</th>
<th>C.01</th>
<th>C.02</th>
<th>C.03</th>
<th>C.04</th>
<th>C.05</th>
<th>C.06</th>
<th>C.101</th>
<th>C.102</th>
<th>C.103</th>
<th>C.104</th>
<th>C.105</th>
<th>C.106</th>
<th>C.107</th>
<th>C.108</th>
<th>C.109</th>
<th>C.110</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVSE.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVSE.26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Not performed due to mismatching plugs or other issues
OK
Failed

6.3 Best practices obtained from practical implementations

Understanding how standards should be implemented and where related problems come from is of paramount importance for interoperability. From the test implemented in COTEVOS, the following main conclusions can be drawn with respect to IEC 61851, ISO / IEC 15118, OCPP and IEC 61850 standards [15].
6.3.1 IEC 61851

The bidirectional information exchange between an EV and an EVSE is achieved by either low-level or high-level communication. The low-level communication is accomplished in terms of PWM signalling (control pilot) as defined in IEC 61851-1. The high-level communication requires the establishment of a TCP/IP-based communication as defined in ISO / IEC 15118. The transition from low-level to high-level communication is achieved by setting the duty cycle of the PWM signal at 5%.

The implementation of a test that emulates the protocols under the two standards is a suitable approach in order to develop an understanding of how the low-level and high-level communications operate and how to facilitate smart grid integration. It involves first-hand experience of how the communication facilitates the charging process from the detection of the vehicle to the optimisation of energy production systems as well as experience with payment systems for the transfer of energy.

Expending the effort to understand how these standards are defined will allow any interested party to begin analysing the necessary hardware and software implementations that facilitate the integration of EV-related services into smart grid laboratories. These standards are now well defined, and obtaining the documentation is a crucial first step towards successful integration.

Dividing the implementation of the two standards into stages can further help simplify the process. Once test rigs for each standard are correctly emulated, understanding how to best incorporate the devices and equipment into a smart grid infrastructure can be achieved more easily.

For example, the emulation of the IEC 61851 standard requires both an EV and EVSE. Testing equipment that emulates an EV is already commercially available. More specifically, it can test the state transitions in order to assess the compliance of a commercial/custom-made charging station with the standard. Such EV emulators allow some tests to be carried out, for instance, initiation of the charging process, control of states, control of power according to duty cycle, or termination of the charging process. Usually, EV emulators cannot emulate the power flow adjustment when duty cycle modifications occur due to the absence of battery units and battery management systems. Moreover, a custom EVSE development enables the complete conformance testing of a commercial EV. The conformance test comprises the state control check, start/stop charging, duty cycle and frequency modification response, EV response time, etc.

In general, all EVSEs reacted according to the specifications, with the following remarks:

- An EVSE did not lock the cable/grip properly; the cable could be removed in C state (charging)
An EVSE was able to deliver power in D state although it was not configured to switch on a ventilation system.

Further issues were identified when testing EVs because IEC 61851 does not clarify what to do in unexpected situations. The following paragraphs summarise the results:

- When the PWM signal was removed, the EV still had its S2 relay connected for 30 seconds, giving an unexpected state (6 V up) not registered in the standard.
- When the frequency violates the specification (900 Hz), the EV remains in charging mode (state C2). Even though the operational behaviour of the EV when exposed to extreme frequency variations is not defined in the IEC 61851, the charging should stop for safety reasons.
- When the frequency violates the specification (1100 Hz), the EV remains in charging mode (state C2).
- When changing the duty cycle, the EV takes a long time to finally reach the requested power limitation.

Concerning the frequency, the EVs that allow charging with low frequencies (900 Hz) reject the charge with high frequencies (1100 Hz).

6.3.2 ISO / IEC 15118

The ISO / IEC 15118 standard mainly focuses on high-level communication and specifies the communication between the EV Communication Controller (EVCC) and the Supply Equipment Communication Controller (SECC). An emulation of this can be achieved by using a microprocessor connected to a power line communication (PLC) modem, with one pair (microprocessor and power line modem) representing a communication controller. There are open source software implementations of the ISO / IEC 15118 standard available on repository sites, such as Github (https://github.com). These complete implementations can be downloaded and saved to the microcontrollers to provide the necessary infrastructure for a test rig compliant with ISO / IEC 15118.

Once such setups are tried and tested, more directed research can be performed on lab integration.

It is important to keep in mind that these tests were not carried out with commercial DUTs but using ISO / IEC 15118 testers. Therefore, the failed tests are rather descriptive by collecting all the data in order to solve the problem afterwards. However, it is not relevant to locate these errors in a report.

Nevertheless, a special issue was found in the hierarchic use of XML substitution groups. In XML substitution groups, ISO / IEC 15118 messages can be dealt with in two different ways:

- The tag element is substituted by one element of the substitution group.
• The tag element remains in the message; the information will be added by using the type attribute.

According to XML, the message is exactly the same despite different representations. While ISO / IEC 15118-2 specifies the first approach, it does not clarify whether a message produced by the second approach should be discarded or not.

6.3.3 OCPP

One of the key actors in the field of e-mobility is the EVSEO, the operator of the charging infrastructure. The EVSEO acts as the middleware between the charging facilities and the different e-mobility stakeholders (i.e., EVSE OEMs, energy suppliers, system operators, and EV users). The communication between the EVSEO and the different EV stakeholders should not be limited due to lack of interoperability. Thus, for each communication link, international standards should be adopted.

The interaction between an EVSEO and an EVSE can be realised using the OCPP protocol. The OCPP is an open protocol and is publicly available at www.openchargealliance.org. It is widely adopted by most commercial charging stations because it offers a uniform solution. Any charging station from any vendor that adopts the OCPP protocol can be coupled with an OCPP compliant EVSEO backend.

The OCPP protocol enables the EVSEO to monitor the status of a charging station (available/unavailable, free/busy, etc.), the charging power level and the energy consumption during a charging session. This information is necessary not only for billing purposes but also for offering demand flexibility.

Furthermore, OCPP enables the remote control of the charging station. It allows the EVSEO to modify the maximum current of the charging station (from zero up to the nominal current of the EVSE). Regarding power settings, the EVSEO is responsible for fulfilling the needs and preferences of different stakeholders, which might be sometimes contradictory, e.g., EV user versus DSO requests. Depending on the management strategy that the EVSEO adopts, it can define the maximum allowable charging power of each charging station with respect to the priority of each request.

The implementation of OCPP enables the development and testing of advanced EVSE management systems avoiding interoperability issues.

6.3.4 IEC 61850

IEC 61850 is a communication standard commonly used by system operators throughout Europe. Hence, it is a promising solution for EV integration services. The standard includes several parts that make it suitable to cover the communication between various smart grids components: EVs, distributed generation, energy storage, energy management systems, or protection systems.
equipment (Figure 28). One of the most recent is a technical report on IEC 61850-90-8 referring to e-mobility and EV integration.

The architecture of the standard is hierarchical and consists of four levels. The highest level refers to physical devices, which are modelled by Intelligent Electronic Devices including at least one Logical Device. The Logical Device model (second level) represents information about the resources of the host itself, including the connection to real equipment and the common communication aspects applicable to a number of Logical Nodes. The Logical Node model (third level) includes a set of signals which represents detailed measurements, statuses, etc. Each signal is represented by sets of parameters (fourth level). In order to describe a device or a part of the power system, Logical Nodes and Logical Devices from different standard parts are utilised.

IEC 61850 is a communication standard for electric substation automation systems, and, therefore, TSOs and DSOs are its natural users. However, it can also be implemented by an EVSEO. The standard cannot be implemented in an EV, but the data model reflects functions and parameters essential for the management of charging processes that can be translated from other standards (e.g., IEC 61851 or ISO / IEC 15118).

Within COTEVOS, IEC 61850 has been used for the following services: primary and secondary frequency regulation, power balancing, voltage management,
MV-LV transformer and power lines overload management, synthetic inertia, island mode operation and black start. Some of these tests require measurement and control of both active and reactive power. The technical report dealing with e-mobility only supports the management of active power. However, IEC 61850 also allows reactive power management by utilising LNs from parts IEC 61850-7-420 and IEC 61850-7-4, which deal with Distributed Generation Resources. Consequently, IEC 61850 helps ensure interoperability for the services before. However, there is still room for further development. The present form of the standard does not cover the whole potential for EV integration, which is in particular true for the field of power quality, e.g., harmonics management.
7. Paving the way for interoperability

This section describes the present and future topics that will be relevant and the facts that are expected to occur in the short and mid-term towards interoperability assessment.

7.1 From Conformance to Interoperability

In order to demonstrate interoperability, it must be shown that the assumed performance is indeed fulfilled by the involved systems.

Usually, the performance of different functionalities is based on different standards, which give “presumption of compliance” of these functionalities. Thus, the level of guarantee that a system actually fulfils these standards is expected to be high after tests are passed.

Furthermore, the test for standard conformance is carried out in accordance to some procedures which might be based on different directives and involve Notified Bodies or Accredited Laboratories. When the result is positive, it can be stated that the system under test is conforming to that standard but the presumed functionality cannot be guaranteed.

Ensuring interoperability is complex since most standards only cover interaction between two entities and are often not applicable to a complete system. Moreover, most standards address the syntax but often not the semantics (the meaning of the data and how it should be applied), which causes interpretation differences.

Thus, it can be stated that the IOP assessment can never be fully ensured. However, the assessment can be fulfilled with relevant expectations depending on the level of complexity of the functions to be performed, the existence and quality of the standards, and the procedures to carry them out.

In order to determine the conformance-critical aspects of communication standards, and, hence, to develop the required conformance tests, it is a good approach to start with interoperability tests. Unlike conformance tests, which try to separate individual requirements into atomic test settings, interoperability tests implement more complex use cases and can involve the whole end-to-end communication chain with several actors and interfaces. Because of this, use cases and test cases become an important part in ensuring interoperability.

Any problems that occur in the interoperability test should be identified and converted into a conformance test for the affected standard(s). Figure 16 shows the process from use cases to interoperability on the SGAM layers.

COTEVOS has made great progress in IOP assessment of devices related to the integration of EVs within the electric network. The standards permitting to assess the functionality of the different interfaces have been analysed, as
described in Chapter 4, and potential alternatives have been proposed in case they were missing (see Section 4.2). Additionally, testing infrastructures and capabilities have been developed, testing procedures have been drafted for selected test cases and the corresponding tests have been performed (round robin when feasible). This describes an early stage of a present and future offer of IOP assessment for EV integration.

Furthermore, the concept of a unified testing infrastructure has been developed, which is intended to be set up at selected facilities across Europe, thus enabling harmonised interoperability tests. The reference architecture described in Chapter 5 provides the basis for this.

### 7.2 Challenges of E-Mobility Interoperability Assessment

Regulatory aspects are crucial in the development of business models regarding interoperability assessment services. The demand for these services will respond to the regulatory conditions given. Regulatory conditions are key for the interoperability levels 0 and 1 as depicted in Figure 15. At the given time it remains unclear how exactly the final solutions will be designed. Nevertheless it is commonly expected that differences will most likely occur in markets at regional level despite the harmonisation efforts taking place at EU level. It is thus likely the continental harmonisation to take a second iteration after first successful business models have matured.

The demand for Interoperability Assessment Services will respond to the charging and flexibility services that are offered and to socio-economic conditions. Overall, differences will most likely occur in markets at regional level despite the harmonisation efforts taking place at EU level. In this context, several business/market models and services related use cases are expected in the e-mobility field in Europe, even if final solutions remain unclear yet.

Different interoperability levels can be considered. A first approach is related to the charging process in public domains. Charging is the main service in the e-mobility context and one objective of interoperability is to guarantee that any EV can easily be charged in the public infrastructure. This can be achieved in several ways, for example, by open access to EVSEs (there is no need of a contract with an EMSP), uncontrolled charge (electromechanical level of interoperability is sufficient to permit charging), or smart charge, leading to the interaction between different stakeholders and involving end-to-end communications. The last option introduces a second approach to interoperability, which is related to the integration of the charging process within smart grid systems.

Considering the approaches mentioned above, several e-mobility interoperability levels can be taken into account with regard to the smartness of the charging process, market model schemes, demand response strategies, and other factors. This facilitates a great variety of interoperability use cases and related test cases.
The integration of e-mobility into the smart distribution grids turns out to be of paramount importance, and an effective combination of both spheres largely relies on ICTs. Some key points are described below:

- The high number of involved stakeholders/roles and systems (components) depicts a complex interaction scenario
- The system operators’ technical and business approaches affect the adoption of solutions
- Distribution electricity systems have different characteristics. This largely determines the deployment of the charging infrastructure, and has an impact on the EV penetration level and on the potential services

Although e-mobility-related standards should provide the basis for IOP testing services, ICT protocols in other fields of smart grids (network operation, AMI, ITS, home automation, etc.) should also be taken into account. An ICT protocol analysis permits to draw the following main conclusions:

- E-mobility-related standards are diverse but improvable
- In practice, some of the standards are too complex to be implemented, therefore product manufacturers (EV, EVSE, ICT, etc.) are expected to assess the opportunity and scope of their application
- Some protocols do not permit providers to cover all the services they wish to offer, which leads to the utilisation of proprietary solutions
- Some of the interfaces between components are not realistic in certain market or business contexts, for example, the direct control of an EV charge by a DSO
- Some standards are still at a development stage
- Many protocols are not properly designed to provide interoperability at all levels. For example, a definition is lacking or a given scope is too wide
- It is expected that standards developed in other fields, such as smart grids, Intelligent Transport Systems (ITS) and home automation, will be part of end-to-end communications for e-mobility-related services. The number of standards is high and their deployment is not uniform yet across Europe yet

7.3 Unified Laboratory Infrastructure

The EU-wide harmonisation challenge in the field of smart grids has driven COTEVOS project efforts towards setting up a unified laboratory infrastructure for e-mobility interoperability testing.

An interoperability-testing framework for e-mobility must be flexible enough to encompass a great variety of use cases and business models. Furthermore, it must be extendable to actors and functions outside the e-mobility system in order to cover smart grid integration. Due to the multitude of involved subsystems, the coverage of all communication interfaces within each single laboratory is not feasible. At the same time, a laboratory cannot cover all
protocol versions, some of which are not widely supported. The testing framework by COTEVOS considers such restrictions by defining a set of core capabilities that need to be available in each laboratory, as well as additional test settings that will not be provided by all institutions.

To respond to the previous requirements, the COTEVOS consortium defined a reference architecture for test laboratories, enabling the execution of the relevant EV interoperability tests without overly restricting the actual implementation options (see Section 5). The unified laboratory infrastructure concept for EV interoperability tests is hence the common reference architecture, including the specifications of involved actors and the interfaces between them. In principle, a given interface can be realized by means of different communication protocols, but a set of core standards has been identified in the project, which are the basis for the current implementations, and ensure a certain degree of compatibility. These core standards cover the interface between EV and EVSE (IEC 61851 and ISO / IEC 15118, with CHAdeMO as an optional alternative), and the interface between EVSE and EVSE operator backend (OCPP).

Since many components of the e-mobility environment are based on ICTs and software applications in backend and frontend systems, it is technically feasible and realistic to exchange data between remote devices located in different laboratories to test interoperability. This way, not all laboratories would be forced to develop the complete architecture containing all components (devices, applications, persons, and organizations) involved in end-to-end communications. This approach was taken, for instance, by TECNALIA and TNO, permitting to test a complex scenario with several actors and interfaces according to a complementary scheme.

Nowadays the market is minor, and is expected to be small in the short-term. Based on this common architecture, laboratories have started to offer interoperability assessment services to all stakeholders in the EV value chain. It is a challenge that represents a relevant approach towards a unified concept of laboratories for e-mobility assessment in Europe, where a pan-European Certificate could also be offered. It would also contribute to the cost effectiveness of test procedures.

Having set up the IOP assessment infrastructures in the context of COTEVOS, the laboratories carried out many tests according to the new procedures, and improved their facilities to offer new testing services. In close relation with the foreseeable mid-term market, the capability regarding the EV-EVSE and EVSE-backend communications has been remarkably upgraded. Several partners have created EV and EVSE emulators able to execute conformance tests for the IEC 61851 and ISO / IEC 15118 standards. These emulators will be potentially enhanced to allow fully automated test runs and to permit their integration into the interoperability testing toolchain.
Infrastructure for assessing test cases for different versions of OCPP has also been developed around the EVSE and EMSP backend communications.

The integration around the DSO-related protocols has advanced less, with IEC 61850 being the preferred one, in particular parts 90-8 and 7-420. Fully standards-based solutions are, nevertheless, still to be developed. The OSCP protocol has also been assessed and could be easily implemented as an alternative means for smart charging, as communication channel between grid operator and backend system of the CSO.

Capabilities for testing a roaming proprietary platform have been developed and verified by COTEVOS. OCHP has also been addressed and the testing platform could be easily developed, though this work has not been carried out since a short-term market seems to be unlikely.

The present market is small but the relevance of Interoperability assessment services is expected to increase as the smart grid becomes more complex. The aim of the unified laboratory is to integrate the network of laboratories capable of executing all the interoperability tests that can be required by the stakeholders around the smart grid infrastructure related to EVs.

DERlab will coordinate the activities around the services for IOP assessment offered by the unified laboratory infrastructure, addressing the queries for testing to the corresponding laboratories, according to their capabilities and service offers. Market and business rules will determine the legal, economic and technical aspects for the best collaboration.

7.4 Future Research and Key Areas of interest

There are still many open questions regarding the grid integration of e-mobility and, thus, on the needs for interoperability, e.g., which ancillary services should be provided by EV systems in the future.

The answer to this question depends on different aspects, such as the penetration level of EVs, the share of DER, technological developments, and, of course, market parameters. Hence, it will vary in time and from region to region. The use of operation data from EV charging stations and DER systems leads to a better monitoring of the distribution network, but it requires standardised interfaces to allow for a cost-efficient realisation.

Research is a key aspect in determining the role that EVs should play in the future to guarantee the grid stability in the most economical way.

The needs for services to be provided and the information to be exchanged to allow it are not known yet, since they depend on the eventual successful business models for EV integration in the grid. Thus, there is no certainty on which will be the protocols that will be used to integrate charging stations into the grid control infrastructure. From the grid operators’ perspective, the use of IEC 61850 or IEC 60870 standards is preferred since they allow for a direct access
to the station from the grid control centre and, in many cases, they are already part of DSOs' systems. Furthermore, specific e-mobility information models have already been established in the technical report IEC 61850-90-8. However, these protocols come with a significant complexity. As an alternative, even if with limited features in comparison to the previous ones, OSCP can still meet the requirements of a wide range of use cases, being much easier to be applied.

Compatibility of EVSEs throughout EU Member States is an important topic, already regulated at hardware level. However, the compatibility of backend solutions is not yet fully established. Standardised test specifications for backend protocols should be developed, in particular for those standards that affect interfaces between different actors. This is also a key for roaming, a term known from mobile communication, allowing using the charging infrastructures and services independently of the station operator and the country.

Security aspects should be recognised (and treated) as an emerging topic, representing both a factor limiting the interoperability and a key aspect of architectural design. ICT systems security is a cross-cutting topic of high relevance for all communication interfaces. Besides obvious commercial implications of security breaches, a high share of vulnerable electrical charging stations may also represent a threat to the electric grid stability.

Data gathered from the charging process at public charging stations allows for the generation of user profiles, including geographic tracking. Hence, confidentiality of the data is paramount. Clear rules should be established for the handling of user data by the different entities involved, and they should be made transparent to the customer.

All smart grid and e-mobility actors (OEM, EMSP, EVSEO, DSO, etc.) should be aware of the security aspects implemented in their companies. Security design shall consider data/device confidentiality, integrity, availability, and non-repudiation aspects, not only in data transmission, but also in data storage. Taking into account these considerations, the most vulnerable components are the EVSE and the EV itself, because these they can be installed or moving around an open area. Current EVSEs only cover the security for data transmission with their central system (confidentiality) when the HTTPS protocol is used for OCPP, but they do not consider local storage of information aspects. Therefore, an EVSE can be attacked, disabled or misused to propagate malware to the grid and to all EVs charged in it by exploiting those cyber security flaws that are not considered at all.

There are several standards, e.g., ISO / IEC 15118, IEC 62351, IEEE 1686, and the ISO / IEC 27000 series, which cover those security features for several scenarios involving EVs and the power system. EVs and EVSEs should be adapted to be integrated into the secured power grid like any other device which is part of it. Therefore, all EV components (including actors) should be secured, taking into account their peculiarities, in order to prevent any physical or remote access of hackers or saboteurs.
8. Recommendations

The work developed within COTEVOS project and summarised in the previous sections of this White Book, has led to the following recommendations, which address the challenge of testing interoperability in the e-mobility and smart grid fields.

**Recommendation 1**: Foster the EV deployment through cost-effective business models development

- **Addressed to**: Investors, policy makers and all stakeholders
- **Description**: The high EV purchase cost and the uncertainties surrounding battery reliability are still the main barriers for the EV market to take off in Europe. In the meantime, new business models and market niche developments play a facilitating role for EV deployment by tackling the economic gap between conventional ICE and e-mobility solutions. To achieve this, it is necessary to be able to assess interoperability, not only at the level of physical systems. The SGAM gives advice to tackle regulation, business, services, components, communication, and information aspects in a comprehensive way. In this line, and regarding products and systems for the smart grid EV integration, collaborative initiatives involving laboratories, service providers and other affected stakeholders are a must to agree on the adequate requirements and the procedures for IOP assurance.

**Recommendation 2**: Foster the use and development of EV standards

- **Addressed to**: All stakeholders, policy makers
- **Description**: The EV system imposes strong interoperability requirements due to the many actors involved. Hence, the widespread use of standards is expected to lead to strong economic benefits on a societal level. COTEVOS, therefore, encourages all stakeholders to become engaged in the development and utilisation of standards, mainly in the framework of IEC TC57/TC69 and eMI3 groups, and to avoid the use of proprietary protocols. In certain critical cases, where the presence of different standards can hinder the achievement of interoperability expectations, it could be appropriate to enforce by regulations a particular standard, as it was the case for the plug type in Europe, for example. The highest agreement between stakeholders should follow. It is also recommended to assess the security needs and implement related standards.

**Recommendation 3**: Make use of the available test infrastructures to validate test specifications for the relevant standards for EV integration

- **Addressed to**: Infrastructure operators, manufacturers, service providers and test laboratories
• **Description:** In order to guarantee interoperability between the components, the critical test cases should be defined based on real-world use cases and upon the consideration of observed incompatibility issues. The quality of the interoperability tests is paramount for the process. Therefore, they should be developed in agreement by all stakeholders involved. Multiple standards are expected to be relevant, since interoperability tests typically involve several communication interfaces.

The COTEVOS infrastructure is well suited for this approach since it considers the whole chain of actors. The testing network should be enlarged with other laboratories as available.

**Recommendation 4:** Consider certification of compliance as requirement for interoperability

- **Addressed to:** Regulators and authorities
- **Description:** Standards are the main tools, de jure and de facto, to procure interoperability between components from different vendors. In practice, interoperability issues may still arise even when standards are available. This has been revealed in different tests performed by COTEVOS, where systems presumed to comply with the same standard did not perform appropriately together.

Interoperability tests can be a good tool to help identify such issues. Thus, operators should ensure that the systems they integrate are compliant with the adequate standards according to the convenient certification by their suppliers.

**Recommendation 5:** Perform plug-test events for standards validation and interoperability assessment

- **Addressed to:** Standardisation committees, EV-related manufacturers, specifically EVSEOs and EMSPs
- **Description:** The reason for a lack of interoperability can be the unavailability of standards or their inadequacy to cover all necessary requirements. Therefore, interoperability assessment and the corresponding tests are crucial.

Test cases based on actual EV charging events, along with their test results, should be made available for standardisation committees (e.g., IEC-TC69: Electric vehicles and IEC-TC57: Power systems management and associated information exchange).

COTEVOS recommends that plug-test events are carried out, allowing stakeholders (OEMs, EVSEOs, EMSPs, DSOs, etc.) to meet on a regular basis and test interoperability with the aid of qualified professionals and validated test infrastructures.

**Recommendation 6:** Develop control strategies for cost-efficient grid integration of EVs and other DER using standards-based communication profiles
- **Addressed to:** Grid operators and aggregators, energy service providers, research institutions

- **Description:** The increasing share of EVs, and DER in general, imposes challenges on the electric grid, both at a local level (e.g., voltage stabilisation) and for the grid as a whole (e.g., loss of inertia). The stable and cost-efficient operation of the grids will require the use of DER, through advanced control strategies, instead of relying solely on conventional power plants.

The eligibility of EVs for different ancillary services, including balancing power or the provision of reactive power, needs to be investigated for different grid parameters and EV penetration levels. Innovative solutions will be required to incentivise grid-friendly behaviour while, at the same time, avoiding a negative impact on the user experience. Grid operators and aggregators dealing with DER, particularly EVs, are encouraged to employ standards-based communication profiles. It is recommended to implement a variety of control strategies and test their interoperability. This would ensure the standards to become robust enough to enable diverse solutions in the future.

**Recommendation 7:** Make use of the available test infrastructures to help develop pan-European interoperable backend systems

- **Addressed to:** Test Laboratories, regulators, service providers

- **Description:** Whereas the problem of incompatible plug types in Europe was solved by the EU alternative fuels infrastructure directive (2014/94/EU), many open problems remain to achieve full EV interoperability within the different EU member states, e.g., problems regarding the interfaces among backend systems. Service contracts concluded in a European country should be valid in any of the other member states, allowing EV users to charge their vehicles everywhere throughout Europe. This is also desirable from a common market point of view. An adequate CH approach would be needed to ensure this interoperability.

Since many components of the e-mobility environment are based on ICTs and software applications, the unified laboratory infrastructure developed within COTEVOS provides a well suited testbed to verify the interoperability of systems developed in different member states.
References


[13] M490_WGI, M/490, Smart Grid Coordination Group - Methodologies to facilitate Smart Grid system interoperability through standardization, system design and testing,


2014.


Imprint

COTEVOS White Book

Business Opportunities for Interoperability Assessment of EV Integration

The White Book does not represent the opinion of the European Union, and the European Union is not responsible for any use that might be made of the content.

Authors and contributors:
Eduardo Zabala (TECNALIA)
Raúl Rodríguez (TECNALIA)
Jure Ratej (ETREL)
Siwanand Misara (DERlab)
Pawel Kelm (TU Lodz)
Blazej Olek (TU Lodz)
Thomas Sørensen (DTU)
Joost Laarakkers (TNO)
Ewoud Werkman (TNO)
René Marklein (Fraunhofer IWES)
Giorgio Mantovani (ALTRA)
Felix Lehfuss (AIT)
Federico Belloni (RSE)

Editing, coordination and layout:
Eduardo Zabala (TECNALIA)
Siwanand Misara (DERlab)
Maria Sosnina (DERlab)

This project has received funding from the European Union’s Seventh Programme for research, technological development and demonstration under grant agreement No 608934

COTEVOS Partners:

www.cotevos.eu

Bilbao, November 2016