4E is the Energy Efficient End-Use Equipment Technology Collaboration Programme, established by the International Energy Agency (IEA) in 2008 to support governments in co-ordinating effective energy efficiency policies. Twelve countries have joined together under the 4E platform to exchange technical and policy information focused on increasing the production and trade in efficient end-use equipment. However 4E is more than a forum for sharing information – it pools resources and expertise on a wide range of projects designed to meet the policy needs of participating governments. Participants find that is not only an efficient use of available funds, but results in outcomes that are far more comprehensive and authoritative than can be achieved by individual jurisdictions.

Current members of 4E are: Australia, Austria, Canada, Denmark, France, Japan, Korea, Netherlands, Switzerland, Sweden, UK and USA.

Further information on the 4E Implementing Agreement is available from: www.iea-4e.org

Network connected devices, including the Internet of Things, are growing rapidly and offer enormous opportunities for improved energy management. At the same time, there is a responsibility to ensure that these devices use a minimal amount of energy to stay connected. 4E’s Electronic Devices and Networks Annex (EDNA) works to align government policies in this area and keep participating countries informed as markets for network connected devices develop.

Further information on EDNA is available at: http://edna.iea-4e.org

This report is authored by Dr. Adriana Díaz and Dr. Wolfgang Wimmer of the ECODESIGN company - engineering & management consultancy GmbH.
Energy Efficiency of Electric Vehicle Supply Equipment - EVSE

Scoping study for IEA – 4E EDNA

By: Dr. Adriana Díaz and Dr. Wolfgang Wimmer

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www.ecodesign-company.com

EVSE Scoping Study

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List of Abbreviations

AC - Alternating Current
BEV - Battery Electric Vehicle
BMS - Battery Management System
CCID - Charge Current Interrupting Device
DC - Direct Current
DR - Demand Response
EDNA - Electronic Devices and Networks Annex
EMC - Electromagnetic compatibility
EV - Electric Vehicle
EVSE - Electric Vehicle Supply Equipment
FCV - Fuel Cell Vehicle
GFI - Ground-Fault Interrupter, equivalent to the European term RCD - Residual Current Detector
HEV - Hybrid and Electric Vehicles
HMI - Human Machine Interface
IEA - International Energy Agency
EC JRC - European Commission’s Joint Research Centre
PEV - Plug-in Electric Vehicles
PHEV - Plug-in Hybrid Electric Vehicle
REEV - Range-Extended Electric Vehicles
RCD - Residual Current Detector, equivalent to the US term GFI - Ground-Fault Interrupter
V2G - Vehicle to Grid
1 Introduction

1.1 Setting the context

Enhancing market and technology knowledge are amongst the important objectives of the Electronic Devices and Networks Annex — EDNA. EDNA is one of the activities within the Technology Collaboration Program on Energy Efficient End-Use Equipment of the International Energy Agency (IEA – 4E).

EDNA enhances the ability of individual countries to gather, analyse and share market, technical and energy data, as well as policy information, to understand the performance and energy cost of existing, new and emerging technologies impacting the energy use and/or performance of electronic devices and their associated networks. Likewise, making recommendations on policy approaches and their alignment is another important objective of EDNA. The Annex also investigates and recommends actions that support the alignment of product test methods, international standards and protocols, energy use or efficiency metrics, product categories, energy performance levels and related technical work that can be used in voluntary or mandatory actions at a regional and international level. EDNA seeks engagement with other platforms and initiatives which cover related topics, for example the Connected Devices Alliances and the G20 Network Devices Task Group.

In line with these EDNA objectives related to market, technology, and cooperation, the delegates from EDNA member countries decided to conduct a Scoping study, to investigate the energy performance of Electric Vehicle Supply Equipment (EVSE), looking also at the existing policy approaches for this emerging product group. This Scoping study shall serve as the basis for further activities, e.g., the possible creation of a dedicated task in EDNA.

This Scoping study is also part of the preparation towards the third term of the EDNA Annex, in line with the strategic overview developed last April 2017 and reviewed last November 2017. EDNA is currently covering products and their networks at different levels, as shown in the strategic map below, as well as their different energy related aspects (e.g., energy use in various modes, and especially network standby) but also their potential for enabling energy savings.

Finally, the scoping study of EVSE might help EDNA members identify organizations, platforms and other initiatives for establishing cooperation on selected aspects of EVSE where these organizations might bring complementary approaches, and benefits from EDNA’s expertise and body of knowledge.
1.2 Goal and objectives

The goal of this scoping study is to present the existing knowledge on, and derive an overview of the energy performance of EVSE, to inform EDNA delegates about the potential to pursue further work (e.g., establish a dedicated task) to investigate the energy impact of EVSE, particularly looking at the information and data collection needed to generate policy recommendations for EVSE.

The specific objectives of the scoping study are to:

- Review the existing technologies for residential/commercial electric vehicle supply equipment (charging systems), looking at current state of the art, classification of the systems, and their market development/adoptions trends in selected regions (EDNA countries).
- Describe the key technical features and aspects of the EVSE with the focus on energy performance.
- Conduct a review of publications relating to charging losses and standby consumption of the different systems.
- Gather information/studies on the methodologies used for (field, test) measurements of power consumption (including standby losses).
- Derive an overview of the energy performance of different charging systems using appropriate indicators.
- Investigate the existing approaches of regulation and elaborate first ideas of possible regulation of the energy performance of EVSEs.
- Identify knowledge and data gaps, especially in areas of specific interest for EDNA countries.
• Explore together with EDNA delegates further steps after the draft Scoping study is complete (e.g., during EDNA management call and/or EDNA meeting), to address areas of relevance and/or emerging issues of interest to EDNA members to potentially derive further activities.
• Elaborate and present final findings and final report to EDNA delegates.

The Scoping study additionally and to the extent possible, takes the following aspects into account:

• EVSE and interaction with the grid, which might have an effect on other connected equipment such as Smart Meter measurements.
• Bidirectional (Vehicle to Grid – V2G) EVSE and the associated transfer losses.
• Energy consumption to preheat and/or maintain vehicle battery temperature. Although vehicle batteries are out of the scope of EDNA, for this Scoping study “climate control” aspects of EVSE have been considered.
• Energy efficiency of Super-fast chargers, for systems going beyond 150 kW up to 350kW. (350 kW systems).
• Relevant aspects for seeking collaboration with other International Energy Agency Technology Collaboration Programs, such as Hybrid and Electric Vehicles (HEV), and/or with the European Commission, Joint Research Centre Directorate for Energy, Transport and Climate Sustainable Transport Unit.
• The potential for EDNA to engage with EVSE industry/market players, aiming at delivering recommendations for decision-makers.

This scoping study will specifically NOT:

• Investigate the charging efficiency of EVSE.
• Compare the energy performance of different EVSE (due to data gaps).
• Extrapolate the energy impact of EVSE roll-outs (due to data gaps).
• Provide a ‘Plug to wheel’ assessment.
• Analyse the financial impacts of EVSE infrastructure.
• Describe different electric vehicle technologies.
• Discuss battery, or range issues associated with electric vehicles.

The methodological approach taken in this Scoping study was to perform solely desk research of published work, including the review of data and information provided by EDNA delegates, and telephone interviews with selected external experts from industry and research.

The study covers the following countries and economies: Austria, Australia, Canada, Denmark, European Union, Japan, Korea, the Netherlands, Sweden, Switzerland, United Kingdom, and the United States of America. Not all countries are covered for every aspect of the Scoping study. Their inclusion depends on whether information was available at the time of the research. Interviews with EVSE manufacturers are not attributed to specific manufacturer with references as they reflect individual opinions and not official company communication.

1.3 Relevance of topic for policy makers

The deployment of electric mobility is advancing as a strategy for reducing greenhouse gas emissions in various world regions. A review of major UK trials and studies pertaining to electric vehicles (EV) in 2016 shows that the topics currently investigated are the growth of the EV sector, the required
charging infrastructure, and the effects introduced by the charging of these EVs. In the residential context, the peak load of EV charging for 66% of owners coincides with the domestic peak demand, and the possibilities to implement demand response (load curtailment) to shift the demand to other times shall be carefully considered\(^1\).

Among other factors, the successful deployment of EVs over the next decade is linked to the introduction of international standards and codes and a “universal” infrastructure\(^2\). This pertains mostly to the issue of inter-operability of electric vehicles and the charging infrastructure, as well as the interaction with the grid, and as such research on these aspects is underway. As an example, the EU is currently establishing the trans-European transport network (TEN-T), rolling out EVSE infrastructure for the widespread roll-out of EVs across the EU\(^3\).

According to expert opinion from the European Commission Joint Research Centre they are recently witnessing that, with the roll-out plans underway in the EU, commercial interest in the energy performance of charging infrastructure, both charging efficiency and standby loads, are also driving research forward\(^4\). Nevertheless, studies looking at the energy performance of charging equipment, defined as the efficiency of the charging process (i.e., efficacy of transferring power from the electricity grid to the vehicle) and the own consumption of the infrastructure (e.g., for core functions, add-on functions, and standby), are rather limited. This scoping study is possibly the first step in developing future activities regarding the energy performance of electric vehicle charging systems in EDNA.

### 1.4 EVSE infrastructure Figures and Trends

In 2016 more than 2 million electric cars were on the road globally, with over 750 thousand units sold over the year\(^5\). China’s booming electric car sales in 2015 made it the main market worldwide, before the United States, for the first time. Substantial new implementation of electric vehicle supply equipment (EVSE) was also observed in 2015, on par with the growth of the global electric car stock\(^6\).

![Figure 2 Evolution of the global electric car stock, 2010-16 (Source: IEA, 2017)](image-url)

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\(^1\) ICF Consulting Services Limited, 2016  
\(^2\) Yilmaz, M. et Krein, P. T., 2013, p.2154  
\(^3\) https://ec.europa.eu/transport/themes/infrastructure_en  
\(^4\) Interview with Dr. H. Scholz, 08.06.2017(15:00h CET).  
\(^5\) IEA, 2017  
\(^6\) IEA, 2016
80% of the electric cars on the road worldwide are located in China, the United States, Japan, Norway and the Netherlands. In 2016, six countries had reached over 1% electric car market share: Norway, the Netherlands, Sweden, France, the United Kingdom and China.  

Figure 3 Electric car sales, market share and BEV versus PHEV sales share in selected countries, 2010-16 (Source: IEA, 2017).

In 2016 there were an estimated total of 2.3 million electric car charging points worldwide. Demonstrating the strong commitment of governments, the deployment rate of publicly accessible charging infrastructure has been slightly ahead of the growth of the electric car stock in the past year.

Figure 4 Geographical distribution of the 2016 stock of EVSE outlets by charger type (Source: IEA, 2017).

Electric cars still outnumber public charging stations by more than six to one, indicating that most drivers rely primarily on private charging stations. Publicly available EVSE shares are also not evenly distributed across markets. This is consistent with the early stage of electric car deployment. Two scenarios of the charging infrastructure are shown below in Figure 5.

---

7 IEA, 2017  
8 IEA, 2017  
9 IEA, 2017
The European Alternative Fuels Observatory has published data on the electric vehicle charging infrastructure in the EU-28 as well as Iceland, Liechtenstein, Norway, Switzerland and Turkey showing the development of the EVSE market in step with the EV market.

GE Energy estimates that 1 EV needs 1.5 EV charging station (home, work, mall, parking). Considering these estimates, all countries in Figure 7 are likely to see significant growth of the EVSE market within the next decade.

The need for public charging stations will increase if consumers who do not have access to a garage or other private or semi-private residential parking - a large share of people living in cities, will also adopt EVs. For instance, in Germany almost two-thirds of all households have a garage or parking space. Looking at the urban metropolis of London, however, two-thirds of homes have neither a garage nor off-street parking.

When it comes to slow vs. fast charging stations, the potentially changing role of the battery electric vehicles (BEV) may shift the ratio required. Experience from Norway shows that currently BEVs are often purchased as a second car for households and used primarily for daily commuting purposes. If the adoption of BEVs grows and more people want to use their BEV for long-distance trips (between cities or even countries), the demand for fast-charging stations will increase.
The European Commission established in 2006 the TEN-T programme, which is since 2014 managed by the Innovation and Networks Executive Agency (INEA), and consists of 30 priority projects (Axes) whose ultimate purpose is to ensure the cohesion, interconnection and interoperability of the trans-European transport network, as well as access to it. This programme includes the development of publicly accessible charging infrastructure. One of the actions for example will deploy a pilot of 25 ultra-fast chargers (150-300 kW) on “TEN-T Corridors” connecting the Netherlands, Belgium, Germany and Austria, and use this pilot to promote the roll-out of ultra-fast charger stations in Europe.\(^\text{13}\)

INEA also administers the Connecting Europe Facility (CEF), which is supporting, for example, the deployment of multi-standard fast chargers in Germany (241) and Belgium (37). This action is complemented by a twin application, FAST-E (CZ/SK) which will deploy 29 fast charger locations in the Czech Republic and Slovakia, on corridors connecting to Germany.\(^\text{14}\)

The development of plug-in vehicles in France is seen as a symbolic step towards more environmentally-friendly transport to achieve national goals. The government has also announced an investment plan to support public infrastructure. The French government adopted a legislation in

\(^{13}\) INEA, 2007a

\(^{14}\) INEA, 2017b
July 2014 to accelerate the installation of infrastructure needed for a wider roll-out of electric vehicles in the country. The law provides tax cuts for companies to encourage them to build electric vehicle charging stations. To take advantage of the tax cuts, companies must be operational in at least two regions in the country and ensure a balanced development of charging points in these areas. France aims to set up 7 million charging stations by 2030\textsuperscript{15}. France accounts 15,883 charging points accessible to the public at the end of 2016 (see Table 1). The number of charging stations has significantly increased in 2016 (+57 %), when compared to the 10,200 listed in 2015. It is still in the Paris region where it is the easiest to charge an EV since the region accounts 7,416 charging spots. The Auvergne – Rhône Alps and the New – Aquitaine are then the regions with more charging points with 1,462 and 1,351 charging spots, respectively.\textsuperscript{16}

Table 1: Information on charging infrastructure in France for 2016 (source: IEA HEV, 2017).

<table>
<thead>
<tr>
<th>Chargers</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Level 1 Chargers</td>
<td>14,250</td>
</tr>
<tr>
<td>AC Level 2 Chargers</td>
<td>362</td>
</tr>
<tr>
<td>Fast Chargers</td>
<td>936</td>
</tr>
<tr>
<td>Superchargers</td>
<td>295</td>
</tr>
<tr>
<td>Inductive Charging</td>
<td>0</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>15,883</strong></td>
</tr>
</tbody>
</table>

Denmark has a very ambitious target of being independent of fossil fuels by 2050. Incentive programmes have focused broadly on electric application in passenger cars, busses, vans, garbage trucks etc., including charging infrastructure. Private and public fleets together with city car sharing systems have been a main priority. Denmark is actively represented and participating in a broad palette of regional, international and EU programmes, ranging from charging and roaming standards, cross bordering charging corridors and smart grid projects to mobility. Many of these projects have been launched to familiarize companies, public authorities, and private consumers with EVs and strengthen Denmark’s position as an important green transport corridor in Northern Europe. Denmark has a strong EV charging infrastructure thanks to the major private e-mobility providers CLEVER, E.ON, CleanCharge Solutions, and Tesla. Combined, the four companies provide publicly accessible recharging networks countrywide.\textsuperscript{17}

\textsuperscript{15} Eltis Platform, 2014  
\textsuperscript{16} IEA HEV, 2017  
\textsuperscript{17} IEA HEV, 2017
In 2016, 3,826 new BEVs were registered in Austria. That’s an increase of 128% compared to 2015. Additionally, 1,237 PHEV and 4,613 HEV passenger vehicles were registered in 2016, +12% and +34% compared to 2015, respectively. In November 2016, the Austrian Minister of Transport, Innovation and Technology (bmvit) and the Minister of Agriculture, Forestry, Environment and Water Management (BMLFUW) presented together with the spokesman of the Austrian automobile importers a package of measures to support electric mobility with 72 million Euros. It includes incentives for buying EVs, installation of charging stations, and a particular number plate for electric vehicles. From March 2017 a bonus for the purchase of electric vehicles is available.\textsuperscript{18}

From April 2017, eleven electricity providers in Austria are combining their charging stations into one network of 1300 public points throughout the nation to make it easier for drivers to use all the stations within this network. The country will reach over 2500 charging stations by the end of 2017, which will increase to 5000 in 2020. This is the latest measure in a series of initiatives to increase the use of EVs.\textsuperscript{19}

In Table 3 the number of Level 2, ChAdeMO and CCS charging stations are shown. Within the 2,438 charging stations, 2,119 allow a charging capacity up to 22 kW. 129 are accelerated charging stations (22 – 45 kW) and 190 offer fast charging above 45 kW. Most public charging stations are operated and/or owned by regional energy service providers and many operators require some form of registration for users to charge a vehicle at their stations.\textsuperscript{20}

\begin{table}[h]
\centering
\begin{tabular}{|l|c|}
\hline
\textbf{Chargers} & \textbf{Quantity} \\
\hline
AC Level 1 Chargers & n.a. \\
AC Level 2 Chargers & 1,675 \\
Fast Chargers & 120 \\
Superchargers & 56 \\
Inductive Charging & n.a. \\
\hline
\textbf{Totals} & \textbf{1,861} \\
\hline
\end{tabular}
\caption{Information on charging infrastructure in Denmark for 2016 (source: IEA HEV, 2017).}
\end{table}

\textsuperscript{18} IEA HEV, 2017  
\textsuperscript{19} Climate Action, 2017  
\textsuperscript{20} IEA HEV, 2017
A report on electric mobility was published by the Swiss federal council in 2015, and the follow-up project “Plattform Ladenetz Schweiz” (Charging network Switzerland) was initiated in 2016, to coordinate the expansion of the charging infrastructure in Switzerland, with a focus set on conductive systems. The goal is to coordinate and support the installation of a nationwide network with meaningfully chosen locations, securing access to users, and providing a standardized billing method among all charging stations. Table 4 shows the data of charging infrastructure EVSE in Switzerland for the year 2016. By the end of 2016, more than 1,600 public charging locations with approx. 4,000 charging points were registered in the Swiss national database. There were 1,400 Level 1 and 2 AC-locations with 1 to 3 EVSEs each and 145 fast charging locations (CHAdeMO, CSS, Tesla Superchargers and 43 kW AC) with 1 to 6 EVSEs each.21

Table 4: Information on charging infrastructure in Switzerland for 2016 (Source: IEA HEV, 2017).

For the Dutch government electro mobility is an intrinsic part of the transition to a truly sustainable energy system that it would like to achieve by 2050. The Ministry of Economic Affairs published a Vision on the Charging Infrastructure for Electric Transport, with a policy agenda looking ahead to 2020. An important item is that Dutch government and companies together call for the use of open standards and open protocols in charging infrastructure, so as to stimulate innovation and global access.

At the end of 2016, there were over 11,700 public charging points and more than 14,000 semi-public charging points in the Netherlands. The number of fast charging points increased from 465 at the end

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21 IEA HEV, 2017
of 2015 to 612 at the end of 2016 – along highways but also in the cities, in total at 150 different locations. This includes 10 Tesla Supercharger locations with 85 chargers in total. Next to the publicly accessible charging points, an estimated minimum of at least 72,000 private charging points were in operation. By turning itself into one huge Living Lab for the Smart Charging of electric vehicles, the Netherlands is rapidly becoming the international frontrunner for smart charging electric vehicles (EVs), using them a.o. to store peak power production of solar and wind energy. Already 325 municipalities (including Amsterdam, Rotterdam, Utrecht and The Hague) have joined the Dutch Living Lab Smart Charging scheme, representing 80 per cent of all public charging stations.22

Table 5: Information on charging infrastructure in the Netherlands for 2016 (source: IEA HEV, 2017).

<table>
<thead>
<tr>
<th>Chargers</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Level 1 and 2 Chargers</td>
<td>26,088</td>
</tr>
<tr>
<td>Fast Chargers</td>
<td>4,612 (150 locations)</td>
</tr>
<tr>
<td>Superchargers</td>
<td>25 (10 locations)</td>
</tr>
<tr>
<td>Inductive Charging</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• For passenger cars 1 pilot project in Rotterdam</td>
</tr>
<tr>
<td></td>
<td>• For buses two cities with a bus line on inductive charging (Utrecht and Den Bosch)</td>
</tr>
<tr>
<td>Totals</td>
<td>30,728</td>
</tr>
</tbody>
</table>

For Sweden in 2016, both politics and the media have been focusing on plug-in electric vehicles and slightly less on biofuels than before. Substantial state-funded R&D support continues to finance innovative research projects in the field of electric mobility and since 2011 there has been a purchase rebate for plug-in electric vehicles. This rebate system will likely be replaced by a cost neutral bonus-malus support scheme in 2018. Experiences gained from PEV demonstrations in the 1990’s showed that public charging infrastructure was not an initial bottleneck, hence governmental support was not prioritised until 2015, where the sales of PEVs had taken off in Sweden.

In 2015 the Swedish government introduced two investment support schemes, which both aimed to facilitate charging infrastructure. The scheme Climate Leap (Klimatklivet) is a local investment scheme that allocates support to charging infrastructure for passenger vehicles. The second scheme, Urban Environment Agreements (Stadsmiljöavtal), aim is to co-invest together with municipalities and public transport providers. The public charging infrastructure is currently being developed (see Table 6). With regards to 50 kW DC fast charging, southern Sweden has reached a point where it could be considered as well-developed and links together all parts of the region. Public normal charging is developed by many actors, both public and private.

<table>
<thead>
<tr>
<th>Chargers</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Level 1 Chargers</td>
<td>1,654</td>
</tr>
<tr>
<td>AC Level 2 Chargers</td>
<td>561</td>
</tr>
<tr>
<td>Fast Chargers</td>
<td>387</td>
</tr>
<tr>
<td>Superchargers</td>
<td>136</td>
</tr>
<tr>
<td>Inductive Charging</td>
<td>1</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>2,739</strong></td>
</tr>
</tbody>
</table>

For the United Kingdom (UK), and looking at the timeframe beyond 2030, the report prepared for the UK DECC “Overview of the Electric Vehicle market and the potential of charge points for demand response” describes that by 2050, 20 to 25 million EV passenger cars are envisaged on the road in the UK, supplied through 10-15 million off-street and on-street charge points, and describes the possibility that 80% of the electricity for charge points could be delivered via residential charging infrastructure.23

The UK has a number of schemes to support the installation of charge points. There is the electric vehicle home charge scheme which offers 75% of the cost, up to a maximum of 600 EUR, of installing a charge point for drivers who access to off street parking. Over 70,000 charge points have been installed under this and predecessor schemes. For those drivers who do not have access to off-street the revamped on-street residential scheme was announced October 2016. This initiative offers local authorities up to 8,900 EUR to install a dedicated on street charge point. Installations could involve new and innovative charging solutions. Also announced October 2016 was the workplace charging scheme which offered a grant of 350 EUR per socket up to a maximum of 20 sockets for organisations in the public and private sectors who want to encourage their employees to use ultra low emission vehicles.24

Table 7: Information on charging infrastructure in the UK for 2016 (source: IEA HEV, 2017).

<table>
<thead>
<tr>
<th>Chargers</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Level 1 Chargers</td>
<td>79,143</td>
</tr>
<tr>
<td>AC Level 2 Chargers</td>
<td>2,451</td>
</tr>
<tr>
<td>Fast Chargers</td>
<td>983</td>
</tr>
<tr>
<td>Superchargers</td>
<td>168</td>
</tr>
<tr>
<td>Inductive Charging</td>
<td>0</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>82,745</strong></td>
</tr>
</tbody>
</table>

23 ICF Consulting Services Limited, 2016
24 IEA HEV, 2017
Moving from European EDNA countries to other EDNA members, their developments concerning charging infrastructure for EVs are described in this section as well.

While electric vehicle uptake in Australia is still very low (approximately 0.3% of annual vehicle sales), the combined impact of price declines in battery technology, the increasing introduction of new EV models into the market and both government and industry support will drive increased uptake over the next 20 years. AMEO’s estimates 2.83 million EVs on the road in Australia by 2036 (or 17.7% of the vehicles by 2036).25

Zero Carbon Australia estimates in an August 2016 report the installation of one public level 2 charge point per electric car in the fleet. The same report assumes that only a small number of Level 3 rapid charge points will be required, specifically one charging station with 10 rapid charge points per 5 km radius region in urban areas (or equivalently, one charging station per 80 square kilometres). This led to 592 charging stations in urban areas around Australia, compared with over 8,000 petrol stations at present. This is considered sufficient because only a small proportion of charging is anticipated to occur at rapid charge stations.26

The Government of Canada, as a member of the Clean Energy Ministerial – Electric Vehicles Initiative (EVI), signed a Government Fleet Declaration during a Zero Emissions Commercial Vehicles session at the Marrakech Climate Change Conference (COP22), in November 2016. The 2016 federal budget allocated 48.3 million USD over two years to Natural Resources Canada to support the deployment of infrastructure for alternative transportation fuels, including charging infrastructure for EVs, as well as natural gas and hydrogen refuelling stations. The funds also support technology demonstration projects that advance EV charging technology. A first deployment project of 25 electric vehicle fast-charging stations at Canadian Tire Gas+ locations across Ontario was announced in December 2016, and is led by AddÉnergie, a Québec-based EVSE manufacturer and network operator. The charging stations will be installed at strategic locations along some of Ontario’s busiest highways.

As a result of investments by federal, provincial and municipal governments, as well as businesses, the number of charging stations installed across Canada in 2016 grew by 20% from 2015. There were approximately 4,215 EVSEs, of which 3,900 were Level 2 (240 V AC) chargers, 135 were Level 3 (DC Fast Chargers), and 180 were Tesla Superchargers (see Table 8)27.

26 Zero Carbon Australia, 2016.
27 IEA HEV, 2017
Table 8: Information on charging infrastructure in Canada for 2016 (Source: IEA HEV, 2017).

<table>
<thead>
<tr>
<th>Charging Infrastructure on 31 December 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chargers</td>
</tr>
<tr>
<td>AC Level 1 Chargers</td>
</tr>
<tr>
<td>AC Level 2 Chargers</td>
</tr>
<tr>
<td>Fast Chargers</td>
</tr>
<tr>
<td>Superchargers</td>
</tr>
<tr>
<td>Inductive Charging</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
</tr>
</tbody>
</table>

n.a. = not available

The Japanese Ministry of Economy, Trade and Industry (METI) compiled in March 2016 the Road Map for EVs and PHVs toward the dissemination of Electric Vehicles and Plug-in Hybrid Vehicles. The **Japan Revitalization Strategy**, revised in 2015, set forth the goal of achieving a ratio of next-generation vehicles among new vehicle sales of 50-70% by 2030. Aiming to achieve this goal, the Study Group on the Road Map for EVs and PHVs discussed necessary strategies for the next five years (until 2020). Information from METI indicates that the number of EVs and public chargers has steadily grown, with more than 160,000 EVs and 27,000 chargers available in Japan, as shown in Figure 8. There are 27,000 public chargers, of which 7,000 are CHAdeMO fast charging stations.  

Figure 8: Cumulative numbers of EV • PHV and Charging stations in Japan (Source: METI, 2017).

In Korea the by the end of 2016 more than 10,000 electric vehicles were delivered to customers. The infrastructure is showing that there are 750 rapid charger Current units, and by June 2017 they shall reach 1,915 units. In this process of expansion, the public and individual chargers shall increase from 9,258 at present to 19,579 in June 2017. The Ministry of Environment also supports up to KRW 4 million (3,220 EUR) for personal charger installation fee for electric car buyers. Private electric power companies such as Korea Electric Power Corporation are installing and operating 259 fast chargers and 873 slow chargers, and planned to install 353 rapid chargers (by February 2017). Korea Electric

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28 METI, 2016.
Power Corporation (KEPCO) was in the process of installing chargers for 4,000 apartment complexes nationwide in 2016. By June 2017 there would be 1,915 rapid chargers and 19,579 slow chargers.\[29]\n
Table 9: Information on charging infrastructure in Korea for 2016 (Source: IEA HEV, 2017).

<table>
<thead>
<tr>
<th>Chargers</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Level 1 Chargers</td>
<td>n.a.</td>
</tr>
<tr>
<td>AC Level 2 Chargers</td>
<td>19,579.</td>
</tr>
<tr>
<td>Fast Chargers</td>
<td>1,915</td>
</tr>
<tr>
<td>Superchargers</td>
<td>n.a.</td>
</tr>
<tr>
<td>Inductive Charging</td>
<td>n.a.</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>21,494</strong></td>
</tr>
</tbody>
</table>

n.a. = not available

The United States Department of Energy (US DOE) released in 2016 a guidance document entitled Guide to Federal Funding, Financing, and Technical Assistance for Plug-in Electric Vehicles and Charging Stations. This document highlights examples of federal programs in support of PEVs and charging infrastructure. For further information, DOE’s Alternative Fuels Data Center provides a comprehensive database of federal and state programs that support EVs and infrastructure. DOE released the Public Plug-in Electric Vehicle Charging Infrastructure Guiding Principles as a guidepost for its efforts and decisions by communities, companies, and other stakeholders working to deploy PEV infrastructure.

In 2016, the EV charging infrastructure in the United States grew considerably, particularly for Level 2 and DC Fast Charging Stations, both of which increased their number of installed stations by 30%. Additionally, the number of plugs per installed station increased by an average of 6 %, largely driven by the 30% increase in plugs per station at fast charger installations. Table 10 shows the number of public charging stations in the US by charger type.\[30]\n

<table>
<thead>
<tr>
<th>Chargers</th>
<th>Installed Locations</th>
<th>Available Plugs</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Level 1 Chargers</td>
<td>1,515</td>
<td>2,983</td>
</tr>
<tr>
<td>AC Level 2 Chargers</td>
<td>13,841</td>
<td>23,906</td>
</tr>
<tr>
<td>DC Fast Chargers:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Tesla Superchargers (120 kW)</td>
<td>357</td>
<td>2,452</td>
</tr>
<tr>
<td>- Other DC Fast Chargers</td>
<td>1,682</td>
<td>3,075</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>17,395</strong></td>
<td><strong>32,506</strong></td>
</tr>
</tbody>
</table>

---

29 IEA HEV, 2017
30 IEA HEV, 2017
Meeting 2030 decarbonisation and sustainability goals requires a major deployment of electric cars in the 2020s, as suggested by the Electric Vehicle Initiative (EVI) target of the EV30@30 campaign. The level of ambition resulting from OEM announcements shows a fairly good alignment with country targets to 2020 and seem to lie within the range corresponding to the RTS and 2DS projections from the IEA\textsuperscript{31}, as shown in Figure 9.

According to the IEA EVI Global EV Outlook 2016 the wide global deployment of EVs across all modes is necessary to meet sustainability targets. The EVI 20 by 20 target calls for an electric car fleet of 20 million by 2020 globally. The Paris Declaration on Electro-Mobility and Climate Change and Call to Action sets a global deployment target of 100 million electric cars and 400 million electric 2 and 3 wheelers in 2030. The IEA 2DS, describing an energy system consistent with an emissions trajectory giving a 50% chance of limiting average global temperature increase to 2°C, outlines an even more ambitious deployment pathway for electric cars by 2030 (150 million) (Figure 9). Meeting these targets implies substantial market growth to develop further the current 1.26 million electric car stock, as well as the swift deployment of electric 2-wheelers and buses beyond the Chinese market\textsuperscript{32}.

Accordingly the charging infrastructure will need to be developed to power these fleets. For example in Europe, Pike Research forecasts that by 2020 more than 2.9 million Plug-in Electric Vehicles (PEVs) will be on the road and that the region will have more than 4.1 million EV charging stations installed. The top five European markets for EV supply equipment (EVSE) will be Germany, France, the United Kingdom, the Netherlands, and Italy, with this group representing more than 60% of the total market. The dynamics of demand for EVSE will be different in Europe than in other parts of the world; for example, residential charging equipment adoption will be slower than in North America, as more EV owners will opt to use base power from a wall outlet or will rely primarily on commercial charging stations\textsuperscript{33}.

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\textsuperscript{31} IEA, 2017
\textsuperscript{32} IEA, 2016
\textsuperscript{33} Pike Research, 2012
2 EVSE technology and functions

Electric Vehicle Supply Equipment (EVSE) provides power for the charging of an electric vehicle. This is a developing product field with many different technologies striving for implementation. General characteristics used to differentiate different EVSE technologies are whether the charger is located on-board or off-board, whether they offer unidirectional or bidirectional charging, and whether there is a galvanic connection (i.e., physical contact) between the EVSE and the vehicle or inductive charging. EVSE are then further subdivided into power categories, with an IEC standard splitting the equipment into four charging modes while the US SAE splits them into three charging levels.

2.1 Definitions and Scope

2.1.1 Scope

This Scoping study primarily covers unidirectional EVSE with galvanic connections to vehicles as these are the prevalent technologies present in the current market. Investigations have been carried out to identify the existing technologies, describe EVSE functions and collate results on the energy performance of different equipment.

The study Investigation of Inductive Charging Systems was completed in September of 2017 by the NTB University of Applied Sciences Buchs for the Swiss Federal office of Energy (BFE) and the IEA 4E EDNA. This study is focusing on EV inductive charging technologies, and is available to complement this EVSE Scoping study of EDNA.

2.1.2 Electric Vehicle Supply Equipment (EVSE)

Electric Vehicle Supply Equipment is the equipment external to the electric vehicle (EV) that provides for the safe transfer of energy between the electric utility power and the EV. EVSE includes EV charge cords, charge stands (residential or public) including attachment plugs, vehicle connectors, protection, and all other fittings, devices, power outlets, or apparatus installed specifically for the purpose of transferring energy between the electric utility power and the electric vehicle.

2.1.3 Electric Vehicle

In this scoping study, the term electric vehicles (EVs) refers exclusively to electric passenger vehicles (cars), which can be charged using EVSE, and excludes other vehicles such as electric scooters or electric buses. This definition includes plug-in electric vehicles (PEV), plug-in hybrid electric vehicles (PHEVs), range-extended electric vehicles (REEVs) and battery electric vehicles (BEVs), as well as all further electric vehicles that can be charged using EVSE.

2.1.4 Charger

A charger converts AC supply power to DC power and uses it to charge the vehicle batteries. Chargers are categorized into off-board and on-board types with unidirectional and bidirectional power flow. Cord sets that come with every PEV and wall-mount units are commonly referred to as

34 NTB, 2017
35 NEMA, 2015
36 ENERGY STAR, 2013
37 EPRI, 2017
38 Amsterdam Round Table, 2014
39 https://pluginamerica.org/get-equipped/charging/
40 Yilmaz, M. et Krein, P. T., 2013
‘chargers’ even though they are actually Electric Vehicle Supply Equipment (EVSE). High power EVSE that deliver DC power directly to the vehicle include an ‘off-board charger’. On-board chargers can be conductive or inductive. While conductive charging systems use metal-to-metal contact between the connector and the charge inlet, inductive chargers transfer power magnetically. These inductive on-board charging systems require external infrastructure, i.e., EVSE.

### 2.1.5 Charging modes
Charging modes categorise EVSE by defining among other things the power thresholds and functions of different modes. While EVSE Power Levels vary among countries these standards are identical worldwide. There are four charging modes in total:

- **Mode 1** describes home charging from a standard power outlet with a simple extension cord, without any safety measures.
- **Mode 2** describes home charging from a standard power outlet, but with a special in-cable device (charge current interrupting device - CCID), providing a moderate level of safety.
- **Mode 3** describes a wired-in AC charging station, allowing a higher power level than Mode 2, but with the identical safety protocol.
- **Mode 4** describes wired-in DC charging stations.

### 2.1.6 EVSE Power Levels (Definition)
The US SAE J1772 defines three power levels, grouping EVSE according to power thresholds. The power levels are split for alternating current (AC) and direct current (DC). Alternating current (AC) EVSE do not convert the utility’s AC power into direct current (DC) power needed for charging, this happens through the EV’s on-board charger. The vehicle charger communicates with the EVSE to identify the circuit rating (voltage and current) and adjust the charge to the battery accordingly.

DC EVSE converts the utility’s AC power into DC power and therefore provide electricity through an off-board charger, delivering DC power directly to the vehicle battery.

AC Level 1 and Level 2 EVSE are low power equipment used primarily for home charging, while DC Level 1 and Level 2 are high power equipment used for commercial fast charging applications. Level 3 power thresholds have not been formally defined yet.

### 2.1.7 On-board and Off-board chargers
As mentioned above, the charger may either be located on-board the vehicle, supplied with AC Level 1 or Level 2 EVSE, or it may be located off-board, i.e., in the EVSE used to supply DC power directly to the battery. An on-board charger allows EV owners to charge their vehicles wherever a suitable power source is available. Typical on-board chargers limit the power to Level 1 and Level 2 because of weight, space, and cost constraints. Off-board chargers enable faster charging due to the higher power levels.

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41 Plug In America, 2017
42 Yilmaz, M. et Krein, P. T., 2013
43 Bräunl, T., 2012
44 ENERGY STAR, 2013, p.1
45 Yilmaz, M. et Krein, P. T., 2013
2.1.8 **Unidirectional and Bidirectional power flow**

As the name suggests, unidirectional power flow describes the flow of electric power from the grid to the vehicle while bidirectional power flow allows for the flow of electric power in both directions, from the grid to the vehicle and from the vehicle to the grid (V2G). Levels 1, 2, and 3 equipment can be unidirectional. Bidirectional equipment is expected only for Level 2 infrastructure, because Level 1 power limits and cost targets are low, and in Level 3 fast charging, reverse power flow conflicts with the basic purpose and premise of minimizing connection time and delivering substantial energy as quickly as possible.\(^{46}\)

2.1.9 **Contactless Inductive Charging**

While conductive chargers use metal-to-metal contact, an inductive charger transfers power magnetically without direct contact. Instead of deep-cycling the battery, the vehicle battery can be topped off frequently while stationary and even while moving, e.g., charging strips can be built into highways. Inductive charging could therefore strongly reduce the need for a fast-charging infrastructure. Although the infrastructure does have relatively lower efficiency and power density, manufacturing complexity, size, and cost, intensive research into optimizing inductive charging systems is ongoing.\(^{47}\) As mentioned before, a separate study covering inductive charging has been prepared in 2017 for EDNA 4E by NTB University of applied Sciences in Switzerland, and as such it will not be further elaborated on these in this Scoping study report.

2.2 **Categories of EVSE**

The two most common ways of categorizing EVSE is by differentiating between power thresholds they can provide to vehicles. These are split into Modes as in IEC EN 61851-1 or split into Power Levels by US SAE J1772. Further categorisations sometimes try to distinguish between different connector types, however, these connector types are in some cases interchangeable, without altering other relevant components of the EVSE, and therefore not suited for categorisation for this purpose.

As can be seen in Table 11 below, SAE Level 1 and EN 61851-1 Mode 1 relates to household charging, with a maximum current of 16 A. Depending on the supply voltage this results in power thresholds between 1.4 kW (single phase) and 7.7 kW (three phase).

Level 2 doubles the voltage to 240 V, with a maximum current of 16 A while Mode 2 uses the same voltages as Mode 1, but doubles the maximum allowable current to 32 A. Importantly, Mode 2 adds a requirement for a control pilot function and system for personal protection against electric shock.

Level 3 has been proposed in SAE J1772 but is yet to be defined. Mode 3 supports fast charging with currents up to 250 A. Above that, EN 61851-1 switches to an external DC supply that may supply up to 400 A.\(^{48}\)

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\(^{46}\) Yilmaz, M. et Krein, P. T., 2013

\(^{47}\) Yilmaz, M. et Krein, P. T., 2013

\(^{48}\) Truite, D., 2012
Table 11 Categorisation overview of the definition of EVSE Power levels and Charging modes (Source: own adaptation from SAE J1772 and EN 61851-1).

<table>
<thead>
<tr>
<th></th>
<th>AC</th>
<th>DC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Voltage</td>
<td>Current</td>
</tr>
<tr>
<td><strong>Level 1</strong></td>
<td>120 V</td>
<td>12 A</td>
</tr>
<tr>
<td><strong>Level 2</strong></td>
<td>240 V</td>
<td>&lt; 80 A</td>
</tr>
<tr>
<td><strong>Level 3 (TBD)</strong></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Mode 1</strong></td>
<td>250 V</td>
<td>16 A</td>
</tr>
<tr>
<td><strong>Mode 2</strong></td>
<td>250 V</td>
<td>32 A</td>
</tr>
<tr>
<td><strong>Mode 3</strong></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Mode 4</strong></td>
<td>NA</td>
<td>See description</td>
</tr>
</tbody>
</table>

2.2.1 EVSE charging modes according to EN 61851-1

EN 61851-1\(^{49}\) describes the different charging modes for energy transfer to EVs and defines EVSE functions.

**Mode 1** represents charging via a standard AC socket outlet, is limited to 16A and typically used for domestic charging.\(^{50}\)

Figure 10: Schematic of Mode 1 charging (Source: Adapted from SCHRACK, 2017).

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\(^{49}\) EN 61851-1:2015, p. 21f  
\(^{50}\) PHOENIX CONTACT, 2015
16 A and 480 V AC, three-phase

EV supply equipment intended for Mode 1 charging shall provide a protective earthing conductor from the standard plug to the vehicle connector. Current limitations are also subject to the standard socket-outlet ratings described in clause 9.3.

Mode 2 describes charging via a standard AC socket outlet with in-cable charge controller and residual current detector (RCD), and is typically used for domestic charging.\(^{51}\)

Figure 11: Schematic of Mode 2 charging (Source: Adapted from SCHRACK, 2017).

![Schematic of Mode 2 charging](image_url)

Source: EN 61851-1:2015, p. 21f

Mode 2 EV charging consists of the use of a cable and plug intended to be connected to a standard socket-outlet, with a control pilot function and system for personal protection against electric shock placed between the EV and the socket outlet. The rated values for current and voltage shall not exceed:

- 32 A and 250 V AC single-phase
- 32 A and 480 V AC three-phase

EV supply equipment intended for Mode 2 charging shall provide a protective earthing conductor from the standard socket-outlet to the vehicle connector. Requirements for the IC-CPD are given in IEC 62752 (to be published). Current limitations are also subject to the standard socket-outlet ratings described in clause 9.3.

Source: EN 61851-1:2015, p. 21f

Mode 3 describes charging via a dedicated AC electric vehicle charging socket outlet or tethered charging cable. It is typically used for domestic or private charging using a wall box or public charging using a charging post.\(^{52}\)

\(^{51}\) PHOENIX CONTACT, 2015

\(^{52}\) PHOENIX CONTACT, 2015
Mode 3 EV charging consists of the use of EV supply equipment permanently connected to the AC supply network (mains), and where the control pilot function extends to control equipment in the EV supply equipment. EV supply equipment intended for Mode 3 charging shall provide a protective conductor to the socket-outlet or to the vehicle connector.

Source: EN 61851-1:2015, p. 21f

Mode 4 describes charging via a dedicated DC electric vehicle tethered charging cable, typically used for public fast charging using a dedicated charging unit.  

Figure 13: Schematic of Mode 4 charging (Source: Adapted from SCHRACK, 2017).

Mode 4 is used for the connection of an EV to DC EV supply equipment. It applies to equipment permanently connected to an AC or DC supply network and to equipment that can be supplied through a plug and cable connection to the supply network. A protective earthing conductor shall be provided to the EV connector. Specific requirements for DC EV supply equipment are given in IEC 61851-23. Specific requirements for DC EV supply equipment that is not permanently connected to the AC or DC supply are under consideration. Only case "C" shall be used for Mode 4. (See Figure 14 for a pictographic description of Case “C”)

Source: EN 61851-1:2015, p. 21f

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53 PHOENIX CONTACT, 2015

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2.2.2 EVSE power levels according to US SAE J1772

As described in the definition, there are three different levels of EVSE. Table 12 below summarizes the characteristics of the different EVSE Power Levels as applied to the US and the EU voltages.


<table>
<thead>
<tr>
<th>Power Level Types</th>
<th>Charger Location</th>
<th>Typical Use</th>
<th>Energy Supply Interface</th>
<th>Expected Power Level</th>
<th>Charging Time</th>
<th>Vehicle Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1 (Opportunity)</td>
<td>On-board 1-phase</td>
<td>Charging at home or office</td>
<td>Convenience outlet</td>
<td>1.4kW (12A) 1.9kW (20A)</td>
<td>4–11 hours 11–36 hours</td>
<td>PHEVs (5-15kWh) EVs (16-50kWh)</td>
</tr>
<tr>
<td>Level 2 (Primary)</td>
<td>On-board 1- or 3-phase</td>
<td>Charging at private or public outlets</td>
<td>Dedicated EVSE</td>
<td>4kW (17A) 8kW (32 A) 19.2kW (80A)</td>
<td>1–4 hours 2–6 hours 2–3 hours</td>
<td>PHEVs (5-15 kWh) EVs (16-30 kWh) EVs (3-50 kWh)</td>
</tr>
<tr>
<td>Level 3 (Fast)</td>
<td>Off-board 3-phase</td>
<td>Commercial, analogous to a filling station</td>
<td>Dedicated EVSE</td>
<td>50kW 100kW</td>
<td>0.4–1 hour 0.2–0.5 hour</td>
<td>EVs (20-50kWh)</td>
</tr>
</tbody>
</table>

**Level 1** EVSE occurs at standard power outlets, and since the required equipment for this level is minimal (i.e., a power cable), it is not a primary focus area for this Scoping study. A lower charge power is an advantage for utilities seeking to minimize peak impact.54 True load management however would require connectivity, as described by ICF Consulting in their 2016 report to UK DECC55.

Standby power requirements for Level 1 EVSE could not be found in literature or technical specifications, likely due to the fact that the equipment is technically simple and may not have standby power requirements. Connectivity would however likely incur standby power losses.

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54 Yilmaz, M. et Krein, P. T., 2013, p.2153f
55 ICF Consulting Services Limited, 2016
ENERGY STAR® Level 2 EVSE is the primary specification for dedicated private and public facilities, and owners seem to prefer Level 2 technology due to the faster charging time as compared to Level 1, and as it is technologically feasible in most homes and affordable, compared to Level 3. Level 2 EVSE may have considerable own power requirements especially during charging but also in standby. ENERGY STAR® presents the following graphic to describe the system boundary of Level 2 EVSE.

Figure 15: Level 2 Charging diagram for a representative product (Source: ENERGY STAR®, 2013).

Level 3 EVSE offers the possibility of charging in less than 1 hour (see Figure 16), typically operates with a three phase circuit and requires an off-board charger to provide regulated AC-DC conversion. It can therefore be understood as providing a different service than Level 1 or Level 2 charging, where the charger location with the AC to DC conversion is built into the vehicle.

Level 3 EVSE, although offering very rapid charging, may have very considerable own power requirements, both in standby and during charge. This is due to several add-on functions (see also section 2.3.3) that are built into DC fast charging stations to ensure optimal performance.

Figure 16: Level 3 Charging diagram for a representative product (Source: ENERGY STAR®, 2013).

56 Yilmaz, M. et Krein, P. T., 2013
57 Yilmaz, M. et Krein, P. T., 2013
2.3 EVSE operating modes and functions

2.3.1 Operating Modes

Due to the lack of measurement standards or definitions for EVSE, the only clear description of operating modes was found in ENERGY STAR®, Programme Requirements for EVSE V 1.0. The document defines six operating modes:

<table>
<thead>
<tr>
<th>Cit. 5 ENERGY STAR® definition of operating modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Disconnected: Condition of the equipment during which all connections to power sources supplying the equipment are removed or galvanically isolated and no functions depending on those power sources are provided. The term power source includes power sources external and internal to the equipment.</td>
</tr>
<tr>
<td>2. No Vehicle Mode: Condition during which the equipment is connected to external power and the product is physically disconnected from vehicle (mode can only be entered or exited through manual intervention). No Vehicle Mode is intended to be the lowest-power mode of the EVSE.</td>
</tr>
<tr>
<td>Note: the vehicle-EVSE interface is in State A of SAE J1772, where the vehicle is not connected.</td>
</tr>
<tr>
<td>3. On Mode: Condition during which the equipment provides the primary function or can promptly provide the primary function.</td>
</tr>
<tr>
<td>a) Operation Mode: Condition during which the equipment is performing the primary function.</td>
</tr>
<tr>
<td>Note: the vehicle-EVSE interface is in State C, where the vehicle is connected and accepting energy.</td>
</tr>
<tr>
<td>b) Idle Mode: Condition during which the equipment can promptly provide the primary function but is not doing so.</td>
</tr>
<tr>
<td>Note: Idle Mode is the condition within On Mode where the EVSE is connected to the vehicle or vehicle simulator but is not actively providing current. The vehicle-EVSE interface is in State C, where the vehicle is connected and ready to accept energy.</td>
</tr>
<tr>
<td>4. Partial On Mode: Condition during which the equipment provides at least one secondary function but no primary function.</td>
</tr>
<tr>
<td>Note: the vehicle-EVSE interface is in State B1 or B2, where the vehicle is connected but not ready to accept energy and the EVSE is or is not ready to supply energy.</td>
</tr>
<tr>
<td>5. Power Management: Automatic control mechanism that achieves the lowest power consistent with a pre-determined level of functionality.</td>
</tr>
</tbody>
</table>

The above described operating modes relate the condition of the EVSE to a certain operating mode. Once this condition is defined it will become key to link specific functions of EVSE to these operating modes.

2.3.2 Functions as defined by ENERGY STAR® and EN 81651-1

Linking the EVSE functions to the operating modes will be a key issue for policy makers. US ENERGY STAR® has created definitions of what they term ‘Primary’, ‘Secondary’ and ‘Tertiary’ functions. IEC EN 61851-1:2015 describes ‘Functions provided for Modes 2, 3 and 4’ split into function requirements and optional functions.

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58 ENERGY STAR, 2017, p. 2f
59 ENERGY STAR, 2017, p. 1f
Table 13 outlines the functions defined in both these documents.

**Table 13: EVSE functions as defined by ENERGY STAR® and EN 81651-1.**

<table>
<thead>
<tr>
<th>Functions</th>
<th>ENERGY STAR®</th>
<th>EN 61851-1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary function</strong></td>
<td>Providing current to a connected load.</td>
<td>Function requirements</td>
</tr>
<tr>
<td><strong>Secondary function</strong></td>
<td>Function that enables, supplements or enhances a primary function.</td>
<td>Optional functions</td>
</tr>
<tr>
<td><strong>Tertiary function</strong></td>
<td>Function other than a primary or a secondary function</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Automatic brightness control for screens or lamps</td>
<td>Ventilation during supply of energy</td>
</tr>
<tr>
<td></td>
<td>Full network connectivity</td>
<td>Retaining/releasing of the vehicle connector and/or the EV plug</td>
</tr>
<tr>
<td></td>
<td>Occupancy sensing (vicinity sensing)</td>
<td>Specifications for Mode 4 combined charging system.</td>
</tr>
<tr>
<td></td>
<td>Communicating with the vehicle</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Illumination of display, indicator lights, or ambient lighting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Public access control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control pilot signal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wake-up function</td>
<td></td>
</tr>
</tbody>
</table>
2.3.3 Further Functions

Most EVSE are sold with basic features such as auto-restart and LED status indicators. EVSE may also provide network connectivity and bidirectional data flow between the utility and vehicle.⁶¹

Besides the aforementioned functions, two further functions were identified in high power EVSE (Level 3 or Mode 4) during the research for this Scoping study. Both may be considered “Secondary functions” according to the above definitions in Table 13:

- Heating and cooling of EVSE dependant on ambient conditions: High power EVSEs have a large range of operating temperatures. To ensure that they remain operational, manufacturers include heating and cooling devices that come into effect outside of a set temperature range.
- Active cooling of charging cables in high power applications: High power transfer to vehicles may require the active cooling of the charging cable, due to resistance in the cable.

2.3.4 Network Connectivity of EVSE

ENERGY STAR® sets out requirements for ‘Connected Functionality’, which is defined as EVSE capable of supporting Demand Response (DR). Compliance with these requirements is optional and equipment that comply will be marked with as having ‘Connected’ functionality. The US EPA recommends that EVSE with DR capability are able to provide both signals-based DR and price response.⁶²

The Transport Ministry of Ontario in Canada has a programme to support the roll-out of EVSE and provides a guideline of minimum technical requirements that each EVSE supported under the program would need to meet:

- The EVSE must have the ability for remote data acquisition, monitoring and control of the EVSE.
- Collected data at a minimum must include the number of unique charge events, the duration of each charge event, and the amount of electricity used.
- Data from the unit must be collected and reported in a non-proprietary format.
- The EVSE must provide open source communications and networking to enable the general public to remotely identify if the EVSE is in use, or available for use, including on a smartphone.
- The EVSE must use an open payment method (credit card, debit card, etc.) with flexibility to accommodate billing users by time, energy consumed and flat rate.
- Must be rated for outdoor operation by a nationally recognized testing laboratory CSA, ULC or other certification marks approved by the Technical Standards and Safety Authority.⁶³

To fulfil these requirements the EVSE needs connectivity, and it has to be capable of communicating with the grid, with the user, and possibly with various commercial operators, as shown in Figure 17.

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⁶¹ ENERGY STAR, 2013
⁶² ENERGY STAR®, 2017, p. 10f
⁶³ Ontario Ministry of Transport.
Connectivity of EVSE with the grid is also being investigated in the Preparatory Study on Smart Appliances by the European Commission, in the context of demand response features, referring to flexibility for load shifting. This preparatory study will be completed by the end of 2017. In this study EVSE are considered in the Category IV: Electric vehicle charging systems.

The connectivity with the user will greatly depend on the business models that are currently being developed around billing and user interaction, for example allowing drivers to locate the nearest (available) charging station.

### 2.3.5 Possible Effects on the Grid

On the wider effects of higher level charging infrastructure, Yilmaz & Krein (2013) note the following: Level 2 and 3 charging can increase distribution transformer losses, voltage deviations, harmonic distortion, peak demand, and thermal loading on the distribution system. Policy makers should be aware that this could significantly impact transformer life, reliability, security, efficiency, and economy of developing smart grids due to reduced transformer life. Degradation of typical distribution equipment can be mitigated by using a controlled smart charging scheme. A reliable

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64 [http://www.openchargealliance.org/](http://www.openchargealliance.org/)
communication network and control of public charging is needed to enable the successful integration of a large number of EVs.\textsuperscript{66}

This raises two important issues. Transformers and grid infrastructure must be built to withstand peak power demand. Looking at the actual use figures from pilots, this peak power is rarely required. The proposed communication network has to be taken into account when considering the energy impact due to a large scale roll-out of higher level EVSE.

Effects on distribution infrastructure equipment, economic costs, and emissions from charging depend on EV penetration and charging strategies. Large-scale unbalanced deployment can have a detrimental impact on the electric grid; thus, grid stability becomes a challenging task.

Uncoordinated charging operations tend to increase the load at peak hours and can cause local distribution grid problems such as extra power losses and voltage deviations that affect power quality. They may lead to overloads in distribution transformers and cables, increased power losses, and reduced reliability and cost effectiveness of the grid. Additionally to issues of grid stability and transformer loads, Van Vliet et al (2011) showed in a model study in the Netherlands that, uncoordinated charging would increase the national peak load by 7% at 30% penetration. This may exceed the capacity of the existing distribution infrastructure. Proposed solutions are two-way energy flow and communication between the aggregated vehicles and the grid can be controlled to maintain grid stability.\textsuperscript{67} This requires connectivity.

\textsuperscript{66} Yilmaz, M. et Krein, P. T., 2013
\textsuperscript{67} Yilmaz, M. et Krein, P. T., 2013
3 Energy performance of EVSE

The overall energy performance of EVSE within the scope of this study encompasses both the charging efficiency as well as the own energy consumption of the equipment itself. Both rely on measurement results of the products’ power requirements in different operating modes and under different conditions.

3.1 Performance Standards for EVSE

Robust energy performance data can only be generated through measurement, irrespective whether it is communicated in a research publication or in technical specifications by the manufacturer. Standardized methodologies and procedures for power and energy performance measurements are therefore centrally important to generate credible and reproducible data. These methodologies and procedures should ensure that the measurement produces real world results.

According to expert opinion from the European Commission Joint Research Centre, real world testing of EVSE is crucial to enabling solid policy advice. To enable the energy performance assessment of EVSE and derive policy, standardised measurement procedures need to define issues such as the installation, ambient conditions, supply conditions, specific measurement points, operating modes, the core functions and scope, charging scenarios (actual power and condition of battery). 68

Performance data obtained through desk research show that individual procedures have been developed by numerous laboratories. Testing procedures were developed in the US for the US ENERGY STAR® programme, and in the EU, where the European Research Center (EC JRC) has derived an own procedure to measure EVSE’s performance 69.

3.1.1 The United States and Canada

In the US, on-board vehicle aspects are generally regulated more on a federal level and are addressed by SAE, while the built infrastructure in the US is normally regulated at the state or local level. 70

In 2013 the U.S. ENERGY STAR® prepared a market and industry scoping report on Electric Vehicle Supply Equipment (EVSE), and measured the energy efficiency of selected electric vehicle supply equipment. 71

The version 1.0 of the ENERGY STAR® requirements for EVSE was finalized last December 2016. Besides general requirements, these include a definition of the maximum power allowance by EVSE in different operating modes including No Vehicle Mode, Partial On Mode, On Mode, Operation Mode and Idle Mode. ENERGY STAR® also describes that ENERGY STAR® certified EV charger on average use 40% less energy than a standard EV charger when the charger is in standby mode (i.e., not actively charging a vehicle). EV chargers are typically in a standby mode for about 85% of the

68 Scholz, 2017
69 Scholz, 2017
70 Yiilmaz, M. et Krein, P. T., 2013
71 ENERGY STAR, 2013
lifetime of the product. Canada has already adopted the US ENERGY STAR® requirements for EVSE.

3.1.2 Europe

The final Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure was adopted by the European Parliament and the Council on 29 September 2014 following the inter-institutional negotiations:

- Requires Member States to develop national policy frameworks for the market development of alternative fuels and their infrastructure;
- Foresees the use of common technical specifications for recharging and refuelling stations;
- Paves the way for setting up appropriate consumer information on alternative fuels, including a clear and sound price comparison methodology.

The European Centre for Interoperability of Electric Vehicles and Smart Grids, European Commission, Joint Research Centre (JRC) is investigating primarily the interoperability issues between the electric vehicles and the charging infrastructure, covering hardware and information exchange protocols. Also interoperability of the EV fleet and the smart grid is investigated. Pre-normative research and support to the formulation of regulations addressing interoperability issues are complemented with performance and safety assessment of the power batteries.

These investigations are often done in the context of specific EU projects, such as the NCE-FastEvNet (No. 2015-SK-TM-0320-S, Fast Charger implementation in Poland and Slovakia). EMC work on chargers is supported by the Exploratory Research Project "Do Not Disturb" of the EC’s JRC. In this case the testing plan concentrated primarily on the aspects of:

- Energy efficiency of the candidate devices in CCS and CHAdeMO, Fast Charging modes.
- Standby power consumption of DC Multichargers (up to 50kW, ca. 400V DC).
- Influence of ambient temperature.
- Readability of display HMI, and usability of devices at various temperatures, ranging from -25°C to 40°C.
- Interoperability of the devices with various CCS and CHAdeMO chargeable electric vehicles
- OCPP back-end communication tests.
- Electromagnetic emissions from these candidate devices when being switched on, and when charging various EVs.

This testing activity aims to support the electro-mobility infrastructure policy of DG MOVE and it’s Innovation and Networks Executive Agency (INEA). The improvement of methodological approaches for charger quality, and notably for efficiency measurement tests was a welcome side-effect of the project, and will lead to a scientific publication with anonymous data for charging equipment.

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72 ENERGY STAR, 2016
73 NRCAN, 2017
74 https://ec.europa.eu/transport/themes/urban/cpt_en
76 Scholz, 2017
As mentioned before, experts from the UK prepared in 2016 an overview of the electric vehicle market and the potential of charge points for demand response, which was brought forward to the ongoing Preparatory study of the European Commission looking at Smart appliances. In this scope the potential for shifting load and the impacts on the electricity grid (demand side flexibility) are being considered.

3.1.3 Australia

According to an August 2016 report by the Australian Electricity Market Operator (AEMO), Australia’s regulatory and policy framework for electric vehicles is yet to be resolved. Standards Australia concluded in a 2010 report that the development of standards relating to vehicle recharging infrastructure should be dealt with as a single item. Bundling the standards development work around functionality was considered a more effective approach than on location alone. Standards Australia also highlights a need to focus standards on performance outcomes rather than on strict technical outcomes and adds: "Much of the discussion on recharging infrastructure, for example, suggests that any future standards might best be focused on the connection and performance of recharging infrastructure (i.e. wiring protocols, safety, design and site considerations), with the technical specifications of the system largely left to determination by market and industry considerations."

As of 2017 the Department of the Environment and Energy in Australia (DEE), which has the lead on appliance and product energy efficiency policy in the first instance, plans for developing standards on energy efficiency (requirements) for EVSE in Australia. DEE considered the benefits and costs of EV charging energy efficiency regulation in the past, but EV charging stations is not an area DEE are currently working on.

3.1.4 Republic of Korea

Korea has also developed standards for electric vehicle charging devices:

- **KS C IEC 61851-1 Electric vehicle conductive charging system, Part I: General requirements.**
- **KS C IEC 61851-23 Appendix No. 23: DC charging facilities, electric vehicle conductive charging system.**

In addition, Korea has standards for the plugs and for interoperability of charging:

- **KS R IEC 62196-1 Plug, Socket-Outlet, car vehicle inlet and connector - Conductive charging of electric cars, Part I: General requirements.**
- **KS R IEC 62196-3 Plug, Socket-Outlet, car vehicle inlet and connector - Conductive charging of electric cars, Part 3: DC and AC and DC tube contact pins and car coupler dimensions for the compatibility and interoperability requirements.**

The configuration for testing EVSE according to the standards is presented in Figure 18.
For the Efficiency test of charging electric vehicles, as shown in Figure 18, the load simulator and waveform monitor are plugged into the device. After being stabilized for 10 minutes, the efficiency is measured over 10 minutes (Total testing time is 20 minutes), and calculated by integrating the input and output wattage:

$$\text{Efficiency} = \frac{\text{Effective Output Wattage} (kWh)}{\text{Effective Input Wattage} (kWh)} \times 100\%$$

In addition testing is described for constant voltage control mode and any deviation, and Load dump test. The standard for EVSE also describes product labelling requirements. The manufacturer shall indicate high-efficiency apparatus in the product (clearly visible), the manufacturer’s name and brand must indicate the following:

- Number of highly efficient authentication, high efficiency marks
- Name of manufacturer, number of model
- Range electric vehicle charging system and capacity of the device classification (Reference Tables 14 and 15)
- Input voltage (V) and Current(A)
- Output voltage(V) and Current(A)
- Degree of protection (IP Code)
- Safety certification and contact information

Table 14: Capacity range electric vehicle charging unit classification (Source: KEA, 2017).

<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>KS C IEC 61851-23, reference annex AA</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>KS C IEC 61851-23, reference annex BB</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>KS C IEC 61851-23, reference annex CC</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>KS C IEC 61851-23, reference annex FF</td>
<td></td>
</tr>
<tr>
<td>etc</td>
<td></td>
<td>Including at least two or more sytems (Each separate charger to the evaluation system)</td>
</tr>
</tbody>
</table>
Table 15: Classification of electric vehicle charging systems (Source: KEA, 2017).

<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity range</td>
<td>I</td>
<td>Less than 10 kW</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>Beyond 10 kW less than 50 kW</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>Beyond 50 kW less than 100 kW</td>
</tr>
</tbody>
</table>

3.1.5 Japan

The Institute of Energy Economics Japan indicated that the Japanese government is currently not planning to develop energy efficiency requirements for EVSE. This topic has similarly not found its way into government policy. In 2015, the government forecasted the long term energy demand and supply, but the impact of EVSE on energy consumption had not been included.82

The Japanese road map for roll out of up to one million EVs by 2020 forsees the installation of public charging infrastructure at convenient locations to alleviate the reservations regarding range of EVs. Similarly the report discusses the need to install charging infrastructure in apartment buildings, housing 40% of the Japanese population.83

In Asia and Australia, alternative testing or measurement standards could not be found in the course of this research. A common level of knowledge for the EDNA delegates on these developments and the particular details concerning the efficiency of the charging equipment is the starting point for any possible (future) policy development and alignment for EVSE.

To understand, which individual pieces of information are relevant to derive policy, this report takes a top down approach. Before defining thresholds or benchmarks, policy makers need to understand the energy performance of the equipment.

3.2 Assessing own energy consumption of EVSE

Deriving the own energy consumption $E_P$ of a product seems fairly straightforward. Assuming the EVSE is marked with the product name ‘x’, it may be understood as the individual energy consumption per EVSE $E(x)$ in its different operating modes over a period of time as shown in Equation 1.

Equation 1

$$E_P = E(x)$$

To calculate the individual energy consumption per EVSE $E(x)$, one would need to add the energy consumption in different operating modes $E_{\text{Mode}}(x)$; in the simplest form, ‘Active’ $E_{\text{Active}}(x)$ and ‘Standby’ $E_{\text{Standby}}(x)$; over a set period; for example one day. In the case of e.g., only two operating modes this would be written as:

$$E_{\text{Active}}(x) + E_{\text{Standby}}(x) = E(x)$$

82 IEEJ, 2017
83 METI, 2016
or in general form:

\[ E(x) = \sum_{\text{Modes}} E_{\text{Mode}}(x) \]

The energy consumption in a specific operating mode \( E_{\text{Mode}}(x) \) over a set period would be a function of the power requirement of that mode \( P_{\text{Mode}}(x) \) and the time spent in that operating mode \( t(\text{Mode}) \) over the set period.

\[ E_{\text{Mode}}(x) = P_{\text{Mode}}(x) \times t(\text{Mode}) \]

Notice that the time spent in an operating mode \( t(\text{Mode}) \) is not a function of the product ‘x’ but a global variable, meaning that the operating modes need to be defined in a way that allows for the definition of scenarios that are applicable to all products ‘x’, ‘y’, ‘z’, etc.

Substituting Equation 3 into Equation 2 and combining it with Equation 1 gives the following expression:

\[ E_P = E(x) = \sum_{\text{Modes}} E_{\text{Mode}}(x) = \sum_{\text{Modes}} (P_{\text{Mode}}(x) \times t(\text{Mode})) \]

which can be summarized into:

\[ E_P = \sum_{\text{Modes}} (P_{\text{Mode}}(x) \times t(\text{Mode})) \]

Equation 4 indicates that, to extrapolate the overall own energy consumption of EVSE for a set time period, one would need to know:

- \( P_{\text{Mode}}(x) \) - the power requirement of the EVSE in its different operating modes (e.g., from measurement), and
- \( t(\text{Mode}) \) - the time spent in those operating modes over a set period (e.g., through scenarios derived from research and pilot projects),

Taking a closer look at these two factors: The assessment of the power requirement of the EVSE in its different operating modes \( P_{\text{Mode}}(x) \) depends on:

- The definition of specific operating modes, in a way to be applicable to the wide range of products. (See next section 3.2.1).
- The specific function(s) provided by the product under investigation i.e., the clear differentiation between the core function of the product and possible add-on functions, as well as the system boundaries. (See next section 3.2.2).
Once these issues are clarified, the power requirement can be measured within these set definitions and boundaries. This requires the aforementioned measurement standard as issues such as the quality of the power supply and the position of the measurement clamps can greatly affect the measurement. (See next section 3.2.3).

The second factor in the equation is the time spent in the operating mode \( t(\text{Mode}) \), which is a function of:

- The specific use scenario adopted for the investigation, differentiating for example between home and commercial settings, frequency of use, and country specific regulations for installation and use (See next section 3.2.4).
- The ambient conditions, which might affect the operating state, such as climatic conditions. For example, cooler temperatures will require heating periods, long nights will require longer periods for signalling lights (See next section 3.2.5).

Taking these factors into account it is currently neither possible to publish a comprehensive comparison of different EVSE, nor to present the results in one overview with the different technologies, or even extrapolate the overall own consumption of EVSE for a country or region. This is due to *the lack of a cohesive measurement standard and the lack of a cohesive definition of operating modes and product functions*. The data available are mostly not comparable in quality, scope, and applicability.

The elements required for deriving overviews, comparisons, and/or extrapolations are further discussed below.

### 3.2.1 Definition of Operating Modes

Defining EVSE operating modes may at first glance seem trivial as they are either actively in use (when charging the electric vehicle) or in standby (the period aside of active use). For standby, published data on measurements\(^8^4\) suggest that the EVSE have different power requirements depending on whether an EV is connected, and whether the connection is *prior to* or *following* a “charging event”.

Additionally other operating modes may be active for specific periods of time, e.g., signalling, cooling, heating or communication modes. To allow for a reproducible measurement these likely EVSE operating modes need to be clearly defined in a standardized way. These definitions could look to build on previous work performed in the area of interoperability testing\(^8^5\).

### 3.2.2 Core Functions and Add-ons

Currently, EVSE systems are split according to their charging modes or power levels, their positioning, their connector types and other features. Defining the “product” boundaries of the EVSE themselves is however much more difficult. A clear definition of the EVSE core and add-on functions is needed for generating reproducible and robust data needed for policy decisions.

\(^{8^4}\) INL, 2011

\(^{8^5}\) Nöhrer et al, 2016
ENERGY STAR® US has created such definitions of what they term ‘Primary’, ‘Secondary’ and ‘Tertiary’ functions.\textsuperscript{86} Similarly, IEC EN 61851-1 describes ‘Functions provided for Modes 2, 3 and 4’, split into function requirements and optional functions\textsuperscript{87}, as shown in Table 13.

Some functions may significantly affect the energy performance of EVSE and should be considered. In an interview for this study, a leading EVSE manufacturer indicated 500 W power requirement for heating and cooling, while another manufacturer indicated 80 W for heating and 100 W for cooling. One manufacturer informed that this feature is active below 0°C and above 35°C ambient temperature. Even higher power requirements might take place for intermittent active cooling of the charging cable during fast charging.

A manufacturer indicated power requirement of 50 W for LED signal lighting. There might be additional power associated to displaying information in EVSE screens and for data transfer (Connectivity). These power needs would also form part of the overall consumption of EVSE. Published data on these power needs is not readily available at the time of conducting this Scoping study.

3.2.3 Measurement and Testing Methods

As described in Section 3.1, there is currently no single (harmonized) international standard describing the setup, procedure and methodology for the assessing the charging efficiency or the own energy consumption of EVSE.

Among other issues such a standard should ideally define the measurement setup (including the connection to the grid and quality of supply), ambient conditions (temperature, ventilation), and the connection points for the measurement equipment (positioning is crucial especially for charging efficiency measurements).

Depending on the measurement setup, it would be expected that the possible own consumption of EVSE during charging events (i.e., Active use) will likely be included as losses in the efficiency measurement of the charging event. This would also be a central point that would need to be defined in the test method or standard, to ensure clear attribution of loads.

It may be difficult to measure the own consumption of equipment while it is in active use, as the own consumption of some components will then turn up as losses in the charging efficiency while some components may still be measureable separately. Therefore a definition /distinction is needed, e.g., all components providing functions in standby need to be measured separately and all components only providing functions while active can be included in the charging efficiency. Or the active mode is separate and all loads in the active mode could be attributed to charging efficiency, while loads in the standby mode(s) should be measured separately.

3.2.4 Use Scenarios

The use scenario is important in obtaining robust energy consumption estimates for real world applications. As the power requirement might differ substantially in different operating modes and ambient conditions, it is crucial to work with a realistic use scenario for the EVSE. Good information for the development of use scenarios already exists from previous research for the roll-out of EVSE.

\textsuperscript{86} ENERGY STAR, 2017
\textsuperscript{87} EN 61851-1:2015
Firstly, actual EVSE use data from pilots and demonstration projects such as the one presented in Figure 19 below from New York State, or specific data for countries or regions where the penetration of electric vehicles is advanced, such as the information presented in the text box below for Norway, can be used especially for EVSE in public settings. Additionally, data on the location of vehicles, as shown in Figure 20, to derive the realistic connection times to EVSE in private settings can be used. This data can then be combined with climate data to build realistic scenarios for country or region specific estimates or extrapolations.

Figure 19: Extract from the on the use of EV charging infrastructure in New York State (Source: 2016 Q1 report of NYSEDA, 2016).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{charging_availability.png}
\caption{Charging Availability: Range of Percentage of All Charging Ports with a Vehicle Connected versus Time of Day*}
\end{figure}

\begin{itemize}
\item \textit{Initial evidence shows that most of the early adopters of BEVs and PHEVs have the opportunity to charge at home, and this is their primary charging location. When asked about their use of public charging stations during the last month, 11% of BEV and PHEV Norwegian owners said they used public charging on a daily basis, 28% – on a weekly basis, and 35% – less frequently than that, 26% reported not using public charging at all in the last month. From the Norwegian survey, 62% of respondents indicated they did not use fast chargers at all in the last month, compared to 9% that used fast chargers at least once a week. It should be noted, however, that the current number of fast-charging stations in Norway is still quite limited (as of June 2013) and the three most popular fast-charging stations in Norway (located centrally and offering free electricity) have had 10,000 charging sessions in one year, averaging approximately 9 charging sessions per day for each of the three chargers.\textsuperscript{*}}
\end{itemize}

Source: Amsterdam Round Table, 2014

Figure 20 shows the location of vehicles throughout the week on the basis of data from the 2001 National Household Travel Survey in the US. The graph clearly shows that the vehicles are either at home (green areas), or at work (red areas) most of the week. These would therefore be prime charging locations. Vehicles only spend a short amount of time parked at commercial locations (light blue areas) or actually driving (dark blue area). This information is helpful to understanding EVSE roll-outs and for deriving use scenarios.
3.2.5 Ambient Temperatures

Research shows\(^88\), and the ongoing work by EC JRC confirms, that ambient temperature as well as the conditions of the battery (State of charge, temperature, and cycle life) do affect the efficiency of the charging process. Similarly and following on from the previous discussion on add-on functions (cooling and heating), the ambient temperature and the EVSE placement indoors or outdoors will have an effect, not only on the design of the product but also on its energy relevant add-on functions. There is an impact on the active charging efficiency and also on the time aside of use.

3.3 Overview of Energy Performance of Different EVSE

As mentioned before, the overall energy performance of EVSE within the scope of this study encompasses both the charging efficiency as well as the own energy consumption of the infrastructure itself. Great efforts have been made to investigate the classical charging efficiency of electric vehicles and a large number of institutions, working groups, projects and laboratories are presenting robust data. Energy efficiency measurements have for example been carried out and published by the Idaho National Laboratory\(^89\) and are currently being undertaken at the EC JRC\(^90\).

This Scoping study concentrates also on the other side of the coin, looking to create an understanding for the own consumption of systems, especially when they are *not actively in use*.

To show the varied data sources, an extract of the data uncovered during this Scoping study work is presented in Table 16, Table 17, and Table 18.

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\(^{88}\) Forward, E. et al., 2013
\(^{89}\) INL, 2011
\(^{90}\) Scholz, 2017
Table 16: Power requirements in different operating modes for selected EVSE.\textsuperscript{91}

<table>
<thead>
<tr>
<th>Product</th>
<th>Max power</th>
<th>30A</th>
<th>15A</th>
<th>4A</th>
<th>No vehicle</th>
<th>Partial On Mode</th>
<th>Idle Mode</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>ChargePoint-CPH12</td>
<td>34,03</td>
<td>-</td>
<td>35,25</td>
<td>2,29</td>
<td>1,90</td>
<td>1,90</td>
<td>2,00</td>
<td>2017</td>
</tr>
<tr>
<td>ChargePoint-CPH25</td>
<td>61,51</td>
<td>52,89</td>
<td>33,12</td>
<td>16,78</td>
<td>1,90</td>
<td>1,90</td>
<td>2,00</td>
<td>2017</td>
</tr>
<tr>
<td>ChargePoint-CPF25</td>
<td>96,44</td>
<td>59,73</td>
<td>29,93</td>
<td>12,02</td>
<td>3,20</td>
<td>3,20</td>
<td>3,00</td>
<td>2017</td>
</tr>
</tbody>
</table>

Table 17: Power requirements measured by the Idaho National Laboratory.\textsuperscript{92}

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>GE</td>
<td>GE Smart Grid EVSE Prototype</td>
<td>98,83%</td>
<td>36,89</td>
<td>18,40</td>
<td>17,70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GE</td>
<td>GE Energy WattStation Wall-Mount Unit</td>
<td>99,00%</td>
<td>31,20</td>
<td>4,90</td>
<td>4,90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blink</td>
<td>Blink Residential Wall-Mount Unit</td>
<td>99,19%</td>
<td>25,60</td>
<td>13,40</td>
<td>12,50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Siemens</td>
<td>Siemens-VersiCharge Model No. VC22NKB</td>
<td>99,21%</td>
<td>24,40</td>
<td>2,50</td>
<td>5,80</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ClipperCreek</td>
<td>ClipperCreek Public EVSE Model No. CS-40</td>
<td>99,24%</td>
<td>23,75</td>
<td>3,21</td>
<td>3,26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leviton</td>
<td>Leviton Residential Wall-Mount Unit</td>
<td>99,24%</td>
<td>25,72</td>
<td>8,18</td>
<td>7,48</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schneider Electric</td>
<td>Schneider Residential Indoor - Wall-Mount Unit</td>
<td>99,29%</td>
<td>22,20</td>
<td>1,30</td>
<td>2,20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AeroVironment</td>
<td>AeroVironment Residential Wall-Mount Unit</td>
<td>99,32%</td>
<td>22,77</td>
<td>5,11</td>
<td>5,00</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>SPX</td>
<td>SPX Residential Wall-Mount Unit Model No. EV20M26318U</td>
<td>99,68%</td>
<td>10,80</td>
<td>1,80</td>
<td>1,20</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

From the data on Table 17, it is worth noting the difference in standby power consumption (pre and post charge) between products (around a factor 10 difference, without considering the prototype).

Table 18 also shows the significant power required by selected products for heating/cooling of EVSE and for cooling the charging cable (up to 500 W and 1000 W, respectively).

Table 18: Power requirements in different operating modes by selected EVSE manufacturers (Source: ECODESIGN, 2017).

<table>
<thead>
<tr>
<th>Company interviews</th>
<th>Overall charge efficiency</th>
<th>Loading cable cooling</th>
<th>Idle</th>
<th>Signalling</th>
<th>Standby heating/cooling</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company A</td>
<td>92,00%</td>
<td>1000</td>
<td>40</td>
<td>unknown</td>
<td>500</td>
<td>2017</td>
</tr>
<tr>
<td>Company B</td>
<td>95,00%</td>
<td>unknown</td>
<td>40</td>
<td>50</td>
<td>80-100</td>
<td>2017</td>
</tr>
</tbody>
</table>

Additional data on efficiency of inductive charging systems is collated and presented in Figure 21, and discussed separately in the investigation of NTB University of Applied Sciences Buchs (NTB, 2017). From these data it can be seen in general that the efficiency of inductive systems is lower than for conductive systems where data is available. An extract is included here, from the analysis presented by the authors (NTB, 2017). They indicate that virtually no internal power consumption data for inductive chargers are available. At best, the power consumption for the prior and post charging states can be estimated based on the (additional) functionalities necessary for inductive charging systems.


\textsuperscript{92} https://atv.inl.gov/evse-type/all-evse-types
For prior charging and post charging states they assume that the inductive charging system consumes more power due to additional functionalities and features necessary for its operation. For example, an EV detection system must identify an approaching vehicle, and will initiate some type of system communication. The efficiency of the energy transfer process of an inductive charger depends on the proper coupling between the transmitter and receiver coils, and thus, a parking assistant is necessary during the prior charging state. This assistant communicates (over a defined communication protocol) with the vehicle, and collects information about the EV battery state and charging mode. These features add to the standby consumption of the inductive system.

For safety reasons a living object detection (LOD) and foreign object detection (FOD) must be active before and while the charging is in progress. Today low power wireless communication protocols (e.g., Bluetooth, ANT+, ZigBee, Wi-Fi, NFC) help to keep the energy consumption low. An estimated 10 W additional power consumption is sufficient for an inductive charging system. That means, the standby losses will increase to roughly 20 W for the prior charging state. In this state most of the electronics on the EV side are deactivated, with nearly no energy consumption.

An estimation of the power consumption for the heating and/or cooling functions for a proper operation before or during the charging process (for inductive systems) is difficult. This depends strongly on the environmental condition of the charger location.

During the charging process the power electronics losses are dominant, and their extent depends on several factors, such as the level of transmitted power, battery voltage, air gap and alignment between transmitter and receiver. Other system functions such as communication, LOD/FOD and signalling require only an insignificant amount of energy compared to the charging losses, and therefore, are not relevant during steady charging. The system efficiencies for different chargers are shown in Figure 21.

After completion of the charging process, the supply equipment still needs to communicate with the on board charging system to detect if the vehicle is still parked. The system also receives information about the state of charge of the battery, e.g., if the battery is (fully) charged or not. These additional

Figure 21: Efficiency of selected inductive charging systems (Source: NTB, 2017).
features on an ICS require an estimated additional 10 W of power consumption after the charging process has been completed.

It should be pointed out that the additional losses of 10 W in the prior and post charging states are based on estimates of power needs to perform the functions, but it is unknown how much power their real implementation consumes, as there is no test data publicly available.\textsuperscript{93}
4 Summary and Recommendations

In the following two sections a general summary and a summary concerning the Scoping study as such are presented, followed by recommendations for further work.

4.1 General summary

The environmental benefits of electric vehicles are generally put forward as a strong argument to promote their deployment. Many studies are focusing on the challenges for EV charging infrastructure deployment, on the conditions, and regulatory environments needed to promote its expansion, especially in urban areas.

The specific aspects concerning the energy performance of the EVSE, especially its own consumption as such are only marginally and indirectly discussed in a larger context, for example in relation to the electricity mix of the country and its connection to e-mobility and the associated carbon emissions.

This EDNA Scoping study took a different view and investigated aspects of the EV charging infrastructure, with its own energy requirements. This information is of interest to the delegates in furthering the strategic work of the Electronic Devices and Networks Annex EDNA.

Considering the energy performance of EVSE and the investigations in this scoping study, it is plausible to say that while the charging efficiency has seen considerable research efforts, the own power requirements of EVSE as such have not been widely assessed.

Indications are that, depending on the functions provided by EVSE, the sheer number of installed units will begin to have a relevant effect on energy requirements. This becomes especially relevant when looking at the widespread roll-outs of Level 3 (Mode 3 and Mode 4) EVSE, installed in public areas, in addition to the Level 2 (Mode 2) EVSE installed in the households. Estimates range from one and a half to two Level 2 (Mode 2) EVSE per EV, to which a large number of high-power Level 3 (Mode 3 and Mode 4) EVSE will be added.

ENERGY STAR® in the US has set energy performance requirements for EVSE94. In 2015 the US EPA estimated the energy savings potential as follows: As EVSE are only charging a vehicle a few hours per day, the EPA has identified a non-charging-state energy savings opportunity of up to 265 kWh per charger over 5 years. That could equate to a national energy savings of close to 4,8 GWh annually.95

Characterisation of EVSE along clearly defined technical boundaries is possible as shown by US ENERGY STAR® and IEC 61851, which define charging power thresholds. The fact that there are currently two major co-existing characterisations seems to stem from historical parallel developments. Harmonizing those would benefit policy development.

The current definitions of operating modes describe specific conditions of the EVSE. To understand the power requirements in specific operating modes it will be key to understand the functions behind these specific operating modes. Assigning functions to operating modes may also facilitate a definition of core functions and add-on functions, a distinction which is not yet available or fully developed.

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94 https://www.energystar.gov/productfinder/product/certified-evse/results
The work on defining operating modes and functions should look to build on the existing IEC and SAE standards, as well as the ongoing interoperability and harmonisation work, as these have defined specific use cases that consider relevant EVSE functions.

Measurement standards for the reliable and reproducible measurement of the overall energy performance of EVSE, including their own energy needs, are currently missing. Developing these standards seems a priority, as any work looking to derive product policies such as MEPS or energy efficiency labelling will need to be built on a solid testing foundation.

Such standards would also be useful for industry, as the EVSE manufacturers and operators do seem to have a keen interest on better understanding the conditions that influence the energy performance of their equipment. Industry interest is driving forward the research on inter-operability and energy efficiency aspects for EVSE. When defining standards for industry the clear definition of operating modes and their link to functions as well as the product boundaries will likely be crucial as some manufacturers may have an interest in setting different product boundaries or defining likely core functions as add-ons.

4.2 Summary concerning the Scoping study

The original objectives of this Scoping study are discussed in light of the completed work:

- The review of existing technologies for residential/commercial electric vehicle supply equipment showed a wide range of systems available on the market. 2.3 million EVSE, classified in different groups from residential slow chargers to commercial fast chargers, are currently deployed in the global market. Markets for EV and EVSE are growing rapidly and projected to continue growing over the next decade. Further technologies such as induction charging and bidirectional power flow capabilities are currently being developed.
- The most important key technical feature of the EVSE with the focus on energy performance was found to be the charging power, used as threshold in the different classifications of EVSE.
- Further energy relevant aspects were found to be heating and cooling of the EVSE, signalling, display, data transfer, and in specific cases, the active cooling of the supply cable.
- The review of publications relating to charging losses and standby consumption of the different systems, as well as the methodologies used in these studies, showed that investigations into charging efficiency are widespread, though a common international standard on the measurement procedure is missing. Investigations looking into the own power consumption of EVSE (including standby) are rare, and lack a standardized measurement approach. Spare data found is not suitable for comparisons or useful for extrapolations.
- Due to the information gaps on the measurement procedures, as well as the different product boundaries possible, it is challenging to generate an all-encompassing overview of the energy performance of different charging systems at this stage.
- The investigation into the existing approaches of EVSE energy performance standards for regulatory purposes showed that the energy performance of EVSE has recently been addressed up by policy makers. Energy performance requirements have been set by US ENERGY STAR® for the US and Canada. Pre-regulation research and testing measurements under real-use conditions are underway at the European Commission Join Research Center.
Likewise, the EU Preparatory study on Smart Appliances has included EVSE into its expanded scope. Other regions do not yet explicitly address the energy consumption of EVSE in their appliance policies.

- The major knowledge and data gaps identified in this scoping study are data on the own energy consumption of EVSE under real use conditions and the measurement/testing procedures to generate reproducible and robust data.
- Emerging issues to keep an eye on are the widespread roll-out of EVSE infrastructure in the coming decade, especially due to the growth of the EV market in some world regions (e.g., in China).
- The development and deployment of inductive charging technology and its associated energy performance have been investigated in a 2017 study, which also underlines the importance of robust data and testing methods for better assessing this emerging technology.
- The Scoping study found that the energy impact of the connectivity of EVSE is currently neither specifically nor separately addressed as an issue.
4.3 Recommendations for Next Steps

Finally this section presents the key aspects for policy makers to be aware of, and areas where further work could be considered for national projects and/or international cooperation, e.g., in the Electronic Devices and Networks Annex of IEA – 4E, with recommendations for next steps:

1. Closing existing data gaps is crucial to enable policy. This would require the definition of measurement standards which include the definition of operating modes, description of functions and setting of product boundaries.

2. The definition of widely applicable operating modes and description of functions requires linking the described functions to the operating modes. This work may be able to build upon the work performed in the interoperability research and testing for EVs and EVSE. This is also important before expanding the scope e.g., to consider efficiency for bidirectional power flow.

3. A clear international definition of terms in a glossary is required to ensure a consistent meaning and clear boundaries between the terms used in the investigations. As an example the following frequent terms have been used, sometimes interchangeably, in the documents reviewed for this scoping study: Charger, charging equipment, charging station, outlet, charging point, charge point and supply equipment. Definition work could build on existing standards such as SAE J1772 or EN 61851-1.

4. Policy makers need to be aware of additional possible impacts of EVSE on the grid, dimensions of required infrastructure, and possible increased maintenance requirements. In the longer term EVSE systems (Conductive and inductive) for EVs will likely operate bidirectionally. That means power flow to and from the vehicle battery will be possible. There are studies showing that a larger number of vehicle batteries can be used to help stabilizing the power grid. In this case, the battery can at least partially replace the local storage. The bidirectional functionality must be designed carefully in order to not jeopardize the efficiency of the charger, as well as the live time of the battery (NTB, 2017).

5. Cooperation opportunities between 4E EDNA with the EC JRC and the IEA Technology Collaboration Program on Hybrid and Electric Vehicles (IEA HVE) should be sought. The IEA TCP Hybrid and Electric vehicles (HEV) issues a yearly report with policy updates for e-mobility in various countries and regions, and its Task 30 assesses the Life Cycle Assessments of hybrid and electric vehicles. EDNA and HEV could mutually benefit from exchange of data and information for each other tasks.

6. Likewise, the IEA is releasing every year its Global Electric Vehicle Outlook96, and do track the global deployment of EVSE. The energy impact of EVSE might become “an important issue that is not yet so visible in the policy discussions.”

7. At national EDNA delegates might profit from established contact with e-mobility platform operators, who could be their interested in the assessment of the efficiency of their charging infrastructure. Having efficiency information would help them better inform their customers and stakeholders. Initial contact with industry and EVSE manufacturers also showed great interest from their side in energy efficiency assessments of their products. Cooperation may therefore also be possible with specific industry partners.

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96 IEA, 2016
8. Expanding the geographic scope of this EVSE work to include China would be beneficial for 4E EDNA in light of the ambitious e-mobility deployments and growing experience in field in this country. EDNA members could profit from insight into Chinese standards, EVSE requirements and/or specific policies. At the time of this Scoping study no information was available to the authors.
List of relevant Standards

**ISO 15118-2013:** Road vehicles -- Vehicle to grid communication interface. ISO 15118 specifies the communication between Electric Vehicles (EV), including Battery Electric Vehicles and Plug-In Hybrid Electric Vehicles, and the Electric Vehicle Supply Equipment (EVSE).\(^97\)

**IEC 61851-1:2017:** Electric vehicle conductive charging system - Part 1: General requirements.\(^98\)

**IEC 61851-21:** Electric vehicle conductive charging system - Part 21: Electric vehicle requirements for conductive connection to an AC/DC supply. IEC 61851-21 gives the electric vehicle requirements for conductive connection to an AC or DC supply, for AC voltages according to IEC 60038 up to 690 V and for DC voltages up to 1 000 V, when the electric vehicle is connected to the supply network.\(^99\) (Identical to Önorm EN 61851-21)\(^100\)

**IEC 61851-23:2014:** Electric vehicle conductive charging system - Part 23: DC electric vehicle charging station. IEC 61851-23:2014, gives the requirements for DC electric vehicle (EV) charging stations.\(^101\)

**IEC 62196-1:2014:** Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 1: General requirements\(^102\)

**IEC 62196-2:2016:** Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 2: Dimensional compatibility and interchangeability requirements for AC pin and contact-tube accessories\(^103\)

**IEC 62196-3:2014:** Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 3: Dimensional compatibility and interchangeability requirements for DC and AC/DC pin and contact-tube vehicle couplers\(^104\)

\(^97\) [https://www.iso.org/standard/55365.html](https://www.iso.org/standard/55365.html)
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