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**Ufficio federale dell'energia UFE**
Sezione Cleantech

**Rapporto finale** del 31 gennaio 2018

# Buffer batteries

## to maximize the use of locally produced renewable energy, especially in electric cars

**Data:** 15 dicembre 2017

**Luogo:** Berna

**Erogatore del sussidio:**
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**Del contenuto e delle conclusioni del presente rapporto rispondono unicamente i suoi autori.**

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# Sintesi

La richiesta di sistemi di accumulo nelle reti elettriche cresce di pari passo con l'evoluzione tecnica ed economica dei sistemi di generazione, distribuzione e utilizzatori dell'energia elettrica. In particolare, l'incremento di energia prodotta da fonti rinnovabili, per loro natura stocastiche, richiederà una sempre maggiore capacità di accumulo.

In questo scenario i veicoli elettrici potrebbero non più essere solo dei semplici utilizzatori, ma grazie alle loro batterie, diventare un elemento attivo della rete.

Il progetto “buffer batteries” ha l'obiettivo di paragonare l'effetto di diversi sistemi di accumulo di energia, installando e sperimentando l'utilizzo di batterie stazionarie e infrastrutture di ricarica bidirezionali, con lo scopo di ridurre al minimo il carico sulla rete e massimizzare l'uso di energia rinnovabile nei veicoli elettrici, valutandone l'impatto sulla rete e sulle abitudini degli utenti.

# Zusammenfassung

Die Nachfrage nach Speichersystemen in den Stromnetzen wächst mit der technischen und wirtschaftlichen Entwicklung der Stromerzeugungs-, -verteilungs und –nutzungssysteme. Insbesondere der steigende Anteil der aus erneuerbaren Quellen erzeugten Energie, die von Natur stochastisch ist, erfordert eine größere Speicherkapazität.

In diesem Szenario könnten Elektrofahrzeuge nicht mehr nur einfache Nutzer sein, sondern dank ihrer Batterien ein aktives Netzkomponente werden.

Der Umfang des Projekts "Pufferbatterien" soll den Effekt verschiedener Energiespeichersysteme vergleichen, indem stationäre Batterien und bidirektionale Ladeinfrastrukturen installiert und getestet werden, mit dem Ziel, die Netzbelastung zu minimieren und den Einsatz erneuerbarer Energien in Elektrofahrzeugen zu maximieren, und ihre Auswirkungen auf das Netz und das Verhalten des Nutzers beurteilen.

# Abstract

The demand for storage systems in the electricity grids is growing together with the technical and economic development of the production, distribution and use of the electricity. In particular, the increasing part of energy produced from renewable sources, stochastic by nature, will require a greater storage capacity.

In this scenario, electric vehicles could be more than simple users and thanks to their batteries, become an active grid component.

Scope of the project "buffer batteries" is to compare the effect of different energy storage systems, by installing and testing stationary batteries and bidirectional charging infrastructures, with the aim of minimizing the load on the grid and maximize the use of renewable energy in electric vehicles, assessing their impact on the grid and the user's behavior.

# Index

# List of Abbreviations

| | |
|---|---|
| AC | Alternating current |
| DC | Direct current |
| EV | Electric Vehicle |
| PHEV | Plug-in Hybrid Electric Vehicle |
| PV | Photovoltaic |
| V2G | Vehicle to Grid |
| CHAdeMO | quick DC charging interface for EV batteries, standardized by the Japanese car industry |
| CCS | quick DC charging interface for EV batteries, standardized by the European and North American car industry |
| ESS | Electronic Switching Systems |
| PRL | Primary Regulation Load |

# Introduction

In Switzerland, 38% of energy consumption and 40% of CO2 emissions are due to mobility needs, which are covered for 96% by petroleum products and correspond to 64% of total oil consumption.

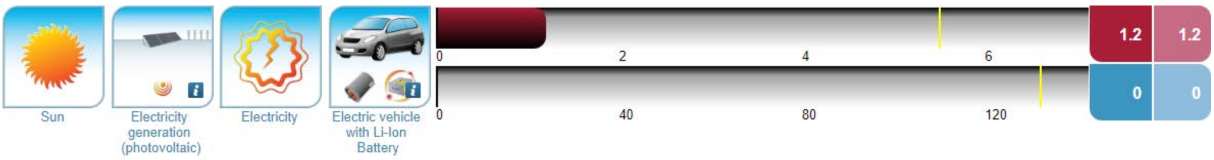
(Source: FSO, Mobility and transport 2015 and 2016).

Electric vehicles (EVs) rely on regular charging from the local electricity grid. The power plants providing that energy aren't 100 % emission-free; in 2015 in Switzerland, 52.04 % of the consumed electricity was from a renewable source, of which 47.46 % from hydroelectric power plants and only 0.62 % from photovoltaic installations. However, from 2009 (< 0.1 %) the part of solar energy has strongly increased.

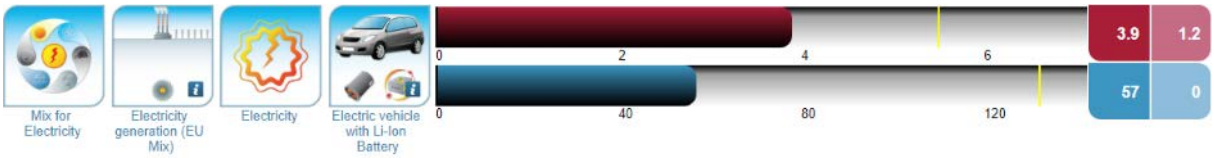
(Source: Swissgrid 2017).

EVs offer today the most efficient propulsion technology for passenger cars, in particular considering the whole energy chain (well-to-wheel). However, the impact in terms of CO2 emissions is valuable only if electricity is produced from renewable sources.

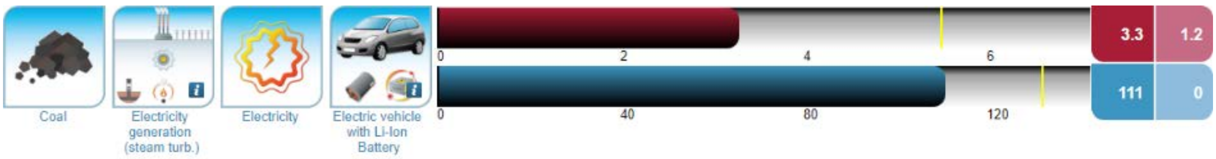
1. EV recharged with electricity produced by a PV installation:



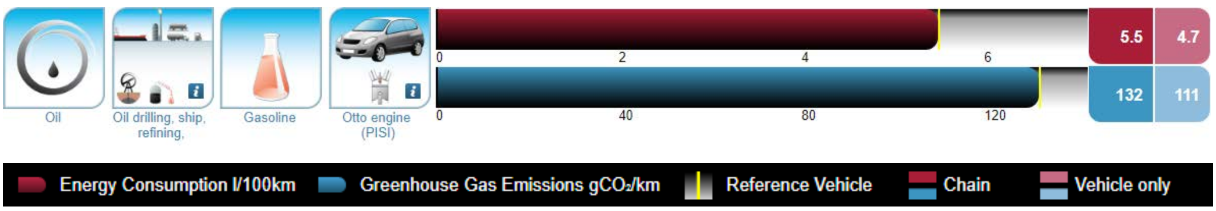

2. EV recharged with EU electricity mix:




3. EV recharged with electricity produced by a coal power plant:




4. Gasoline combustion engine:




(Source: [www.optiresource.org](http://www.optiresource.org))

The above comparison show that only an EV recharged with electricity produced from a renewable source (1) has in fact no $CO_2$ emissions. The same vehicle supplied with electricity produced by a coal power plant (3) brings just little benefits in terms of global $CO_2$ emissions compared to a conventional gasoline combustion engine (4), with 111 g CO2 / km instead of 132 g $CO_2$ / km!

Solar energy is not available on demand, therefore, within the next years, together with its largest diffusion, energy storage is expected to become an issue.

Currently the most common energy storage system are composed by stationary batteries.

The development of battery technologies, has considerably increased range and performances of the new generation of electric vehicles, which in general can now cover more than common daily mobility requirements.

From this assumption comes the idea to use part of the vehicle battery capacity as a storage system, in combination with a device that, in addition to recharge the vehicle, is also able to extract the energy stored in its battery.

As a side effect, storage systems have a positive impact on the distribution grids, allowing to smooth their loads.

# Purpose of the project

In order to verify the impact of a storage systems and their influences on grid, vehicles and user behavior, in 2013 the project “buffer batteries” was launched.

The project is based on the comparison of 3 different technical approaches, which differ from the application of the battery (mobile in EVs or stationary in the building) and the control (decentralized / centralized). To maximize the use of locally produced solar energy and minimize the grid load, the following combinations were investigated:

- Configuration 1: installation and operation of four local, stationary, networked battery, which can be centrally controlled, in order to buffer locally produced solar energy for the household and EV charging.
- Configuration 2: installation and operation of four intelligent bidirectional charging stations, connected to the vehicle through CHAdeMO DC plug and controlled by a decentralized algorithm developed by SUPSI-IDSIA and based on local measurement of the grid voltage.

In order to validate the data measured on the first two configurations a third configuration has been examined:

- Configuration 3: stationary buffer batteries controlled by a decentralized algorithm developed by SUPSI-IDSIA, based on local measurement of the grid voltage.

The project investigates whether intelligent charge management approaches can reduce the load in the distribution grids (i.e. minimize load and injection peaks) or even contribute to the reduction of grid load. The aim of this project is to build up the two solutions for daily use, to test them under typical user behavior and to evaluate them, using suitable batteries and corresponding charging and inverting infrastructure.

# Basis - Framework conditions

Solar energy is stochastically produced by a photovoltaic installation. Consequently, either this energy is consumed at the same time, or it has to be stored and used later, when required. This energy can be stored in pumped-storage power plants, batteries or converted to hydrogen. Thank to technical development and mass production, battery storage is becoming attractive and it is supposed to be even more attractive in the next years.

The batteries can be stationary, with a continuous iteration with the grid or in alternative, it is possible to use the batteries of an electric car as soon as it is connected to the mains.

The specificity of the project is to compare, install, operate and evaluate several architectures for stationary and bidirectional energy storage.

# Plan - System description

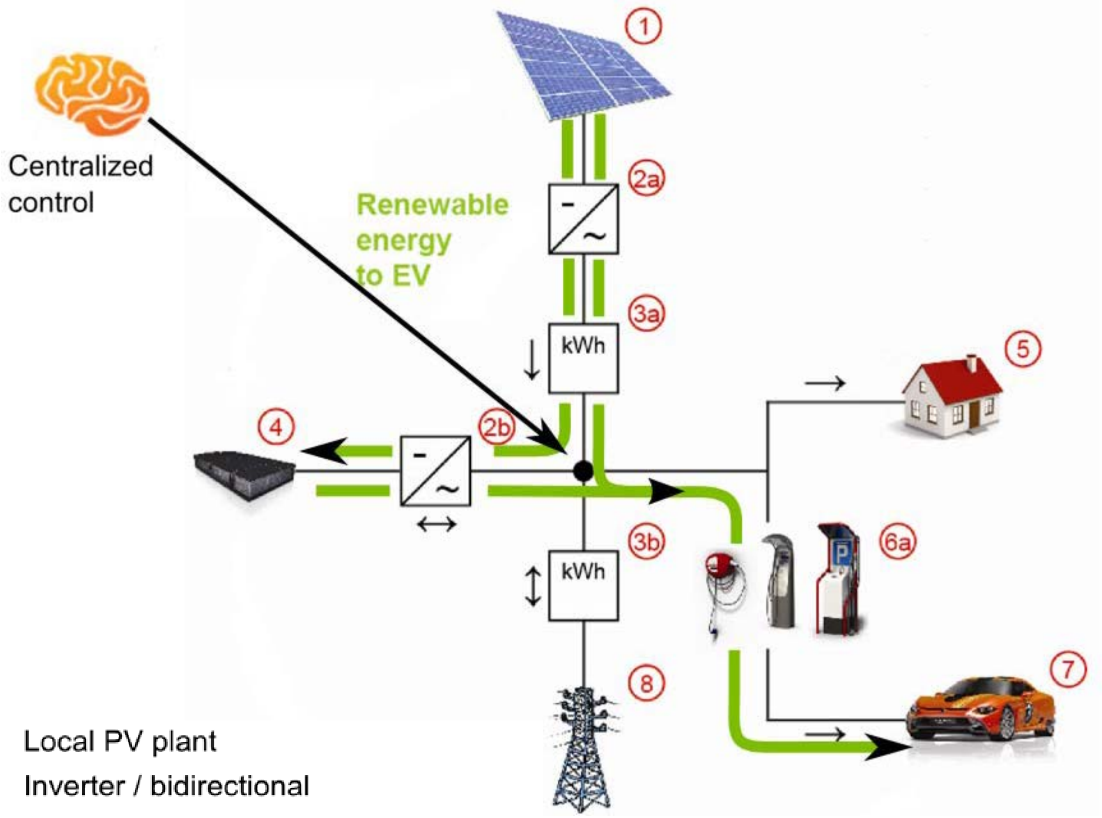
## Configuration 1 - Stationary battery, centralized control

Battery is meant to store the energy produced by the PV and when required, supply the household and recharge the electric vehicle (EV).

When the battery is full, the energy not absorbed by the household or by the EV is flowing into the grid.

Charge and discharge of the battery are managed by a controller, which is able to react either according to locally measured parameters (battery, PV, load, grid) or on commands received from a centralized control.

In fact, to help grid load regulation, battery can be asked to supply or absorb energy, independently from the local energy production/consumption.




| | |
|---|---|
| 1 | Local PV plant |
| 2a/2b | Inverter / bidirectional |
| 3a/3b | Production meter / bidirectional |
| 4 | Battery Stationary |
| 5 | Building electric loads (appliances etc.) |
| 6a | Charging Device |
| 7 | Electric Vehicle |
| 8 | Grid |

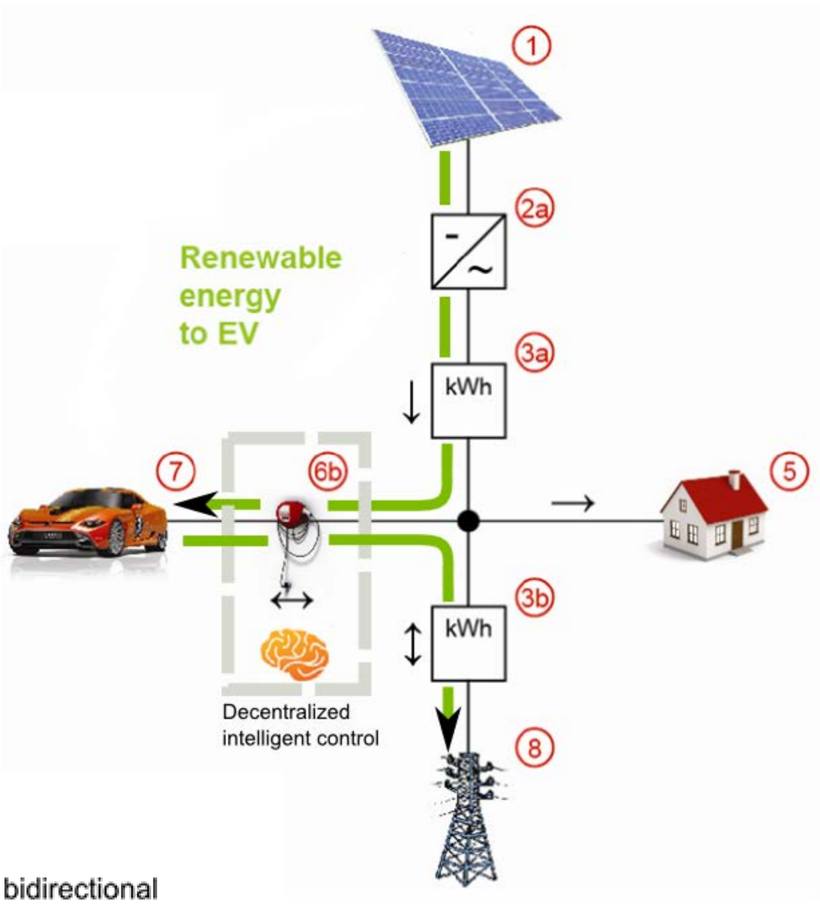
## Configuration 2 - Mobile battery (in EV), decentralized control

Part of the battery capacity of the electric vehicle (EV) is used to store the energy produced by the PV and when required, the EV can supply the household through a bidirectional charging station.

When the EV is fully charged, the energy not absorbed by the household is flowing into the grid.

Charge and discharge of the EV are managed by a controller, which reacts according to the parameters measured on the bidirectional charger. PV, load and grid measurements are not available. Therefore, when the battery is asked to be recharged, the energy could be either from the PV or from the grid. Similarly, when the battery is asked to be discharged, the energy could be either supplying the household or flowing into the grid.

In any case the algorithm does not allow the EV battery to be discharged below 50%, in order to keep a reasonable driving range.



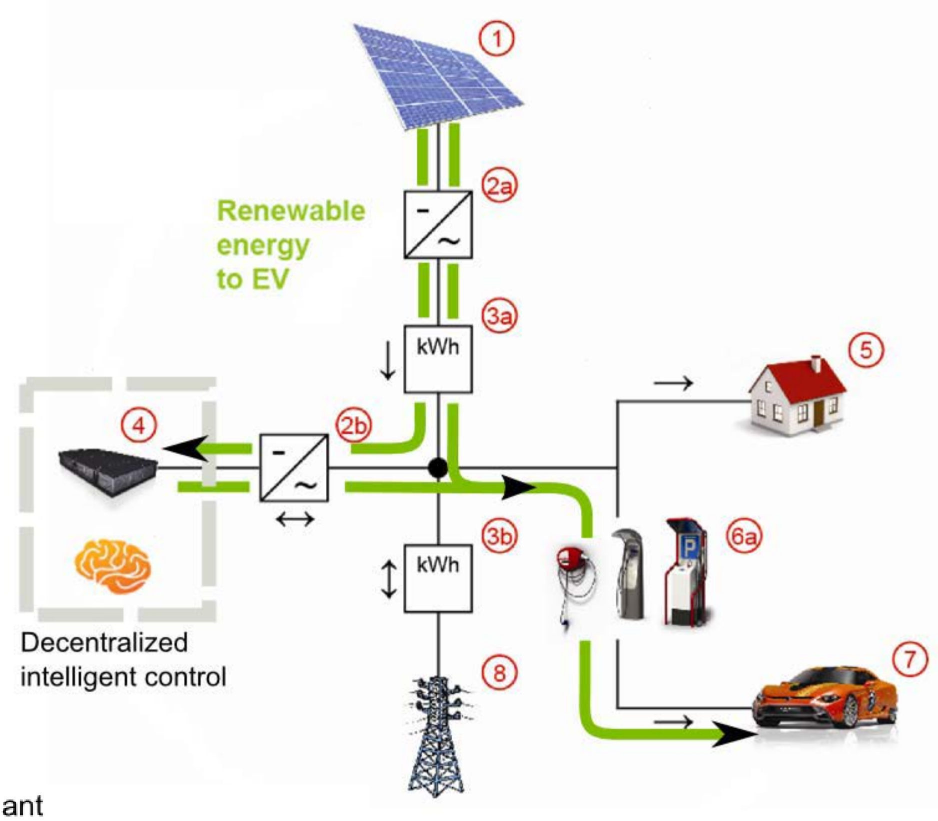

- (1) Local PV plant
- (2a) Inverter
- (3a)/(3b) Production meter / bidirectional
- (5) Building electric loads (appliances etc.)
- (6b) Charging Device "bidirectional"
- (7) Electric Vehicle
- (8) Grid

## Configuration 3 - Stationary battery, decentralized control

Similar to configuration 1, battery is meant to store the energy produced by the PV and when required, supply the household and recharge the electric vehicle (EV).

When the battery is full, the energy not absorbed by the household or by the EV is flowing into the grid.

Charge and discharge of the battery are managed by a controller, which reacts according to locally measured parameters only (battery, PV, load, grid). In principle the battery is always recharging from the PV, while the stored energy is normally supplying either the EV or the household.




| | |
|---|---|
| (1) | Local PV plant |
| (2a)/(2b) | Inverter / bidirectional |
| (3a)/(3b) | Production meter / bidirectional |
| (4) | Battery Stationary |
| (5) | Building electric loads (appliances etc.) |
| (6a) | Charging Device |
| (7) | Electric Vehicle |
| (8) | Grid |

# Procedure / method

## Configuration 1

### 1.1. Specifications

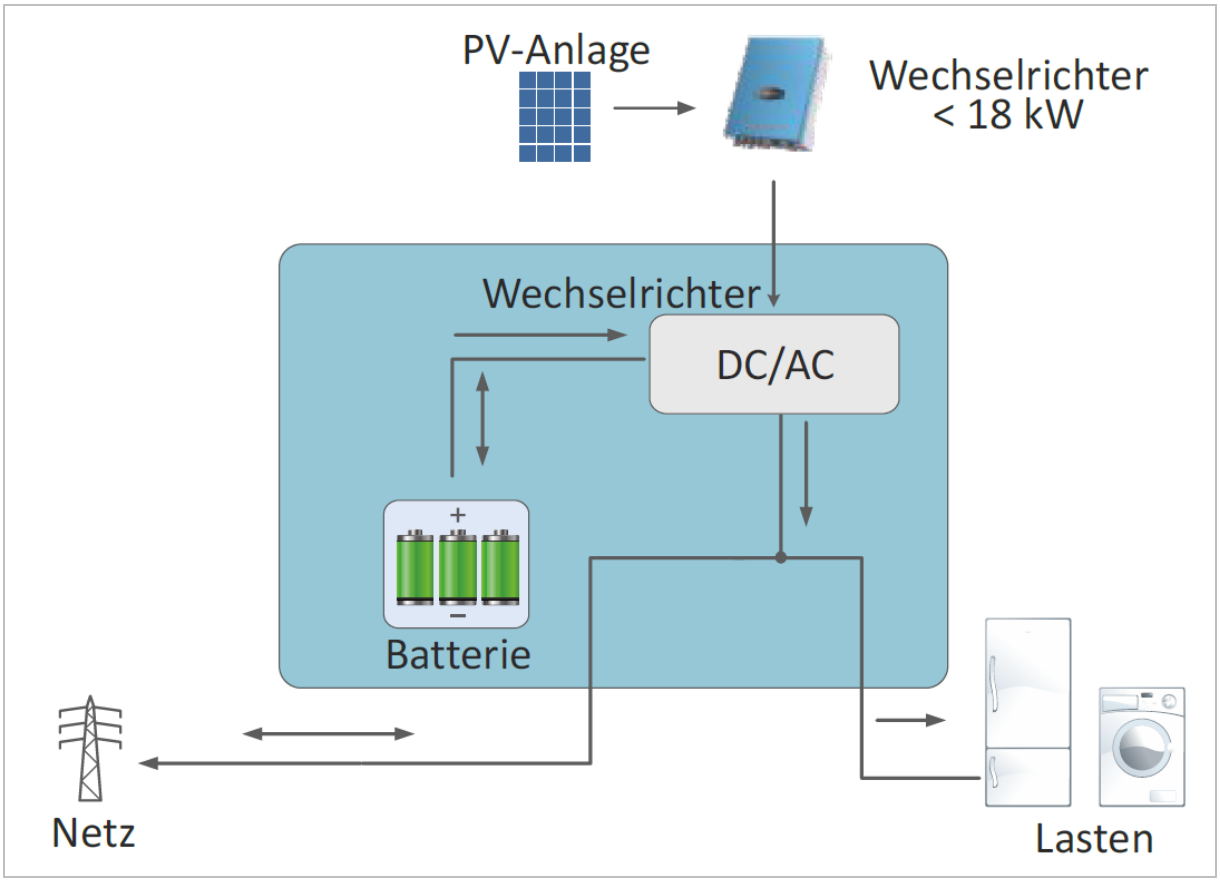
The stationary batteries type BYD DESS AC P09B10-C00 have been supplied by Ampard/ Divigrid, which is one of the project partners.

This model has been chosen because its battery capacity (10 kW) is similar to the EV battery capacity allocated in configuration 2 for buffering (40% of 24 kWh):

## Technische Parameter

| | | P09B10-C00 |
|---|---|---|
| Systemtyp | | AC |
| Max. Netzkopplungsstrom | | 3 x 30 A |
| Max. AC Generatorleistung | | 18 kW (Ladeleistung max. 9 kW) |
| Wechselrichter | Nennleistung | 3 x 3 kVA |
| | Nennspannung | 230 V / 400 V |
| | Frequenz | 47,5 - 51,5 Hz |
| | Max. Ausgangsstrom | 3 x 13,1 A |
| | Leistungsfaktor (cos phi) | 0,9 (übererregt) - 0,9 (untererregt) |
| | Wirkungsgrad | 93 % |
| | Umschaltzeit USV | < 200 ms |
| | THD | < 4 % (Strom im Netzbetrieb)<br>< 2 % (Spannung im Inselbetrieb) |
| | Zertifizierung | VDE-AR-N 4105 / IEC 62109 / EN 61000-6-3<br>EN 61000-6-2 / AS4777 / CEI 0-21 |
| Batterie | Nennspannung | 51,2 $V_{DC}$ |
| | Zelltyp | $LiFePO_4$ |
| | Zyklenanzahl | 6.000 (bis 80% Restkapazität) |
| | Batteriekapazität | 10 kWh |
| | Entladetiefe (DOD) | 85 % |
| | Batteriemanagement | Ja |
| | Aktives Balancing | Ja |
| Schnittstellen | | RS485 / Ethernet |
| IP Schutzart | | IP 20 |
| Temperaturbereich | | 0 - 45 °C |
| Luftfeuchtigkeit | | 10 - 90 % |
| Einsatzhöhe über NN | | < 2.000 m |
| Max. Lautstärke | | 65 dB |
| Abmessungen (B/T/H) | PCS | 750 x 608 x 1.270 mm |
| | Batterie | 581 x 608 x 1.270 mm |
| Gewicht | PCS | 190 kg |
| | Batterie | 206 kg |

Batteries have a separate input/output for PV, small loads (< 9 kW), large loads (< 40 kW) and grid:




Data are measured on each input/output. Batteries can be monitored through a dedicated web interface and data exported for further analysis and comparison with the other system configurations.

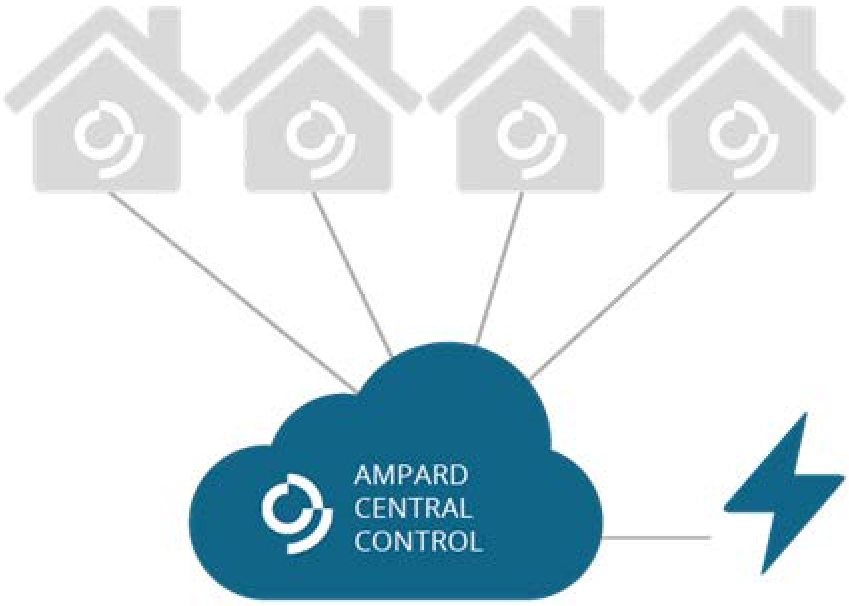
## 1.2. Primary regulation

Ampard offer to all its customers the possibility to sell primary regulation power to Swissgrid.

Primary regulation compensate an imbalance between generation and consumption within a few seconds through charging or discharging of the stationary batteries, leading to the stabilization of the frequency in the interconnected electricity grid.

This is applicable on configuration 1 devices only and, according to Ampard, the additional power peaks absorbed by the batteries, are not affecting the battery lifetime.

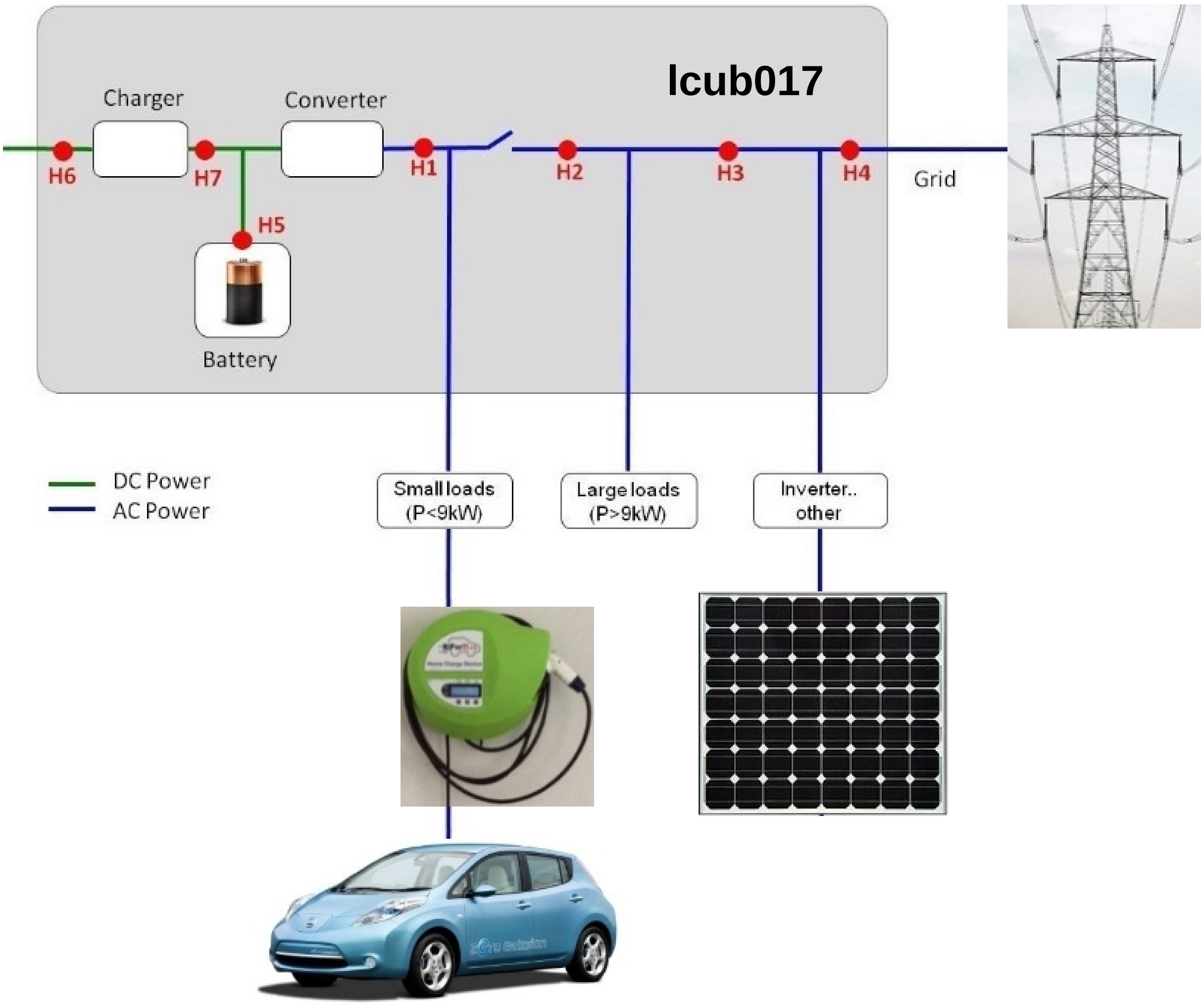
Ampard aggregates buffer batteries installed by its customers in several locations into virtual power plants. Such storage swarms can consequently sell primary regulation capacity to the grid operator.




This function is centrally managed by Ampard for all installed batteries participating to the primary regulation pool and it is independent from the load, PV or battery status, which has though to remain between the operating limits defined by the manufacturer.

## 1.3. Location 1

| | |
|---|---|
| **Address:** | **AET**<br>**Azienda Elettrica Ticinese**<br>**El Stradún 74**<br>**6513 Monte Carasso** |
| **Date of installation** | **20.05.2015** |
| **PV power:** | **16.4 kWp** |




**Description:**

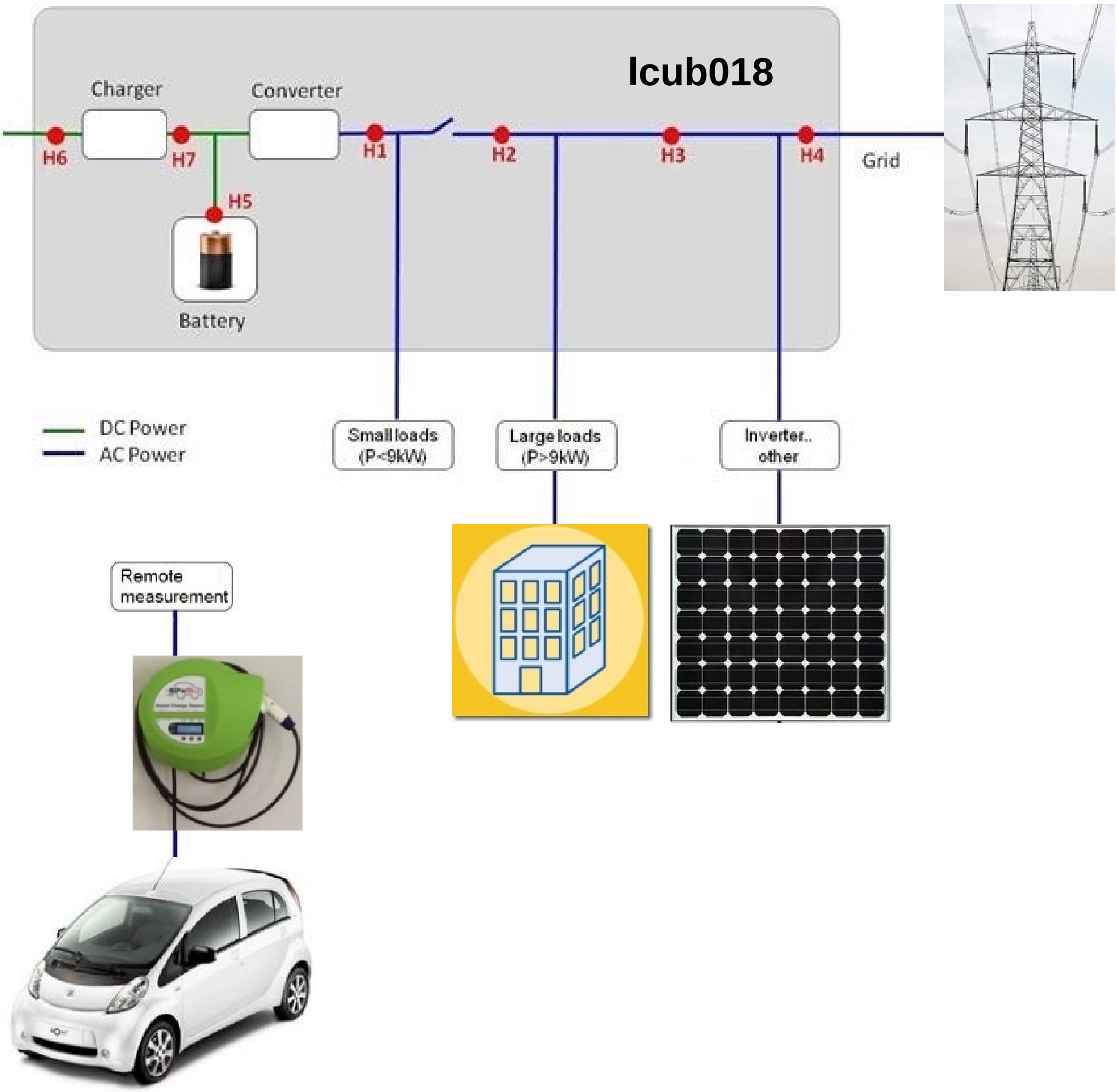
The buffer battery provides a DC input (H6) with a DC/DC converter, where it is possible to directly connect a PV. However, the 16.4 kWp PV is connected to the input “inverter/other”, because it has already its own DC/AC converter.

An EV with a 24 kWh battery is regularly recharged through a 3.7 kW AC charger, connected to the “small loads” output.

Buffer battery has also a connection to the grid, which can absorb energy in excess produced by the PV or supply the system in case of insufficient PV production.

## 1.4. Location 2

| | |
|---|---|
| **Address:** | **AIL**<br>**Aziende Industriali di Lugano**<br>**Via industria 2**<br>**6933 Muzzano** |
| **Date of installation** | **16.03.2015** |
| **PV power:** | **19.6 kWp** |




**Description:**

The buffer battery provides a DC input (H6) with a DC/DC converter, where it is possible to directly connect a PV. However, the 19.6 kWp PV is connected to the input “inverter/other”, because it has already its own DC/AC converter.

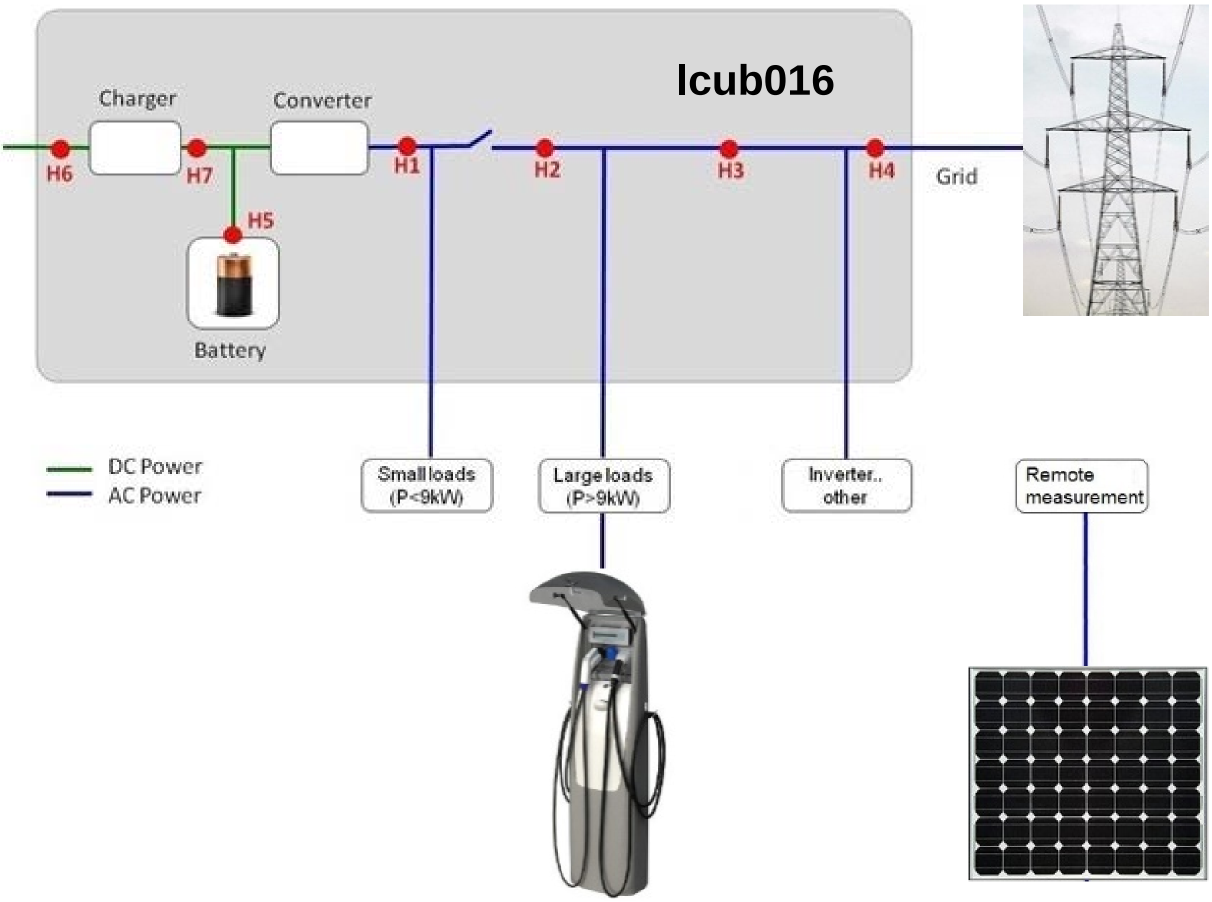
An EV with a 16 kWh battery is regularly recharged through a 3.7 kW AC charger, which couldn’t be directly connected to the battery output.

A dedicated meter has been installed on the AC charger in order to measure the energy feed into the EV, while the battery is supplying the whole building.

Buffer battery has also a connection to the grid, which can absorb energy in excess produced by the PV or supply the system in case of insufficient PV production.

## 1.5. Location 3

| | |
|---|---|
| **Address:** | **AMB**<br>**Aziende Municipalizzate Bellinzona**<br>**Vicolo Muggiasca 1 A**<br>**6500 Bellinzona** |
| **Date of installation** | **11.01.2016** |
| **PV power:** | **5 kWp** |




**Description:**

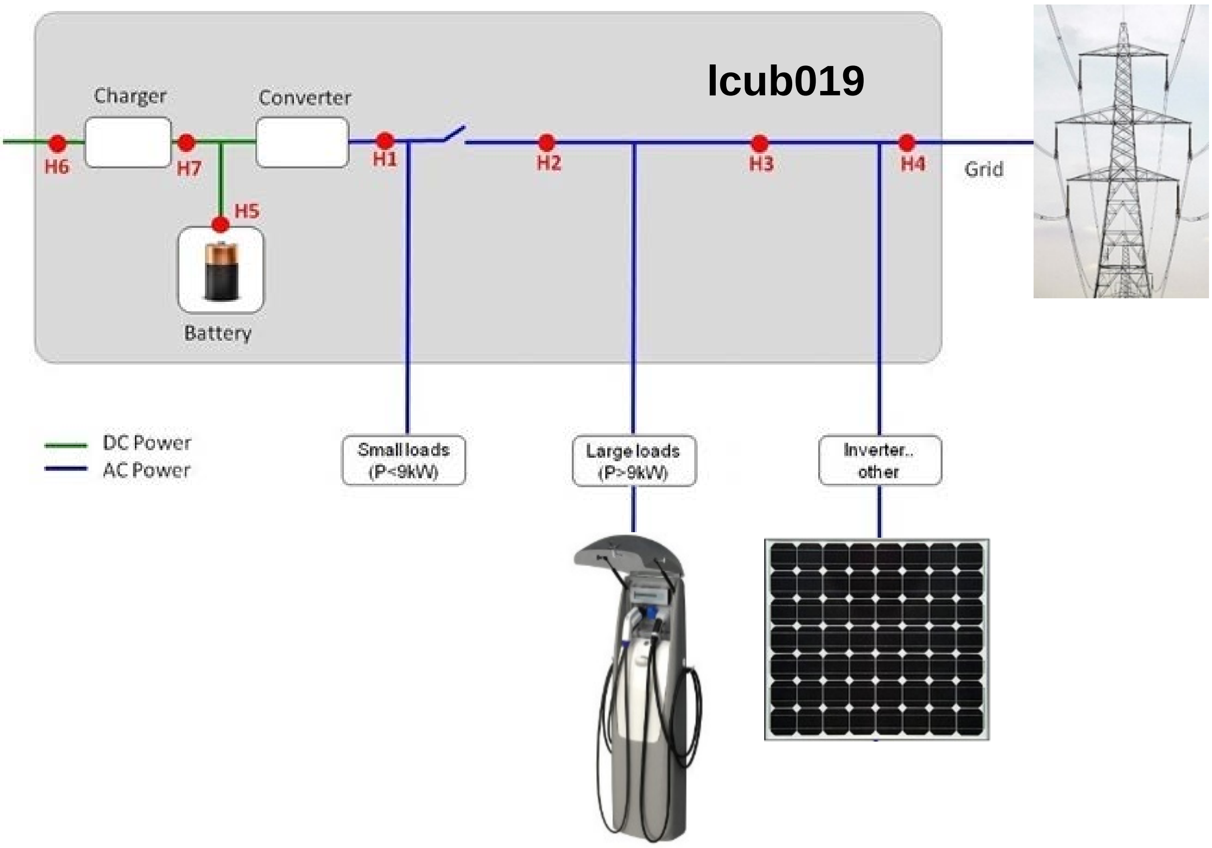
Close to the location where the buffer battery is installed there are several PV installations, but none of them could be directly connected to the battery input.

The assumption was that during the daylight, the energy on the grid is mainly supplied by the neighboring PV installations. Therefore, starting from a real charging profile, the battery was programmed to be recharged from the grid according to a virtual profile that corresponds to a 5 kWp PV installation.

The battery output feeds a public EV charging station, which can recharge simultaneously two vehicles with 3.7 kW (type 1 plug) and 11 kW (type 2 plug) for a total maximum power of about 15 kW.

## 1.6. Location 4

| **Address:** | **AIM**<br>**Aziende Industriali Mendrisio**<br>**c/o Centro CPI**<br>**Via Franco Zorzi**<br>**6850 Mendrisio** |
|---|---|
| **Date of installation** | **17.05.2016** |
| **PV power:** | **20 kWp** |




## Description:

The buffer battery provides a DC input (H6) with a DC/DC converter, where it is possible to directly connect a PV. However, the 20 kWp PV is connected to the input “inverter/other”, because it has already its own DC/AC converter.

The battery output, feeds a private EV charging station, which can recharge simultaneously two vehicles with 3.7 kW (type 1 plug) and 11 kW (type 2 plug) for a total maximum power of about 15 kW.

Buffer battery has also a connection to the grid, which can absorb energy in excess produced by the PV or supply the system in case of insufficient PV production.

# Configuration 2

## 1.1. Preamble

Since 2014, the second generation of Nissan Leaf, together with Mitsubishi I-MiEV and Outlander PHEV, offer “Vehicle2Grid Ready” CHAdeMO interface. Means that if the EV is connected to an appropriate device it is able to deliver the energy stored in its batteries.

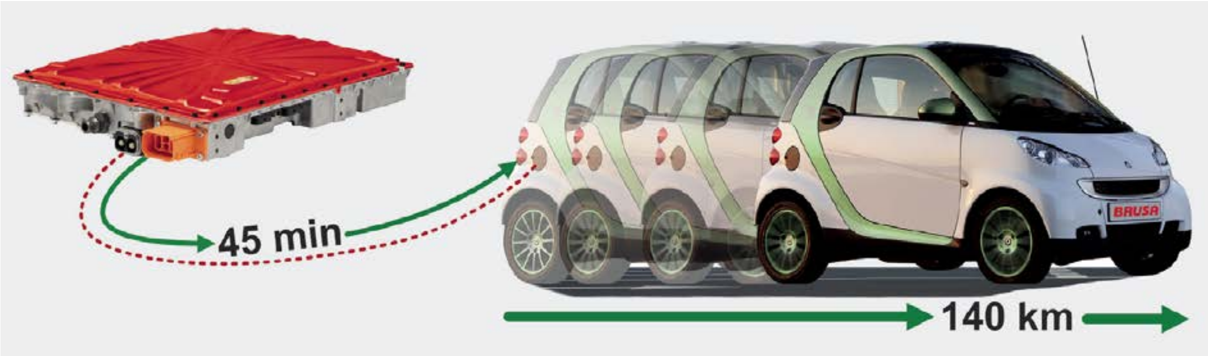
According to the manufacturers, bidirectionality does not affect vehicle warranty.

When the project was launched, only a few bidirectional charging stations were available on the marked. In addition, all devices had a single-phased 32 A connection, which is not suitable for the European grids, where, for power higher than 3.7 kW a three-phased connection is more adequate.

## 1.2. Development

After a deep market analysis, it figured out that none of the few commercial devices were able to meet all system requirements. In addition, among the several power electronic manufacturers it was even not possible to find a commercial bidirectional three phased 22 kW inverter.

Together with the project partners, it was consequently decided to build four prototypes, specifically for the project. The key component of the new development is a NLG664-U0-01B-B from Brusa, which was sold as fast charging option (22 kW) for the smart ED.




However, additional development work was required to Brusa, in order to implement the vehicle to grid capability, not included in the commercial version.

The 4 bidirectional inverters delivered by Brusa, were B-samples prototypes, which had to be integrated into an EV charging station.

In addition to vehicle and user interface, the charging station has to be controlled by an algorithm developed by SUPSI, able to recognize when the EV needs to be recharged or when the energy stored in its batteries can be used to supply the grid or other loads of the same household.

The development of the EV charging station, hosting the Brusa inverter and the SUPSI algorithm, was assigned to EVTEC.

As manufacturer of EV charging stations, EVTEC had already the know-how and some products in its catalogue that could be adapted for the assigned work. In particular, to allow the operators to select the most suitable solution, EVTEC has proposed to integrated the NLG664 prototypes in a modified move&charge case for mobile installations, or in a modified coffee&charge case for the installation on a standard OPI 2020 basement.

Both configurations (mobile and OPI2020) are supplied with a 22 kW, 400 VAC / 32 A grid connection.

In total, two mobile (AIM and AIL) and two OPI2020 (AET and AMB) bidirectional charging stations have been delivered by EVTEC.

Following features have required EVTEC a specific development and integration work:

- NLG664 is liquid-cooled, while the standard version of move&charge and coffee&charge devices are air cooled. A liquid/air heat exchanger and all the necessary circuitry have consequently been developed.


- The room for all components necessary for the cooling system has required some modifications to the original move&charge / coffee&charge case, in particular the rear panel, where the NLG664 is installed.
- Implementation of the interface between controller and NLG664.
  The NLG664 charger is built to be interfaced with a vehicle (Smart ED). The controller of the bidirectional charging station has to reproduce exactly the same commands and to react on the parameter given by the NLG664. In particular the CAN BUS interface (HW and SW), commonly used by the automotive industry was developed.
- Implementation of the bidirectional protocol on the CHAdeMO interface.
  On the controller of a standard charging station the part of the CHAdeMO protocol allowing to discharge the EV batteries is not implemented but it has to be on the four charging stations built by EVTEC for the project purposes.
- Integration of a PCI Express, used by computer storage interfaces, where managing algorithm and measured data are stored.
- Integration of a GSM modem, to allow remote diagnostic and transfer of the measured data to be analyzed for the project purposes.
- Implementation of a HMI interface, showing device status (including errors) and allowing the user to select the charging options, as for instance the possibility to bypass the bidirectional algorithm.
- Implementation of the circuitry for the measurement of the mains voltage and all the parameters required by the control algorithm.

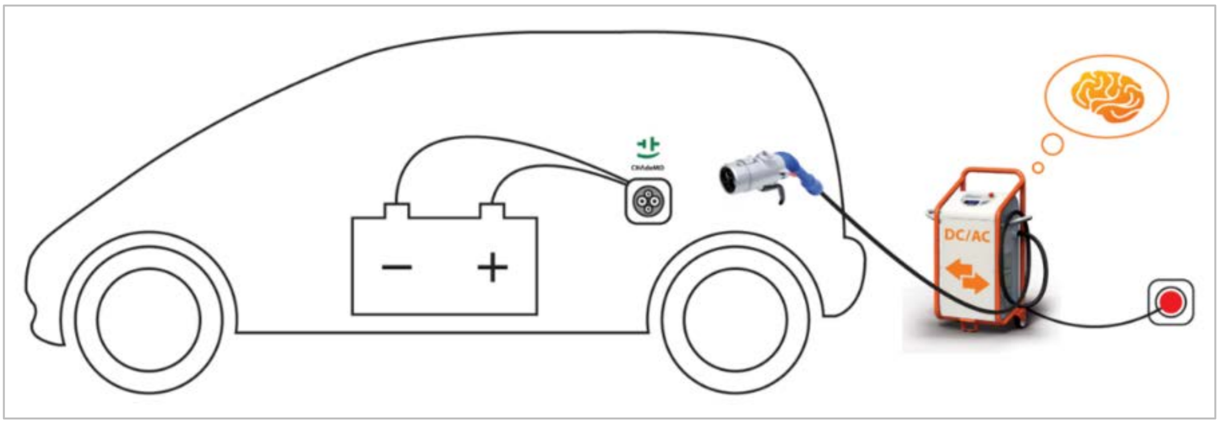
## 1.3. Specifications

In order to avoid overheating and consequently damages to the charger, the maximum output power has been limited to 15 kW.

| | |
|---|---|
| Reverse Flow | Yes (Energy flow from grid to EV and from EV to grid) |
| Output power [kW] | 15 kW for prototype |
| DC Voltage Range | 200 – 410Vdc for Charge<br>314 – 410Vdc for Discharge |
| Connector type | CHAdeMO (Fujikura Plug) |
| Weight | 45kg prototype |
| Charging cable length/diameter | 6m / 35sqmm (Fujikura Plug) |
| Homologation/ Certification | Not yet (Unidirectional chargers certified by CHAdeMO and CE) |
| Communication functionality | Physical layer: Ethernet, GSM<br>High layer communication: OCPP 1.5 or customised XML |

The device has a bidirectional CHAdeMO interface for the vehicle and a three-phased grid connection. Vehicle/grid data are measured and can be exported for further analysis and comparison with the other system configurations.

However, no direct PV input is provided. By a local measurement of the grid voltage, the algorithm is supposed to recognize the situation where on the grid is energy produced by a neighboring PV installation and react accordingly.



## 1.4. Vehicles

Nissan Leaf, Mitsubishi I-MiEV and Outlander PHEV, were the only candidates with a CHAdeMO interface and “Vehicle2Grid Ready” capability.

Some test have been performed on a Mitsubishi Outlander PHEV, but similarly to the Mitsubishi I-MiEV, the battery voltage is not fully compatible with the voltage range of the bidirectional NLG6 charger from Brusa, which has been integrated by EVTEC in the bidirectional charging station:

| | **Nominal battery voltage** |
|---|---|
| **Mitsubishi I-MiEV** | 325.6 V |
| **Mitsubishi Outlander PHEV** | 300 V |
| **Nissan Leaf** | 360 V |

On the new Euro Leaf, the CHAdeMO interface is already bidirectional, although it is not on the first generation.

With the participation of Nissan Motor Manufacturing (UK) Ltd, it was possible to update the SW of four vehicles that have been used within the project.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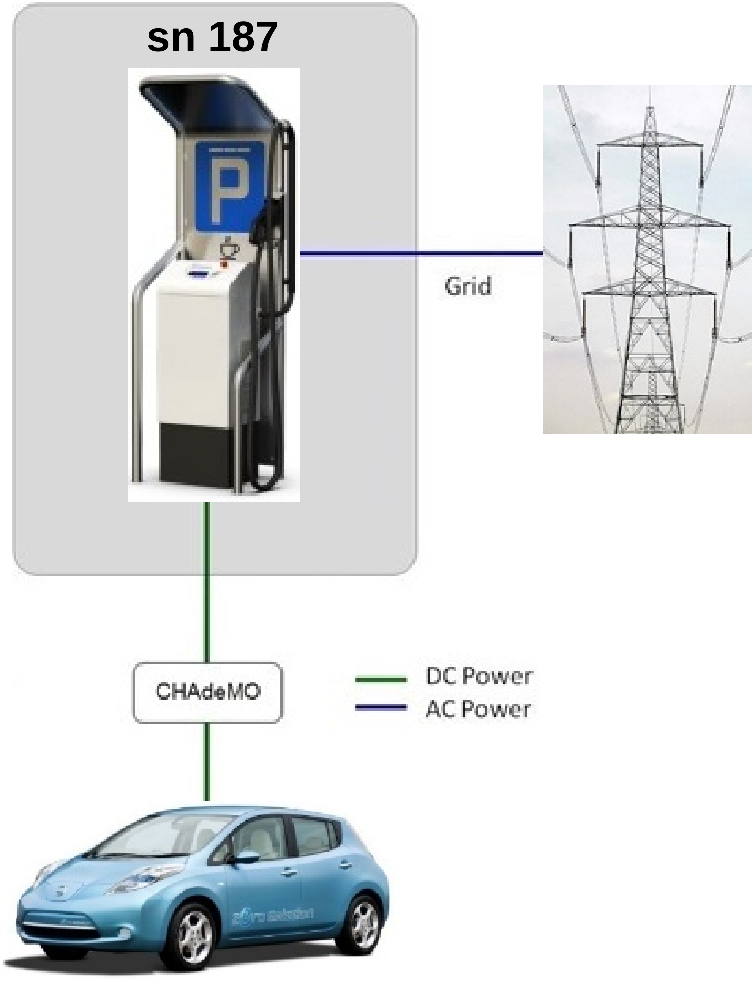
INFINITI.

## 1.5. Location 1

| **Address:** | **AET**<br>**Azienda Elettrica Ticinese**<br>**El Stradún 74**<br>**6513 Monte Carasso** |
|---|---|
| **Date of installation** | **04.02.2015** |




**Description:**

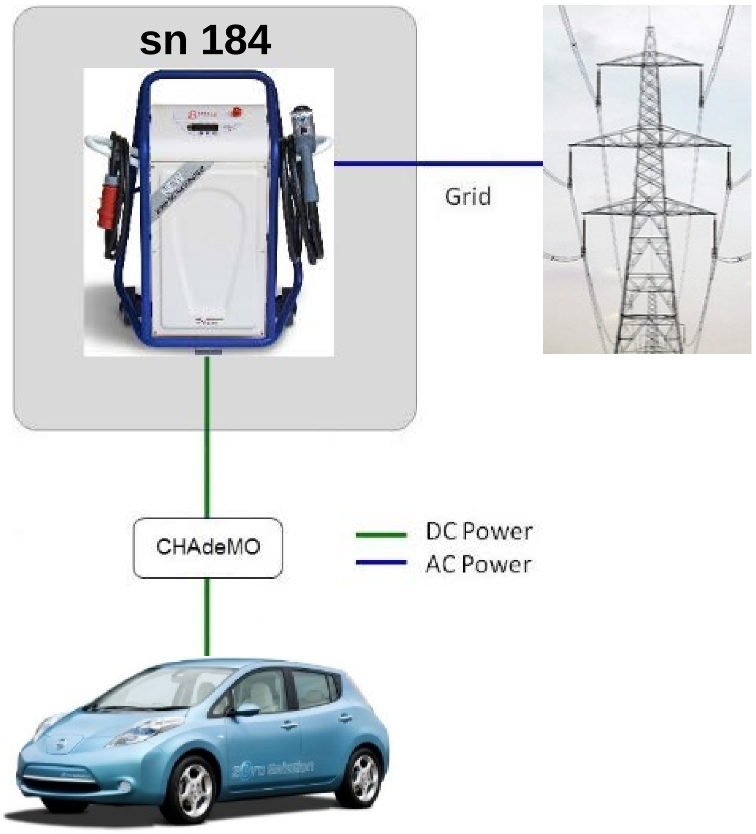
The device is installed on a standard OPI 2020 basement and provides a bidirectional CHAdeMO interface for the vehicle and a 15 kW three-phased grid connection.

The vehicle is a first generation Nissan Leaf with a 24 kWh battery.

Close to the charging station is a 16.4 kWp PV installation.

## 1.6. Location 2

| | |
|---|---|
| **Address:** | **AIL**<br>**Aziende Industriali di Lugano**<br>**Via industria 2**<br>**6933 Muzzano** |
| **Date of installation** | **23.04.2015** |




**Description:**

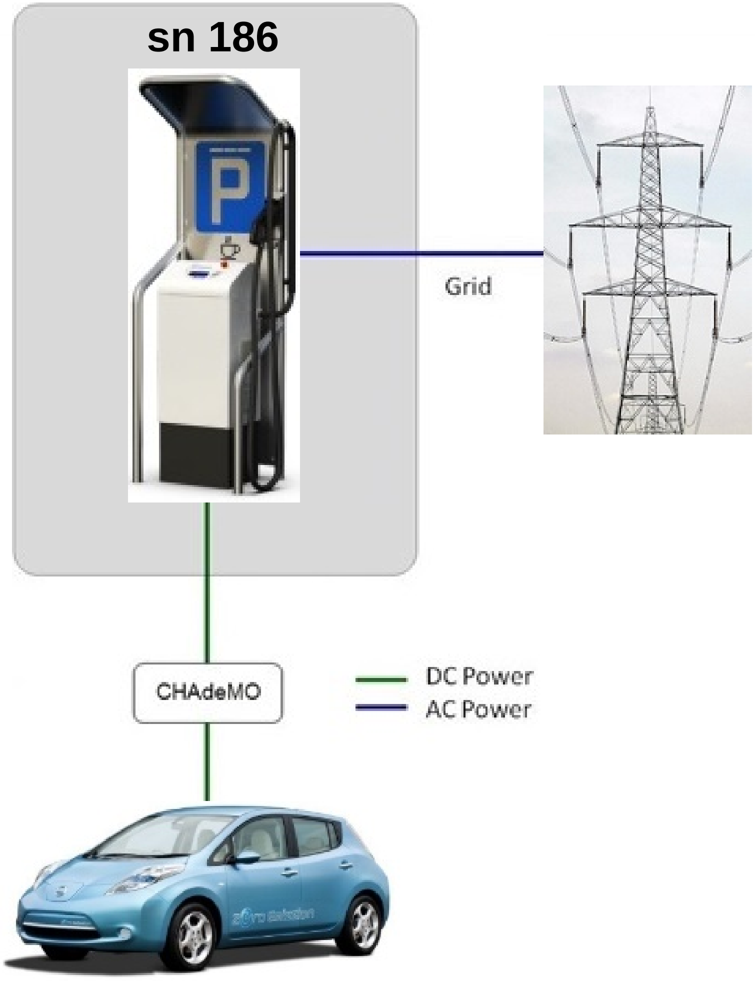
The device is built in a mobile frame and provides a bidirectional CHAdeMO interface for the vehicle and a 15 kW three-phased grid connection.

The vehicle is a second generation Nissan Leaf with a 24 kWh battery.

Close to the charging station is a 19.4 kWp PV installation.

## 1.7. Location 3

| | |
|---|---|
| **Address:** | **AMB**<br>**Aziende Municipalizzate Bellinzona**<br>**Via Seghezzone 1**<br>**6512 Giubiasco** |
| **Date of installation** | **19.04.2016** |




**Description:**

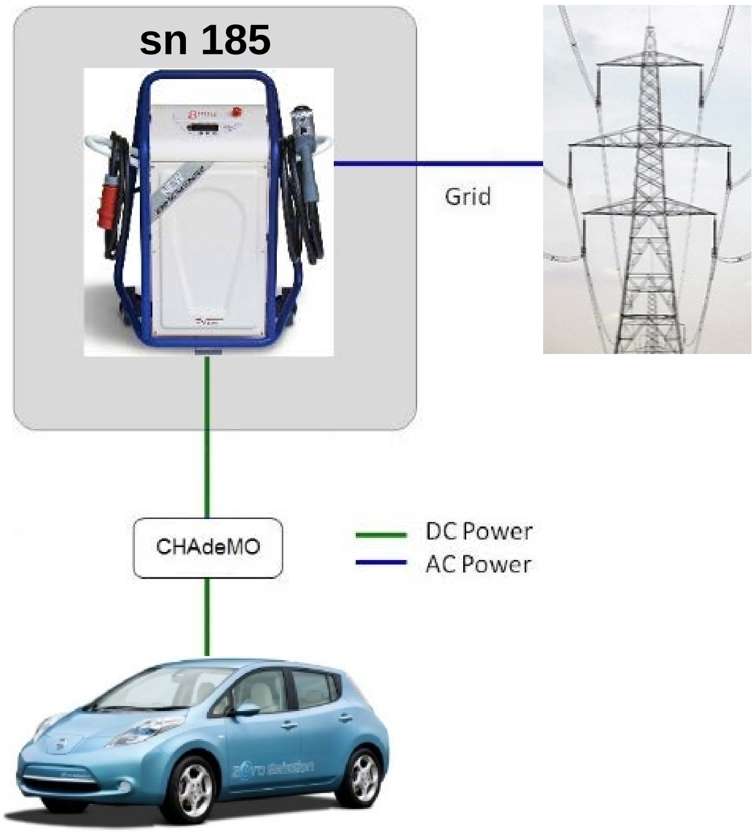
The device is installed on a standard OPI 2020 basement and provides a bidirectional CHAdeMO interface for the vehicle and a 15 kW three-phased grid connection.

The vehicle is a second generation Nissan Leaf with a 24 kWh battery.

Close to the charging station is a 24.1 kWp PV installation.

## 1.8. Location 4

| | |
|---|---|
| **Address:** | AZIENDE INDUSTRIALI MENDRISIO **AIM**<br>**Aziende Industriali Mendrisio**<br>**c/o Autosilo comunale**<br>**Via Franco Zorzi**<br>**6850 Mendrisio** |
| **Date of installation** | **02.06.2016** |




**Description:**

The device is built in a mobile frame and provides a bidirectional CHAdeMO interface for the vehicle and a 15 kW three-phased grid connection.

The vehicle is a second generation Nissan Leaf with a 24 kWh battery.

Close to the charging station is a 20 kWp PV installation.

# Configuration 3

## 1.1. Specifications

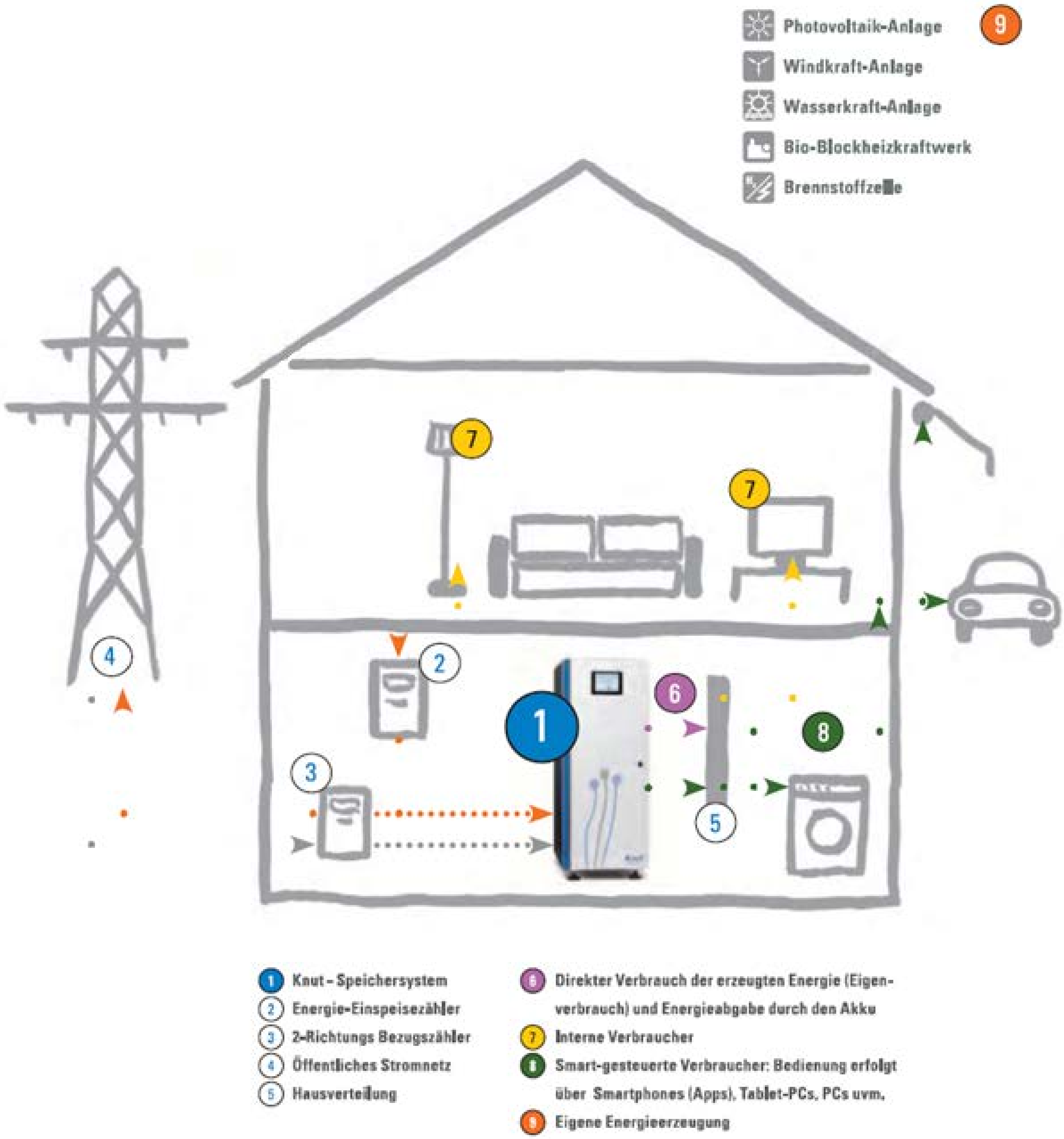
Configuration 3 is not an installation of the project, but data supplied by SUPSI are used to validate the results of the analysis on configuration 1 and configuration 2.

The stationary batteries type **Knut 3.3 11 (kWh)** were supplied by Knubix.

This model has a battery capacity (11 kW) similar to configuration 1 (10 kWh) and to the EV battery capacity allocated in configuration 2 for buffering (40% of 24 kWh):

| Knut 3.3 (3 x 3000) | |
|---|---|
| | 11 kWh |
| **Allgemeines** | |
| AC/DC gekoppelt | AC gekoppelt |
| Art der Phasenversorgung | Drehstrom 400 V |
| Netzformen - Netzseite | TN-C / TN-C-S / TN-S |
| Netzformen - Verbraucherseite | TN-S-System |
| Notstromoption | Ja - Serienausstattung |
| USV-Typ | Dauerwandler- bzw. Online-Qualitäten |
| Volleinspeiser / Nulleinspeiser | Nein / Ja |
| Energiemessung | digitale 3-Phasen Drehstromzähler (1 x intern / 1 x extern) RS 485 |
| Bedienung | Über 8" Touchscreen am System und durch Routeranbindung an jedem Multimediasystem |
| Visualisierung | Betriebszustände, Messdaten, etc. |
| Datenbevorratung | lokal / Portal |
| Routeranbindung | Powerline Communication (PLC) im Hausnetz / Ethernet am System |
| Steuerung Energiemanagement | Vollautomatisch / manuelle Serviceprogramme |
| Weitere Funktionen / Ausstattung | modular erweiterbar / zukunftssicher |
| Daten- und Hardwareschnittstellen, Protokolle | Ethernet RJ 45, TCP/IP, CAN , RS485, ModBus, USB. Protokolle zwischen Netzleitsystemen und Unterstationen: IEC 61850, GOOSE, etc.. |
| Umgebungstemperaturen | zwischen +5 °C und + 25 °C |
| Abmessungen (H x B x T) | 1390 x 560 x 600 mm |
| Gewicht | 151 kg zuzüglich Batterie-Rack |
| **Leistungselektronik allgemein** | **AC** |
| Wechselstrom-Eingang - ACin (X1) | - Eingangsspannung: 400 VAC<br>- Eingangsspannungsbereich L1, L2, L3: 187 – 265 VAC<br>- Eingangsfrequenz: 45 -65 Hz |
| Wechselstrom-Ausgang - ACout (X2) (Unterbrechungsfrei) | - Ausgangsspannung: 400 VAC<br>- Ausgangsspannung L1, L2, L3: 230 VAC +/- 2% (400 VAC)<br>- Ausgangsstrom L1, L2, L3: max. 50 A<br>- Frequenz: 50 Hz +/- 0,1% |
| Durchschaltbarer Transferstrom | max. ∑ 150 A; L1, L2, L3 je 50 A |
| **Batteriewechselrichter** | **AC** |
| Eingangs-Spannungsbereich (V DC) | 38 - 66 |
| Ausgang - AC out (X2) | - Ausgangsspannung: 400 VAC<br>- Ausgangsspannung L1, L2, L3: 230 VAC +/- 2%<br>- Frequenz: 50 Hz +/- 0,1% |
| Dauerleistung bei 25 °C | 9.000 VA |
| Dauerleistung bei 25 °C | 3 x 2.500 W (3 x 3000 VA) |
| **Batterieladegerät** | **AC** |
| AC-Input | Eingangsspannungsbereich: 187 – 265 VAC |
| Möglicher Ladestrom Netzbatterie | 0 – 105 A |
| **Batterie-Daten** | **DC** |
| Anzahl | 2 |
| Formfaktor / Gewicht | 19" Rack 6 HE / 58 kg |
| Datenkommunikation | CAN |
| Batteriemanagementsystem | Einzelzellenüberwachung |
| Batterietechnologie | Lithium-Eisen-Mangan-Phosphat |
| Energie | 11 kWh |
| Entladetiefe (DoD) | 90 % |
| Nutzbare Energie | 8,8 kWh |
| Maximale Ladeleistung | 3.200 W |
| Anzahl Vollzyklen | 5.000 |
| Lebensdauerzyklen | 20 Jahre |
| Absicherung | DC-Sicherung |
| Zeitwertgarantie | 7 Jahre |

Batteries have a separate input/output for PV, loads and grid:



## 1.2. Location 1

| | |
|---|---|
| **Address:** | **EBM**<br>**Weidenstrasse 27**<br>**4142 Münchenstein** |
| **PV power:** | **8 kWp** |
| **EV:** | **Peugeot iOn** |

# Results

## Methodology

All values calculated in the following chapters are based, for configuration 1 and configuration 2, on data measured from February 2017 to August 2017 and integrated over 1 year.

Data measured on configuration 1 devices are supplied by Ampard, whereas SUPSI-IDSIA has direct access to the data measured on configuration 2 bidirectional chargers.

For configuration 3, only values measured by SUPSI-IDSIA in April 2016 are available and could be integrated over 1 year.

## Coverage of renewable energy

In general we could assume that if an EV is recharged during the day, the coverage of renewable energy would be very high even without a buffer battery. However, the vehicles monitored within the project were company cars, which are in general operated during the day and recharged at night.

Storage capacity of configuration 1 (10 kWh) and configuration 3 (8.8 kWh), is though insufficient to store all the energy for a complete EV recharge (16 to 24 kWh), but in general during daily operation, the whole driving range is rarely used.

In configuration 2, if the vehicle is operated during the day and recharged at night, it will theoretically never have the possibility to recharge (and store) the locally produced renewable energy.

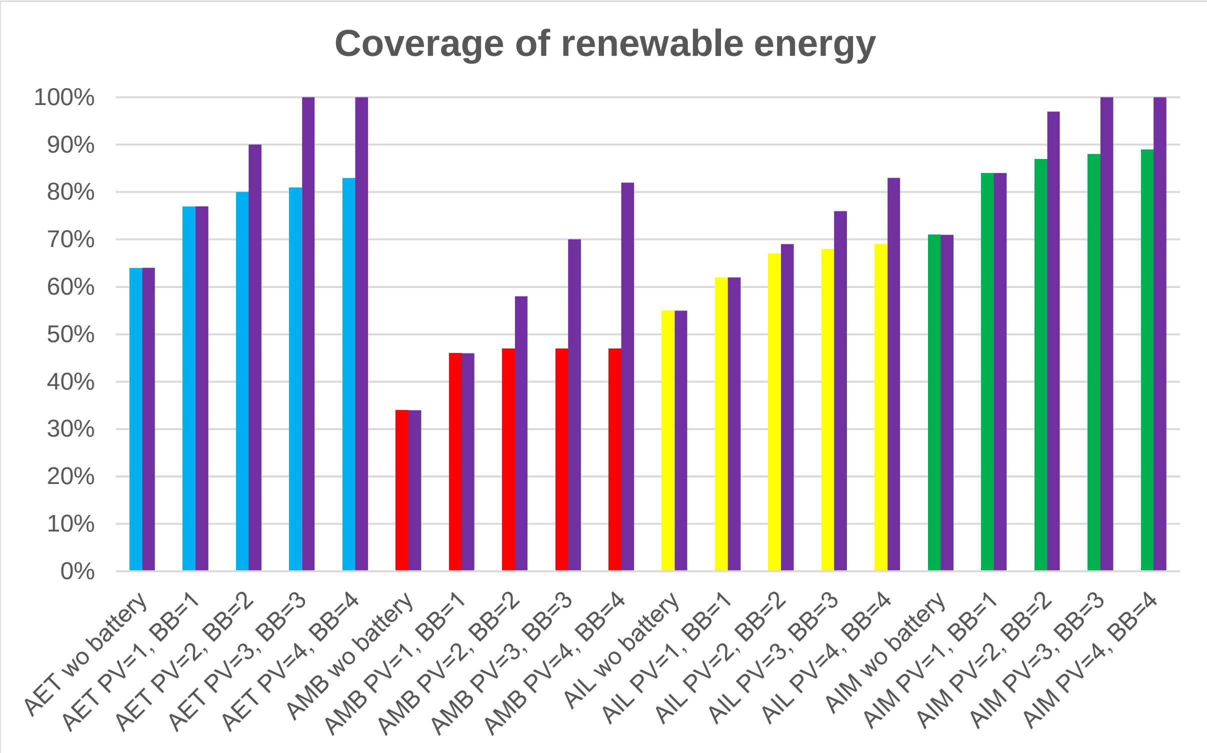
For each system configuration, the part of renewable energy over the total energy recharged into the EV battery has been calculated. The assumption is that all buffered energy is from renewable source.

**Configuration 1:** **((E_PVtoEV + E_BBtoEV) / E_EV) * 100 [%]**

E_EV = Energy recharged into EV [kWh]

E_PVtoEV = Energy produced by PV and feed to EV [kWh]

E_BBtoEV = Buffered energy feed to EV [kWh]




In order to evaluate the impact of a stationary battery, for all locations the “coverage of renewable energy” without buffering capability, has been calculated and reported in the above diagram as “wo battery”. This value corresponds to the fraction between energy recharged into EV during daylight (with PV production) and the total recharged energy.

In addition, in this configuration energy from PV is measured. If we assume that on the grid we may have other PV installations, we can consider that under some conditions, also the energy loaded from the grid has been generated by a PV.

Therefore we have introduced the parameter “PV”, which can vary from 1 to 4, where “PV” simulates the number of PV installations with similar power generation (including the measured one) connected to the grid in the same location.

It is interesting to notice that “coverage of renewable energy” does not increase linearly with the “PV” parameter.

In fact, with PV=∞, the “coverage of renewable energy” would correspond to the fraction of time the EV is charged during the day or with the energy supplied by the battery. This gives an idea of the potential benefits of a larger PV installation, which on the four locations that have been analyzed for configuration 1, is marginal: with a double sized PV installation, the part of renewable energy would be increased from 1 to 5%.

To analyze the effect of the storage capacity, the parameter BB has been introduced; BB can vary from 1 to 4 and shows the size of the battery:

- BB = 1 → 10 kWh (corresponding to the capacity of the battery that has been tested);
- BB = 2 → 20 kWh;
- BB = 3 → 30 kWh;
- BB = 4 → 40 kWh.

The value of the “coverage of renewable energy” calculated with the different battery capacities has been reported in violet in the above diagram.

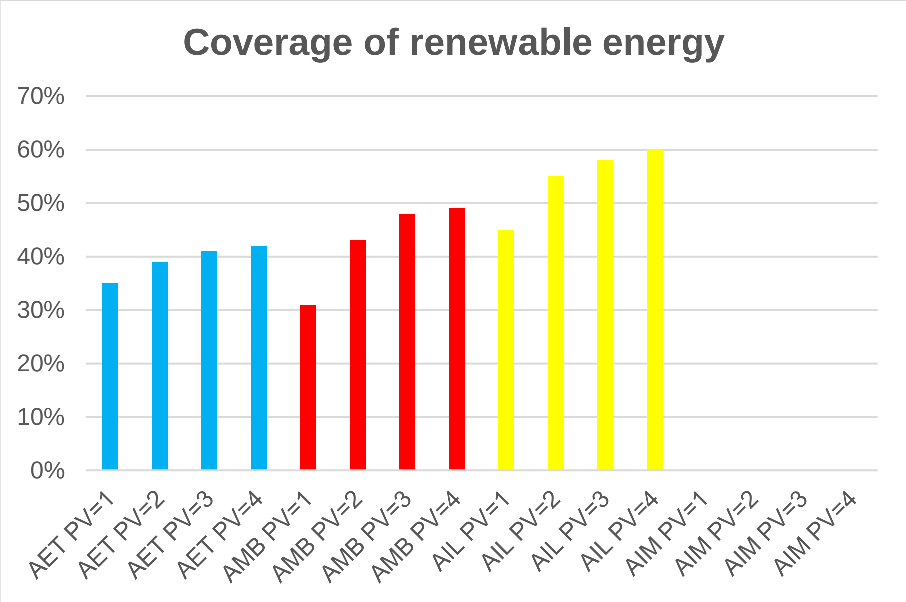
The stationary batteries have improved “coverage of renewable energy” from 7 to 13%, and observing the data of the four installation, we can state that in particular for AMB and AIL applications, a larger storage capacity would further increase the part of renewable energy.

The different impact of buffer batteries on “coverage of renewable energy”, noticeable on the four monitored locations, is in principle due to the various load profiles. In fact except AMB, where the (simulated) PV power is 5 kWp, all other installations are connected to a PV installation with a power range from 16.4 to 20 kWp.

**Configuration 2:** **(E_PVtoEV / E_EV) * 100 [%]**

E_EV = Energy charged into EV [kWh]

E_PVtoEV = Energy produced by PV and feed to EV [kWh]




Devices used for configuration 2 are located close to buffer batteries of configuration 1, where energy from PV is measured. Therefore it is considered that energy produced by the PV is flowing into the EV, when connected.

If we assume that on the grid we may have other PV installations, we can consider that under some conditions, also the energy loaded from the grid has been generated by a PV.

Therefore we have introduced the parameter "PV", which can vary from 1 to 4, where "PV" simulates the number of PV installations with similar power generation (including the measured one) connected to the grid in the same location.

It is interesting to notice that "coverage of renewable energy" does not increase linearly with the "PV" parameter.

In fact, with PV=∞, the "coverage of renewable energy" would correspond to the fraction of time the EV is charged during the day. However, this gives an idea of the potential benefits of a larger PV installation.

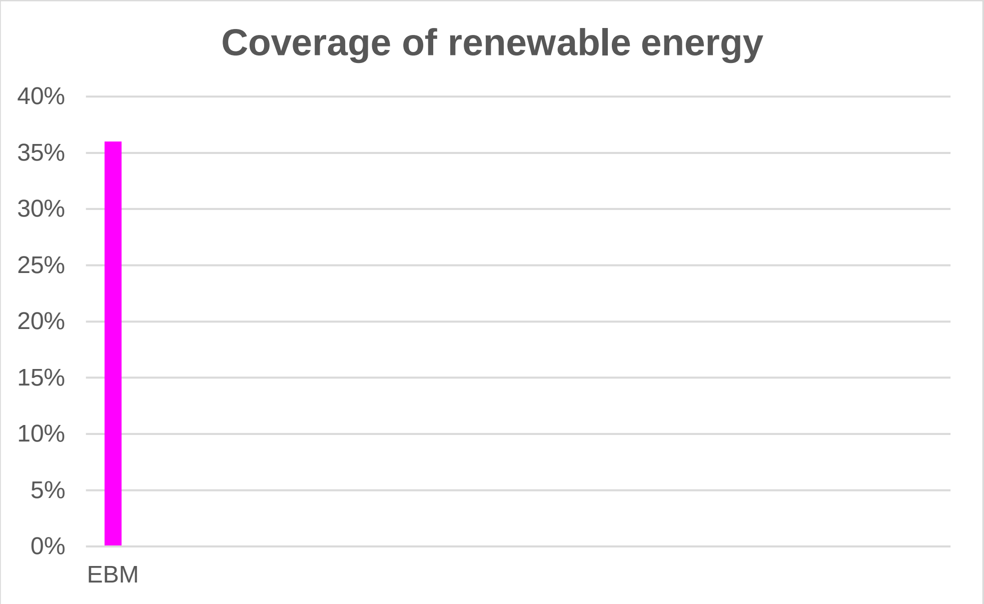
Compared to configuration 1, the lower "coverage of renewable energy", can be explained by the fact that EV can recharge (and store) the locally produced renewable energy, only if it is connected to the bidirectional charging station during PV production. This is of course a limitation in particular when the vehicles are operated during the day and recharged at night, but it is exactly one of the limits of this configuration that we were aiming to monitor along the project.

**Configuration 3:** **((E_PVtoEV + E_BBtoEV) / E_EV) * 100 [%]**

E_EV = Energy charged into EV [kWh]

E_PVtoEV = Energy produced by PV and feed to EV [kWh]

E_BBtoEV = Buffered energy feed to EV [kWh]




Configuration 3 is not an installation of the project, but data supplied by SUPSI are used to validate the results of the analysis on configuration 1.

In particular “coverage of renewable energy” of the four monitored configuration 1 installations, is similar or higher.

## km/day driven with solar energy

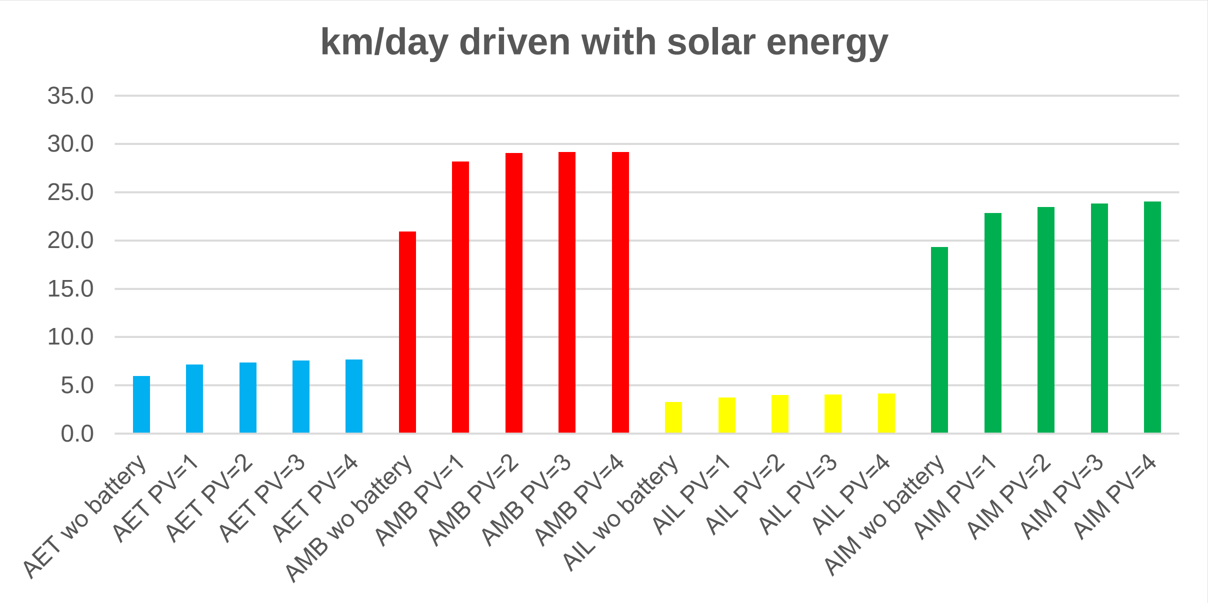
According to “coverage of renewable energy”, for each system configuration, the “km/day driven with solar energy” have been calculated. The assumption is that all buffered energy is from renewable source.

**Configuration 1:** **E_EV / E_EV_100km / N_Days**

E_EV = Energy charged into EV [kWh]

E_EV_100km = Average EV consumption = 20 kWh/100 km

N_Days = Number of days of the year = 250 for business operation (AET / AIL / AIM)
365 for public operation (AMB / EBM)




For AET, AIL and AIM, daily km have been calculated considering 250 working days, because the vehicles that have been considered are company cars. On the other hand, AMB buffering system is connected to a public charging station, which is operable during 365 days/year.

In configuration 1 energy from PV is measured. If we assume that on the grid we may have other PV installations, we can consider that under some conditions, also the energy loaded from the grid has been generated by a PV.

Therefore we have introduced the parameter “PV”, which can vary from 1 to 4, where “PV” simulates the number of PV installations with similar power generation (including the measured one) connected to the grid in the same location.

As observed in the previous chapter, the benefits of a larger PV installation on the four monitored locations would be negligible.

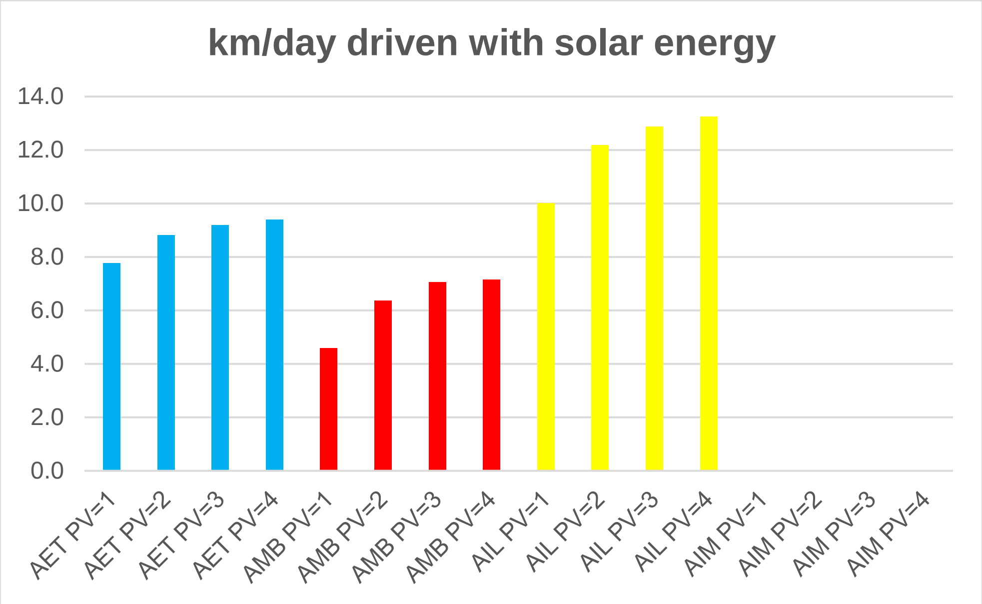
Unsurprisingly, mileage is higher when a public charging station (AMB) or a fleet charging station (AIM) are connected to the battery, compared to the case where a single EV is operated (AET, AIL).

**Configuration 2:** **E_EV / E_EV_100km / N_Days**

E_EV = Energy charged into EV [kWh]

E_EV_100km = Average EV consumption = 20 kWh/100 km

N_Days = Number of days of the year = 250 for business operation




Daily km have been calculated considering 250 working days, because all the vehicles that have been considered for configuration 2 are company cars.

Devices used for configuration 2 are located close to buffer batteries of configuration 1, where energy from PV is measured. Therefore it is considered that energy produced by the PV is flowing into the EV, when connected.

If we assume that on the grid we may have other PV installations, we can consider that under some conditions, also the energy loaded from the grid has been generated by a PV.

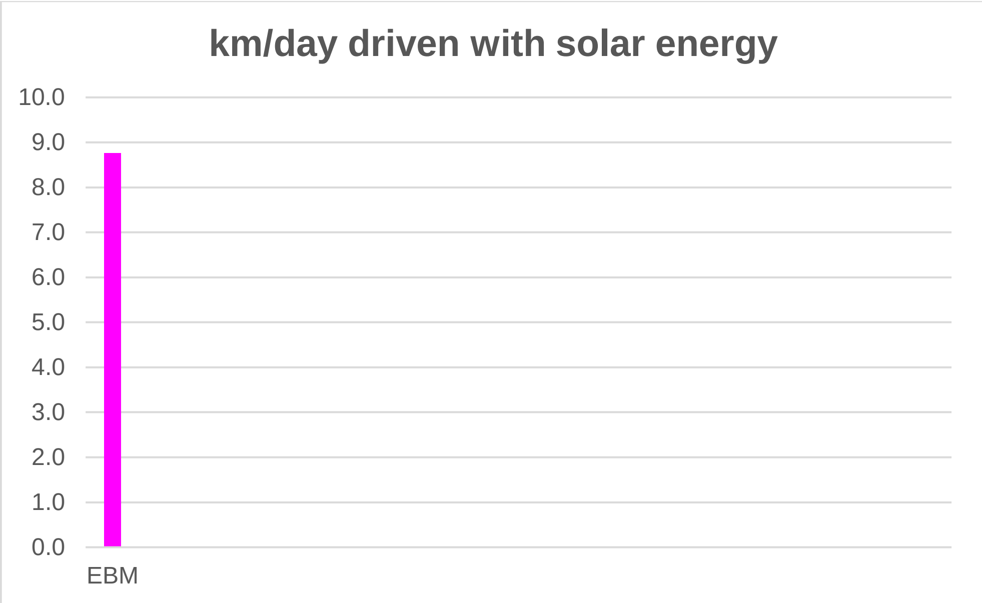
Therefore we have introduced the parameter “PV”, which can vary from 1 to 4, where “PV” simulates the number of PV installations with similar power generation (including the measured one) connected to the grid in the same location.

As observed in the previous chapter, km driven with solar energy do not increase linearly with the “PV” parameter.

**Configuration 3:** **E_EV / E_EV_100km**

E_EV = Energy charged into EV [kWh]

E_EV_100km = Average EV consumption = 20 kWh/100 km




Configuration 3 is not an installation of the project, but data supplied by SUPSI are used to validate the results of the analysis on configuration 1.

In particular “km/day driven with solar energy” of the four monitored configuration 1 installations are within the same range, when a single EV is operated (AET, AIL), higher in the case of public or semi-public charging stations (AMB, AIM).

**Consistency check of driven km**

AET buffer battery and bidirectional charger feed each a Nissan Leaf.

AIL buffer battery feed a Peugeot iOn and bidirectional charger a Nissan Leaf.

With the km recorded on the vehicles it is possible to crosscheck the value calculated assuming an average consumption of 20 kWh/100 km.

| AET Nissan Leaf 1 | | Configuration 1 | | |
|---|---|---|---|---|
| Driven km 1.1.2017-05.05.2017 | Driven km/year | km driven with solar energy | Coverage of renewable energy | km/year (calculated) |
| 1'403 km | **2'806 km** | 1'786 km | 77% | **2'319 km** |

| AET Nissan Leaf 2 | | Configuration 2 | | |
|---|---|---|---|---|
| Driven km 1.1.2017-30.09.2017 | Driven km/year | km driven with solar energy | Coverage of renewable energy | km/year (calculated) |
| 4'343 km | **5'791 km** | 1'941 km | 35% | **5'545 km** |

| AIL Peugeot iOn | | Configuration 1 | | |
|---|---|---|---|---|
| Driven km 1.1.2017-30.09.2017 | Driven km/year | km driven with solar energy | Coverage of renewable energy | km/year (calculated) |
| 1'430 km | **1'906 km** | 929 km | 62% | **1'498 km** |

| AIL Nissan Leaf | | Configuration 2 | | |
|---|---|---|---|---|
| Driven km 1.1.2017-30.09.2017 | Driven km/year | km driven with solar energy | Coverage of renewable energy | km/year (calculated) |
| 4'610 km | **6'147 km** | 2'505 km | 45% | **5'568 km** |

In all cases, the difference between recorded and calculated km is little and can be explained by the fact that energy consumption may be lower than 20 kWh/100 km and in addition vehicles may also be recharging occasionally from the public infrastructure.

## Cost / benefits ratio

Cost / benefits ratio is calculated considering the operating costs over 1 year, divided by the benefits accumulated over 1 year.

**Configuration 1:** **(C_BB + C_admin) / (C_energy + C_conn + C_PRL)**

C_BB = Depreciation stationary battery = 13'000 CHF / 12 years = 1'083 CHF/year

C_admin = maintenance + administration = 0 CHF

C_energy = Energy cost reduction = Energy cost without battery – Energy cost with battery

C_conn = Reduction of connection fees = 0 CHF

C_PRL = Earning due to primary regulation control

| Location | Configuration 1 | | | | |
|---|---|---|---|---|---|
| | **Depreciation stationary battery** | **Earning of primary regulation control** | **Energy costs with battery** | **Energy costs without battery** | **Energy cost reduction** |
| AET | 1'083 CHF | 352.52 CHF | -1'962 CHF | -2'095 CHF | -132.26 CHF |
| AMB | 1'083 CHF | 352.52 CHF | 762 CHF | 624 CHF | -137.82 CHF |
| AIL | 1'083 CHF | 352.52 CHF | -1'032 CHF | -1'130 CHF | -97.17 CHF |
| AIM | 1'083 CHF | 352.52 CHF | -2'312 CHF | -2'426 CHF | -114.10 CHF |

The negative sign on "Energy costs" means that three among four installations produce more energy than absorbed by the EVs or loads.

The negative sign on "Energy cost reduction" means that energy costs are higher when a buffer battery is used. As a consequence to the negative values, costs / benefits ration was not calculated.

This unexpected result is due to peak shaving/load smoothing algorithm that has a negative impact on energy costs. In fact energy taken from the grid costs currently about the double of the price payed by the operator for the energy feed into the grid. In addition, in configuration 1, batteries have average losses from 100 to 132 W!

**<u>Configuration 2:</u>** **(C_bidir + C_EVB + C_admin) / (C_energy + C_conn)**

C_bidir = Depreciation bidir charging station = (50’000 CHF* – 24’599 CHF**) / 10 years =
= 2’540 CHF/year

C_EVB = Life reduction of the EV batteries = 0 CHF
if < 20’000 km/year (guarantee of 5 years or 100’000 km)

C_admin = maintenance + administration = 980 CHF/year – 980 CHF/year = 0 CHF

C_energy = Energy cost reduction = Purchase price of buffered energy – Selling price of buffered energy

C_conn = Reduction of connection fees = 0 CHF

| Location | Configuration 2 | |
|---|---|---|
| | Depreciation bidir charging station | Energy cost reduction |
| AET | 2'540 CHF | 62.21 CHF |
| AMB | 2'540 CHF | 1.33 CHF |
| AIL | 2'540 CHF | 38.32 CHF |
| AIM | 2'540 CHF | |

Costs / benefits ration was not calculated, because it cannot be compared with configuration 1 and configuration 3.

For “Depreciation of the bidir charging station”, the cost difference between the bidirectional charging station and an equivalent unidirectional charging station has been considered.

The reason is that in addition to bidirectionality, the device allows fastcharge capabilities as well.

In addition also maintenance and administration fees are the same for a bidirectional charging station and an equivalent unidirectional charging station, therefore they have not been considered.

**<u>Configuration 3:</u>** **(C_BB + C_admin) / (C_energy + C_conn)**

C_BB = Depreciation stationary battery = 13’000 CHF / 12 years = 1’083 CHF/year

C_admin = maintenance + administration = 0 CHF

C_energy = Energy cost reduction = Energy cost without battery – Energy cost with battery

C_conn = Reduction of connection fees = 0 CHF

| Location | Configuration 3 | | | |
|---|---|---|---|---|
| | Depreciation stationary battery | Energy costs with battery | Energy costs without battery | Energy cost reduction |
| EBM | 1'083 CHF | 1'512.55 CHF | 1'372.37 CHF | -140.18 CHF |

The negative sign on “Energy cost reduction” means that energy costs are higher when a buffer battery is used. As a consequence to the negative values, costs / benefits ration was not calculated.

This unexpected result is due to peak shaving/load smoothing algorithm that has a negative impact on energy costs. In fact energy taken from the grid costs currently about the double of the price payed by the operator for the energy feed into the grid.

In addition, similarly to configuration 1, battery self-consumption has also to be considered.

## TCO (Total Cost of Ownership)

Total Cost of Ownership is the difference between costs and benefits over 1 year, divided by the km driven in 1 year.

**Configuration 1:** **(C_BB + C_admin – C_energy – C_conn – C_PRL) / km**

C_BB = Depreciation stationary battery = 13’000 CHF / 12 years = 1’083 CHF/year

C_admin = maintenance + administration = 0 CHF

C_energy = Energy cost reduction = Energy cost without battery – Energy cost with battery

C_conn = Reduction of connection fees = 0 CHF

C_PRL = Earning due to primary regulation control = 352.52 CHF/year per device

E_EV = Energy charged into EV [kWh]

E_EV_100km = Average EV consumption = 20 kWh/100 km

km = E_EV / E_EV_100km

| Location | Configuration 1 | | |
|---|---|---|---|
| | Costs - benefits | km/year | TCO |
| AET | 863 CHF | 2'318 | 0.37 CHF/km |
| AMB | 869 CHF | 22'469 | 0.04 CHF/km |
| AIL | 828 CHF | 1'489 | 0.56 CHF/km |
| AIM | 845 CHF | 6'776 | 0.12 CHF/km |

**Configuration 2:** **(C_bidir + C_EVB + C_admin – C_energy – C_conn) / km**

C_bidir = Depreciation bidir charging station = (50’000 CHF* – 24’599 CHF**) / 10 years =
= 2’540 CHF/year

C_EVB = Life reduction of the EV batteries = 0 CHF
if < 20’000 km/year (guarantee of 5 years or 100’000 km)

C_admin = maintenance + administration = 980 CHF/year – 980 CHF/year = 0 CHF

C_energy = Energy cost reduction = Purchase price of buffered energy – Selling price of buffered energy

C_conn = Reduction of connection fees = 0 CHF

E_EV = Energy charged into EV [kWh]

E_EV_100km = Average EV consumption = 20 kWh/100 km

km = E_EV / E_EV_100km

| Location | Configuration 2 | | |
|---|---|---|---|
| | Costs - benefits | km/year | TCO |
| AET | 2'478 CHF | 5'605 | 0.44 CHF/km |
| AMB | 2'539 CHF | 3'664 | 0.69 CHF/km |
| AIL | 2'502 CHF | 5'560 | 0.45 CHF/km |
| AIM | | | |

**Configuration 3:** **(C_BB + C_admin – C_energy – C_conn) / km**

C_BB = Depreciation stationary battery = 13’000 CHF / 12 years = 1’083 CHF/year

C_admin = maintenance + administration = 0 CHF

C_energy = Energy cost reduction = Energy cost without battery – Energy cost with battery

C_conn = Reduction of connection fees = 0 CHF

E_EV = Energy charged into EV [kWh]

E_EV_100km = Average EV consumption = 20 kWh/100 km

km = E_EV / E_EV_100km

| Location | Configuration 3 | | |
|---|---|---|---|
| | Costs - benefits | km/year | TCO |
| EBM | 1'224 CHF | 8'878 | 0.14 CHF/km |

## Load smoothing / peak shaving

Load smoothing / peak shaving is calculated with the root-mean-square deviation of the peak power to the mean power value over 24 hours, according to standard EN 50160.

The measurements have been performed with the battery and as a comparison, the value without the influence of the battery has also been calculated.

**Configuration 1:**

**With buffer battery:**

$$\sqrt{\frac{\sum_{i=0}^{i=T-1} (P\_wBB\_i - P\_mean)^2}{T}}$$

**Without buffer battery:**

$$\sqrt{\frac{\sum_{i=0}^{i=T-1} (P\_woBB\_i - P\_mean)^2}{T}}$$

i = Defined sampling time = 1 min

T = Number of samples over 24 h = 24 * 60 = 1440

P_wBB_i = Mean power over 1 min, with buffer battery

P_woBB_i = Mean power over 1 min, without buffer battery

| Location | Configuration 1 | |
|---|---|---|
| | root-mean-square deviation with buffer battery | root-mean-square deviation without buffer battery |
| AET | 3.41 | 3.37 |
| AMB | 1.50 | 1.55 |
| AIL | 2.75 | 2.82 |
| AIM | 4.07 | 4.06 |

In some cases, batteries have apparently a negative impact on the grid. The reason is that load regulation increases grid stability at the transformer level, consequently values measured at the “household level” can be worse, because the algorithm is compensating the load/production of other users connected to the same transformer.

**Configuration 2:**

The bidirectional charging station is a single component, therefore the value without the influence of the battery cannot be calculated.

**Configuration 3:**

**With buffer battery:**

$$\sqrt{\frac{\sum_{i=0}^{i=T-1} ( P\_wBB\_i - P\_mean )^2}{T}}.$$

**Without buffer battery:**

$$\sqrt{\frac{\sum_{i=0}^{i=T-1} (P\_woBB\_i - P\_mean)^2}{T}}$$

i = Defined sampling time = 1 min

T = Number of samples over 24 h = 24 * 60 = 1440

P_wBB_i = Mean power over 1 min, with buffer battery

P_woBB_i = Mean power over 1 min, without buffer battery

| Location | Configuration 3 | |
|---|---|---|
| | root-mean-square deviation with buffer battery | root-mean-square deviation without buffer battery |
| AET | 1.57 | 1.50 |

Similarly to configuration 1, batteries have apparently a negative impact on the grid. The reason is that load regulation increases grid stability at the transformer level, consequently values measured at the “household level” can be worse, because the algorithm is compensating the load/production of other users connected to the same transformer.

# Efficiency and losses

Efficiency and losses is the ratio between the total energy loaded during one year and total energy delivered by the storage systems during the same year.

**Configuration 1:** **(E_BBout / E_BBin) * 100 [%]**

E_BBin = Energy feeding in to battery

E_BBout = Energy feeding out from the battery

| Location | Configuration 1 | | |
|---|---|---|---|
| | Energy feeding out from the battery | Energy feeding in to the battery | Efficiency |
| AET | 1'010 kWh | 1'883 kWh | 54% |
| AMB | 2'081 kWh | 3'203 kWh | 65% |
| AIL | 1'363 kWh | 2'522 kWh | 54% |
| AIM | 1'065 kWh | 2'011 kWh | 53% |

According to the measured values, the efficiency of the Ampard stationary batteries is very poor.

Those values corresponds to the following average losses:

- AET =100 W → 874 kWh/year
- AMB =128 W → 1’122 kWh/year
- AIL =132 W → 1’159 kWh/year
- AIM =108 W → 946 kWh/year

From Ampard specifications, battery efficiency is 85 % and efficiency of the inverters 93 %, which theoretically means that efficiency of the complete system should be about 79 %.

The calculated values are between 53 and 54 % for AET, AIL and AIM installation, whereas it is 65 % on the device operated by AMB.

As a comparison, efficiency measured on configuration 3 equipment is 73 %.

Ampard admit that efficiency of the battery system is in fact an issue they are working on already in cooperation with their suppliers. In particular, focus is on reduction of ESS losses (Electronic Switching Systems). However, Ampard claims having experienced values in the range of 70 % on similar devices.

The reason for such a poor results is, according to Ampard, the low load power consumption, especially after sunset, which would increase the impact of ESS standby losses.

This hypothesis is corroborated by the fact that on the AMB device, which is connected to a public EV charging station and consequently subject to more important loads all along the day, a higher efficiency has been calculated.

**Configuration 2:**

Efficiency and losses cannot be calculated for configuration 2, because a part of stored energy is used by the EV.

**Configuration 3:** **(E_BBout / E_BBin) * 100 [%]**

E_BBin = Energy feeding in to battery

E_BBout = Energy feeding out from the battery

| Location | Configuration 1 | | |
| --- | --- | --- | --- |
| | Energy feeding in to the battery | Energy feeding out from the battery | Efficiency |
| EBM | 229 kWh | 168 kWh | 73% |

Compared to the Ampard stationary batteries, the Knubix system used in configuration 3 has higher efficiency.

## Primary regulation

Primary control restores the balance between power generation and consumption within seconds of the deviation occurring. During this operation, the frequency is stabilized within the permissible limit values. Ampard batteries (configuration 1) have the possibility to react on specific commands, acting as a regulators, in absorbing/delivering energy from/to the grid.

The four Ampard batteries are participating to a pool with batteries from other operators. The revenues paid by Swissgrid, deduced management fees and other costs, are according to Ampard 88.13 CHF per unit per quarter.

This integrated over 1 year gives the following figures:

| Location | Configuration 1<br>Earning for primary regulation control<br>Year 2017 |
|---|---|
| AET | 352.52 CHF |
| AMB | 352.52 CHF |
| AIL | 352.52 CHF |
| AIM | 352.52 CHF |

# Discussion / evaluation of the results / acquisitions

## Results

### 1.1. Buffered energy

The benefits due to stationary batteries (configuration 1) and bidirectional charging (configuration 2), are highlighted in the following table, showing the amount of energy that was feed into the grid by the devices of the two configurations over one year:

| Location | Configuration 1<br>Energy feed from the stationary battery into the grid in 1 year | Configuration 2<br>Energy feed from the EV battery into the grid in 1 year |
|---|---|---|
| AET | 1'010 kWh | 760 kWh |
| AMB | 2'081 kWh | 13 kWh |
| AIL | 1'363 kWh | 596 kWh |
| AIM | 1'065 kWh | |

In order to be recharged and buffer renewable energy, in configuration 2 the EV has to be connected to the bidirectional charging station as long as possible, in particular during daylight. In addition, if the bidirectional algorithm is disabled by the user, who need the whole EV range available, the impact on the grid in terms of buffered energy is even minor and explains the differences between configuration 1 and configuration 2 reported in the above table.

## 1.2. Increase of renewable energy coverage

The impact of stationary batteries on coverage of renewable energy, for the EVs that have been regularly recharging from configuration 1 devices all along the project, has been calculated and, as reported in the table below, shows an increase from 7 to 13 %.

In addition, other loads connected to the same grid point have been taking advantage from the stationary batteries. In fact, the buffered renewable energy supplied to other consumers in one year, dependent from the location, vary from 1'010 to 2'081 kWh (see table under 1.1. Buffered energy).

The case for configuration 2 is different: in fact the coverage of renewable energy depends on the part of energy recharged in the EV during PV production. This part is thus independent from the use of a bidirectional or unidirectional charging station.

However, similarly to configuration 1, other loads connected to the same grid point have been taking advantage from the bidirectional charging station. In fact, the buffered renewable energy supplied to other consumers in one year, dependent from the location, vary from 13 to 760 kWh (see table under 1.1. Buffered energy).

| **Location** | **Increase of renewable energy coverage in EV, due to buffer battery**<br><br>**Configuration 1** | **Increase of renewable energy coverage in EV, due to bidirectional charging**<br><br>**Configuration 2** |
|---|---|---|
| AET | 13% | 0% |
| AMB | 12% | 0% |
| AIL | 7% | 0% |
| AIM | 13% | 0% |

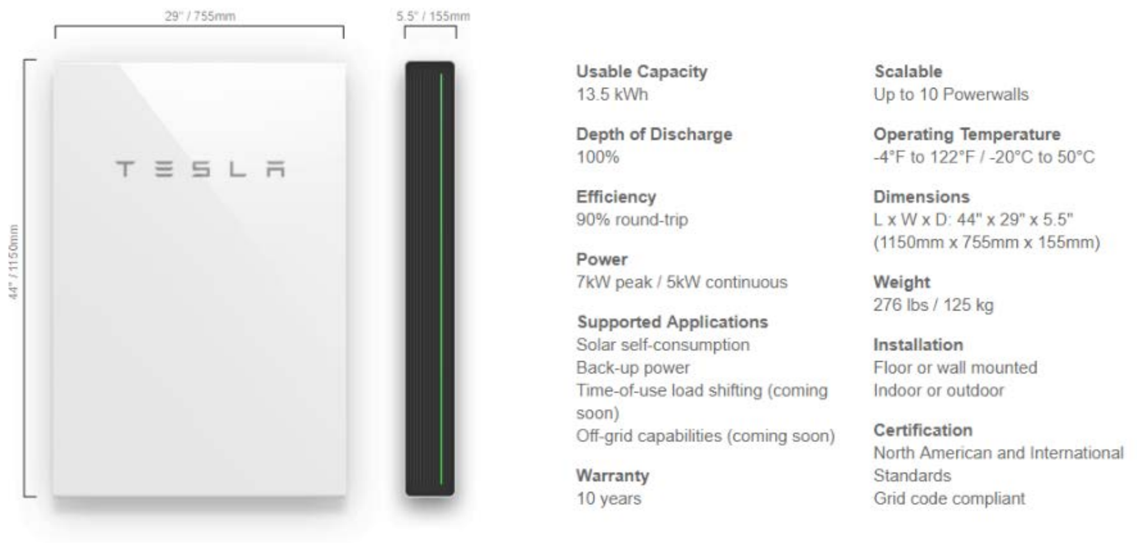
## Stationary storage vs bidirectional charging

| | Configuration 1 | Configuration 2 |
|---|---|---|
| **Advantages** | + No impact on user's behavior<br>+ Reliability | + Suitable for outdoor installation<br>+ Easy to install |
| **Disadvantages** | – Volume / space needed<br>– Indoor installation only<br>– Installation / wiring<br>– Efficiency / Losses | – Reduced EV range, due to incomplete battery charging (SOC < 100%)<br>– EV has to be connected to the charging station as long as possible, especially during PV production hours<br>– Reliability |

Stationary batteries, tested in configuration 1 have no impact on the user behavior, who does even not noticing that behind his charging station is a storage infrastructure.

In addition, considering that project was launched in 2013, in more than four years, technology has been further developed: on the market there are today product from different competitors, with increased performances and reduced purchase price.

An example over all, is the “Powerwall” offered by Tesla at 6’540 CHF, with a storage capacity of 13.5 kWh, 90 % efficiency and 10 years warranty!




This product is in addition very compact and would solve the issues arisen in terms of volume and space required by the storage infrastructure tested in configuration 1.

Regarding configuration 2, although there are several projects aiming to experiment the use of bidirectional chargers, there are not many commercial products on the market.

The only alternative seems to be still “Nichicon EV Power Station”, also advertised by Nissan with the new Leaf and sold in Japan at a price of 480’000 yen, corresponding to about 4’200 CHF.

However, this product has a single-phase, 100 VAC, 50/60 Hz output, designed for the Japanese grid and not adequate to European grid specifications.

In fact, even a large car manufacturer such as Honda has recently announced the experimentation of the V2G technology, using a product developed by EVTEC:


# The Mobility House installs new bi-directional charging technology at Honda R&D Europe

8. December 2017 | PR (http://www.mobilityhouse.com/en/author/eva-maria-ritter/) | Press (http://www.mobilityhouse.com/en/category/presse-en/) | Tags: energy solutions (http://www.mobilityhouse.com/en/tag/energy-solutions/), Honda R&D Europe (http://www.mobilityhouse.com/de/tag/honda-rd-europe/), V2G (http://www.mobilityhouse.com/en/tag/v2g-en/), vehicle-to-grid (http://www.mobilityhouse.com/en/tag/vehicle-to-grid-en/) | 0 Comments (http://www.mobilityhouse.com/en/the-mobility-house-installs-bi-directional-charging-technology-honda-research-institute-europe/#respond)

- **Energy can be drawn from and returned to the grid with Vehicle-to-Grid technology (V2G)**
- **New technology is another step towards a zero-emission society**
- **Project is collaboration between Honda, EVTEC and The Mobility House**
- **Installation tests the integration of electric vehicle batteries and renewable energy sources**

Consequently if we can state that stationary energy storage is now a mature technology and in fact on the products currently available on the market, the major inconvenient encountered during the experimentation seem to be solved, the same development did not occur during the 4 years of the project for bidirectional chargers.

In fact if selling price of “Nichicon EV Power Station”, seems to be attractive and gives an idea of the price range of a commercial product, this architecture has a couple of inherent problems.

First of all the reduced EV range, due to an incomplete battery recharge will still remain a limitation for the user, even if the battery development constantly increases the driving range.

Secondly, in order to be recharged and buffer renewable energy, mainly produced by PV installations, EV needs to be connected to the charging station as long as possible, in particular during daylight.

This is of course an important disadvantage when we consider that EVs are mainly recharged at home during evening/night time.

# Conclusions

Project was launched in 2013 and in more than four years technology has been further developed, therefore on the market there are different competitors, who are offering stationary storage systems.

As confirmed by the measurements, both storage systems, stationary and bidirectional, bring important benefits in terms of coverage of renewable energy and grid stability.

The new products currently available on the market, seem to solve the major problems pointed out along the project on configuration 1 devices, making stationary storage very attractive.

In order to be more financially attractive, energy tariffs should be adapted for the use of storage devices. In fact, although grid operators are taking advantage from primary regulation and from load smoothing/peak shaving, this continuous energy exchange between the storage device and the grid, is currently paid by the customer, who is asked to pay the energy absorbed from the grid, more that the double of the price the distributor pays him for the energy feed in to the grid!

In addition, on the devices tested in configuration 1, in presence of important loads all along the day, the efficiency of the storage system was higher.

On bidirectional chargers, the development was not so impressive. In reality the options on the market are the same compared to four year ago.

However, several projects aiming to study this technology have been launched, involving also important car manufacturers such as Nissan and Honda.

This architecture has though important limitations for the users. First of all the reduction of the EV range, due to an incomplete battery recharge and secondly the need to have the EV connected to the bidirectional charging station as long as possible, in particular during daylight, in order to be recharged and buffer as much as possible renewable energy, mainly produced by PV installations.

In addition, bidirectional chargers use CHAdeMO interface, which is the quick DC charging port standardized by the Japanese car industry, while all other EVs use CCS interface, which has similar fastcharging capability, but not the bidirectionality!

This means that in addition to the above mentioned limitations, the only EVs compatible with a bidirectional charger are models from Nissan, Mitsubishi and Kia, which are today representing only a small portion among all EVs available on the market (see “Annex 1”).

As observed during the last years, energy storage systems will benefit also in future from the development on EV batteries. Although EV range will farther increase, it is unlikely that their batteries will be used as energy storage, in particular due to the high costs and the limitations that this architecture impose to the user. Intelligent EV charging would be a more viable and cost effective solution. The method consist in stopping or reducing vehicle charging power, when other loads are active, ensuring in any case that EV is fully charge when needed. This method, can be applied to AC charging, which is available on all EVs and PHEVs (see “Annex 1”) and does not require bidirectionality.

On the other hand, thanks to the EV battery development, stationary batteries will become more affordable and reliable, have higher performances and reduced weight/volume. In fact on products already available on the market, the major problems encountered during the experimentation have been solved already.

# Next steps after the project closure

All the infrastructure installed during the project are property of their operators.

Stationary buffer batteries from Ampard installed for configuration 1, will continue to operate after project closure. Ampard will keep the operators informed on the battery status, which is also trackable through the Ampard web interface and will refund them with the revenues of the primary regulation control.

During the final project meeting, the operators of the bidirectional charging stations, have wished to disable bidirectional functionality, in order to use them as standard CHAdeMO fastcharging devices.

The reason is the reduced EV range, due to an incomplete battery recharge, which on vehicles having barely 100 km range is a significant limitation.

# Perspectives

The project provided important information and with the available infrastructures it was possible to answer the initial questions, providing confirmations but also revealing some weaknesses of the different configurations/components under test.

From the point of view of the grid operators, it would now be interesting to test buffer batteries from the new generation, applying a tariff model which, unlike the current system, makes local energy storage attractive from a financial point of view. This basically means a dynamic tariff where the energy cost is lower in case global production exceeds consumption, respectively a higher remuneration, for the energy injected to the grid by a storage system, when global consumption is greater than production.

On the same way it would also be interesting to apply the same tariff model, to the bidirectional charging, but in order to minimize the inconvenient due to an incomplete recharge, it is mandatory to use an EV with a battery capacity of at least 40 kWh (200 to 300 km real driving range).

In addition, company cars, which are in general driven during the day and recharged at night, do not have the adequate use profile to allow storage of electricity produced from renewable sources, in particular PV, copiously available during the daylight.

A much more favorable use profile would be an EV operated for car sharing. In fact, these vehicles are randomly used and in general the trips are booked in advance. In addition, when not circulating, they are always connected to a charging station.

Having in mind that in future, mobility will be very likely based on autonomous driving, we could imagine that a car sharing operated vehicle would reach independently the charging station, not only when a recharge is necessary but also, in case of bidirectionnality, when the grid requires the energy stored in its batteries, or at least a part of it.

If this sounds like music of the future, even if probably not too far, from a technical and technological point of view it will surely be an exciting challenge, for which it is important that all operators are prepared.

# Annex 1

Overview of electric vehicles and charging options (Alpiq).

# Übersicht aktueller Elektrofahrzeuge

Steckertypen, Ladezeiten …

## Fahrzeugmodelle

| Marke | Modell | [kWh] | Ladeleistung in kW AC | Ladeleistung in kW DC |
|---|---|---|---|---|
| Audi | A3 Sportback e-tron | 8.8 | 3.7 | - |
| | Q7 e-tron | 17.3 | 7.2 | - |
| BMW | i3 (60Ah) | 18.8 | 3.7 | 40 |
| | i3 (94Ah) | 33 | 11 | 50 |
| | i8 | 7.1 | 3.7 | - |
| | 225xe plug-in hybrid | 7.6 | 3.7 | - |
| | 330e plug-in hybrid | 7.6 | 3.7 | - |
| | 530e plug-in hybrid | 9,2 | 3.7 | - |
| | 740e plug-in hybrid | 9,2 | 3.7 | - |
| | X5 xDrive40e plug-in hybrid | 9 | 3.7 | - |
| Chevrolet | Volt | 16 | 3.7 | - |
| Citroën | C-Zero | 16 | 3.7 | 50 |
| | E-MEHARI | 30 | 3.7 | - |
| Fisker | Karma | 20 | 3.7 | - |
| Ford | Focus Electric | 23 | 3.7 | - |
| | Focus Electric (2017) | 34 | 3.7 | 50 |
| | C-Max | 7.6 | 3.7 | - |
| KIA | Soul EV | 27 | 3.7 | 70 |
| | Optima Plug In Hybrid | 9.8 | 3.7 | |
| Hyundai | Ioniq PHEV | 9.8 | 3.7 | - |
| | IONIQ electric Launch / Plus | 28 | 3.7 | 70 |
| Mercedes | B-Class B 250 e | 28 | 11 | - |
| | S 500 e L Plug-in Hybrid | 8.7 | 3.7 | - |
| | GLC 350e Plug-in Hybrid | 8.5 | 3.7 | - |
| | GLE 500e Plug-in Hybrid | 8.8 | 3.7 | - |
| | C 350 e Plug-in Hybrid | 6.2 | 3.7 | - |
| MINI | Cooper S E Countryman ALL4 | 7.6 | 3.7 | - |
| Mitsubishi | i-Miev | 16 | 3.7 | 50 |
| | Outlander PHEV | 12 | 3.7 | 50 |

ALPIQ

| Fahrzeugmodelle | | | Ladeleistung in kW | | Ladedauer in h | | Steckertypen | | Ladepunkt im Fahrzeug |
|---|---|---|---|---|---|---|---|---|---|
| **Marke** | **Modell** | **[kWh]** | **AC** | **DC** | **AC** | **DC*** | **AC** | **DC** | |
| **Nissan** | Leaf (24kwh) | 24 | 3.7 | 50 | | | | | |
| | Leaf (30kwh) | 30 | 3.7 | 50 | | | | | |
| | Leaf II ZERO Edition | 40 | 3.7 | 50 | | | | | |
| | e-NV200 | 24 | 3.7 | 50 | | | | | |
| **Opel** | Ampera | 16 | 3.7 | - | | | | | |
| | Ampera e | 60 | 3.7 | 80 | | | | | |
| **Peugeot** | iOn | 16 | 3.7 | 22 | | | | | |
| | ePartner | 22.5 | 3.7 | 50 | | | | | |
| **Porsche** | Panamera S E-Hybrid | 9.4 | 3.7\|7.2 | - | | | | | |
| | Panamera 4 E-Hybrid (Executive) | 14.1 | 3.7\|7.2 | - | | | | | |
| | Panamera 4 E-Hybrid Sport Turismo | 14.1 | 3.7\|7.2 | - | | | | | |
| | Panamera Turbo S E-Hybrid (Executive) | 14.1 | 3.7\|7.2 | - | | | | | |
| | Cayenne S E-Hybrid (Platinum Edition) | 10.8 | 3.7\|7.2 | - | | | | | |
| | 918 Spyder | 6.8 | 3.7 | - | | | | | |
| **Range Rover** | Sport P400e | 13 | 3.7 | - | | | | - | |
| **Renault** | Fluence Z.E. (Typ 1) | 22 | 3.7 | - | | | | | |
| | Kangoo Z.E. (Typ 1) | 22 | 3.7 | - | | | | | |
| | Kangoo Z.E. (Typ 2) | ?? | 3.7 | - | | | | | |
| | ZOE | 22 | 11 - 22 | - | | | | | |
| | Zoe Z.E. 40 | 40 | 11 - 22 | - | | | | | |
| **Smart** | fortwo electric drive | 17.6 | 3.3 | - | | | | | |
| | fortwo electric drive (22 kW) | 17.6 | 22 | - | | | | | |
| | smart electric drive (2018) | 17.6 | 3.7 \| 22 | - | | | | | |
| **Tesla** | Model S (Single Charger) | 70\|90 | 11 | 130 | | | | | |
| | Model S (twin Charger) | 70\|90 | 22 | 130 | | | | | |
| | New Model S (ab 2016) | 60\|75\|90\|100 | 11\|16.5 | 130 | | | | | |
| | Model X | 60\|75\|90\|100 | 11\|16.5 | 130 | | | | | |
| **Toyota** | Prius Plug-in Hybrid | 4.4 | 3.3 | - | | | | | |
| | Prius IV Plug-in Hybrid (2016) | 8.8 | 3.7 | - | | | | | |
| **Volvo** | V60 T6 PHEV | 11.2 | 3.7 | - | | | | | |
| | XC90 T8 twin engine | 9.2 | 3.7 | - | | | | | |
| | XC60 T8 twin engine | 9.2 | 3.7 | - | | | | | |
| | V90 T8 twin engine | 9.2 | 3.7 | - | | | | | |

| Fahrzeugmodelle | | | Ladeleistung in kW | | Ladedauer in h | | Steckertypen | | Ladepunkt im Fahrzeug |
|---|---|---|---|---|---|---|---|---|---|
| Marke | Modell | [kWh] | AC | DC | AC | DC* | AC | DC | |
| VW | e-up | 18.7 | 3.7 | 50 | | | | | |
| | GTE | 8.8 | 3.7 | - | | | | | |
| | Golf GTE (2017) | 9.9 | 3.7 | - | | | | | |
| | e Golf | 24.2 | 3.7 | 50 | | | | | |
| | e Golf (2017) | 35.8 | 7.2 | 50 | | | | | |
| | Passat GTE | 9.9 | 3.7 | - | | | | | |
| | Passat GTE Variant | 9.9 | 3.7 | - | | | | | |

**Steckertypen (AC)**

**Typ 1**

Japanisch
Leistung bis 7.4kw/ 32A
Einphasig, nur AC

**Typ 2**

Europäisch
Kommunikationsfähig
Leistung bis 43kW/ 63A
Ein- bis dreiphasig,

**Steckertypen (DC)**

**CHAdeMO**

(japanisch)
Leistung bis 63kW/ 200A
Schnellladung via DC

**Combo 2**

(Europäisch und amerikanisch Combined Charging System (CCS)

Leistung bis 170kW/ 200A
Schnellladung via DC