FLOW's D1.2 - Baseline: Scenarios and definitions

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integration of EVs deployment Wave

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Deliverable 1.2

Internal Baseline

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Deliverable title	Internal Baseline
Description	Based on a state-of-the-art review, T1.2 establishes the internal assumptions, scenarios and definitions on which FLOW bases its work. This is an important step in giving FLOW partners a common and synchronized framework. T1.2 starts by providing VGI definitions and terminology used in FLOW and promoted as commonly accepted in all the relevant fields. High-level EVs mass deployment scenarios are listed according to literature review/roadmaps - and serves as an input to WP5. T1.2 also focuses on charging technologies and forecasts to establish the state-of-the-art of charging technologies from partner experiences which includes charging power, efficiency, technical capabilities, battery loss (DTU PowerLab, IREC SmartEnergy lab, BMW), etc. The task touches upon disruptive charging technologies including ultrafast charging, inductive public charging which may change charging patterns significantly. Finally, T1.2 presents scenarios definition for EV charging demand (per location type) in terms of energy demand and flexibility quantification.
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List of Acronyms

Acronym	Meaning
AC	Alternating Current
AEV	All-Electric Vehicle
BEV	Battery Electric Vehicle
CPO	Charging Point Operator
DC	Direct Current
DSO	Distribution System Operator
TSO	Transmission System Operator
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
EMSP	Electro Mobility Service Provider
FCEV	Fuel-Cell Electric Vehicle
FHEV	Full-Hybrid Electric Vehicle
V1G/CC	Grid-to-vehicle / Unidirectional Controlled Charging
HEV	Hybrid Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
MHEV	Mild Hybrid Electric Vehicle
PHEV	Plug-in Hybrid Vehicle
POD	Point of Distribution
SOC	State-of-charge
SOH	State-of-health
TSO	Transmission System Operator
UX	User Experience
V2G/BC	Vehicle-to-grid / Bi-directional Coordinated Charging
VGI	Vehicle-Grid Integration
WP	Work Package

Executive Summary

This deliverable (D1.2 Internal Baseline) documents the work carried out in work package 1, task 1.2 “Baseline: scenarios & definitions”.

The deliverable starts by listing all the relevant vehicle-grid-integration definitions and terminology, regarding both the electric vehicles (EVs), and the electric vehicle supply equipment (EVSE).

We first list the most relevant terminology for the different types of EVs, hybrid ones included, and look at their technological aspects, battery technology included. Then, the deliverable delves into the description of the charging equipment standards, analysing the most relevant European regulation documents by IEC and ISO. A table tries to clarify and link the available charging modes and the currently available charging power levels, providing rough estimates of the typical charging time associated to each one. Then, a classification of the possible EV charging policies is presented, introducing the topics that will be covered more in detail in D1.3. We also look at the charging equipment, specifically the “dumb” and “smart” chargers, trying to understand the differences between them, and listing what a future smart charger should be able to do. This section will be further expanded in D1.4.

Then, EV mass deployment scenarios are presented, based on the most updated data from the EU, and the main demo countries: Italy, Denmark, and Spain. We focused our attention on the most relevant parameters that are going to be analysed in WP5: the size of the EV fleet, the recommended installed charging power, and the total yearly energy demand increase to cover electromobility needs. At the single country-level, we rely on scenarios made by local authorities or research centres, thanks to the help provided by FLOW project partners.

A review of the future mobility trends is also presented, shortly touching upon car sharing, mobility-as-a-service, and autonomous driving, with a special focus on how they could impact the grid. Disruptive charging technologies are shortly described as well, specifically inductive charging, ultrafast DC charging, and battery swap.

Finally, leveraging a small database of EV charging sessions provided by one of the project partners, we try to describe the most frequently found charging patters, and link them to the locations the chargers are installed at.

With this document, the WP1 partners tried to provide a common terminology and some EV mass deployment baseline scenarios to use as a foundation for the grid impact studies to be performed in the following WPs.

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1. Background and Objectives

The activities of WP1 are aimed at providing a common knowledge baseline for FLOW, with specific attention towards the creation of a number of scenarios of mass EV deployment, which are going to be used for future project activities. In this regard, inputs from project partners are particularly important, as they represent their unique point of view on the described subjects, which can only come from first-hand experience.

D1.2 documents the activities carried out in Task 1.2 “Baseline: scenarios and definitions”, so its main objectives are:

- Providing a common nomenclature regarding VGI, to be used throughout the whole lifespan of the project.
- Reviewing EU and single country-level EV mass deployment scenarios, to serve as an input to WP5.
- Analyzing the features of the different charging technologies, specifically regarding charging power, efficiency, and flexibility capabilities.
- Shortly reviewing present and future mobility trends and disruptive charging technologies, along with their impact on VGI.
- Describing the different locations where EV charging may be located, along with the charging patterns and flexibility quantification.

The quantification of the flexibility associated to each charging location and pattern was moved to D1.3, but as a compensation, particular relevance was given to the definition of the EV mass deployment scenarios, which will serve as an input to WP5.

2. Vehicle-grid Integration Definitions

2.1 List of Terms and Definitions

A list of specific terms regarding electric mobility is provided in this section, for future reference in the FLOW project activities. Note that not all the acronyms used throughout this report are reported here, since a table of abbreviations is available at the beginning of this document.

Table 1. List of Relevant VGI Terms and Definitions

Term	Acronym	Description
EV	Electric Vehicle	Used to define light (cars/vans) and heavy-duty vehicles (buses/trucks) propelled by an electric motor, hybrid vehicles included.
BEV	Battery Electric Vehicle	Used to define a type of electric vehicle (EV) that exclusively uses chemical energy stored in rechargeable battery packs, with no secondary source of propulsion.
FCEV	Fuel-Cell Electric Vehicle	Defines a type of electric vehicle that runs on the electricity produced by a “fuel cell”, which

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		converts the hydrogen stored in the car tank into electricity.
ICE(V)	Internal Combustion Engine (Vehicle)	Traditional vehicles propelled by an internal combustion engine which burns a fuel such as gasoline or liquified petroleum gas (LPG).
HEV	Hybrid Electric Vehicle	Most commonly cars and small vans, propelled by both an ICE and an electric motor, usually equipped with a battery to store the electricity produced by regenerative braking or the electricity charged at a station (if possible).
PHEV	Plug-in Hybrid Electric Vehicles	Used to define hybrid electric vehicles whose batteries can be charged externally.
AEV	All-Electric Vehicle	Vehicles propelled by an electric engine alone, either running on electricity only (stored in an onboard battery), or on hydrogen (in case a fuel cell is available).
EVSE	Electric Vehicle Supply Equipment	All the required electric components, software, and communication devices allowing the EV charging station to properly function.
CPO	Charging Point Operator	Company that owns and/or operates the EVSE, maintains the network connection, and sets the prices for the use of EVSE.
EMSP	Electro-Mobility Service Provider	Company/entity directly interfacing with the EV owners through an application or similar. They provide a range of “charging services”, such as payments management and customer care.
CC/V1G	Grid-to-vehicle / Coordinated Charging	Interaction between electric vehicle and electricity system in which the EV modulates its charging schedule and magnitude in response to an external signal. The power flow is unidirectional, i.e., from the grid to the EV only.
V2X/BC	Vehicle-to-grid / Bidirectional Coordinated Charging	Interaction between electric vehicle and electricity system in which the EV modulates its charging schedule and magnitude in response to an external signal. The power flow can be bidirectional, i.e., from the grid to the EV, or from the EV to a building (V2B), the grid (V2G), or other vehicles (V2V).
SOC	State-of-charge	Ratio between the energy available in the battery and its total original capacity.
SOH	State-of-health	Ratio between the available capacity after a variable number of years of usage and the original initial capacity.
VGI	Vehicle Grid Integration	Generic term referring to the challenges and potentials related to the interaction between electromobility and the power grid.
	Charging Destination	A location whose primary purpose is to charge the EVs (comparable to today’s gas stations) and

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		other nearby activities are secondary to that purpose.
	Destination Charging	The term refers to charging in a location where the car normally parks in relation to the owner's natural, recurring, activities and patterns (e.g., work, school, shopping, etc.)

2.2 Electric Vehicles Terminology

In the following figure, the different types of existing electric vehicles (EVs) are classified based on their characteristics, which influence the way they are charged, the required infrastructure, and their usage patterns as well.

Hybrid EVs (HEVs) are a relevant part of the worldwide fleet of EVs, plug-in hybrids (PHEVs) alone adding up to 47% of the total EV fleet. In some countries, especially the ones whose EV market is still developing such as Italy, Brazil, Chile, and Mexico, PHEVs are more numerous than BEVs, due to the lower social acceptance barrier (traditional engine is also available for backup).

Hybrid EVs deploy both an electric and internal combustion engine (ICE), and even if they are considered as a transition technology, several models are available in the market, each with its own specific characteristics.

Mild-hybrid vehicles (MHEV) are equipped with both an electric and ICE, but they are not able to run on the electric engine only, because of a lack of sufficient power to drive the vehicle. Regenerative braking is used to create electricity, which is then stored into a battery and re-used to smooth-out the start and stop operation or assist the ICE as a range extender, when the vehicle is not accelerating ("cruise" mode). The increase in fuel efficiency is around 20-25% [1].

A **full-hybrid electric vehicle (FHEV)** instead, can run on the electric engine only, due to a bigger battery size and electric motor.

Different modes are available in modern "Synergy" Hybrids (the ones not aimed at the best driving performance), such as:

- Normal: uses a combination of the ICE and electric engines to allow for a comfortable use of the car in cities.
- Power: redirects part of the power available from the battery to help the ICE in providing fast response to acceleration.
- "Eco": optimizes air conditioning and reduces ICE responsiveness to achieve the lowest power consumption levels.
- Electric Vehicle: forces the vehicle to run on battery power only.

Typical fuel efficiency increases are around 40-45%, compared to ICEVs, partially due to the smaller required ICEVs [1].

The main difference between a FHEV and **plug-in hybrid (PHEV)** instead, lies in the possibility to charge the battery up by drawing power from the main grid. This type of HEV requires a charger to be installed either on-board or in the charging station, and generally features much bigger electric components (motor and battery) and an even smaller engine. Plug-in hybrids generally have a longer driving range

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and can make a more efficient use of the electric motor due to a larger storage capacity (up to 15-20 kWh, depending on the model). All the HEVs can use regenerative braking to charge up their batteries and start/stop techniques to reduce fuel consumption and engine wear when the car is standing still, for example at a traffic light.

In the category of **all-electric vehicles (AEVs)** instead, it is possible to find **battery EVs (BEVs)** running entirely on the electric motor, since no ICE is present. The battery sizes are the largest between the all the types of EVs, and they run on "battery depleting" mode only, i.e., they constantly discharge except for regenerative braking. These EVs can be charged externally at charging/refilling stations, and generally have longer driving ranges, from 100 to 500 km, due to larger battery sizes (up to 100 kWh). BEVs are generally much more fuel efficient due to the higher electric motor torque and acceleration response and produce lower CO2 emissions, if the electricity is produced from renewable sources. They however achieve lower top speeds and are generally limited in size and driving range, compared to ICEVs.

Another type of AEVs are **fuel-cell electric vehicles (FCEVs)**, which are fed by hydrogen usually coming from a gas station and contained in highly pressurized tanks in the car trunk or under the floor. The fuel cells produce electricity by means of a chemical reaction between the hydrogen from the tank and oxygen from the outside environment, and that energy drives an electric motor connected to the transmission system. These EVs are ideal for continuous power supply but require a battery for abrupt power requirement fluctuations: that way, the FC can run at the optimal efficiency, whereas the battery serves the engine and is recharged by regenerative braking. FCEVs are faster to charge than BEVs (approximately as long as an LPG charge), but the hydrogen needs to be produced by means of renewable power [2] in order to keep the CO2 emissions lower than the ones from traditional cars.. Moreover, the efficiency of absorbing a kWh of electricity from the grid, then convert it into chemical energy (hydrogen) and finally reconvert it into electricity in the fuel cells is lower than the efficiency of BEVs, which directly use that kWh to run the car engine. This leads to higher emissions per distance driven, around 70 gCO2/km for BEVs, against 110 gCO2/km for FCEVs [3].

2.2.1 Battery Storage Technologies

As previously mentioned, the energy storage unit is a fundamental component of both PHEVs, since it allows for a more efficient use of the fuel, and of the BEVs, since their driving range is highly influenced by the storage type and capacity. Even if car manufacturers are trying different solutions for HEVs, including ultracapacitors or flywheels [1], the only commercial option for the storage unit, at the moment, is electro-chemical batteries. Both BEVs and HEVs deploy "secondary" batteries, the rechargeable ones, and several types can be distinguished, based on their main features, as shown in Table 1:

Table 2. Battery technologies and their main features.

Type	Specific energy (Wh/kg)	Power/weight coefficient (W/kg)	Number of recharging cycles	Self-Discharge (%)	Energy Efficiency
Pb-acid	30	180	<2000	Low	<80%
Ni–Cd	50	150	<2000	Low	<90%
NiMH	70	1000	<3000	High	<80%
Li-ion	150	1800	<2000	Medium	<85%
Li-ion polymer	200	3500	>1200	Medium	<70%

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The most widely adopted are Li-ion and Li-ion polymer ones, due to their good combination of high specific energy, power-weight coefficient, and number of recharging cycles [4] .

The specific energy and power coefficients are important to have lighter vehicles that can still drive long distances, whereas the number of recharging cycles ensures an extended lifetime, which also contributes to reducing the battery waste from the electro-mobility sector.

In this regard, a few novel battery technologies are being tested, with some of them also appearing on the market in some EV models:

1. Solid-state: deploying solid electrolytes and electrodes, they are expected to have higher energy densities compared to liquid-ion and liquid-polymer ones. The topic has been investigated in-depth since the early 2000 in the scientific literature especially in relation to EV charging [5]. Some companies, most notably Toyota, announced plans to use this technology for PHEVs, and others are investing a lot of resources in research and development (Ford, BMW, Mercedes).
   Technology readiness: Medium – demonstrated in controlled experiments, first commercial examples are close to being available.
2. Lithium-air: metal-air batteries using lithium at the anode and oxygen at the cathode to create a current flow. Using ambient oxygen theoretically leads to the highest possible specific energy, comparable to the gasoline one, and several times higher than the commercially available Li-ion ones. Considering the higher efficiency of electric motors, this technology could be a serious competitor to traditional fossil fuels, but their short lifespan [6] is currently slowing down their commercialization.
   Technology readiness: Low – available only as a concept, or in controlled experiments.
3. Graphene: graphene "doping" of traditional batteries could lead to significant improvements to the main parameters listed in Table 1, mainly due to the characteristics of graphene. Indeed, high porosity, surface area, and electric conductivity make graphene a highly suitable material for electricity storage. For EVs, this is particularly interesting for high-power charging, since the high electric conductivity of graphene-based materials can accelerate the chemical reaction in the battery and allow for fast and ultra-fast charging. Even though graphene is probably the most promising technology for EV storage [7], its high production cost and low cycling efficiencies are still hampering the development of commercial products.
   Technology readiness: Low – available only as a concept, or in controlled experiments.

2.3 Electric Vehicle Supply Equipment

2.3.1 EV Supply Equipment Standards

Several standards are used worldwide to regulate the EV charging. In the USA, SAE (Society of Automotive Engineers) standards are mostly used to regulate on and off-board charging equipment, regulate the charging voltage and current ratings, define communication standards, and wireless charging requirements. IEEE (Institute of Electrical and Electronics Engineers) standards are instead used to regulate the integration of the charging stations into the electric grid, both from an operation and a protection point of view. China also has its own charging standards, the GB/T ones, whereas

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Japan has its own CHAdeMO standards. In Europe instead, **IEC (International Electrotechnical Committee)** standards are mostly used, and Table 2 describes the most important ones:

Table 3. Relevant European EV Charging Standards and Regulation.

Name	Application	Description
IEC 61851	On and off-board equipment for charging EVs with supply up to 1 kV AC and 1.5 kV DC.	• (Part 1) General standards for cables, on and off-board chargers, and charging stations. • (Part 21) Electromagnetic compatibility requirements for residential and commercial EV charging stations • (Part 23) Requirements for DC fast-charging stations. • (Part 24) Digital communication for DC charging.
IEC 61980	Wireless power transfer for supplying voltage up to 1 kV AC and 1.5 kV DC.	• (Part 1) Characteristics, operating conditions, and required level of electrical safety of a supply device. • (Part 2) Communication between the electric vehicle and the charging infrastructure. • (Part 3) Specific requirements for magnetic field wireless power transfer systems.
IEC 62196	Plugs, socket outlets, EV connectors and inlets for conductive charging.	• (Part 1) General requirements. • (Part 2) Dimensional compatibility requirements for AC pins. • (Part 3) Dimensional compatibility requirements for DC and AC/DC pins. • (Part 4) Dimensional compatibility and interchangeability requirements for DC pins.
IEC 62840	Electric vehicle battery swap systems requirements.	• (Part 1) General overview and guidance. • (Part 2) Safety requirements. • (Part 3) Safety and interoperability requirements.
IEC 62893	Charging cables for electric vehicles for rated voltages up to 0.6/1 kV.	• (Part 1) General requirements. • (Part 2) Test methods. • (Part 3) AC charging cables. • (Part 4) DC charging cables.
ISO 15118	Vehicle to grid communication interface.	• (Part 1) General information and use-case definition. • (Part 2) Network and application protocols. • (Part 3) Physical and data link layers. • (Part 4-5) Conformance tests. • (Part 6-8) Wireless communication. • (Part 20) 2nd generation network and application protocol requirements.

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Two fundamental parts of EVSE are the charging ports and connectors, the first ones being the “socket” on the charging station, whereas the second ones are the “plugs” connecting the EV to the charging station. The main difference between the countries lies in how they design this kind of equipment.

In Europe, the regulation IEC 61851-1:2019 defines the following charging modes and related connectors:

1. Mode 1, for slow AC charging in single-phase (standard electric outlet)
2. Mode 2, for slow AC charging up to three-phase (standard electric outlet, Type 1 and 2 connectors)
3. Mode 3, for slow to fast AC charging in single or three-phase (Type 1 and 2 connectors)
4. Mode 4, for fast DC charging, produced by adding DC charging pins to the AC charging port (CCS Combo, CHAdeMO connectors)

In **Mode 1** there is no dedicated circuit or equipment for the electric vehicle charging, and the EV owner can use a standard domestic AC outlet, without any additional charging equipment. However, circuit breakers could trip in case of excessive power consumption, and a risk of fire/electroshock in case of failure is present. This is mostly used in domestic charging and generally requires hours to complete.

In **Mode 2** instead, the EV owner can use a domestic standard electric outlet, but a personal protection system is integrated in the connection cable to avoid electric shock issues. Both modes 1 and 2 are typically used by domestic chargers.

In **Mode 3**, a proper EV charging station is available and permanently connected to an AC supply network. The maximum charging power levels are higher, up to 22 kW, which enables fast charging EVs. The availability of an EV charging station allows for higher protection and safety standards, and the charging schedule optimisation, according to the users’ needs.

Finally, **Mode 4** entails the use of a DC EV supply equipment, following the specifications from IEC 61851-23:2014. The DC current is delivered directly to the battery, and the EV on-board charger is bypassed. Specific standards for communication between the EV and the charging station should be followed, as described in IEC 61851-24.

Both modes 3 and 4 are currently deployed mostly on public or workplace charging stations.

2.3.2 Charging Power Levels

The EV charging power levels can roughly be associated to the IEC 61851 charging modes, as described in 2.3.1. Even though the nomenclature frequently changes, we will stick to the following terminology for the remainder of the project: Slow, Medium and Fast-AC, and Fast and Ultra-Fast DC charging.

Table 3 summarizes the charging power levels and provides an estimate of the charging times for both PHEVs (<30 kWh, median around 12.5 kWh) and small to large BEVs (50-100 kWh).

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Table 4. Summary of Charging Power Levels and Modes as per IEC 61851 and AFID (2014/94/EU).

Name	Mode	Phases	Current (A)	Voltage (V)	Power (kW)	Battery Size (kWh)	Full Battery Charging Time
Slow AC	1 & 2	1	<16	230	<3.7	15	>4.1 h
	2 & 3	1	16	230	3.7	15	4.1 h
						50	13.6 h
			32	230	7.4	15	2 h
						50	6.8 h
Medium AC	2 & 3	3	16	400	11	15	1.4 h
						50	4.5 h
			32	400	22	15	0.7 h
						50	2.3 h
						100	4.5 h
Fast AC	3	3	63	400	44	15	0.3 h
						50	1.1 h
						100	2.3 h
Slow DC	4	N.A.	125	400	50	50	60 min
						100	120 min
Fast DC	4	N.A.	375	400	150	50	20 min
						100	40 min
Ultra-Fast DC - Level 1	4	N.A.	500	400	200	50	15 min
						100	30 min
			<437.5	800	<350	50	9 min
						100	17 min
Ultra-Fast DC - Level 2	4	N.A.	[437.5,500]	[800,1000]	>350	50	<9 min
						100	<17 min

Starting from the Slow AC power level, electric scooters, bikes, or small PHEVs can charge directly from the house plug, without a dedicated equipment. As such, the maximum allowed current is very low (under 16 A), and the full battery charging times, even for small PHEVs, is high (over 4 h). Mode 1, which is being phased out in some countries, only appears at these very low power levels. When it is instead to raise the ampere limitation to either 16 or 32 A, it is possible to charge at 3.7 or 7.4 kW. This can be either performed in Mode 2 (specific EV charging cable) or mode 3 (charging station available). Charging times vary between 2 and 13.6 h for PHEVs and small BEVs (up to 50 kWh battery size). Most of the EV owners currently charge their cars with these power levels, hence the particular importance of V1G services at the domestic sector level.

In Medium AC instead, it is possible to charge in three-phase at 400 V, the power can range between 11 and 22 kW, provided a dedicated charging infrastructure is available (Mode 3 only). 11 kW stations are also starting to be chosen by domestic customers, whereas 22 kW is frequently found in public chargers along city streets and in workplaces. Charging times range between 40 minutes and 4.5 h, depending on the EV battery size.

Fast AC chargers instead, allow for twice the charging current, so up to 44 kW of charging power, which allows for the full battery charging time to be under 2.3 h even for BEVs equipped with large batteries (100 kWh). These AC chargers are "borderline" between AC and DC charging, and are currently very difficult to be found, since the average onboard EV charger does not allow for such a high power to be charged into the battery.

Mode 4 is now also available, allowing for charging powers over 50 kW. Indeed, Slow DC charging allows for a maximum of 125 A, which are raised to 375 for Fast DC. It has to be noted that, while the charging power increases, the voltage level stays at 400 V maximum in order to match the charging voltage level of the largest part of commercially available EVs.

The Level 1 Ultra-Fast DC charging points are nowadays still not available everywhere, but will try to provide, in the close future, the same type of service that gasoline stations presently do. Since the maximum allowed current for a single cable is 500 A, the maximum charging power at this power level is 200 kW, which allows to fully charge a 100-kWh battery in 30 mins. Very few BEVs are also able to charge at 800 V, which allows for a maximum charging power of 350 KW.

The AFID directive lists Level 2 Ultra-Fast DC Charging stations as well, with charging powers ranging from 350 to 500 kW, which will be most likely used to charge heavy-duty vehicles along motorways or in gasoline stations but are nowadays not very common in the EU.

It must be noted that most of the currently available BEVs are not able to reach charging power levels over 100 kW, and that would act as the limiting factor to shorten the charging time. Hence, the full battery charging times shown in Table 3 are to be considered as a "best case scenario" with regards to power exploitation, and a "conservative" scenario when it comes to the amount that needs to be charged. Indeed, full charge events are not the norm, since people will most likely charge before the battery is completely empty.

2.3.3 Charging Policies Classification

A very important aspect when dealing with VGI is the chosen charging policy, which can either be "uncoordinated" (UC), "coordinated unidirectional" or "coordinated charging" (CC), and "coordinated bidirectional" or "bidirectional charging" (BC).

The most important distinctions come from the following three aspects:

1. **Coordination Requirement:** degree of coordination between the EVs to achieve a particular objective/target.
2. **Power Flow Direction:** which can either be uni- or bi-directional, based on the available chargers.
3. **Centralization:** possibility to have the EV deciding its own schedule, or following the signals optimized by a central aggregator.

Table 4 describes the main features of the different policies, and lists some of the available flexibility services, which are going to be described with a greater level of details in D1.3.

Table 5. Charging policies, main features and available services.

	Uncoordinated Charging (UC)	Unidirectional Coordinated Charging (CC)	Bidirectional Coordinated Charging (BC)
Smart	No	Yes	Yes
Coordination Requirement	None	Low/High	Low/High
Power Flow Direction	G2V	G2V	G2V+V2G
Centralization		Decentralized/Centralized	Decentralized/Centralized
Technological Complexity	None	Low	High
Consumer Acceptance Barrier	High	Medium	Low/Medium
Technological Readiness	High	High	Medium
Inverter Type	Unidirectional	Unidirectional	Bidirectional
Flexibility Services/Opportunities		Frequency Regulation	Frequency Regulation
		Voltage Regulation	Voltage Regulation
		Congestion Management	Congestion Management
		Improved RES Utilization	Improved RES Utilization
			Vehicle-to-grid, vehicle-to-building, vehicle-to-vehicle

"Uncontrolled" or **"uncoordinated"** charging entails each EV to connect and charge at maximum power up until the required SOC is reached. This charging policy does not require any extra equipment other than the standard charger, and potentially has the highest impact on the electric grid due to the possibility of having a high number of EVs connecting at the same moment and drawing the maximum available power from the station.

If a "smart" charging controller is added to both manage the charging rate, and modulate the power and time of charging, then **"unidirectional coordinated charging" or "controlled charging" (CC)** is possible. Such a policy allows for frequency regulation, peak-shaving, and valley-filling, as well as the provision of additional flexibility services like active and reactive power balancing and voltage regulation. It must be noted that, besides the smart charger other devices, such as the measurement ones, need to be present in order to make CC possible.

Whenever a bidirectional smart charger is instead available, power can flow both from the EV to the EV charging station, and the other way around. In **"bidirectional coordinated charging" or "bidirectional charging"**, it is thus possible to feed power back to the grid whenever required, improving the efficiency of services CC provides, and functioning as a backup power source for the grid to cover a larger portion of the grid demand with renewable energy. New services, such as "vehicle-to-grid", "vehicle-to-vehicle", and "vehicle-to-building" are also available, in this scenario.

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The Authors in [8] define the flexibility as “the power adjustment sustained by an EV from a particular moment in time, for a certain duration, at a specific location”. This definition not only includes the “magnitude” of the adjustment, but also underlines the importance of the “moment in time”, which is crucial in every type of smart scheduling mechanism. As said, in order smart chargers are the key enablers of the flexibility services provision, thus in the following section we will try to define what a “modern” smart charger should be able to do.

2.3.4 Charging Equipment

EV Chargers Classification

As shown by one of FLOW project partners, EATON, it is firstly possible to distinguish chargers based on where they are located, either on the EV itself (on-board) or in the charging station (off-board).

On-board AC chargers are lighter and more compact than off-board ones, since they need to be installed in the car. They generally allow for charging powers between 3.7 kW and 22 kW, and allow the EV owner to charge wherever any type of power supply is available.

Off-board DC chargers instead are not limited in size and weight, thus can perform fast and ultrafast charging (up to 300 kW, at present). They are however more expensive and difficult to set-up, since multiple charging ports need to be set-up for the different EV models, and more strict regulations are present for electric components protection and safety.

A second distinction, which is becoming nowadays more and more relevant, is the one between “smart” and “dumb” chargers.

Following the definition given in [9] a “dumb charger” is a “device containing circuit breakers, relays, and a voltage oscillator which maintains a constant control pilot duty cycle to charge the EV”. External scheduling devices can turn on and off the charger if needed, but no “intelligence” is present in the charger itself to perform that action.

A “smart charger” instead, contains an additional communication module that can interface with an external control signal and the ability to change the control pilot duty cycle, allowing to shift the charging session starting time, and modulate the instantaneous power absorbed during the process [9]. Some smart chargers already implemented the possibility to perform phase curtailment and balancing, in order to switch from a 3-phase to a 1-phase supply. This ability is needed for single-phase residential connections, and benefits the prosumers when paired with single-phase photovoltaic installations. Phase curtailment can also be used to balance the grids, in case discrepancies in the loading levels of the single phases arise in time.

Contemporary Smart Chargers Capabilities

The capabilities of a representative sample of commercially available smart chargers are reported in [9], concerning user interaction, status information, electric parameters, and physical properties. The part of the review most relevant to the FLOW project is, however, the one detailing the communication protocols, and available “smart” or “flexibility” features.

The study found out that all the examined chargers are controllable via the Open Charge Point Protocol (OCPP), specifically the version 1.6. Some of them are already equipped with version 2.0, which was published in 2018.

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In the communication protocols section, it is shown how most of the models tend to use 4G, followed by Wi-Fi and Ethernet. Some others also use Bluetooth and RS485.

Some "smart" features are also listed in the review, namely the possibility of modulating the power drawn from the grid (all the models can do that), and the possibility to do price-based charging (around 78% of the models). Slightly more than half of them can do power-sharing between nearby devices, or using the locally available generation, whereas 63% are able to communicate with smart home devices with the HAN (Home-Area-Network) protocol. Finally, 59% of the models can get data from the energy-meter, to allow for informed decisions based on that information.

The available "flexibility" features are instead more closely related to the grid integration part. While all the analysed chargers can shift the charging session (minimum requirement to be "smart"), the vast majority can effectively modulate the charging current, whereas only a few can perform three-to-one phase switching.

V2G chargers instead, should also be able to reverse the power flow and discharge the battery through a bidirectional inverter. One of the first commercially available models from some of the FLOW partners are the Fermata and Virta V2X Wallbox by Heliox, or the Juice2Grid 15 kW DC V2G used by Enel X Way in different R&D projects. The latter model includes V2G and V2B (vehicle-to-building), and mostly serve the passenger market. The latter has already been tested in several projects. High-power bidirectional chargers are also available in the same catalogue, mostly for depot charging of heavy-duty vehicles.

3. EVs Mass Deployment Scenarios

In order to support FLOW's activities in the next months, we present an overview of the possible EV mass deployment scenarios, both in the European Union and FLOW's main demo countries (Italy/Spain/Denmark). The analysed time horizon is 2030 for the EU, and 2040 for the demo countries due to the availability of the analysed data.

Three parameters are going to be analysed:

- **EV fleet size** (if possible, split between BEVs/PHEVs and cars/vans).
- Associated **total yearly electricity demand** for electromobility in TWh.
- Recommended **public EV charging installed capacity** in GW**.**

The analysed data comes from different European and national sources, which group the vehicles in different ways and sometimes do not provide all the required parameters.

As such, several common underlying assumptions had to be made:

1. BEVs are assumed to consume around 2.05 MWh per year, around 30 km/day and 11300 km/year, which is the EU average value. Assuming the overall driving efficiency of an EV to be 0.2 kWh/km [10], and the minimum size of a BEV to be 25 kWh, the estimated driving range is 125 km, more than enough for daily commutes. However, this is a specifically strong assumption for PHEVs, since their batteries are smaller. As the median PHEV battery size is 12.5 kWh, following the same approach, it is possible to drive 62.5 km with one charge, which is still enough to cover the daily 31 km. For the sake of simplicity, the average consumption of

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a PHEV was considered as high as the BEV one, albeit with a higher frequency of connecting to a station and charging.

2. In order to obtain the required public EV charging power to supply the electricity demand for EVs, the "recommended" installed kW capacity per EV ratios found in ICCT's review [11] of the AFID proposal were considered. Those values are reported in Table 5, and assume that at the "early stages" of EV adoption, when EVs account for up to 2% of the total vehicles, the utilization of the public charging stations is less efficient, thus a higher installed charging power is required per EV. Whenever the 20% mark is reached, these values collapse to the AFID proposed ones for 2030. Note how 0.55 is slightly lower than the 0.66 proposed by AFID for PHEVs, but for the sake of homogeneity we used the ICCT values throughout the whole document.

Table 6. ICCT's "recommended" kW/EV ratios, based on the EV penetration levels.

EVshare [%]	kW/BEV	kW/PHEV
2%	2.1	0.95
10%	1.25	0.625
20%	1	0.55

3. We only consider light-duty vehicles in the calculation, so cars and vans. For the sake of simplicity, buses and trucks are not considered in the calculations, thus their required consumption is detracted from the total electricity demand for e-mobility in every scenario. That helps as well with the estimation of the required installed charging power since the average consumption per EV can be considered as in 1).
4. In estimating the "recommended" installed EV charging capacity, we do not consider that domestic charging stations are going to be available. That is a very strong assumption, which could be true mostly in cities, where people will be relying on public charging due to the lack of space to install a domestic charging station. Thus, the recommended EV charging power levels are very "conservative", since a sizeable part of the energy requirement will be covered by domestic EV stations.

3.1 European Union

The following tables are based on the "policy" scenarios available in IEA's Global EV Data Explorer, and complemented by the EV market data from the EU Alternative Fuels Observatory.

Several scenarios are identified:

- **STEPS:** "Stated Policies" scenario, reflecting the current policies in place in the different EU countries. Provides a benchmark to assess the limitations of recent developments in energy and climate policies.
- **APS:** "Announced Pledges" scenario, assuming all the climate commitments made by governments, as well as universal access to energy, are met in full and on time. The objective is highlighting the difference compared to the Paris 2015 agreement goals.
- **NZES:** "Net-Zero Emissions" by 2050 scenario, which assumes the energy sector to achieve net—zero CO2 emissions by 2050 without relying on emissions reductions from outside the energy sector itself.

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- **MARKET AFO:** based on an interpolation of the EV market sales data from the Alternative Fuels Observatory from the last 10 years, a "trend" is extrapolated, to understand how the market could behave by 2030.

Table 7. Number of EVs in Europe between 2020 and 2030.

EV Fleet	STEPS		APS		NZES		MARKET AFO	
	BEV	PHEV	BEV	PHEV	BEV	PHEV	BEV	PHEV
Year	Cars							
2020	1.80E+06	1.40E+06	1.80E+06	1.40E+06	1.80E+06	1.40E+06	1.80E+06	1.40E+06
2025	1.10E+07	8.90E+06	1.30E+07	8.80E+06	1.40E+07	1.15E+07	2.88E+06	2.65E+06
2030	2.80E+07	2.10E+07	4.10E+07	1.80E+07	5.49E+07	3.45E+07	8.11E+06	9.07E+06
Year	Vans							
2020	1.50E+05	7.30E+03	1.50E+05	7.30E+03	1.50E+05	7.30E+03	1.50E+05	7.30E+03
2025	1.40E+06	1.20E+05	1.70E+06	1.80E+05	1.78E+06	2.30E+05	2.01E+05	1.24E+04
2030	4.90E+06	4.30E+05	6.60E+06	6.40E+05	8.38E+06	1.29E+06	3.01E+05	3.11E+04

Table 8. Required electricity demand.

Electricity Demand [TWh]	STEPS		APS		NZES		MARKET AFO	
	BEV	PHEV	BEV	PHEV	BEV	PHEV	BEV	PHEV
Year	Cars							
2020	4.10	0.76	4.10	0.76	4.10	0.76	4.10	0.76
2025	23.00	20.00	28.00	20.00	28.62	23.48	5.90	5.42
2030	58.00	37.00	88.00	43.00	112.48	70.72	16.59	18.57
Year	Vans							
2020	0.53	0.01	0.53	0.01	0.53	0.01	0.53	0.01
2025	4.80	0.96	6.10	1.00	6.24	1.17	0.70	0.06
2030	17.00	3.10	23.00	4.00	29.40	6.58	1.05	0.16

Table 9. Recommended public charging installed power.

Recommended EVSE Capacity [GW]	STEPS	APS	NZES	MARKET AFO
2020	5.43	5.43	5.43	5.43
2025	21.14	23.99	27.02	5.52
2030	44.69	57.85	83.04	13.41

In the STEPS and APS scenarios, which are "policy based" ones, the pledges from the different governments in terms of number of EVs are considered. Assuming those pledges are met, those numbers add up to the total EV fleet size, from which the energy demand and recommended charging installed power is estimated. The NZES scenario instead, starts from the final objective of reaching net-zero emissions by 2050 in the energy sector, while the MARKET AFO one interpolates the EV sales market data over the last 10 years and derives a possible future prediction, which of course is highly dependent on the market fluctuations.

As it is possible to see from the EV fleet numbers, the EU estimate of 30 million EVs on the road by 2030 is reached before 2030 in the NZES scenario only and surpassed by all the "policy" scenarios by 2030. We can thus conclude that the AFID estimated number of EVs is lower than the EV fleet size promised by the "actual" and "announced" pledges, and much lower than the required net-zero emissions target. The EV sales do not overcome the AFID estimate by 2030, but rapidly increase from 2025 to 2030, thus if the market trend stays the same, we should reach 30 million EVs shortly after 2030.

When it comes to the electricity requirement instead, considering the EU electricity demand was 3700 TWh in 2020, the yearly increase by 2030 would be around 5.9% in the NZES scenario. Covering that demand, even including the electrification of the heating sector, should not pose any threats in terms of energy supply.

From the power perspective, instead, the maximum installed capacity for charging EVs could reach 83 GW by 2030. Considering a coincidence factor of 0.33, which is a good value for public charging places with a 22 kW max charging power [12], the additional power demand translates into a 15% increase of the EU 540 GW peak load consumption (registered in 2017). From these rough estimates, we can conclude that providing the instantaneous power to charge the EVs could pose more challenges than providing the required energy.

3.2 Demo Countries

Since a lot of FLOW's activities take place in the three main demo countries (Spain, Italy and Denmark), we felt like it could be interesting to take a look at how the EU numbers translate in the different demo countries.

Compared to the EU scenarios, a few key differences exist:

1. The information starts to be less linked to global emission targets scenarios, and more related to market data surveys from different associations operating in the countries. That means current numbers are more accurate, but the predictions for distant time horizons are less accurate.
2. The numbers start to depend much more on country-specific parameters, such as electricity cost, development of the charging infrastructure, drivers' population, and willingness to switch from ICEVs to EVs.

3.2.1 Italy

For Italy, the three main scenarios described in the TERNA-SNAM 2022 Scenarios Description document are investigated: a "late transition" one, based on the 2019 Integrated Energy and Climate National Plan (PNIEC), and two fit-for-55 (FF-55) ones, complying with the EU recommendations of 55% reduction of the emissions by 2030 by means of low carbon-intensive technologies, EVs included.

The data from the scenarios was cross-checked and homogenised with ARERA (Autorità di regolazione per energia reti e ambiente – the Electric Market Italian National Regulatory Authority)'s consultation

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document 449/2022 and with the various yearly reports from the Motus-E association, providing market analysis data.

More specifically, the investigated scenarios are:

1. **LT (Late Transition):** does not consider the recent developments in European policies, such as the ban on petrol cars by 2035. The latest policy targets would be reached 5-10 years later than described by the FF-55 and DE/GA scenarios.
2. **GA-IT (Global Ambition-Italy):** bridges the FF55 scenario, ending in 2030, to the 2050 net-neutrality target. As such, it envisions the use of biomethane, hydrogen, and electricity in the transportation of both people and goods.
3. **DE-IT (Distributed Energy-Italy):** closely related to the GA-IT one, envisions the use of electricity for people and light goods transportation, whereas alternative fuels are going to be used for heavy-goods transportation only.

It must be noted, however, that while the GA-IT envisions a reduced development of distributed energy technologies, DE-IT forecasts a much higher increase in distributed generation and storage technologies as well.

Table 10. Circulating EV fleet in Italy for the different considered scenarios.

EV Fleet	LT		GA-IT (FF-55)		DE-IT (FF-55)	
	BEV	PHEV	BEV	PHEV	BEV	PHEV
2021	1.25E+05	1.19E+05	1.25E+05	1.19E+05	1.25E+05	1.19E+05
2030	4.00E+06	2.00E+06	8.00E+06	2.50E+06	8.00E+06	2.50E+06
2040	1.01E+07	5.03E+06	1.25E+07	1.50E+06	1.40E+07	1.50E+06

Table 11. Required electricity demand for EVs in Italy.

Electricity Demand [TWh]	LT	GA-IT (FF-55)	DE-IT (FF-55)
2021	0.49	0.49	0.49
2030	21.00	34.00	34.00
2040	55.00	51.00	64.00

Table 12. Recommended installed EV charging capacity in Italy.

Recommended EVSE Capacity [GW]	LT	GA-IT (FF-55)	DE-IT (FF-55)
2021	0.38	0.38	0.38
2030	5.10	9.38	9.38
2040	12.83	13.33	14.83

In 2021, the number of BEVs was equal to the PHEVs one, which confirms that the transition to a full-electric mobility is still underway. The biggest increase in the number of EVs is expected to happen

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between 2021 and 2030 for all the scenarios, around 10 times the increase happening between 2030 and 2040.

DE envisions 1.5 million BEVs more than GA-IT by 2040, which equals 10% of the total number of BEVs. The main driver behind the EV fleet increase from the LT to the GA and DE scenarios is the increasing number of BEVs, which are twice the PHEVs in LT, but account for 3-10 times the PHEVs in GA and DE by 2030-2040.

The difference between the DE and GA scenarios, instead, increases when we look at the energy demand, with the GA being lower than the LT scenario by 2040, due to biofuels and hydrogen covering a sizeable part of the energy demand for mobility.

The installed public charging capacity of 326 MW in 2022 from both Motus-E and ARERA is around 0.9 times the recommended power by ICCT. However, by 2040, the recommended installed EV capacity following ICCT's recommendation raises up to 13-15 GW for DE and GA, so the current installed power is only 3.5-6.4% of the charging power required in 2030 by both ICCT and AFID, highlighting the steep increase in charging power required to cover the increasing number of EVs.

At the single country-level, it is useful to compare the number of EVs to the population as well. By 2030, Italy should have around 6-10 million EVs, which means that one in 6-9 people has an EV. The current circulating fleet of cars (ICEVs included) is around 38 million, with 1.3-2 million new cars registered per year.

3.2.2 Denmark

For Denmark, the two scenarios presented in Bilstatistik.dk (the former sector organisation for Danish car importers) are considered.

The first one, named "SLOW transition", envisions around 1 million BEVs on the road by 2030, whereas the second, named "FAST transition", envisions around 1.5 million BEVs by the same year.

Table 13. Circulating EV fleet in Denmark, based on the analysed scenarios.

EV Fleet	SLOW		FAST	
	BEV	PHEV	BEV	PHEV
2021	5.29E+04	6.78E+04	5.29E+04	6.78E+04
2030	7.02E+05	3.01E+05	1.07E+06	4.59E+05
2040	1.35E+06	5.34E+05	2.09E+06	8.50E+05

Table 14. Required electricity demand for EVs in Denmark.

Electricity Demand [TWh]	SLOW	FAST
2021	0.25	0.25
2030	2.05	2.81
2040	3.86	5.37

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Table 15. Recommended installed EV charging capacity in Denmark.

Recommended EVSE Capacity [GW]	SLOW	FAST
2021	0.18	0.18
2030	1.07	1.63
2040	1.64	2.56

It must be noted that, since no predictions were available for 2040, we assumed that between 2030 and 2040, the same increase in EV fleet happening between 2020 and 2030 will occur.

Once more, the main driver behind the increasing EV fleet are the BEVs, which increase from being 78% of the PHEVs, up until 2.3 times their number in 2030 and 2040.

The electricity consumption also sharply increases, around 8-11 times between 2021 and 2030, and almost twice between 2030 and 2040.

The recommended installed EV charging capacity also increases by 6-9 times between 2021 and 2030, while the increase between 2030 and 2040 is around 1.5 times. The current installed power is around 181 MW in 2021, which is 3% more than the recommended value by ICCT. By 2030, the current installed power will be 11-17% of the value recommended by ICCT, and 13-20% of the value recommended by AFID, highlighting once more that a lot of charging power will need to be installed to meet the EV fleet targets.

By 2030, Denmark should have around 1-1.5 million EVs, which means that one every 4-6 people has an EV, a much higher proportion than the one seen in the Italian scenarios.

3.2.3 Spain

Regarding electro-mobility, the situation in Spain is similar to the one in Italy, since both the countries share some economic similarities, and their EV market is still undergoing rapid transformations.

As such, the first scenario we analysed is the MARKET ANFAC one, where the EV sales data coming from the Spanish Association of Automobile and Truck Manufacturers (ANFAC) in its 2021 annual report and position paper. Secondly, we analyse the Integrated National Plan for Energy and Climate (PNIEC) estimates, predicting around 5 million EVs and 400000 public charging points by 2030.

Table 16. Circulating EV fleet in Spain, based on the analysed scenarios.

EV Fleet	MARKET ANFAC		PNIEC	
	BEV	PHEV	BEV	PHEV
2021	7.13E+04	8.30E+04	7.13E+04	8.30E+04
2030	3.08E+06	3.50E+05	3.50E+06	1.50E+06
2040	7.75E+06	8.81E+05	8.81E+06	3.77E+06

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Table 17. Total yearly electricity demand from EVs in Spain.

Electricity Demand [TWh]	PNIEC	MARKET ANFAC
2021	0.32	0.32
2030	17.50	12.00
2040	45.83	31.42

Table 18. Recommended EVSE Capacity in Spain.

Recommended EVSE Capacity [GW]	PNIEC	MARKET ANFAC
2021	0.23	0.23
2030	5.31	4.07
2040	10.88	8.23

Note how the proportion between BEVs and PHEVs was kept constant at 70% vs. 30% for 2030 and 2040, which is ANFAC's target in its "Barómetro de la electromovilidad".

At present, in Spain, the circulating EV fleet is composed by 71300 BEVs and 83000 PHEVs, a value between the ones seen in Italy and Denmark. The PNIEC scenario foresees a sharp increase in the EV numbers from 2021 to 2030 (BEVs increase by 49 times and PHEVs by 18 times). The estimates from ANFAC instead, show that the increase in PHEVs will be much lower around 4 times, and much lower than the BEVs increase, which is comparable to the one from PNIEC. This creates a 1.57 million EVs difference between the PNIEC and ANFAC estimates, which means that the market needs to quickly ramp up in the next years to get to the levels forecasted by PNIEC.

The connected electricity demand abruptly raises from 0.32 TWh in 2021 to 17.50 TWh (55 times higher) in 2030, whereas a 2.6 times increase is forecasted between 2030 and 2040. Since the number of PHEVs in 2030 is much lower in the ANFAC scenarios, the electricity demand is also lower, so the 2021-2030 increase is around 38 times, still a sizeable increase.

The recommended installed charging capacity raises from the 230 MW for 2021 (actual installed power is already 20% more than that), to 4-5.3 GW in 2030, and 8.2-11 GW in 2040. The currently installed power is thus 5-6% of the values recommended by ICCT and AFID by 2030 and suggests once more that the installed power also needs to sharply rise to meet the EVs demand.

By 2030, Spain should have around 3.1-5 million EVs, which means that 1 person out of 9-14 will have an EV, a proportion close to the Italian one.

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4. Mobility trends

4.1 Car Sharing and New Vehicle Ownership Models

Car sharing can be described as a practise where people can use multiple vehicles, which are shared by a for-profit or non-profit organisation in exchange for a fee [13]. It follows the idea of providing individual access to shared vehicles as an alternative to private vehicle ownership, public transportation, cycling and walking. In addition to the traditional car sharing systems based on fixed stations, new types of cars sharing systems such as “free-floating car sharing” and “peer-to peer car sharing” have developed [13]. In station-based systems, vehicles are available at specific locations and their use is usually limited by having to return the EV where it was rented. “Free-floating” car sharing schemes are more dynamic and offer users more flexibility as they can use public parking spaces to pick up and return the vehicle more easily. “Peer-to peer” car sharing is a form of car sharing where private owners temporarily share their private vehicle with other citizens in exchange for money. Car-sharing can reduce car ownership [13], lead to a reduction of travelled kilometers [14], and emissions [15]. However, one of the main motivations for car sharing use is the reduced costs comparing to owning a car, the increased flexibility and the environmental aspects [16]. On the other hand, a study on European car sharing schemes suggests that car sharing has a much smaller impact on reducing car ownership than described in other studies [17]. The success of car sharing schemes depends more on local factors such as infrastructure and accessibility than on general transport [17]. Thus, the main influencing factor for switching to car sharing services compared to private cars is the frequency of use of the service. The more kilometres users drive with these cars, the more likely they are to sell a private car [18]. A Free-floating car sharing membership also has a positive effect on reducing car ownership as well as a changing household composition, access to private parking and the initial number of cars in the household [19].

Some car sharing providers are willing to switch to electric vehicles. However, for this to happen, authorities need to develop the infrastructure to support electric vehicles, e.g., by creating more accessible charging stations in the city and suburbs, as well as reasonable charging prices [13]. The use of electric vehicles in car sharing would lead to a reduction in energy consumption by up to 47% and a corresponding reduction of CO2 emissions by up to 65% [20]. In addition, people's awareness of electric vehicles can be raised, which promotes the diffusion process in society and plays an important role in reducing CO2 emissions and improving urban mobility [21].

4.2 Mobility-as-a-service and Multi-Modal Transportation

In addition to buses, trains, private cars, scooters and bicycles, carsharing services complement the modern multimodal transportation system. They are an efficient and flexible mode of transport that has an impact on urban mobility and quality of life [22]. In addition to a reduction of private car ownership, less urban space for parking facilities will be required if shared vehicles replace privately owned cars due to high utilisation [22]. Studies show that free-floating car sharing is mainly a substitute for public transport and to a lesser extent for cycling and owning a car [22]. For the use of car sharing systems, in addition to the possibility to reserve a vehicle, a reduced access and parking search time are also seen as important factors [22].

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The integration of bicycles and public transport use into a multimodal mobility behavior provide additional sustainable and pro-environmental benefits [23]. Despite the known positive environmental effect of multimodal sharing systems, such services are relatively novel and often not comparable, due to city-specific solutions, even within a single nation [24].

Vehicles and buses are embracing electrification as well. In the public transport sector, the adoption of electric buses is now accelerating worldwide [25]. In Western Europe, the number of new electric buses registrations was 2062 in 2020, which is almost four times increase compared to the 562 buses registered in 2018 [25]. However, the growing popularity of electrified transport requires a similar expansion of the charging infrastructure [25]. Not only the number of charging points would increase, it would also lead to a development of shared charging hubs to provide integrative energy management for electric vehicles and buses [25]. The advantages of shared charging hubs lie in the cost-effectiveness and use of shared power equipment e.g., distribution wires, converters, inverters, and sub-stations [25]. This would result in a transport expansion without additional equipment costs and space. In addition, the shared charging stations allow coordinated charging between electric vehicles and buses, reducing peak electricity demand at the charging stations, and saving both the initial investment in the power supply equipment and the long-term charges for peak electricity demand [25].

4.3 Autonomous Driving

Automation is generally defined as “the execution by a machine agent (usually a computer) of a function that was previously carried out by a human” [26]. One relevant research area is the automation of driving, which has been developed in the last years [27].

The motivation behind this progress is a considerably number of positive aspects regarding the traffic flow, environment and the driver itself. In particular, it is expected that the automation of driving will lead to an improvement in traffic flow, the reduction of congestions, consumption and emissions as well as to an increased road safety. The positive effects in the field of electro mobility can be found primarily in a significant reduction in energy consumption while driving and the associated achievement of higher driving ranges [28]. Automated vehicles may require less powerful engines and obtain reduced congestions and more homogeneous traffic flows. Further, a shorter searching time for parking lots and charging stations will be expected. Moreover, the driver will be relieved since the driving task is simplified. As a result, driving and charging will be perceived as more comfortable, and an increased mobility can be expected – especially for elderly people or persons with disabilities [27][29].

Nevertheless, there are also some challenges, which are currently being addressed in the recent research on human factors, i.e., driving style and comfort, acceptance and trust, communication and interaction with automated vehicles, drivers awareness, and takeover request [30].

5. Disruptive charging technologies

The scope of FLOW is primarily the use of conductive, mode 3 and 4,- uni- and bi-directional charging, as described in section 2, as these technologies are bound to dominate the market on the short and medium term (next 5-10 years), and will therefore be the primary charging technologies supporting the large-scale diffusion of EV foreseen by the EU commission (see D1.1).

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There are, however, technologies which may disrupt and fundamentally alter how, where, and when electric vehicles will recharge their batteries. These developments are important to consider and foresee as they in turn may alter the VGI challenges and potentials.

In this section we will briefly describe some of these technologies, their prospects, and describe the possible impact they may have on VGI.

Some technologies like dynamic wireless charging, pantograph charging, and catenary charging are not included here as they are primarily aimed at heavy-duty vehicles, which are outside of the scope of FLOW.

5.1 Inductive (Static)

Also named “wireless” or “magnetic” makes use of an electromagnetic field to charge the battery, thus not requiring any cabling. The energy is transferred between an underground coil, and one installed in the vehicle assembly. A fluctuating magnetic field is generated by an alternating current flowing in the transmitting coil at a specific frequency. The magnetic field then induces a current in the receiving coil. For destination charging, power options are available similar to conductive charging with ~3, 11 and 22 kW. Wireless charging also address opportunity charging with higher power levels though this market is not as mature. The efficiency of wireless charging typically spans between 88- 95 %. It also is possible to support V2G through inductive charging.

Prospects

Pros

- Added convenience to the user.
- A technological match for autonomous vehicles.
- A potential for added availability and charging flexibility because the users may spend more time connected to the grid.

Cons

- Higher costs compared to conductive charging.
- Supported charging power levels are still slightly lower than the range offered by conductive charging – especially for fast charging.
- Standardization and interoperability at the early stages.
- Need to interact with control systems by different companies, usually protected by trade secrets.
- Slightly higher losses than conductive charging.

Assessment

Wireless charging will likely not overtake conductive charging in the short or medium term (5-10 years) but is still likely to be disruptive on the long-term due to the offered convenience, and the efforts to improve efficiency, harmonization and costs.

Impact on grid integration

As EV owners, using inductive charging at private houses, are not required to manually connect the car, it is possible that EVs will connect more often and therefore be available to participate in grid services for a larger fraction of the time. As such inductive charging may strengthen the potential for VGI services. While bidirectional charging can be supported - the slightly lower charging efficiency may become an issue as the total accumulated losses of charging/discharging should be kept as low as possible.

5.2 Battery Swapping

"Swap" stations should contain and manage several batteries where a fully automatic system would replace depleted batteries with fully charged ones in a matter of minutes. The solution is primarily seen as a support for range extension for electric vehicles travelling longer distances. A very efficient, widespread, and cost-efficient system may ultimately mean that the technology could compete with destination charging.

A battery swapping station may be able to manage and optimize the charging according to energy prices or renewable energy availability. Furthermore, it may aggregate the batteries to perform several grid services.

However, the concept requires the customer to participate in a "sharing scheme" where the battery is not owned by the user itself, but rather by the company providing the service – i.e., Battery-as-a-Service (BaaS).

Prospects

Pros

+ Added convenience for the user.
+ Strong support for range extension.
+ May allow stations to optimize battery charging and perform grid services.
+ Battery-as-a-service schemes may lower vehicle upfront costs and remove degradation concerns from the user.

Cons

- Lack of harmonization/adoption across car brands could be an obstacle to its diffusion.
- Standards are not yet fully developed.
- Uncertain prospects (customers take a risk if the technology is discontinued).
- High investment costs due to the advanced automation needed.
- Users must accept the BaaS model to participate.
- The few projects started in the past years were not successful in developing a solid business model for BaaS.

Assessment

Battery swapping has been proven to be technically feasible, but a large uncertainty lies in the lack of harmonization across car brands, and whether it will be able to compete with high power charging. Battery swapping is not seen as a competitor to conductive charging in the short- or medium-term, but can have a large effect on long-haul travel, if successful.

Impact on grid integration

Battery swapping stations may be able to manage how and when the batteries are charged (within the constraints imposed by the users' need for battery replacement), and may also aggregate the individual batteries, acting as "one large battery" to offer grid services.

Swapping stations will then be able to add more flexibility from EV batteries to the grid. If battery swapping ultimately replace destination charging, it would contribute to a general centralization effect of the transportation sector, which would interact with the grid in fewer places but with greater volumes of energy and power.

5.3 Ultrafast DC (Level 2) with Battery Storage

This technology allows EVs to charge with charging powers that exceed what is possible today (>350 kW). This would be based on an extension of the Combined Charging System (CCS) standard which currently allows up to 350 kW.

The charging would rely on off-board DC charging, where the charging station converts the power to DC current and provides it directly to the vehicle battery through the DC contacts of an IEC 62196-type connector. The high power would likely necessitate the vehicle to be based on a high-voltage battery system (i.e., 800V). This would bring charging time down to < 10 minutes.

It is expected that future ultrafast DC charging stations will be equipped with energy storage as to reduce consumption peaks. Though the primary purpose may be to reduce grid related costs while meeting the peaks in charging demand – smart charging of the energy used at the station and the provision of grid services may be secondary objectives.

Prospects

Pros

+ Added convenience to EV drivers.
+ A strong support for long-haul driving.
+ Direct extension of existing standards and technologies which may make the solution more feasible.
+ Battery storage may increase the stations' potential for grid integration.

Cons

- Neither standards nor vehicles are ready to support level 2 ultrafast DC charging.
- Technical challenges are present, such as cable cooling and vehicle support.
- Aggravates the existing challenge of getting and paying for the needed grid capacity and would likely heavily rely on local battery storage.

Assessment

This technology builds on a more direct evolution of the fast-charging technology used today and the likelihood of its success is therefore greater. Still, there are several technical and cost barriers which will delay the introduction of level 2 ultrafast DC charging – including high-voltage systems, vehicle support and power capacity costs. While the likelihood of disruption may be greater than that of wireless charging and battery swapping – it is not expected that this technology will significantly supress or replace known charging technologies in the short or medium term.

Impact on grid integration
As is the case for battery swapping, it is the inclusion of additional battery storage at the charging station that may allow for charging flexibility and grid services. Theoretically, the technology can be improved to a point where it may challenge traditional AC destination charging and re-introduce the gas-station approach that ICE cars drivers have grown accustomed to. If so, this technology will considerably alter VGI and make the ultrafast charging stations the primary connection point between EVs and the grid, whenever domestic charging is not an option.

6. Charging Locations, Demand, and Flexibility

6.1 Factors Influencing EV Charging

Charging demands

The "charging behavior" can be described as the result of the EV user's decision to charge his EV, when, where and for how much time he desires to do so [31], [32]. The vehicle range is one of the most important attributes for EV users [33]. Studies have shown that EV users are willing to pay more for an increase in the minimum guaranteed charge per charging session, resulting in an additional driving range [34]. The demand for a high minimum charge can be explained by the fear of restrictions on personal freedom and independence [34]. Indeed, the minimum state of charge of an EV, the charging time, and the availability of fast charging stations are also important requirements for the EV users [35] and the stability of the charging network [36].

Charging patterns

There are three main types of factors influencing charging patterns: factors related to the driver, to the charging infrastructure, and to the EV [31]. Driver-related charging factors include the time the driver feels the intention to charge his EV [31], the EV driving experience, the willingness to plan a trip and charging process, and the social interaction [31]. The more experience, the more consistent the charging behavior becomes. Furthermore, there are groups of EV users that carefully plan to charge on trips and users that decide to charge as soon as they see a free charging spot [31]. The infrastructure-related factors describe the interaction between the user and the charging infrastructure. They include the charging point area or density, parking pressure, the ratio of types of charging points, and infrastructure policy. For example, there is a difference in charging behavior in busy or steady situations and in high or low parking pressure environments [31]. Vehicle-related factors such as vehicle type, battery size, range, and energy consumption, are the third factor influencing charging behaviour, mostly influencing the charging frequency and the energy[31].

6.2 Charging Session Types

Besides these factors, EV users differ in their charging sessions. Three categories are distinguished: daytime medium duration charging sessions, short duration charging sessions, and overnight charging sessions [32]. The daytime medium duration charging sessions typically lasts from 8 am to 6 pm and usually takes place on weekdays [32]. The locations of these sessions are mostly the same as the previous ones, indicating that this type of session is closely related to work [32]. Visitors also charge their EV during the day, but they are expected to have irregular arrival patterns and are more likely to

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charge at weekends than on weekdays [31]. On the other hand, short daytime charging events, also called "opportunity charging", have a connection duration of one to two hours and occur anytime between 8 am and 9 pm [32]. The location and charging times may vary in between each session. These charging patterns are related to car sharing activities or taxi drivers [31]. Car sharing users are expected to charge at different charging points throughout the day (except for late at night) while taxi drivers charge at any location for a short time between their work shifts [31]. Finally, the most stereotypical session is the overnight charging session, which typically takes place at home on weekdays [32]. The starting time is around 6 pm and end time around 8 am [32], a behaviour which is typical for residents and commuters [31]. Residents are expected to have a clear pattern on weekdays and no fixed pattern on weekends, while commuters share this pattern but leave on the same day as they arrive [31]. Additionally, there are also atypical user types with irregular charging patterns [32].

6.3 Charging Locations

The charging demand and flexibility provision from EVs vary depending on the environment in which the charging infrastructure is established. The Danish FUSE project defined seven locations in which electric vehicles may be charged. Figure 1 illustrates these locations and how they will differ in terms of parking duration, available charging flexibility, and typical establishment costs.

In general, the majority of the overall charging demand from privately owned vehicles will have to be satisfied in the private and semi-public domain. This will make the overall charging infrastructure cheaper, more convenient, and able to provide more flexibility to the grid.

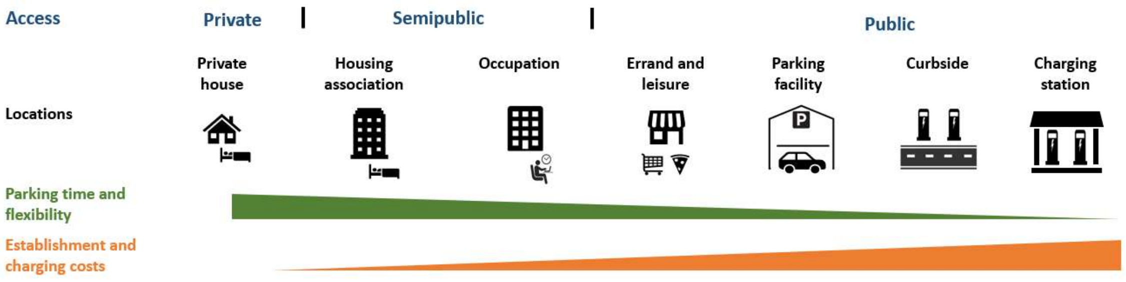

Figure 1. Private, semi-public, and public charging stations characteristics.

If the tariff schemes stay as they are nowadays, private charging points will be the most common ones, since charging at home is cheaper than in public areas. Indeed, a recent study [37] found that in the EU, charging at home costs around 0.20 and 0.35 euros/kWh (factoring in the domestic station installation costs), whereas public DC chargers range between 0.40-0.65 euros/kWh. Compared to a similar range ICEV, this study estimated a cost reduction of 51-56% for home charging, and 9-13% at a DC fast charger. However, the private charging power is limited due to cost and technical constraints, thus the parking duration will be still very high. This is generally not a problem, since EV owners are expected to charge their vehicles overnight, a behaviour which yields the highest possible flexibility profit.

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Semi-public charging points instead, are higher power chargers installed close to offices or commercial activities in cities. They can only be used by people working or spending their time there, so they are subject to opening/closing times of the commercial activity they are linked to. Their installation cost is likely to be slightly higher than the domestic ones, but can be socialised between the users charging there, making it an interesting opportunity to also provide benefits to the employees.

Finally, public charging points, especially the fast and ultra-fast DC ones installed in close proximity to locations that "aggregate" a lot of people, are the most expensive ones due to the higher safety and grid-related establishment costs. Despite the high available power, they yield the minimum flexibility value because people will most likely just charge their EVs in the shortest possible amount of time and then leave. Some cities, e.g. Rome, started to implement the possibility of leaving the car for overnight charging, which would improve the possibility to provide flexibility services.

Still, all the above charging locations are important to electrify the transportation sector, and it is therefore important to investigate and understand the VGI potentials for each. As such, the demonstration activities in FLOW will be designed to cover a location in each of the three categories – private, semi-public, and public.

In the next section we will look at examples of demand curves for such locations.

6.4 Charging Demand and Patterns

The following plots are the result of an elaboration from a dataset of charging sessions provided by one of FLOW partners, Spirii, and detail the consumption of a number of users from Denmark under a flat charging tariff.

The plots show the charging power profiles of several EVs which are connected to private, semi-public, and public charging stations, normalized by the total available charging power.

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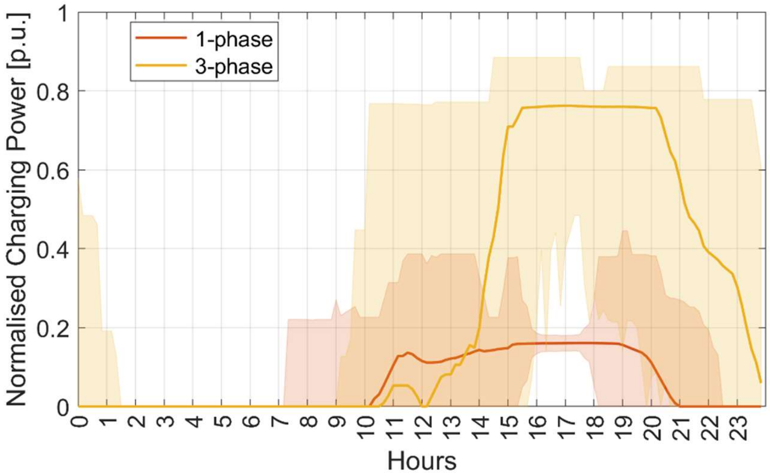

Figure 3. Example of daily private EV charging profiles. Shaded area represents the interquartile range of the distribution.

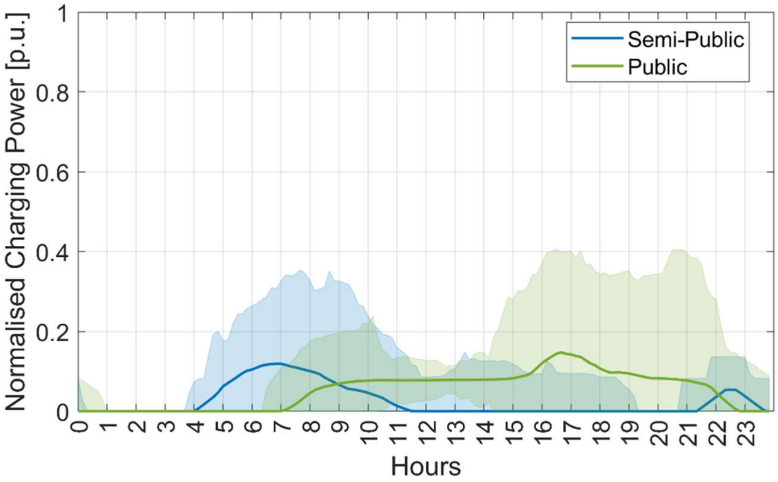

Figure 2. Example of daily public and semi-public EV charging profiles. Shaded area represents the interquartile range of the distribution.

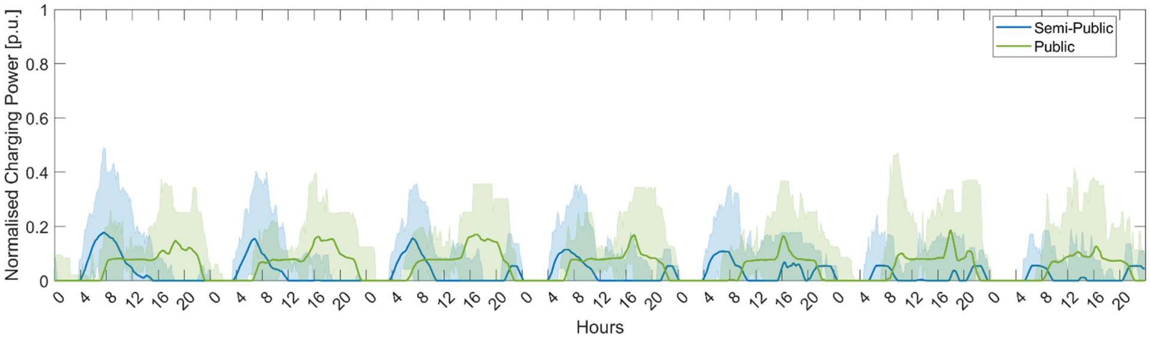

Figure 4. Example of daily public and semi-public EV charging profiles. Shaded area represents the interquartile range of the distribution.

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The private charging profiles are split into single- and three-phase connected users, based on the EV charging architecture, and are normalized by 11 kW, which is the maximum available charging power. It is possible to notice how charging mostly happens between 10 a.m. and 20 p.m., so during the day, which is unusual for private EV owners but highly depends on their routine and working habits (remote or in-office work). Three—phase charging uses all of the 11 kW, whereas single-phase uses around a third of the available power.

The semi-public chargers instead, interestingly show a peak of charging request in the early morning, when people arrive at work, around 7 a.m. The consumption then slowly lowers until 12, when most of the connected EVs are probably charged. In the weekly profiles instead, it is possible to see how the consumption lowers on Saturdays and Sundays, but it still remains noticeable.

Public charging profiles exhibit an entirely different trend. The charging power is almost constant through the day, with a higher variability noticeable between 16 and 22 p.m., most likely due to people leaving work and parking their car to charge during the early evening. During the week, consumption is constant because people are charging their cars at public stations also on weekends.

This very brief analysis highlights, once more, the importance of considering not only the users' habits but also the chargers' location and charging tariffs, in order to extract the correct information from the charging profiles and run any kind of modeling activity.

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