OVERVIEW SEEV4-CITY PLAYING FIELD

State-of-the-Art Assessment of Smart Charging and Vehicle 2 Grid services

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Executive Summary

Electro-mobility – especially when coupled smartly with a decarbonised grid and also renewable distributed local energy generation, has an imperative role to play in reducing CO_2 emissions and mitigating the effects of climate change. In parallel, the regulatory framework continues to set new and challenging targets for greenhouse gas emissions and urban air pollution.

- EVs can help to achieve environmental targets because they are beneficial in terms of reduced GHG emissions although the magnitude of emission reduction really depends on the carbon intensity of the national energy mix, zero air pollution, reduced noise, higher energy efficiency and capable of integration with the electric grid, as discussed in Chapter 1.
- Scenarios to limit global warming have been developed based on the Paris Agreement on Climate Change, and these set the EV deployment targets or ambitions mentioned in Chapter 2.
- Currently there is a considerable surge in electric cars purchasing with countries such as China, the USA, Norway, The Netherlands, France, the UK and Sweden leading the way with an EV market share over 1%.
- To enable the achievement of these targets, charging infrastructures need to be deployed in parallel: there are four modes according to IEC 61851, as presented in Chapter 2.1.4.
- The targets for SEEV4City project are as follow:
    - Increase energy autonomy in SEEV4-City sites by 25%, as compared to the baseline case.
    - Reduce greenhouse gas emissions by 150 Tonnes annually and change to zero emission kilometres in the SEEV4-City Operational Pilots.
    - Avoid grid related investments (100 million Euros in 10 years) by introducing large scale adoption of smart charging and storage services and make existing electrical grids compatible with an increase in electro mobility and local renewable energy production.
- The afore-mentioned objectives are achieved by applying Smart Charging (SC) and Vehicle to Grid (V2G) technologies within Operational Pilots at different levels:
    - Household.
    - Street.
    - Neighbourhood.
    - City.
- SEEV4City aims to develop the concept of 'Vehicle4Energy Services' into a number of sustainable business models to integrate electric vehicles and renewable energy within a Sustainable Urban Mobility and Energy Plan (SUMEP), as introduced in Chapter 1. With this aim in mind, this project fills the gaps left by previous or currently running projects, as reviewed in Chapter 6.
- The business models will be developed according to the boundaries of the six Operational Pilots, which involve a disparate number of stakeholders which will be considered within them.
- Within every scale, the relevant project objectives need to be satisfied and a study is made on the Public, Social and Private Economics of Smart Charging and V2G.
- In order to accomplish this work, a variety of aspects need to be investigated:
    - Chapter 3 provides details about revenue streams and costs for business models and Economics of Smart Charging and V2G.
    - Chapter 4 focuses on the definition of Energy Autonomy, the variables and the economy behind it;
    - Chapter 5 talks about the impacts of EV charging on the grid, how to mitigate them and offers solutions to defer grid investments;

- Chapter 7 introduces a number of relevant business models and considers the Economics of Smart Charging and V2G;
- Chapter 8 discusses policy frameworks, and gives insight into CO_2 emissions and air pollution;
- Chapter 9 defines the Data Collection approach that will be interfaced with the models;
- Chapter 10 discusses the Energy model and the simulation platforms that may be used for project implementation.

STATE-OF-THE-ART REPORT

Contents

Glossary

AC	Alternating Current
ADEME	(French) Environment & Energy Management Agency
AHF	Advanced Harmonic Filter
ANSI	American National Standards Institute
AVERE	The European Association for Electromobility
BESS	Battery Energy Storage System
BEV	Battery Electric Vehicle
BM	Balancing Mechanism
BMS	Battery Management System
BPEV	Belgian Platform on Electric Vehicles
BRP	Balance Responsible Party
BS	Black Start
BSP	Balance Service Provider
CAES	Compressed Air Energy Storage
CC	Combined Cycle
CDR	Charge Point Detail Records
CDS	Clean Dark Spread
CENEX	Centre of Excellence for Low Carbon and Fuel Cell Technologies
CHP	Combined Heat and Power
CME	Clean Mobil Energy
CPS	Contour Positioning System
CSS	Clean Spark Spread
DACF	Day-Ahead Congestion Forecast
DC	Direct Current
DG	Distribution Generation
DG CONNECT	European Commission Directorate-General for Communications Networks, Content and Technology
DNO	Distribution Network Operator
DOD	Depth of Discharge
DOE	US Department of Energy
DPP	Discounted Payback Period
DSM	Demand Side Management
DSO	Distribution System Operator
DTU	Demand Turn Up

EAN	European Article Number
EC	European Commission
EEA	European Economic Area
EECA	Energy Efficiency and Conservation Authority
EEF	Energy Efficient Frontier
EMT	Electromagnetic Transient
EMSP	E-Mobility Service Provider
END	European Noise Directive
ENTSO-E	European Network of Transmission System Operators for Electricity
EPSRC	Engineering and Physical Sciences Research Council (UK)
ERDF	European Regional Development Fund
ETS	European Trading Scheme
EV	Electric Vehicle
EVPP	Electric Vehicle Power Plant
EVSE	Electric Vehicle Supply Equipment
EVSEO	Electric Vehicle Supply Equipment Operator
EVSP	Electric Vehicle Service Provider
FCDM	Frequency Control by Demand Management
FCR	Frequency Containment Reserve
FES	Future Energy Scenario
FEV	Full Electric Vehicle
FFR	Firm Frequency Response
FIT	Feed-In Tariff
FR	Frequency Regulation
FRR	Frequency Restoration Reserve
GFCI	Ground Fault Current Interrupter
GHG	Green House Gas
GIS	Geographic Information System
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GWP	Global Warming Potential
HEV	Hybrid Electric Vehicle
HV	High Voltage
HvA	Hogeschool van Amsterdam
HVDC	High Voltage Direct Current

ICE	Internal Combustion Engine
ICT	Information and Communication Technology
ID	Identity
IDCF	Congestion Forecasts Two Days prior to real time
IEA	International Energy Agency
IEC	International Electro-technical Commission
IEEE	Institute of Electrical and Electronics Engineers
IET	Institution of Engineering and Technology
IOS	iPhone Operating System
IOT	Internet of Things
IRR	Internal Rate of Return
ISO	Independent System operator
ITSES	Integrated Transport and Smart Energy Solutions for Major Urban Developments
KPI	Key Performance Indicator
LCA	Lifecycle Assessment
LCC	Load Carrying Capacity
LCN	Low Carbon Networks
LCOE	Levelised Cost of Energy
LFP	Lithium-Iron Phosphate
LMO	Lithium Manganese Oxide
LTO	Lithium Titanate Oxide
LV	Low Voltage
MC	Minimum Cost
MCHP	Micro-Combined Heat and Power
MFR	Mandatory Frequency Response
MG	Micro Grid
MILP	Mixed Integer Linear Program
MPC	Model Predictive Control
MTCO	Modified Total Cost of Ownership
MV	Medium Voltage
NCA	Lithium-Nickel Cobalt Aluminium
NEM	Net Energy Metering
NET	Network
NEVA	Norwegian Electric Vehicle Association
NG	National Grid

NIP	Network Infrastructure Portal
NMC	Lithium-Nickel Manganese Cobalt
NOX	Nitrogen Oxide
NPV	Net Present Value
NSFC	Natural Science Foundation of China
NSR	North Sea Region
OBD	On-board diagnostics
OBIS	Object Identification System
OCHP	Open Clearing House Protocol
OD	Ozone Depletion
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OP	Operational Pilot
ORPS	Obligatory Reactive Power Service
OSS	Open Source Software
PBL	PBL Netherlands Environmental Assessment Agency
PCI	Public Charging Infrastructure
PCP	Personal Contract Purchase
PERC	Passivated Emitter Rear Cell
PEV	Plug-In Electric Vehicle
PHEV	Plug-In Hybrid Electric Vehicle
PIA	Future Investment Programme
PLDV	Passenger Light-Duty Vehicle
POF	Photochemical Oxidant Formation
PP	Pulsed Power
PV	Photovoltaic
PVPS	Photovoltaic Power System
R&D	Research and Development
RCD	Residual Current Device
RD	Regulation Down
RE	Renewable Energy
REE	Rare Earth Elements
RES	Renewable Energy Source
RFID	Radio Frequency Identity
RPM	Revolution per Minute

RTO	Regional Transmission Organization
RTS	Reference Technology Scenario
RU	Regulation Up
SAE	Society of Automotive Engineers
SCADA	Supervisory Control and Data Acquisition
SHET	Scottish Hydro Electric Transmission
SC	Smart Charging
SOA	Service-Oriented Architecture
SOAP	Simple Object Access Protocol
SOC	State of Charge
SOH	State of Health
SQL	Structured Query Language
SR	Spinning Reserve
STOR	Short Time Operating Reserve
SUMEP	Sustainable Urban Mobility and Energy Plan
SVC	Static VAr Compensator
TCO	Total Cost of Ownership
TCU	Total Cost of Use
TMH	The Mobility House
TOU	Time of Use
TSO	Transmission System Operator
UKGDS	United Kingdom Generic Distribution System
ULEZ	Ultra Low Emission Zone
UMTS	Universal Mobile Telecommunications System
UNN	University of Northumbria at Newcastle
USB	Universal Serial Bus
V2C	Vehicle to City
V2G	Vehicle to Grid
V2H	Vehicle to Home
V2N	Vehicle to Neighbourhood
V2S	Vehicle to Street
V2V	Vehicle to Vehicle
V4ES	Vehicle for Energy Service
VAT	Value Added Tax
VPN	Virtual Private Network

VPP	Virtual Power Plant
VRP	Vehicle Routing Problem
VSC	Voltage-Sourced Converter
V4ES	(electric) Vehicle for Energy Service (eV4ES)
WP	Work Package
WSDL	Web Services Description Language
XML	eXtensible Mark-up Language
ZEB	Zero Energy Building
ZEV	Zero Emission Vehicle
ZIP	Zoning Improvement Plan code

Part I: SEEV4-CITY PROJECT
1. Introduction

1.1. *Why electro-mobility?*

In recent years, a significant deployment of Electric Vehicles (EVs) and in particular electric cars, is seen around the world. In most of the mature industrialized countries, as well as in a number of key recently industrialised and still industrialising ones (China, India. Brazil) measures to facilitate the penetration of EVs in the car and van market are undertaken, and targets of EV share in national fleet have increased, although with a few exceptions (e.g. Norway) still at a low percentage basis of overall vehicles as well as new registrations, despite some ambitious national targets in different countries. Electro-mobility or e-mobility refers to vehicles that can be plugged in the electricity network and may or may not have and auxiliary internal combustion engine (ICE) [1.1].

The Global EV Outlook 2019 depicts the situation at the end of 2018 in various countries, and points out those most along the electrification of road vehicle transportation [1.2]. At the end of 2018 there were more than 198,048 electric cars in the UK, 142,686 in The Netherlands, 249,043 in Norway, 196800 in Germany, 78,228 in Sweden, 165897 in France, 2,310,000 in China, 1,120,000 in the United States and 257,400 in Japan. They still only represent penetration levels of 2.50%, 6.0%, 49.10%, 1.90%, 8.10%, 2.10%, 4.20%, 2.10% and 1.13% of the total cars registered in the respective countries [1.2]. The deployment trend is significantly increasing year by year: in 2018, new registrations of battery electric vehicles (BEVs) were more than 17,513 (UK), 23,938 (The Netherlands), 46,112 (Norway), 35,238 (Germany), 7,109 (Sweden), 30,989 (France), 984,000 (China), 241,413 (US) and 52,000 (Japan). PHEVs have increased by more than 43,115, 2,829, 26,545, 31,041,14556, 271,000, 119,894 and 23,222, respectively. Some countries are setting new targets for electric car market shares; the UK Government wants to see at least 50%, and as many as 70%, of new car sales and up to 40% of new van sales being ultra low emission by 2030 [1.3]

Further to the publicly-facing stated project justification on the SEEV4-City website – that a top priority for public authorities on all levels in the North Sea Region area is to stimulate clean transport solutions powered by clean renewable energy - we would like to address the question as to why EVs are important.

The most obvious answer comes from environmental concerns, as this is one of the main reasons for the significant Electric Vehicle (EV) adoption so far. According to the European Environment Agency [1.1], that the major environmental impacts of ICE vehicles include the emission of greenhouse gases, air pollution, and noise (as well as land consumption for the transportation infrastructure).

Emissions

While GHG emissions from all other major economic sectors have fallen in recent decades, those from transport have actually increased. In the EU, road transport's emissions are today around 1% above 1990 levels, while the contribution of road transport to total EU GHG emissions has increased by around half — from 13% of the total in 1990 to almost 22% in 2019 [1.4].
By the substitution of ICEs (petrol or diesel), these abovementioned tailpipe emissions can be completely avoided with full battery EVs, however, for hybrid Electric Vehicles this depends on the degree of electrification and driving modes. The decarbonization and cleaning that EVs can achieve depends on the energy mix as well as components [1.1]. In fact, manufacturing grid components

also cause CO_2 emissions and by deferring grid investments with controlled charging (Smart Charging or V2G), these can be saved. However, it is worth pointing out that the CO_2 emissions throughout full EV lifecycle (well to wheel, or even cradle to grave) are not zero, because in order to manufacture the physical parts (including charging infrastructure) some CO_2 has to been emitted.
The decarbonisation of the electricity used for EV charging is also of a high significance to the CO_2 emissions. This opens up a new perspective on what EVs can represent for the electric system, and the transportation service can help to achieve this goal.

Air pollution

Road transport remains an important source of harmful air pollutants such as nitrogen oxides (NOX) and particulate matter (PM). Pollution released by vehicles is particularly important for health, as these emissions generally occur close to the ground and in areas where many people live and work, such as in cities and towns. Users can contribute to improve the quality of their lives, by driving electric and reducing air pollution [1.1].

Noise

It is estimated that as of 2018 about 100 million people in the EU were exposed to excessive noise levels from road traffic noise (i.e. that are above 55 dB). Exposure to noise from night-time road traffic is also significant, with approximately 70 million EU citizens exposed to harmful levels above 50 dB [1.5].

The temporal mismatch between electricty demand and renewable energy generation output (e.g. solar PV-power) is a problem for renewable energy integration. Electric transportation presents both a challenge and an opportunity going forward, which is not just a technological but also a systems governance and behavioural one at organisational, household and individual level [1.6]. Through smart charging, PEVs offer benefits for renewables by potentially matching up the charging profile with the renewable generation output profile, and at the same time decarbonisation is achieved by replacing the conventional electricity generation for EV charging with renewable energy. If PEVs are enhanced with V2X functionalities, the renewable-integration benefits can be increased, and the use of PEVs as supply-side resources is also likely to reduce the investment costs required in other flexible power plants to accommodate renewables. The benefits do however depend on the scale of PEV adoption. This needs to be much higher than currently observed, given the significant infrastructure investments and societal and behavioural changes required for synergistic benefits to materialise at a scale useful for electric power systems [1.7].

This is where the Smart Grid concept comes in: “A ‘smart grid’ is an electrical grid which includes a variety of operational and energy measures including smart meters, smart appliances, renewable energy resources, and energy efficiency resources” [1.8]. Essentially, it is an intelligent and active grid, that instead of only providing power to the loads also optimizes the energy flow, which can be bi-directional, making the consumers more developed, interactive and smart entities: prosumers. According to the measurements, if considered profitable, the power flow can be reversed locally, making the most of what is called distributed generation, that are small generators - if sensible - aided by local storages, distributed over the territory. The energy is usually generated by photovoltaic (PV) systems, given that relatively small size local micro-grid wind generators tend not to be suitable, and it is supported by batteries, which store the energy that has not been consumed during the day, and provide it in a delayed time. This is an evolution of the conventional electrical grid towards a system that optimises the benefits of the whole structure: these include the minimisation of the losses, the maximisation of the profits of the components, stabilisation of the grid, improvement of the safety, reliability and quality of the service. With the upgrade from the current transportation technology to a more electric-driven one, EVs will play an important role in this system. However, whether EVs are going to provide a significant contribution to the Smart Grid, depends on the financial assessments and the regulatory framework [1.9]. The former is addressed with optimal business models whilst the latter refers to supportive national, regional and local policies to favour EV integration.

From the user point of view there may be some concerns about battery degradation (since this is a the most expensive component part of a BEV), and the relatively short (though expanding, and quite large with a Tesla) range of electric cars: BEVs are known to have a lower range compared to conventional ICE cars, which is mainly due to the higher energy density of fossil fuels compared to EV batteries and their volume. Regarding this issue, the remarkable progress in battery technology, specifically with regard to the predominantly used Li-ion batteries, is continuously increasing battery efficiencies and reducing their volumes for the same energy [1.2]. Battery degradation is one of the downsides that still hampers mass EV adoption. According to [1.10], after 5 years the overall capacity of the battery decreases to 80%, determining the end of the automotive scope for the battery. On the other hand, Nissan currently supplies a State of Health (SOH) warranty which covers the EV user for 5-8 years or 60,000-100,000 miles whichever occurs first, according to the size of the battery [1.11]. However, these batteries can in principle be sold as Second Life batteries, to continue their life for use as static storage; this could be considered as an extra benefit to improve the returns from the car. Besides, sometimes it is difficult to find an available charger, and even if this is available issues related to interoperability may hinder user acceptance. Moreover, according to recent surveys, there is low public awareness of the benefits an EV can give; on the other hand, negative stereotypes persist as well as inadequate know-how and information about the charging infrastructure [1.1]. However, early adopting and early following users appear keener to accept EVs nowadays because of the small fuel (electricity) costs, the better transportation efficiency (electric motors have higher efficiencies than ICEs, at maybe 90% [1.12] compared to 20-40% thermal [1.13]), fewer mechanical parts which leads to a reduction in mechanical faults and hence to less replacement needs.

1.2. *General introduction to SEEV4-City and problem definition*

The North Sea Region is most advanced in both electric vehicles (EV) and renewable energy sources (RES). But the developments of increasing amount of EVs and RES create a challenge. Renewable energy supply does not match the electricity demand from the electrical vehicles. Due to the difference in demand and supply of renewable energy electrical vehicles are not charged with renewable energy sources. Further, differences in demand and supply of electricity leads to inefficient grid use and possible instability problems. Every country in the North Sea Region faces these problems. Increasing numbers of electrical vehicles and renewable energy installations aggravate the problems. These problems are shared; all EU national electricity grids are interconnected.

The challenge is to structure the system and control it in such a way that EVs charge from locally produced renewable energy. Technically, this system is within reach and all it needs to happen is to develop appropriate business model(s) and have the right policy, incentives and disincentives (for conventional vehicles).

Electrical vehicles and renewable energy in combination with Smart Information and Communication Technology (ICT) can turn problems to solutions. These systems are often referred to as Vehicle-4-Energy-Services (V4ES) or Vehicle2Grid (V2G) systems. Within the SEEV4-City project, different levels of V4ES are integrated to:

1. Promote and prepare wider roll out of clean and zero-emission electricity for EV with the help of V4ES;
2. Demonstrate the business potential of EV where EV and RES are integrated in operational V4ES systems.

The core of the SEEV4-City project is to create a huge step forward in green city development by electric vehicles in combination with renewable energy sources and smart ICT solutions. The whole North Sea Region area is facing challenges related to reducing carbon footprint of transportation and stimulating the application of clean transport solutions powered by clean renewable energy.

1.3. *Main project objectives and research questions*

The main aim of this project is to develop the concept of 'vehicle4energy services' into sustainable (commercially and socially viable) business models to integrate electric vehicles and renewable energy in a Sustainable Urban Mobility and Energy Plan(ning process) (SUMEP).

Projects focusing on electric vehicles, RES and smart ICT conducted in Europe so far have been mostly inside university environments & small-scale innovation laboratories. Projects which apply bidirectional energy flow (so-called Vehicle2Grid) with electric vehicles have just started to be implemented in Operational Pilots.

SEEV4-City will transfer this technology outside this restricted domain into operational, real life applied city circumstances in the public domain. SEEV4-City will implement different aspects of V4ES to turn the barriers and negative side effects of electrical vehicles into chances for expansion of the electrical vehicle market. This will be conducted in four different environments and levels:

1. Vehicle2Home (V2H);
2. Vehicle2Street (V2S);
3. Vehicle2Neighbourhood (V2N);
4. Vehicle2Business (V2B).

This approach represents different types of V4ES applications; all important in the total commodity shift where RES and EV are used together with Smart ICT for Demand Supply management.

The four different levels have the following research subjects:

- Implementing renewable energy sources to charge EVs;
- Storage of electricity in EVs;
- Variation in EV charging connected to local energy sources;
- Vehicle to grid (V2G) applications;
- Balancing the grid (supply-demand);
- Energy market participation;
- Provide back-up services.

Specific KPIs of this project are:

1. Increase energy autonomy in SEEV4-City OPs by 25% overall, as compared to collective baseline.
2. Reduce greenhouse gas emissions by 150 Tons annually and change to zero emission kilometres in the SEEV4-City Operational Pilots.

3. Avoid grid related investments (100 million Euros in 10 years) by introducing smart charging and storage services at large implementation and make existing electrical grids compatible with an increase in electro mobility and local renewable energy production.

This brings us to the chief research question of the project, which is:

How to optimise EV charging costs, increase PV consumption, and reduce stress on the grid, while avoiding significant increase in the peak demand by implementing ICTs and V4energy services?

1.4. *SEEV4City project partners:*

Partners include:

- Hogeschool van Amsterdam, HvA (Project Coordinator + WP1 and WP3 Lead);
- Katholieke Universiteit Leuven, KUL (WP2 Lead + OP);
- Centre of Excellence for Low Carbon and Fuel Cell Technologies, Cenex UK and Cenex NL (WP4 Lead + OP);
- University of Northumbria at Newcastle, UNN (WP5 Lead);
- Gemeente Amsterdam (OP);
- Stadion Amsterdam BV (OP);
- Leicester City Council, LCC (OP);
- Oslo Kommune (OP);
- The European Association for Battery, Hybrid and Fuel Cell Electric Vehicles, AVERE;
- Promotion of Operational Links and Integrated Services aisbl, POLIS (The network of European cities and regions cooperating for innovative transport solutions).

1.5. *Scope of the project*

The scope of SEEV4-City project is to make a large step forward in green city development by a smart combination of electric vehicles and renewable energy sources using ICT solutions. Seven operational pilots in six European cities are being developed and their performance will be evaluated. The scope of the project is as follows:

- Only PV renewable energy source is considered for analysis, energy modelling and simulation. Therefore, wind and geothermal technologies are excluded for the purposes of this report.
- Battery swapping, induction charging and other non-conventional technologies are not within the scope of the study
- Investment for upscaling the PV are not within the scope of the Operational Pilots.

1.6. *Purpose and overview of the report*

The purpose of this report is as follows:

- To understand and absorb relevant, up to date topics which will summarise the background to the SEEV4city project. By writing this state-of-the art report, we will be able to understand different methodologies, analyses, lessons learnt from various relevant projects and frame specific research questions that will aid us to realise the objectives of the SEEV4City project.

- Partners can refer to this report as and when required to understand the project better.
- This report can also be used by other parties, such as academia, industries and policy makers, to keep themselves updated with the current developments related to EVs and their utilisation.

This report provides a state-of-the-art assessment of existing EV, RES, ICT services, barriers and potential for vehicle for energy services (V4ES) in cities within the NSR and the EU. It presents a review of relevant projects in the NSR, EU and beyond that have been completed or are currently running as well as available literature on relevant state-of-the-art technologies. The review covers the pros and cons of each project, the assumptions made and how the projects contribute to SEEV4-City and the added values the SEEV4-City project bring.

Literature regarding EV trends, market development and battery technologies is also considered. Further, consideration is also given to renewable energy generation and EV driving profiles as well as potential network services that EVs can provide in order to determine EVs' potential for V4ES, e.g. availability, potential energy/power demand or supply, etc. Finally, data analysis, system modelling, energy management and optimisation tools will also be considered.

1.7. *Project implementation methodology*

Work package 3 (HvA), 4 (CENEX) and 5 (UNN) will work closely with each other to achieve the targets from the economic, environmental and social aspects. As is shown in Figure 1.7-1, CENEX will collect the data from 6 operational pilots (OPs) and make it ready for HvA to develop energy models and for UNN to develop business models. By bringing in the consideration of synergy between EV transportation requirements, grid operation, renewable integration, optimal EV battery operation, environmental improvement and local or national policy, UNN will provide various smart charging/V2G scenarios at different scales (household, street, neighbourhood and city) to HVA, who will then evaluate these scenarios for the OPs and feed information back to UNN for scenario adjustment and model improvement. Each component in the business model and energy model has been looked into and will be presented at different chapters and subchapters in this state-of-the-art report.

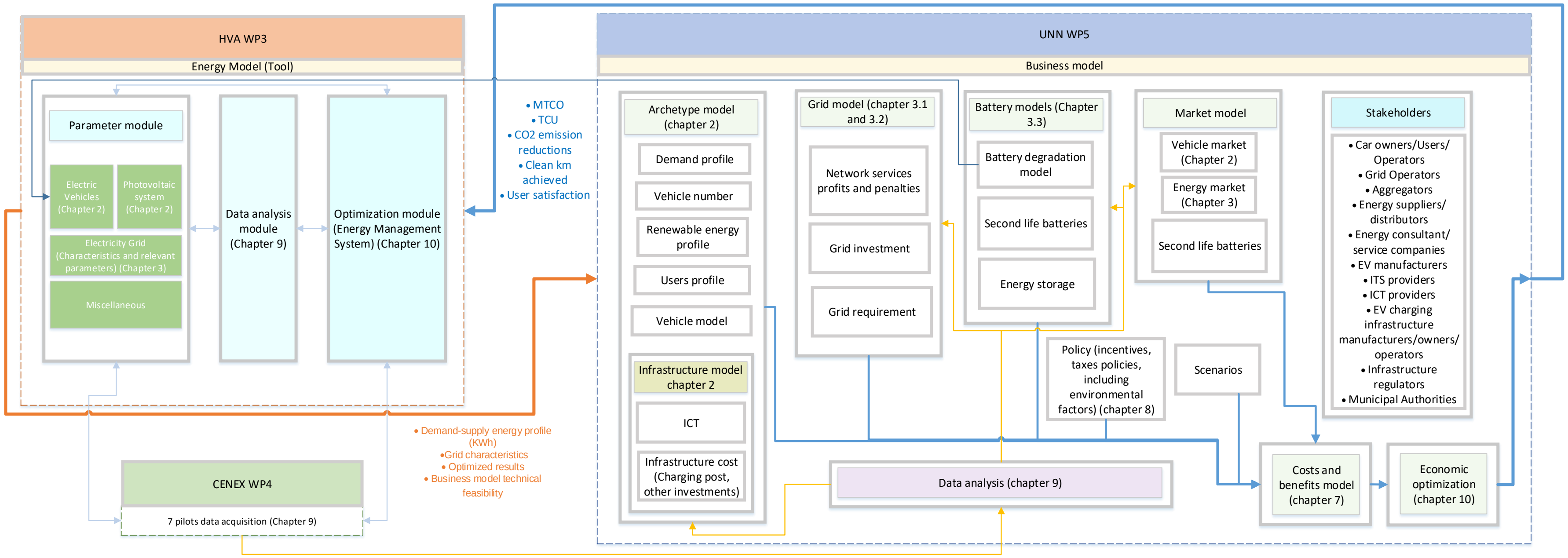

Figure 1.7-1: Structure diagram of WP3, 4 and 5

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Part II: STATE-OF-THE-ART REVIEW

2. Electric Vehicles, Renewable Energy (Photovoltaic) and V2G Technologies

This chapter presents different types of EVs, their adoption and penetration rates. EVs can be classified into two main categories: Hybrid Electric Vehicles (HEVs) and Plug-In Electric Vehicles (PEVs); this second category may be sub-divided into Plug-In Hybrid Electric Vehicles (PHEVs) and BEVs. These two types have different pros and cons but for the scope of SEEV4-City both will be considered although greater emphasis will be given to BEVs because of their inherently larger battery capacities, which allow the storage of a greater amount of energy. The charging of EVs is also discussed because this operation may limit EV deployment due to potential overloading of the electricity grid. In addition, control of the timing of the EV charging may lead to advantageous business and energy models. Given the different charging levels and protocols in Europe, US, Japan and Canada, there exists an essential need for standardization and interoperability. The deployment of photovoltaic energy generation started earlier than the introduction of Li Ion battery in EVs, but these two developments may be seen in parallel, one supporting the other because of the synergies between these two technologies. At the end of this chapter, the up-to-date solutions for EV charging and Vehicle-to-Grid (V2G) technology are presented. This will be the key factor that will favour the integration of EVs in a smart electric grid, extending the perspective on EVs from mere vehicles or loads to a vital part of the electric system. This will be possible only if the major shortcomings of V2G are solved making this technology technically and economically advantageous.

This chapter introduces and analyses the main actors for SEEV4-City, those that will determine the success of SUMEPs. This will be done by describing EVs and relevant technologies, evaluating their interconnections, compatibilities and affinities and answering the fundamental research questions:

- How can EVs help to meet the KPIs and which types are most suitable for this?
- How can EV batteries be managed to favour EV integration in a smart grid keeping in mind the fundamental function of transportation?
- What is (are) the optimal EV battery charging level(s) for the implementation of V4ES and what are the required charging equipment and the associated costs?
- What targets and scenarios can SEEV4-City produce to supplement those already available and which factors will help in doing this (these will be discussed in detail in the next chapters)?
- How can charging of EVs be controlled in order to utilise economically the maximum amount of PV energy within the electric system?
- Finally, what are the technical and economic advantages/disadvantages of V2G? How can it provide benefits in business and energy models?

This chapter will address these research questions and give a detailed examination into the aims of SEEV4-City.

2.1. ***Electric vehicles, types, charging and standards***

2.1.1. Types of electric vehicle

In this report, an electric vehicle is defined as ‘a vehicle using at least one electric motor for propulsion. The engine will be replaced by an electric motor as the propulsion system, and fossil fuel will be replaced by batteries as the energy source. The vehicle produces less or no harmful emissions’ [2.1] [2.2].

An electric motor, converting electricity into mechanical energy with a conversion efficiency of 80-90% is more energy efficient than an ICE. An ICE uses conventional fossil fuels as its power source. Depending on the method of replenishing energy, design, and topology, EVs can be distinguished into three categories - Hybrid Electric Vehicle (HEV), Plug-in EVs (PHEV) and Battery EV (BEV)/ Full EVs (FEV) [2.1] [2.3]. Figure 2.1-1 shows the structure of a typical EV.

An HEV is driven by a conventional engine as well as an electric motor; the conventional engine uses petrol, diesel, or any other suitable liquid fuel as its energy source. In an HEV, the primary source of power is drawn from a combustion engine and a secondary source of power from an electric motor. The batteries of an HEV cannot be recharged through an external plug. The batteries are charged by a mechanism known as regenerative braking. Regenerative braking is a method of recovering and converting kinetic energy (that is normally lost during coasting and braking) into electrical energy, which is then stored in the batteries. HEVs can be divided into three configurations based on their topology and engineering - Series hybrid vehicles, Parallel hybrid vehicles and Combined hybrid vehicles (series-parallel combination) [2.4]. The characteristics of different types of HEVs can be seen in Table 2.1-1.

Table 2.1-1: Drive train configurations of different types of HEVs [2.4]

Types of HEV	Drive train configuration	Purpose and Efficiency
Series	The ICE engine is mechanically decoupled from the transmission and is not connected to the wheels of the vehicle. Meanwhile, the electrical motor is mechanically attached to the wheels and transmission.	Suitable for city driving for frequent stop-and-run driving patterns. Overall efficiency is about 25% higher compared to ICE vehicles.
Parallel	Both ICE and electric motor are mechanically coupled to the transmission and they both simultaneously transmit power to the wheels for propulsion.	Suitable for both city and highway driving patterns, since both electric motor and ICE can provide propulsion during various driving conditions. Overall efficiency is about 40% higher compared to ICE vehicles.
Series-Parallel	Combination of both series and parallel drive train configurations. Complicated drive train configuration.	City and highway driving patterns. Efficiency varies from 25% - 40%, based on driving conditions. However, Series-parallel HEVs are relatively expensive due their complexity.

The PHEV also uses both a combustion engine and an electric motor to run the vehicle. The PHEV carries more batteries and can be recharged through an external plug.

BEVs or FEVs have no conventional engines in them. Electric motors are the only available propulsion system powered by on-board batteries. By using only electric motors, air pollution is reduced to almost zero, and the vehicle is a lot more silent. As in the case of PHEVs, the batteries in a BEV can be charged only via an external plug. Since the batteries are the only energy source, they have the largest batteries amongst all types of EVs. The benefits of each type of EV is mentioned in

Table 2.1-2.

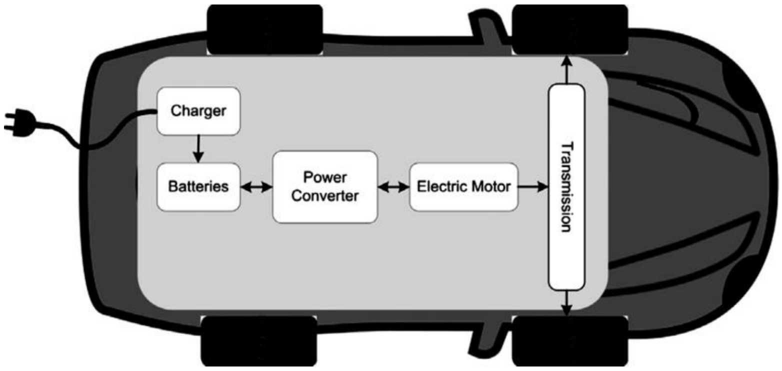

Figure 2.1-1: Diagrammatic representation of a fully Electric Vehicle [2.4]

Table 2.1-2: Overview of Electric vehicles and their benefits [2.2], [2.5], [2.6].

Benefits	Hybrid Electric Vehicles (HEV)	Plug-in Hybrid Electric Vehicles (PHEV)	Battery Electric Vehicles (BEV)
Fuel economy	Better than all conventional fuel-operated vehicles. e.g. 38% fuel savings on a city drive, and 20% savings on a highway drive, with a hybrid Honda Civic, compared to conventional Honda Civic.	Better than conventional and most hybrid electrical vehicles. 40% - 60% less fuel usage and varied speeds can be obtained by using electricity stored in batteries.	No liquid fuels – only electricity as fuel.
Emission reduction	Lower emission levels than ICE vehicles. This depends upon the type of hybrid power system used and size of the system. Mainly HEVs are used to offset fleet emissions to meet local air quality improvements.	Lower emission levels than ICE vehicles and HEVs. This is because PHEVs run on electricity most of the time, compared to HEVs.	EVs are zero emission vehicles. Although emissions are produced during the production of electricity from power plants, but most categories of emissions are generally lower for electricity generated from power plants than vehicles running on conventional fuels, like petrol / gasoline and diesel.
Flexibility and Fuelling	Can be fuelled at petrol bunks/ gas stations, or any other alternative fuelling sites.	Can be fuelled at petrol bunks/ gas stations or any other alternative fuelling sites. Can be charged/ recharged at residential and public charging stations.	Can be charged/ recharged at residential and public charging stations.
Fuel cost and savings[1]	Less operating cost involved than conventional vehicle	Less operating cost involved than conventional vehicle and HEV	Operating cost is lower compared to conventional vehicles and PHEVs
Examples	Honda Civic Hybrid, Ford Fusion Hybrid, Toyota Prius Hybrid	Accord Plug- in Hybrid, Toyota Prius Plug-in Hybrid, Mitsubishi Outlander P-HEV	Chevrolet Volt, Nissan Leaf, Mitsubishi i-MiEV

[1] This is a general comparison of energy cost and savings between ICE engines and several types of EVs. The fuel cost of driving an electric vehicle depends on the cost of electricity per kilowatt-hour (kWh) and the energy efficiency of the vehicle. Hence, the cost and savings vary based on the location where the EVs are charged. On an average, it costs about half as much to drive an electric vehicle when compared to cars that run on gasoline. Here are some simple online tools which indicate the benefits of shifting to EVs in terms of fuel costs and its saving : (1) eGallon (2) Can a Hybrid Save Me Money 3) Vehicle cost calculator

2.1.2. Electric vehicle conductive charging

This section presents a brief introduction on conductive charging of EVs, along with charging power levels and energy usage. Conductive charging can be defined as the charging performed by transmitting electricity through a physical path (conductor).

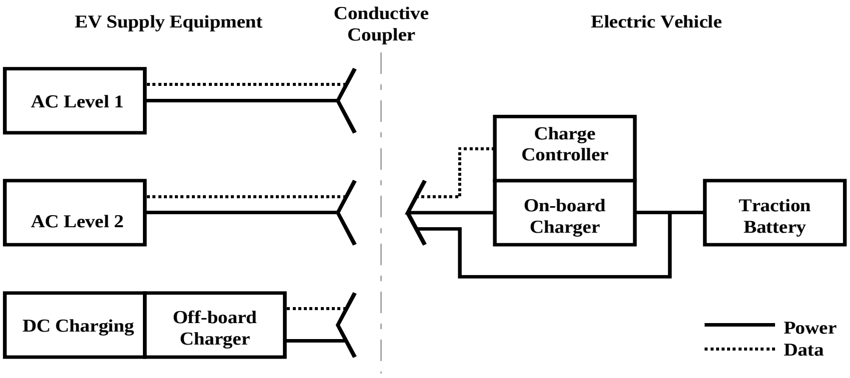

Figure 2.1-2: Conductive EV charging system architecture [2.7]

The EV charging system architecture includes three components, the EV Supply Equipment (EVSE), conductive coupler and the EV itself; the conductive coupler consists of a connector / EV inlet set with electromechanical contacts embedded in an insulator and contained within housing, for each of the mating parts. The contacts provide a physical connection at the vehicle interface for the power conductors (power transfer) and data conductors (communication) conductors between the EV and EVSE. Figure 2.1-2 shows the schematic for the conductive charging system architecture.

The next section has been divided into three segments. Firstly, we discuss batteries used in EVs, and their different types. In the second segment, charging power levels and AC distribution charging architecture are explained. In the last segment, different modes of conductive charging are discussed in brief.

2.1.3. EV battery and energy storage

A traction battery is the most fundamental and central component of all EVs. The stored chemical energy in it is converted to electrical energy (discharging), and this electrical energy acts as a power source to propel the vehicle (mechanical energy). Batteries can be recharged by converting external electrical energy into chemical energy (charging), which can be stored in them for a definite time. They act as a whole or combined (battery + ICE) energy source for PHEVs; complete or only energy source for BEVs.

A battery is characterised by its energy density, power density, efficiency, and life-time. The life cycle of a battery is determined by the number of charging and discharging cycles completed, before it loses the ability to hold a useful charge – this is typically when its output capacity drops under 80% of its initial capacity. By multiplying the life cycle and the energy content, one can find the lifetime of a battery, which gives us an estimate as to how many times it should be replaced during the lifespan of a vehicle.

While charging and discharging the battery, there will be losses which will influence the total output – that is, it may not provide all the energy which is stored in it. This relates to the efficiency of the battery.

The energy density or specific energy of a battery is the amount of energy, based on volume, which can be taken from an energy source; this determines the range of the vehicle and is measured in kWh/litre. The power density or the specific power is the rate of energy, based on volume, which can be taken from an energy source; this determines vehicular performance and is measured in Watts (W). The ideal battery for an EV should have high power density and energy density. Batteries can be optimised based on modifying energy density or power density. A very important parameter of an EV's battery is the State of Charge (SOC), which describes the amount of electric charge remaining in the battery; it is expressed in percentage of the total charge of the battery. In all EV applications, the SOC of a battery is used to determine the vehicle's range [2.8]. EVs can have a series battery configuration, a parallel battery configuration, or a combination of both, depending on the size and type of vehicle.

EV battery requirements

Good battery performance is essential for an EV. Thus, special attention must be paid while choosing a battery for the vehicle; the battery's performance will directly determine the vehicle's performance to a large extent. There are a few essential features which a traction battery must possess, and they are as follows [2.9]:

- Safety;
- High power and high capacity;
- Small and lightweight;
- Long life cycle;
- Low cost.

These characteristics can be seen in detail in Table 2.1-3 and

Table 2.1-4.

Table 2.1-3: Overview of EV battery requirements [2.9]

<table>
<tr><th colspan="2">Safety</th><th colspan="2">High power and capacity</th><th colspan="2">Dimensions/ weight/ battery life and costs involved</th></tr>
<tr><td>Measures</td><td>Possible causes</td><td rowspan="4">High power</td><td rowspan="4">Power = volts * current

Voltage level changes with current and SOC

Battery efficiency around ~ 95%</td><td rowspan="2">Small and lightweight</td><td rowspan="2">For handling and reliability</td></tr>
<tr><td rowspan="2">Prevent over-charging</td><td rowspan="2">Thermal run away, heating and fire</td></tr>
<tr><td>Large format</td><td>Minimises interconnections</td></tr>
<tr><td>Avoid short circuiting (internal or external)</td><td>Accident</td><td>Long life</td><td>Minimises the need for battery replacement, effort and cost involved</td></tr>
<tr><td>Prevent damage</td><td>Leakage of acid</td><td>High capacity</td><td>Energy = voltage * amp hours

Higher capacity = higher vehicle range between each charge</td><td>Low overall cost</td><td>Minimises replacement and maintenance cost</td></tr>
</table>

Table 2.1-4: Important characteristics of batteries storage technologies commonly used in EVs [2.6]

Characteristics	Storage technologies					Others
	Nickel based	Zinc-based	Lead-based	Sodium-based	Lithium-based	Super capacitors, Flywheels and Fuel cell technology
Voltage	1.2V	1.4 -1.6V	2V	2-2.5V	3.5V	
Energy density	50-85Wh/kg	75-80Wh/kg	30-35Wh/kg	90-130Wh/kg	200Wh/kg	
Power density	180-700W/kg	100-125W/kg	70-130W/kg	100-170W/kg	1000W/kg	
Energy efficiency	~ 85%	~ 85%	~ 85%	~ 90%	~95%	
Life cycle	~2000	~2000	~1000	~1000	>1000	
Cost	Very high	Average	Low	Moderate	Moderate	
Examples	Nickel cobalt aluminium [NCA], Nickel manganese [NMC]	Zinc bromide, Zinc air	Lead acid	Sodium chloride, Sodium sulphur	Lithium iron phosphate [$LiFePO_4$], Lithium cobalt[$LiCoO_2$] Lithium polymer [$LiMn_2O_4$]	

Figure **2.1-3** shows the comparison of batteries based on their specific power and specific energy density. Li-ion has an edge over other electrochemical technologies when optimised for both power and energy.

In the immediate future, the existing configuration of Lithium-ion (Li-ion) batteries and a few other types will be enhanced. In the longer term, new battery chemistries with higher significant energy densities will be developed and used for longer driving range and performance. This will require important changes in the battery design. Increased energy densities and improvements in other characteristics translate to less active materials, cell area, and module hardware for energy storage. These improvements will result in better, smaller and less expensive batteries [2.8]. Recent improvements have led to the specific energy of Li Ion batteries increasing to as much as 684.2 Wh/l [2.10]

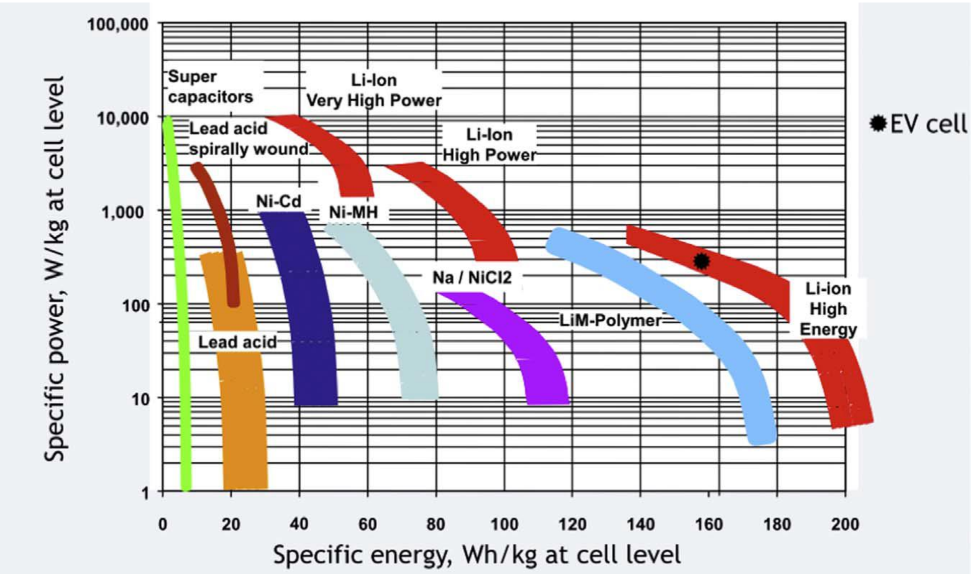

Figure 2.1-3: Battery characteristics based on specific power and specific energy density [1]

Key findings for the battery

- The most important technical features for all EV batteries are – energy density, power density, discharging and charging characteristics, round trip efficiencies, temperature range, and environmental friendliness.
- Important environmental and economical features – high safety, low cost, portability, and less weight.
- Battery management is necessary for all EVs.
- Current batteries support the V2G - vehicle to grid concept - which can increase grid reliability, decrease power quality issues, improvements in grid stabilization.

2.1.4. Charging power levels and AC distribution charging architecture

Charging power levels

The electric energy drawn by an EV from the grid can be obtained by integrating the immediate power needed at the wheels to propel the vehicle over time; taking into account the immediate efficiencies of the mechanical transmission of the drive-train, power electronics, electric motors, batteries and the charger system [2.12].

$$E = \int_0^t \frac{P_w}{\eta_t * \eta_m * \eta_p * \eta_b * \eta_c} dt$$

where E- Energy consumption of an EV from the grid

P_w - Immediate power at the wheels

η_t - Mechanical transmission efficiency

η_m – Electric motor efficiency

η_p – Efficiency of power electronic converters

η_b - Battery efficiency

η_c – Efficiency of the charger

Charging power levels can be defined according to the electric energy taken from the grid and the related possible charging rate. Charging power levels for EVs are generally divided into two schemes, slow charging/normal charging, and fast charging [2.12].

Slow charging / normal charging

Slow charging can be defined as the charging which uses power levels corresponding to the standard power outlets usually present in residential installations. It is mostly associated with overnight charging. As the name states, an EV charging with this scheme, takes 6 to 8 hours for a full battery recharge. According to IEC standards, Mode 1 and Mode 2 charging levels are slow charging (charging modes will be discussed later in this document). In European countries, the standard outlet for slow charging is 230 V,16 A which takes 7-8 hours on average for a full charge of the battery. North America uses a supply of 120 V, 15 A, which takes 5-6 hours on average for a full charge of the battery. In Japan, the normal charger operates at either 100/200 V which takes 8/14 h respectively for a full charge [2.13]. In China, the single-phase charger operates at 220 V and provides a current of ≤32 A [2.14].

Semi- fast / fast charging

Fast charging involves high power levels for charging the vehicle. Fast charging of EVs can either be performed using AC or DC power. Fast charging would provide a 50% charge in 10 to 15 minutes (depending on the charging level and protocol) which gives consumers an experience almost like conventional gasoline refuelling. According to IEC standards, Modes 3 and 4 are used for fast charging of EVs.

Three-phase connections allow considerably higher power for modest current levels compared to single-phase connections. For example, let us consider a case of 16 A per phase and 400 V:

For a three-phase connection, one can get,

$P = \sqrt{3} * V * I * cos\emptyset;$ usually $cos\emptyset = 1$, thus

$P = \sqrt{3} * 400 * 16 * 1 = 11.1\ kW$

For a single-phase connection:

$P = V * I * cos\emptyset;$ usually $cos\emptyset = 1$, thus

$P = 230 * 32 * 1 = 7.4\ kW$

By increasing the level of the current, its respective power is also increased. Not only are higher power levels achieved by using three-phase distribution compared to single-phase, but it is also beneficial for load spreading of electric networks. North America uses a three-wire split phase system, allowing a 240 V supply, effectively doubling the available power for the given current.

Table 2.1-5 provides an overview of the available charging levels in Europe and North America [2.15] [2.16].

Table 2.1-5: Overview of charging power levels in Europe and North America [2.15] [2.16].

Standards	Voltage [V]	Current [A]	Phase Φ	Power [kW], cos Φ = 1
European slow/ normal charging	230 V	16 A	Single-phase [1Φ]	3.7kW
European slow charging with higher current	230 V	32 A	Single-phase [1Φ]	7.4 kW
European semi-fast	400 V	16 A	Three-phase [3Φ]	11.1 kW
European AC fast charging with higher current	400 V	32 A	Three-phase [3Φ]	22.2 kW
North America level 1 charging	120 V	15 A	Single-phase [1Φ] split system	1.8 kW
North America level 2 charging	240 V	30 A	Single-phase [1Φ] split system	7.2 kW

2.1.5. Modes of EV charging

In this subdivision, we will discuss more about conductive charging modes or charging levels of PHEVs and BEVs. These different charging modes are defined by the IEC 61851 [2.4] [2.17] and are listed in Table 2.1-6.

Table 2.1-6: Overview of Modes of conductive charging [2.4] [2.17]

Mode	Definition
Mode 1 (AC)	slow charging from a standard household-type socket-outlet
Mode 2 (AC)	slow charging from a standard household-type socket-outlet with an in-cable protection device
Mode 3 (AC)	slow or fast charging using a specific EV socket-outlet and plug with control and protection function permanently installed
Mode 4 (DC)	fast charging using an external charger

<u>Mode 1:</u>

"Mode 1 charging" stands for the connection of the EV to the A.C. supply network utilizing standardized socket-outlets at the supply side, single-phase or three-phase, and utilizing phase (s), neutral and protective earth conductors [2.18] [2.12].

In mode 1 charging, as illustrated in Figure 2.1-4, the electrical installation should follow certain safety regulations. The installation must have circuit breakers to protect the overall system against overloads, an earthing system and earth leakage protection for increased safety and reliability. This type of connection is the most commonly used scheme in most parts of Europe. The European standard socket outlet provides a charging range of 16 A at 230 V. Standard American socket outlets provide a charging range of 15 A at 120 V – this is referred to as Level 1 charging in the United States. This scheme is simple and direct to implement. The main advantage of mode 1 is that it enables the end users to charge their vehicle almost anywhere. It is like plugging in a mobile phone for charging when one finds a normal electric socket. Although this scheme is easy and direct to use, there are certain limitations and risks involved when not used properly.

Figure 2.1-4: Mode 1 - fixed, non-dedicated socket [2.19]

Due to incorrect plugging in, sockets and cables may get overheated which may lead to fire hazards. Fire accidents can also occur in case of electrical installations becoming obsolete or if a certain protective device is absent. The safe use depends on the presence of a Residual Current Device (RCD) on the supply side. Use of an RCD is now enforced by national codes in various countries; however, many older installations continue to exist without employing RCDs, or even without protective earthing connections. Such systems are susceptible to faults, leading to hazardous circumstances. Figure 2.1-5 shows a schematic representation of an RCD system.

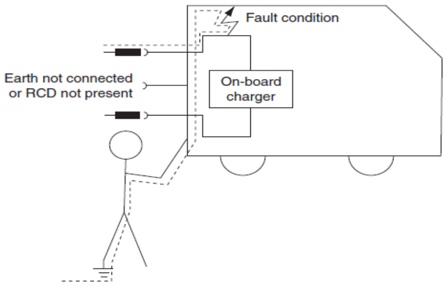

Figure 2.1-5: Residual Current Device (RCD) [2.7]

Mode 1 charging, without a protective system, leaves safety responsibilities to the end user themselves, this charging technique is prohibited in most countries, or limited with controlled access.

Mode 2:

"The connection of the EV to the AC supply network utilizing standardized socket-outlets, single-phase or three-phase, and utilizing phase(s), neutral, and protective earth conductors together with a control pilot conductor between the EV and the plug or in-cable control box." [2.12].

Mode 2, illustrated in Figure 2.1-6, uses a standard, non-dedicated socket outlet with an additional protection for the vehicle and cable. This protection is added between the electric vehicle and plug or control box. This mode was mainly aimed at North American standards, associated with their existing infrastructure adopted by the national electrical code. The plug used carries an RCD and an additional protection device called control pilot. In mode 2 charging, cables and the vehicle are protected by the control pilot system. This scheme is seldom used in European nations. The main disadvantage of mode 2 mode charging is that there is no protection (control pilot box) for the plug itself.

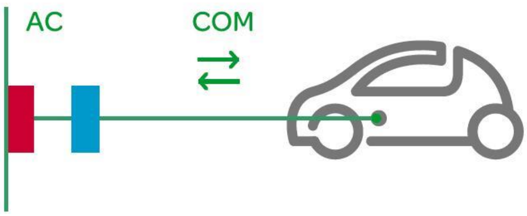

Figure 2.1-6: Mode 2 - Non-dedicated socket with cable incorporated protection device [2.19]

Mode 3:

"Mode 3 charging refers to specific electric vehicle charging stations, with a direct connection of the EV to the A.C supply network, utilizing dedicated EV supply equipment where the control pilot conductor extends to equipment permanently connected to the A.C supply." [2.11].

Figure 2.1-7: Mode 3 - dedicated circuit socket [2.19]

Mode 3, shown in Figure 2.1-7, has dedicated infrastructure, especially designed, and reserved for PHEV and BEV use. This charging mode has a control pilot that acts as a protective device which controls the integrity of the earthing connections and provides other additional safety functions.

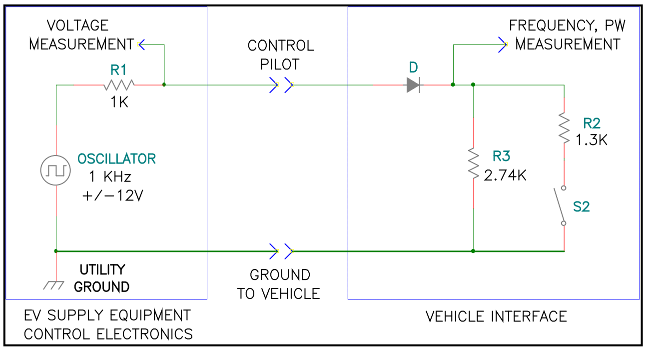

Figure 2.1-8: Generic circuit diagram of a control pilot [2.7]

The control pilot is represented in Figure 2.1-8 The primary control conductor is connected to the equipment ground through control circuitry on the vehicle and performs the following functions:

- Verifies that the vehicle is present and connected
- Permits energization/de-energization of the supply
- Monitors the presence of the equipment ground
- Establishes vehicle ventilation requirements
- Transmits supply equipment current rating to the vehicle.

Mode 4 - DC fast charging:

In Mode 4, the indirect connection of the EV to the A.C. supply network is utilizing an off-board charger where the control pilot conductor extends to equipment permanently connected to the A.C supply [*2.12*].

Figure 2.1-9: Mode 4 - DC charging with an off-board charger [2.19]

In the DC charging mode, shown in Figure 2.1-9, the control pilot and communication devices are mandatory. DC fast charging is explained in detail in the following section. Table 2.1-7 gives a comparison between the different modes.

Table 2.1-7: Comparison of Electric vehicle charging modes [2.20]

	Current type	Current ratings (A)	Voltage (V)	Power Kilowatts (kW)	Charging duration and mileage	Prime Use	Equipment and safety
Mode 1	Alternating current (AC)	12 A – 16 A	120 V	1.3 kW – 2.0 kW	3-8 km per hour of charging	House charging	Household socket and extension cord No dedicated safety system
Mode 2	AC	32 A - up to 80 A	240 V	16 kW - 19.2 kW	1-2 hours 16-32 km per hour of charging	House charging and public charging	Domestic socket Cable with a dedicated protection system
Mode 3	AC	80 A	400 V	Up to 43 kW	Around 30 minutes 90-125 km for 30 minutes of charging	Public charging	Specific socket on dedicated circuit Dedicated Safety system
Mode 4 DC fast charging	Direct current (DC)	125 A - up to 200 A	200 V – 600 V	50 kW – to be determined	20- 30 minutes 90-125 km for 30 minutes of charging	Public charging	Direct Current connection Dedicated safety system

2.1.6. DC Fast charging

Fast charging involves high power levels for charging the vehicle. The exact definition or set of definitions is much more complex. In simple words, fast charging could be defined as any scheme other than slow charging. The fast charging mode creates the need for specific infrastructure further than standard domestic or industrial sockets [2.12]. Fast charging of PHEVs or BEVs can be performed by using either AC or DC power; in the case of DC charging, a rectifier is connected to the battery involving heavier and more expensive fixed infrastructure. The function of a rectifier is to convert AC to DC power. In case of AC fast charging, the rectifying is performed on-board of the vehicle; with the most commonly used traction inverter which can recharge the battery at a high current (regenerative braking) and can also be fed by the grid.

Typically, DC fast charging generally uses an off-board charge to provide an AC to DC conversion. This off board charger is serviced by a 3-phase circuit from 200-600 V AC and the fast charging infrastructure can provide power levels up to 250 kW. Fast charging would provide a 50 percent charge in 10 to 15 minutes, once the EV inbuilt hardware can take this level of power, which gives the consumer an experience somewhat like conventional gasoline refuelling.

The architecture of the DC distribution charging station is different from an AC distribution charging station. In a DC charging station, a main AC/DC power converter is designed to supply power to the entire station. Figure 2.1-10 gives a clear pictorial representation of a DC charging station/ architecture. The high voltage from the grid is stepped down to a low voltage using an LV transformer; a circuit breaker is connected to this LV transformer to protect the circuit from overloads and short-circuits. Its basic function is to detect a fault condition and, by interrupting continuity, to immediately discontinue electrical flow. The circuit breaker and DC bus bar are connected via an inverter where it converts AC- DC as mentioned above. The power distribution to all the charging terminals is realized with a DC bus bar. On each terminal, a DC/DC converter is used for controlling the charging power levels. EVs are connected to this output via an external plug. With this architecture, harmonic problems are reduced by a centralized advanced harmonic filter (AHF) connected between the LV feeder and the AC/DC converter [2.21] [2.22].

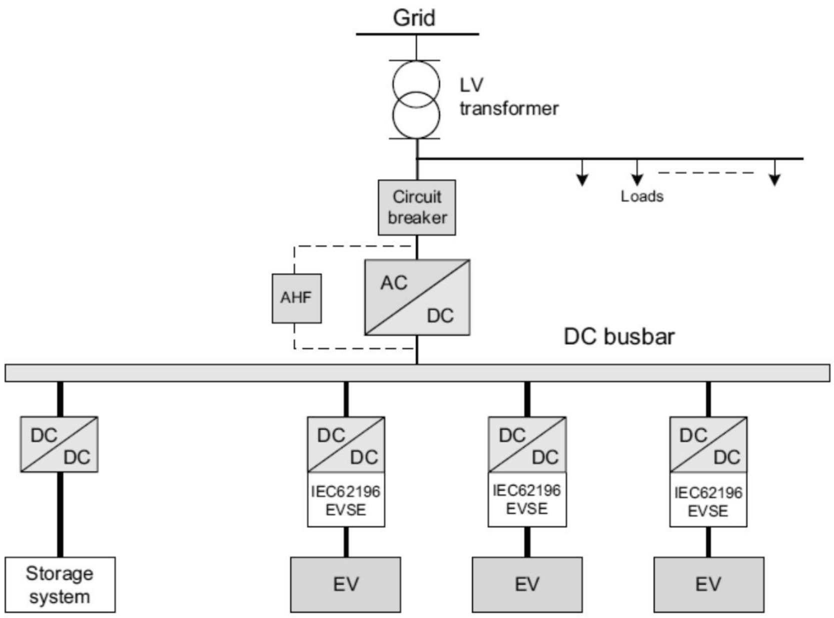

Figure 2.1-10: DC distribution charging architecture [2.21] [2.22]

A special type of connector is employed to charge EVs using DC charging. According to SAE standardization, it is referred as a level III connector. A Level III connector enables fast charging and directly supplies the EV battery pack with DC power, allowing power and communication at the same time. In Europe, IEC 61851 applies to equipment for charging PHEVs and EVs at standard AC and DC supply voltages. The different levels are listed in Table 2.1-8.

Table 2.1-8: DC charging configurations and rating terminology [2.23] [2.24]

Level	Current rating (A)	Voltage rating VDC	Power rating (kW)	Current type
Level I	≤80 A	200-450 V DC	≤ 36 kW	Direct current (DC)
Level III	≤200 A	200-450 V DC	≤90 kW	Direct current (DC)
Level III	≤400 A*	200-600 V DC*	≤240 kW*	Direct current (DC)

In Table 2.1-9, a simple calculation of how fast a DC fast charging station can charge a PHEV is presented. A few assumptions are made, like nominal battery voltage to be 400 V and distance travelled to be 10 km/kWh. The inputs are taken from Table 2.1-8.

Table 2.1-9: DC charging time duration table * [2.23]

Level	Current rating (A)	Voltage rating VDC	Power output (kW)	Km/hour of charge	km/minute of charge
Level I	~80 A	~400 V DC	32 kW	32*10=320 km/hour	320/60=5.4 km/minute of charge
Level III	~200 A	~400 V DC	80 kW	80*10=800 km/hour	800/60=13.3 km/minute of charge
Level III	~400 A*	~400 V DC*	160 kW*	160*10=1600 km/hour	1600/60=26.6 km/per minute of charge

***** *General and simple math for calculating the distance coverable per minute of charge at a DC charging station*

Current rating * Voltage rating = Power delivered
Power delivered * distance = total no of Km coverable/ per hour of charge
km/60 minutes = total no of km coverable / minute

From the above simple calculation, we can conclude that a DC fast charging configuration will be able to charge an electric vehicle in less than 10 minutes for a reasonable travel distance, which is comparable with the refuelling time of a conventional petrol-powered vehicle.

This user flexibility linked with a DC fast charging configuration comes, however, with many drawbacks.

- The cost involved in construction and maintenance of the fixed infrastructure is high compared with slow charging.
- The most important drawback is causing high burden on the distribution network if spot loads of this intensity (EVs) are introduced. It leads to high cost of the electric energy particularly when the EVs are used at peak load times.

The accessibility and presence of fast charging stations however provide a psychological benefit to EV drivers and EV enthusiasts, allowing them to fully exploit the range of vehicles and to overcome range anxiety. Furthermore, the high-power connection of these charging stations makes it particularly exciting for the V2G concept.

2.1.7. Electric vehicle charging infrastructure (domestic and non-domestic)

In this section, the EV charging infrastructure and their standard accessories will be discussed. An important consideration that need to be drawn is the investment behind this infrastructure; this is also a parameter that need to be taken into account in a cost-benefit analysis. According to the capacity installed in the charging station, the cost can range from £426.30 for a single 7.2 kW charger point excluding installation costs [2.25] to £2 million for a cluster of fast chargers [2.26].

Electric Vehicle supply equipment

"Electric Vehicle Supply Equipment (EVSE) is the term given to systems that recharge EVs and consists of a converter, connector, and coupler. Connectors vary according to standards, with vehicle manufacturers employing different connector types. Also, meters, and safety & communication systems are installed on EVSE" [2.9].

An electric vehicle charging station or electric vehicle supply equipment, represented in Figure 2.1-11, is generally in the form of a fixture coupled directly to an electrical outlet or to an electrical distribution board. This infrastructure is an element that supplies electrical energy for recharging EVs. It has a charging cable outfitted with a connector that can be connected to a socket on the EV. The socket and connector together make up a coupler that connects the EV to the grid for charging. The plug will resemble the structure of a gas pump and the charging is also done the same way. The charging station will have an indication light (LED) that indicates if the EV is connected properly and is being safely charged.

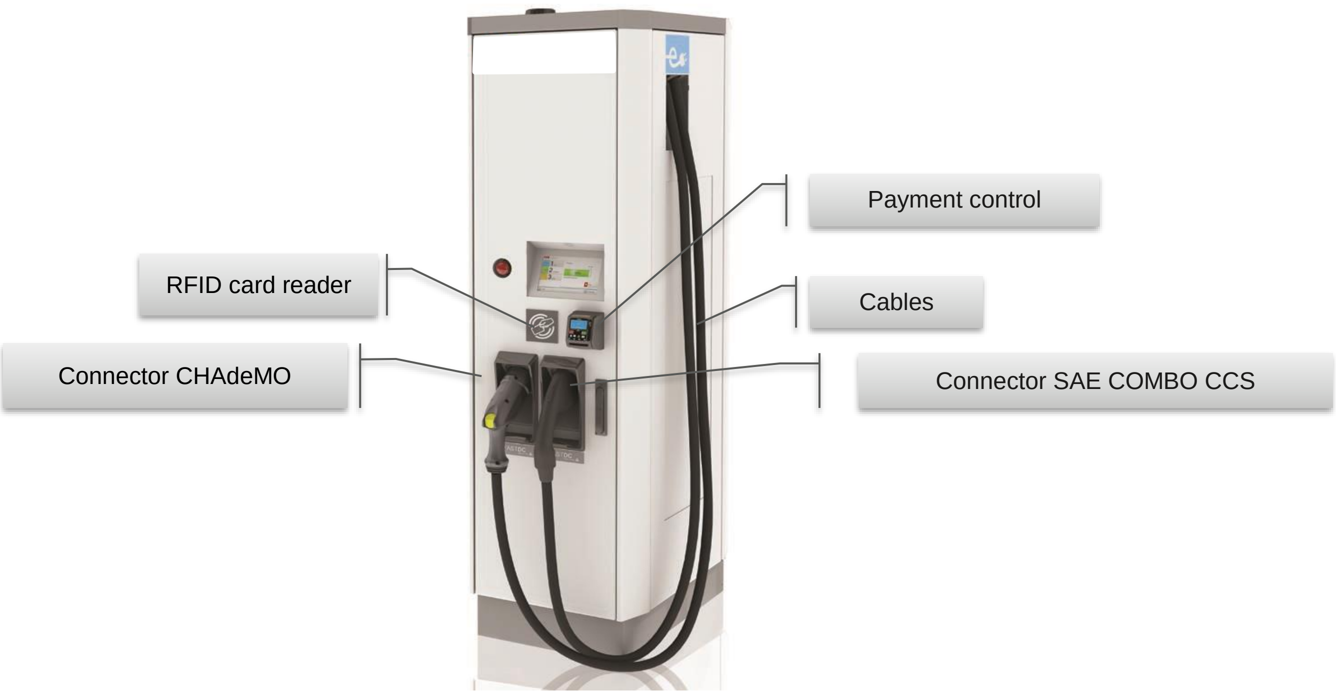

Figure 2.1-11: A typical DC Charging station or EVSE (for illustrative purpose only) [2.27]

EVSE facilitates the end user by providing him/ her with information about the start and stop of the charging operation – it mainly depends on the end user's choice, i.e. the user can initiate or cease the charging process of his vehicle whenever he/she wants to. Charging stations nowadays have extra features such as a billing system facility, card-controlled access, energy, and smart meters for electronic payment facilities.

Charging accessories and connection cases

Important and standard charging accessories includes, chargers – off-board and on-boards chargers, connectors, couplers, cables, and sockets. Each one of these components, listed in Table 2.1-10, has its own specific standards and codes framed by IEC or SAE.

Table 2.1-10: Definitions - Electric Vehicle charging accessories [2.20]

Equipment	Definition and function
Charger	An electrical device that converts alternating current energy to regulated direct current for replenishing the energy of an energy storage device (i.e. battery) and may also provide energy for operating other vehicle electrical systems. Off-board charger – A charger located off the vehicle On-board charger – A charger located on the vehicle
Connector	Having the ability to transmit electricity through a physical path (conductor).
Coupler	A mating vehicle inlet and connector set.

Standards are another factor causing charging anxiety. There are many of them. Only IEC standard connectors and couplers are represented below Figure 2.1-14 and Figure 2.1-16. Mode 1 and 2 charging configurations involve standard plugs, sockets and power line communication encompassing only phase, earth, and neutral contacts. These are mainly considered as domestic standard grades and are not really suited for the heavy-duty operations of EV charging.

Currently, all commercially available charging stations allow conductive charging, which means that electricity is transmitted through cables carrying conductors. Conductive charging stations are covered by SAE J11722 and IEC standards. One more standard for conductive charging station is the CHAdeMO, which is a DC charging standard for electric vehicles.

Specifically, CHAdeMO-type fast charging stations are increasingly becoming popular and are being installed in great numbers across the globe in recent years. It enables seamless communication between the car and the charger [2.27]. This protocol currently enables EV charging from 6 kW up to 50 kW power. This protocol is well recognised across the globe and certified with IEC EN and IEEE standards (Europe and internationally). The CHAdeMO association aims to develop next generation CHAdeMO chargers having charging capability up to 150 kW.

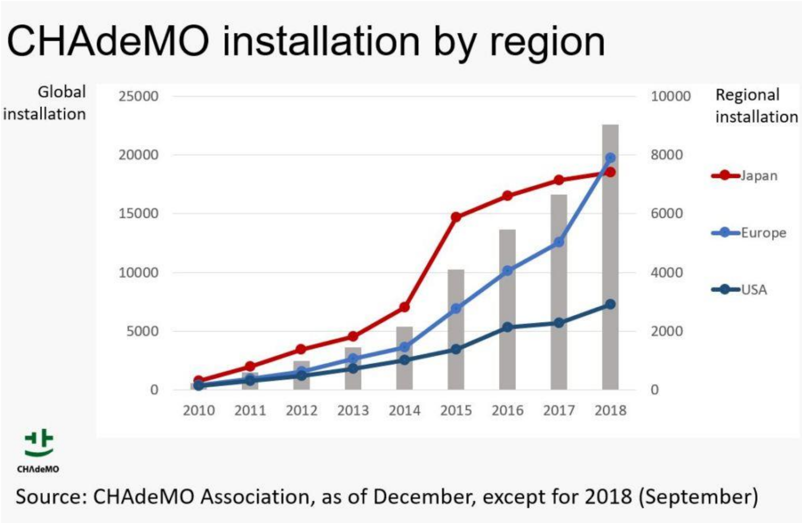

Figure 2.1-12: CHAdeMO charge point evolution across the globe (2010 – September 2018) [2.27]

In recent years, the CHAdeMO association has provided 'Vehicle to X' (V2X) certified products to its users. By September 2018 there were 7,936 (Figure 2.1-12) chargers installed in total across Europe [2.27]. Figure 2.1-13 shows the different couplers currently available worldwide and Figure 2.1-14 illustrate the connectors and couplers from IEC – 62196 currently used in Europe.

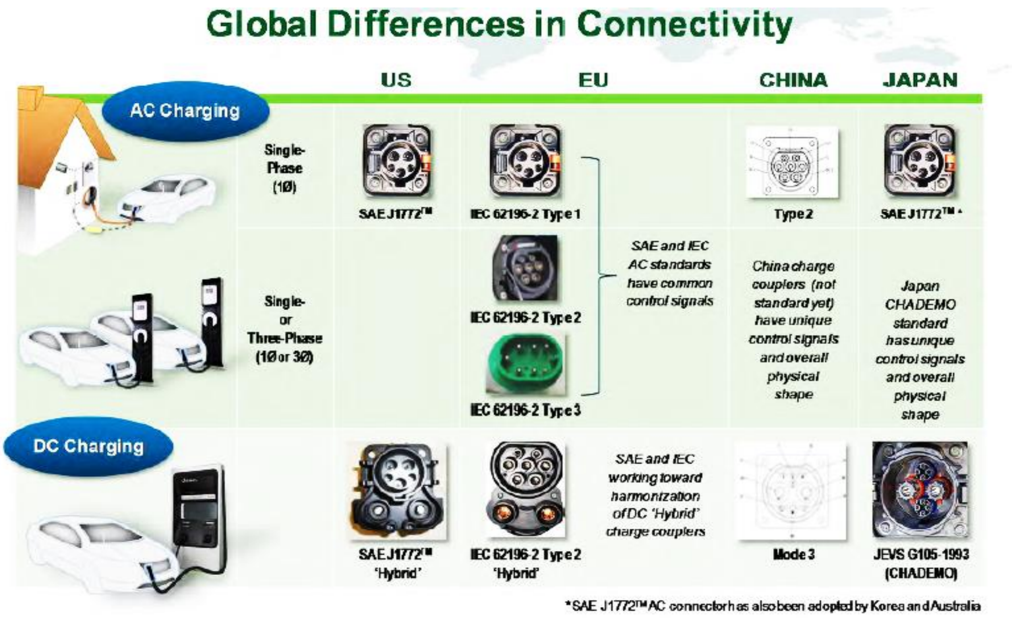

Figure 2.1-13: Electric Vehicle Couplers around the world [2.28] [2.29]

Figure 2.1-14: IEC standard - 62196: single-phase and three-phase couplers and connectors used in Europe [2.28] [2.29]

Overview of standards and codes of the charging accessories

IEC SC 23H: Industrial plugs and socket-outlets published IEC 62196-1 covering general requirements for EV connectors and is currently close to finalizing IEC 62196-2, which standardizes the following elements needed for AC charging [2.29a]:

- Type 1 – single phase vehicle coupler (vehicle connector and inlet);
- Type 2 – single and three phase vehicle coupler and mains plug and socket-outlet without shutters, for example VDE-AR-E 2623-2-2;
- Type 3 – single and three phase vehicle coupler and mains plug and socket-outlet with shutters, for example SCAME plug developed by the EV Plug Alliance;

SC 23H is also developing IEC 62196-3 (DC) on requirements for the vehicle coupler.

Interface Functions

"The conductive coupler consists of a connector/vehicle inlet set with electromechanical contacts imbedded in an insulator and contained within housing for each of the mating parts. The contacts provide a physical connection at the vehicle interface for the power conductors, equipment grounding conductor, control pilot conductor, and under certain conditions serial data conductors between the EV and EVSE" [2.7].

The interface consists of 9 possible contacts that perform the interface functions as shown in Figure 2.1-15 and Table 2.1-11.

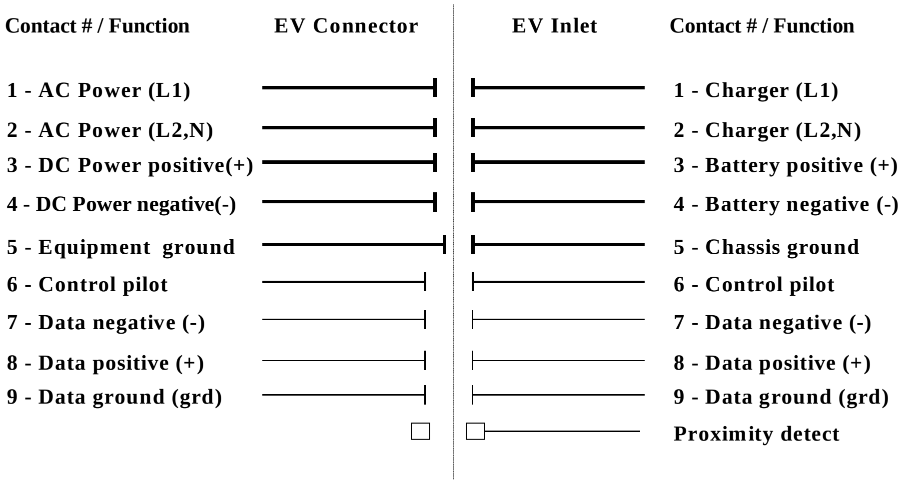

Figure 2.1-15: Generic conductive coupler contact interface functions [2.7]

Table 2.1-11: Generic conductive coupler contact functions [2.7]

Contact	Connector Function	Vehicle Inlet Function	Description
1	AC Power (L1)	Charger 1	Power for AC Level 1 and 2
2	AC Power (L2, N)	Charger 2	Power for AC Level 1 and 2
3	DC Power positive (+)	Battery positive (+)	Power for DC charging
4	DC Power negative (-)	Battery negative (-)	Power for DC charging
5	Equipment ground	Chassis ground	Connect EVSE equipment grounding conductor to EV chassis ground during charging
6	Control pilot	Control pilot	Primary control conductor (operation described in Section 5)
7	Data negative (-)	Data negative (-)	Negative serial data conductor (SAE J1850 Type 2 only)
8	Data positive (+)	Data positive (+)	Positive serial data conductor (SAE J1850 Type 1 and 2)
9	Data ground	Data ground	Serial data ground conductor (SAE J1850 Type 1 and 2)

Cable connection cases

The connection of the cable between the vehicle and the charging outlet can be carried out in 3 ways as defined in IEC 61851-1 [2.29]. These are listed in Table 2.1-12 and illustrated in Figure 2.1-16.

Table 2.1-12: Connection cases and their definitions [2.29]

Connection case	Definition
Connection case A	The cable and plug are permanently attached to the vehicle. This type connection is generally found only in very light vehicles
Connection case B	The cable assembly is removable and connected to the vehicle with a connector. This type of connection is for normal and fast charging
Connection case C	The cable and vehicle connector are always attached to the EVSE. This arrangement is typically used for DC fast charging (Mode 4). This eliminates the user to carry heavy cables for charging. One disadvantage is that copper theft is possible

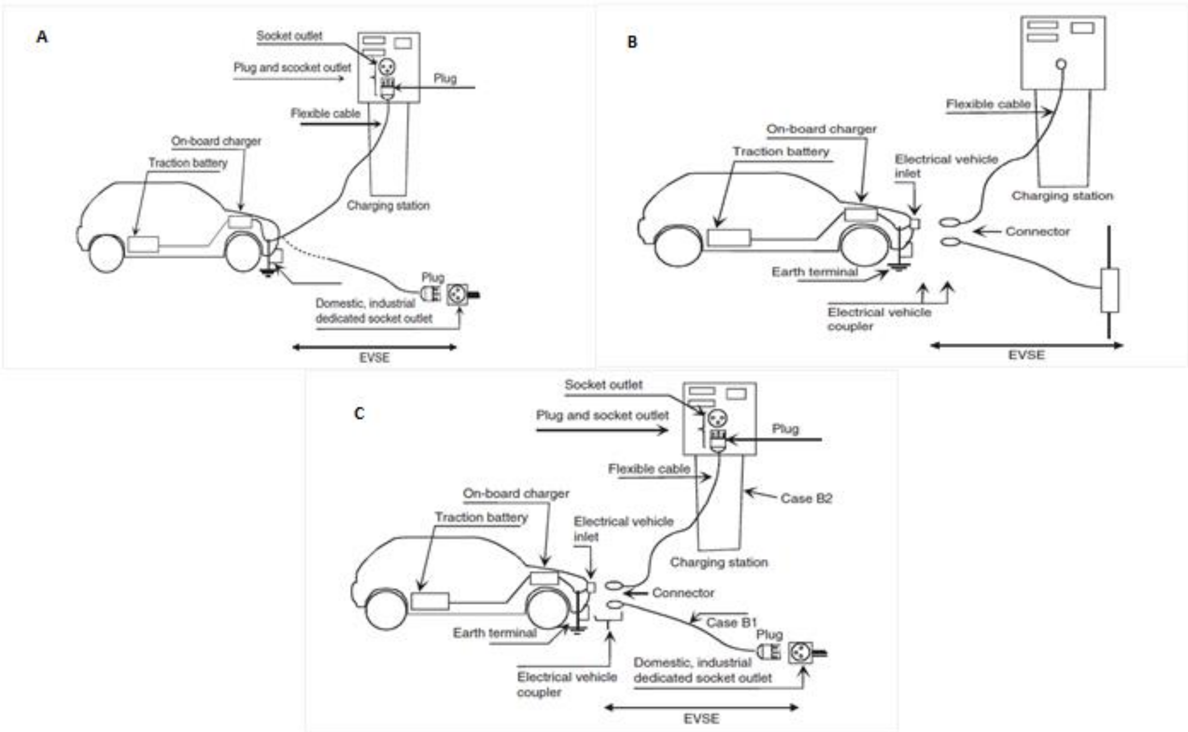

Figure 2.1-16: Connection of the cable between the vehicle and the charging outlet is carried out in three ways as defined in IEC 61851-1. Case 'A', 'B' and 'C' (clockwise) [2.29]

2.1.8. Electric vehicle communication system, safety, and infrastructure

Communication system

The EV Communication system is a system which enables electric vehicles such as BEVs and PHEVs to communicate (exchange data) with the EVSE for electricity services, safety inputs and feedback. The communication between the vehicle and the charging infrastructure can be of various types depending on their sophistication level. Mode 1 charging involves non-dedicated sockets that have no communication system in them, i.e. exchange of data between the vehicle and the EVSE does not happen. Mode 3 and Mode 4 charging consist of a two-way communication system which controls the data exchange between the vehicle and the EVSE; this communication system's most basic operation is to fulfil essential safety functions and ensure proper operation levels [2.29].

Mode 3 uses control pilot communication through the control pilot function which takes care of the essential safety functions. More functionality can be added by using Pulse Width Modulation signals in the control pilot circuit. The communication system ensures that the PHEV or BEV is connected properly to the charging post and provides information on whether the earth connection is healthy or not.

Mode 4 uses an advanced communication system: an off-board charger. The charger which supplies DC to the PHEV or EV, will communicate with the vehicle to supply the battery with the correct level of current and voltage. They also provide safety information to the driver or the person who is charging the vehicle from EVSE [2.29].

A standardised protocol for communication between the charging points and the aggregator management system plays a key role. Various communication protocols for charging have been proposed, such as DIN70121 [2.30], and ISO15118 [2.31]. A widely adopted and harmonized open communication protocol is also needed to make EV charging and billing interoperable, and regulations to reinforce standardization is therefore required to enable interoperability between different systems and EVs. The Open Smart Charging Protocol (OSCP) [2.32], and the Open Charge Point Protocol (OCPP) [2.33], are two recent developments in communication standardisation to improve the system interoperation.

Grid management communication

The maturation of new concepts such as smart grid technology and Vehicle-to-Grid (V2G) concept has created a mode for suitable communication protocol for PHEV or BEV charging, beyond mere safety functions and proper operation levels. Recharging of batteries creates high load on the electricity grid, but this can be reduced or even eliminated by an appropriate scheduling the time of charge of the EVs. This reduces the burden on the electricity grid and cuts down the electricity cost for charging the vehicle at non-peak hours (charge cost optimization- appropriate time window for charging when the electricity cost is low). To schedule the recharging, either the vehicle or the charging station should communicate with the smart grid system. Not only this, other functionalities such as vehicle identification and billing for charging the vehicle from the desired charging station can be implemented; individual charging bills for the energy consumed can be sent to the user's dedicated account when the vehicle is connected to outlets linked with smart meters [2.34].

Vehicle to Grid (V2G) communication

"V2G refers to bidirectional power flow to and from the grid typically under the control of the power utility company (or the aggregators), through a communication channel between EVs and the power grid." [2.35].

This technique can be used with bi-directional charging -ready vehicles such as PHEVs or BEVs with appropriate communication configurations. Mostly, vehicles are normally parked on an average of 95 percent of the time [2.36] [2.37]; their batteries can be used as a temporary energy source, where the electricity can flow from the EV's battery back to the power grids; that is, they act as an energy storage system that can be used for offsetting peak loads and electricity shortages.

The development and deployment of such communication protocol involves various actors, including EV manufacturers and utilities.

Safety

While most electric vehicles can be recharged from a household wall socket, a charging station is typically accessible to several electric vehicle (EV) end users. An EV charging station, unlike residential sockets, has additional current or connection sensing safety systems to disconnect the power when an EV is not essentially charging. That is, in case an EV might be carelessly driven away before being disconnected (unplugged), and so brutally rip away the charging cable insulation and expose their electric conductors - which (except for the sensor mechanism) may possibly be hazardous [2.38].

There are two main types of safety sensors:

- 'Sensor wires': provide feedback signal such as specified by the under mentioned SAE J1772 and IEC 62196 schemes that require special (multi-pin) power plug fittings [2.38];
- Current sensors: monitor the power consumed, and only maintain the connection if the demand is within a "window" (for example between 1 and 15 A).

Sensor wires can react more swiftly, have fewer parts to fail and are possibly less costly to design and implement. Current sensors however can use standard connectors and can easily provide alternatives for suppliers to monitor or charge for the electricity consumed. For user safety, all charging stations have a ground fault circuit interrupter (GFCI) to reduce the risk of electric shock.

In summary, Electric Vehicle Supply Equipment (EVSE) is the term given to systems that recharge EVs, which usually include a converter (AC-DC) and a connector. Connectors vary according to various different standards, with vehicle manufacturers employing different connector types. Also, meters, and safety & communication systems are installed on EVSE. The large number of possibilities for EVSE highlights the need for standardization and interoperability. Common standards and protocols should be preferred to proprietary protocols to improve user experience and engagement. The European electricity industry association (Eurolec) has issued a declaration calling upon all stakeholders, transport and energy policymakers, companies in the relevant sectors, and standards bodies to support the drive towards standardisation in electric vehicle charging systems [2.40]. In particular, there are already some widely used rapid DC charging standards for EVSE, e.g. CHAdeMO, CCS, Tesla supercharger, etc. A recent development of EVSE is the concept of integrating EVSE with V2G technologies, in which an EVSE and EV work together to become a distributed energy source to feed electricity back to the grid. An additional device (inverter) s required to convert the EV battery DC energy into AC and synchronize it with the grid. The DC-AC inverter can be installed in either the EVSE or the EV. However, more study and research are needed to understand the impacts of the emerging EVSE-V2G systems on the grid, as well as how the EVSE-V2G can work with other existing distributed energy resources, such as solar PV, small wind turbines, stationary storage systems and gas micro-turbines.

2.2. ***EV trends, market penetration and forecast***

The number of EVs BEVs and Plug-In Electric Vehicles (PHEVs)) is an important factor that has to be considered because the success of new business models in terms of benefits, both economic and environmental, depends on this. The higher is the number of EVs in the fleet of a nation the higher are the possibilities to develop a Sustainable Urban Mobility and Energy Plan (SUMEP) featuring EVs in a significant way. National and European policies are developed in order to foster the uptake of EVs. The historical trends show that EVs have started to attract a significant volume of users, after 2010. For example, in Figure 2.2-1 the situation of the national EV (BEV and PHEV) sales of new vehicles is depicted for a number of countries including the United Kingdom, The Netherlands, Norway, Germany and Sweden between 2013 and 2018.

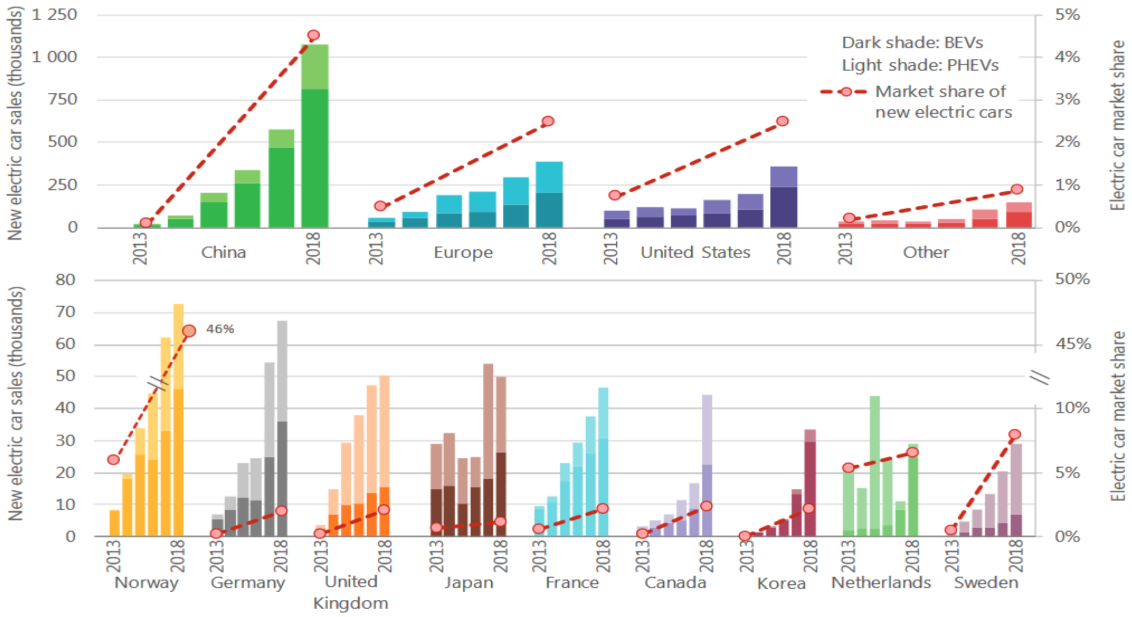

Figure 2.2-1: EV national sales 2013-8 [2.39]

As can be seen, a significant growth in EV car uptake has taken place between 2013 and 2018, when almost all the countries have seen a significant increase [2.38]. in Germany, eleven times compared to the number of EVs sold in 2013. In 2018, the global EV stock crossed five million up 2 million from the previous year [2.39]. In 2018, China exceeded the US in total EV stock and currently these two represent over 60% of the global electric car stock, whereas all the European countries consisted of 23.5%. EVs are currently concentrated in a few countries: the top five represent 80% of the total while the top ten account for 96%: China, the US, Japan, Canada and the six leading European countries. It is also useful to understand how the national EV fleet is divided into BEVs and PHEVs, because BEVs have only the battery as energy resource and therefore their capacity is higher than in PHEVs. Therefore, it is a cleaner technology and more suitable for different energy services, due to the higher battery capacity. Figure 2.2-2 shows the national stock for BEVs in 2018.

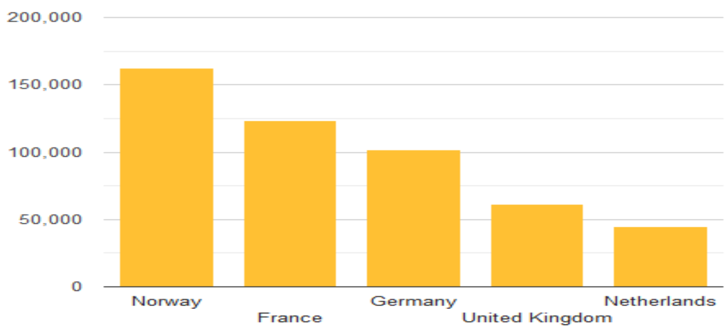

Figure 2.2-2: BEV car national stock 2018 [2.41]

In countries like Norway, Germany and the UK, BEVs represent a significant part of the national EV fleet; for instance, in Norway in 2018 they had a market penetration 31.20% of all new car sales with 17.90% for PHEVs [2.41]. Figure 2.2-3 illustrates the situation for the stock of PHEVs in 2018.

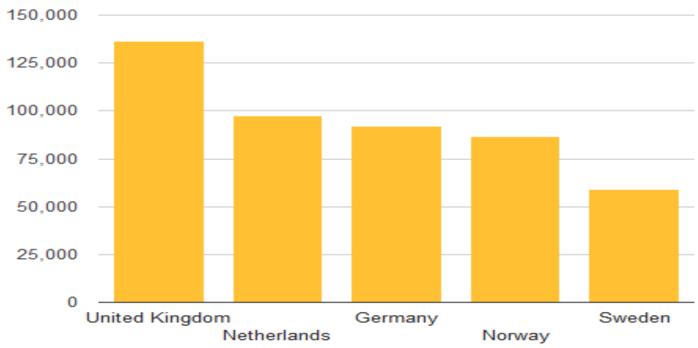

Figure 2.2-3: PHEV car national stock 2018 [2.41]

As can be seen in The Netherlands, and the United Kingdom, the situation is the opposite: there are more PHEV cars than BEV cars: in the Netherlands 97,702 out of 142,686, which represents a percentage of 68%. In the EU as a whole, BEV cars represent 50% of the total stock and this percentage has not changed much from 2015.

It is interesting to analyse the new registrations of BEV and PHEV cars because it allows us to understand when users have started to adopt them in large numbers. Figure 2.2-4 and Figure 2.2-5 show the new annual registrations of BEV and PHEV cars respectively.

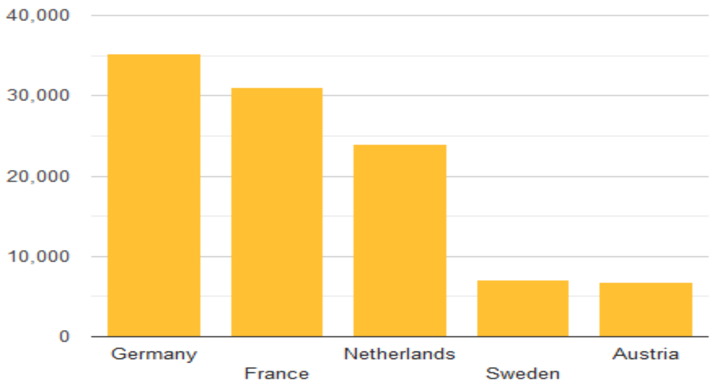

Figure 2.2-4: New national BEV car registrations 2018 [2.41]

For most of the countries, in 2011, the new registrations rose from hundreds to thousands (in Norway from 394 in 2010 to 2,010 in 2011 which represents a growth of 716% and in Sweden the increase in new registrations was by 326% from 2010 to 2012).

For the PHEV, the increased uptake is delayed by only one year, in 2012, but the numbers reach the thousands of units over a couple of years. By the end of 2018, new EV registrations in the UK numbered more than 60,000 [2.41]

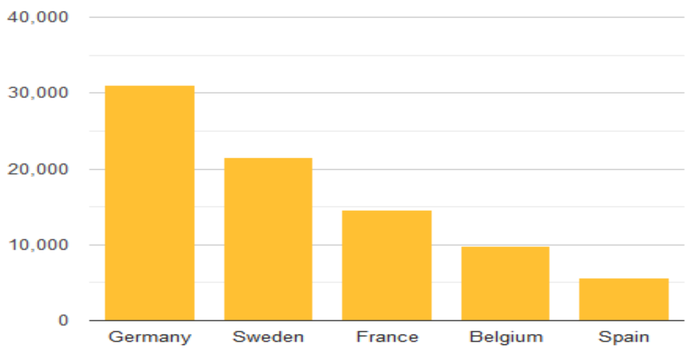

Figure 2.2-5: New national PHEV car registrations 2018 [2.41]

BEV cars have experienced a higher growth than PHEV cars in the EU since 2013: in 2018 BEV cars increased by 57% while PHEVs did only by 42%. In 2018, there were some 2 million EV sales worldwide almost doubling the number of new electric car sales in 2017 [2.39].

As for battery powered electric buses, in the EU the stock consists of 1,761 vehicles by 2018, compared to 398 in 2014.

Another important aspect is the number of EVs as a percentage of the total vehicle fleet of a nation, because it shows the penetration of EVs and consequently the potential increased benefits as compared against ICE vehicles. Figure 2.2-6 shows the EV market share in the five countries.

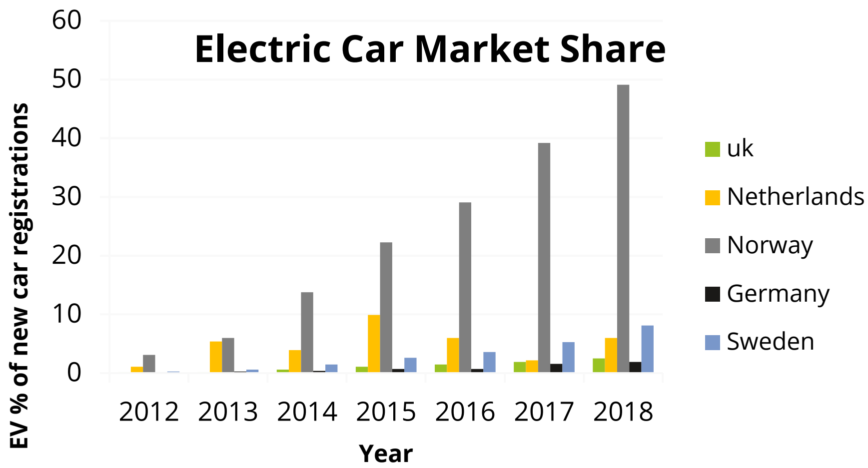

Figure 2.2-6: National market penetration for EVs [2.41]

As can be seen, in countries like The Netherlands and Norway EVs are a significant part of the vehicle fleet, and this proves the success of effective policies adopted to foster EV uptake. In fact, in 2018, 2 million electric cars were sold worldwide, which represents an increase of 100% compared to the previous year. However, in 2018, the global EV car stock still made up only 0.4% of the total number of Passenger Light-Duty Vehicles (PLDVs) in the world [2.42]. At the end of 2018, the EV market penetration of six countries managed to exceed 1% of the total national car stock: Norway leads with 49.1% followed by Sweden with 8.1%, The Netherlands with 6.0%, whereas China has 4.2%, France 2.1% the UK having 2.5% and Germany 1.9%. As for future scenarios, the National Grid's Future Energy Scenarios 2019 report [2.43] says that in all the scenarios they developed by 2030 there will be between 2.3 and 12 million EVs on the UK's roads. There are four scenarios that are presented:

- *"Community Renewables":* Local energy schemes flourish, Consumers are engaged and improving energy efficiency is a priority. UK homes and businesses transition to mostly electric heat. Consumers opt for electric transport early, and simple digital solutions help them easily manage their energy demand. Policy supports onshore generation and storage technology development, bringing new schemes which provide a platform for other green energy innovation to meet local needs
- *"Two Degrees":* Large-scale solutions are delivered and consumers are supported to choose alternative heat and transport options to meet the 2050 target. UK homes and businesses transition to hydrogen and electric technologies for heat. Consumers choose electric personal vehicles, and hydrogen is widely used for commercial transport. Increasing renewable capacity, improving energy efficiency and accelerating new technologies such as carbon capture, usage and storage are policy priorities
- *"Steady Progression":* The pace of the low-carbon transition continues at a similar rate to today but then slows towards 2050. Consumers are slower to adopt electric vehicles, and take up of low-carbon alternatives for heat is limited by costs, lack of information and access to suitable alternatives. Although hydrogen blending into existing gas networks begins, limited policy support means that new technologies such as carbon capture, usage and storage and battery storage develop slowly
- *"Consumer Evolution":* There is a shift towards local generation and increased consumer engagement, largely from the 2040s. In the interim, alternative heat solutions are taken up mostly where it is practical and affordable, e.g. due to local availability. Consumers choose electric vehicles and energy efficiency measures. Cost-effective local schemes are supported but a lack of strong policy direction means technology is slow to develop, e.g. for improved battery storage.

Figure 2.2-7 shows the numbers of EVs in the UK for every decade until 2050 for these four scenarios, though these need to be caveated with battery cell production capacity, target markets by Original Equipment Manufacturers (automotive), and actual car production capacity.

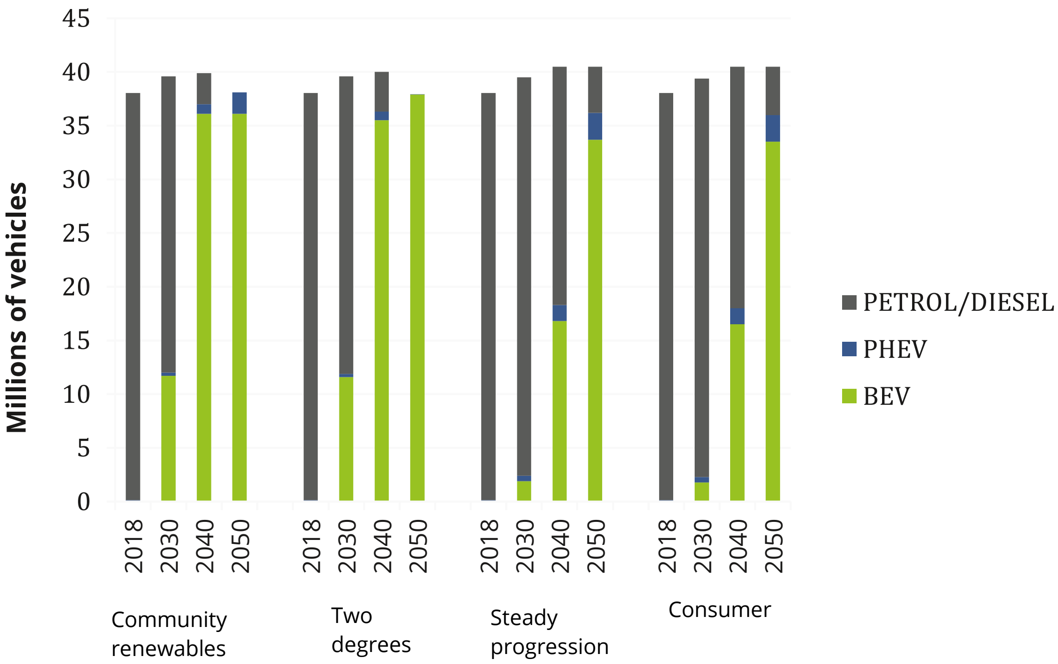

Figure 2.2-7: EV numbers in the UK for the four scenarios [2.43]

As can be seen the "Two Degrees" is the greenest scenario in the range where all the vehicles in 2050 are expected to be EVs whereas the "Consumer Evolution" sees the lowest EV uptake as 'business as usual' (BAU) prevails and there is a focus on cost reduction.

Whether these scenarios will actually be close to the reality depend on many factors, such as political incentives and user preference but more concretely, it depends on the battery manufacturing capacity. Figure 2.2-8 shows the forecast for the demand of automotive lithium-ion batteries for 2020, 2025 and 2030.

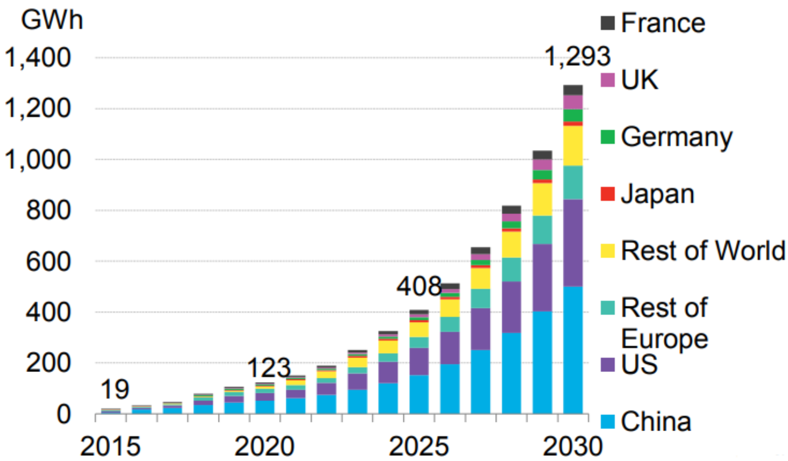

Figure 2.2-8: Forecast demand for Lithium-ion batteries for EVs, 2010-2030 (GWh) [2.44]

This forecast depends on the number of EVs that are set as a target for the respective years. However, this does not help much on forecasting the number of EVs manufactured in those years, if this information is not combined with the expected automotive battery sizes. To this end, future projections are not straightforward, since as battery prices fall there will be a tendency to provide EVs with larger batteries to enhance range.

In their 2012 report produced for the Committee on Climate Change, Element Energy assume that EV battery power remains at 24 kWh in 2030 [2.45]. Therefore, from a simple and straightforward calculation, it can be forecasted that by 2030, there will be a global EV production capability of 1,293,000,000/24 kWh=53.88 million. On the other hand, the authors of [2.46] predict that the demand of automotive lithium-ion batteries by 2025 will be 37-117 GWh. According to [2.47], the annual manufacturing capacity of Li-ion cells in the world that are fully commissioned in early 2019 was already 316 gigawatt-hours (GWh). This shows how various forecasts can be obtained as results of different assumptions and that the actual situation is influenced by a multitude of factors.

In [2.48] two IEA scenarios are presented along with the Reference Technology Scenario (RTS), which represents projections that correspond to policies on energy efficiency, energy diversification air quality and decarbonisation that have been declared or are under consideration and these projections show a global EV stock of 56 millions of vehicles. The two scenarios are related to the Paris Agreement, which sets the goal of limiting the global average temperature increase to below 2°C above preindustrial level and ensuring efforts to limit the temperature increase to 1.5°C above preindustrial level. They are:

- Two "Degree Scenario" (2DS) with a carbon budget of 1,170 Gt CO_2 of cumulative emissions in 2015-2100 giving 50% chance of achieving the goal; this corresponds to a target of 160 million of electric cars in circulation by 2030 (10% of the total) and 1.2 billion by 2060 (more than 60%).
- "Beyond Two Degree Scenario" (B2DS) with 750 Gt CO_2 of cumulative emissions for 2015-2100 and a 50% chance to limit the average future temperature increase of 1.75°C; to do so, 25 million EVs must be deployed by 2020, more than 200 million by 2030 and EVs must represent 80% of the total PLDV by 2060.

Within the 2DS scenario, net-zero Green House Gas (GHG) emissions must be reached close to 2090 whereas for the B2DS scenario this has to be achieved close to 2060. The requirements for the two scenarios are shown in Figure 2.2-9.

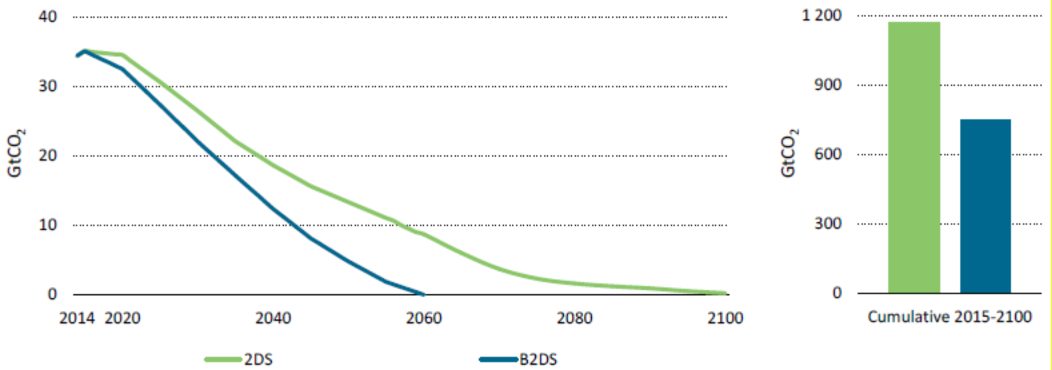

Figure 2.2-9: Emission budgets and trajectories for 2DS and B2DS [2.48]

The Paris Agreement on Electro-Mobility and Climate Change aspires to exceed 100 million by 2030, about a third below the 2DS scenario target and a half below the B2DS scenario target. Furthermore, in 2016, 14 countries set national targets: China, India, the US, the UK, The Netherlands, Japan, France, Germany, Korea, Denmark, Austria, Ireland, Portugal and Spain. The aggregate assessment of the targets embodies an ambition to deploy 13 million of EVs in these countries by 2020. This requires a stock growth of 60% a year until 2020, which is satisfied by the one showed in 2016, but in order to align with the 2DS scenario the annual increase rate must be 85%. As can be seen, the 2DS and the B2DS scenarios require higher EV deployment and a consequent annual growth, compared to the Paris Agreement, whereas the cumulative OEM targets determine a range of values for 2020 and 2025, which anyways are lower than the B2DS scenario.

In the IEA Global EV Outlook 2019 [2.39] two scenarios are considered: the "New Policies" scenario and the "EV30@30" scenario. Dynamic developments in policy implementation and technology advances underpin the projections to 2030 in the "New Policies" scenario, which aims to illustrate the consequences of announced policy ambitions. Projections in the "EV30@30" scenario are underpinned by proactive participation of the private sector, promising technology advances and global engagement in EV policy support. It is aligned with the goal of the EVI EV30@30 campaign to achieve a 30% market share by 2030 for EVs in all modes except two-wheelers (where market shares are higher).

In the "New Policies" scenario, China leads with the highest level of EV uptake over the projection period: the share of EVs in new vehicle sales reaches 57% across all road transport modes (i.e. two-wheelers, cars, buses and trucks), or 28% excluding two/three-wheelers. It is followed by Europe, where the EV sales share reaches 26% in 2030 and Japan, one of the global leaders in the transition to electric mobility with a 21% EV share of sales in 2030. In North America, growth is particularly strong in Canada (where EV market shares reach 29% by 2030), as well as in California and US states that have adopted zero-emissions vehicle (ZEV) mandates and/or have stated an intention to continue to improve vehicle fuel economy. Other parts of the United States are slower to adopt EVs, bringing the overall EV sales share to 8% of the US vehicle market in 2030 [2.39].

OEMs have also set some targets, which are presented in

Table 2.2-1.

Table 2.2-1: OEM objectives as of April 2017 [2.48]

OEM	Announcement	Source
BMW	0.1 million electric car sales in 2017 and 15-25% of the BMW group's sales by 2025	Lambert (2017b)
Chevrolet (GM)	30 thousand annual electric car sales by 2017	Loveday (2016)
Chinese OEMs	4.52 million annual electric car sales by 2020	CNEV(2017)
Daimler	0.1 million annual electric car sales by 2020	Daimler (2016a)
Ford	13 new EV models by 2020	Ford (2017)
Honda	Two-thirds of the 2030 sales to be electrified vehicles (including hybrids, PHEVs, BEVs and FCEVs)	Honda (2016)
Renault-Nissan	1.5 million cumulative sales of electric cars by 2020	Cobb (2015b)
Tesla	0.5 million annual electric car sales by 2018 1 million annual electric car sales by 2020	Goliya and Sage (2016), Tesla (2017a)
Volkswagen	2-3 million annual electric car sales by 2025	Volkswagen (2016)
Volvo	1 million cumulative electric car sales by 2025	Volvo (2016)

In [2.39a] updated OEM targets are presented, as shown in Figure 2.2-10. These are contrasted with the two projections the “New Policies” scenario, and the “EV30@30” scenario shown in Figure 2.2-11.

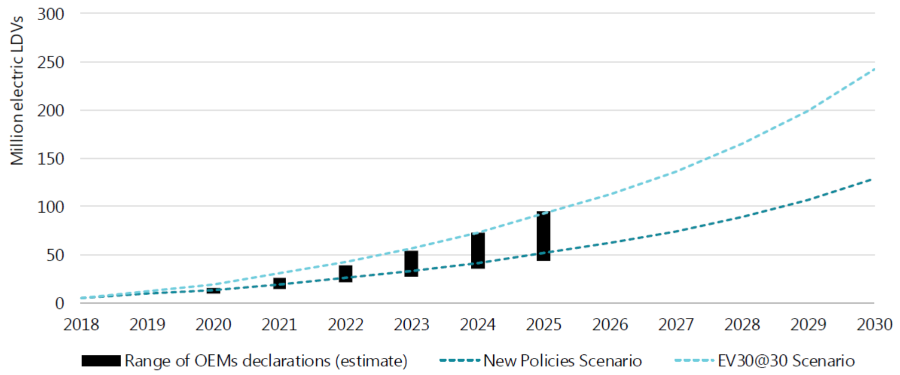

Figure 2.2-10: projected global electric car stock OEM targets (2020-25) [2.39]

Considering all the OEM targets from Table 2.2-1, the EV stock would reach between 9 million and 20 million of units by 2020, if indeed they could be met (including taking into account battery cell production capacity). In [2.38] it is stated that global EV stock exceeded 5m vehicles an increase of 63% from the previous year. From the OEM targets given in [2.38] between 45 million and 95 million units will be deployed by 2025. which contrast with the 2017 estimate [2.48] of 40-70 million of cars that could be deployed by 2025. In order to meet these targets, battery production capacity has to be increased. It is inferred that the mid-point of the previously mentioned ranges deriving from the OEM targets require around ten factories with the same size as the Tesla Giga-factory. In the later projection from [2.39], EV deployment will reach between 45 million and 95 million units by 2025

The global EV stock scenarios for 2030 are depicted in Figure 2.2-11.

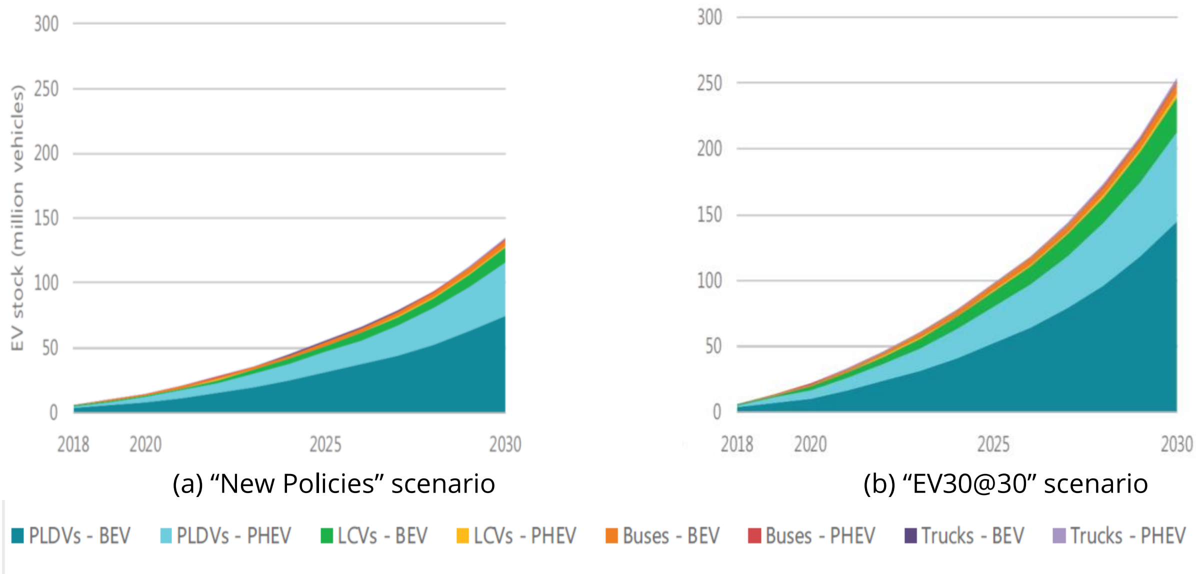

Figure 2.2-11 Deployment scenarios for global EV stock for 2030 [2.39]

Furthermore, the EV30@30 campaign, which sets the ambition of reaching a collective market share of 30% by 2030 (except for two-wheelers) aligns with the B2DS scenario, but this only holds if at the same time also the power generation technology is decarbonized.

2.3. *Renewable energy source: Photovoltaic*

2.3.1. Introduction to the PV system

The solar electric generation system usually known as Solar Photovoltaic or solar PV uses sun light to produce electricity, for instance to power electrical appliances. Photovoltaic systems use cells, generally consisting of one or more layers of semi-conducting (generally, silicon) material – P and N type semi-conductors. When each cell is connected appropriately in series/parallel they can form a panel. When connected, these panels form a PV system [2.49].

When sunlight falls on to the semiconducting cells, it releases electrons and creates an electric field across the layers. Consequently, this causes electrons to flow, creating electricity. The energy cycle of a photovoltaic system in a household is depicted in Figure 2.3-18.

The system consists of a solar panel, DC/AC inverter and meter. The solar panels are mounted on the roof of the household, and are called roof top solar panels [2.49].

- Photons from the sun are converted into electricity by roof top solar panels
- The electricity produced by the solar panels is Direct Current (DC). This DC is converted into AC current (mains) by the DC/AC inverter so they can be used in the home.
- The usage meters measure the amount of electricity produced by the solar panels.
- Unused electricity (surplus) is exported into the electricity grid and used by the utility company; this set up is called a grid-tied solar panel system.
- If a storage system (battery) is installed, the surplus can be stored in the battery and can be used during low or no sun light. By doing this, the energy consumption of the house is reduced.

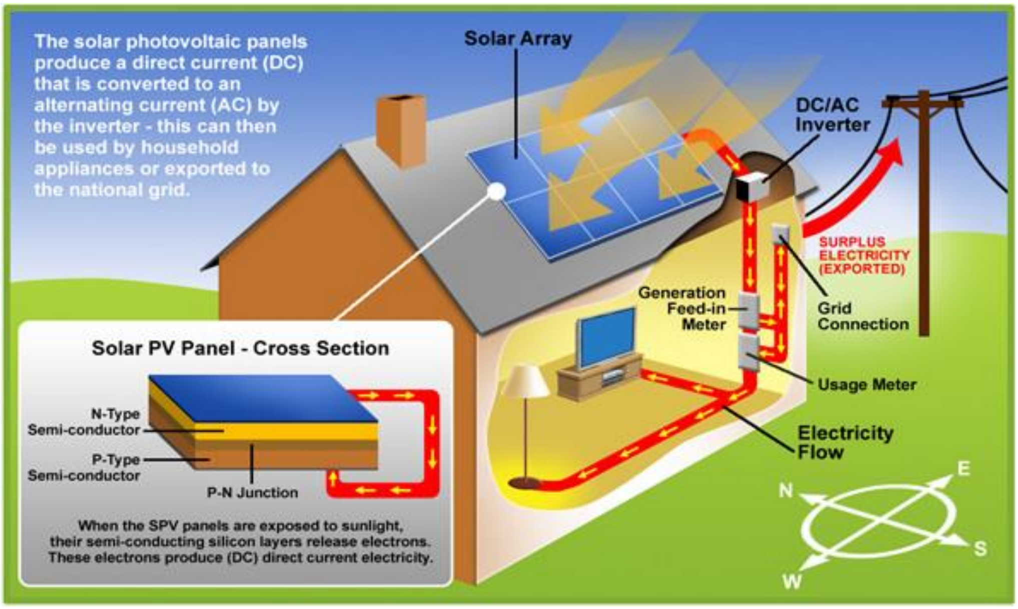

Figure 2.3-1 Energy cycle of Photovoltaic (PV) system in a household [2.49]

In this report, only solar photovoltaic systems are addressed; solar thermal systems are out of scope.

2.3.2. PV trends, market penetration and forecast

This section will discuss global PV trends, the market penetration over the years and the forecast results.

In the past 30 years, PV technology has grown from a niche segment into a high growth market. The years 2015-2016 showed growth in the PV market; especially 2016 showed a remarkable rise in the amount of GW installed in the world [2.50]. The increase is graphically presented in Figure 2.3-29. The global demand for solar electricity grew by about 25.6% in 2016 as compared to 2015. Solar PV costs were cheaper than that of on-shore wind power and this milestone suggests that PV will be the main pillar of future renewable energy-based system. The major reason for this increase in the installed GW capacity is due to various climate agreements across the world - the Paris climate summit (120 countries) held in the year 2015 was one of the many initiatives across the world [2.51]. The increase in worldwide PV deployment is shown in Figure 2.3-2. from [2.50]

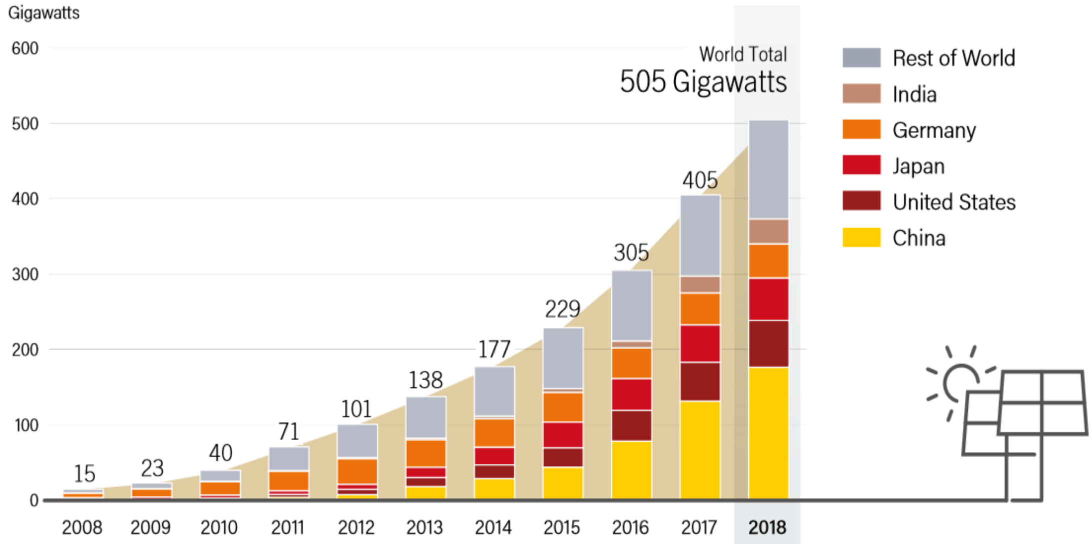

Figure 2.3-2 Global total Installed solar PV capacity (2008-2018)

The Global Market Outlook [2.52] foresees a more positive solar development than other reports. They anticipate that total global installed solar capacity could grow to over 600 GW by 2020 - more than a 160% percent growth rate from 229 GW of commissioned PV systems at the end of 2015. The "High Scenario" estimates even more than 700 GW by 2020. In fact, the 2018 global total of installed PV reached 505 GWp from 405 GWp in 2017 [2.50].

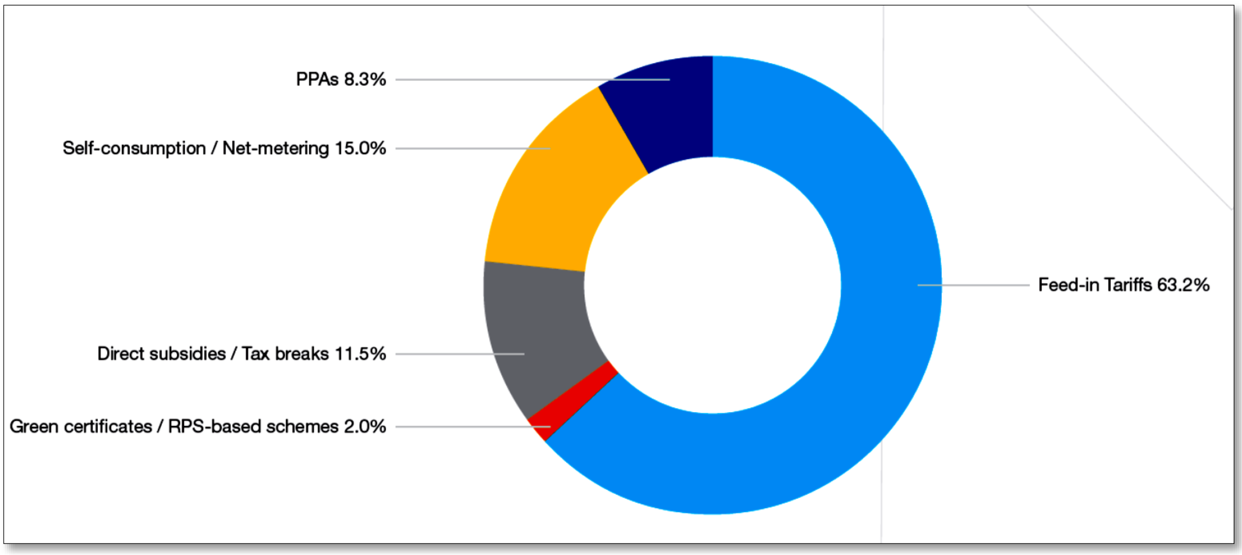

Figure 2.3-3 Primary policy drivers for solar in the year 2015-2016 [2.53]

According to IEA-PVPS [2.53], around the world solar power remains driven by incentive mechanisms. Other than traditional feed-in tariffs, incentives like Renewable Portfolio Standards (RPS) & green certificates, power purchase agreements (PPAs), and tax credits have contributed to the growth of solar power globally. Figure 2.3-330 presents the main policies that supported the deployment of solar energy in 2015-2016.

Solar power in EU and NSR regions:

This section will further discuss solar power, particularly in the NSR and EU regions.

In 2015, the European solar market saw an increase in the total installed solar power (GW) after several years of decline in the past. The data until 2018 is presented in Figure 2.3-41. In 2016, the the rate of increase in demand fell. This is mostly due to the termination of support for utility-scale solar power in the UK, which contributed to most of Europe's 2015 solar power growth [2.52].

However, Europe crossed 100 GW of cumulative gird-connected solar PV capacity in the first quarter of 2016. Solar power contributes about 4% to the EU's power mix. Italy is the forerunner in this case as it reached 8%, along with Germany, which is second in line. As of 2017, solar PV in Europe is expected to grow, and this trend will continue for the following years.

It is interesting to note that although there is an increase of solar power percentage in the EU's mix, this is not enough to meet the 2020 renewable energy targets – many European member states are lagging in this respect. ETS did not deliver well, because the mechanism has not (at least yet) driven coal out of the EU system, as one quarter of the system still depends on fossil fuel technology.

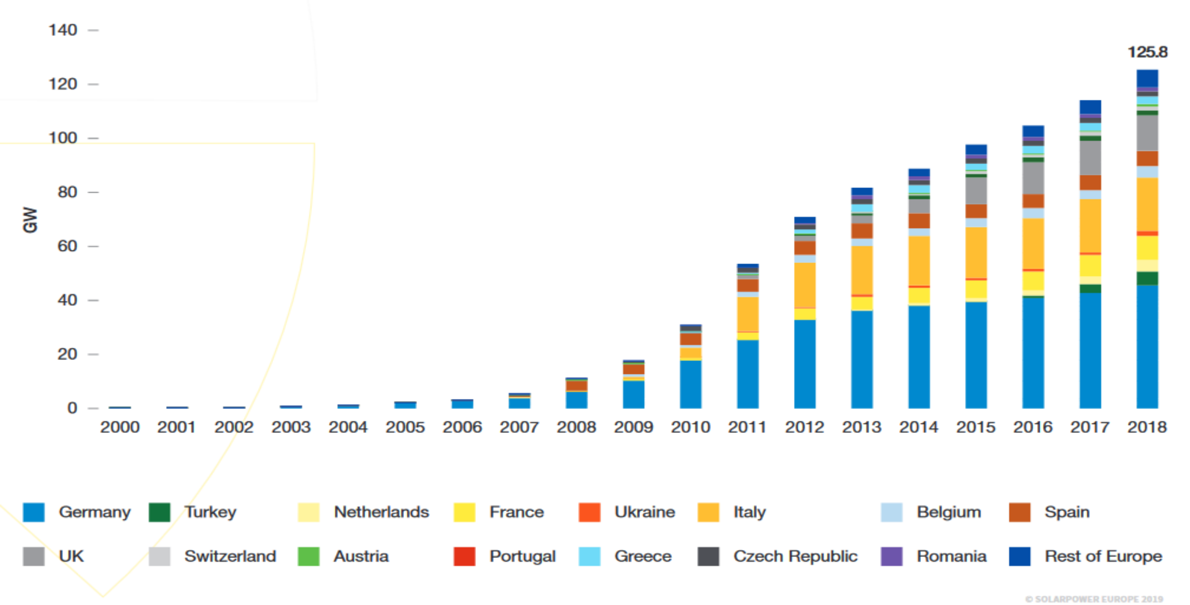

Figure 2.3-4: Total solar electric power in Europe from (2000-2018) [2.52]

Figure 2.3-52 represents the percentage of the solar electric system in EU countries based on installed locations – Residential (mostly roof top), Commercial areas, Industrial and Utility scale.

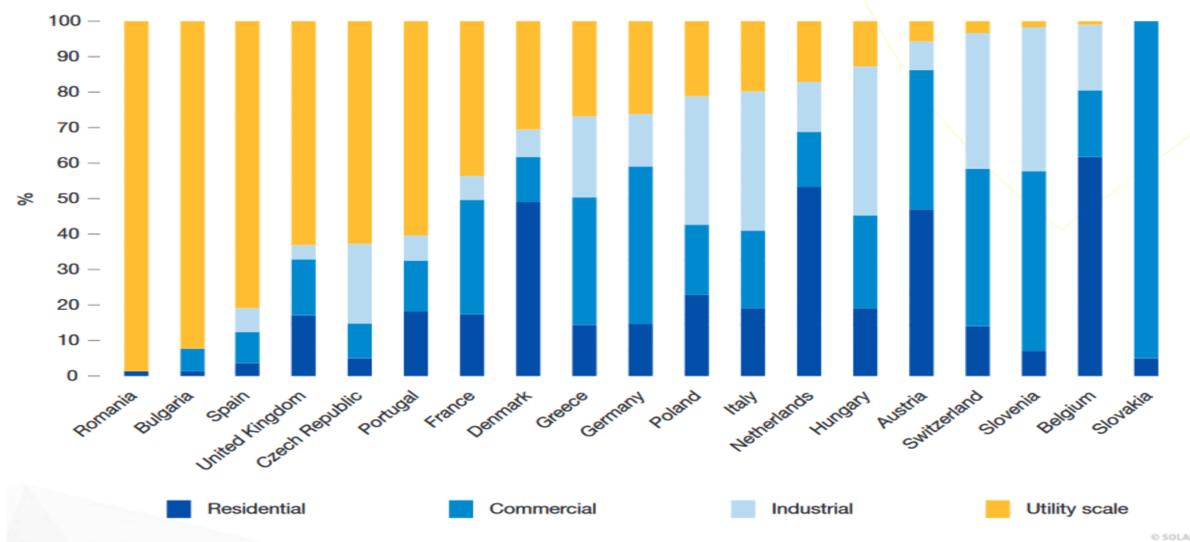

Figure 2.3-5: Percentage of solar electric system based on installation location (an EU perspective) [2.52]

In the figure above, the legends signify the capacity of the solar electric system, and thist is further explained in Table 2.3-1 below.

Table 2.3-1: Different scales for PV systems [2.52]

System	Power
Residential	<= 10 kWp
Commercial	10 to 250 kWp
Industrial	>250 kWp
Utility scale (built on the ground)	<1000 kWp

According to Global Market Outlook (2019-2023) by Solar Power Europe [2.52a], three scenarios can occur for the future – 'low', 'medium', and 'high'. As the names suggest, the intensity ("low", "medium", and "high) represents the growth of PVs (based on both market analysis and historical data).

It is estimated that the most likely global and European scenario will be a "medium" scenario, assuming that the annual demand growth will be 30 GW in 2023. Figure 2.3-63 represents the PV market scenarios for the period 2014-2023 in Europe [2.52a].

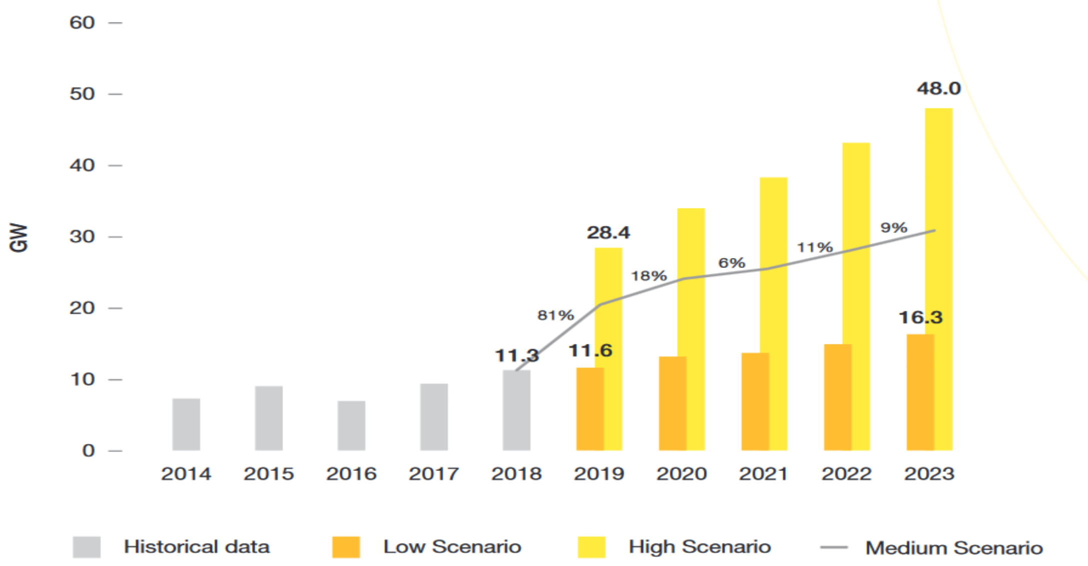

Figure 2.3-6: Annual solar PV Market scenarios for Europe (2046-2023) [2.52]

Figure 2.3-74 below represents the European total solar PV market scenario for the years to 2023. It is known that in 2016, Europe surpassed the impressive 100GW mark, and now it is estimated that the growth will be around 318 GW by the year 2023 in the high scenario case, and in the worst ("low") case - 195 GW in 2020. However, "medium" to "high" scenario growth is necessary to satisfy various climate agreements ratified around the world. Table 2.3-2 provides figures about Europe's market prospects for 2015-2020.

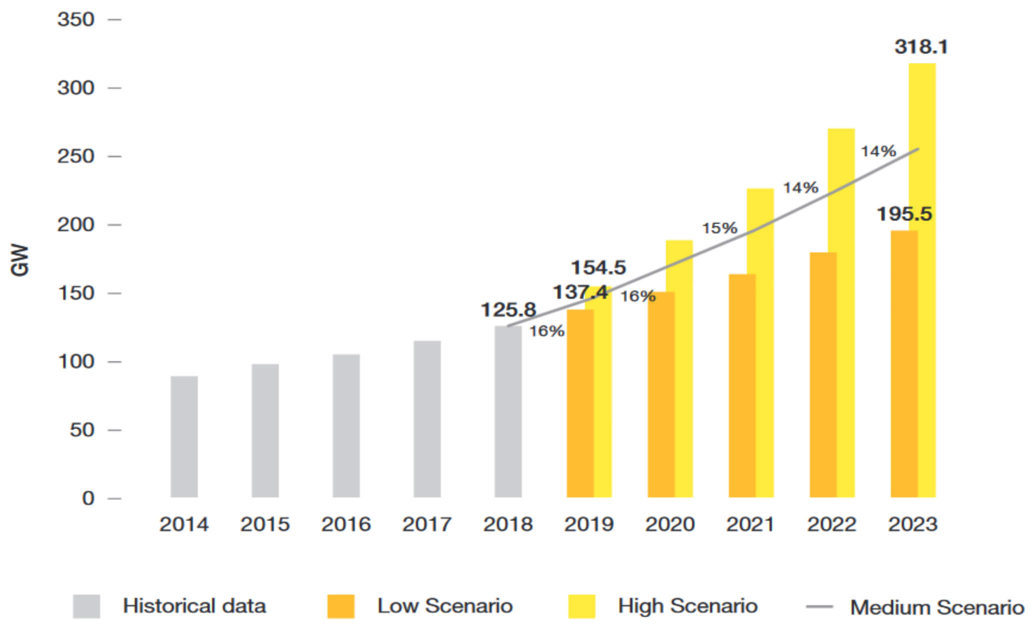

Figure 2.3-7: Total solar PV market scenario for Europe (2014-2023) [2.52]

Table 2.3-2: Solar PV markets' prospects (2018-2023) according to "Medium"'scenario 2023 in Europe [2.52a]

Country	2018 Total installed capacity (MW)	2023 Total installed capacity (MW) – Medium scenario 2023	2019 - 2023New installed capacity	2019 - 2023 Compound annual growth (%)
Germany	45920	72,611	26,692	10%
United Kingdom	12,962	15,674	2,711	4%
Netherlands	4,181	20,059	15,878	37 %
Belgium	4,075	6,367	2,292	9 %
Italy	19,877	29,498	9,621	8 %

It is estimated that Germany and Italy will be the largest European solar markets in 2023.

Figure 2.3-85 represents the future possible PV contribution to the electricity demand by 2030.

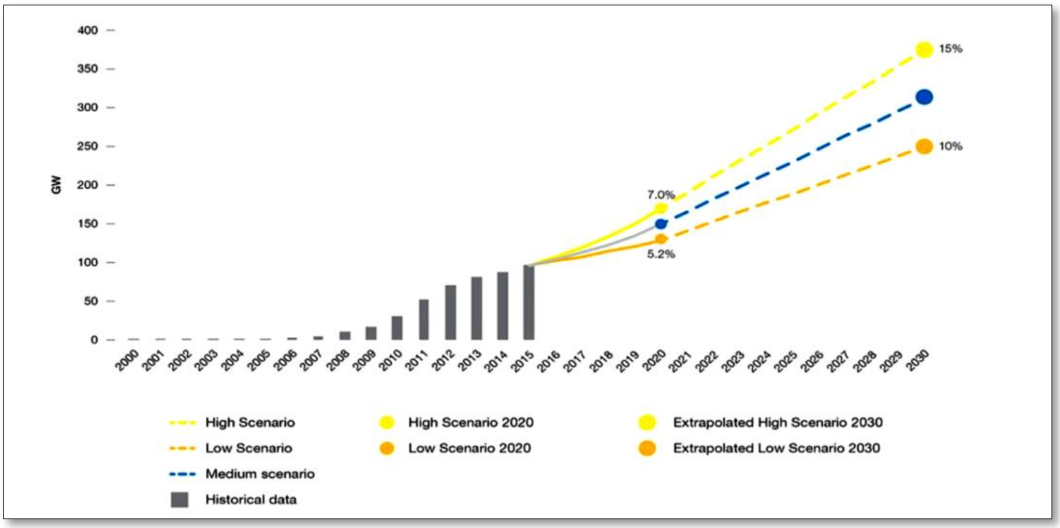

Figure 2.3-8: Possible contribution of Solar PV to EU-28 electricity demand by the year 2030 [2.54]

According to Solar Power Europe, if the solar market is designed appropriately, solar electricity cost will be the lowest (electricity generated by solar electric system) as compared to electricity from other RES; also, solar PV electricity can reach up to 15% of the EU's energy mix by 2030 [2.52].

Key findings:

- In 2020, it is estimated that the total global installed capacity will be 700 GW [2.50]
- Europe reached the '100 GW' milestone – a cumulative installed PV capacity - in the year 2016
- It is estimated that solar power in Europe would cover up to 15% of electricity demand by the year 2030 [2.54]. EPIA, "Global Market Outlook for Solar Power / 2016 - 2020]
- Compared to fossil fuels and onshore wind power, PV is becoming increasingly cost competitive
- Crystalline silicon remains the most employed (90% of all PV installation) solar module in the world
- Solar PV was forecasted to be among the top 3 electricity sources in Europe in 2020 [2.54]. EPIA, "Global Market Outlook for Solar Power / 2016 - 2020]

Reason for growth of installed solar capacity [2.48]:

- The cost of the solar panels is declining faster (2014-2016) than anticipated by many solar experts around world. The trend continued in 2018 with Solar PV equalled Wind as the cheapest form of bulk electricity generation [2.54].
- Increase in the cell and module efficiency by constant research by various researchers across the globe – a recent development in solar technology, called Passivated Emitted Rear Cells (PERC), is gaining much popularity.
- New utilities are welcoming solar installations in their buildings, similarly new players in other sectors are going solar to make the organisation greener.
- Active participation of prosumers; environmental conscious individuals.

Levelised Cost of Energy

The concept of Levelised Cost of Energy (LCOE) is used to depict the average generation cost of PV over its lifetime, including manufacturing costs, CAPEX (investment cost), installation costs, OPEX (O&M costs) and the cost of financing [2.55]. A general definition of LCOE is given below, where I_t is the investment expenditures in year t, M_t is the O&M expenditures in year t, F_t is fuel expenditures in tear t, which is zero for PV electricity, E_t is electricity generation in year t, r is the discount rate, and n is financial lifetime of the calculation [2.56].

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad (1)$$

The LCOE can vary according to many factors such as the Weighted Average Cost of Capital (WACC), or otherwise said discount rate, OPEX, market growth, learning rate, currency rate, efficiency increase, lifetime and degradation but most importantly the market segment; in fact, this has the biggest influence on the variations of the LCOE [2.55]. The LCOE can vary drastically according to different markets and this is shown in Figure 2.3-9 where the situation in 2015 for the UK, Sweden, Germany, France, Italy and Spain has been presented and predictions for 2020, 2030, 2040 and 2050 have been made. It can be seen that the annual insolation has a significant influence on the LCOE since locations with higher solar irradiation has a lower LCOE [2.57]. Furthermore, Figure 2.3-10 compares the LCOE of different solar technologies with others. As can be seen, even though PV rooftop is among the most expensive PV technologies, others are cheaper than the conventional ones. A 4 kWp system installed in the UK with no FiT payments but with current export payments of 5.24 p/kWh would yield a rate of return of 4.85% [2.58].

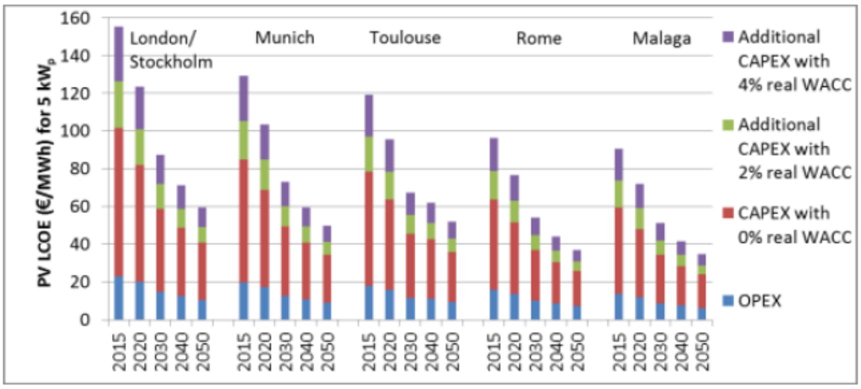

Figure 2.3-9: LCOE in different European countries / cities [2.55]

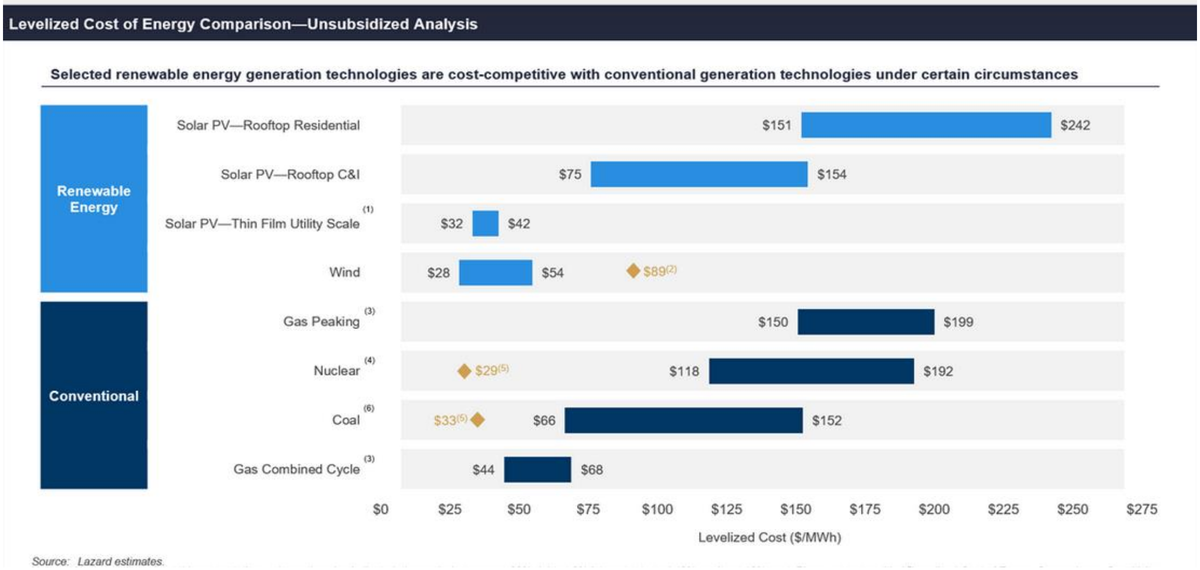

Figure 2.3-10: LCOE of different technologies in 2019 [2.59]

The PV module price, which is a capex component, is driven by both the technological development and market conditions. Over the last four decades, the average selling price of PV module fell 20% for each production volume doubling, decreasing from over usd_{2016} 80/Wp in 1970s to less than usd_{2016} 1/Wp in 2016 [2.56]. Despite continuous improvement in PV manufacturing technology and significant scaling up of PV production, a fairly constant price at roughly USD$ 4-4.5/Wp remained between 2004 and 2008 due to the expanding markets in Germany and Spain with profitable FiTs for the developers [2.56]. 2008 to 2012 saw a massive drop of 80% in PV module price [2.55, 2.56], as a result of the ambitious investment and huge overcapacities between 2005 and 2011. It is estimated that PV generation costs will fall by 25% between 2018 and 2028 and, in the favourable case, PV LCOE would fall to £0.09/kWh in 2028 [2.60]. The "US Energy Information Administration" report in February 2020 estimated that by 2023 the LCOE for onshore wind and solar PV will both be lower than that for coal fired power generation [2.61].

2.4. *Vehicle to Grid technologies*

Vehicle-to-Grid denotes the control and management of EV loads (batteries) by the power utility company or the aggregators through a communication channel between EVs and the power grid [2.62] [2.63] [2.34].

The introduction to the concept of smart grids has enabled the modernisation of power and communication systems around the world. This in turn gave rise to the concept of Vehicle-to-Grid technology (V2G). V2G is one of the smart technologies which use electric vehicles to improve the operation of a power system. The structure behind it is shown in Figure 2.4-1. When electric power is absorbed to charge the EV batteries (load), it is called Grid-to-Vehicle (G2V), whereas in V2G the opposite also occurs, since the batteries in EVs are considered as an energy storage from the perspective of the power grid [2.33].

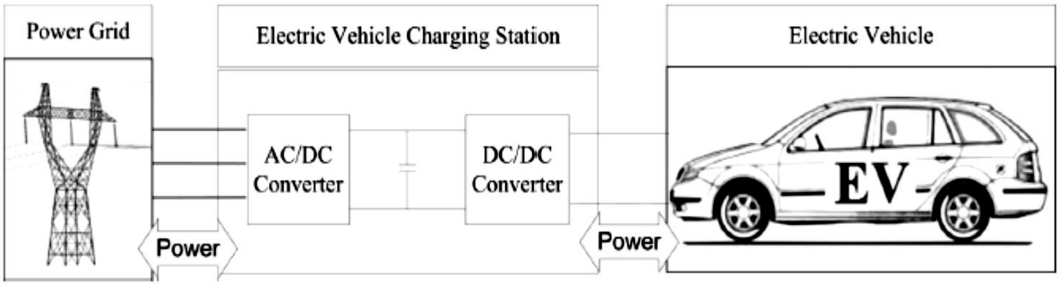

Figure 2.4-1: Vehicle to Grid power flow diagram [2.34]

The energy exchange between the EV and the power grid gives rise to various energy services for the power grid. One of the benefits for the EV owners participating in V2G is revenue obtained. V2G technology can further be categorised into unidirectional and bi-directional.

Uni-directional V2G (some-times also referred to as V1G):

Uni-directional V2G engages communication between power grid operator and EV to control the charging rate of each EV. This is quite often employed to prevent system instability; voltage drops and grid overloading [2.34].

Bi-directional V2G:

With bidirectional V2G, energy exchange occurs between EV batteries and the power grid both (though obviously not simultaneously) for EV charging and grid support. Bi-directional V2G provides more flexibility for the power grid utility to control the EV batteries to further improve the sustainability and reliability of the power system [2.34].

A comparison between the two modes [2.34] is provided in Table 2.4-1.

Table 2.4-1: Unidirectional and bidirectional V2G comparison [2.34] [2.62] [7]

9Power flow (V2G)	Uni-directional	Bi-directional
Infrastructure/hardware	EV battery, communication system	EV battery and bi-directional battery charger, Communication system
Power levels	Level 1, 2 and 3	Level 1 and 2
Services	Spinning Reserve, power gird Power Regulation	Active Power Support, Spinning Reserve, Reactive Power Support, Power Factor Correction, improve power system stability, Harmonic Filter, Frequency Regulation Energy backup
Cost	Low	Expensive
Advantages/benefits	Prevent overloading of power grid, minimise emissions and maximise revenue	Further improved grid stability and load profile, maintain voltage levels, reduce renewable energy intermittency, prevent power grid overloading, failure recovery, minimise emissions and maximise revenue
Disadvantages	Limited services	Battery degradation, investment cost, complex setup, and social/behavioural barriers

There are three types of grid-connected EV technologies: V2H (Vehicle-to-Home), V2V (Vehicle-to-Vehicle) and V2G (Vehicle-to-Grid). These concepts generally involve EVs, power sources & loads, power grid aggregators, electricity transmission system, communication system and V2G chargers. The aggregator is responsible for managing and controlling a large group of fleets of EVs to provide the ancillary services. Figure 2.4-2 represents the framework for V2G, V2V and V2H concepts. The diagram is self-explanatory. The main objective of V2G is to provide ancillary services to the power grid, mitigate renewable energy intermittence, support active power & reactive power compensation, maximise profits and reduce emissions. Upon request from power grid operators, V2G provides ancillary services to the power grid by controlling the charging rates of EVs.

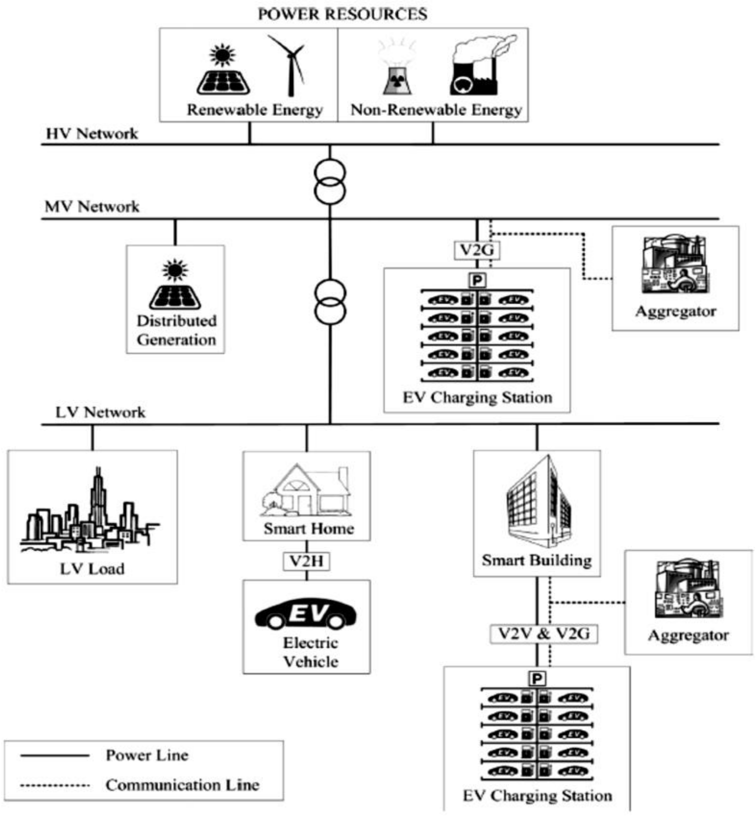

Figure 2.4-2 Power and communication flow and frameworks of V2G, V2G and V2H [4]

Detailed explanations of various ancillary services are provided in Chapter 3 under Section 3.2: Network services.

- ***Key findings for SEEV4City:***
- V2G can be classified into uni-directional and bi-directional.
- There are three concepts of grid-connected EV technologies: V2V, V2H and V2G.
- V2G technology has not yet matured; the biggest disadvantages include battery degradation and there are a number of barriers to its up-take, including social/behavioural ones.
- V2G becomes complex as large number of EVs (non-linear variables) are integrated into the power grid (grid constrains and limitations). This presents in principle at least, unless

stochastically aggregated, acomplicated unit-commitment problem with a large number of constraints and potentially conflicting objectives.

- V2G technology can be successfully achieved by optimisation techniques – important techniques include genetic algorithm and particle swarm optimisation.
- Proper V2G management systems, along with appropriate policies (incentive-based), are important for successful implementation of V2G technologies.
- V2G does come with technical issues, mostly related to the stability (transient and dynamic) of the grid:
    - While modelling V2G, it is essential to consider detailed and practical models (characteristics of real EV batteries) for steady-state and stability analysis.
    - Precise forecasting of V2G capacity is paramount in both system and V2G operations. Improper forecasting will have negative consequences for both EV fleet managers and grid operators. More information on V2G impacts are discussed in Chapter 5.
- Electricity price and economic benefits of EVs owners are the most motivating factors to obtain load levelling.
- Only limited practical studies have been carried out with real-time V2G models, RES, and power flow analysis in previous years.

2.5. ***Summary***

In this chapter, the potential of EVs as a critical part of the electric system is examined: Both PHEVs and BEVs, via their car batteries, can provide energy storage for the grid allowing the provision of various services as will be discussed in chapter 3. In terms of emission reduction and fuel costs savings BEVs are ahead, but when it comes to mileage and flexibility PHEVs can be considered advantages better because their IC engine allows a much longer driving range. From the point of view of the electricity grid, BEVs are more suitable than PHEVs. The larger batteries of BEVs require fewer of them to be collectively managed (aggregated) to meet minimum rating requirements for grid support, as will be described in Chapter 3. This is also true for the KPIs: fewer BEVs are required, compared to PHEVs, to obtain the same level of energy autonomy, GHG emission reduction and grid investment savings. The main part from the point of view of the cost of an EV is the car battery and in order to be integrated in the electric system it has to conform to requirements of safety, high power/energy capacity, reliability and efficiency, both from a technical and an economic perspective. From this perspective, the battery cost is highly relevant for the system because EVs will be employed for energy storage only if considered economically competitive against other solutions.

As will be discussed in the next chapter, in some countries the role of EVs in the grid has not yet been clearly defined by network operators and utilities. Therefore, there is not yet a general dedicated segment of the market and consequently the regulatory structure for aggregated EVs is set up in the same way as for conventional generators. This translates into high minimum rating requirements and a very large number of EVs of a high discharging rate is required, in order to satisfy these. Hence, for some services, very large fleets of EVs, represented for instance by private or organisational vehicles slow-charging during the night, will be ideal; or other, faster services for the central grid require a large amount of power and consequently high discharging rates are necessary. An EV with capacity to sustain a high charging rate also reduces the charging time which can provide a better EV user experience. However, the effect of fast charging can cause excessive battery degradation which must be taken into account and this will be covered in the next chapter.

A positive synergy between EVs and PV has been discussed in this chapter: EVs can act as storage for PV energy which can be deferred in time and utilized when there is need for energy; the EV batteries would be charged with the extra PV energy which will serve the load in night-time; this is an efficient way to mitigate PV intermittency and increase Energy Autonomy in a system. Smart charging and V2G have been introduced as a possible solution and, as mentioned above, this can be uni-directional and bi-directional; both have various pros and cons: although bi-directional V2G allows for a broader control of EV batteries, enabling the provision of a wider range of services to the grid, bi-directional V2G can cause higher battery degradation as compared to uni-directional smart charging.

One of the aims of SEEV4-City is to evaluate which form of Smart Charging and V2G is more beneficial according to different needs, i.e. for the different system boundaries of the OPs. The analysis will consider the technical and economic characteristics of these two approaches, and the benefits from the different services will be compared against the associated costs. This will be further explained in the next chapters. SEEV4-City will address these questions, and provide the necessary answers.

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3. Electricity Grids and Battery Energy Storage

This chapter presents a vital part of the EV for energy service business model: the power distribution network and related services. An essential component of the system, the energy storage system is also described continuing from Chapter 2.1.3 where it was introduced as part of an EV.

The traditional role of the grid is to distribute energy from a few large 'central' generators to the many consumers. However, with the advent of the Smart Grid technology the role of the grid changes from being solely an energy supplier to that of a service provider or a customer, because the grid requires certain 'ancillary' services to operate, such as energy storage and provision of reactive power. These can be provided by other agents, including EV owners connected to the grid. In this situation, the role of the customers connected to the grid changes from a mere user of electricity to (also) that of a producer, when adequately equipped and in sufficient numbers; the so-called ***pro-sumer***. With these new roles, the need for new business models that allow for the profitable provision of these ancillary services is evident. However, in order to produce these models, the existing structure in terms of the electricity market and price, the existing and new services and the stakeholders that are involved need to be studied and modelled. The services provided to the grid represent the main source of income for the business models developed within SEEV4-City: the various services include power provision, energy arbitrage and balancing services. Therefore, in Chapter 3.1 the current situation in terms of energy prices and the balancing services in the NSR countries is presented. Section 3.1.1 gives details about the absolute values and the variations of energy prices in the past years for various European countries. This is needed because there is an interconnected system and the price in one country is dependent on the situation of the whole system, and the potential reasons behind these fluctuations. The available ancillary services, their characteristics, requirements and approaches change according to the country considered and this subject is analysed in Section 3.1.2. Section 3.2 focuses on the most recent balancing services with an emphasis on the UK and their compatibility with the objectives of SEEV4-City. This work gives an insight into the payment structure for the different schemes because these will provide benefits for V4ES and ease the problem of EV integration into the electrical distribution system. A brief calculation of the expected revenues, from what are considered the most profitable services, is also provided. Section 3.3 scrutinizes the technological status and future developments of various energy storage systems: their function, operation, different chemistries and the development of this technology to date. When EV batteries are discharged to provide services to different stakeholders, the inevitable consequent phenomenon, battery degradation, arises. The causes and effects, the reason it is so important for SEEV4-City, and some examples of how to minimize it are explained in Section 3.3.2. The chapter closes with some indications as to future developments in the battery storage field and how this is relevant for SEEV4-City.

This chapter aims to provide a basis for the exploration of the following research questions:

1. What is the effect of the energy price within the business model?
2. How do the different market structures and their related prices influence the business model and which are the most suitable for large-scale introduction of EVs?
3. What is the effect of price variations on the outputs in terms of profitability of an EV business model?
4. For which services can the business model allow for profitable provision?
5. How the results of a business model change according to the disparate schemes available in different countries?

6. Is the payment structure for individual services sufficient to secure a profit under the business model?
7. Should the business model focus on only one service or provide a group of ancillary services according to their profitability?
8. What is the impact of the different Li-ion battery chemistries on the business model?
9. How do the future scenarios regarding battery technology and cost development influence the business model?
10. How should battery degradation be considered within the Business model?
11. What is the effect of the different parameters and their interactions on the business model?
12. How should the battery-charging schedule be controlled in order to optimize the battery State of Health (SOH) and limit battery degradation?

The chapter will address these questions, establish the links between the different parts of the system with SEEV4City and set the basis for the development of the methodology of V4ES.

3.1. *Electricity grid in EU and NSR*

3.1.1. 3.1.1 Electricity grid and energy prices in the NSR countries

This section discusses the basics of the electric grid, its structure and the methodology for the determination of the generation costs. The power grid is divided in two parts [3.1]: transmission and distribution. The transmission grid has a meshed topology, which improves the continuity of service and system stability, and connects the centralised power plants to the largest consumers and to the primary substations which step down the voltage to create the link with the distribution grid at the medium voltage level. The distribution grid is mainly built in a radial topology, and through the distribution transformers supplies the customers at low voltage.

The grid equipment is characterized by a long lifetime and a large cost, which means that every grid upgrade implies considerable investment, hence, every decision must be carefully evaluated in terms of its impact on the system security, on the complementary investments required and the effect on the operational costs.

For every nation, the generation mix is an ensemble of strategic choices made according to the available resources and political decisions. The energy mix is made by base load, semi-base load and peak load power plants and some percentage of RES. In the second part of the last century, vertically-integrated companies built generation capacity under public regulation and centralised plants connected to the HV grid were favoured. The suitability and flexibility of each generation technology depends of various factors: start-up and shut-down costs and durations, ramping limits to change the operating point through increments or decrements in MW/s, and minimum value of the operating point. An optimal power plant must be flexible in order to participate to the balancing of generation-demand. With the liberalisation, started in 1996 in Europe, the governments have split the vertically integrated electricity companies in new smaller companies, developing competitivity among some and creating monopoly activities for transmission and distribution which need to be regulated, so that the users are treated fairly.

The generation cost of a grid is determined by considering the average electricity generation costs of the different technologies (stand-alone generating costs) and then minimizing them. Not only that, but also the associated risk should be taken into account in terms of uncertain cost fluctuations. Because in a grid the electricity is generated by a portfolio (mix) of plants, a joint analysis must be undertaken. The energy portfolio gives a set of weightings X_i (each between 0 and 1), and collectively they add up to unity) to determine the quantities produced by the different technologies. The following equation determines the average electricity generation cost of a certain energy portfolio:

$$\overline{CC} = \sum_{i=1}^{n} X_i \, \overline{C_i} \qquad (1)$$

Where $\overline{CC}$ is the average generation cost of the energy mix, X_i are the weights related to the different technologies and $\overline{C_i}$ are the associated costs. The minimum average cost of the portfolio is given by a combination of the most economic technologies. This information must be combined with that of the risk given by the cost volatilities of the involved technologies. The risk for a single technology is given by its cost dispersion, i.e. standard deviation. Also, cross-correlation costs between the different technologies must be considered as well. Then, an efficient mix minimizes the volatility for a given level of average cost trying to find the most convenient combination, considering also technological restrictions. All the efficient portfolio, i.e. that minimize the cost or the volatility, can be represented in the Energy Efficient Frontier (EEF) shown in Figure 3.1-1 for a hypothetical mix.

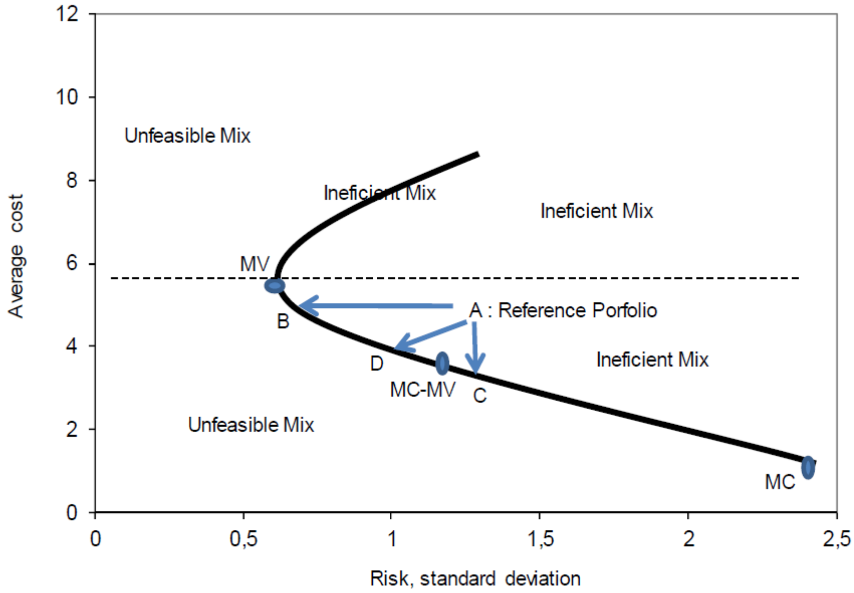


Figure 3.1-1 EEF for a hypothetical mix [3.1]

Minimum Cost (MC) represents the portfolio with the cheapest technologies by considering the given technological restrictions. Moving to the left along the curve, the average cost increase in favour of a more diversified portfolio and a reduced volatility, until the Minimum Volatility (MV) portfolio is reached. The more concave is the curve and the greater is the possibility to reduce the risk by diversification, because of the positive correlations between the different technologies. The mix is unfeasible if it falls to the left of MV, or it is inefficient if it is above MV or to the right of the curve. An acceptable efficient mix is the one in the mean of the MC and the MV: the MC-MV mix. Once the frontier has been defined, a generic inefficient mix A can be made efficient by shifting it in the curve, either in the position B which has the same average cost and lower risk or in the position C which has the same risk but a lower average cost. Again, the mean between B and C, represented by D is an optimal alternative mix.

This section describes the wholesale Energy Prices in the NSR countries with more detailed insights into the situations of the Netherlands, Belgium and Germany [3.2]. The prices in the remaining countries, the United Kingdom, Norway, Sweden and Denmark, are also presented here because Europe has an interconnected network, which means that the price in the continent depends on the situation of the individual countries, so a comparison with the prices in France is also necessary.

There are two fundamental energy markets: the wholesale markets for generators, large industrial consumers and electricity suppliers and the retail electricity market where suppliers sell electricity to final consumers. In order to understand the dynamics of the energy prices, it is useful to analyse the situation from a high level; therefore, only the scenario of the wholesale market is presented. Within this framework, there are other sub markets, which are characterized by different time frames: the forward and futures market deals with time intervals from years before, up to the before delivery. The day-ahead market is traded one day before delivery and the intra-day market allows providers to fix their schedules with better renewable feed-in forecasts, demand changes and unexpected power plant outages.

The day-ahead market is traded hourly and the wholesale prices for the Central Western Europe (CDS) region for 2016 and 2015, which includes The Netherlands, Germany, Belgium and France, is presented hereafter. The monthly average price was lower compared to 2015 for all markets in Europe; this is the result of the low generation costs as a consequence of the low prices for fuel and CO_2 emissions allowance, and the price difference between the different market areas was small; in Germany, the minimum of €22MWh was reached in February 2016. However, in the last third of 2016, the prices divided in two regions: Belgium and France, and The Netherlands and Germany. For the former group, the price went from €25.52/MWh to €65.14/MWh whereas for the latter only €37/MWh was reached at the end of the year. This can be associated to the inflexibility of the nuclear power generation in France and Belgium, which affected also Germany and The Netherlands because they had to provide this lack of generation. Figure 3.1-2 provides an insight into the situation [3.2].

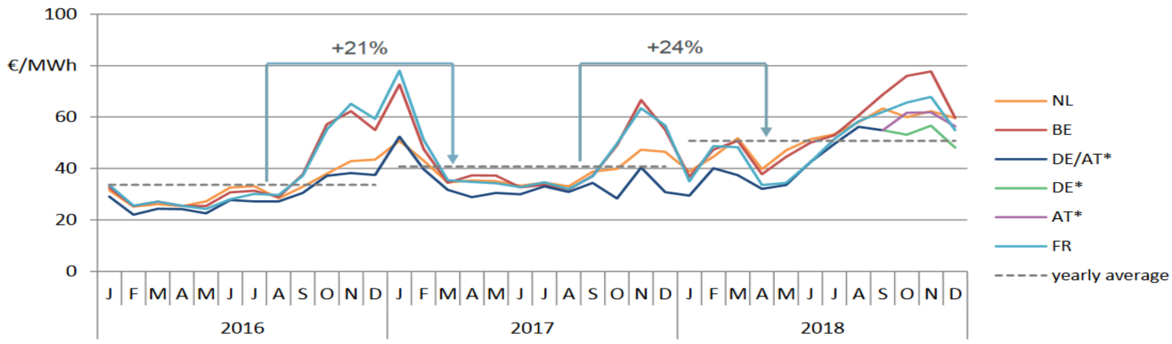


Figure 3.1-2 Monthly average hourly day-ahead wholesale prices [3.2]

The wholesale prices in the rest of the NSR countries can be described as following [3.3]: in 2018 in UK the average price was almost €64.9/MWh, in Denmark nearly €44.1/MWh, in Sweden nearly €48.5/MWh and in Norway a lower price of €43.7/MWh. The situation became slightly better (for consumers) compared to 2016 for the UK where a lower average price of nearly €57/MWh was achieved. Moreover, the 2018 price converged more compared to 2017, as can be seen in Figure 3.1-3. In fact, the price convergence, expressed in percentage of hours in which a country had the same wholesale price as the Dutch and German area, has increased.

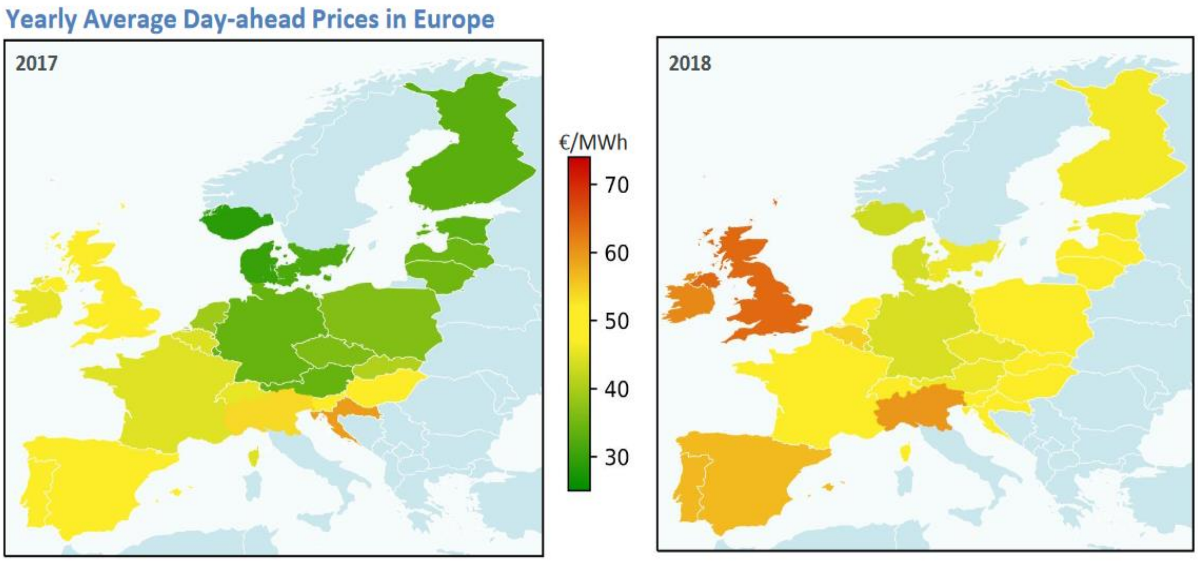


Figure 3.1-3 Price convergence of the European countries with Germany and the Netherlands [3.3]

This is further evidenced by Figure 3.1-4 where the monthly price convergence for 2017 and 2018 between various couplings of countries is presented.

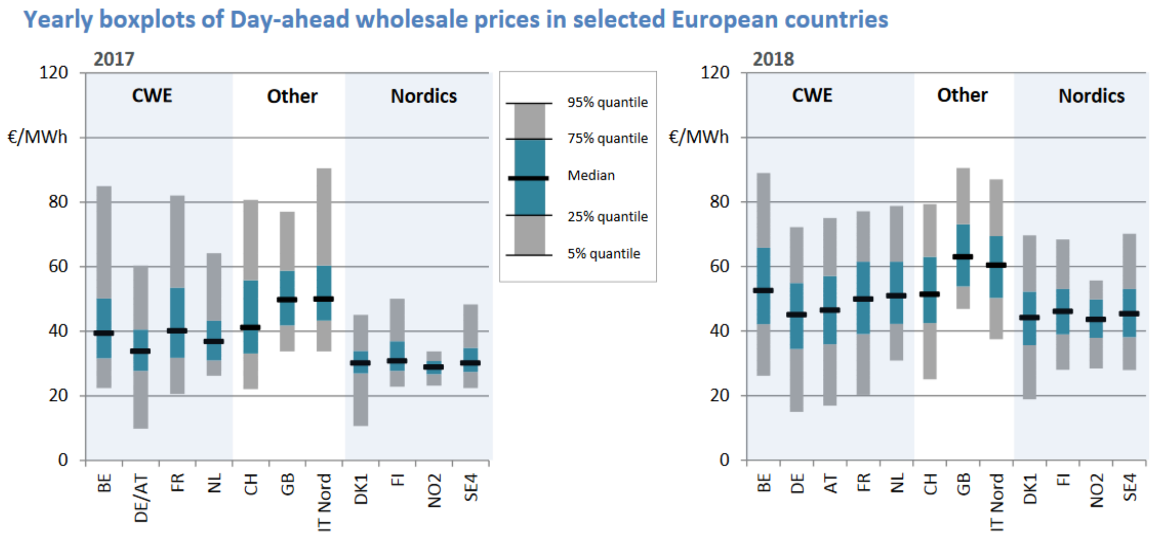


Figure 3.1-4 Monthly price convergence between the countries [3.3]

It can be seen that the price convergence between Germany - The Netherlands and Germany - France is higher in 2018 compared to 2017, and higher volatility in general in almost all countries and smaller differences in volatility between countries. The complementary of price convergence is the price difference and this has been represented in Figure 3.1-5.

Figure 3.1-5 Hourly price difference between the countries [3.2]

As can be seen, the price difference between Germany and The Netherlands decreased in 2016 and the price was equal for almost 4000 hours per year. This was mainly due to lower prices in The Netherlands caused by cheaper gas generation. The situation did not change much from 2015 to 2016 for The Netherlands – Belgium, although there were hours where the prices in Belgium were higher than in The Netherlands at the end of the year. Between France - Germany the difference became smaller in 2016 and finally for Belgium - France, in 2016, prices in France were generally higher than those in Belgium, due to again the unavailability of the nuclear plants.

In order to address the volatility of the prices in the European countries, it is useful to consider the standard deviation of the day-ahead wholesale prices. This is illustrated in Figure 3.1-6.

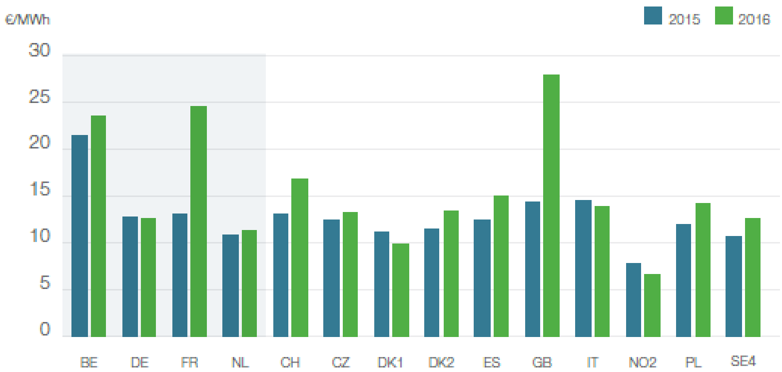


Figure 3.1-6 Standard deviation from the European day-ahead wholesale price [3.2]

High volatility can be noticed in the UK, Belgium and France. In France and Belgium there were high peaks, during the day, in the second half of 2016, whereas in the UK, heavy infrastructure maintenance were undertaken as well as unplanned power plant shut-down, which caused concerns about the security of supply and the currency market reactions to the outcome of the UK's Brexit Referendum in June 2016 decreased the value of the British pound.

It is also interesting to analyse the price duration curve for Germany and The Netherlands for 2015 and 2016. For Germany, the difference between the two years was not significant, but for The Netherlands an overall lower price curve, which was also closer to the German one, is seen for 2016 in Figure 3.1-7. Besides, on the German side, the prices became negative for 97 hours, due to the high share of renewables and 'must run' power plants that have to operate continuously.

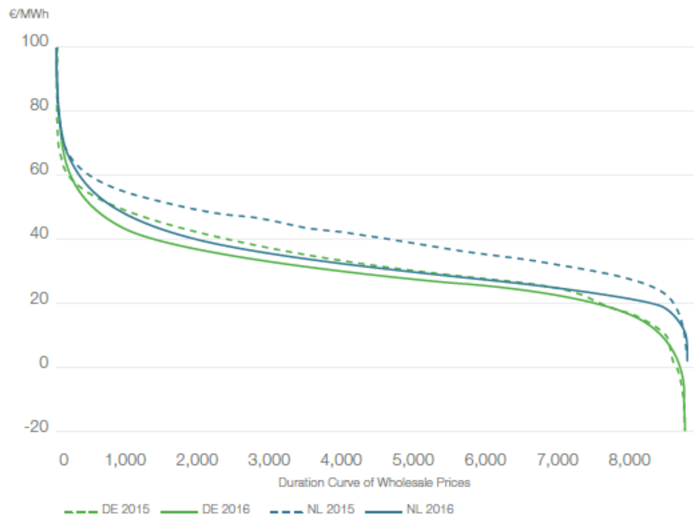


Figure 3.1-7 Duration curve of wholesale prices in Germany and the Netherlands [3.2]

The inspection of the prices in the futures market gives more understanding on how different aspects can influence the prices. A future is a contract by which two parties, the buyer and the provider, agree to purchase/sell a certain volume of electricity at a specified date or period at a fixed price. The price depends mostly on the futures of the fuel prices because of their significant impact on the generation cost. In Figure 3.1-8, the prices of the futures for 2018, 2019 and 2020 in 2015 and 2021, for Germany and The Netherlands can be seen.

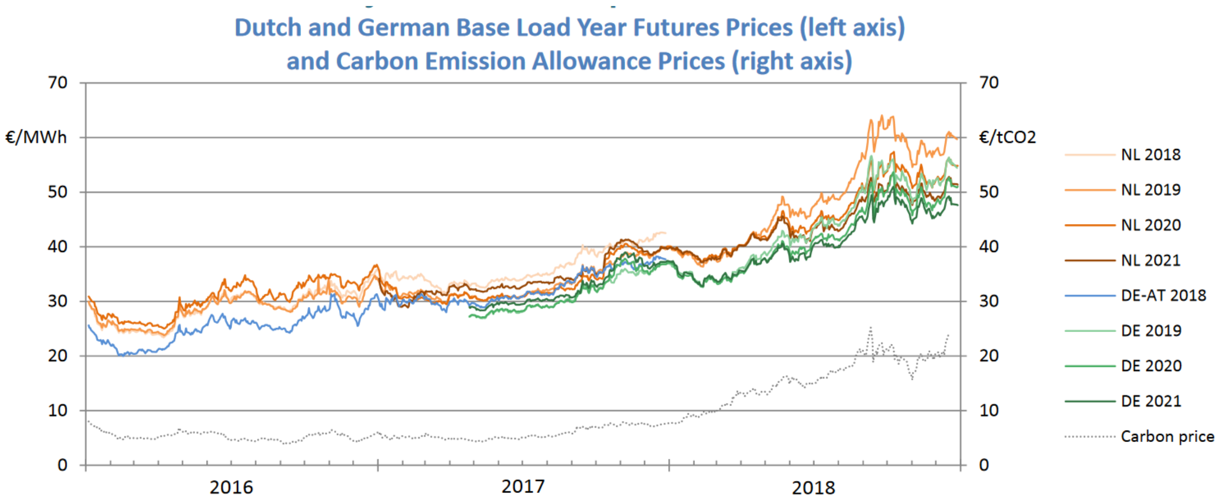


Figure 3.1-8 Baseload futures prices for 2018, 2019 and 2020 and 2021 for Germany and Holland [3.3]

During 2017 the futures prices are similar, while from Autumn 2017 the futures prices for 2018-2021 rose drastically over the others, due to the increasing demand for these futures, because market participants wanted to hedge against possible future events [3.3].

As afore-mentioned, for fossil fuel plant operators the fuel price covers a big part of the generation cost; hence, variations of fuel price have direct impact on the energy price. Apart from the fuel, plant operators need to purchase CO_2 emission allowances for the volume of CO_2 that their plants are emitting. Hard coal, natural gas and crude oil are traded on the global market, thus their price is transparent, whereas Lignite and Uranium are not traded in global markets and therefore they do not have a transparent price. CO_2 emission allowances are traded on international exchanges. In Figure 3.1-9, the price evolution for natural gas, hard coal and CO_2 emission allowances is depicted. It can be noticed that the natural gas price decreased from €20/MWhth (MWhth is the amount of heat released during the combustion of the fuel) to €15MWhth in the first half of 2016, whereas at the end of there had been an increase that brought back the price close to €20/MWhth. This can be attributed to the price rising of crude oil, and because natural gas is its substitute, the price increased implicitly. The price of the hard coal had a shallow decrease in the first third of 2016, but then increased significantly by 96% reaching over €12/MWhth in Autumn 2016, a four-year record high. One of the reasons can be the decision of China to limit coal mines annual operating days to 276; but because coal is still China's top energy source, some restrictions had been reversed which dropped the price to 6.7€/MWhth in December 2016. The reason for the drop of the CO_2 emission allowances, seen at the beginning of 2016, has to be attributed to the low oil price that dragged down the natural gas price, which made the latter convenient against the coal. Hence, there was less need for CO_2 emission allowances and the prices dropped. In 2016, the price was also more volatile compared to 2015. Subsequently rising oil prices brought CO_2 prices up significantly [3.3].

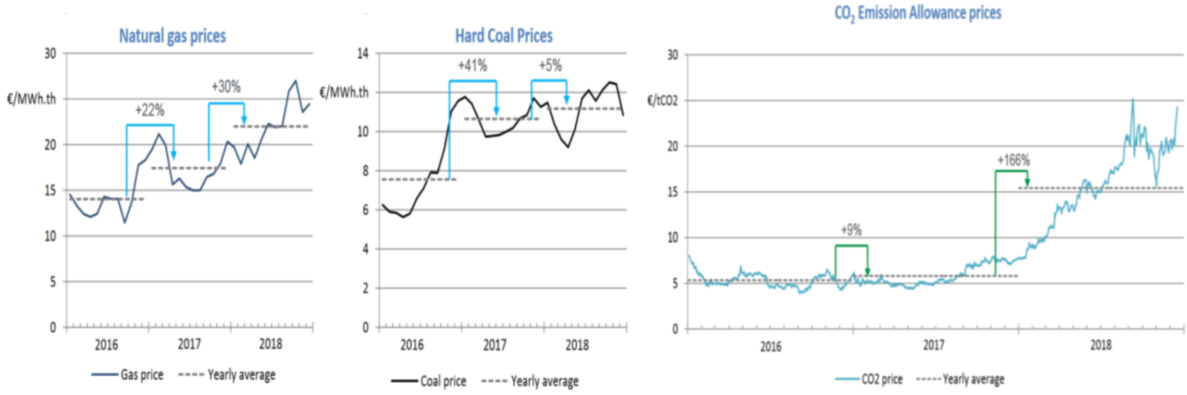


Figure 3.1-9 Daily day-ahead gas prices, monthly hard coal prices and daily CO2 emission allowance prices [3.3]

Another aspect that provides more insight into the dependence of the generation cost on the fuel costs are two parameters, identified as Clean Dark Spread (CDS) and Clean Spark Spread (CSS), that give basic indications on the potential revenues per unit of electricity generated with a conventional coal or gas plant respectively. All the additional costs must be covered by these spreads. CDS is calculated on the average day-ahead base price (coal plants are usually base load plants), whereas the CSS is calculated with the day-ahead base price and the day-ahead peak price, because natural gas-based plants can provide both base load and peak load. Figure 3.1-10 shows CDS and CSS for Germany from 2016 to 2018 [3.3].

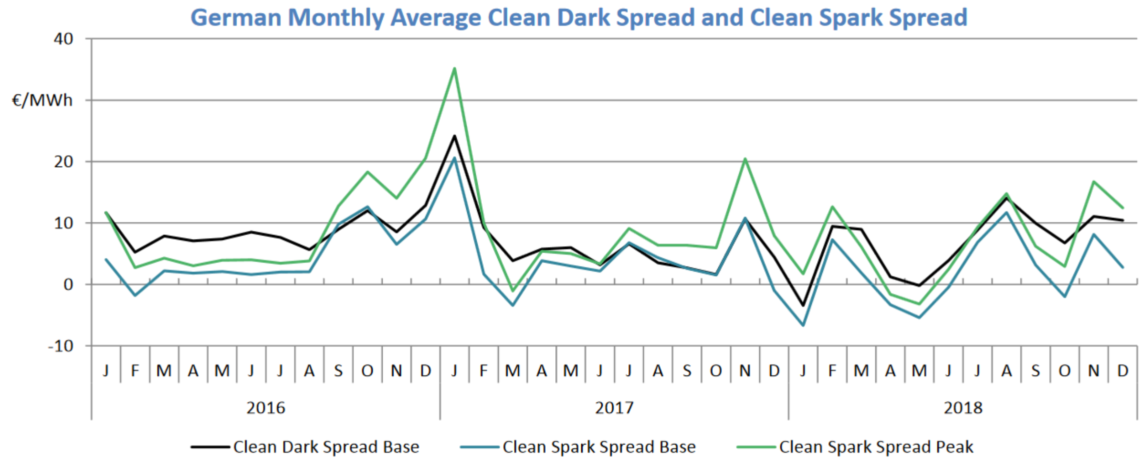


Figure 3.1-10 CDS and CSS for base and peak for Germany [3.3]

As can be seen, in 2016 the natural gas plants are more convenient in peak hours and from August 2016 also in off-peak hours, although this remain less competitive against the base load electricity from coal. Because natural gas peak plants represent a competitor of battery storages, in terms of peak provision, it can be deduced that this market became more competitive in 2016. Figure 3.1-11 shows the situation for The Netherlands.

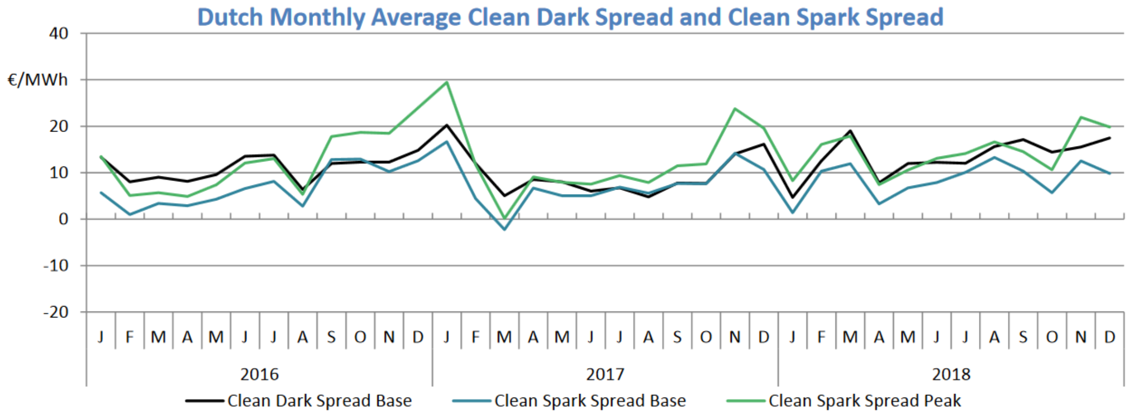


Figure 3.1-11 CDS and CSS for base and peak for The Netherlands [3.3]

The spreads in the Netherlands are slightly higher than those in Germany, because the average day-ahead price in The Netherlands is higher than the one in Germany, whereas the fuel costs do not change significantly. The CSS increased in 2016 reaching €20/MWhth at the end of the year. This means, providing peak power with battery storages is more competitive in The Netherlands than in Germany [3.3].

In conclusion, the energy prices can vary significantly according to the different market, which have different characteristics in terms of periods and procurement systems and due to reasons, which are not always technical, but also commercial, related to logistics and political. The fundamental influence of the price of hard coal and gas drives the dynamics of the energy market; hence, these have to be taken into account, while evaluating whether EVs can be as competitive as, and even more so, than ICEs.

3.1.2. Network services in the NSR countries

This paragraph considers the different Ancillary services available in the NSR countries and their requirements, as asked by the Network operators [3.4]. The main services that will be presented are the Frequency Response (or Reserve in this case), the Imbalance Settlement, the Load participation (specifically considered for Belgium where this is not included in the same market of the generation), Voltage regulation and Black start. Before going into the detail of these services, it is useful to have an idea of how the balancing process is undertaken:

- Central Dispatch; the Transmission System Operator (TSO) decides the commitment and the required amount from a majority of generation or demand by directly giving them dispatch instructions;
- Self-Dispatch – Portfolio based; a portfolio of generators start/stop/increase/decrease their output in real time, according to an aggregated schedule of actions;
- Self-Dispatch – Unit based; generators start/stop/increase/decrease their output in real time, according their own schedules.

Among the NSR countries, The Netherlands, Germany, Denmark and Sweden have a Self-Dispatch – Portfolio based approach whereas Belgium and Norway opt for the Unit based approach. No information is available for the United Kingdom about this.

This is normally activated in order to stabilize the System Frequency after an imbalance in all the NSR countries. The following table defines the characteristics of this service such as the providers, the product resolution, the procurement scheme, the price types, the monitoring process and others. The service is divided in two parts: a capacity provision and an energy provision. In addition, the payments are different. The characteristics of this service is presented in Table 3.1-1.

Table 3.1-1 Frequency Containment Reserve characteristics in the NSR countries

Characteristic	Options	UK	Netherlands	Belgium	Norway	Germany	Denmark	Sweden
Capacity - Procurement schemes	Bilateral market							
	Free offers							
	Hybrid				☒			
	Mandatory offers	☒						
	Mandatory provision							
	Mandatory provision without reservation							
	Organised market		☒	☒		☒	☒	☒
	Other							
Capacity – minimum bidding quantity (MW)	No minimum bid size							
	x≤1MW			☒	☒	☒	☒	☒
	1MW≤x≤5MW		☒					
	5MW≤x≤10MW							
	x>10MW							
	Year or more							

Capacity – maximum bidding time	Month(s)			⊠				
	Week(s)		⊠			⊠		
	Day(s)							
	Hour(s)				⊠		⊠	⊠
Capacity – time distance from auction	Year or more							
	Month(s)							
	Week(s)	⊠	⊠	⊠				
	Day(s)				⊠	⊠	⊠	⊠
Capacity - Provider	Generators only		⊠		⊠			⊠
	Generators + load						⊠	
	Generators + Pump Storage units pumping							
	Generators+ Pump Storage units pumping	⊠		⊠		⊠		
Capacity – symmetrical product	Has to be symmetrical		⊠			⊠		⊠
	Doesn't need to be symmetrical	⊠		⊠	⊠		⊠	
Capacity – settlement rule	Pay as bid	⊠	⊠	⊠		⊠		⊠
	Marginal pricing				⊠		⊠	
	Regulated price							
Capacity – Monitoring	Real-Time monitoring					⊠		
	Ex-post check		⊠	⊠				
	Hybrid	⊠			⊠		⊠	⊠
Energy-Procurement schemes	There is not sufficient information for the NSR countries							
Energy - Provider	Generators only							⊠
	Generators + Load						⊠	
	Generators + Pump Storage units pumping							
	Generators + Load + Pump Storage units pumping	⊠						
Energy – minimum bidding quantity (MW)	No minimum bid size						⊠	
	x≤1MW							⊠
	1MW≤x≤5MW							
	5MW≤x≤10MW	⊠						
	x>10MW							

Energy – maximum bidding time	There is not sufficient information for the NSR countries							
Energy – time distance from auction	There is not sufficient information for the NSR countries							
Energy – settlement rule	Pay as bid	☒						
	Marginal pricing							☒
	Regulated price							
	Hybrid							
Energy – Monitoring	Real-Time monitoring							
	Ex-post check			☒			☒	
	Hybrid	☒						☒

Frequency Restoration Reserve (FRR)

This service is activated in order to restore the System Frequency and, if applicable, balance the power to the expected value. This can be done either automatically or manually. Currently, all the NSR countries with the exception of the UK adopt automatic FRR, and the following table describes the characteristics of this service in the involved countries. The service is divided in two parts: a capacity provision and an energy provision. Also, the payments are different. The requirements for FRR in the NSR countries are listed in Table 3.1-2.

Table 3.1-2 Frequency Restoration Reserve automatic requirements in the NSR countries

Characteristic	Options	UK	Netherlands	Belgium	Norway	Germany	Denmark	Sweden
Capacity - Procurement schemes	Bilateral market		☒					
	Free offers							
	Hybrid							
	Mandatory offers							
	Mandatory provision							
	Mandatory provision without reservation							
	Organised market			☒	☒	☒		☒
	Other							
	Pre-contracted Offers only						☒	
	Pre-contracted and Mandatory offers							
	Pre-contracted and Free offers							

Capacity – minimum bidding quantity (MW)	No minimum bid size							
	x≤1MW			☒				
	1MW≤x≤5MW		☒		☒			☒
	5MW≤x≤10MW					☒		
	x>10MW							
Capacity – maximum bidding time	Year or more						☒	
	Month(s)			☒				
	Week(s)					☒		
	Day(s)							
	Hour(s)		☒		☒			☒
Capacity – time distance from auction	Year or more		☒				☒	
	Month(s)							
	Week(s)			☒				
	Day(s)				☒	☒		☒
Capacity - Provider	Generators only		☒		☒			☒
	Generators + load							
	Generators + Pump Storage units pumping			☒				
	Generators+ Pump Storage units pumping					☒		
Capacity – symmetrical product	Has to be symmetrical		☒					
	Doesn't need to be symmetrical			☒	☒	☒		☒
Capacity – settlement rule	Pay as bid		☒	☒		☒		☒
	Marginal pricing				☒			
	Regulated price							
Capacity – Monitoring	Real-Time monitoring					☒		
	Ex-post check			☒				
	Hybrid				☒			☒
Energy - Procurement schemes	Bilateral market							
	Free offers							
	Hybrid							
	Mandatory offers							
	Mandatory provision							
	Mandatory provision without reservation							
	Organised market			☒		☒		
	Other				☒			☒

	Pre-contracted Offers only						☒	
	Pre-contracted and Mandatory offers							
	Pre-contracted and Free offers		☒					
Energy – Activation Rule	Pro Rata (Parallel Activation)			☒	☒		☒	☒
	Merit order		☒			☒		
Energy – minimum bidding quantity (MW)	No minimum bid size						☒	
	x≤1MW			☒				
	1MW≤x≤5MW		☒			☒		☒
	5MW≤x≤10MW							
	x>10MW							
Energy – maximum bidding time	Hours (or blocks)							☒
	30 minutes							
	15 minutes		☒	☒				
Energy – time distance from auction	x>H-1		☒					
	15 min<x≤H-1							
	5min<x≤15min							
	1min<x≤5min				☒			☒
	x≤1min			☒		☒	☒	
Energy – Provider	Generators only		☒		☒			☒
	Generators + load						☒	
	Generators + Pump Storage units pumping			☒				
	Generators+ Pump Storage units pumping					☒		
Energy – settlement rule	Pay as bid			☒		☒		
	Marginal pricing		☒					☒
	Regulated price							
	Hybrid						☒	
Energy – Monitoring	Real-Time monitoring					☒		
	Ex-post check		☒	☒			☒	
	Hybrid							☒
Energy – Activation time of FFR from 0 to max	x≤90s							
	90s<x≤5min				☒	☒		☒
	5min<x≤15min		☒	☒			☒	
	x>15min							

Every NSR country uses also manual FRR, and the characteristics are shown in Table 3.1-3. There are two parts to this: a capacity provision and an energy provision - and the payments are, or course, different.

Table 3.1-3 Frequency Restoration Reserve manual requirements in the NSR countries

Characteristic	Options	UK	Netherlands	Belgium	Norway	Germany	Denmark	Sweden
Capacity - Procurement schemes	Bilateral market		☒					☒
	Free offers							
	Hybrid							
	Mandatory offers							
	Mandatory provision							
	Mandatory provision without reservation							
	Organised market			☒	☒	☒	☒	
	Other							
	Pre-contracted Offers only							
	Pre-contracted and Mandatory offers							
	Pre-contracted and Free offers							
Capacity – minimum bidding quantity (MW)	No minimum bid size							
	x≤1MW			☒				
	1MW≤x≤5MW	☒				☒		
	5MW≤x≤10MW		☒		☒		☒	☒
	x>10MW							
Capacity – maximum bidding time	Year or more		☒	☒				
	Month(s)							☒
	Week(s)							
	Day(s)							
	Hour(s)				☒	☒	☒	
Capacity – time distance from auction	Year or more		☒					
	Month(s)			☒				☒
	Week(s)							
	Day(s)				☒	☒	☒	
Capacity – Provider	Generators only							
	Generators + load		☒		☒		☒	☒
	Generators + Pump Storage units pumping							
	Generators+ Pump Storage units pumping			☒		☒		

Capacity – symmetrical product	Has to be symmetrical							
	Doesn't need to be symmetrical	☒	☒	☒	☒	☒	☒	☒
Capacity – settlement rule	Pay as bid	☒	☒	☒		☒		☒
	Marginal pricing				☒		☒	
	Regulated price							
Capacity – Monitoring	Real-Time monitoring			☒		☒	☒	
	Ex-post check							
	Hybrid	☒			☒			☒
Energy - Procurement schemes	Bilateral market							
	Free offers							
	Hybrid							
	Mandatory offers							
	Mandatory provision							
	Mandatory provision without reservation							
	Organised market				☒	☒		☒
	Other							
	Pre-contracted Offers only							
	Pre-contracted and Mandatory offers							
	Pre-contracted and Free offers		☒	☒			☒	
Energy – Activation Rule	Pro Rata (Parallel Activation)							
	Merit order	☒	☒	☒	☒	☒	☒	☒
Energy – minimum bidding quantity (MW)	No minimum bid size							
	x≤1MW			☒				
	1MW≤x≤5MW	☒	☒			☒		
	5MW≤x≤10MW				☒		☒	☒
	x>10MW							
Energy – maximum bidding time	Hours (or blocks)				☒	☒	☒	☒
	30 minutes		☒	☒				
	15 minutes							
Energy – time distance from auction	x>H-1		☒					
	15 min<x≤H-1							
	5min<x≤15min				☒	☒	☒	☒
	1min<x≤5min							
	x≤1min		☒					

	Depends on the unit	☒						
Energy - Provider	Generators only							
	Generators + load		☒		☒		☒	☒
	Generators + Pump Storage units pumping	☒						
	Generators+ Pump Storage units pumping			☒		☒		
Energy – settlement rule	Pay as bid	☒		☒		☒		
	Marginal pricing		☒		☒		☒	☒
	Regulated price							
	Hybrid							
Energy – Monitoring	Real-Time monitoring					☒	☒	☒
	Ex-post check		☒					
	Hybrid	☒		☒	☒			
Energy – Activation time of FFR from 0 to max	x≤90s							
	90s<x≤5min							
	5min<x≤15min				☒	☒	☒	☒
	x>15min							
	Depends on the unit	☒						

Replacement Reserve

This service is used to restore/support the required level of FRR that has to be prepared for further imbalances. It includes operating reserves that require times from those necessary to restore frequency to hours. Only the UK among the NSR countries has this service. For the capacity part: the minimum bidding quantity has to be between 1 MW and 5 MW, the maximum bidding time is in terms of weeks, the time distance to auction is again in terms of weeks, the providers are generators, loads and pump storage units pumping. The contracted parties who provide the service are paid based on the bid price and the monitoring is a hybrid system. As for the energy provision, the units are activated according to a merit order (from lowest marginal cost to the highest) the minimum bidding quantity, again, has to be between 1MW and 5 MW the providers are generators, loads and pump storage units pumping the settlements rule is set pay as bid, the monitoring is a hybrid system. The activation time is the time between the receipt of a valid instruction by the Activation Optimisation Function and when the ramping to meet that instruction has ended and this depends on the unit.

Imbalance settlement

There is a Balancing obligation expected that may be applied when the Balance Responsible Party (BRP) provides imbalanced volumes. This obligation is only financial in France, Denmark and Norway, whereas it has legal consequences in the UK, Belgium, The Netherlands and Germany. The RES are exempted from it only in Belgium. The number of Imbalance Volumes to be calculated, attributed and charged to the BRP per settlement time unit is a fundamental characteristic of the local market design. In Germany, Belgium and The Netherlands there can be just 1 portfolio whereas in the UK, Denmark, Norway and Sweden there can be 2. The related characteristics can be found in Table 3.1-4.

Table 3.1-4 Imbalance settlement requirements in the NSR countries

Characteristic	Options	UK	Netherlands	Belgium	Norway	Germany	Denmark	Sweden
Settlement Time Unit – If 1 volume	15 min		☒	☒		☒		
	30 min							
	1 hour							
	>1hour							
Settlement Time Unit – If 2 volume - Generation	15 min							
	30 min	☒						
	1hour				☒		☒	☒
	>1hour							
Settlement Time Unit – If 2 volume - Consumption	15min							
	30min	☒						
	1hour				☒		☒	☒
	>1hour							
Number of prices – If 1 portfolio	Single pricing		☒	☒		☒		
	Dual pricing							
Number of prices – If 2 portfolios – Generation	Single pricing							
	Dual pricing	☒			☒		☒	☒
	Other							
Number of prices – If 2 portfolios – Consumption	Single pricing				☒		☒	☒
	Dual pricing	☒						
	Other							
Main component of Imbalance prices – If 1 portfolio – Aggravating imbalance	Average Control Energy Price					☒		
	Marginal Control Energy Price		☒	☒				
	Day-Ahead market Price							
	Intraday Market Price							
	Other							
Main component of Imbalance prices – If 1 portfolio – Reducing imbalance	Average Control Energy Price					☒		
	Marginal Control Energy Price		☒	☒				
	Day-Ahead market Price							
	Intraday Market Price							
	Other							

Main component of Imbalance prices – If 2 portfolios – Generation – Aggravating imbalance	Average Control Energy Price	☒						
	Marginal Control Energy Price				☒		☒	☒
	Day-Ahead market Price							
	Intraday Market Price							
	Other							
Main component of Imbalance prices – If 2 portfolios – Consumption - Aggravating imbalance	Average Control Energy Price	☒						
	Marginal Control Energy Price				☒		☒	☒
	Day-Ahead market Price							
	Intraday Market Price							
	Other							
Main component of Imbalance prices – If 2 portfolios – Generation - Reducing imbalance	Average Control Energy Price							
	Marginal Control Energy Price							
	Day-Ahead market Price				☒		☒	☒
	Intraday Market Price	☒						
	Other							
Main component of Imbalance prices – If 2 portfolios – Consumption – Reducing imbalance	Average Control Energy Price							
	Marginal Control Energy Price				☒		☒	☒
	Day-Ahead market Price							
	Intraday Market Price	☒						
	Other							
Is there a minimal incentive?	Yes	☒			☒		☒	☒
	No		☒	☒		☒		
Control Energy Prices used - FCR	Yes	☒			☒			
	No		☒	☒		☒	☒	☒
Control Energy Prices used – FRR (automatic)	Yes	☒	☒	☒		☒		
	No				☒		☒	☒

Control Energy Prices used – FRR (manual)	Yes	☒	☒	☒	☒	☒	☒	☒
	No							
Control Energy Prices used - FRR	Yes	☒						
	No		☒	☒	☒	☒	☒	☒
Start/Stop costs in Imbalance Charges	Yes	☒						☒
	No		☒	☒	☒	☒	☒	
Time before real time for BRP to carry out a re-schedule in Internal ID	15 min							
	30 min							
	45 min					☒		☒
	1 hour				☒		☒	
	x>1hour							
Internal Intra Day Market time period	15 min			☒		☒		
	30 min							
	1 hour				☒		☒	☒
Can market participants change the approved schedules after delivery?	Always		☒	☒		☒		
	Never	☒			☒		☒	
	Only in case of IT or any other problems (TSO approval)							☒

Load participation

For this service only in Belgium among the NSR countries, Load providers cannot use the same market mechanisms and actual processes as generation. Therefore, there is a specific market solution: the minimum bidding size has to be between 1 MW and 5 MW, the settlement rule has been fixed as pay as bid and aggregators, large consumers, aggregated small size consumers, small consumers and other consumers can participate in the balancing services. The minimum size for Balancing Service Providers is less than 1 MW, the monitoring of the performance is done after the event (ex-post check) and the TSO has a medium level direct control.

Voltage control

Voltage control is part of the ancillary services for every NSR country except Denmark, and the characteristics are represented in Table 3.1-5.

Table 3.1-5 Voltage control requirements in the NSR countries

Characteristic	Options	UK	Netherlands	Belgium	Norway	Germany	Denmark	Sweden
Determination of the optimal use of reactive energy	Optimisation program							
	Operator's experience, studies		☒		☒	☒		☒
	Both	☒		☒				
Type of optimisation approach	Centralised optimisation approach							
	Regional-oriented approach							
	Both			☒				☒
Implicit/explicit offer bids from BSP	Explicit	☒	☒					
	Implicit						☒	
	Both							
Providers - Generators	Yes	☒	☒	☒	☒	☒	☒	☒
	No							
Providers - DSO	Yes		☒					☒
	No	☒		☒	☒	☒	☒	
Providers – Industrial consumers	Yes		☒					
	No	☒		☒	☒	☒	☒	☒
Providers – Windfarm producers	Yes		☒	☒		☒		
	No	☒			☒		☒	☒
Providers – Photovoltaic systems	Yes		☒					
	No	☒	☒	☒	☒	☒	☒	☒
Providers – HVDC links	Yes		☒			☒	☒	
	No	☒		☒	☒			☒
Provider – Windfarm producers or photovoltaic systems connected on the DSO	Yes		☒			☒		
	No	☒		☒	☒		☒	☒
Provider – Transformers of the transmission grid	Yes		☒	☒		☒	☒	
	No	☒			☒			☒
If a power plant is able to	Transmission grid			☒			☒	

provide voltage control, which grid it should be connected to	Distribution grid							
	Both							
	Transmission grid or distribution grid	☒	☒		☒	☒		☒
Is it a service paid by the TSO?	Yes	☒		☒	☒			
	No							☒
	Partly		☒			☒	☒	
Settlement rule	Pay as bid	☒						
	Marginal price							
	Regulated price				☒			
	Free					☒		
	Hybrid						☒	
	Regulated price + Free							
	Pay as bid + Free		☒	☒				
Monitoring	Real-Time monitoring	☒					☒	☒
	Ex-post check					☒		
	Hybrid		☒	☒	☒			
Does the TSO own reactive power compensation systems?	Yes	☒	☒	☒	☒	☒	☒	☒
	No							
Owing by the TSO the reactive power compensation systems - Inductance	Yes	☒	☒	☒	☒	☒	☒	☒
	No							
Owing by the TSO the reactive power compensation systems – Capacitor banks	Yes	☒	☒	☒	☒	☒	☒	☒
	No							
Owing by the TSO the reactive power compensation systems - SVC	Yes	☒			☒		☒	☒
	No		☒	☒		☒		
Owing by the TSO the reactive power compensation systems –	Yes	☒			☒	☒	☒	☒
	No		☒	☒				

Synchronous compensator								
Settlement rules for the exchange of reactive power between transmission and distribution grids – Respect a Reactive/Active power ratio	Yes	☒	☒	☒		☒		☒
	No						☒	
Settlement rules for the exchange of reactive power between transmission and distribution grids – Min/max fixed value for reactive power	Yes						☒	
	No							
Settlement rules for the exchange of reactive power between transmission and distribution grids – No rules	Yes						☒	
	No							
Settlement rules for the price of reactive power between transmission and distribution grids	Charges and/or fees	☒	☒	☒		☒		
	Charges and/or fees + Regulated price							
	Bonus link to a specific diagram							
	Regulated price							
	No rules				☒			
	Free						☒	☒

Black start

This service can be mandatory or not for some plants according to the criteria of different TSOs; also, the types of plants that can provide this service varies. Table 3.1-6 describes the required characteristics.

Table 3.1-6 Black start requirements in the NSR countries

Characteristic	Options	UK	Netherlands	Belgium	Norway	Germany	Denmark	Sweden
If a power plant is able to provide black start service, which grid it should be connected to	Transmission grid			☒	☒	☒	☒	☒
	Distribution grid							
	Both							
	Transmission grid or distribution grid	☒	☒					
Is it a service paid by the TSO?	Yes	☒	☒	☒		☒	☒	☒
	No				☒			
Settlement rule	Pay as bid	☒	☒				☒	☒
	Marginal price							
	Regulated price							
	Free					☒		
	Hybrid							
	Pay as bid + Free			☒				
Does the TSO own units for Black start service?	Yes						☒	
	No	☒	☒	☒	☒	☒		☒
Does the TSO have a regulated amount of BS control (regarding the whole control area)?	No	☒		☒	☒	☒	☒	
	Yes, 1-500MW							
	Yes, 501-800MW		☒					
	Yes, more than 800MW							☒
	All the units who are able to provide BS must provide it							
How often does the TSO practise the method of the BS process (for example using a training simulator)?	Regularly/once a year		☒					
	Regularly/several times a year			☒				☒
	Occasionally						☒	
	Regularly	☒			☒	☒		
Should be the Black start provided by a single unit or it is allowed	Yes							
	No, it has to be a single unit	☒	☒	☒		☒	☒	☒

to be part of a power plant?								
How long is the acceptable non-availability period of the BS unit (planned, for example: resurrection & maintenance of the unit)?	It is not allowed		☒					
	Less than one day							
	Between 1 and 3 days							
	Between 4 and 7 days							
	Depending on the availability of other BS units					☒		☒
	More than one week	☒						
Is there a regulated gradient for the BS unit?	No	☒		☒		☒		
	Yes, 0-100MW/15min						☒	
	Yes, 101MW-200MW/15min							
	Yes, more than 200MW/15min							
Monitoring	Real-time monitoring/tests	☒					☒	
	Ex-post check							
	Hybrid		☒	☒		☒		☒

3.2. ***Network services***

3.2.1. Balancing services

There are services that a Battery Electric Storage System (BESS) may provide, and these can be categorized according to the stakeholder group that receives the biggest share of the benefit for delivering each service [3.5], although some services may benefit more than one group. The stakeholder groups are the following: Independent System Operator (ISO) and Regional Transmission Organizations (RTOs), utilities and customers.

From the ISO point of view, Ancillary services can be provided either with a vertically integrated approach, where the system operator schedules/coordinates the dispatch of the generation assets to provide both energy and ancillary services, or traded on wholesale electricity markets.

The services that mainly involve ISOs are Energy Arbitrage, Frequency Regulation, Spinning/Non-Spinning Reserve, Voltage Support and Black Start. With Energy Arbitrage, cheap electricity is bought during night-time hours and sold back to the grid when the prices are at the highest. Spinning Reserve consists of the online generation capacity that immediately serves the load in case of an unexpected contingency event. In case of Non-Spinning Reserve, the response is not instantaneous, but takes a short period, typically less than 10 minutes. The other services will be defined in the next paragraphs.

Utilities can provide Transmission and Distribution Deferral, Resource Adequacy and Transmission Congestion Relief. Usually, in case of a peaky load profile distribution infrastructure upgrades, which need considerable investments, are required. On the other hand, Transmission upgrades are required to alleviate congestion or to satisfy the necessity of new interconnections. Energy storage can provide significant benefits in both of these situations by dealing with limited time durations and consequently deferring large investments. The latter two services meet the system's peaks on a day-to-day basis.

BESSs can also provide services at a customer level, which provide direct benefits to the user; these are Time-of-Use (TOU) Bill management, Increased PV Self-Consumption, Demand Charge Reduction and Backup Power. TOU Bill management is exploited at the best when electricity purchases are shifted from peak hours to hours with lower rates. BESSs can provide backup power, paired with a local generator in case of grid failure, ranging from a day-to-day basis to a daily backup. The value coming from these services, go directly in the customer's pocket, but also ISOs and utilities receive benefits, such as a reduction in the peak of the load profile. The afore-mentioned services are listed in Figure 3.2-1, according to the characterization just discussed.

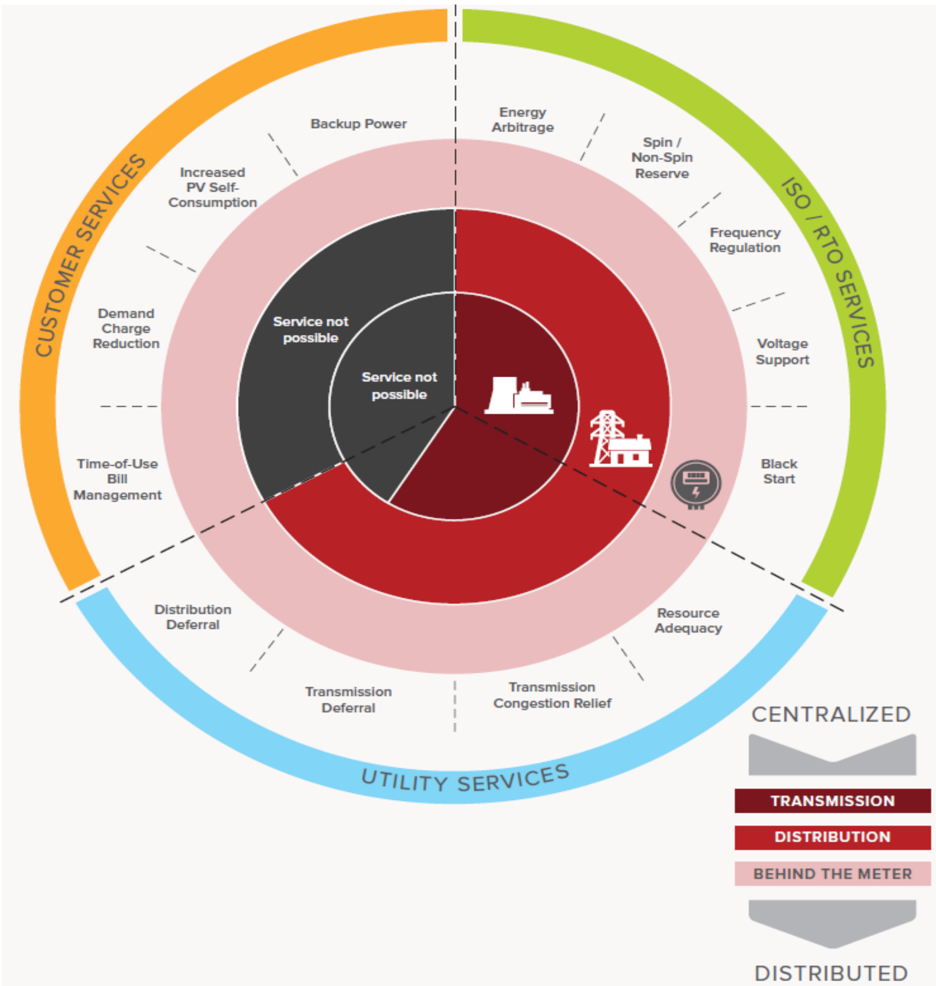


Figure 3.2-1 Ancillary services approachable by Battery systems [3.5]

The value that BESSs can deliver through all these services heavily depends on variables that are specific to the level where the assets are placed. It can be at transmission level, where BESSs can provide peak power, or at distribution level, where upgrades can be deferred and finally, there is also behind the meter where services like demand charge reduction can be provided. Energy storages can provide more services the further downstream it is located in the electric system: when the storage is at the distribution level, it loses the ability to provide services behind the meter and accordingly it cannot provide services from the utility level downwards once it is placed at the transmission level. Although from this discussion it appears that behind the meter is the ideal position for energy storages, as many times the regulatory framework (rate-related rules) does not allow BESSs located at customer level to access the market.

Within V4ES, EVs are used to provide different services to various targets; these can be household demand satisfaction, Renewable Energy (RE) integration, Energy Autonomy, efficient transportation services and Network service provision.

The electricity grid needs multiple services to be exercised in an efficient, safe and cost-effective way. These are power provision, which can be divided, according to Section 3.1, in base-load, semi-base load and peak load and the Balancing services. Generation is usually carried out by conventional generators and according to the categories defined above they are:

- Run-off river hydro and nuclear plants for base load;
- Coal and gas turbines semi-base load;
- Pumped hydroelectric, Gas plants or oil combustion turbines for peak load.

Because the different categories have different requirements, the applying plants must present different characteristics: base power plants have considerable fixed cost, given by the massive investments that are required for their installation and low variable costs because the fuel is cheap. Intermediate plants still have significant investments costs, but not as enormous as those required for base plants and moderate variable costs (although, for hydroelectric plants, the fuel expense is nearly zero). Finally, the peak plants are economical in terms of fixed costs because the investments required for these are much lower compared with base plants, and the variable costs are high because of the expensive fuel that is employed for power generation. Different energy prices correspond to the different types of energy provisions: the prices are higher going from the base demand towards peak demand. This is why base plants are operated for long times, ideally they should not be stopped, and peak plants are required only when extra power has to be provided in urgent cases. The previous section showed how the electricity price is strongly dependent on the fuel prices and how variabilities of the latter result in significant variation of the electricity price.

The Balancing services are those that are employed by the network operator in order to guarantee a secure and quality service by ensuring the balance between demand and supply. The main balancing services are: **Frequency response, Reserve** and **Reactive power provision**. Figure 3.2-2 shows the occurrence of the different balancing services once an instability is noticed.

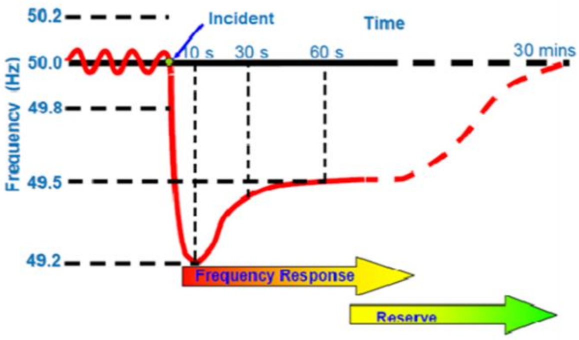


Figure 3.2-2: Different occurring times for different balancing services [3.6]

As can be seen, the first service to be employed is the Frequency Response and after some time the Reserve services are summoned.

3.2.2. Frequency response

Frequency response means that the appointed generator must automatically change the active power output in response to a frequency change. This is because if there is an unbalance between demand and supply, there will be a frequency deviation from the nominal value, which in Europe is 50 Hz. In order to avoid significant frequency deviation some actions need to be undertaken to prevent it: if the frequency is decreasing, then active power has to be provided to the grid because the load is higher than the supply. Whether the frequency exceeds the nominal value, then more power has to be absorbed from the grid because, in this case, the supply exceeds the demand. This service has to be provided by all the generators connected to the transmission system. The statutory frequency limit is 49.5-50.5 Hz and the operational limit is 49.8-50.2 Hz. This service is divided in **Primary Response, Secondary Response** and **High Frequency Response**. In order to provide ***Primary Response***[2], extra active power has to be supplied or the demand has to be reduced ***10 s*** after requested and for a further ***20 s***. The ***Secondary Response*** needs the active power in ***30 s*** and for a further ***30 minutes*** whereas the **High Frequency Response** needs the provision in **10 s** and for an **indefinite time**.

The technical requirements for the participation are the following:

- Allow a frequency drop between 3-5%;
- Continuous modulation with an automatic governing system.

A delay of a maximum of 2 seconds before a measurable response is seen from a generating unit in response to a frequency deviation is accepted.

There are two operating modes:

- Limited Frequency Sensitive Mode where if the frequency is below 50Hz a generator has to maintain power output and when above 50.4 Hz it has to reduce the output by a minimum of 2% for every 0.1 Hz rise. If the output goes below the Designed Minimum Operating Level, then the park has to be disconnected;
- Frequency Sensitive Mode where the generators have to respond to any frequency change by adjusting the output. Above 50.5 Hz the limits are the same of Limited Frequency Sensitive Mode. Figure 3.2-3 shows how a FR provision system should be, in order to allow a generator to provide regulation.

[2] All the requirements for the different services are obtained from the National Grid website [1].

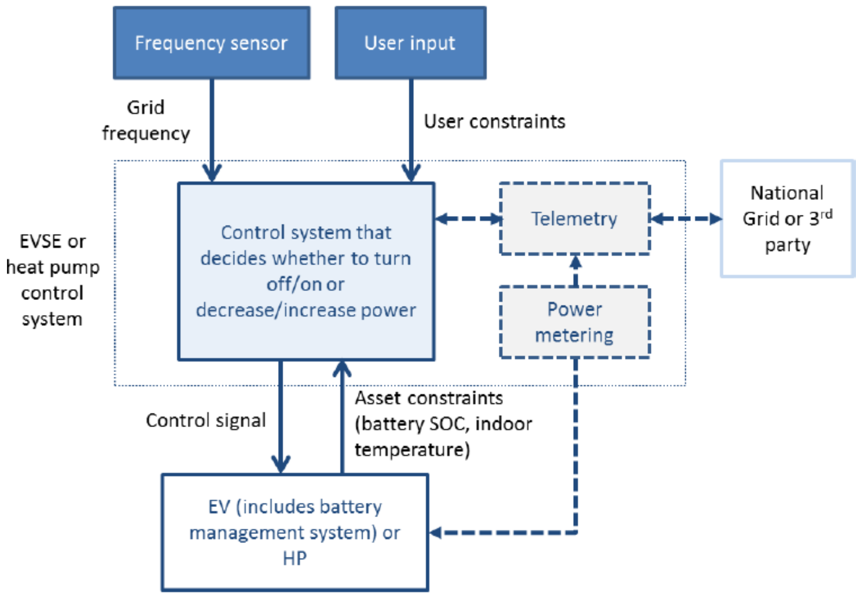


Figure 3.2-3 FR provision system [3.7]

The system illustrated here shows the necessity of a frequency sensor, which notices any possible variation in the system frequency and notifies the control system. The latter, based on power measurements, SoC and temperature measurements from the battery controls the charging of the EV. As will be seen in the next paragraphs, this is a common technical requirement asked by National Grid (NG) in the UK, in order to be allowed to participate to the market.

Mandatory Frequency Response

All generators that exceed a minimum rating have to provide this service. The minimum rating changes according to the operator. For example, for the UK:

- National Grid: generators with a nominal power ≥100 MW;
- Scottish Power: generators with a nominal power ≥30 MW;
- Scottish Hydro Electricity Transmission: generators with a nominal power ≥10 MW.

Every large generator that complies with the Grid Code has to provide this obligatory service, so as opposed to other optional services there is no extra participation test that has to be passed. A very important clarification that needs to be done is that, when not explicitly mentioned, the power ratings have to be considered both for Regulation Up (RU) and Regulation Down (RD).

The payment structure is built in the following way:

- Holding payment (£/h), for the capability to respond when requested;
- Response Energy Payment (£/MWh) for the energy provided.

This service is obligatory for considerably large generators and in the National Grid context a minimum rating of 100 MW is a demanded requirement. Although for the primary response the service provision time is limited to 20 s, which would allow EV to provide more power for such a short period, it has to be considered that the charging infrastructure, as well as the connection lines, have a limited rating. Even if current battery technologies allow to deliver relatively large powers, hence a reasonably small number of EVs would be required to meet the minimum requirement. The rating limitations, as well as the management issues given by dealing with many vehicles at the same time, make this service unapproachable for EV fleets for now, though in future aggregations of EVs could perform this service on a city-wide basis.

Firm Frequency Response

The different services under the Firm Frequency Response (FFR) are the same as those for the Mandatory Frequency Response (MFR): Primary, Secondary and High Frequency Response. The minimum power requirement in order to provide this service is:

P_{min} ≥ 10 MW. This more viable limit allows EV fleets to participate to this service. There are other technical requirements that have to be met in order to provide regulation:

- The unit must have appropriate metering;
- An assessment has to be passed, and the unit has to prove it is competitive against other options both in economic terms and in terms of certainty of the service provision;
- Meet the tendered level;
- To have the capability to provide dynamic response automatically;
- To have an automatic Logging Device;
- If a unit consists of two sites, they must have a single point of contact.

As said earlier, the different services within the FFR are the same as those for MFR, thus, the minimum reaction times and services time for the different services do not differ.

However, FFR is an optional service. Therefore, in order to participate, a prequalification assessment has to be passed and then the regulation provider must sign a framework agreement. Only after completing these steps, will the provider have access to a monthly electronic tender process.

The temporal frequency for the regulation calls are different for static and dynamic response:

- Static response 10-20 times a year;
- Dynamic response few times a year, [3.8; 3.9].

The payment is composed by the following elements:

- Availability fee (£/h) for the hours that the service is made available for;
- Window Initiation Fee (£/window) for each FFR nominated window;
- Nomination Fee (£/h) Holding fee for each hour within the window;
- Tendered Window Revision Fee (£/h) for the window nomination;
- Response Energy Fee (£/MWh) for the energy provided.

The relatively small capacity requirement compared to other services makes this one of the most approachable. The short time requested for both the Primary and Secondary response lets fleet operators approach the service with confidence. However, the indefinite service provision time, which is ideally asked for the High Frequency Response, is not suitable for fleets of EVs. Although the requested reaction time is short, in [3.10] the FFR has been considered unsuitable for EVs because it is argued that the response time of EV fleets will not be enough rapid, but other literatures state that the fast ramping up/down characteristics of EVs will make the task possible. In fact, according to [3.10] for BESSs the reaction time is 20 ms. Assuming this is only referred to the battery itself, for the charger another delay time constant is required. Usually the charger consists of an AC/DC converter and a DC/DC converter. Assuming to operate both the converters at 20 kHz, the delay time introduced by a single converter corresponds to the step time, which is in this case, 50 μs. Considering both the converters, the sum of the two-time constants account for 0.1 ms. There is also the communication time required to receive the control signal, coordinate the EVs and finally react to the control signal. In a National Grid report [3.7], it is said that EVs can provide frequency response without any significant technical barriers or hardware changes in the EV itself. If prompted by a control signal, EVs respond is approximately 1 second and this is suitable for provision of very fast frequency response. According to the IEC 61851 standards for EV charging, the battery has to respond to a control signal within 5 seconds, but in practice response times are much less. Hence, this service is technically approachable for EV fleets, also because of the frequent but shallow discharges caused to the battery. But whether it is economically feasible depends on what the EV penetration rate is, how many economic inputs are considered in the business model and how they are combined, how the battery degradation is addressed, what the appropriate payment structure is, and what the relevant policies are.

Frequency Control by Demand Management

Frequency Control Demand Management (FCDM) is employed to regulate the frequency by interrupting part of the demand customers (those who have agreed to participate to the scheme, and receive a payment). If the low frequency relay, installed by National Grid (NG), notices frequencies that are lower than the settings, then the electricity is automatically interrupted. This can last for at least 30 minutes, and the frequency of the interruptions occurring are roughly ten to thirty times a year.

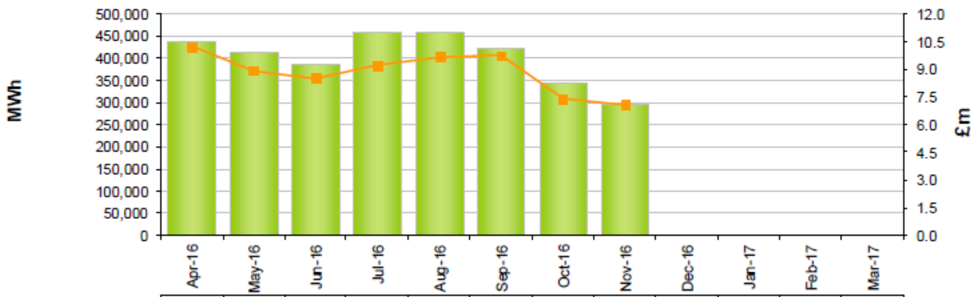
Large deviations in frequency can occur when significant generation is lost. FCDM is one of the solutions to these unbalances. This allows demand-side providers to enter in the marker, and it includes other non-dynamic service provisions.

The minimum rating in order to provide FCDM is 3 MW, which is feasible for aggregated EV fleets. Other technical requirements are:

- The minimum rating can be met by aggregating small loads;
- Appropriate metering has to be installed in the unit;
- To allow monitoring by providing output signals to the NG equipment.

The maximum response time is 2 s. It is arranged by bilateral negotiations: the equipment is provided by NG and tested. The availability has to be declared in the settlement period on a weekly basis.

The payment consists of an Availability fee (£/MW/h) against the metered demand in the settlement period. This is feasible for fleets of EV: charging schedules can be adjusted in order to decrease demand. Quality estimation of the power availability for RU and RD will allow the fleet operator to identify the EVs that are close to leave and those which will stay longer and then contract the appropriate settlement period. Figure 3.2-4 shows the volumes for Commercial Frequency Response, which includes FFR and FCDM for different months of 2016.



	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17
Holding Volume	438,892	413,683	387,950	457,395	457,395	424,888	345,251	298,251				
Response cost	10.26	8.92	8.53	9.23	9.68	9.76	7.39	7.08				

Figure 3.2-4 Commercial Frequency Response volumes [3.11]

Firm Frequency Response Bridging

This is a sub-category of FFR is FFR Bridging. This allows smaller Demand Side Providers and other small parties to secure a contract within which to develop a portfolio of new FFR volume. The aim of the contract is to address the current arrangement that limits the entry into the FFR tendered market to parties who already have 10 MW or more of contracted volume. It is clear that it is possible for Demand Side Providers to achieve this level of volume over time; however, there is no route to market for this volume until 10 MW has been achieved. This contract aims to bridge this gap and to reduce the barrier to entry into the FFR market. The FFR Bridging contract is for a set term of one or two years, with a mandated price per MW that is dependent upon the type of service being provided (e.g. Secondary, Primary + High, etc.) and which increases as more MWs are aggregated. Other technical requirements are:

- To have a low or high frequency relay that have to monitor every 150 ms or less and have an accuracy of +0.01 Hz;
- To be ready to provide the service again as soon as possible.
- The required response times are:
    - For Primary response, ≤10s; trigging frequency 49.7;
    - For Secondary response, ≤30s; trigging frequency 49.7;
    - Finally, for High Frequency Response, ≤10s, only RD; trigging frequency 50.3.

The duration times for the service are:

- For Primary response, 20 s;
- For Secondary response, 30 min;
- For High Frequency Response, 30 min.

The service is arranged through a FFR Bridging contract, and the payment structure is the following:

- Capacity payment (£/MW/settlement period); if more products combined, the capacity payment accounts to the smallest among the products;
- Energy payment (£/MWh), depending on the energy provided under a given FR product.

3.2.3. Reserve service

The UK National Grid needs to access to sources of extra power in the form of either generation or demand reduction, in order to be able to deal with unforeseen demand increase and/or generation unavailability. Additional power sources are required by the National Grid to be able to act in case the demand suddenly increases or a generation unit is unavailable: these services represent Reserve, and they comprise of synchronised and non-synchronised sources. In order to be ready to deliver the service, different times are required for the various services. Figure 3.2-5 shows the different time scales.

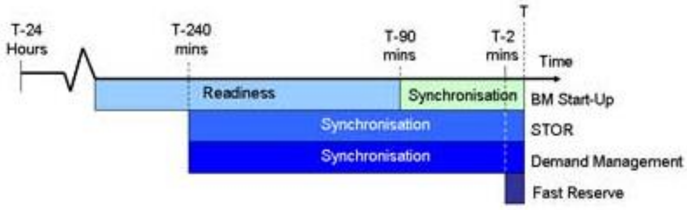


Figure 3.2-5 Different reserve services and occurring times [3.5]

Fast Reserve

Fast Reserve is employed to control the frequency if any unpredictable deviation occurs because of changes in demand or generation. In this case, extra active power has to be provided or the demand reduced. The maximum response time is 2 minutes after receiving instructions, with at least 25 MW per minute rate and a minimum of 50 MW provided. The service has to be provided for a minimum of 15 minutes. The appointed provider makes the service available for a pre-agreed period and keeps the relevant units ready in case the National Grid needs it. Other technical requirements are the following:

- The service should be repeatable;
- Reliable delivery; time tolerance of ±30s and always volume of more than 90% of the contracted amount.

The providers have to submit tenders after the assessment process where applicants are always economically compared against other options. The payment structure is composed by the following elements:

- Availability fee (£/h), for the hours of a Tendered Service Period;
- Utilisation fee (£/MW/h) for the energy provided;
- Holding fee (£/h) possible.

The high minimum rating of 50 MW makes this service very demanding in terms of available capacity, although the required service time is relatively short. This may be approachable at a large scale, within V4ES, for instance at the city level. However, this requires serious management and communication efforts.

Short Time Operating Reserve (STOR)

The Short Time Operating Reserve (STOR) requires a minimum power provision of 3 MW of generation or demand reduction. The delivery has to happen within 240 minutes or less, and when instructed full MW have to be provided for at least 2 hours. According to [3.8], the applying units must be able to provide STOR at least 3 times a week. For this service, there are 3 tenders per year. A pre-qualification test needs to be fulfilled by signing the Framework Agreement. The payment is composed by the following elements:

- Availability Payment (£/MW/h) for an Availability window;
- Utilisation Payment (£/MWh) for the energy delivered.

The relatively long duration is a negative aspect if compared to other services with a shorter duration. But this does not mean that STOR is unfeasible. From a technical point of view, in workplaces or parking hotspots, where a car is supposed to stop for some hours, this is feasible. The higher the EV deployment, the easier it is to guarantee a minimum availability.

BM Start Up

For BM start up the contracted generators, when notified by the National Grid, has to start readying the plant to start the generation. This is additional generation provided by Balancing Mechanism Units (BMUs) that would not otherwise been accepted in other balancing mechanism because of their technical characteristics and associated lead-times. Requirements for providers are that they have to prepare the generator in 89 minutes from receiving the instruction, and the hot standby which means that the unit has to be kept ready for an agreed period. This service is arranged through a bilateral agreement. The payment for this service is composed by

- BM Start-Up Payment (£/h) differentiated in three parts according to the different lead times;
- Hot Standby Payment (£/h) the cost to keep the unit ready.

In order to be competitive against the other alternatives, during the assessment process long durations of readiness have to be offered. Also, the synchronisation requirement is not optimal for EV fleets as stated in [3.8]. This is against the short availability of EV charging.

Demand turn up (new concept)

It allows preventing any instability given by an unbalance between an excess renewable generation and a low demand, by allowing demand side providers to increase their demand (through either shifting consumption or reducing generation). The necessity of this new service has been highlighted by a constant renewable generation increases. The entry threshold for participation is 1 MW. This can be aggregated from sites 0.1 MW and larger. Fractions of megawatts are acceptable, e.g. 4.2 MW, providing they meet the entry threshold.

There are particular times of the day or week when the service is more likely to be required. These are defined as 'availability windows' and cover the following periods:

Overnight window:

23:30 – 08:30 for May, September, October (base months)

23:30 – 09:00 for June, July, August (peak months)

Weekends and bank holidays afternoon window:

13:00 – 16:00 for May to October

The periods in between availability windows are classed as 'optional windows'. During these periods, there is likely to be a reduced requirement for demand turn up. Providers can declare themselves to be available during these optional windows, and receive a utilisation payment only.

Other technical requirements consist of:

- Minute by minute or half hourly metering;
- Contacted via mobile phone/landline and email.

The service is procured through tenders for a limited time, when needed. Fixed DTU was procured through a tender in February 2018 for service start on 1st May 2018.There is also an optional route which offers the ability to change availability and utilisation payments frequently to reflect weather and market conditions.

The payment structure is described below:

- Availability Payment;
- Utilisation Payment.

This is a great opportunity for EV fleets because of the low minimum rating required and because when asked EVs could start charging at the maximum safe (from a battery point of view) rate, and they would be paid for this [3.12]

Black Start

Black Start is the procedure to recover from a total or partial shutdown of the transmission system. Most power stations need an electrical supply to start up. Under emergency conditions, Black Start stations would receive this supply from small onsite auxiliary generation. When there is a total or a partial shutdown of the grid in order to recover from this situation there is the necessity of DC sources.

Isolated power stations are started individually and are gradually connected to each other in order to form an interconnected system again. If there is an emergency, then black start stations are powered by a small auxiliary generation plant but not all power plants have this capability. The requirements are:

- Ability to start up the main generation plant or at least one module and be ready to energise part of the Network;
- Accept instantaneous loading or demand blocks of 35-50 MW and controlling frequency and voltage levels;
- Provide at least three sequential Black start;
- High service availability.

There is an agreed availability fee per settlement period and an utilisation payment. These are stipulated through bilateral contracts. This kind of service requires high reliability and availability. Moreover, the size of the unit is a matter of consideration because it has to be big enough to start a big plant. In future, with a huge deployment of EVs and EVSE, this service may be viable.

3.2.4. Reactive power service

The voltage levels are influenced by the Reactive power flows. Across the network, the voltage changes and a voltage profile for every point can be considered. If the right amount of reactive power is provided, then the network voltage can be controlled.

Obligatory Reactive Power Service

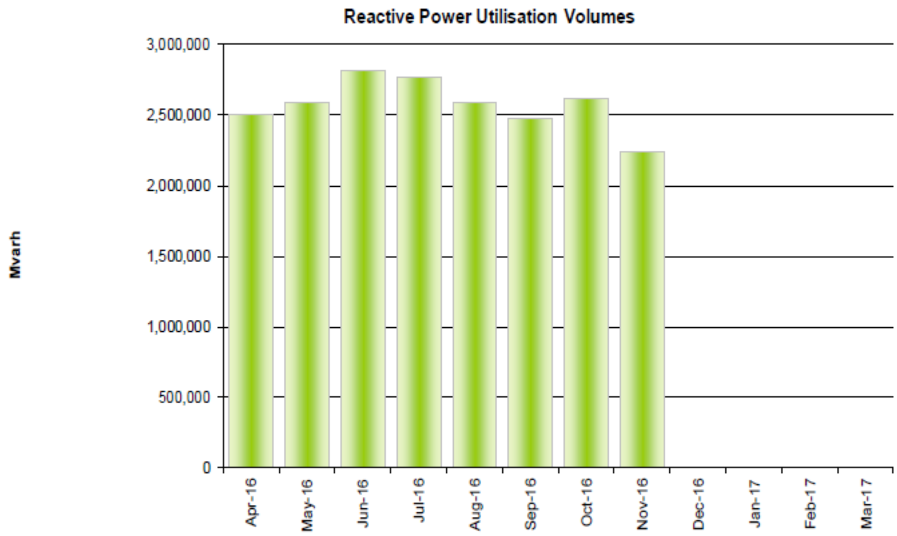
Any large generator that is larger than 50 MW has to provide or absorb reactive power in order to regulate the voltage at the closest connection point. Therefore, it is a local service. The technical requirements are the following:

- To supply the rated MW at any point between 0.85-0.95;
- Short Circuit Ratio <0.5;
- To provide reactive power to maintain the voltage within ±5%;
- To have an automatic continuous excitation control system to avoid instabilities.

This is an obligatory service and therefor, no prequalification assessment processes are expected. The payment is represented by a Default Payment Arrangement (£/h). EV fleets do not have the required rating to be applicable for this service, yet.

Enhanced reactive power service

This service is for those generators that are not required to supply the obligatory reactive power service. Technical requirements are the same as the ORPS. The commitment is given through tenders held every six months. The term of the contract is at the minimum for 12 months, and increasing by 6 months afterwards. The payment is composed by the Available Capacity Price (£/MVArh) and/or a Synchronised Capability Price (£/MVArh) and/or a Utilisation Price (£/MVArh). Figure 3.2-6 shows the reactive power volumes utilized by NG for some months of 2016.



	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17
Reactive Default Utilisation Volume (MVArh)	2,513,289	2,586,839	2,825,319	2,772,155	2,588,418	2,478,561	2,627,580	2,244,462				
Reactive Market Utilisation Volume (MVArh)	0	0	0	0	0	0	0	0				

Figure 3.2-6 Reactive power volumes for default and market utilization in 2016 [3.13]

It is clear that no market utilization is employed, because there has not been any volume tendered in some tendering rounds. This can happen for three reasons:

- After the tender was issued, not enough volumes were offered;
- The tendered volumes were not successful in the selection process and have been rejected;
- The volumes have not been procured, maybe in the phase of price negotiation.

On this occasion there was not enough information to clarify the exact reasons. After being unsuccessful, the units refused to tender again - as can be seen from Figure 3.2-7.

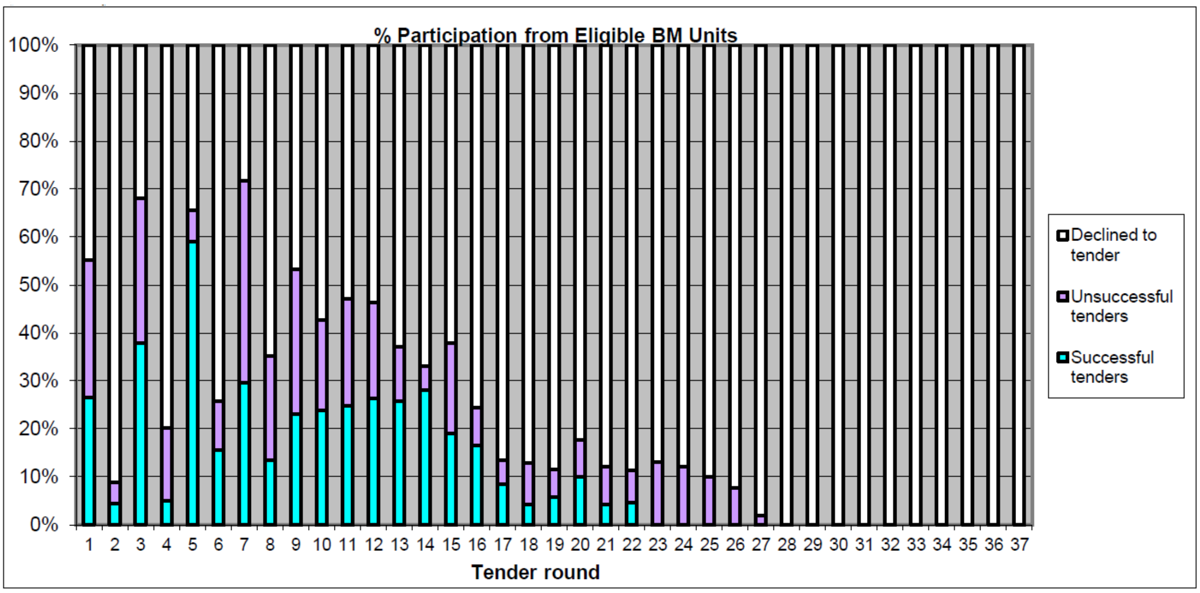


Figure 3.2-7 Participation to reactive power provision in the different tendering rounds [3.13]

However, if EVs are utilized to provide reactive power when idle, and no other balancing service is provided, this can result in extra profit. Moreover, this service will not engage the battery, because no active power will be provided; only the charger will be employed.

3.2.5. Capacity market

This is a scheme started in 2014, proposed by the UK's National Grid to reserve capacity for the future winter peaks. It has to be noted that, this service is not included in the Balancing Mechanism, hence, providers can opt for both. Electricity storages, power plants and Demand Side Operators are allowed to participate in the market. After the preselection, a Competitive Auction Process is undertaken in order to select the providers: the units submit a price in terms of £/kW, the price starts form the Price Cap and it is decreased every round; units declare the minimum price they are available to accept for their capacity. With the price decreasing, the auctioned capacity decreases. A "Clearing price" is reached when the auctioned capacity matches the demanded capacity. The contract terms range from 1 to 15 years. Some peculiar capacities, such as those that receive Low Carbon Support (i.e. Feed in Tariff (FIT)), those that provide Short Time Operating Reserve (STOR) and also non-GB capacities, are not allowed to participate. An availability payment is given to Capacity Market Units (CMUs) [3.14].

When the Grid Operator is short of capacity, it issues a warning to CMUs which have 4 hours to provide the full auctioned power. This service must be provided until the National Grid does terminate the "stress event". The minimum rating required to provide capacity in this market is 2MW [3.15].

3.2.6. Frequency Containment Reserve in The Netherlands and Germany

TenneT [3.16] is one of the major European Transmission System Operators (TSOs), and its jurisdiction is mainly focused in two of the NSR countries: The Netherlands and Germany. As other TSOs, TenneT requires some Ancillary services to ensure a reliable, efficient and economic energy provision and among these, the Frequency Containment Reserve (FCR) is fundamental to keep the frequency of the synchronous system of continental Europe within the statutory limit. Within this service, unlimited or limited sources must provide (absorb) power whenever a frequency deviation is perceived. Power stations are classified as unlimited sources because of their inherent capability of providing more power by just burning more fuel, whereas other providers such as Battery systems are considered as limited sources. The primary reserve stabilises the frequency counteracting to possible disruptions. ENTSO-E Regional Group Continental Europe determines the minimum rating required for each controlled area, and these are proportioned to the total electricity produced in that control area. In order to provide this service, the assets must pass a prequalification process and sign a framework agreement. After this, they will gain access to the auction platform. The product specification for the primary reserve is summarized in Table 3.2-1.

Table 3.2-1 Primary reserve product requirement [3.16]

Minimum bid size	1 MW (up or down)
Accuracy of the measurement of frequency control	10 mHz or better
Insensitivity range of the frequency control	Maximum 10 mHz
FCR full activation time	30s for the complete bid
Full Activation frequency deviation	±200 mHz
Real-time operating measurement of power	In MW with a resolution of no more than 4-10 seconds

The primary reserve supplier operates for a 24-hour period, receiving different frequency targets and correcting the set point. Limited sourced suppliers must provide the full quantity of primary reserve, and in case of a deviation in frequency of 200 mHz for a period of not less than 30 minutes. After this period, the limited unit must have the full energy available in maximum 2 hours. The unit or the group of units must be able to provide constant support to the frequency within the “standard frequency range” which is 49.95-50.05 Hz. The prequalification documents must include the description of the charging management; this contains also details about the charging/discharging capacity of the battery. The fact that the operator considers also limited sources, which can be batteries, and for them some dedicated conditions are considered. This is a promising situation for EVs, considering also the relatively small minimum bid size of 1 MW.

3.2.7. Contract and remuneration policy

Firm Frequency Response

Dynamic Frequency Response means providing the service in order to control the frequency on a second to second basis. Not Dynamic or Static Frequency Response means that this discrete service is provided when a frequency deviation occurs. For fleets of EVs, the Static FR is more suitable because they are asked to deliver the full power when an event occurs rather than delivering a continuous service. It has to be considered that the discharging type for these two services will be different: for the Dynamic FR the batteries will have a shallow discharge, whereas in the Static FR the batteries will face deep discharge in order to provide the required power in a small time.

For the month of November 2016, no **Primary Dynamic Frequency Response** or **High Dynamic Frequency Response** were required and a maximum 300 MW (in the slot 22:30-23) of **Secondary Dynamic Frequency Response** was necessary in the daytime (7-23). These quantities had to be purchased from contracts after the tendering process.

For the same month, a maximum of 610 MW (23:30-24) was required for the **Primary Static FR overnight,** a maximum of 835 MW (in the slot 23:30-24) of **Secondary Static FR** was required all day long and a maximum of 550 MW of **High Static FR** was required from 7 to 23. [3.17]

The payments for these contracts, that last 6 months, have to be decided between the National Grid and the provider.

Commercial Frequency Response Holding consists of both **Frequency Control Demand Management (FCDM)** and **Firm Frequency Response (FFR)** employed 298,251 MWh and had a cost of £7.08 M**.** Form these data, the MWh was payed, in average, 23.74 £/MWh.

As for the tendering processes: **Availability Fee** ranging from 1,195-38.5 £/h and a **Nomination fee** of 983-0 £/h had been accepted [3.18].

STOR

The **Average availability price** payed for the STOR contracts in the month of November 2016 was 3.32 £/MWh with an outturn of 8.62 £/MWh and the **Average utilisation price** was 154.15 £/MWh with an outturn of 116.68 £/MWh. The **contracted power** was 2,810 MW and an outturn of 2,243.41 MW [3.11].

Fast Reserve (not tendered)

In November 2016, the amount of MWh contracted for Fast Reserve was 269,540 MWh and these have been payed £4.91 M. The **average payment** for the MWh was then: 18.22 £/MWh [3.11].

Reactive Power

No **Market Utilisation Volume** of Reactive power was employed for the month of November 2016 because no Balancing Mechanism Units offered to tender, and hence **no payment** was made for these. The **Default Payment** for the **Obligatory Reactive Powe**r was £6.63 M for a volume of 2,244,462 MVArh**.** The average payment for one MWh was therefore 2.95 £/MVArh. [3.11]

From the user point of view, "non-performing" users are charged by distributors for the excess Varh consumed, because of a low power factor. For UK Power Networks, if a reactive power exceeding 33% of the total active power is measured then charges are applied. These are 0.017-0.337 p/kVArh [3.19]. The London Electricity Former Tariff Customer Scheme, managed by EDF, applies 0.39-1.25 p/kVArh [3.20]

Table 3.2-2: Summary of the main Balancing mechanisms and their characteristics.

Service	Minimum rating	Other requirements	Reaction time	Service time	Participation method	Calls frequency	Payment
Frequency Response							
Mandatory Frequency Response	NG: ≥100 MW[3] SP: ≥30 MW SHET: ≥10 MW	• 3-5% governor drop characteristics; • Continuous modulation with an automatic governing system.	• Primary response, ≤10s; • Secondary response, ≤30s; • High Frequency Response, ≤10s, only RD.	• Primary response, 20 s; • Secondary response, 30 min, • High Frequency Response, indefinitely	Obligatory for large power plants complying to the Grid Code.		• Holding Payment (£/h) for the capability to respond when requested; • Response Energy Payment (£/MWh): for the energy delivered.
Firm Frequency Response	≥10 MW	• Appropriate metering; • To pass the assessment; • Meet the tendered level; • Capability to provide dynamic response automatically; • Automatic Logging Device; • If a unit consists of two sites, must have a single point of contact.	• Primary response, ≤10 s; • Secondary response, ≤30 s; • High Frequency Response, ≤10 s, only RD.	• Primary response, 20 s; • Secondary response, 30min, • High Frequency Response, indefinitely	Monthly electronic tender process after a prequalification assessment and once have signed up a framework agreement.	• Static response:10-20 times a year; • Dynamic response: few times a year [3.7][3.8]	• Availability fee (£/h) for the hours that the service is made available for; • Window Initiation Fee (£/window) for each FFR nominated window; • Nomination Fee (£/h) Holding fee for each hour within the window; • Tendered Window Revision Fee (£/h) for the window nomination; • Response Energy Fee (£/MWh) for the energy provided.
Frequency Management by Demand Management	≥3 MW	• The minimum threshold can be met by aggregating small loads;	≤2 s	≥30 min	Bilateral negotiation: the equipment is provided by NG and	10-30 times a year	Availability fee (£/MW/h) against the metered demand in the settlement period

[3] When not explicitly specified, the power is to be intended both in terms of increasing of the production or decreasing of the demand for RU and decreasing of the production or increasing of the demand.

		• Appropriate metering; • Give output signal to the NG monitoring equipment.			tested. The availability needs to be declared in the settlement period on a weekly basis.		
Enhanced Frequency Response (new concept)	50 MW?	To provide the 100% of the active power within 1s	≥1 s		Tender		
Reserve							
Fast Reserve	≥50 MW	Delivery rate ≥25MW/min	≤2 min	≥15 min	Tenders, once the Assessment is passed		• Availability fee (£/h), for the hours of a Tendered Service Period; • Utilisation fee (£/MW/h) for the energy provided; • Holding fee (£/h) possible.
STOR	≥3 MW	Full MW to be delivered within 2 h	≤20 min ≤2 h According to the utilisation characteristics	≥2 h	Tenders, total 3 per year. Pre-qualification needs to be fulfilled by signing the Framework Agreement	Must be able to deliver at least 3 times a week [3.8a]	• Availability Payment (£/MW/h) for an Availability window; • Utilisation Payment (£/MWh) for the energy delivered.
BM Start-Up + Hot Standby		BM Start-Up: • Prepare the generator within BM timescales; • Terminate BM Start-Up before starting Hot Standby.	≤89 min	Until Hot Standby is started	Bilateral agreement		BM Start-Up Payment (£/h) differentiated in three parts according to the different lead times
BM Start-Up + Hot Standby Demand Turn Up	≥1 MW	Hot Standby: -to keep the unit ready for the agreed time.		Time agreed in the contract	Bilateral agreement Tenders for limited time; when needed: Fixed DTU has a tender in February		Hot Standby Payment (£/h) the cost to keep the unit ready
		• Fraction of MW can be provided if the					• Availability Payment; • Utilisation Payment.

		threshold is overcome. More sites can be aggregated; • Min by min or half hourly metering; • mobile phone/landline and email			2018 and for Flexible DTU it is open for the British Summer Time.		
Reactive Power Services							
Obligatory Reactive Power Services	≥50 MW	• To supply the rated MW at any point between 0.85-0.95; • Short Circuit Ratio<0.5; • To provide reactive power to maintain the voltage within ±5 %; • To have an automatic continuous excitation control system to avoid instabilities.			Mandatory Service Agreement		Default Payment (£/MVarh)
Enhances Reactive Power Services		The reactive power capability has to be the same as the ORPS			Tenders held every six months. The term of the contract is minimum for 12 months and increasing by 6 months afterwards.		• Available Capability Price (£/MVar/h) and/or Synchronised Capability Price (£/MVar/h) and/or Utilisation Price (£/MVarh)

3.2.8. New Developments

In their 'Future of Frequency Response Industry update' February 2019 [3.21], National Grid ESO in the UK note that as Great Britain transitions to a low carbon economy, system operation is becoming increasingly complex, and National Grid's provider base is becoming increasingly diverse. To meet future challenges of operating the electricity system and address issues raised by providers, they are in the process of reforming their balancing products and markets to make them more standard, more transparent and more easily accessible for all technologies. Two deliverables core to the reform of frequency response are a weekly auction trial (which will launch Spring 2019 and facilitate the entry of providers with variable demand and generation), and new frequency response products (to optimise the services bought and to improve the system management). Both deliverables are key steps in ensuring equitable opportunities for all provider types). There are plans to rationalise, or retire, a number services that had become obsolete, including Frequency Control by Demand Management (FCDM) and Firm Frequency Response (FFR) Bridging.

There are four proposed new products; Dynamic Regulation, Dynamic Moderation,Dynamic Containment and Staic Containment:

	Operational Range (Hz deviation)	Lag (s)	Ramp (s)	Duration
Proportional to frequency	+0.015 to +0.1 -0.015 to -0.1	2	8	Continuous

The service is symmetrical meaning that providing 1 MW of the service means providing 1 MW of upward (low) response and 1 MW of downward (high) response.

The design of this product would mean that providers do not need to respond as rapidly as for the other products but must have a duration that allows for continuous operation.

Figure 3.2-8: Dynamic Regulation from [3.21]

	Operational Range (Hz deviation)	Lag (s)	Ramp (s)	Duration (minutes)
Proportional to frequency	+0.1 to +0.2 -0.1 to -0.2	0.5	0.5	20

The service is symmetrical meaning that providing 1 MW of the service means providing 1 MW of upwards (low) response and 1 MW of downwards (high) response.

The design of this product would mean that providers need to deliver rapid proportional response occasionally to assist with the continuous Dynamic Regulation service.

Figure 3.2-9: Dynamic Moderation from [3.21]

	Operational Range (Hz deviation)	Lag (s)	Ramp (s)	Duration (minutes)
Proportional to frequency	+0.2 to +0.5	0.5	0.5	20
Proportional to frequency	-0.2 to -0.5	0.5	0.5	20

This service is not symmetrical – a provider can choose to provide either or both upwards (low) and downwards (high) response.

The design of this product would mean that providers need to deliver rapid proportional response for infrequent containment events.

Figure 3.2-10: Dynamic Containment –High and Low from [3.21]

	Operational Range (Hz dev.)	Lag (s)	Ramp (s)	Duration (minutes)
Frequency triggered	+0.3 to +0.5	1	n/a	20 to 30
Frequency triggered	-0.3 to -0.5	1	n/a	20 to 30

This service is not symmetrical – a provider can choose to provide either or both upwards (low) and downwards (high) response.

The design of this product would mean that providers need to deliver rapid response for infrequent containment events.

Figure 3.2-11: Static Containment – High and Low from [3.21]

3.3. ***Battery Energy Storage (BES)***

3.3.1. Battery technologies and historical development

Batteries are self-contained units that store chemical energy and, on demand, convert it directly into electrical energy to power a variety of applications. Batteries in general use are divided into two general classes: primary batteries that are discharged once and then discarded, and secondary, rechargeable batteries that can be discharged and then restored to their original condition by reversing the current flow through the cell. Secondary batteries are the most common system for electrochemical energy storage. Common features of batteries are that the energy-providing processes takes place at the phase boundary of the electrode/electrolyte interface and that electron and ion transport are separated in the systems. All batteries consist of two electrodes in contact with a conductive electrolyte solution.

The first rechargeable battery, the lead acid cell, was discovered by French physicist Gaston Planté in 1859, consisting of two lead plates immersed in dilute Sulphuric acid. In a modified form this design is still used today. The cell is cheap to make, and fairly durable, but has a high mass compared to the energy stored which translates in low specific energy as we will see, making it less than ideal for traction applications.

In 1899, the Swede Waldmar Jungner invented the nickel-cadmium (NiCd) battery that used nickel as the positive electrode (cathode) and cadmium as the negative (anode). High material costs compared to lead limited its use. Two years later, the American inventor Thomas Edison replaced cadmium with iron, the battery being called nickel-iron (NiFe). Low specific energy, poor performance at low temperature, and high self-discharge limited the success of the NiFe battery.

In 1932, Schlecht and Ackermann achieved higher load currents and improved the longevity of the NiCd technology by inventing the sintered pole plate. In 1947, Georg Neumann succeeded in sealing the cell, rendering it portable. For many years, NiCd was the only rechargeable battery for portable applications. In the 1990s, environmentalists in Europe became concerned about the harm incurred when NiCd cells were carelessly disposed of. The resulting EU Battery Directive 2006/66/EC now restricts the sale of NiCd batteries in the European Union except for specialty industrial use for which no replacement is suitable. The alternative is nickel-metal-hydride (NiMH), a more environmentally friendly battery that is similar to NiCd in its electrical properties.

All of the above types of secondary battery have a relatively low energy storage capability per kg (specific energy). A great improvement was made with the introduction of the Lithium Ion secondary battery, first commercialized by Sony in 1991. Besides powering cellular phones, laptops, digital cameras, power tools and medical devices, Li-ion is also used for electric vehicles and satellites. The battery has a number of benefits, most notably its high specific energy, simple charging, low maintenance and having an environmentally benign nature.

In batteries, electrical energy is generated by conversion of chemical energy via redox reactions at the anode and cathode. As reactions at the anode usually take place at lower electrode potentials than at the cathode, the terms negative and positive electrode (indicated as minus and plus poles) are used. The more negative electrode is designated as the anode, whereas the cathode is the more positive one. Batteries are closed systems, with the anode and cathode being the charge-transfer medium and taking an active role in the redox reaction as “active masses”. In other words, energy storage and conversion occur at the same location in the cell. The terms “specific energy” [expressed in watt-hours per kilogram (Wh/kg)] and “energy density” [in watt-hours per liter (Wh/L)] are used to compare the energy contents of a system, whereas the rate capability is expressed as ‘specific power’ (in W/kg) and ‘power density’ (in W/L), [3.22a].

Some comparisons for the different technologies are given in Figure 3.3-1.

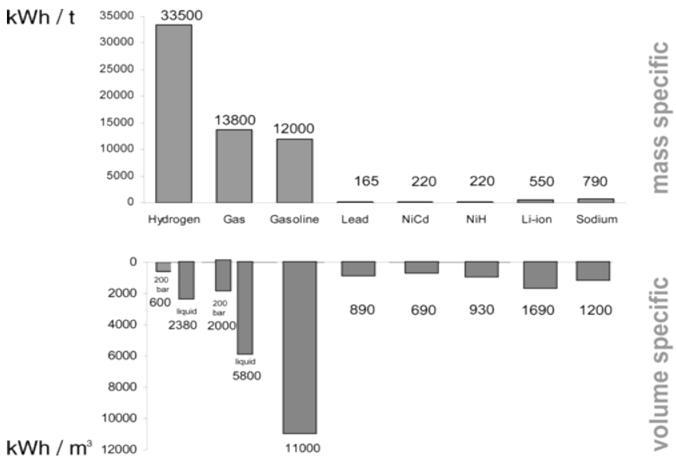


Figure 3.3-1: Theoretical specific energies [(kW h)/tonne] and energy densities [(kW h)/m3] of various rechargeable battery systems compared to fuels, such as gasoline, natural gas, and hydrogen [3.22a].

A numerical comparison of the performance figures of the various forms of secondary cell, together with those for the ultra-capacitor, is presented in Table 3.3-1 taken from [3.23]. As may be seen, the Li-ion technology is to be preferred for Electric Vehicle applications since it provides superior energy density, specific energy and specific power when compared to rival cells.

Table 3.3-1: Different types of battery chemistry demonstrating the superior energy density of Li-ion [3.23]

Characteristics unit	Lead Acid	NiMH	Li ion	Ultra capacitor
Cell voltage (V)	2.1	1.2	3.6	2.5
Efficiency	85	80	93	97
Energy density (Wh/l)	50-70	200	150-250	5
Specific energy (Wh/kg)	20-40	40-60	100-200	/
Specific power (W/kg)	300	500-1300	800-3000	15000
Temperature range [°C]	30-60	-20-50	-20-55	-30-65
Self-discharge [%/month]	4-8	20	1-5	30
Number of cycles @ 80% DoD	200	>2500	<2500	/
2008 costs [$/kWh]	150	500	800	2000
Costs [$/kW]	10	20	50-75	50

Operation of the Li-ion cell

Within SEEV4City, lithium-ion batteries will represent the reference battery technology due to their large adoption in the automotive industry. They store electric energy by moving lithium ions backwards and forwards between low and high potential energy states via a set of electrochemical processes [3.24]. Lithium ions have the lowest energy when they are in the positive electrode (cathode) and the highest energy when they are in the negative electrode (anode). During charging, external current forces lithium ions to move from the cathode to the anode. During discharge, ions naturally move from the anode to the cathode, creating a useful current. Lithium ion movement is governed by the potential difference applied to the electrodes (over-potential), which allows ion diffusion and the electrochemical reactions, which create the required ions and the energy transfer. Lithium ions migrate to the graphite (carbon) anode during charging, intercalate in to the anode, absorb electrons from the (copper) charge collector and form a lithium carbon compound. The process is reversed during discharge when the electrons return through the circuit, the lithium ions decalate from the anode, give up their electrons and migrate to the lithium cathode. This is illustrated in Figure 3.3-2 [3.25].

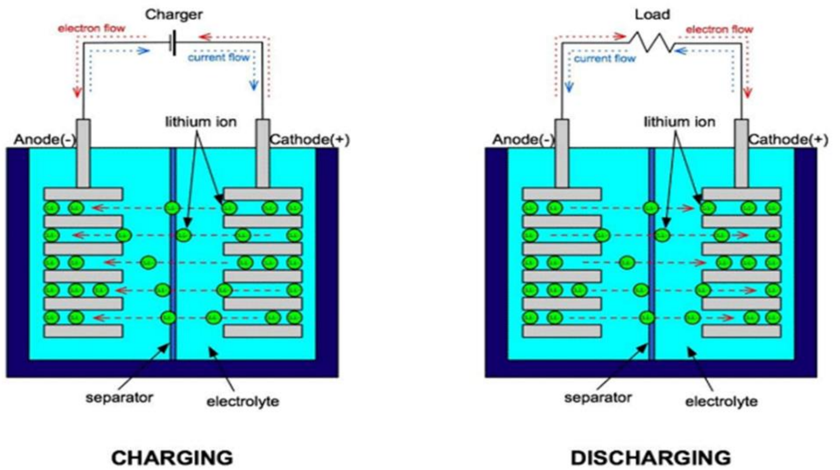


Figure 3.3-2: Graphical representation of cell in charge and discharge modes [3.25]

The lithium ion cell stores energy via a reversible reaction between the lithium ions in the material of the cathode (LiX) and the carbon in the graphite anode. During charging, the lithium ions gain electrons and release them as current flow during discharge. This may be represented as (the reactions refer to a specific chemistry but the process extends to all Li-Ion batteries):

On Charge:

Negative electrode (anode) reduction reaction: $xLi^{+} + C + xe^{-} \rightarrow Li_{x}C$

Discharge:

Positive electrode (cathode) reduction reaction: $Li_{1}\text{-}xCoO_{2} + xLi_{+} + xe\text{-} \rightarrow LiCoO2$

The reaction absorbs energy in the forward (charging) direction, and releases the energy during discharge in the reverse reaction. In this way, it can act as an energy storage device.

Cells are generally constructed in the discharged state. On charge the positive electrode, cathode, material is oxidized, Li+ ions are de-intercalated from the layered lithium intercalation host, e.g. $LiCoO_2$, pass across the electrolyte and are intercalated between the graphite layers in graphite by an electrochemical reduction reaction proceeding at the negative electrode.

When the cell is discharged, an oxidation reaction occurs at the negative electrode, Li+ ions are de-intercalated from the anode and migrate across the electrolyte to be re-intercalated into the cathode material, due to charge balance the equivalent number of electrons travel through the external circuit. A simultaneous electrochemical reduction reaction proceeds at the positive electrode and accepts electrons from the external circuit, Li+ ions from the electrolyte, to reform the starting material. A change from electronic current to ionic current occurs at the electrode/electrolyte interface, as shown in Figure 3.3-3 [3.26].

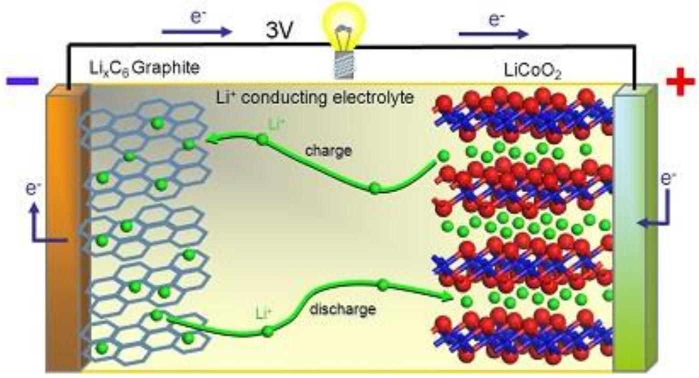


Figure 3.3-3: showing intercalation - the reversible insertion of a guest atom into a solid host structure without inducing a major disruption of the host material [3.26]

Physically the cathode and anode consist of a porous meshed structure in order to allow a large surface area for intercalation. They are attached to metal conductors that allow the electrons absorbed and released to flow around an external circuit to provide current flow to a load. The electrodes are placed in an organic electrolyte that allows the ions to travel through it, being kept apart by a porous separator to prevent the electrodes from touching in order to prevent a short circuit. The cell must be kept free from water contamination lest the electrolyte decay.

Lithium has the highest electrode potential per unit mass of any metal, so a lithium-ion cell theoretically has the highest specific energy of any configuration. When fully lithiated, the maximum theoretical capacity per gram of active lithium is 372 mAh g^{-1}

The battery is the most vital part of an EV, because it provides the energy for transportation. The energy stored in the EV battery may also be used to provide auxiliary services, including network support and renewable energy integration. In economic terms, the cost of the battery accounts for a big part of the vehicle's cost. Owing developments in battery technology, manufacturing costs of EV batteries have fallen very significantly in recent years. Because the cost of the battery forms a major part of the EV purchase price, it influences the Total Cost of Ownership (TCO); therefore, this has to be considered when comparing an EV to an ICE vehicle. The value chain of automotive batteries consists of: production operations carried out on the components such as raw materials for production of the cells, module production into the battery packs (a cooling system is also included), battery-vehicle integration and usage in the lifetime and recycling. Manufacturing costs can be minimized by focusing on the optimization of the first four steps by both developing battery technologies and through economies of scale.

Figure 3.3-4 represents the value chain of EV batteries [3.27].

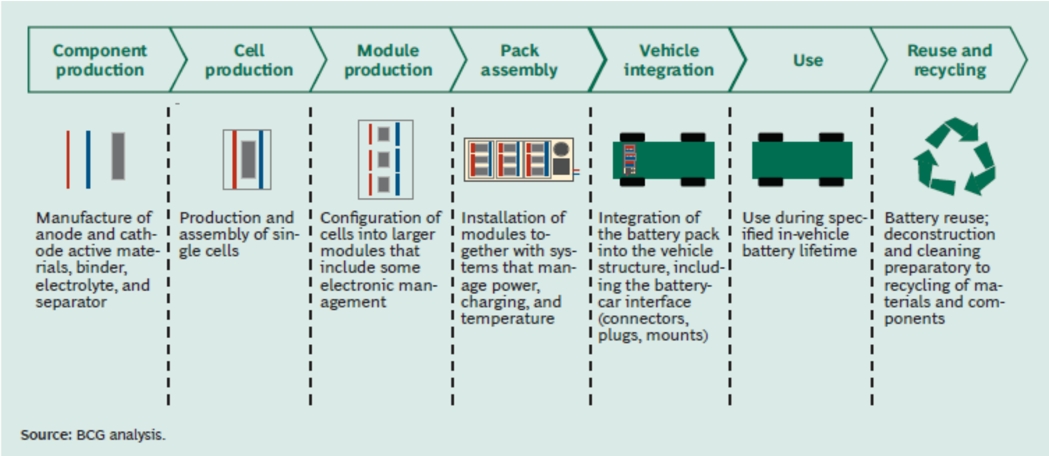


Figure 3.3-4: Automotive battery value chain [3.27]

The cost of the raw materials is only some 12% of the cost of the battery according to the same report [3.27]. The chart in Figure 3.3-5 illustrates this, based on 2009 figures. Thus, the actual cost of the raw materials, including the Lithium used to make the battery will set a lower limit to the production cost, which is still well below 2017 battery prices.

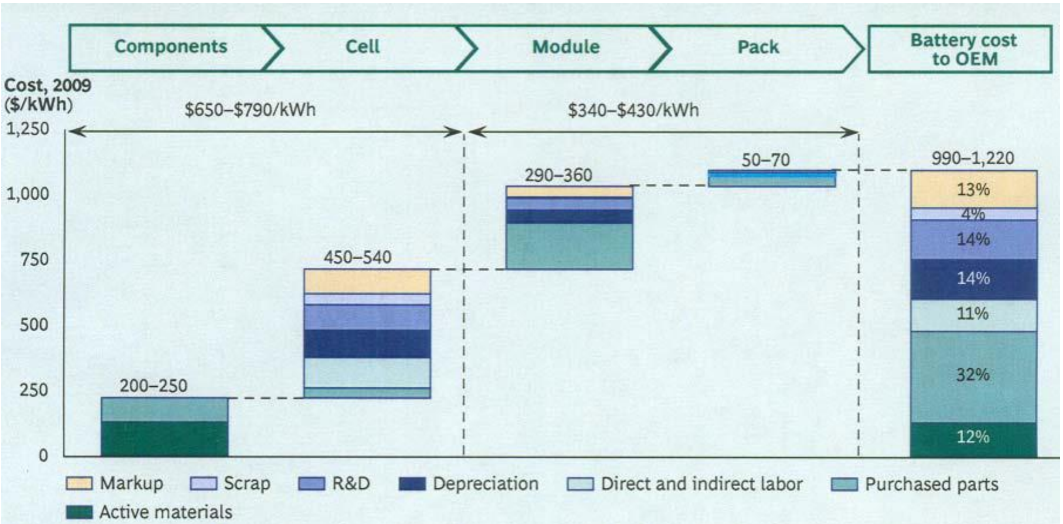


Figure 3.3-5: Breakdown of the cost of a Li-ion EV battery [3.27]

Battery degradation during the lifetime of the EV largely determines the Cost of Use and at the end of the battery's useful life in the EV, the battery residual value, represented by the remaining capacity (usually taken to be 80% of the original capacity). In favourable circumstances, an EV battery can be employed as second life battery and this will additionally reduce the overall cost of vehicle ownership.

It is important to know the Li-ion battery chemistries commercially available and utilized for automotive purposes, because they have different characteristics, strengths and drawbacks. Only the lithium-ion batteries, that are currently the most efficient technology commercially available for automotive purpose, will be discussed. According to [3.27], the most promising chemistries are lithium-iron phosphate (LFP), lithium-nickel-cobalt-aluminium (NCA), lithium-nickel-manganese-cobalt (NMC), lithium-manganese oxide spinel (LMO) and lithium-titanate (LTO). These chemistries can be compared according to six different criteria: (a) lifespan (maximum number of charging/discharging cycles), (b) performance which refers to peak power, (c) energy stored per kg known as specific energy, (d) specific power and perhaps the two most important, (e) cost and (f) safety.

Figure 3.3-6 depicts the performance of the different chemistries on these six dimensions. It can be seen that maximising one dimension means inevitably some lacking in others; a chemistry that performs well along every criterion is not at present known. The safety issue consists essentially in preventing thermal runaway with a possible ensuing fire; a battery fire can cause significant physical damage and affect the user perception of the technology. The presence of a high discharge rate, battery overcharging or a short circuit, favoured by a positive feedback loop, can cause chemical reactions that release heat and originate a fire. This is why a cooling system is a fundamental component of any automotive battery pack to ensure a controlled and safe energy release and avoid thermal runaway. There is usually a compromise between high energy and inherent safety which requires and expensive thermal management system. Although the cycling of batteries is well known for fixed Depth of Discharge (DoD), in fact in the information provided by the manufactures, there is a curve relating the number of achievable cycles before the End of Life (EoL) for different fixed DoDs, it has to be related also to other parameters, such as SoC, charging rates and the overall age of the battery. One solution to tackle the degradation issue is to install batteries that are larger than required, so that even after years of degradation, the battery will still have enough capacity to provide for automotive usage. The drawback to this approach is a higher initial cost and weight for the battery pack. However, by minimizing the degradation, possibly by optimising the charging schedule, the life of automotive batteries can be extended and therefore the degradation cost minimized; this is one of the aims of Smart Charging and V2G in SEEV4City.

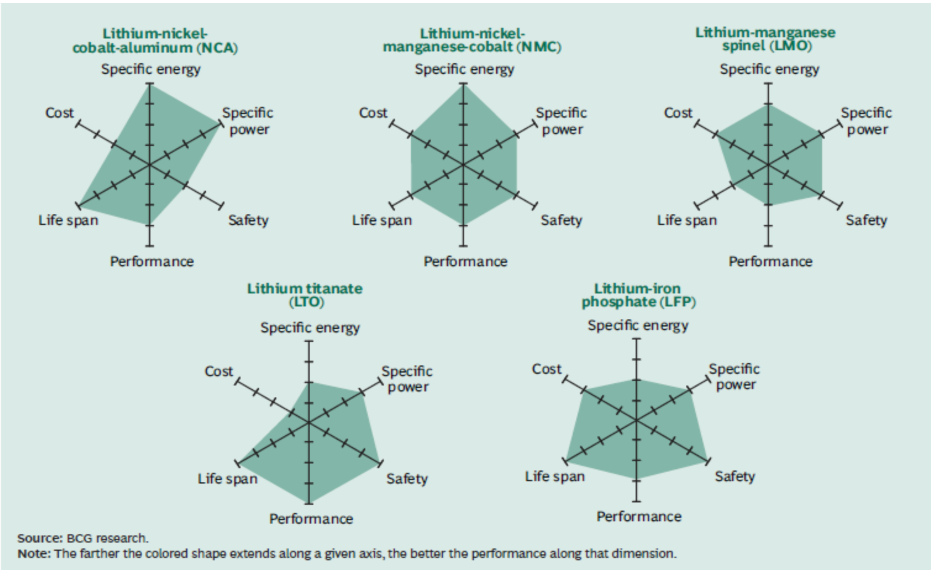


Figure 3.3-6: The further the coloured shape extends along any axis, the better the performance along that dimension [3.27]

It is difficult to ensure a good performance of the batteries in both cold and hot climates, but on the other hand characterizing a battery for a specific climate limits the mobility across regions; it is again a matter of engineering compromise. Although the specific power delivered by a Li-ion battery is comparable to the power provided by ICE vehicles, in terms of specific energy EVs are still well behind. However, the situation is improving; in [3.28] the energy density, or specific energy, for BEV batteries is reported to have reached near 300Wh/l in 2015 and according to the US Department of Energy (DOE) more than 330 Wh/l for PHEVs in 2016. In recent years, the specific energy has increased to as much as 684.2 Wh/l [3.29] Figure 3.3-7 depicts the global outlook for EV batteries.

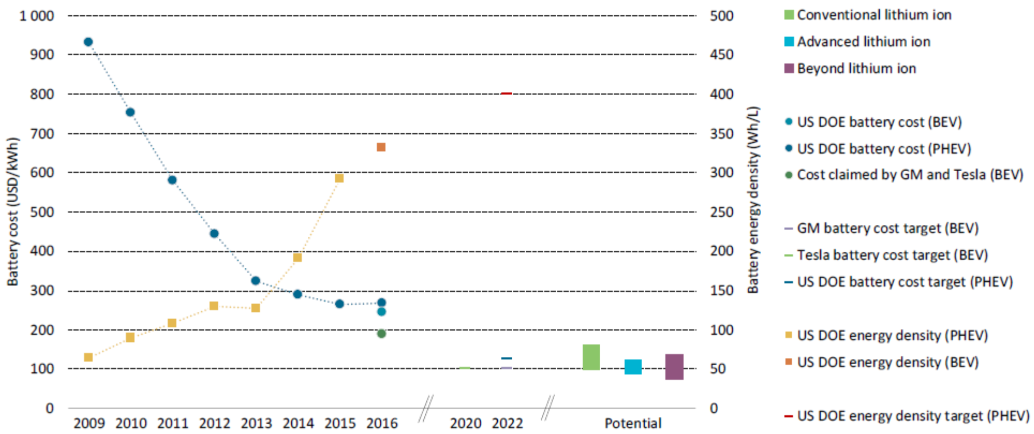


Figure 3.3-7: Battery cost and energy density trends and targets [3.28]

Even though the energy density has almost doubled between 2009 and 2016, the absolute value is still far below the significant specific energy of gasoline. As for the cost factor, Figure 3.3-7 also depicts the situation of battery costs in USD up to 2016. As can be seen, the battery cost has dropped from 1000$/kWh in 2008 to below 300$/kWh in 2016, for PHEVs, according to US DOE, while for BEVs the cost is even lower. Bloomberg New Energy Finance (BNEF) in its 2019 Battery Price Survey, found that industry-weighted average battery pack prices have already fallen to $156 per kWh. This is over 13% lower than the 2018 average ($180/kWh, when adjusted for inflation), and BNEF foresees cost reductions continuing, with $100/kWh potentially being reached by 2023 [3.30]. The Bloomberg values are shown in Figure 3.3-8 which show battery pack prices well below $200/kWh.

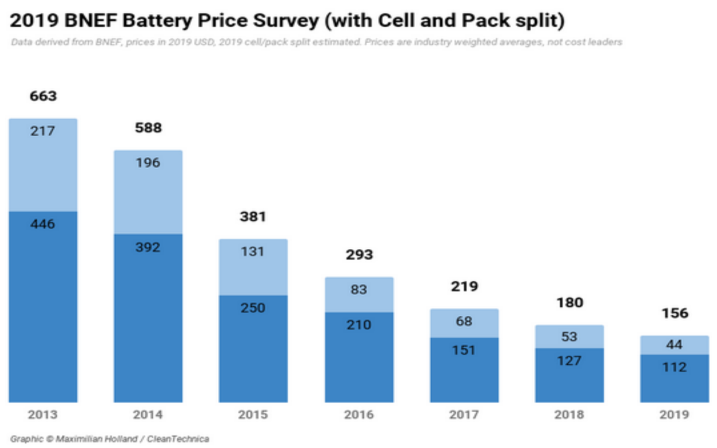


Figure 3.3-8: Li-ion battery cost history 2013-2019 [3.30]

This confirms that the technologies that are currently accessible in R&D have higher performance than those commercialized in the market.

Furthermore, according to the US DOE [3.28], the production volume has a significant impact on the cost: scaling up from 25000 units to 100000 units for BEV batteries allows for cost reduction per kWh of 13%. In 2015, production volumes over 200000 units provide a cost for a single battery pack of about 200$/kWh or less, which is two third of the 300$/kWh obtained for volumes between 10000 and 30000. In addition, the capacity of the batteries has an important influence on the costs: producing 100 kWh batteries rather than 60 kWh ones (which is reflected in an increase in the range from 200km to 300km) results in a cost reduction per unit of 17%.

It is often said that EVs will be competitive against ICE vehicles when automotive Li-ion batteries will have reached a cost of 150$/kWh [3.31] but the authors of [3.27] argue that these kinds of estimates are often unreliable. To clarify, figures from other reports are also provided. Figure 3.3-9 presents information gathered from multiple sources in order to represent the situation regarding Li-ion battery packs costs until 2014 [3.32].

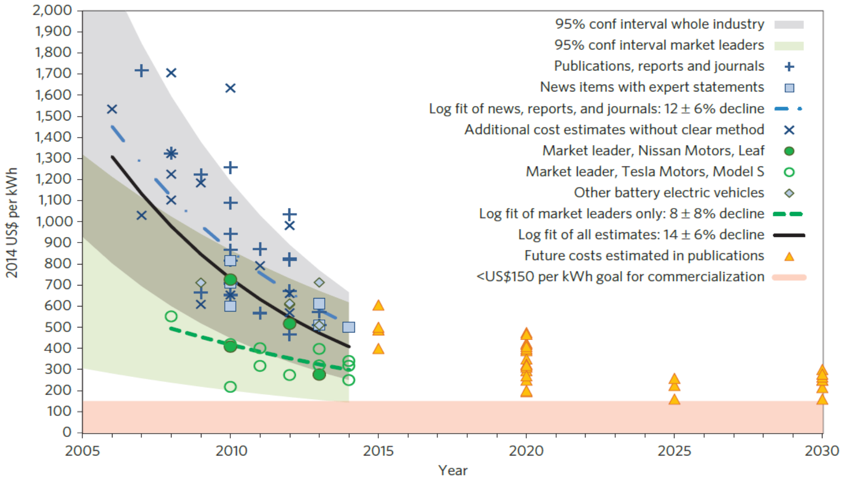


Figure 3.3-9: Real values, estimates and targets for Li-ion batteries [3.31]

The numbers coincide reasonably with the previous figures. According to [3.27] battery pack prices projections indicate a future price below $190/kWh by 2020 and below 100$/kWh by 2030. According to [3.28], battery prices decreased by 35% in 2015 and they predict that by 2040 long-range electric cars will have a cost that is below $ 22,000 and that 35% of the new cars will be EVs.

Figure **3.3-10** and Figure 3.3-11 illustrate these considerations.

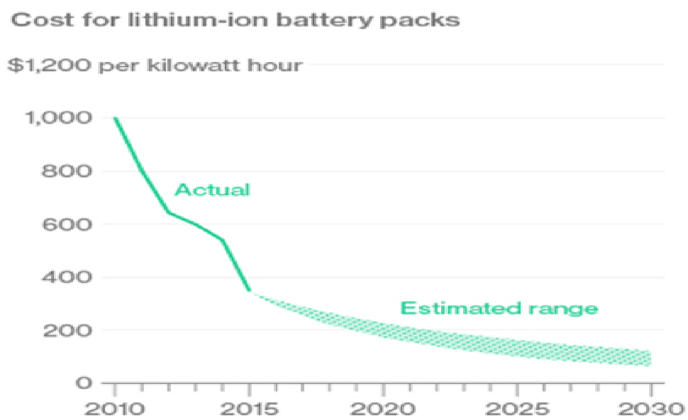


Figure 3.3-10: Li-ion battery cost trends and estimates [3.32]

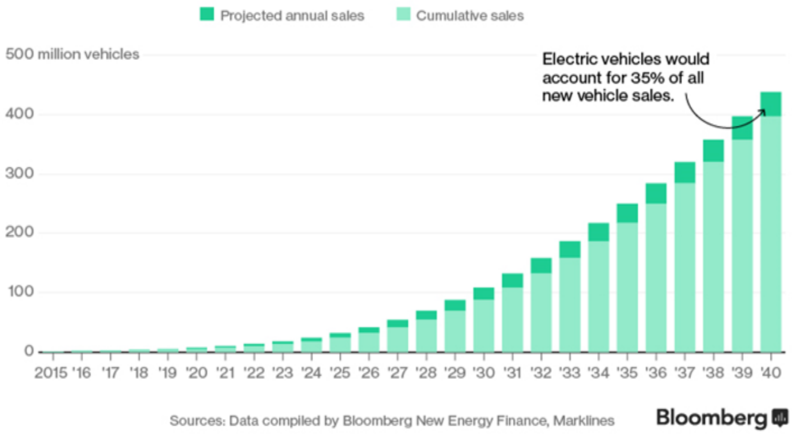


Figure 3.3-11: Global EV purchase projections [3.32]

Reference [3.27] raises an interesting point: if the cost of the raw materials used in battery manufacturing increases, then this will hinder the cost decrease needed to make EV adoption viable. However, this is not a major issue given that, according to the predictions, quantities lower than 1 percent of the known reserve of lithium, nickel, manganese and copper will be required for the battery packs in 2030; so there will not be any shortage from widespread EV adoption.

Key players in the battery market are the OEMs because they allow the development of the battery technologies by commercializing them in large volume, allowing a learning curve to be followed. In order to reach, or at least go close to, the goals fixed for 2020, 2030 and 2040, OEMs have to join forces with cell manufacturers and suppliers. By establishing alliances with cell manufacturers, OEMs have access to new technologies and know-how but this limits their framework if relevant technological advances are reached by other manufacturers. If the cell manufacturers team with suppliers, then they have access to different OEMs; on the other hand, OEMs know less about battery technology but the economy of scale is further improved and it is easy for them to switch between different technologies. An important choice that OEMs need to make is between either control over a technology or scale and flexibility. In [3.27], the authors predict that in the short-term OEMs will join forces with cell manufacturers to learn about new technologies in order to allow their development and be the firsts to introduce them in the market. Economy of scale will be favoured in the longer term, when the technologies will be mature; hence, OEMs will establish alliances with suppliers.

In conclusion, it appears that the current battery technology development trend is in line with expectations, perhaps with costs falling even faster than in the earlier predictions. This makes possible an EV cost abatement that will favour the massive penetration into the global vehicle fleet that is required now. Moreover, EV batteries at the end of their automotive life could be sold as second life batteries to supply the ever-developing energy storage market. This may mean less of a need to manufacturing batteries for grid energy storage afresh, and thus competing with production of new batteries for EVs. As a consequence, this will improve the total cost of ownership of EVs.

Cost reduction is expected from improved production processes and larger scale production. As mentioned, the right partnerships between the battery market players are fundamental in order to follow every step of the technology and production development. But other factors, such as the minimization of degradation with smart charging, revenues from V2G, national policies that subsidise EV purchases or other type of subsidies like tax exemptions and penalties against ICE vehicles, are essential in order to reduce the Modified Total Cost of Ownership (MTCO) and make EVs competitive and better than ICE vehicles.

A final possibility is that different battery chemistries may be employed, perhaps not even using Lithium. In [3.33a] an Aluminium Ion cell is reported which exhibits discharge voltage plateaus near 2 volts, a specific capacity of about 70 mA h g(-1) and a Coulombic efficiency of approximately 98 per cent. The cell affording charging times of around one minute with a current density of ~4,000 mA g(-1) (equivalent to ~3,000 W kg(-1)), and it was able to withstand more than 7,500 cycles without capacity decay. If such a cell can reach the mass production stage, it could be even cheaper than the present Lithium based cells, given the low cost of Aluminium, and the energy density might be better since Aluminium is trivalent, whilst Lithium is monovalent.

3.3.2. Battery degradation

Battery modelling technology

The purpose of a business model is to allow the maximisation of benefits and the minimization of costs, allowing optimization of the overall business operation. When this is done in a Vehicle for Energy Services (V4ES) context, the model must deal with the use of Electric Vehicles (EVs) to provide different services for various stakeholders. These stakeholders will typically include households or organisational owners, with all their domestic loads, the grid and its balancing requirements, the aggregator, which accumulates the storage capability of many vehicles to provide bulk services to the grid and EV users, who use the EV for its main purpose: transportation. Although any one vehicle's plug availability is unpredictable, the availability of thousands or tens of thousands of vehicles is highly predictable and can be estimated from traffic and road-use data. An EV can readily provide services because the majority of EVs are parked for 95% of the time on average [3.34]. There are two main areas in which the EV battery can provide grid support: they can provide direct storage of power, charging when aggregate power demand is low during the night and discharging when demand is high, such as during the 6 p.m. peak. Less obviously, aggregated EVs can provide what are known as Ancillary Services, most importantly Regulation up, Regulation down and provision of a Spinning Reserve. The EV battery is the focal point of V4ES because as a mobile energy storage system it is the main energy resource and because it comprises a major part of the cost of an EV. Currently, more than 50% of the vehicle cost is accounted for by the battery [3.34]. Thus, the cost of provision of grid support in terms of battery degradation is very important. For any business model to be valid, the financial rewards accruing to the EV owner, after deduction of sums retained by third parties such as aggregators, must exceed the financial burden borne by the EV owner in terms of enhanced battery degradation. Estimates suggest that direct power storage will be less profitable for the EV owner than provision of ancillary services such as Regulation, where demands on the battery are less than for the provision of Spinning Reserve or Storage, so degradation is less, and if both up and down Regulation are provided, the effect on battery charge may be limited [3.35].

Some technical and economic considerations regarding the current situation of batteries and the upcoming challenges are the following:

- In order to be cost competitive with conventional ICE vehicles, EV batteries at existing price levels have to achieve lifetimes of 10-15 years before battery capacity falls to 80% of nominal.
- Due to battery degradation, in order to meet automotive requirement for adequate lifetime the batteries are oversized; in the context of V4ES, this represents an extra cost and the minimization of the degradation will result in an extended life of the battery and thus will reduce the need for expensive oversizing.

A viable business model aims to maximise the economic benefits of the involved factors, such as: choice of grid service provided, appropriate charging hours, convenient options in terms of network services, renewables integration, costs in terms of additional battery degradation and others, and resulting profits. Correct handling of the factors can give a 'Modified Total Cost of Ownership' (MTCO) that incorporates the effects from the different parts of the business model and a modified 'Total Cost of Use' (TCU). The selected parameters are then applied to an Energy model that technically implements what has been advised as optimal from the business model and this optimization is tailored for an Operational Pilot (OP) to validate the results. These results are fed back into both the energy and business models to optimize the solution. Going into details, charging patterns are derived from the optimization process, and provide the control signals sent to the EV chargers. If the charging pattern, chosen in order to maximise the benefits to the stakeholders, optimizes the life of the battery, perhaps ending up by increasing the battery life compared to so called 'Dumb charging', where the battery starts charging as soon as it's connected without any optimal scheduling in order to minimize the degradation, then an extra value can accrue to the battery and this will contribute to reducing the MTCO.

In order to calculate the degradation cost of the battery, one approach could be the following [3.36a]:

$$c_d = \frac{c_{bat}}{L_{ET}} = \frac{(E_S\, c_b) + (c_1\, t_1)}{L_C\, E_S\, DoD} \qquad (2)$$

Where the cost of the battery has been split in material cost and labour cost, L_{ET} represents the total energy throughput for a particular cycling at a given DOD, LC is the battery lifetime in cycles and not in calendar life and E_S is the total energy of the battery in kWh. In both the definitions knowledge of the expected lifetime is essential for the degradation cost evaluation, although in the first example the calendar life and in the second instance the cycle life is considered; this is because in the second definition, the cycling is supposed to be performed at only one DOD. This is impractical in reality where the DOD that the automotive battery is subject to varies according to the user's necessities. Therefore, such a kind of lifecycle definition is not realistic and one of the aims of a battery degradation model is to define the lifetime by relating it to the different parameters. Thus, it has to predict how the lifetime of the battery is affected by providing Vehicle to Grid (V2G) services, which entail extra DOD, additional power throughput in terms of increased variation of battery SOC, adverse changes in C-rate and associated additional temperature increases.

One of the main objectives of V4ES is the optimization of the SOH, which represents the current capacity when compared to nominal. The remaining capacity in a battery between the capacity at any time and the 80% level reflecting EOL determines the residual value, representing an asset that could be exploited by selling the then 'Second Life' battery, which will continue to provide energy storage even after it has left the automotive context.

The battery's SOH has been defined [3.37] in the following way: $\boldsymbol{SOH} = \frac{C_{act,disc}}{C_{ini,disc}}$ that is the ratio between the actual capacity of the battery measured in kWh at a given time and the initial or nominal capacity.

It is clear that the creation of a realistic Battery Degradation Model represents a fundamental part of the business model: to provide the cost of battery degradation associated with an intervention having as inputs different measured or assumed physical parameters. In [3.38] battery models present nowadays are categorized in three groups: they can be based on physics, semi-empirical and empirical. An essential requirement asked of an effective battery degradation model is to allow extrapolation/interpolation of the results obtained from laboratory experiments to the arbitrary cycling common in everyday life. A model has to accommodate the main aging phenomena in batteries due to the main charging/discharging cycles, calendar life, storage conditions and driving schedules. For the present purpose, such a model must allow for the effects of grid support interventions as well as the effects of 'normal' use. In the context of V4ES, degradation caused only by normal driving is out of scope, but any developed model must consider these effects, since these provide a significant contribution to the overall degradation. An increase of the EV battery internal resistance and the decrease in capacity are the most important effects of battery degradation and these respectively result in power and energy loss. The reasons for the occurrence of these two phenomena are:

- For the resistance increase: electrolyte degradation, isolation or fracture of active material, reduction in the number of electrical conduction paths in the electrode;
- For capacity loss: isolation, chemical degradation, fracture of active material and loss of cyclable active material (Lithium).

According to [3.39], the main variables that accelerate battery degradation are:

- **Battery cell temperature:** the ambient temperature is also important. The literature suggests that operating at a cell temperature of about 20°C gives least degradation [3.40; 3.41]. Operation at higher cell temperatures than 20°C tends to reduce battery lifetime due to unwanted side reactions damaging the cell [3.42]. Reduced cell temperatures reduce performance and lifetime due to an increase in the internal cell resistance [3.43].
- **State of Charge (SOC):** the lower the average SOC, the lower the battery degradation, this is verified by the literature [3.44]. Average SOC changes with cycling schedule. If a certain amount of charge is to be applied to the battery within a 24-hour period, then the time and duration of charging can be altered to change the average SOC. For example, leaving the EV battery at a low SOC with subsequent delayed recharging can yield a lower average SOC over a 24-hour period than early charging with the battery then remaining at a high SOC for some hours.
- **Depth of Discharge (DOD)/amount of charge transferred:** the more charge is transferred during cycling, i.e. the greater the DOD per cycle and the greater the number of cycles, the greater the degradation [3.45].
- **Current rate (C-rate)**: increasing the charge rate accelerates degradation. The literature indicates that this factor is linear at rates under 1C [3.46]. Domestic chargers provide power at either 3 kW or 7 kW (i.e. under 1C for passenger EVs). Faster discharge due to high driving speeds and/or hard acceleration has similar effects on degradation due to an increased battery discharge rate.
- Figure **3.3-12** shows the inputs and the outputs involved in the potential battery degradation model that has to be developed.

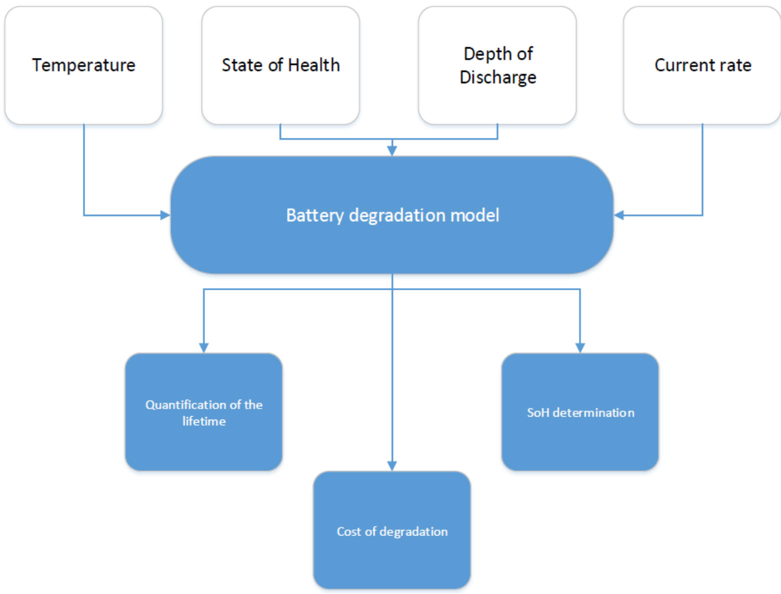


Figure 3.3-12 Battery degradation model concept

The model will consider the four parameters involved and their effects on degradation, combine them with a realistic approach (for instance, it is known that high current rates can cause high losses if the internal resistance is high, and this leads to high working temperatures), determine the lifetime implied by the provision of the different services and how to improve it, and evaluate the cost of degradation by keeping in mind the replacement cost of the battery. This will be included in the cost-benefit analysis employed by the business model and, because it is an important output, the battery model will determine the SOH of the battery and the impact of the different V4ES services on it.

A battery degradation model has to quantify the effect of the extra battery utilization and charge transfer due to V2G, which results in increased influence of the aforementioned parameters on the Battery SOH and residual value. The costs accruing to the operation of each factor have to be allowed for, so that the cost of degradation can be compared with the revenues from the different services provided and the amount of the overall benefit/loss can be defined. Therefore, it is essential to know which parameters have been considered in battery degradation models present nowadays and how.

The National Renewable Energy Laboratory (NREL) for Li-ion batteries has developed a model with Nickel-Cobalt-Aluminium (NCA) cathode and graphite anode [3.45; 3.47; 3.48; 3.49]. It has not been established how well the NCA model will represent other Li-ion chemistries, but it is anticipated that other chemistries with similar degradation mechanisms could be modelled in a similar fashion after adjustment of model parameters [3.48; 3.49; 3.50].

Charging/discharging optimization

Several battery degradation models have been applied in cost/benefit optimization processes, and some interesting conclusions emerged.

In [3.51a] a battery model that uses the cycle life data provided by battery manufacturers is developed. This presents a major disadvantage: within V4ES, business models will be developed and the output of these will feed the energy models. These have to be applied to real world Operational Pilots (OPs); hence, every component of the system has to be modelled and the related data has to be collected. If an approach as the one mentioned here is adopted, then every time the business model has to be implemented in an OP, manufacturer data for every single battery have to be considered and processed in order to operate with the model. The aimed at battery degradation model will have to represent the batteries that will be involved in the OP with a reasonable accuracy and this has to be easy to implement; hence, a certain level of generality is required. Of course, a comprehensive model that represents the exact behaviour of every battery technology is still a long way down the line. The cost function employed here includes the cost of the electricity for household consumption, Frequency Regulation compensation and revenues coming from energy arbitrage. Only the cycle life aspects are analysed, and the total lifetime is not considered. They continue by defining a total wear cost W(SOC) function, and specifically they refer to the power delivered. This expression is very useful from a business model point of view because it allows us to consider directly the depreciation given by battery degradation, and it can be included in cost benefit calculations. An application of the developed model is then proposed by evaluating the revenues from V2G service provision: the revenues from RU and RD diminished by the electricity cost for household, which also includes photovoltaic generation, are maximised through an optimization process.

Figure 3.3-13 shows the results of the actual battery’s SOC manipulated in such a way that the overall benefits are optimized.

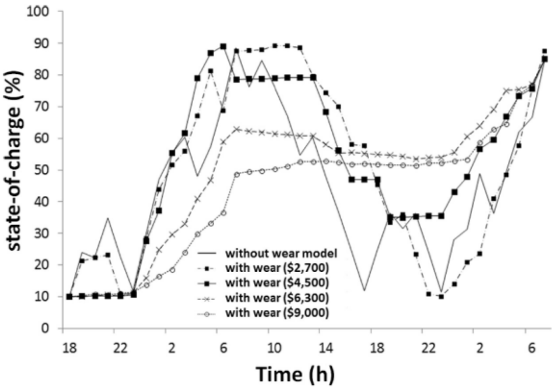


Figure 3.3-13 SOC resulting from optimization [3.51]

It is observed that when the battery wear cost is not considered, the general tendency is to charge the most possible during the night when energy is cheap, and discharge during daytime when the price is high. Price arbitrage in itself may not be enough to fully incentivise users. Hence, a more rounded way of using EVs to participate in energy and network service is discussed in a later section of this report. The more the battery wear is relevant compared to the energy cost, the more flattened is the SOC curve. The study reference in Figure 3.3-13 continues by considering different charging strategies: one starts charging the EV immediately, the second considers optimization of the electricity cost without including the battery wear and the third considers the battery wear cost in the optimization process. Figure 3.3-14 depicts the overall costs implied by different charging patterns and battery prices.

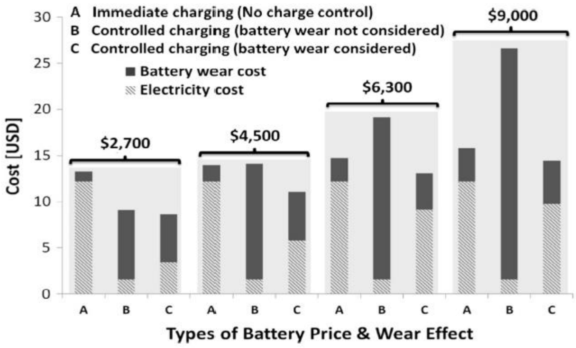


Figure 3.3-14 Total costs with different charging patterns and battery prices [3.51]

It is observed that, with the first method, battery wear is at the minimum compared to the other cases because the battery is not discharged and recharged again in order to obtain profit, but the overall benefits are maximised with the third method. It is worth noting that an EV being plugged in and providing V2G availability does not necessarily implies battery cycling. On the contrary, smart charging or even V2G could optimize the battery life by keeping the battery at a low SOC as opposed to dump charging.

The third method is also applied with and without the Regulation and Figure 3.3-15 provides the outcome.

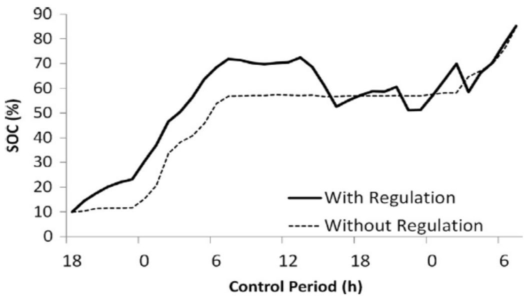


Figure 3.3-15 Evolution of SOC with and without regulation [3.51]

The results show that, in case Regulation is applied, the system tends to store more energy than required in periods where the energy is cheap and to provide it afterwards when the prices rise. This employs the battery more, compared to the normal usage, and this is done to minimize the cost of the electricity as long as it is economic taking into account the battery wear. Figure 3.3-16 shows the cost comparison with and without Regulation.

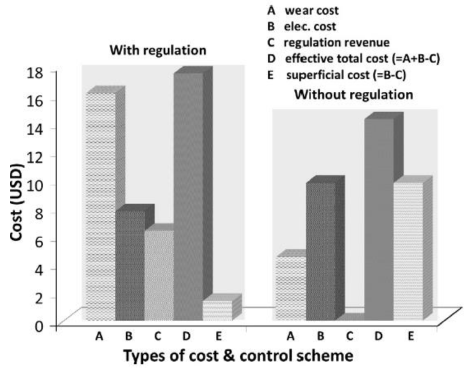


Figure 3.3-16 Cost and benefit representation with and without regulation [3.51]

Finally, the costs compared to the revenues from Regulation are presented and from what can be seen in the figure presented above, the effective total cost resulting is higher in the Regulation case compared to the case without Regulation. This is mainly due to a higher battery cost: technology development focused on increasing energy and power densities, and reduction of battery cost, efficient charging patterns that improves battery life, higher revenues from network service provision and potentially favourable policies are some major requirements to make a business model imprinted on V2G profitable.

In [3.49a] an optimization process is performed which aims to find the power profile that allows the minimization the total cost of charge given by the electricity cost and the battery degradation cost. Figure 3.3-17 shows the outcome.

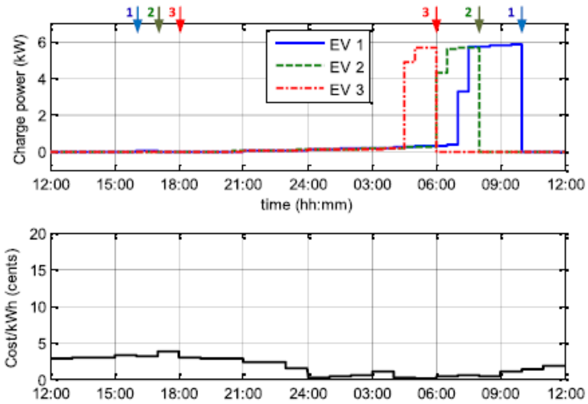


Figure 3.3-17 Charging optimization with a variable electricity price [3.49]

The results of the optimization show different tendencies:

- To charge late in the available time span in order to avoid high SOC for a long time which is harmful for the battery health. Obviously, this has to be compared with the advantages/ disadvantages given from the electricity price. It also has to be considered that this can overload the distribution transformer when simultaneous charging of EVs will start, and this is likely to be expected in early morning when daily activities start and the price of the electricity starts rising.
- Distribution of the total charge over time is done in order to decrease the power exchanged.

If the price difference between time intervals is lower than the degradation cost, then the optimization process does not start charging intensively even though the price can be at its lowest. V2G is known to increase the degradation of the battery because, if some energy is provided to the grid it has to be absorbed again in order to meet the user's requirements; thus, if the price difference for energy arbitrage is not high enough compared to the degradation cost, then V2G is not performed even in the presence of price spikes. This indicates once again how technological progress in the battery field is an essential requirement to make V2G economically feasible. The advantageous characteristics of FR such as shallow charging/ discharging and high frequency is particularly suitable in this case, because if the battery is mildly cycled then the degradation is less compared to deep discharges (i.e. peak provision), and on top of that there is a capacity payment for the availability of the plugged capacity. This has not been considered in this model. It is explained how a thermal management system can alleviate the extra thermal stress caused by V2G, thereby reducing battery degradation and hence making this service provision more profitable.

In [3.52] the authors analyse two different operating modes for Plug-in Hybrid Electric Vehicles (PHEVs): one depends on the utilization of the battery and the other relies on the ICE. A small and a big size of the battery are assumed. Two charging patterns are considered, both at 1.6 kW rate (slow charging, fast charging/high current rate is not considered): immediate night charging after the last trip of the day and opportunity charging where the vehicle is charged at every stop longer than 2 minutes. The smaller battery suffers from occasional charging more than the larger one because it is deeply cycled. If high SOCs are accompanied by high cycles per day, this results in the shortest life. If high daily mileage is considered, then the small batteries spend more time at low SOC because the ICE is used; this extend the life of the battery; having low daily mileage gives the same result in terms of remaining capacity after 8 years. If for the same EVs opportunity charging is applied, then the situation becomes worse because in this case the battery is used more and hence the degradation is higher; from the fuel-consumption point of view this is however beneficial in economic terms, because electricity is used instead of fossil fuel. With the large battery, the effect of charging is less evident in remaining life: with opportunity charging the battery is shallowly cycled. This paper focuses on charging and discharging cycles based on driving considerations. Even though this gives a practical insight in the usage of an EV, because before everything it must accomplish the automotive purposes, the effect of charging/ discharging when the car is parked is not considered. In fact, fast charging is not investigated and frequent discharging for frequency regulation has not been analysed.

After the analysis of the available battery degradation models, a conclusion about the completeness of the current work can be drawn. Most of the studies only consider some of the relevant parameters and their effects but not all: some of them are neglected with assumptions on the working conditions (i.e. they suppose that the C-rate is kept reasonably below 1C, hence the effect of the charging current is not considered). The combinations of these parameters are sometimes neglected (i.e. the working temperature and the current rate are strongly dependent on each other but in some studies the effects are not merged together), and in no case all four the parameters have been considered together. As an example, it can be said that as in [3.39] the effect of DOD has been neglected with some assumptions. In most of the models seen so far, some parameters and their combined effects are frequently ignored. This damages the reliability of the battery model because, if this has to be applied to physical OPs, it has to be consistent with reality. If, for instance, in the business model the effect of a parameter is assumed to be negligible, but in the practical implementation there is a strong presence of the variable, then the results obtained from the optimization will not be correct.

Most of the studies focus on specific Li-ion battery chemistries, whereas in order to be applied to a fleet of vehicles, where there would be EVs with different batteries, a more generalized battery degradation model should be developed. If the parameters are fitted from manufacturer data, the model lacks of generality and cannot be easily and widely implemented, for instance, in a fleet of vehicles. A lack of studies on non-accelerated analysis has been noticed because most of the time a constant current profile is adopted instead on realistic load profiles. Following these considerations, in order to impact positively on the business model, the battery model has to incorporate the effects of the four parameters initially mentioned, allow the co-existence of the different effects of these parameters, define cost functions related to the variables, reasonably conform to the reality, in the sense that it does not have to depend on experimental tests too much and, of course, because it has to be included in an optimization process it has to be computationally efficient enough to run on an embedded system for better user experiences.

3.3.3. Future technologies and forecasts of batteries

In the previous sections the technological solutions for battery storage have been presented and important aspects such as specific energy, cost per kWh of capacity and battery degradation investigated. However, that represents the current situation whereas, as will be seen from the section 7.3 – Economics of Smart Charging and V2G – the success of future EV business models depends in a significant part on the future development in battery technologies. If, as predictions say, the cost will come down to the benchmark of 100$/kWh [3.30], many business models (i.e. those providing network services that are currently assigned to cheap alternative solutions and if implemented by EVs may imply considerable extra battery degradation due to V2G) will become profitable. It is also a matter of the cheapest and most suitable technology for the goals of an EV business model. Currently, Li-ion are the most efficient and economic BESS but, as will be shown briefly, this technology has just reached the level of commercialization, thanks also to the meaningful R&D conducted for electro mobility purpose, and a clear path is not defined yet. This means that there is still the possibility that some technologies may overtake Li-ion batteries in the future, and the scenario study that will be conducted within SEEV4City will address these dynamics as well.

However, no matter what technology will be adopted, it is clear that batteries are going to be deployed in a large scale. In fact, the study conducted in [3.53] estimates that by 2025, roughly 25% of the global vehicle fleet will be electrified resulting in an energy consumption of ≈175GWh from batteries. Nevertheless, they do not represent only a burden for the grid, but rather a resource: actually, batteries will play a major role as storage solutions for the electric system, to the point that the total available market for battery systems may be of $100-$150bn. Currently this position is covered by Pumped hydro, which has been technically and economically proven valid, currently taking 99% of the market [3.54]. However, it is a mature technology whereas the new and more economic battery solutions have to show their full potential yet. Figure 3.3-18 shows an overview of the technologies currently available and their level of maturity, along with the number of MW of energy storage globally installed in 2015.

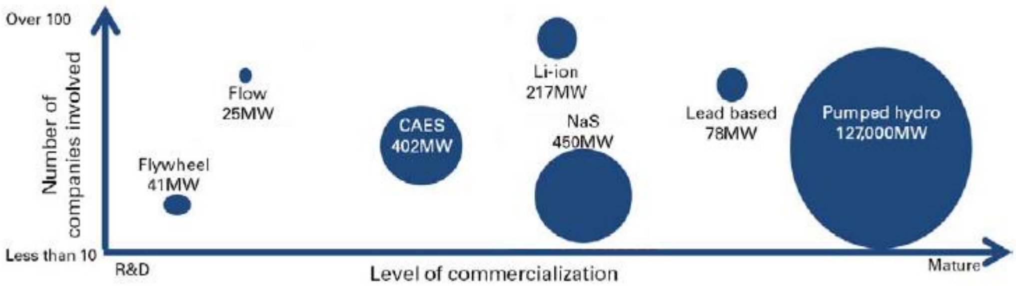


Figure 3.3-18 Maturity level of energy storage [3.55]

As can be seen, the Pumped Hydro is heavily utilized, while new technologies that can be successful in the near-to-medium term, such as Sodium-sulfur (NaS) and Li-ion (which are at the level of commercialization) and Flow (which are in the R&D phase) have just started to be adopted. The other technologies shown in the figure above are Flywheel, which convert and store AC energy in form of kinetic energy: an angular momentum of a spinning mass. Compressed Air Energy Storage (CAES) use electricity to compress air. Among batteries, the currently most prominent one has been mentioned above, and Figure 3.3-19 gives a detailed insight on their characteristics.

Mature ⟵ Level of commercialization ⟶ R&D

	Lithium ion (Li ion)	Flow	Sodium Sulfur (NaS)	Emerging
Installed base	150 MW+	50 MW+	450 MW+	N/A
Chemistries	Li Nickel Cobalt Aluminum Oxide; Li Iron Phosphate; Li Nickel Maganese Cobalt Oxide; Li Manganese Oxide	Vanadium redox; Iron-Chromium; Zinc-bromine	NaS	Liquid metal; metal air
Storage duration	Short (1-4 hours)	Medium (4-10 hours)	Medium (4-10 hours)	Short - Long
Lifespan	5 - 15 years	10 - 20 years	10 - 15 years	2 - 10 years
Cycles	2,000 - 10,000	10,000 - 15,000	2,500 - 4,500	Varies
Efficiency	85%-98%	60%-85%	70%-90%	Varies
Energy density	High	High	High	High-Low
Capital cost	$350/kWh - $1000/kWh	$600/kWh - $200/kWh	~$500/kWh	$200/kWh-$1000/kWh
Levelized Cost of Storage	$0.15-$0.75 per kWh	$0.11-$0.28 per kWh	$0.23-$0.57 per kWh	$2-$0.05 per kWh
Key limitations	Safety - risk of igniting	Size, cost	Safety, discharge rate, heat requirement; monitoring needed	Safety, low efficiency

Figure 3.3-19 Technical characteristics of the most advanced battery technologies [3.53]

As can be seen, there is not one type that satisfies all the ideal requirements: i.e. Flow batteries – as will be explained – have significant cycle life and longer storage duration but are not as efficient as Li-ion ones. On the other hand, Sodium Sulfur have safety issues and a considerable discharge rate.

Lithium-ion batteries have been heavily adopted in electronics, and because of this the Compound Annual Growth rate (annual growth rate of investments over a specified period longer than one year, CAGR) was 5% for the past decade and a half. EV deployment might spur a CAGR of 42% for the next decade based on EV penetration forecasts. To date, research on Li-ion batteries has covered the short-duration grid application whereas there are Li-ion chemistries that can ensure larger-scale and longer-duration applications. The different types of Li-ion batteries are shown in Figure 3.3-20, where a comparison in specific energy and energy density is presented.

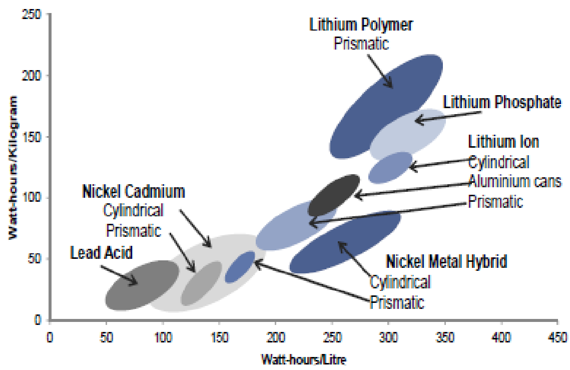


Figure 3.3-20 Energy density and specific energy of different types of Lithium-Ion batteries [3.53]

As shown, Lithium Polymer and Lithium Phosphate ensure high specifications on both sides whereas other types are behind. In Figure 3.3-21, the technical characteristics of common lithium-ion technologies are listed.

	Lithium Titanate	Lithium Nickel Cobalt Aluminum Oxide	Lithium Iron Phosphate	Lithium Nickel Maganese Cobalt Oxide	Lithium Manganese Oxide
Specific energy (capacity)	70-80Wh/kg	200-260Wh/kg	90-120Wh/kg	150-220Wh/kg	100-150Wh/kg
Cycle life	3,000 - 7,000	500	1000-2000	1000-2000	300-700
Thermal runaway	Among the safest Li-ion technologies	150C (302F) typical, high charge promotes thermal runaway	270C (518F) Typically safe regardless of charge level	210C (410F) typical. High charge promotes thermal runaway	250C (482F) typical. High charge promotes thermal runaway
Applications	Distributed storage, EVs	Medical devices, industrial	Portable and stationary	EVs, industrial	Medical, EV, industrial
Note	Long life, fast charge, wide temperature range but low specific energy and expensive	Similar to Ci cobalt	High self discharge relative to others	Market share is increasing	High power but less capacity; safer than Li-cobalt; commonly mixed with NMC to improve performance
Industry participants		Tesla	Alees, Changs Ascending Enterprise Co, Phostech Lithium, Johnson Matthey	Umicore, BASF, Targray, Tesla Energy	Umicore, BASF TODA Battery Materials

Figure 3.3-21 Technical specifications of common Lithium-Ion batteries [3.53]

Lithium Nickel Manganese, Lithium Titanate and Lithium Iron Phosphate are adopted for EVs. As discussed before, it is essential to evaluate the costs of these batteries, which anyways are rapidly coming down. Manufacturers such as Tesla and BYD can achieve 15% of annual cost decline by the end of this decade; hence, an achievable cost range of $125-$200/ kWh is estimated by 2020. This is shown in Figure 3.3-22. As mentioned earlier, Li-ion pack price fell to $156/kWh by 2019, in line with this projection, which felt that $100/kWh would be achievable by 2023 [3.30].

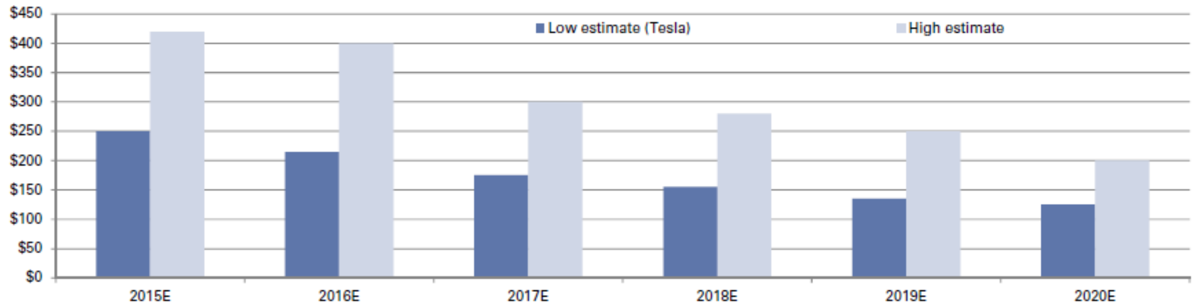


Figure 3.3-22 Battery costs by 2020 for the Lithium-Ion technology [3.53]

The cost reduction is also supported by advancements in energy density, which increase the duration of storage availability in one discharge cycle. Recently, some manufacturers have achieved values in the range of 200-300 Wh/kg: Panasonic and Tesla have accomplished 267Wh/kg for PCs and LG Chem is aiming to develop a battery with 252 Wh/kg for cars. Energy densities can be increased by switching to Cobalt, Manganese and Nickel for cathodes, like in NMC and NCA. By improving the performance of components such as anode, electrolytes, separators, energy densities in the range of 300-350 Wh/kg can be obtained by mid 2020s. In recent years the specific energy has increased to as much as 684.2 Wh/l (approx. 265 Wh/kg) [3.29]. As for the manufacturing capacities, globally there was a Li-ion battery production of 90-100 GWh in 2014 (not considering the Tesla Giga-factory which will increase these numbers by another 50 GWh), whereas the global demand for all applications (including electronics, EVs, etc.) approaches 50 GWh: there is underutilized capacity, as shown in Figure 3.3-23.

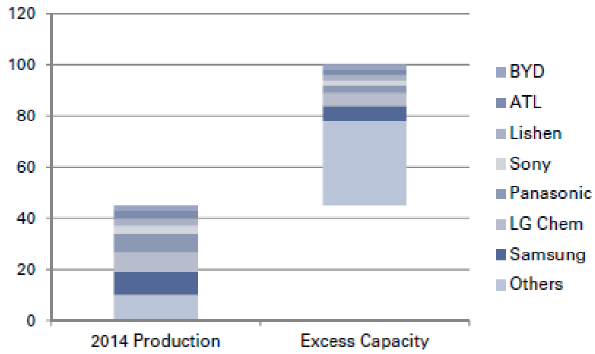


Figure 3.3-23 Production capacity in 2014 and global demand for Lithium-Ion batteries [3.53]

Another advanced battery technology is the Flow battery: two tanks of different solutions, one releasing electrons and the other receiving, are separated by a membrane. The electrons create an electrical current in a closed circuit. The energy is stored in the electrolyte and not in the electrode, unlike other batteries. Vanadium redox batteries can achieve charging/discharging cycles up to 20000 showing negligible degradation. This is shown in Figure 3.3-24 where Flow batteries are compared against other battery technologies.

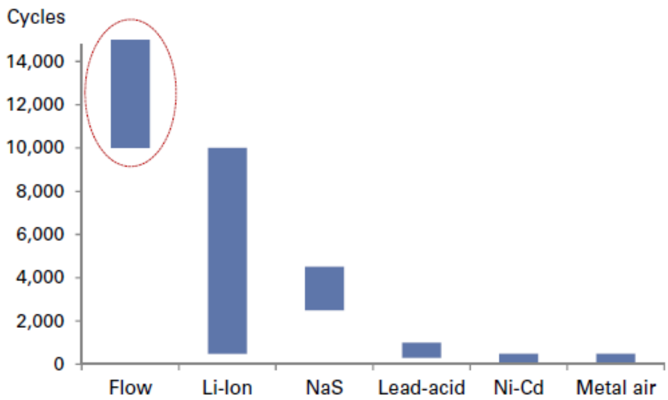


Figure 3.3-24 Achievable charging/discharging cycles for different battery technologies [3.53]

They could also be recharged almost instantly by replacing the electrolyte. Only 79 MW were installed until 2015. Their lifetime is governed by years and not by cycles, and this gives higher flexibility while planning for load variability. The energy capacity of these batteries depends on how big the tanks of electrolyte are. Because of this, they are suitable for large grid-scale applications.

The Sodium Sulfur (NaS) technology employs a Sulphur cathode and a Sodium anode in a Sodium-Alumina electrolyte. The operation is similar to Lead acid batteries, but the materials are more advanced. They are suitable for large installation, rapid response and long duration discharge (approximately 7 hours), and this makes them applicable to RES integration and grid services. They are popular for wind integration but there are not many manufacturers for this technology. There were some safety concerns in 2011 in Japan while the high operating temperature is still a concern.

Other emerging technologies include:

- Solid-state batteries, based on the Li-ion technology but they replace the liquid electrolyte with a thin not inflammable material layer. They are very safe and have higher energy density compared to Li-ion batteries but the manufacturing/cost are unproven.

- Metal-Air batteries, such as Zinc-air, Aluminium-air and Lithium-air have very high energy densities, but for the aluminium in particular a rapid degradation of the anode and a release of hydrogen gas in early models have been noticed.
- Flywheels; they have considerable cycle life, 100,000 full charge-discharge cycles according to the developers.

3.4. *Summary*

In this chapter energy prices, energy markets, balancing services and the requirements for their provision, energy storage systems and their development, and battery degradation have all been discussed. It presents how the electricity prices can merge or diverge across the territories of the EU, and how the variations are caused for various reasons: technical, political, arising from the regulatory framework (environment policies) and, mainly, the price of fuel. It can be deduced from the analysis undertaken that for energy produced from RES these kinds of variations do not take place to the same degree, although they have other issues such as the intermittency and the unpredictability of their energy production. As these factors vary, the economics of the business model will change because for grids with high carbon density the EV charging cost can vary significantly at different times of the year. Then, the different types of Ancillary Services have been introduced along with their numerous requirements, which vary according to the country considered. The most important services are Frequency Regulation, Reserve, Reactive Power Provision and Black Start. What emerged quite strongly is the diversity between the countries in terms of requirements for these services, which makes it impractical to try to fit one single business model for all. Hence, the business models will have to suit the range of grid services that are required in a given country, and indeed they will be tailored for the specific OPs - as mentioned earlier.

The payment structure includes an availability and a service payment. The availability payment seems extremely favourable for EVs, because it is not linked with the actual service provision but rather the commitment to make a certain capacity available for an agreed time. This means that in that time no actual power is provided by the EV battery, hence no degradation is caused. One previous study showed how important it is to provide a complementary group of different ancillary services to make the economics positive and how essential the services provided behind the meter are when the customer is involved and obtains some benefits. Many studies have stressed the importance of technological development in the battery storage field, and how important is to have a low battery price to make the business model profitable.

Various chemistries for Li-ion batteries are available on the market, and each one of them has its pros and cons. Therefore, there is a need of a battery model that tries to represent the most efficient Li-Ion battery technologies with a reasonable accuracy. The parameters that influence battery degradation have been enumerated in this chapter, and the consistent lack of a model that considers all of them and quantifies the related costs is perceived. The available literature shows that the study of the economics of battery degradation has been carried out in a cost function form, which was included in the equation that merges the revenues and the costs. Few studies that have optimized the charging schedules of Lithium-ion batteries to optimize the benefits have been presented: it is shown that the cost of battery degradation is fundamental in deciding whether the business model is profitable or not. Also, the appropriate handling of the charging is essential: batteries were cycled a larger number of times only when the consequent revenue was higher than the related degradation cost. SEEV4-City will address the gaps discovered in the existing literature and will develop business models that will incorporate these aspects.

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4. Energy Autonomy

The IPCC Report of October 2018 highlights the need to limit Global Warming to 1.5°C, and refers to a 'climate emergency' and the need for humankind to reduce CO2 emissions [4.1]. The August 2019 IPCC Report [4.2] noted the continuing degradation of agricultural land through human activities and that the problem of climate change is becoming more serious. Energy Autonomy (EA) can help to reduce CO_2 emissions through the use of local RES, which often includes PV and Battery Energy Storage (BES). A reduced need for energy transmission and distribution from central networks has additional benefits in reduced environmental impacts of this infrastructure and required technology [4.3]. This will only be seen by continued movement along the pathway to achieve energy autonomy, with systemic and practical efforts at local and regional levels [4.4].

Within SEEV4-City, EVs are used in a context that draws inspiration from the smart grid concept in order to improve sustainability and promote efficient energy services. To do this, EVs have to be combined with other sub-systems in order to develop an autonomous, reliable and efficient grid. Two important factors among the available options are **distributed generation** and **energy autonomy**. These two are strongly correlated because distributed generation in combination with storage systems can enable energy autonomy, which results in energy savings, cost reduction, improved efficiency due to reduced transmission/ distribution losses, deferral of grid investments and positive environmental effects such as CO_2 emission reduction. This idea can be implemented from the lowest level, such as a single household, up to an entire city that can go off grid to form an autonomous micro-grid. Whatever the scale, the common elements are the generation system (this can be diesel generators, bio fuel or RES such as hydro, solar, wind, tidal and geothermal), the electricity demand (household, street, neighbourhood or city) and the electrical storage system.

The generation system converts the energy from disparate sources, and the main aim is to satisfy the internal demand. By doing this, the grid absorption is reduced and this creates two advantages for an initial investment: the first is electricity cost reduction and the second is the potential CO_2 emission savings (since the distributed generation is likely to be RES). The investment is paid back through the electricity cost savings and subsidies for RES, in case these are adopted, and this kind of evaluation is considered in the following parts of the chapter. A certain degree of autonomy is already available, but further improvements in terms of savings and autonomy are achieved by combining the generation system with a storage system. Specifically, for RES, which are intermittent and sometimes unpredictable, a battery system stores the excess energy in periods when the generation is higher than the demand in order to return it later, when there is a shortage of electricity. EVs can, if aggregated, substitute for conventional energy storage, and let their batteries store and provide the energy. In this way, the EV becomes an integral part of the smart system. Modern Li-ion automotive batteries are more efficient than the conventional ones, which is an advantage for V2G.

However, the effect of providing V2G service on the lifetime of the battery still need to be considered. Since charging/discharging in order to provide energy for the autonomous system will tend to cause extra battery degradation, the costs of this sacrifice have to be compared against the advantage of savings and an improved energy autonomy. In this chapter, studies conducted on micro-grids and distributed generation, which aim to optimize energy autonomy, will be presented. Particular emphasis will be given to the correct definition of energy autonomy, as this will determine the resulting outputs which will have to satisfy the SEEV4-City targets. The factors that influence the overall energy autonomy, self-consumption or the self-sufficiency will be presented, and it will be explored how changing these aspects causes the outcomes to vary.

Therefore, this chapter addresses the following research questions:

- What is the suitable definition of energy autonomy or self-sufficiency within SEEV4City?
- What are the parameters that are involved in energy autonomy?
- In which way are variations of the considered parameters reflected in changes of autonomy?
- How much do the parameters need to vary to reach the saturation of the energy autonomy?
- What are the interventions that increase energy autonomy?
- In which time scale should energy autonomy be calculated based on the defined boundaries of a system?
- How is Energy autonomy translated in monetary terms and in CO_2 emission reduction?

This chapter attempt to answer these questions by giving a review of the methodologies, assumptions, definitions and the results of some studies available in literature and brings them in the context on SEEV4-City.

4.1. *Relevant studies*

A combination of central and local power generation offers a framework within which money may be saved and energy from renewable energy sources (RES) used more fully, since some renewable energy can often be consumed at the point of generation and a surplus can usually be exported via the grid. In this way, security of supply can also be enhanced. A general review of EA may be found in [4.5].

In [4.6], a comprehensive framework for conducting economic analysis of a residential house along with the integration of solar PV units and BESSs is presented. The analytical framework is developed by considering a generalized tariff structure, which can accommodate any tariff within the electricity bills. The option of selecting tariffs from different tariff structures would allow residential consumers to choose the right one based on their requirements. Grid independency and reduction in CO_2 emissions of the residential building are also calculated. These analyses and calculations are conducted for an Australian house by considering both standalone and grid-connected operating modes. Sizes of PV and BESSs are varied. Energy can both be sold to and purchased from the grid with rates that can be flat rate or time-of-use tariff. Economic evaluations of installing solar PV and BESSs are characterized through the following considerations: investment cost, replacement cost, electricity bills, simple payback period, Net Present Value (NPV), Discounted Payback Period (DPP), levelized cost of energy, reduction in CO_2 emission and grid independency.

The economic evaluations are carried out based on Australian energy markets and five different sizes of solar PV units are considered in this paper which are 3 kW, 4 kW, 5 kW, 8 kW and 10 kW and the corresponding battery sizes for the PV units are 4 kWh, 5 kWh, 6 kWh, 10 kWh, 12 kWh, respectively. It results that both investments costs and saving in electricity bills increase with the sizes of PV and BESS. Payback periods are smaller for the options with smaller sizes. Replacement costs are much higher for PV and BESSs compared to PV only. The main reason is the lifetime of the BESS, which is 2.5 times less than that of the PV unit. Moreover, the replacement costs are increasing with increases of the capacity of the PV unit and the BESSs. The payback period results greater than the lifetime of the project for some of the options: the two biggest sizes of the PV in the standalone case and the same is for the PV and BESS in standalone mode. This happens again for the grid-connected operation of PV unit with BESS. The Net Present Value (NPV) is positive only for the 3 smallest sizes of the PV unit for the grid-connected operation only and is negative for all the other cases. The discounted payback period is calculated only for the mentioned cases of positive NPV. The NPV and the DPPs clearly indicate that the grid-connected solar PV units with smaller capacities are more viable options to invest on solar PV system. The obtained levelized cost of energy is around 0.1 $/kWh for the solar PV unit only and between 0.25 $/kWh and 0.3 $/kWh, it is equal for the standalone and grid-connected operation modes and does not change with the tariff. In Figure 4.1-1, the achieved reduction in CO_2 emissions are shown.

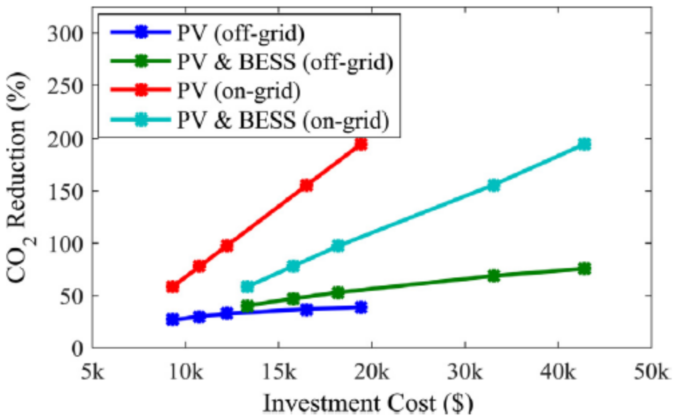

Figure 4.1-1: Sensitivity of the reduction in CO2 emissions against investment costs [4.6]

As can be seen from the general trend, the higher the investment more CO_2 emission reduction is achieved. From this point of view, in a business model the achieved CO_2 tax savings should be compared against the investment made and other benefits, such as savings from a lower grid absorption due to a higher self-sufficiency rate. In Figure 4.1-2, grid independency is compared against the required investment.

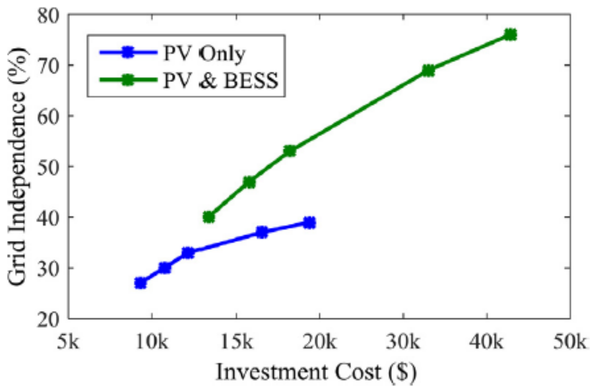

Figure 4.1-2: Sensitivity of the grid independency against investment costs [4.6]

The higher the investment, thehigher is the level of the achieved grid independency. At the same time, the investment is more profitable, which means that it allows a higher grid independency if PV is combined with BESS. Grid independency is here defined as follows:

$$Grid\ Independence = \frac{Total\ Yearly\ Energy\ Savings}{Total\ Yearly\ Demand} \times 100\% \quad (1)$$

According to this study, since the feed-in tariff rate is declining, the payback period can be improved by selling the excess energy to the neighbours with the development of a power sharing framework among the neighbours through a micro grid and conduct similar analyses. This is essentially Vehicle to Neighbourhood, which has not been considered; grid support can constitute another revenue stream. Although the research presents interesting conclusions in terms of investment studies, CO_2 emissions and grid autonomy, the developed cost analysis addresses only this specific case and no flexible business model that analyses future and different scenario is developed. Services behind the meter, e.g. PV-self consumption and energy bill reduction, are increasingly gaining relevance as subsidies for RES are systematically phased out [4.7].

The reduction in the costs of PV can make EA economic at a local level. Levelized Cost of Energy (LCOE) of PV generation in Germany is about 12 €ct/kWh, which is less than the German domestic electricity charge (about 30 €ct/kWh) [4.8]. In the UK, the average domestic electricity price in 2018 was £0.151/kWh [4.9]. Assuming German levels of cost of PV generation, EA is now potentially profitable in the UK.

In [4.10], a model-based study of Micro Grids (MGs) that consist of solar generation and battery storage shows the relationship between system autonomy and battery utilization applied to multiple demand cases. In this study, an assumption is that the MG demand will never exceed its load, and that the storage does not charge and discharge when the price is low or high respectively. Four different types of demand were studied: trapezoidal, parabolic, constant and sinusoidal. The generation source is sized in a way that it can produce the daily energy required. It is assumed that battery can safely undergo 100% DOD without side effects, although it is not practical. For solar irradiation and power generation from panels perfect half sine curves are used and scaled depending on the length of the day. For the battery, they use a Single Particle Model (SPM) that approximates the dynamics of a battery's porous electrode with a single particle for each electrode while incorporating battery kinetics; it is essentially a chemical model. The parameters that have been utilised are: the ratio between Battery Energy Capacity and Solar Energy Capacity (BCSC) that measures the energy storage capacity of the battery, in relation to the amount of energy supplied from the solar array during a day of 12h solar insolation and the ratio between the Maximum Power Demand and Maximum Solar Power Output Ratio that measures how the power demand relates to the power output of the solar array (MDMP). It results that including storage within the system will increase the autonomy, but the energy capacity of the battery will determine how much the autonomy changes. As battery capacity increases, autonomy will increase, but only to the point where the power demanded exceeds the combined capacity of the solar array and battery. The shape of the MG demand affects the autonomy and battery utilization. Figure 4.1-3 shows the autonomy and battery utilization for the four different types of demand curves with the MDMP Ratio normalized on an energy supplied basis (with the same amount of energy demanded).

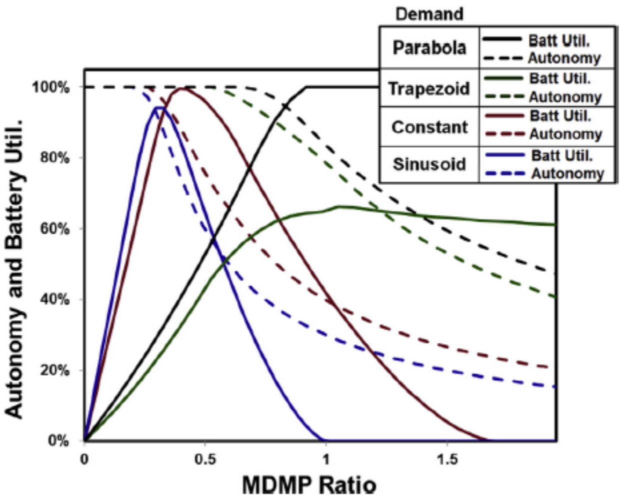

Figure 4.1-3: Autonomy and battery utilization of each of the four demand types for the same system size (BCSC) [4.10]

When the demand exceeds the solar output, the battery utilisation is at the maximum with the parabola load, around 60% with the trapezoidal, whereas it reaches the peak for the constant and sinusoidal load in proximity of MDMP=0.5. Although these load profiles are not realistic, it gives an idea about the impacts of different load shapes on the autonomy. Autonomy and battery utilization were affected by the time of demand, with the battery utilization being more linear for demands that are not coincident with solar insolation. It results that autonomy and battery utilisation cannot be maximised simultaneously in most cases. One assumption is that increased battery utilization is always beneficial in the lifetime effectiveness of a battery system; this goes against the findings from Chapter 3 about battery degradation. Achieving the highest battery utilisation is considered beneficial for system economics, although no quantification of the battery degradation is considered. No clear definition of energy autonomy is provided in this study.

In [4.11] a Mixed Integer Linear Program (MILP) is employed to assess the effects of aggregation across different scales that are individual buildings, neighbourhoods and districts, on the economics of energy autonomy in residential buildings. The model minimises the total energy costs over the life-time of the energy system, including Micro-Combined Heat and Power (MCHP), PV, thermal and electrical storage, and boilers, at five distinct scales and for nine demand cases. The total annual cost per household determined as the least costly option among the results for the given levels of electrical self-sufficiency decreases with an increasing number of households within the building cases. The optimal degree of electrical self-sufficiency, corresponding to the least-cost solution, increases with an increasing number of households in a monotone way:

- The **Degree of Self-Sufficiency** (DSS_{el}) is calculated as the **ratio** between the **electricity production for internal use** for direct consumption or charging battery storage from both CHP and PV and the **demand for electricity**.
- The **Self-Consumption Rate** (SCR_{el}) is defined as the **ratio** between the **electricity production for internal use** for direct consumption or charging battery storage from both CHP and PV and the **electricity production for internal and external use** from both CHP and PV.
- The **Degree of Electrical Autonomy** (DA_{el}) defined as the **ratio** between **DSS_{el} and SCR_{el}**.

From Figure 4.1-4 it is clear that the optimum level of self-sufficiency increases with the number of households. According to the curve fitted to the data, above 560 households it is economically advantageous to make a district 100% self-sufficient.

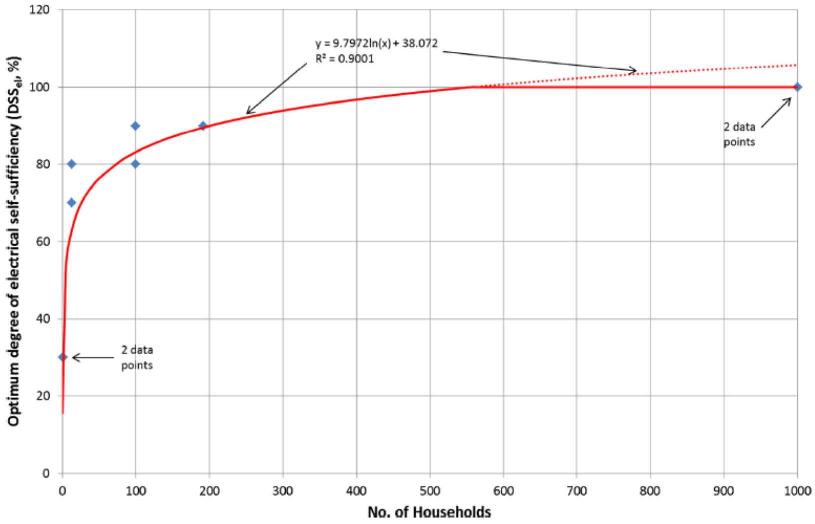

Figure 4.1-4: Self-sufficiency against the number of households [4.11]

For the Single-Family House (SFH) demand cases, the value of DA_{el} is consistently higher than that of the DSS_{el}, lying to the upper left of the dashed line in the figure. In general, at higher scales, such as 100 SFHs or 1000 SFHs and especially for the Multi-family houses (MFHs), the value of DA_{el} is reduced, therefore it is closer to the value of DSS_{el}. The reasons identified for this effect are: a larger number of households imply an increased demand for electricity and heat in absolute terms and the households benefit from economies of scale for the energy supply technologies, a reduction in demand fluctuation, a smoothing effect and a reduction in peak load due to the superposition of the individual profiles. Consequently, the generating technologies can operate in a more uniform way, reaching a higher number of operating hours per year. It is likely that an additional consideration of demand side measures for energy efficiency and/or demand side management would modify the results encountered although this kind of operation has not been considered.

Following the previous analysis, some environmental and economic considerations are presented: even abolishing the financial incentives on in-house PV electricity consumption, and moving to a system of network fees based on the amount of installed capacity instead of the energy utilized, under the energy-political framework in Germany it is likely that, with lower specific investments in batteries in coming years, the maximization of in-house consumption will become economically attractive and the cost of generation and storage would still lie significantly below the cost of electricity for end users. A sensitivity analysis is carried out. The results show a very weak sensitivity of the total annual household energy costs to the electricity price: a 60% change in the latter results in less than 1% change in the former. Stronger sensitivity is shown to gas price: 60% change brings 7% change of costs. Changing the investment cost for batteries and PV has the strongest sensitivity for the PV, where 50% reduction results in a 3% reduction in costs. In this paper, the degradation effects for the battery systems have not been considered and it is assumed that the local energy infrastructure is able to assimilate the respective energy flows, while in practise there is a capacity constraint on these energy flows.

In this case, a slightly different definition of energy/ electrical autonomy is presented in function of the number of households, which seems to be in line with the previous study where the investment was considered. This is because the investment can be considered proportional to the number of installations in the houses. Besides, in one case the energy autonomy is the ratio between the yearly energy savings and demand, whereas in the other case it is the ratio between the electricity production and the demand. If the savings are considered proportional to the production then the two definitions are equivalent.

4.2. *Methodology and assumptions*

It is essential to adopt a common definition of energy autonomy that can be extrapolated in two definitions: self-consumption and self-sufficiency [4.12]. The absolute self-consumption is the part of the load that is satisfied by the RES generation, but often a relative definition for both parameters is preferred. Figure 4.2-1 helps to understand the various definitions.

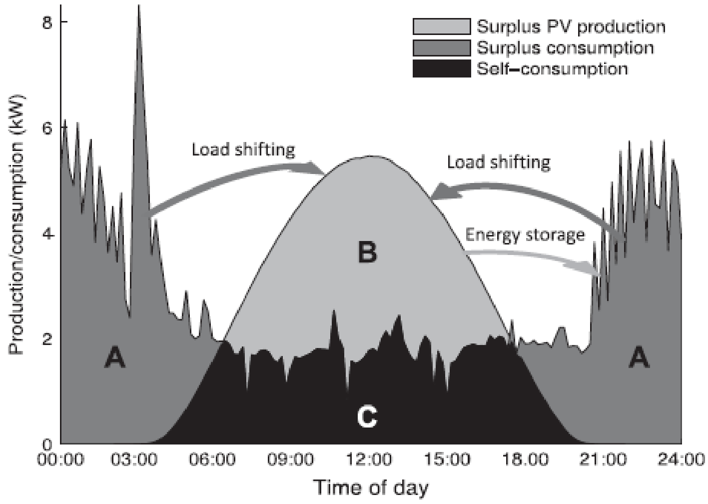

Figure 4.2-1 Load profile, PV generation and self-consumption [4.12]

The self-consumption is therefore, the absolute self-consumption which is the overlapping part between generation and consumption, relative to the total RES generation. This is show in the following equation:

$$Self - consumption = \frac{C}{B+C} \quad (2)$$

Another interesting parameter that explains if the generation can satisfy the load, is the self-sufficiency, as depicted in the equation below:

$$Self - sufficiency = \frac{C}{A+C} \quad (3)$$

The ratio Self-consumption/Self-sufficiency, which determines the ratio between the load demand and generation, is relevant because it determines the relative values of achievable self-consumption and self-sufficiency for that particular system. The factors that influence self-consumption and self-sufficiency are:

- Relative sizes of RES generation and demand; if the generation increases, the self-consumption decreases whereas the self-sufficiency either increases or remains unchanged; when the self-consumption corresponds to the self-sufficiency, or in other words, the generations is equal to the load, a Net Zero Energy Building (ZEB) is achieved.
- Time resolution is important because a lower resolution leads to an overestimation of the self-consumption because the fluctuations are averaged, thus, part of the mismatch between generation and load is not considered. Besides, the appropriate billing period, according to the situation that has to be investigated, should be used: if an instantaneous time frame of 15 min is used then the resulting self-sufficiency will focus only in that period losing the insight on what is happening in other moments. Instead, if a net metering in a year basis is used, then the overproduction during summer is compensated with the overconsumption during winter, and by doing so, a deep insight is given up in favour of a different view in terms of overall self-sufficiency.

- Number of archetypes: the generation and the load profiles of an ensemble of buildings can have random coincidence, therefore the effect of different loads can be tamed in this kind of combinations.

To increase the self-sufficiency and the self-consumption there is a number of actions that can be undertaken. The self-sufficiency is already improved with just the installation of a PV system in a household; but of course, the aid of a battery system increases the achieved level of self-sufficiency. Storage technologies, as afore-mentioned, are a valid method to improve self-sufficiency and a diverse variety of technologies such as, Batteries, Fuel Cells, Pumped Hydro Storage, Flywheels, Compressed Air Energy Storage (CAES) and Super Capacitors can be adopted. An interesting and relatively economic method is the Demand Side Management (DSM), which is the control of the consumption in order to modify the shape of the load profile to match the generation.

When self-consumption is evaluated, the electrical losses do not have to be counted because it would increase the numerator more than the denominator, causing a wrong overestimation of this parameter.

This study analyses previous works that evaluated actions, undertaken to increase self-consumption. They have considered a storage capacity of 0.5-1 kWh/ kW PV that leads to the conclusion that the storage is not used for the whole day; this is mainly due to the current high cost of the batteries. The studies found self-consumption increased in a range of 13% to 24%. An important observation is that an increase on the battery capacity, normalized in respect with the rated PV power, causes and increase in self-consumption, although this growth is not linear. This can be seen in Figure 4.2-2.

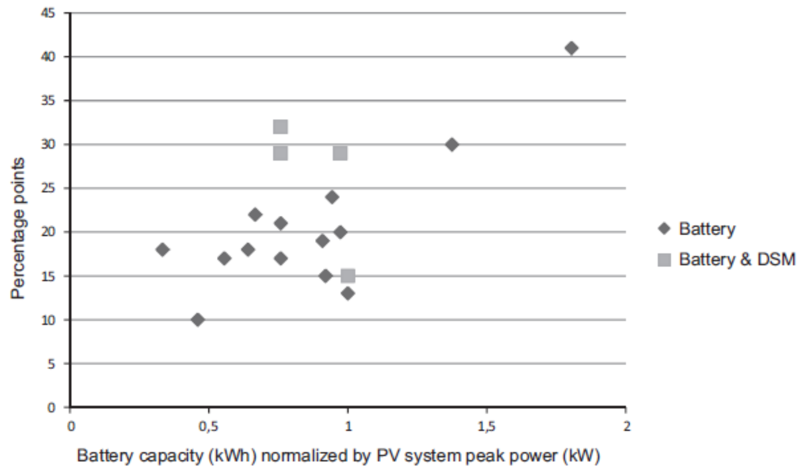

Figure 4.2-2 Increase in self-consumption due to battery system and DSM [4.12]

As can be seen, DSM provides a higher energy self-consumption although no clear trend has been noticed: 29-32% of increase compared with a system with only PV and battery storage. Applying only DSM provides an increase in energy self-consumption of 2-15% according to the size of the PV system. When applying measures to increase self-consumption, it has to be borne in mind that the more the current level of self-consumption is high, the more difficult is to rise it.

The control strategy of the storage system or DSM also affects the level of self-consumption that can be achieved: if the battery is charged simply when there is a surplus of PV production and discharged when the consumption is higher, part of the peaks is not reduced. On the other hand, is better to use the storage in a way to address the peaks as can be seen from Figure 4.2-3.

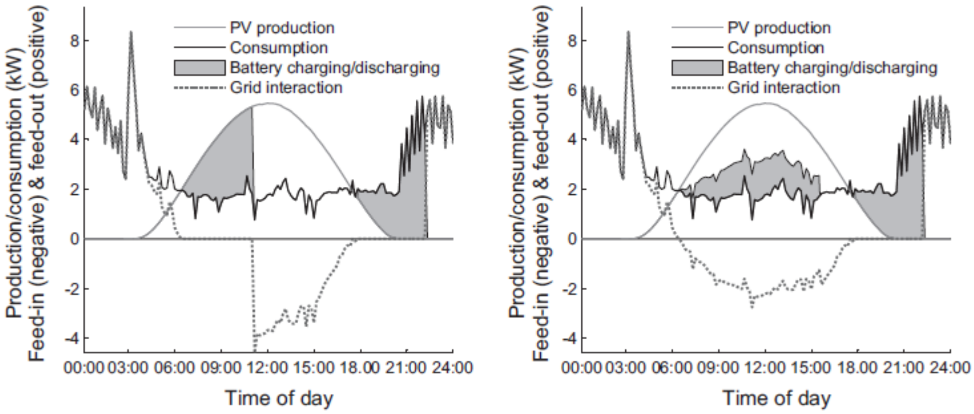

Figure 4.2-3 Different control approaches of battery systems and consequent peak reductions [4.12]

As can be seen, in the second case - when the storage is not filled just when there is surplus in PV production - the peak is reduced and the grid interaction is optimized: this requires a weather forecast. This is exactly where smart charging for EVs, aimed to decrease the interaction with the grid, can intervene. Also, the effects of the local climate impact on the self-sufficiency: for instance, in cooler regions, the energy is used for heating, specifically in winter when the PV production is low, so the self-sufficiency is low. In warmer regions, the energy is used for cooling and this corresponds with the highest PV productions.

Another study evaluates the influence of social-economic and technical behaviours on Energy Autonomy in Social communities [4.13]. Here, the energy autonomy or energy self-sufficiency is defined as the "ability of an energy system to function (or have the ability to function) fully, without the need of external support in the form of energy imports through its own local energy generation, storage and distribution systems". The main issues that influence energy autonomy are:

- Degree and scale of energy autonomy;
- Matching demand with supply;
- The importance of socio-economic and political factors.

In the first instance, the scale of the system determines the number and range of the stakeholders that are involved, the available resources and the available decision-making processes, but in detail these depend on the site where the system is located. Moreover, the motivation of achieving energy autonomy has to be compared with the financial and technological barriers; for instance, a street will be able to reach a certain level of self-sufficiency, and fetching more will mean an increase of the investment against limited advantages, because the grid connection is available and allows a cheaper energy provision. On the other hand, although island operation provides the biggest motivation to achieve a high degree of self-sufficiency, these systems have to be operated at high costs and level of uncertainty. Hence, with a grid connection available, there is an appropriate level of energy autonomy that can be achieved, which balances the possibility of unnecessary financial disadvantages with the benefits of an increased energy autonomy.

Again, two options for the matching of demand and supply are mentioned: storage systems and Demand Side Management (DSM). The storage, usually represented by batteries, are used to eliminate or at least minimize the mismatch between PV production and demand. Because the grid connection is available, the grid itself can be used as a storage: when there is PV surplus, the extra energy is transferred to the grid as opposed to when there is PV stagnation, and the demand is satisfied with the energy absorbed from the grid. However, this has a major drawback: the grid can be negatively affected by the injected energy, which, therefore, is not always useful. The battery allows to have local storage/energy availability and to utilize it without losses. Although on one hand the grid is managed and maintained by external parties, on the other hand the cost of the small-scale energy storage system has to be borne by the community that adopts it.

DSM is identified as an economic and easy way to achieve a certain level of energy autonomy. It delays (or even removes in some cases) the necessity of a new generation plant by exploiting the existing local generation. This also increases the lifetime of the existing technologies. Nevertheless, DSM implies a change in user behaviour and this can be challenging because it has to be appropriately identified what is “needed” and what is ‘required’. Thus, the social aspects are also involved as most of the applications that involve user participation: an appropriate education on the correct usage of the technology and a wide understanding is essential to bring behavioural change. In fact, some studies have shown that, if users are aware of the benefits that renewable energy development can bring to the local community, they are less resistive to them. This is because the sustainability and renewable energy development actions are seen in a positive view if the stakeholders are involved. Moreover, willingness shown for small scale local developments is twice as high compared to the willingness shown to large scale developments. The lack of government support for local community projects, the difficulties to enter the market and network connections are identified as major barriers for community projects, as opposed to financial incentives, support systems and training/education systems that foster user engagement. Successful examples of community projects can provide some motivation for the uptake of new projects at a local scale.

4.3. ***Summary***

In this chapter, the topic of Energy Autonomy has been introduced and discussed. Some studies that deal with this have been presented and useful definitions for self-sufficiency, self-consumption and grid independence have been highlighted. A frequent scenario for a distributed generation system is one that includes a PV system and battery storage. It is well known that having a RES (PV) system already gives some degree of self-sufficiency but it has been pointed out that the two ways to increase energy autonomy are through a storage system and/or with the adoption of DSM. The former implies some significant investments, and studies have shown that the higher the investment in storage capacity, the higher is the achieved grid independency. The same argument applies to the achieved CO_2 emission reduction.

The degree of achievable grid autonomy depends also on the shape of the load curve for various times of day and seasons: one of the studies simulated disparate load curve shapes, and found that the conditions for maximum grid independency are reached differently for different load curve shapes. This also depends on the scale of the system: the higher is the number of elements of consumption and generation involved, the higher is the achieved self-consumption (autonomy). Although this relationship is linear in an initial phase, which means that there is a proportional increase in the grid investments with increasing number of households, it reaches a saturation point after an optimal number. Moreover, the right time scale is essential for a correct evaluation of energy autonomy, because a long interval will lead to inaccurate calculations whereas shorter intervals will require more calculations; the same can be applied for the billing period: if instantaneous billing is adopted then the compensation of the lack of PV generation in winter with the overproduction in summer with net metering is not considered.

Finally, DSM has been indicated as the most economic and easy way to achieve higher energy autonomy, although when it is paired with a battery system a higher level of energy autonomy is achieved. Besides, if there is already a high level of energy autonomy, increasing it is more difficult and this requires considerable investment. The importance of a suitable definition for energy autonomy is once again stressed because in order to calculate this parameter within an OP, a coherent definition is essential. Energy autonomy can be linked with the achieved CO_2 emission reduction because they both depend on the energy produced by RES which represent clear savings in CO_2 emissions when compared with fossil fuel technologies.

4.4. ***References***

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5. Impacts of EVs and RES on Electricity Grid

This chapter discusses the potential impacts of EVs on the electricity grid. The widely distributed location of the connections of EVs to the grid results in complex and interlinked technical and economic impacts, which need to be adequately analysed and clearly defined. In the coming years, it is anticipated that most conventional ICE vehicles will be replaced by EVs that have large batteries with different capacities and demand for electricity from the grid. According to the IEA Global EV Outlook 2019 [5.3], global EV/PHEV stock is on a trajectory to exceed 200 million by 2030, and the World Nuclear Association predict that the stock will rise to “one billion by 2050''. The charging of all these EVs needs to be accommodated, and this requires considerable investment in grid reinforcement. In other words, the ability to rapidly accelerate widespread EV adoption will be determined to a large extent by the capability of the local electricity network to supply the required power to charge these vehicles. Other important considerations are: the energy needed to charge the vehicle is better generated locally or have to be transmitted all the way from central generating plants via the transmission and distribution networks; secondly, the period in the day in which EVs are charged; and finally, the various charging durations. Charging the vehicle during peak hours should be avoided, as the grid may be easily overloaded.

In this chapter, the charging variables that determine the impact caused by EV charging on the grid will be considered; among these there are, the structure of the grid, the load profile, the EV penetration level, the charging level, the timing and the period during the day in which the EVs are charged. A number of projects that addressed this topic along with their results are also presented. Another equally relevant issue is the impact of PV systems on distribution networks and, as it will be explained, this depends on the size of these systems. This chapter focuses on the following research questions in the context of the objectives of SEEV4-City project.

- What are the main consequences of bulk EV charging on the grid?
- What are the main parameters that influence the impact?
- What are the most critical time slots during the day in terms of peak power?
- Which are the grid components that are affected by a significant EV penetration level?
- What are the solutions to these issues?
- How can these impacts be quantified within SEEV4City?
- How can EVs mitigate these issues?
- What are the effects of PV systems on the grid and how can EVs minimize them?

5.1. *Impacts of EVs*

Impacts on the generation side

As explained in Chapter 3, a typical power system structure consists of a generating station, a transmission network and a distribution network. The additional energy required for EV charging must be produced by the generation side, which primarily consists of a blend of base and peak load power plants and other renewable energy generations – such as wind and solar farms. The supply and demand profile should always be matched, continuously and instantaneously with respect to time and frequency; this is an optimal and desired base case. Supply and demand profile can be matched with proper execution of load dispatch mechanism; however, it can be very difficult to predict a precise demand requirement as there are always variations in the daily load. Thus, the power plant may or may not work in an optimal operating efficiency; as the load demand does not always coincide with generation, the difference between the load and generation is offset by the use of an additional generation unit, such as a coal power plant, or power plants based on gas. This unit takes care of the fluctuating or increasing demand. As the demand increases, generation capacity should also increase; consequently, this creates a need for one more additional generation unit in the existing system. Additionally, increase in the penetration of EVs will amplify the uncertainty of the mismatch in supply and demand in future. Infrastructural upgrades will be necessary and the installation of a new generation plant may also be demanded. Another aspect to be considered is the generation cost: additional usage of even one generation unit creates technical and economic burden on electricity generation power plant. At present, most vehicle fleets can be charged using existing power plants, but these power plants will be loaded heavily for a significant part of the day. The increase in time when these generators work at full power increases the operational costs and some of the generators may even not be optimally loaded which creates inefficiencies. In the future, EVs may reach a penetration level so that they will determine the number of times the power plants must be switched on and switched off if well-timed measures are not undertaken.

Impacts on the distribution grid and its components

Distribution systems are normally designed for specific load-carrying capacity, based on a typical consumption pattern. EVs affect the distribution grid based on their charging characteristics, which are represented by charging times and power levels. Even with a minimal penetration level of EVs, there will be a huge influence on the supply quality and grid capacity. Fast charging of EVs needs the delivery of the required energy in a short time interval, usually in a range of minutes, which results in high charging powers and high system losses. The high charging power demand from several EVs can produce **pulsating loads** in the system, which lead to **voltage flickers** in the distribution grid and affects **transformer loading** as well. This can also cause overheating of distribution transformers and cables, which in turn causes early degradation of these components. Fast charging will have impacts on the **system bus voltage** profile.

The magnitude, location and distribution in time of the charging will determine whether the power plant should generate additional energy to charge the batteries of EVs. These vehicles could add local/ regional constraints to the distribution grid. Simultaneous charging from the same location can create burden on the low voltage grid, under which it will not be able to handle this situation within acceptable limits – this will have major impact on local infrastructure and peak demand. Therefore, it is necessary to know from which penetration level of EVs, devices like the substation, transformer and feeders become overloaded. However, overloading of a distribution transformer may not result in device breakdown completely, but the life span of the device will be reduced significantly.

The charging profile influences how the distribution system is impacted as it partially determines daily and annual EV loading patterns. Figure 5.1-1 represents the charging profile, for different charging rates, over time.

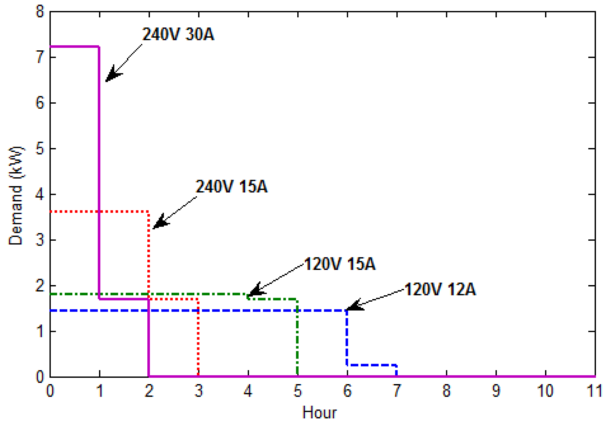

Figure 5.1-1: Charging profile varying over time [5.1]

The charge profile or electrical demand over a certain period is influenced by the battery efficiency, size, charge type and miles driven by the vehicle. The charging profiles can be of two types:

- An **uncontrolled charging profile**, as the name indicates, is one which the time of charging of the EV battery is not controlled, so it starts immediately after the EV reaches its destination assuming that this location is equipped with charging infrastructure. This can give rise to EVs being charged at sub optimal times, such as 6.0 p.m. when demand from other loads starts to peak. The impact of uncoordinated charging of batteries has impacts on the performance of the distribution leading to power losses and voltage deviations and power quality issues for different charging periods and penetration levels.
- **Controlled charging**, when the time of commencement of charging is coordinated to suit system requirements, has fewer impacts compared to uncontrolled charging. If coordinated charging is being carried out, the power losses are significantly reduced compared to uncontrolled charging. This can be done using smart metering systems.

When an EV is charged from the electricity grid, a voltage drop occurs at that point in the distribution grid. When a large number of EVs are charged simultaneously at a certain time, this effect is compounded, and basic **voltage-regulating** equipment will not be effective.

Different strategies are therefore required to avoid potential damage and impacts of increasing number of electric vehicles on the grid. The first is the improvement and expansion of the existing infrastructures – which requires high capital investments, whereas the second is the deployment of smart grid technologies with intelligent charging options - i.e. charging batteries at off peak periods or when the charging cost is less. In the latter case, the EVs can be considered as dispatchable loads to reduce the cycling of power plants to realize more constant power outputs.

All distribution grids are dimensioned to a given extent and capacity to ensure regular operation, but increasing demands can upset the grids, and they may operate at maximum capacity. Therefore, to overcome this overloading problem the distribution grid has to become active and more efficient. And smart charging can be a solution to use the distribution infrastructure more efficiently.

For EVs there is also the V2G concept – energy is stored and supplied if the load or the grid needs it. It allows to use the grid more proficiently and optimize the use of the feeders. This can be achieved by employing intelligent smart meters and active elements.

In the National Grid's Future Energy Scenarios 2019 report [5.2], four scenarios are presented, as discussed in Chapter 2.2. Figure 5.1-2 shows the annual projected energy demand expected for the four scenarios.

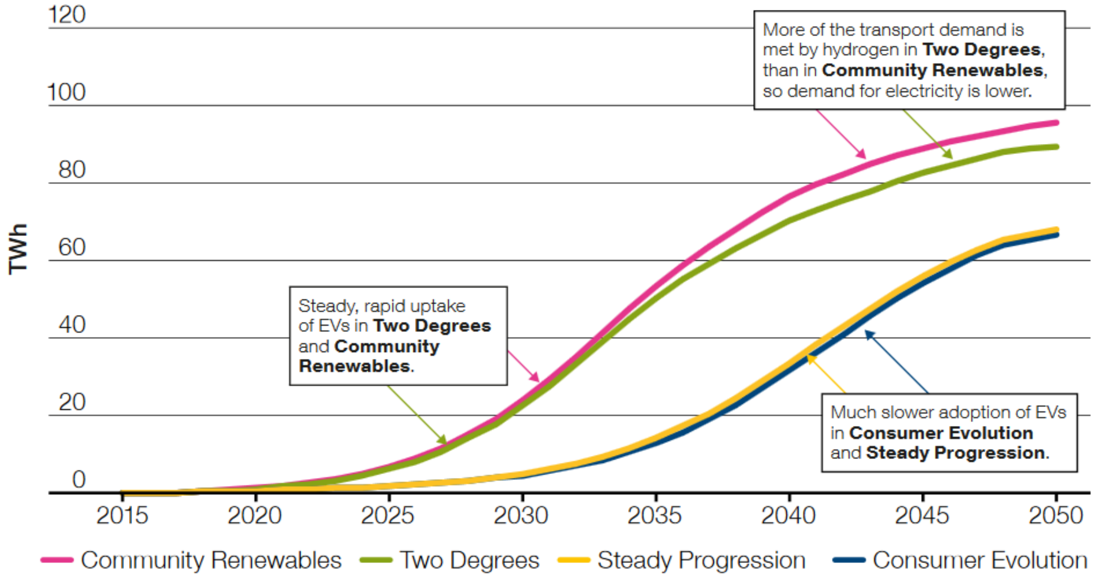

Figure 5.1-2 Annual energy demand for EVs for the four scenarios [5.2]

As can be seen in Figure 5.1-2, in the *"Community Renewables"* scenario, almost all road transport is powered by electricity by 2050; however, some hydrogen or natural gas is still used by vehicles which do very high mileage, or carry very heavy loads. Limitations in battery capacity could prevent their use of electricity, even by 2050. The hydrogen in this scenario is generated via localised, smaller-scale production using electrolysis. This is of sufficient purity to be used directly by road transport. In the *"Two Degrees"* scenario, most road transport is electric powered by 2050, but with more hydrogen used for heavy duty vehicles with greater access to hydrogen produced at scale either via electrolysis or via methane reforming with carbon capture, usage and storage (CCUS). Hydrogen produced via methane reforming/ CCUS typically requires additional purification before use in fuel cell vehicles. The *"Consumer Evolution"* and *"Steady Progression"* scenarios see a much slower take-up of alternative fuels, with most car users retaining their petrol or diesel vehicles until after 2030.

In these scenarios, over four million petrol or diesel vehicles are still in use by 2050, with most of those being vans and motorcycles. Heavy goods vehicles (HGVs) switch away from petrol and diesel to natural gas. In the *"Two Degrees"* and *"Community Renewables"* scenarios, we no longer expect plug-in hybrid EVs (PHEVs) to be used as a stepping stone to battery electric vehicles (BEVs).

Changes in the Government's plug-in car grant scheme encourage the purchase of lower-emission vehicles than PHEV. These scenarios assume no new conventional petrol or diesel cars are sold after 2040, and by 2050 no petrol or diesel cars remain on the roads. There have been improvements in diesel emissions, and the additional costs to this two-step approach are recognised. Some vehicles may use natural gas, but this will be kept at low levels by the availability of other low-carbon fuels and as part of a transition to renewable/green gas. Regarding the electrification of heavy use, long-range vehicles, potential solutions include electrification of sections of roadway, with overhead systems similar to those used by railways. Another approach could include an electric rail built into the roadway, to which the vehicle can connect. Currently the cost of hydrogen refuelling appears more viable. Given the uncertainty associated with these immature technologies they do not currently feature in the above four scenarios.

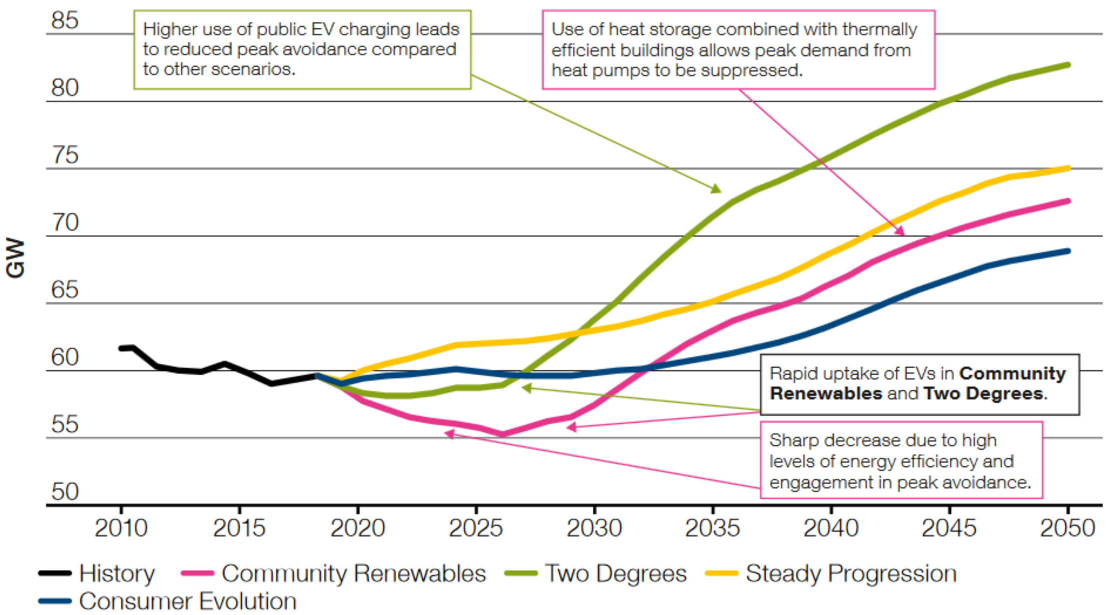

Figure 5.1-3 Increase in peak demand caused be EVs in the four scenarios [5.2]

At present, the highest demand for electricity, called 'peak demand', is generally on a winter weekday evening at around 5:30 p.m. As the adoption of technology like smart meters and smart devices increases, the daily demand profile may change as flexible demands like electric vehicles (EVs) take advantage of cheaper prices when system demand is lower or renewable output is high. Underlying peak demand is currently around 60 GW. Moving further into the future, the effects of electrifying first transport and then heat become apparent as these outweigh the improvements in energy efficiency and peak avoidance. EV growth is highest in Two Degrees and Community Renewables and, even though they also have the highest energy efficiency and peak avoidance, demands start to increase as a result of consumers who do not use smart charging buying EVs.

Decentralisation also plays a large role in avoiding charging at peak. In the *"Two Degrees"* and *"Steady Progression"* scenarios, there is far more centralised charging of EVs which restricts peak avoidance as consumers want to charge there and then. In the "Community Renewables" and "Consumer Evolution" scenarios, there is more decentralised residential charging which is more suited to smart charging. In terms of heat, thermal storage and insulation suppress peak electricity demand in the "Community Renewables" scenario while, across the scenarios, increased use of hybrid heating means that other fuels provide heat energy during peak electricity demand.

Key findings:

- Impact of EVs on the electricity grid depends on:
    - The intensity/ magnitude of the EV penetration;
    - Charging time of the vehicle [peak or off peak];
    - Duration of the charging of electric vehicles [slow or fast charging];
    - Power system infrastructure;
    - Load and demand management;
    - Renewable energy mix contribution;
- This also impacts the reliability of the power system.

5.2. *Relevant projects and case studies*

***1. PlanGridEV project* [5.4], [5.5]**

Introduction and Objectives:

'The overall objective of PlanGridEV is to develop new network planning tools and methods for European DSOs for an optimized large-scale roll-out of electromobility in Europe whilst at the same time maximizing the potential of DER integration'.

This study analyses the impact of EVs on real distribution networks in Europe: in particular, the impact of EV penetration and its flexibility on the distribution network is studied.

Location: Europe

Scenarios: An existing LV network with two feeders of 18 and 32 households respectively is studied. Figure 5.2-1 illustrates the system.

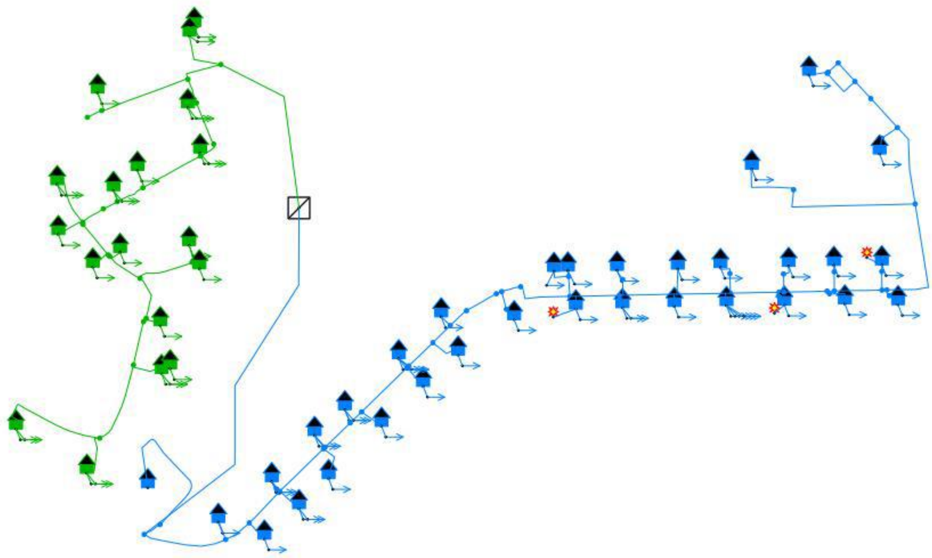

Figure 5.2-1 The simulated system [5.5]

The network includes a HV/MV node, MV lines, MV/LV nodes and LV lines. Two modes, conventional or uncontrolled charging and smart charging, are compared. Maximum battery charging power for both is 3.3 kW or 6.6 kW. For conventional charging, the EVs start to charge as soon as they reach home with constant rate of charge. In case of smart charging, the rate of charge can be modulated in order to reduce the peak demand. In this study 800 EVs are charged in a 24-hour period. Also, a Distributed Energy Resources (DER) is considered in the form of PV feed-in. The achieved results are as follows.

Impacts of EV flexibility (Dumb charging vs Smart charging) on the distribution grid:

The evening peak observed for the smart charging is relatively lower than the one caused by uncontrolled charging as shown in Figure 5.2-2. Moreover, the charging loads of EVs are distributed throughout the day.

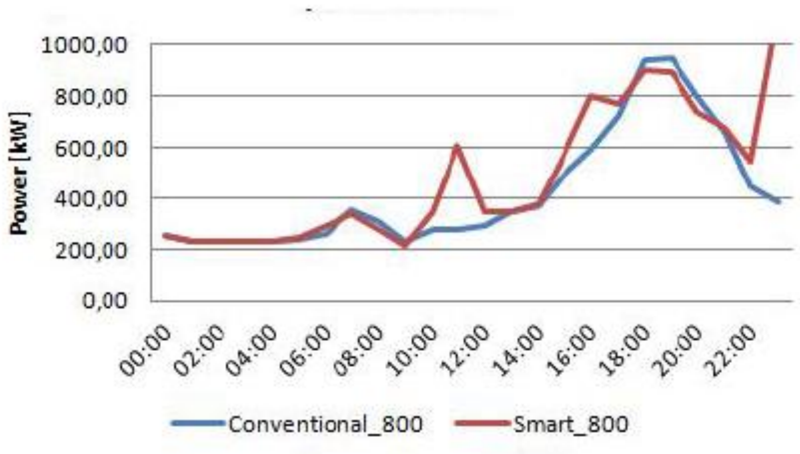

Figure 5.2-2 Uncontrolled and smart charging schedules [5.5]

The number of EVs charging simultaneously is higher for the smart charging case than uncontrolled charging, as shown in Figure 5.2-3. As can be seen the peak load for the two cases are relatively similar. In other words, by adopting smart charging a higher number of EVs users can be accommodated, without violating the distribution grid.

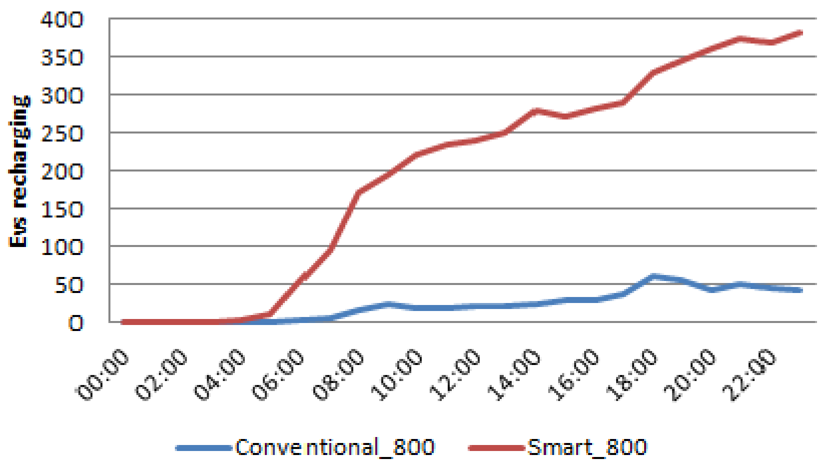

Figure 5.2-3 Number of EVs accommodated with uncontrolled and smart charging [5.5]

Test case with 50% PV (18 panels) and 100 % EV penetration (32 EVs)

Impact of Uncontrolled charging on distribution grid:

Figure 5.2-4 shows that EVs are charged after arriving home between 16:00-19:00 hrs in the uncontrolled charging mode. Apart from the EV load, the loads of household and PV feed-in are also active. The resultant load is represented by the purple line (residual load). The peak of the residual load has a value of 135 kW at 19:00 hrs.

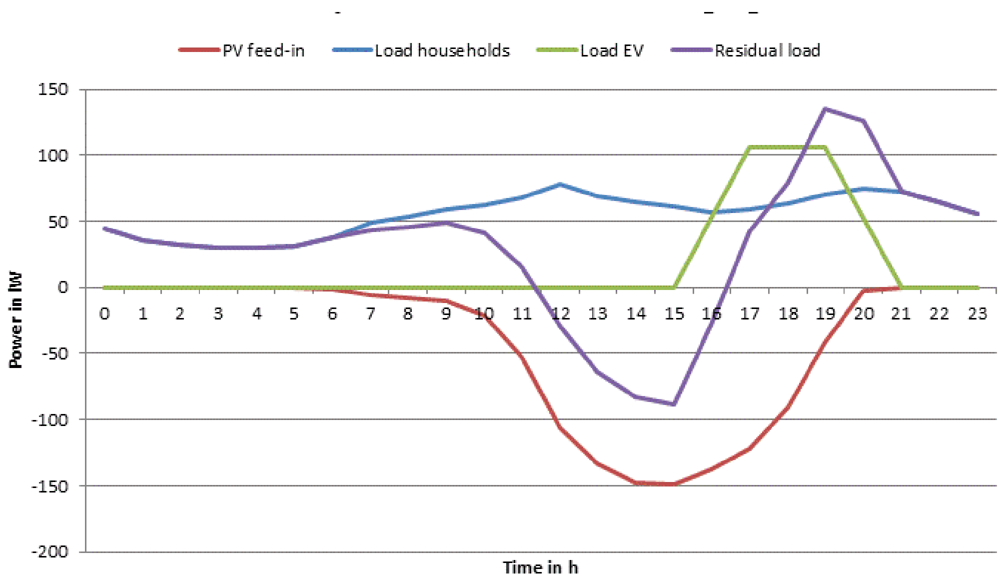

Figure 5.2-4 Loads involved in the system [5.5]

Impact of Smart charging on distribution grid:

This shows the same scenario but with smart charging. The household load and PV feed-in remain unchanged. Here it can be seen that, the residual load, has a smaller peak of 100 kW at 18:00 hrs and remains constant thereafter. This is because smart charging enables the EVs to be charged at different charging rates, and charging time thus achieving peak shaving at 19:00 hrs with respect to uncontrolled charging.

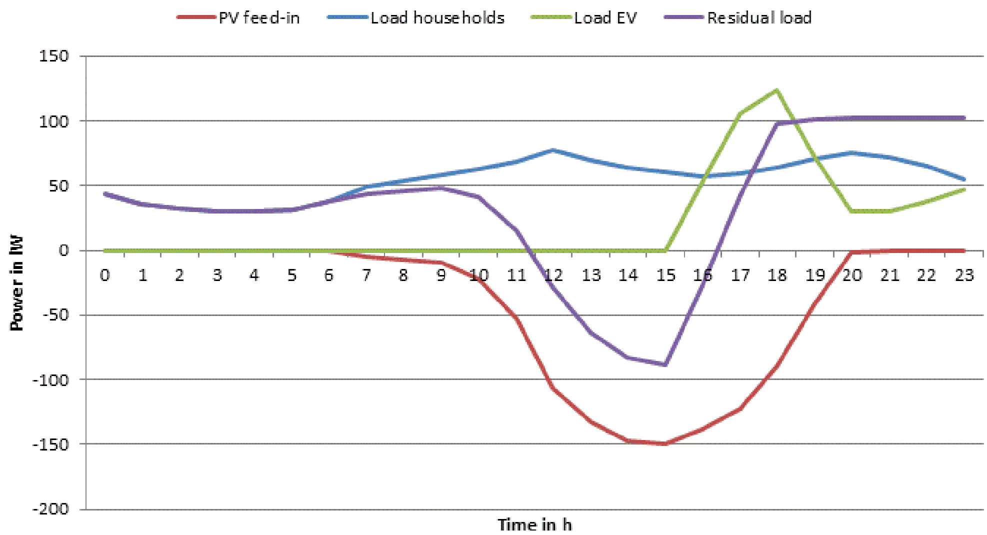

Figure 5.2-5 Smart charging applied to the system [5.5]

Key findings:

- A higher number of EVs can be charged simultaneously in the smart charging mode, that in uncontrolled charging mode with the same peak load, without stressing the grid.
- Smart charging reduces the peak power by shifting the load from peak hours to off peak hours which helps reducing the overall operating cost of the power plant.
- In the long run, this will also lead to less deterioration of the distribution components and avoid grid reinforcement.

2. Grid4Vehicles (G4V) project **[5.6], [5.7]**

Introduction and Objectives:

The G4V project focused on the effects of a mass rollout of electric vehicles on the electricity grid in Europe. This study looks at the impacts of EVs on the European grid, and what changes need to be made to the grid to ensure smooth EV deployment.

Location: 5 European countries – Sweden, Germany, Italy, Spain, Portugal

Scenarios, data and assumptions:

- The grid data is from the 5 countries analysed and is collected for low and medium voltage level, and for different area – rural, urban and suburban.
- For each country, the number of households, the number of vehicles and the peak load of the country are summarized in Table 5.2-1. This information has been given by the grid operators of each country.

	Sweden	Germany	Italy	Spain	Portugal
Million Households	4	40.03	23.65	19.03	4.98
Million Vehicles	4.28	41.73	35.68	22.14	5.76
Peak Load [GW]	27.3	76.8	52.1	43.9	9.4
Vehicles/MW	156.9	543.3	684.4	504.0	612.7
Vehicles/HH	1.07	1.04	1.51	1.16	1.16

Table 5.2-1 Boundaries of the system in the five countries [5.6]

- **Driving patterns for 20,000 drivers have been picked randomly from databases of each country respectively. This provides the charging load profile for the EVs.**
- **In this study, a probabilistic approach is adopted. This is done since it is not precisely known which EV is allocated to which bus.**
- **In the load flow simulations, the main scenario parameters considered are:**
  - connection powers (3.7 kW, 11 kW, 55 kW and a mix of these 3 values);
  - 4 charging locations (e.g. at home, at home and at work, everywhere);
  - 21 penetration rates (0 %, 5 %, ..., 100 %);
  - 202 distribution grids;
  - 96-time steps (1 day in 15 minutes resolution);
  - 200 iterations per time step;
  - 8 charging strategies (e.g. uncontrolled, time-dependent, tariff-dependent and controlled).

- The results are depicted in 3-dimensional graphs, where the axes are: the time axis (x-axis), asset number axis (z-axis), load per unit axis (y-axis) and the one per-unit-layer (1 p.u. layer). Here, the asset number refers to a particular component of the grid, that is, a line, MV transformer, and a secondary sub-station. In total, the effects of EV charging on a 100 components or assets of each type are considered.
    - The results are shown hereafter.
- Effect of EV penetration on the loading of secondary sub-stations.

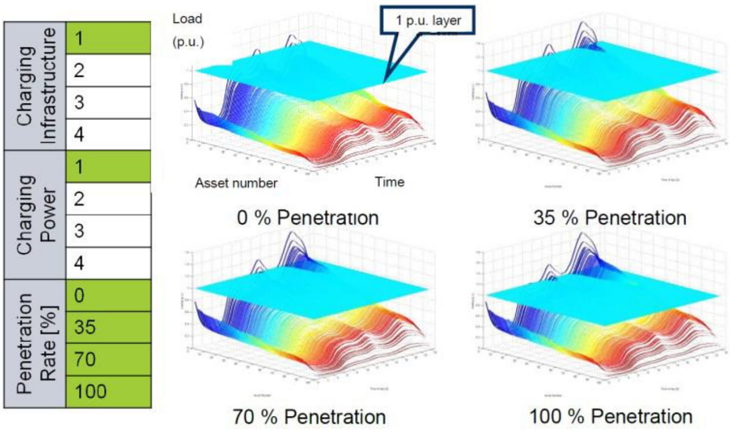

Figure 5.2-6: Loading of secondary substation for different EV penetration levels. Charging infrastructure =1 refers to home charging. Charging power =1 refers to 3.7 kW, 16 A [5.7]

The graph above shows the effect of different penetration levels, while maintaining a constant charging power of 3.7 kW, 16 A, and charging infrastructure is considered to be at home. As seen from the graph above, with a 0% penetration rate, only a couple of secondary sub-stations are overloaded. With an increase in the penetration rate to 35%, 10 assets (secondary sub-stations) are overloaded. At a penetration rate of 100%, more than half of the secondary sub-stations are overloaded. Thus, it is obvious that as EV penetration increases, the number of secondary substations or MV transformers being overloaded increases.

- Effect of different charging power levels on the loading of secondary substations
- Four different charging powers have been considered here, which are as follows:
    1. 3.7 kW (AC, 1 phase, 16 A);
    2. 11 kW (AC, 3-phase, 16 A);
    3. 55 kW (DC, fast charge);
    4. A mix of the charging powers: 70% of (1), 20% of (2), 10% of (3).

The figure below shows how different charging power levels affect the secondary substations. As most of the EVs come home in the evening, the secondary substations are overloaded in the evening. As the charging levels increase, the number of overloaded secondary substations increases. For the 55-kW case, almost all the secondary substations are overloaded. For a mix of charging levels, the number of substations overloaded is less than that of the 55-kW case.

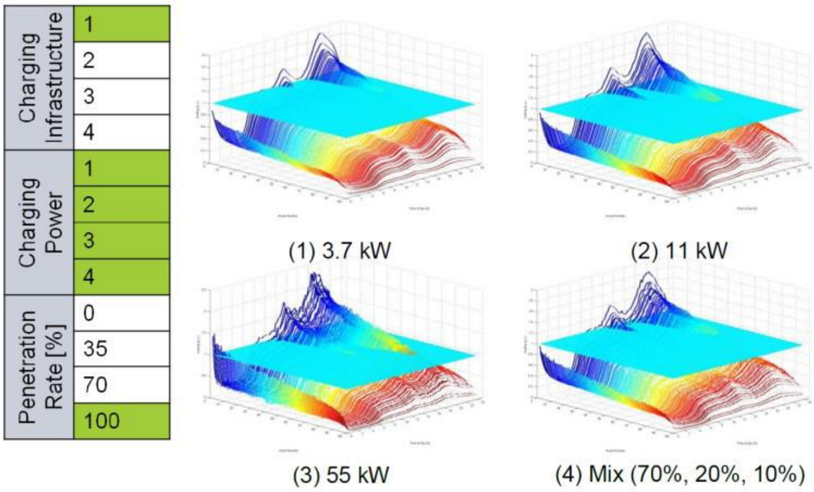

Figure 5.2-7 Loading of substations for different charging levels (1) 3.7 kW, (2) 11 kW, (3) 55 kW and (4) a mix of the three [5.7]

- Effect of different charging infrastructure on secondary substations
- For this case, four kinds of charging infrastructures have been simulated:
    1. At home (residential areas);
    2. At home and at work (residential and industrial areas);
    3. Everywhere (charging possible at every grid node);
    4. At home and at work, but at work outside the considered grid.

This shows that in Case 1, since the vehicles only charge at home, there is a significant peak in the evening. Some vehicles which are at home during the day are charged in the afternoon. This accounts for the slight peak in the afternoon. This case assumes home charging only. One may argue that, in real life most people would see multiple options for charging, say home and work place. For EV owners with domestic charging being the only charging option, they do not need charging every day/night; however, the substation gathers the feeder load which is an averaged profile from multiple households and this is where the evening peak come from.

In Case 2, the EVs charge at home as well as at work (in the same grid). Accordingly, the evening peak reduces compared to case 1, but in the afternoon the number of secondary substations being overloaded in case 2 is higher. In case 3, which is charging everywhere in the same grid, the afternoon peak is higher than that of case 2, while the number of overloaded secondary substations in the afternoon increases. In the last case, since the EVs are charged outside the grid at work, the number of overloaded secondary substations in the afternoon as well as the evening are less compared to the other cases.

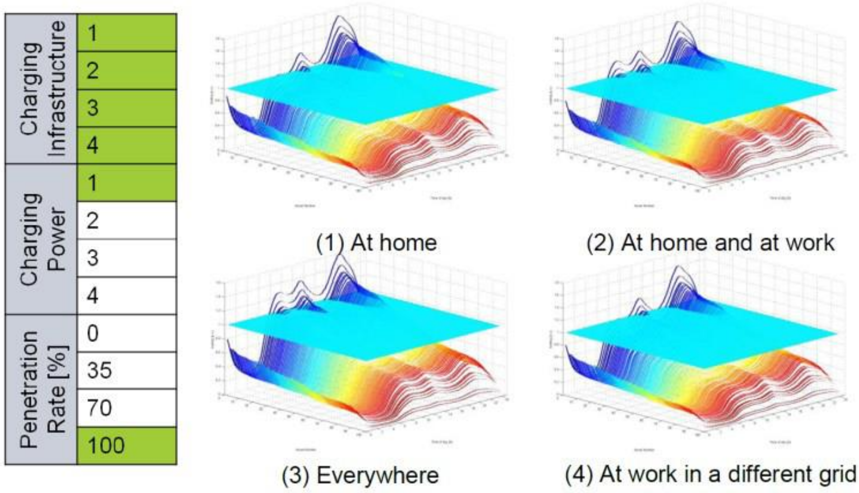

Figure 5.2-8 Effect of different charging locations on the system (1) at home, (2) at home and at work, (3) in every node of the grid and (4) at work in a different grid [5.7]

Key findings:

- A probabilistic approach can be considered to account for the uncertainties related to EVs and their behaviour.
- Amongst the 200 networks simulated, some of them need to be reinforced even without any penetration of EVs, while some can handle 100% EV penetration without any charging strategy. This is true for all the countries considered.
- For uncontrolled charging, as the EV penetration increases, the cost to reinforce the grid increases steadily. This can be observed in Figure 5.2-9. The investment required to strengthen the lines and transformers is higher than that for the voltage-regulating equipment and other distribution components.

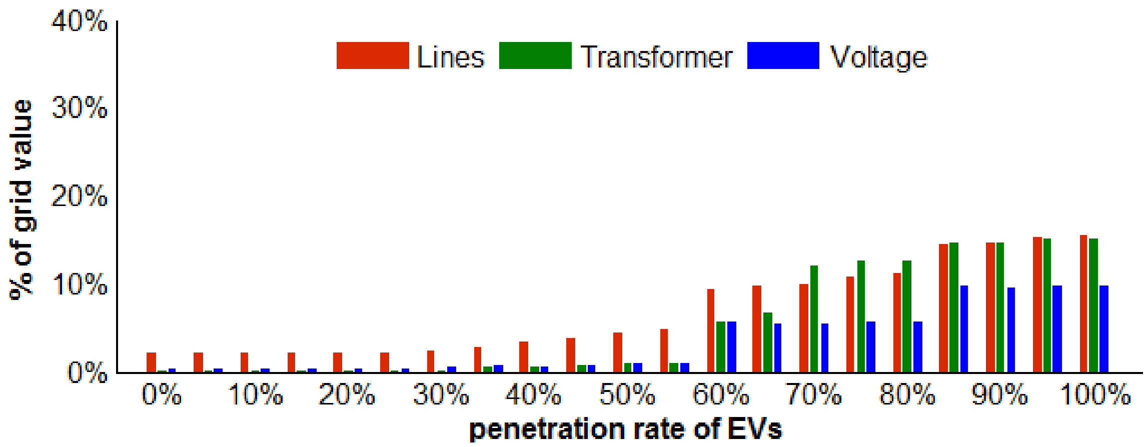

Figure 5.2-9 Reinforcement costs for different penetration rates of EVs [5.6]

3. Network impacts of EV charging in The Netherlands **[5.8], [5.9]**

Introduction and Objectives:

The objective of this study was to investigate the impacts on EV charging on a Dutch LV residential network. For this study, real-life data of both driving patterns and a large number of electricity networks are considered. The primary focus is to compare the effects of uncontrolled and controlled charging of EVs.

Location: The Netherlands

Scenarios, data and assumptions:

The assumptions made in this study are as follows:

- A large number of operational LV networks in The Netherlands have been considered for this study. This data is obtained from the Distribution Network Operator (DNO).
- Only transformers and cables of residential networks have been considered here. Large consumers have not been taken into account.
- Real-time data of the LV networks, cable and transformer loadings have been used. Moreover, detailed driving patterns were available, which led to creating realistic load profiles of EVs, without using probabilistic analysis.
- Future EVs shall maintain the same driving patterns as the current EVs.

Scenarios:

- Uncontrolled charging, 3 kW
- Uncontrolled charging, 10 kW
- Controlled charging, 0-10 kW

Figure 5.2-10 shows the three charging scenarios along with the household load.

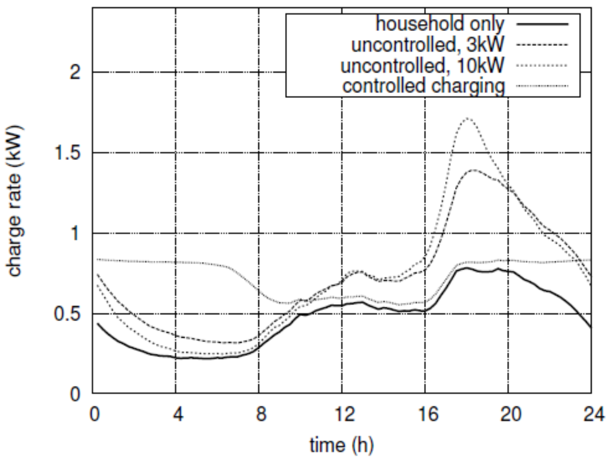

Figure 5.2-10 Three charging scenarios and the household load [5.9]

The figure above represents aggregated load profiles of the above-mentioned charging strategies, along with the standard household profile, having 1 EV per house, in The Netherlands.

The results are shown in the following figures.

- Figure 5.2-11 shows the growth of peak of the regular household profile for different EV charging scenarios and with a growth of the household load for some cases.

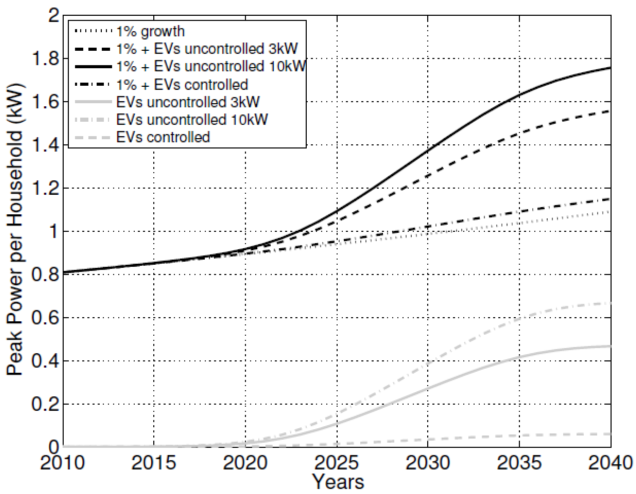

Figure 5.2-11 Growth in peak power for different charging levels and types and load growth [5.9]

The figure above shows the increase in the aggregated peak household demand profile, for a growth of 1%, from the base case, along with the EV charging strategies. It can be seen that a 1% growth in household electricity demand has a drastic effect on the peak power in all the years. Also, adding EVs to this 1% growth case drastically increases the peak power per household, for both the uncontrolled charging scenarios. However, controlled charging can lessen the peak significantly.

- Overview of transformer and cable loadings for different charging scenarios

In Table 5.2-2 the percentage of overloaded transformers, cables and voltage drop for 2040, with approximately 75% of households owning an EV, is represented.

Table 5.2-2 Overloading of transformers, cables and voltage drop for different scenarios [5.8]

Property	Treshold Value	1% Growth only	Uncontrolled 3kW	Uncontrolled 10kW	Controlled
Transformer Loading Total Area	Loading > 1.16	19.1%	41.2%	50.5 %	21.0%
Transformer Loading Selection	Loading > 1.16	19.4%	38.7%	48.4%	25.8 %
Cable Loading Selection	Loading > 1.2	2.8%	9.0%	13.1 %	4.8 %
Voltage Drop Selection	$\Delta V > 20V$	2.1%	4.4 %	5.2 %	2.5%

In Row 1, the percentage of transformers that are overloaded for different charging strategies in 2040 is shown. Here the threshold value for overloading is considered to be >1.16. It can be seen that the 1% growth of household demand without EVs, results in 19.1% of transformers being overloaded. The uncontrolled 3 kW case results in 41.2% of transformers being overloaded, uncontrolled 10 kW results in 50.5% of transformers being overloaded, while the controlled charging gives a favourable outcome of 21% of transformers being overloaded. This means that there is a reduction of 59% in the number of transformers being overloaded, compared to the 10-kW uncontrolled charging scenario. The distribution of the overloaded transformers is shown in Figure 5.2-12.

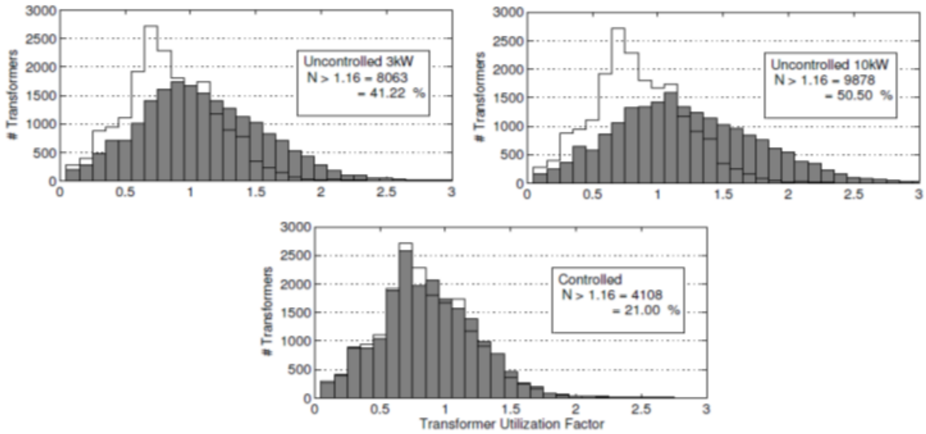

Figure 5.2-12 Distribution of overloaded transformers in uncontrolled 3kW, uncontrolled 10kW and controlled charging scenarios [5.8]

Similarly, in the case of cable loading (Row 3), for the uncontrolled 3 kW and 10 kW cases, 9% and 13.1% of cables are overloaded, while for the controlled case it is only 4.8%. The values are presented in Figure 5.2-13.

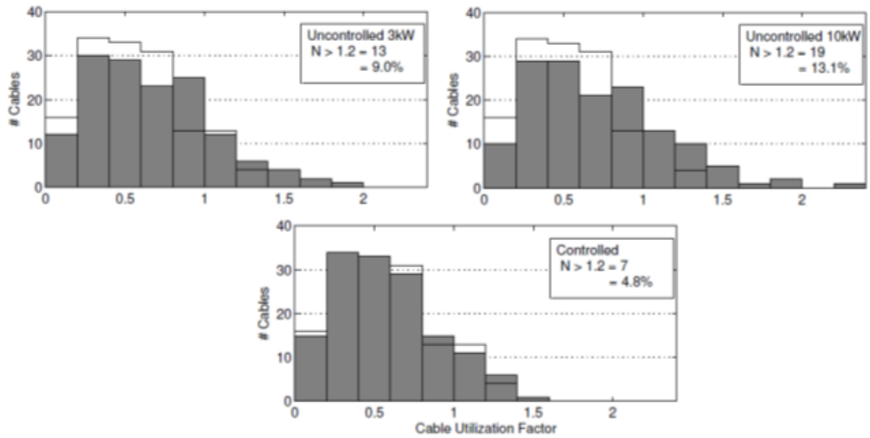

Figure 5.2-13 Cable overloading for the uncontrolled 3 kW, uncontrolled 10 kW and controlled charging scenarios [5.8]

Finally, the voltage drop along 150 cables for different charging strategies are shown in Figure 5.2-14.

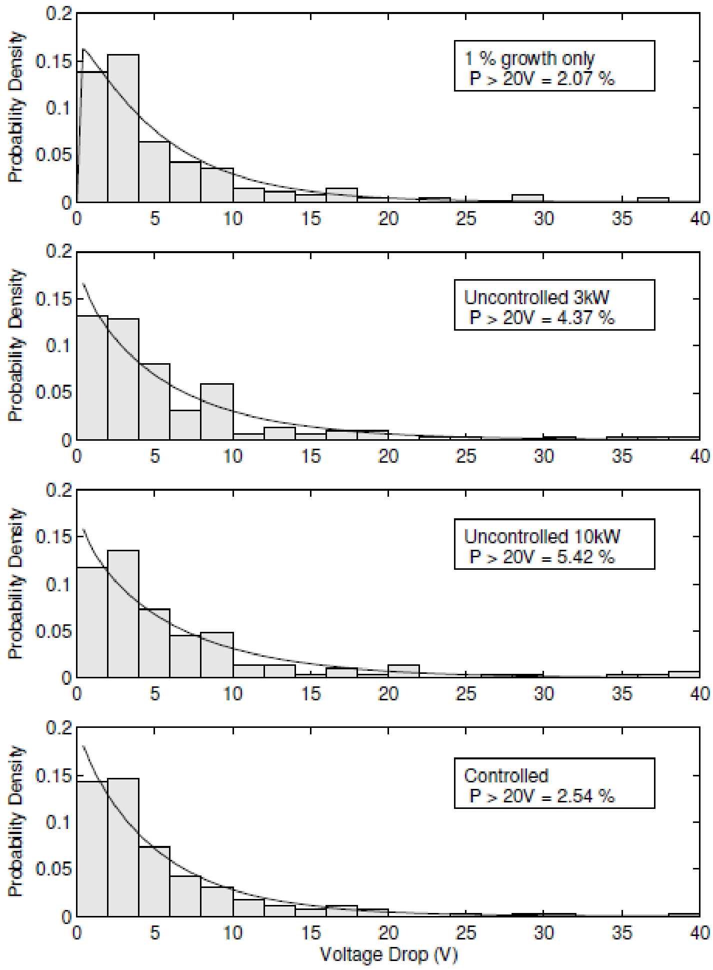

Figure 5.2-14 Voltage drop for the uncontrolled 3 kW, uncontrolled 10 kW and controlled charging scenarios [5.8]

Key findings:

- Real-time driving data was used in this study, which eliminated the need to use probabilistic analysis (which is usually the case in a number of other studies).
- It was found that more impacts can be expected on transformer loadings than on cables and voltage.
- The peak of large numbers of loads is much smaller than the sum of individual peaks. In other words, transformers are being operated closer to their rated capacities, in comparison with cables. Hence, transformers can accommodate fewer EVs than cables.
- Even without significant penetration of EVs, certain transformers and cables will have to be replaced in the future.
- The impacts of EV penetration in the future can be avoided to a certain extent by adopting controlled charging strategies.

4. Impact on the generation mix in the Canary Islands [5.10]

The study analyses the effect of an integration of 122,000 EVs in an isolated system such as the Canarias market in 2025. A Levelized Cost of Electricity (LCOE) according to previous studies were calculated for every technology available in the generation mix: it is the cost over the useful lifetimes of the plants and averaged in order to have a total production cost. The generating costs included: investment, production and operation, maintenance, emissions and interruption costs (only wind because PV did not have a significant share). In the calculation, EVs were used to create the following positive impacts: higher penetration of RES (mainly wind), diesel turbines utilization reduction and reduction in intermittency costs for RES. The assumptions that had been adopted are the following:

- Charging level of 3 kW, with a consequent charging time between 1:30 to 4 hours;
- Battery capacity of 24 kWh;
- Maximum driving rage of 150 km;
- Rate of use considered for the EV batteries of 20% and 40%;
- Average round-trip between home and office required two hours.

These 122,000 cars could generate about 12% of the electricity in the Canarias marker in 2025. The average cost of the energy portfolio was calculated with the same equation presented at the beginning of Chapter 3.1 for an economic dispatch, giving different weights (that range from 0 to 1 and collectively add up to unity) to the generation costs of CC gas plants, diesel, oil plants, on-shore wind, PV and more efficient oil plants. The weight given to diesel had a lower limit of 0.15 for the use of these in small islands, whereas wind and PV had a maximum limit of 0.25 and 0.05 respectively to ensure stability of the system due to the intermittency of these two technologies. The risk associated with the energy supply for each technology had also been considered. The volatilities, calculated as a measure of the cost dispersion of the related technology, were:

- 1.29 for the fossil technologies;
- 0.65 for the renewables.

The cost correlations are:

- Among fossil fuels, 0.95 (fuel and diesel oil);
- Compared to gas, 0.87;
- Correlation between RES, 0.5;
- Correlation between fossil fuels and RES, 0.25.

The baseline scenario did not have any EV penetration, and the shares of the different technologies were: 71% for fuel-oil, 22% for diesel, 6% for wind and 1% for PV. An increase of wind penetration from 25% to 33% for wind and from 5% to 7% for PV and a decrease of the lower limit of the diesel from 15% to 10% were assumed caused by the EV penetration. By reducing the intermittency cost for the wind, an increase in its penetration from 30-35% to 40-45% is possible in the third scenario. Figure 5.2-15 shows that with the introduction of EVs, a reduction in average cost and risk in generation of electricity was possible.

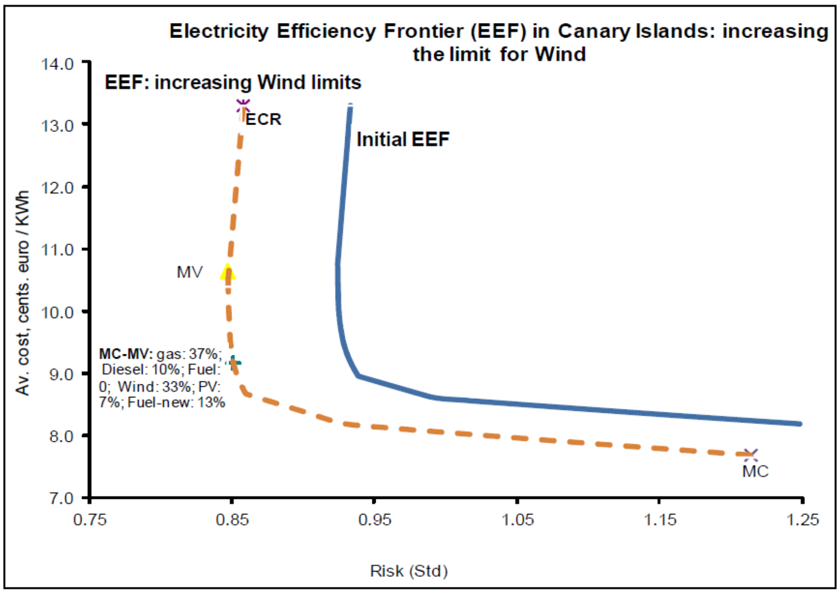

Figure 5.2-15 Energy Efficient Frontier (EEF) for the baseline and the EV scenario [5.10]

RES penetration has been increased against fossil fuels, especially gas and diesel. The new scenario allows a cost reduction of 3%, risk reduction of 8.4% and CO_2 emissions reduction of 14.3%. The details of generation costs under the different energy mixes and the related scenarios are presented in Table 5.2-3.

Table 5.2-3 Comparison between the baseline and the EV scenario [5.10]

	Reference portfolio, Canary 2008–2011	*Minimum risk (MV)*	*Minimum cost (MC)*	*Equal cost than reference (ECR)*	*Average between MV-MC*
Cost (cents euro/kWh)	13.31	10.63	7.68	13.31	9.16
Risk, std	1.20	0.85	1.21	0.86	0.85
CO2, TM/kWh.	0.55	0.31	0.44	0.32	0.30
Gas	0.0	25.8	84.5	8.0	37.1
Diesel	22.0	22.3	10.0	52.0	10.0
Fuel-oil (old)	71.0	7.2	0.0	0.0	0.0
Wind	6.0	33.0	5.5	33.0	33.0
PV	1.0	7.0	0.0	7.0	7.0
Fuel-oil (new)	0.0	4.7	0.0	0.0	12.9

With the increase in the load factor of wind and the reduction of its intermittency caused by the EV integration the mean of the Minimum Cost (the energy mix that gives the minimum cost)–Minimum Variance (the energy mix that gives the minimum variance), the MC-MV scenario, allows a cost reduction of almost 8% and a risk reduction of 1% compared to the previous EV scenario; the CO_2 emissions remain unchanged. Because wind has been made cheaper, by reducing the intermittency costs, a more expensive technology, like fuel-oil, can be increased, and since it is efficient, it increases the diversification among the alternative fossil technologies without increasing the cost. Figure 5.2-16 shows the EEF of the two cases compared to the baseline and Table 5.2-4 lists the generation costs.

This new case allows a cost reduction of almost 11% compared against the Baseline case, risk reduction of 9% and CO_2 emissions reduction of almost 13%. Besides, the authors infer that, according to previous studies, by switching from the Baseline scenario to the one with EVs could imply savings of 500 M€/year and the introduction of EVs would give another 80 M€/year of savings in average cost.

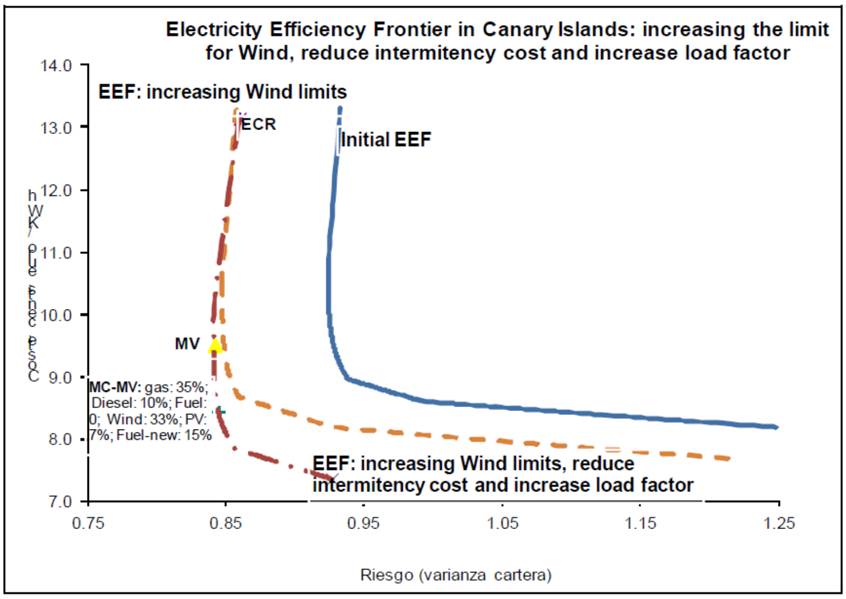

Figure 5.2-16 EEF for the Baseline, EV and the increased wind scenarios [5.10]

Table 5.2-4 Generation costs for the Baseline and the increase wind scenarios [5.10]

	Reference portfolio, Canary 2008–2011	*Minimum risk (MV)*	*Minimum cost (MC)*	*Equal cost than reference (ECR)*	*Average between MV-MC*
Cost (cents euro/kWh)	13.13	9.50	7.35	13.13	8.42
Risk, std	1.20	0.84	0.93	0.86	0.85
CO2, TM/kWh.	0.55	0.32	0.31	0.33	0.30
Gas	0.0	23.6	57.0	2.2	34.9
Diesel	22.0	16.4	10.0	57.8	10.0
Fuel-oil (old)	71.0	8.5	0.0	0.0	0.0
Wind	6.0	33.0	33.0	33.0	33.0
PV	1.0	7.0	0.0	7.0	7.0
Fuel-oil (new)	0.0	11.5	0.0	0.0	15.1

Key findings:

- EV integration in electric grid can have positive impacts that optimize the generation mix.
- EV integration allows a higher RES penetration to be accommodated in the energy mix.
- EV integration allows a better diversification of the energy mix.
- EV integration imply a lower generation cost, lower risk of supply and lower CO_2 emissions, by utilizing more RES.

Overall **key findings** of impacts on EVs for SEEV4City:

- Many studies conclude that, greater impacts are on the distribution system: EV loads have impacts on electricity generation adequacy, transformer ageing, and on distribution power quality.
- Time-of-use (TOU) pricing can be adopted to mitigate EV load impacts; clearly smart charging is effective than uncontrolled charging. Smart charging algorithms can be used to mitigate EV load impacts – that is, controlled EV charging to maximize utility benefits and maximize customer benefits.
- Grid impacts are local, which means, for every grid analysis study different impact occurs at different section of the grid. For example, in a same grid some transformers are overloaded, and some are not. Some transformers are already working on their full capacity even without any addition of EVs and PVs to them. This is also in case of cables and other electrical components. In other words, results will be different for different grids – the results can be generalized on a larger scale, but when it comes to specific locations generalization should not be done. For SEEV4-City, there must be grid models of all the pilots to assess and analyze the impacts of EVs on the grid for detailed output. The results might vary from pilot-to-pilot, scenario-to scenario.
- Many studies (2011-2016) achieved similar results, such as the points mentioned above.

5.3. *Impacts of PV systems*

Generally, grid-connected PV systems are employed to improve the performance of the electric power network. PV systems in this case, are considered as generators and they provide energy at the load side of the distribution network. This setup reduces the feeder active power loading and thus improves the voltage profile and enhances the life time of shunt capacitors and series voltage regulators. The Load Carrying Capacity (LCC) can be increased by employing PV systems – which is the amount of load a power system can handle without comprising on certain reliability criteria of the existing network [5.11].

Nevertheless, PV systems can have various negatives impacts on the power systems, particularly if the penetration is high. The impacts of PV systems on electric networks are divided into two categories based on the size of the PV system: impacts of small and medium PV systems and large PV systems.

Note: in SEEV4-City project, the Amsterdam pilots will come under either large or medium PV system setup. The remaining pilots may employ a small PV system setup [5.12].

Impacts of large PV system

- **Serious power, frequency and voltage fluctuation** – this is due to the erratic and unpredictable nature of PV arrays, as they are highly dependent on environmental conditions such as solar irradiation and temperature. For example, shading caused by passing clouds can vary the insolation affecting the production of PV system, thus leading to rapid fluctuations in its output. This will lead to power quality issues. Active power fluctuations cause frequency variations, reactive power and consequently voltage fluctuations.
- **Stability of electric power systems**: The erratic nature of the PV system output has greater impacts on the power system operation. When a large PV system cannot provide the dispatchable supply in each point of time to the varying demand, it not only fails to deal with the uncontrolled demand, but also the uncontrolled generation. This will result in severe power system instability.

- **Large PV system means increased ancillary services requirements**:
  - The electric gird must act as a buffer to compensate the power fluctuation of the output of the power PV system. Other generators must be adjusted frequently to deal with this PV power fluctuations to maintain the overall power grid frequency and maintain the nominal operation of the electric power grid.

Impacts of small and medium PV systems

- **Reverse power flow: i**n the normal operation of a distribution system, the power flow is uni-directional from higher voltage system to lower voltage system, i.e. MV to LV system. At high PV penetration level, especially during noon, there will be some instances when the net production is more than the consumption (the demand); this results in a reverse power flow from the LV side to the MV side. This reverse power flow results in overloading of the **distribution feeders**, increased system power losses, hampers the operation of automatic voltage regulators installed along the distribution feeders and affects the **online tap changers** of the distribution transformers.
  - The voltage control becomes difficult as they affect the capacitor banks and voltage regulators.
  - Increases power losses in the system.
  - Phase unbalance may take place when PV generations are not distributed evenly.
  - Power quality issues: the inverters used to interface PV system with the power gird produce harmonic currents, contributing to the total harmonic distortion of both current and voltage at the point of common coupling.

Key findings for SEEV4-City:

- PV systems reduce losses in the distributions feeders if optimally sized and assigned.
- The load carrying capacity (LCC) can be doubled with just 10% increase in PV penetration level [5.11].
- Impacts of PV are dependent on the location and size of the PV system.
- Voltage fluctuations happens more frequently with high penetrations of PV systems during cloud transients.

Table 5.3-1 shows the results of some studies that provide PV penetration limits caused by different limiting factors.

Table 5.3-1 Examples of percentage of EV penetration allowable limits from the literature

Case studies	PV penetration limits	Limiting factor
DG power quality, protection, and reliability case studies report. A Simple Technique for Islanding Detection with Negligible Non-detection Zone [5.13]	40%	Voltage regulations issues
Impact of widespread photovoltaics generation on distribution systems [5.13]	33%	Overvoltage
Report on Distributed Generation Penetration Study (NREL) [5.15]	5%	System distribution losses

It can be understood from the above table that the percentage of the PV penetration has clear influence on the electricity grid. In every electricity grid, only a certain percentage of PV penetration is allowable and recommended; above the allowable limit there are several negative impacts on the electricity grid. For SEEV4-City, during grid modelling (sizing of PVs) of the pilots and various scenarios this key point must be kept in mind.

5.4. *Summary*

This chapter presented a detailed overview of the potential impacts of EV charging and PV generation on the grid. These include mismatch between generation and demand, pulsating loads, voltage flicker, line and transformer overloading, and voltage deviations. The level, the location and the time of charging and grid structure play key roles in determining the level and consequences of the impact. The critical time slots that have been observed were the morning peak and the more significant evening peak. The system components that are affected are transformers and cables.

The projects reviewed showed that currently there are areas of the network that are already overloaded, or close to, whereas there are parts of the grid that can accommodate EV charging for modest penetration levels. It can be seen that the impacts of EV charging need to be locally evaluated and a generalization may be possible only on large-scale networks. Bulk uncontrolled EV charging always tends to lead to overloading of system components whereas smart charging is a solution that mitigates these issues. Therefore, EVs charged according to smart charging schedules can contribute to the solution of the problem. In fact, studies showed how controlled or smart charging can reduce the peak power even with a growth of the load profile. In the same way, large deployment of PV systems may cause power, frequency and voltage fluctuations, reverse power flow, instability and unbalance.

If EV charging is controlled in such a way to act as a storage medium in order to enable the maximum PV generation possible, then less energy is injected in the grid and this has a dual benefit of minimizing the grid interaction which results also in a decrease in operation costs and a maximization of the energy autonomy within the area (as discussed in Chapter 4). Within SEEV4-City, the deferred grid investments that would have otherwise been necessary to accommodate large deployment of EVs and PV systems, achieve energy autonomy and minimise the related operational costs will be evaluated.

5.5. ***References***

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6. Electric Vehicle for Energy Services (eV4ES) in EU and NSR

Significant numbers of projects have been undertaken to investigate the integration of EVs and RES into future smart grids. In order to answer the research question of 'what areas have been covered for EV and PV integration; and what are the gaps and how the SEEV4-City project can contribute', various electric vehicle for energy services (eV4ES, or simply V4ES) related works in the NSR and EU have been reviewed and are presented in this chapter. This includes the projects that have been completed or are currently running in the NSR and EU, review of state-of-the-art technologies, coordination of EV charging with local RES and ICT solutions to support their integration as well as business issues regarding smart charging and V2G with associated economic and environmental benefit and influence on the user's perception/ behaviour. This work is summarised in terms of the system boundary (time span and geographical scale), assumptions made, methodologies used for calculation, and results achieved, where applicable. The added values brought by this research and how it can contribute to the SEEV4-City project are also discussed.

6.1. *Relevant projects*

This session presents the V4ES related projects that have been completed or are currently running in NSR and EU, literatures on state-of-the-art relevant technologies, as well as business applications.

6.1.1. Concluded projects

The projects with concluded results are presented here, including those from trials and simulations (with potential projections), and they are categorised into smart charging based and those involve V2G implementation, as well as social oriented projects.

6.1.1.1 Smart charging projects

1. Network Innovation Allowance (NIA) project – UK

This NIA project [6.1] is commissioned by the National Grid and carried out by Element Energy to assess the technical and commercial potential of EVs to support frequency response at UK national level in the year of 2030, including both private EVs and EV fleet.

The division of vehicles into private and fleet and the charging archetypes within private vehicles are based on the Department for Transport vehicle licensing statistics for 2014, [6.2], and the Ultra Low Carbon Vehicle Demonstrator Programme [6.3], respectively. The associated vehicle archetype has been broken down into home (47%), work (33%), public (11%) and fleet (9%) in this report, though public charging is excluded for frequency response provision here. The time available for EV charging and the daily energy requirement are assumed to be constant across archetypes with the following constraints:

- EVs plugged in between 17:00 and 21:00 must be charged by 05:00.
- EVs plugged in between 21:00 and 01:00 must be charged by 06:00.
- Otherwise, EVs have 8 hours available for charging.

To quantify the EVs' potential for Frequency Response services, the aggregate frequency response profiles are calculated for each day in a given year, where each individual EV are assumed to support both low and high frequency response within the parking period when there is a signal.

And it is worthwhile to point out that the frequency response in this work is provided by turning on and off the charging or varying the charging rate, but excluding V2G. The results show a potential of 754 MW annual average from EVs for low frequency response, which corresponds to 52% of the projected 2030 requirement under the National Grid's gone green scenario. This represents an annual potential of £66 million based on current tendered prices, i.e. holding payment of 10 £/MWh for combined low and high frequency response provision, for the 2030 medium scenario which corresponding to the Gone Green scenario in National Grid Future Energy Scenario (FES) 2015 [6.4]. Economic benefits get diluted when spreading among individual assets, showing annual revenue of £45/EV/year, which corresponds to the net profits of £26 and £35 for a home charging EV and a fleet EV, respectively. The associated difference between the gross and net revenue is due to the frequency provision costs, including hardware, operational and overhead business costs. Battery degradation cost however has not been taken into account.

Other promising figures include CO_2 emission reduction of 1 tonne per EV per year, due to the replacement of capacity holding of coal/gas power plants for dynamic frequency response with EV based energy. This is calculated using the average increase in emission, of 0.26 tonnes of CO_2 per MWh, due to capacity holding, assuming an operation of 80%-part load.

It is realised that the limited revenue per asset may become a barrier for EV adoption for the frequency response services, and the deployment of EVs is claimed to require the support of very efficient business models where effective combination of frequency response with other DSM services would increase the value of customer propositions. For instance, the requirement for primary frequency response is shown to be the highest overnight between midnight and 6 a.m., due to the fact that lower demand overnight means that a single plant outage would have a larger impact on the system frequency. This provides opportunity for combination of frequency response with other DSM services which require V2G at a different time of day, often at peak load. It has also been pointed out that there are no technical concerns for the development of V2G based frequency response, e.g. EV batteries and battery management systems are able to respond to a control signal in approximately 1 second, which lies well within the requirement from IEC 61851 standards of 5 seconds [6.5] making them suitable for meet the frequency response requirements with very high response rates and accuracy; though a standardised protocol for communication between the charging points and the aggregator are required for the interoperability for frequency response.

This work provides results on an aggregate level nationwide, but the potential issues within the local network has not been analysed though various network impacts and system operation issues due to localised clustering has been pointed out. Qualitative criteria have been proposed to select the commercial model for frequency response, but the commercial relationship and the associated stakeholders for each identified model are yet to be clarified.

2. My Electric Avenue Project – UK

The My Electric Avenue Project [6.6] was delivered between January 2013 and December 2015 by EA Technology and Scottish and Southern Energy Power Distribution (SSEPD), with partners, as part of the Ofgem Low Carbon Networks (LCN) Fund. This project aims to determine the impact clusters of charging EVs might have on local electricity networks at peak times, to manage the strain on the distribution network and develop a low-cost solution for future EV network where clusters of EV owners put potentially significant demand on the local network.

Participants from neighbours, of over 100 people from different clusters around Britain, are encouraged to the trials of year 2030 simulation for 18 months where their EV chargers are allowed to be controlled and an extensive range of data regarding EV driving and charging behaviour is collected, via a new technology 'Esprit'. The Esprit system is designed to avoid any potential power outages and damage to network infrastructure by temporarily curtailing high-load devices on a rolling basis (15 minutes for each EV), in order to reduce the overall load on a single feeder or transformer. Coordination between DNOs, technology developers, communities, EV manufacturers, academics and car leasing companies has made the success of the trail. Results differentiate the charging habit between weekday and weekends.

Technical, economic and social benefits by employing the intelligent controller, 'Esprit', have been summarised in Table 6.2-1 in the next section. It is shown that around 70% of EVs only charge once per day, and more than 65% EVs are charged until the battery is full. These insights of EV charging behaviours point out the savings opportunity for the SEEV4-City, such as via optimized battery operation, i.e. keep battery at a lower SoC level when further journeys are not immediately required. As the first Ofgem Low Carbon Networks Fund project that has been led and managed by a non-DNO company, blueprints for a contractual arrangement have been developed to assist with future collaborative working between a DNO and a third-party SME.

<u>3. Green eMotion project – EU</u>

According to [6.7], the objectives of the eMotion project are:

- Open access to charging infrastructure;
- Reduce grid and energy costs;
- Find viable business cases for charging services;
- Policies and regulation.

The ICT systems of all participating companies are networked by means of a so-called 'Marketplace'. Together with the so-called 'Clearing House', this system allows roaming between all partners, meaning that EV drivers can use public charging infrastructure independent from whom it owns or operates. In the Green eMotion demonstrations, all demo regions were connected to the marketplace and the feasibility of this solution, especially for roaming between all the demo regions, was successfully demonstrated [6.8].

The solutions/results of the projects are [6.7] [6.9]:

- Implement a European roaming solution;
- Time dependent power tariffs motivate user to accept smart charging, optimised location, load management, integration of renewable energy sources;
- Cost benefit analysis of different business models to identify viable business cases for public infrastructure:
    - Home charging → TCO better than for ICE already today;
    - Highway charging → might be viable business in future;
    - Street side charging → critical case.
- Public charging is profitable in case of highly frequent use of EVSEs that are located at points of interest. A viable financial approach is yet to be found;
- Guidance document for policymakers.

The power quality impact of charging infrastructure was studied under real life and also lab conditions. These measurements revealed no issues in the concerned low voltage grids. A reduction of energy costs can be achieved by optimization of energy demand over time if different tariffs are in force. Smart grid management schemes are useful for the optimization of integration of renewable energy sources (RES). Another and cheaper option for controlling the power demand from the grid resulting from EV charging is load management. On a local level, it can be used to reduce the necessary grid tie capacity and therefore save grid reinforcement cost. An option to avoid grid reinforcement costs for the low voltage grid is a power management for distribution networks (Soft Open Point). The SOP has the potential to balance load across adjacent feeders and control local system voltages [6.8].

A possibility to improve the business case for public charging infrastructure is the combination with other services, e.g. shopping. The idea is that the option for charging increases the attractiveness of the basic service. In case of shopping that means that more people would visit the shop or buy more while charging. As part of the Green eMotion demonstration, chargers were installed at the parking facilities of 12 REWE sites. The chargers were operated by SMATRICS and also the charging service was provided by SMATRICS. The result of this demonstration was that customers indeed appreciate to have the opportunity for charging during shopping. However, based on the available data it cannot be evaluated if the basic business of shopping was really supported by the charging service. Beside the costs for EVs, also costs for the operation of public charging infrastructure should be minimized whenever possible. On the software side, this can be achieved by sharing of a charge-management-systems in the form of software as a service. Within Green eMotion IBM developed the 'Network Infrastructure Portal' (NIP), which can be offered via the marketplace [6.8].

For what concerns the battery degradation it is pointed out that data did not provide enough evidence to confirm that the battery capacity was actually degrading during the project. Although the battery management systems on board the vehicles themselves report a decreasing SOH, this could not be translated directly into a measureable loss of capacity [6.10].

4. SmartCEM – EU

Four European cities/regions (Barcelona, Gipuzkoa-San Sebastian, Newcastle upon Tyne and Reggio Emilia) came together under the project smartCEM (Smart Connected Electro Mobility) [6.11] from the start of 2012 to the end of 2014, to demonstrate the role of ICT solutions to overcome the limitations of electro mobility for cities and citizens. The objectives of the projects were [6.12]:

- Prove that user acceptance of electrical vehicles can be increased by at least 15% thanks to smartCEM services;
- Evaluate how much the efficiency of transport can be optimised, taking into account environmental sustainability;
- Develop of tools for measuring, monitoring and assessing carbon emissions;
- Identify and address all deployment elements such as business models, legal aspects and privacy;
- Optimization of the energy use in the vehicle and infrastructure;
- Support pan-European interoperability by standardisation between operations performed by different services and facilitating the interoperability between different systems and vehicles;
- A complete integration of new services such as car-sharing within the public transport system;
- Expand the pilot to more cities, operators, or service providers.

This project aimed to achieve the abovementioned objectives through five complementary services:

- EV navigation: navigation of EV charging points or charging stations;

- EV efficiency driving;
- EV trip management: existing multimodal journey planning and potential EV sharing;
- EV charging station management: station operation, station energy management, power supply status, range estimator, charging point booking, payments and scheduling;
- EV sharing management: online and offline.

SmartCEM used a combination of technologies. The hardware architecture was based on the following components:

- On-boards units: a bidirectional onboard system, which is connected to the vehicle CAN bus and manages all internal and external data (from the back office);
- Back office platform: general management system that controls all vehicles, charging spots, energy and commercial transactions;
- Web interface: to give users access to electro mobility management and booking systems;
- Nomadic devices: whose use will also be studied and proposed as an alternative flexible media.

The software architecture was based on standards like web services (SOA, XML, WSDL, SOAP protocol). Standard communication channels such as GSM/UMTS were used and technologies like 5.9 GHz–M5 were studied and proposals were made for their use.

The smartCEM services were implemented and operated in four European pilot sites using different types of vehicles and practices:

- Barcelona focused on motorcycles; there were 141 charging points available for 45 scooters;
- Gipuzkoa combined urban and interurban car-sharing facilities and a hybrid bus in the capital (San Sebastian); there were 33 charging points available for 1 hybrid bus and 30 electric vehicles;
- Newcastle developed the use of existing EVs assigned to the public;
- Reggio Emilia evaluated the potential of light electric vehicles' integration in the car-sharing fleet of a public administration; there are 10 vehicles in the fleet.

Highlights of the smartCEM survey for non-EV users are illustrated in Figure 6.1-1 and Figure 6.1-2, where the main factors that discourage people from buying an EV are: a lack of charging infrastructure, a high market price and a short battery range of EVs; on the other hand, the low running cost is seen as the most important motive to buy an EV, together with the reduction of carbon emissions that is involved in the use of this type of vehicles [6.13]

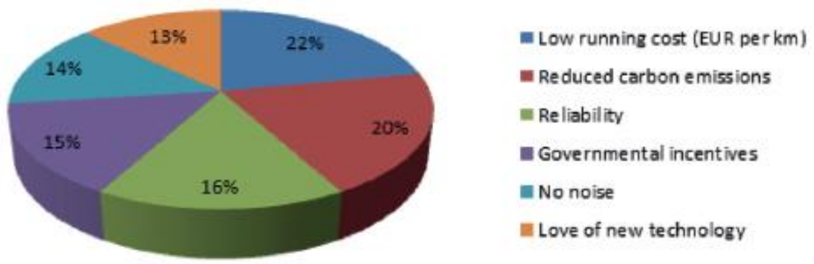

Figure 6.1-1 Factors encouraging to buy an EV [6.13]

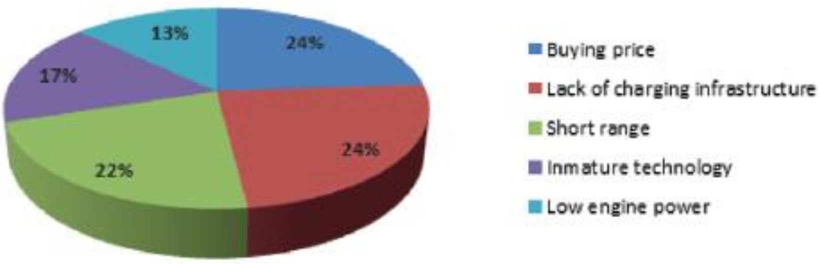

Figure 6.1-2 Factors discouraging from buying an EV [6.13]

5. MeRegioMobil – Germany

The MeReioMobil project [6.14] aimed at a range of goals with the common denominator being the most convenient use of electro mobility, which includes:

- Home charging;
- Public charging;
- Use of the EV as a mobile energy storage;
- Grid provision;
- PV utilization.

Among the services that have to be provided by mean of electro mobility there are: load smoothing in LV network with EV integration and cooperative dynamic mobility plan that makes the most out of the available capacity

In order to implement this, different players have to be involved, such as, energy suppliers, consumers and dealers and the communication among them has to be guaranteed. Therefore, to bring together the different participants of the system an Energy marketplace has been developed, where service providers and customers can interact with each other.

Figure **6.1-3** shows an overview of the project structure.

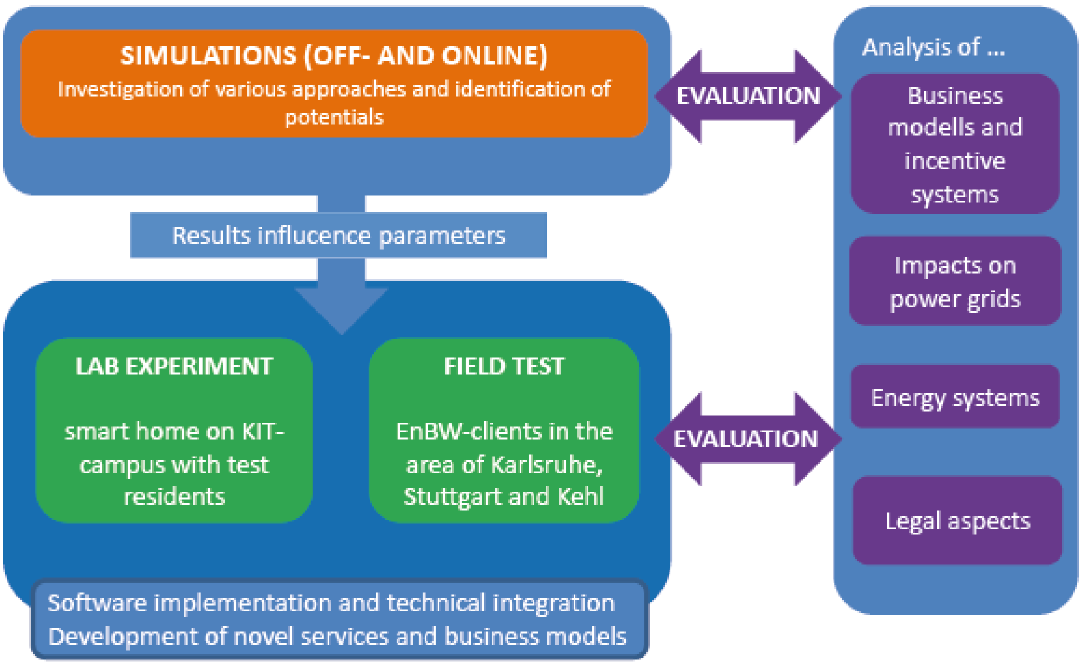

Figure 6.1-3: MeRegioMobil project structure [6.14]

As can be seen from the figure, a laboratory experiment was set up in order to test every aspect within a realistic environment. This consists of a house of 60 m^2 with decentralized energy production such as photovoltaic panels, consumer loads, like washing machine, dish washer and a refrigerator, and energy storage systems that is represented by the EV itself. Every device is monitored by an observer that analyses the behaviour and passes the information to a controller which decide the required interventions. The grid state is also analysed by simulating different grid states; for instance, different time-dependent tariffs are considered. How the decentralized RES production can be optimally coordinated with the energy storage offered by the EV is also another research question for the project: the EV will act as a buffer, to store the excess energy during the off-peak hour and provide in order to reduce the peak load.

Another important aspect is the simulation part: business models, different ICT technologies, consumption behaviour and log-time consequences are analysed. These will be done in parallel with real experiments and the feedback from these will adjust the simulations: online simulations. Offline simulations are however necessary because these are employed before the real experiments are settled, in order to pre-select the appropriate cases to study. Scenarios such as extreme weather, power outage, large share of energy injected in the grid and power outages will be simulated.

Different aspects have to be evaluated: feasibility of business models in terms of EV integration, user acceptance, in the context of how customers accept EVs, how they respond to different business models and their willingness to pay for different services, the impact of different load curves, the power network reinforcement required with a large EV deployment, the possibility to provide balancing services with these stations, the grid impact in terms of stress caused by a significant EV penetration and the economic analyses related to each of the previous. The cost/benefit analysis has to consider the advantages and the costs given by a large EV deployment, such as the requirement of more parking and charging stations.

Once the laboratory tests have been proved effective, field tests were undertaken on a large scale in Karlsruhe, Stuttgart and Kehl. Finally, the main objectives of MeRegioMobil were:

- Business model development;
- Efficient route identification;
- Research and demonstration of EV integration in a smart home;
- Testing of different price models;
- Intelligent charging strategies;
- RES integration;
- Different ICT utilization;
- Evaluation of user acceptance of business model and pricing schemes;
- Evaluation of different incentives;
- Evaluation of the grid impact due to EV deployment;
- Techno-economic analysis of EV integration in the power system.

Although this project is particularly interesting in the context of SEEV4-City because of the synergies, the results of the study has not been made available in a viable public domain.

6. EDISON – Denmark

The EDISON project [6.15] has utilized Danish and international competences to develop optimal system solutions for EV system integration, including network issues, market solutions, and optimal interaction between different energy technologies.

The main goals for the project were:

- To develop system solutions and technologies for Electric vehicles (EVs) and Plug-in hybrid vehicles (PHEVs) which enable a sustainable, economic and reliable energy system where the properties of EVs are utilised in a power system with substantial fluctuating renewable energy.
- To prepare and provide a technical platform for Danish demonstrations of EVs with emphasis on the power system integration aspects.
- To develop standard system solutions for EVs which are applicable globally, by utilising the Danish leading knowledge within distributed energy resources and operation of energy systems with high wind power penetration, and thereby release the potential for Danish export of technology, system solutions, and knowledge.

Results

Five EV charging scenarios have been considered and these are:

- Charging upon plugging (dumb charging);
- Locally controlled charging (timer based or price signal-based charging);
- Aggregated and controlled charging (EV Virtual Power Plant, EVPP, as a balance responsible party);
- Aggregated and controlled charging (EVPP under a balance responsible party);
- Advanced scenario (both decentralized and aggregated control).

A fleet operator aggregates the consumption of a number of EVs and interacts with the electricity market as one unit with a centralized/direct control, and by doing so EVs can participate to the regulation market. This is the major concept in the EDISON project. However, the electricity market study mainly focuses on power markets, prices and price signals. To demonstrate the possibility for EVs to participate in both power market and the market for regulating power an EVPP was developed that took the role of the Fleet Operator. Intelligent charging, battery technology and the different effects of the various charging patterns have been investigated. Both a mathematical model was developed and a lot of laboratory test on batteries were performed. Test showed that intelligent charging schemes can be performed without any negative influence on the battery lifetime.

Using RES to charge EVs as much as possible is one of the major objectives of the project. It has been noticed that when energy produced by wind is injected in the grid the spot prices are low, which means that EVs have to be charged in those times.

The timed charging and fleet operator based EV charging demands are more concentrated, and may cause higher peak demands than dumb charging and may cause congestions in electric distribution networks.

The aim of the grid impact study of EV integration is to investigate and quantify the impact of different EV charging scenarios on the grid operation from the power component loading and voltage drop perspectives.

In the line loading of an urban Bornholm 10 kV system, it has been observed that all the charging strategies can cause overloading. This will cause problems in the distribution grid. The fleet operator has the ability to limit its consumption although in the current market setup there are no incentives to do so. A congestion market is seen as a possible solution; this introduces limits to the maximum transferrable power.

The line loading of the Bornholm 60 kV grid with and without the arbitrary 5 MW limit is considered It is shown that the line overloading can be alleviated by the arbitrary limit. Therefore, it is very important for reducing EV consumption, for instance with smart charging, the grid can be put out of stress which will save significant investments in grid reinforcements.

The major findings of the EV grid impact study results are:

- 20% EV penetration in most cases and the fleet charging scenario benefits are more obvious. The voltage drop along feeders is higher than the limit (5%) with 20% EV penetration and three-phase 16 A charging.
- The transformers and lines are overloaded with high EV penetration (20%) and three-phase 16 A charging. From the loading perspective, the low power charging option is more favourable, i.e. the existing grids can accommodate
- The voltage drop along feeders is higher than the limit (5%) with 20 % EV penetration and three-phase 16 A charging.
- The dumb charging EV demands are well distributed due to the quite flat distribution of EV reaching home time. However, this conclusion has to be verified with fine-tuned EV driving data before it can be used as a general conclusion.
- In the case of three-phase 16 A charging, it is very important to design an efficient scheme to alleviate the congestion caused by EV charging demands, e.g. efficient DSO market to stimulate the EV charging demand, direct control, etc.

Battery testing

An NMC and an LFP battery have been tested. The NMC battery pack has shown negligible capacity degradation since the battery was assembled two years ago, during which, different tests have been conducted, including also repeated fast charging cycles which indicates that the battery has a good capacity retention during cycle life and calendar life. On the other hand, the LFP battery has shown a capacity loss of 10-15 % in 2 years, which means it has a less impressive life time. Temperature has been found to be a critical parameter for the performance and lifetime of the batteries, hence cooling/heating management is an important factor to secure optimal operation of the batteries. The NMC battery has shown a higher increase of temperature during charging and discharging and requires stronger cooling, especially during fast charging whereas, the LFP battery has shown minor temperature changes during cycling under comparable cooling conditions and current rates. The permanent degradation of the cell increases dramatically if the cell voltage goes beyond the given limits. Energy balancing of the cells to the same SOC is crucial. These results however cannot be generalized and should be considered as an indication only. An attempt to develop a battery degradation model has been made but again, an accurate outcome has not been reached. The results should be considered indicative. The conclusion on the battery model validation is that in general, it is possible to model an EV battery's lifetime as a function of the usage pattern at an indicative level, but it is difficult to predict the battery life quantitatively based on any collection of test data of any given load pattern. A Battery Management System (BMS) is seen as a valid solution in order to protect the battery against overloading. The conclusions that can be drawn are: batteries are still a critical component in the EV industrialization due to their high price, technical complexity, limited records of long-term operational data, etc.

BMS functionalities are very important for the optimal use and handling of batteries. To validate battery aging models, one needs to understand the correlation between stress patterns and battery degradation mechanism; the lifetime prediction of the batteries can only be made generically and semi-quantitatively based on the battery type, charging and driving patterns, quality of the battery product and diagnostic measurements of SOH.

Fast charging tests

Three 90 kW DC Fast Charging systems have been used in the Edison Project: Electric Vehicles in a Distributed and Integrated market Using Sustainable Energy and Open Networks (EDISON). The DC chargers were designed to be used for charging and discharging of Li-ion batteries as specified in the specific BMS protocol. The degradations of the electrical performances of the battery cells are very sensitive to the voltage, the current and the temperature, and the loading and operation conditions of the battery should always be kept within the intervals specified for the specific battery to protect the cells from being permanently degraded. Different fast charging profiles, including constant current (CC), constant power (CP), forced power (FP) and pulsed power (PP), and different charging rates, corresponding to 2 C, 3 C and 4 C, have been applied for the two different types of EV batteries. The conclusions from the tests performed are that: if fast charging is done properly, it does not seem to degrade the batteries significantly; the main barrier for fast charging is the heating up of the batteries, requiring efficient cooling system of the batteries in the EV, and the battery's maximum charging current; the batteries can only be partly charged by fast charging. Because fast charging allows charging 50% of the capacity in few minutes, it is seen as a positive option for a quick and easy charging option.

7. COTEVOS – EU

The main aim of the project [6.16] [6.17] is to test the conformance, interoperability and the performance of the system behind the e-mobility, which comprises of, the EVs, the EVSE, the Electric Vehicle Supply Equipment Operator (EVSEO), the E-Mobility Service Provider (EMSP), the energy distributor, the OEM and others depending on the structure of the business model. The compatibilities of different systems for the EV charging, grid interaction and communication among stakeholders are also tested. This is done by looking both at the own performance of the individual component and its function as a part of the system. With this goal, a reference structure for interoperability assessment based on 3 layers has been employed: the first layer involves the stakeholders and the physical components, the second layer introduces the services and the information exchange whereas the third level maps the services in different configurations to test laboratories. The different stakeholders have been included in the reference structure shown in Figure 6.1-4 where the interfaces among the actors are shown. These can be assessed by the available standards but some of them are either unmanaged or have just started to be considered.

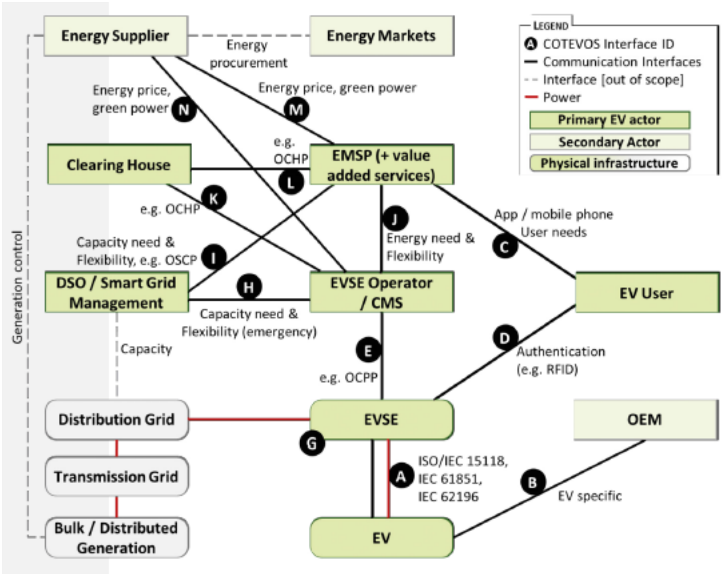

Figure 6.1-4 Reference architecture for COTEVOS [6.16]

In this project, three types of EV utilisation have been considered and these are: private, corporate and car sharing. A number of business models for EV integration have been mentioned: for public and semi-public charging and for private domain charging. Other business models, such as Mobile metering and Fleet management have also been briefly discussed. Different options for EV charging service have been presented: Open access, without roaming, roaming, with roaming through a market place and private charging. According to the necessities, some roles can be merged in one actor.

Figure **6.1-5** shows the information protocol system considered within COTEVOS.

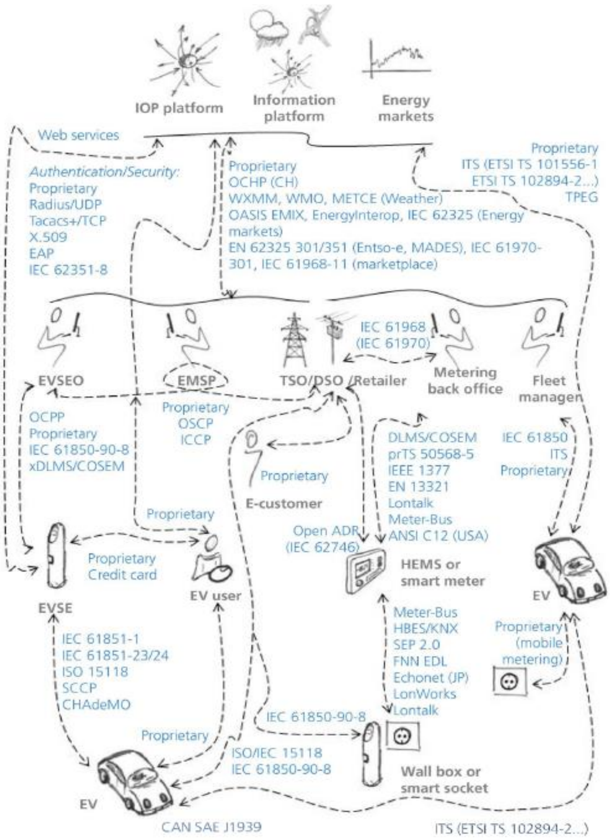

Figure 6.1-5 Information protocols among the stakeholders [6.16]

The most important standards and protocols according to COTEVOS are: IEC 62196, IEC 61851, ISO/IEC 15118, OCPP, OCHP, OICP, IEC 61850 and OSCP. The evaluation made lead to the conclusion that most of the available standards cover the EV-EVSE interface, and for the following services: EVSE search, charging session management, EV, EVSE, charge station management, billing, authorisation, identification and roaming whereas for energy management, grid management and e-mobility services there are very few standards available. And because the regulatory framework covers a fundamental role in the success of a business model, this shows how there are many scopes for the improvement of the current standards and protocols. Furthermore, too many different solutions for the communication between EV and EVSE have been developed, whereas a standardized method for payment, roaming and communication between EVSE and EVSE management system must be developed yet. Finally, seven test cases have been considered to assess interoperability. The EVSE have been tested against existing standards to verify their compliance; a positive result would be the compliance of many EVSE types, which will mean that the standard is sufficiently adopted:

- TC1 considers the coherent functionality of the EV when charging;
- TC2 considers the functionality of the EVSE;
- TC3 highlights the user interaction with the charging point;
- TC4 deals the interaction between the EVSEO and the EMSP;
- TC5 considers the adaptive charging to satisfy grid constrains and market requirements;
- TC6 deals with potential grid services and bidirectional power flows;
- TC7 considers wireless charging.

Moreover, in the 1st V2G Interoperability Plug test COTEVOS provided the technological support to test interoperability. A total of 262 tests were conducted from which 215 tests passed, which means they were compatible with the standards. The remaining 47 did not pass, which means they did not comply with the standards and protocols. Further work that has been suggested are more standardisation for energy management and grid interaction, as well as for the provision of ancillary services, smart charging and V2G. It is suggested to the stakeholders to adopt common standards and avoid the use of proprietary protocol. The requirement of a higher security for the data management and the importance of EV business models have also be pointed out.

6.1.1.2 V2G projects

1. Amsterdam Vehicle 2 Grid Project

The Amsterdam Vehicle 2 Grid project [6.18] addressed the following problems:

- Time mismatch between PV production and household demand;
- An increase of the energy demand due to EVs especially during the evening peak and consequent grid overloading; Figure 6.1-6 illustrates graphically the first two problems and could be the approach to address them properly: EVs are used to store the excess production from PV and to provide it when required;
- Battery degradation caused by an increased cycling, because of Vehicle to Grid (V2G) service provision.

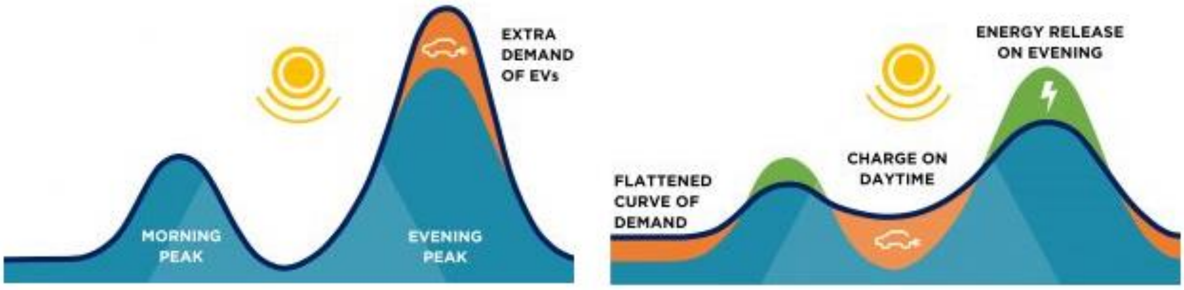

Figure 6.1-6: Daily demand profile increased by EV charging load compared to PV production [6.18]

The main objectives of the project are therefore to optimize the consumption of the local RES, to evaluate what is the behavioural change of the system with the introduction of EVs, and to quantify the minimum level of vehicle autonomy necessary to overcome the social acceptance issue. The system exercised within the project has been modified from its previous setting with the introduction of the EV in a household level. Figure 6.1-7 shows the old and the upgraded system setting.

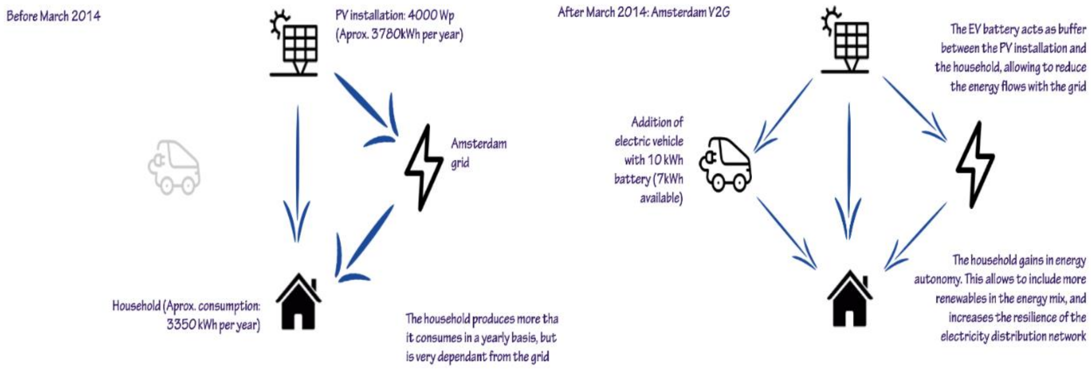

Figure 6.1-7: The old energy system and the upgraded version with the EV [6.18]

Although the annual PV production of 3780 kWh, given by 30m^2 of panels and the annual house consumption of 3350 kWh, seem to match adequately, due to the time divergence between them only 34% of the energy that is consumed by the household had been produced from the PV system; because of this the grid was essential to provide the residual demand. With the introduction of an EV, an e-boat, with an effective storage capacity of 7 kWh, coming from a nominal battery capacity of 10 kWh, the autonomy has been increased considerably. This is done in order to minimize the degradation of the battery by not discharging the battery completely.

Results

During the two years, the household consumption and the PV production vary compared to each other. From the previous figure of 34% for the household consumption from direct PV, with the introduction of an EV, a new value of 65%, of energy consumed by the household, from direct PV or indirect storage from EV is reached. Therefore, the **energy autonomy has been increased by 31%**. Figure 6.1-8 presents the situation of the energy autonomy with and without V2G.

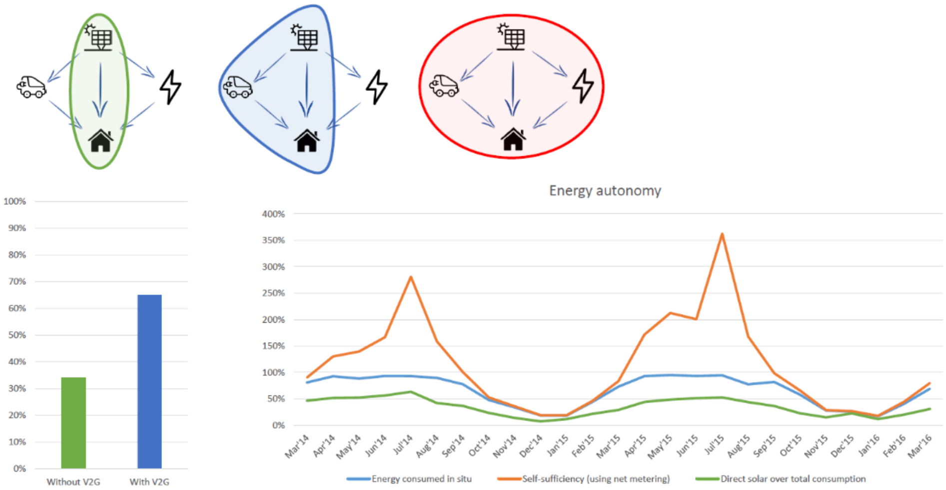

Figure 6.1-8: Energy autonomy with the V2G setting [6.18]

It has been found that with the introduction of the EV, only **36% of the total PV production is injected in the grid** whereas the **33% is stored in the EV**. The remaining supplies directly the household. As for the household energy consumption, with the new settings, the **35%** as before **comes from direct PV**, **33% is purchased from the grid** and **32% is received from the EV battery**. In addition, the battery utilization has been considered: 26% of the total was absorbed from the PV production, 22% has been provided to the household from solar, 23% purchased from the utility and 29% provided to the grid. It is reasonably inferred that if it was not for the EV, all the energy would have been exchanged with the grid: roughly, **grid involvement is halved**. The grid use reduction is also considered: with the V2G setting, the monthly energy flow with the grid is at the lowest. Another research question addressed the appropriate size of the battery in order to optimize the benefits from the PV. With 7 kWh of capacity, the 93% of the PV production has been correctly managed. The battery has been cycled for approximately 500 full cycles in the two years. Investigations on the battery degradation that have been conducted gave the conclusions that, considering only March and September, when the highest battery utilization has been registered, the battery efficiency decreased from 90% to 82% in the two years. The efficiency has been considered representative of the battery degradation because it was defined with the following equation:

$$Efficiency_{ratio} = \frac{V2G}{Solar\ Charge} = \frac{Energy\ to\ household}{Energy\ from\ PV} \tag{1}$$

A not nil degradation will result in a higher energy absorbed and a lower energy provided, therefore the efficiency will decrease. During the winter months this ratio has not been reliable because the battery was not sufficiently used, and for the maintenance operations. To summarise the findings from the project, a good evaluation in terms of energy autonomy has been carried out. However, the definition of energy autonomy that is adopted for this study has not been presented. The vehicle has been considered available throughout the day which does not fit to the reality. A cost-benefit analysis that considers the costs, savings from less grid energy utilization, and revenues from grid provision has not been performed. Furthermore, within the benefit optimization, subsidies are not considered. The battery degradation cost has not been addressed: the degradation has been considered only in terms of efficiency which does not allow to perform any charge optimization with the aim of minimizing battery degradation.

2. Smart grid: profit for all – The Netherlands

From 2012-2015, a consortium of companies, universities and governments worked together on the smart grid of the future services in the project "Smart Grid: profit for all" [6.19] aiming to develop and test a series of new, scalable and user-driven services related to power grids of the future. The tests took place in two medium-sized Dutch smart grids in Utrecht Lombok and Amersfoort Nieuwland, each with one hundred households participating. The purpose of pilot Utrecht is to integrate and use as much solar generation as possible, where participants can either consume the energy produced themselves or sell to the neighbours. Through interaction with the participated residents, the pilot in Amersfoort aimed to develop new services that allow residents to consciously deal with their energy and the electricity they produce, by using smart meters that are installed in the house. By measuring the solar generation and the behaviour of the 'controllable' appliances, a better understanding is achieved for the types of demand and associated flexibility of control, which could then be converted to financial benefits through behaviour changes.

Eight innovative services as follows are developed in co-creation with the end-users with potential results, amongst which E-Car4all, Insight4all, Advice4all and Flex4all foster the acceleration of the energy transition:

1. **E-car4all: Share Cars on solar power from the district**

   54 % more solar power is utilised by coordinating with EV charging.

2. **Insight4all: Understanding consumption and generation per household**

   The Insight4all provides insight into the energy consumption and production for end users, such as households and SMEs, and this awareness could potentially change their behaviour, leading to financial benefits. Main benefits include:

   - Direct cost savings could be achieved with insight into energy save for a household on the consumption of gas and electricity.
   - Insight4All helps people to better cope with their own renewable solar power.
   - For end users, the Insight4All tool (app, smart thermostat, web portal) is often an attractive gadget.
   - Peak load reduction from behaviour changes means less expenditure on network reinforcement.
   - Network operator and energy supplier know the behaviour and preferences of consumers.
   - Insight4All tools can help to deploy smart meters and can also help in the acceptance of the smart meter.
   - If people use a tool that provides insight, it is then possible to also offer other services, such as Profit4All service that shifts demand.

3. **Advice4all: Tailored advice per household**

   Advice4all aims to advise participants when solar power becomes available by forecasts, so that they can increase the share of solar energy in the total energy consumption. Through specific advice on when to use their own generation, an individual household achieves on average 12% direct cost save on consumption of gas and electricity.

4. **Flex4all: Optimal timing by automatic control (demand side management)**

Flex4All examines the feasibility of using household electrical appliances for demand side management, and negligible profits have been achieved even regardless of the cost for energy management system. The business case in the pilot in Amersfoort points out the importance of ICT technology and the requirement for its further development.

5. **Profit4all: Incentives send energy behaviour (smart charging)**

The service concept Profit4all aims at households to shift their energy consumption to adapt to the available energy supply, with price incentives. A web portal is developed with information of daily price profile, which is inversely proportional to the energy availability. It is shown in the pilot in Amersfoort that the participants manage to achieve an energy consumption increase of more than 10% in the sunny hours. It is learned during the pilot percentage of energy can be shifted by financial compensation, however the development of this service as a separate business model is not viable. Adjustments in current legislation in the field of energy prices for the consumer is still required.

6. **Solar4all: Prediction of solar**

This service predicts the output of individual solar installations in the short term, i.e. for the next five minutes to two or three hours. This prediction is provided to the owners of the solar panels, network operators and energy suppliers. Potential benefits include:

- program managers and the TSO can better anticipate the power imbalance and thereby reduce it;
- network operators will be better able to foresee better pressure on the network, thus they can better plan maintenance;
- Energy traders can make better energy price predictions.
    - The prediction service consists of many third parties owned PV systems, upon which the service depends, implying a risk to its viability. The proper functioning of this service will depend heavily on the continuous quality of the data provided.

7. **Storage4all: Storage of solar power (V2G)**

V2G function is enabled by using EV battery as storage to better match supply with demand. A Nissan Leaf with its discharging system is used in pilot Lombok. Unfortunately, no relevant measurements were taken due to low solar radiation at the time.

8. **Together4all: Corporate smart energy services**

Rather than being controlled as individuals, the households gather as a group in this Together4all service to approach products and services through offered by companies. Companies involved in this pilot are Miele, Shifft, Stedin. Operating in such a manner lowers the communication/ marketing cost and also encourage people to actively share information with each other. Participants using this service show more active involvement in energy coronation. As a result, a large amount of energy has been saved during the pilot implementation. For example, the energy consumption of all the participants at night is decreased by 20%, and the associated total energy saving is 15 %. However, it is difficult to achieve a positive business case for this service due to the facilitator payment by a company.

3. G4V project – EU

The objective of the G4V project, [6.20] is to develop an analytical method to evaluate the impact of a large scale introduction of EV and PHEV on the grid infrastructure and a visionary "road map" for the year 2020 and beyond, taking into account all stakeholders and generating fast and openly available results.

Three different scenarios are used to develop the project ("conservative world", "pragmatic world," and "advanced world"), in each of which the values of some key parameters are considered such as charging control, prices, services, grid infrastructure, ICT and stakeholders - as shown in Figure 6.1-9.

	Conservative World	Pragmatic World	Advanced World
Charging control	No	Yes, simple charging control	Yes, complex charging control
Prices	As today	Dynamic tariffs	No limitation
Regulation	Conservative	Some liberalization	Optimal situation for EVs
Services	Unidirectional, no services	Unidirectional, all services can be provided	Bidirectional, all services can be provided
Grid infrastructure	Conventional development	Smart grids	Advanced smart grids, virtual power plant etc.
ICT	As today	Innovative	Advanced
Stakeholders	Traditional stakeholders	Traditional stakeholders with new roles	New stakeholders

Figure 6.1-9: Scenario description for G4V project [6.20]

For what concerns system operation and control strategies, the case of aggregation has been considered; this facilitates the provision of flexibility services by EVs. A decentralised market-based approach (EVs decide locally when to charge/discharge according to price signals that include the cost of generation and the cost of network constrains) instead requires advanced ICT and a market/cost-based approach. The results are evaluated from technical aspects, social aspects, ecological aspects and economic aspects.

Stochastic load flow simulation is used to obtain results of overloads in lines and sub-stations. It is found that control strategies can postpone reinforcement for considerable penetration levels even if some grids can integrate 100% EVs even without any control strategy.

Considering the economic impact of electro-mobility and also the role of the EVs in integrating renewable energy source, the approach is to undertake a minimization of overall production costs. It is pointed out that an increase in peak demand due to EV uptake will increase more than the increase in energy demand, and there would be a significant reduction in asset utilisation if uncontrolled but flexibility of EVs is significant, for example considering that cars are stationary 90% of the time. There is an analysis of integration of wind using EVs as energy storage in the case of Spain, considering a penetration of 10% but assuming that the charge of vehicles is done in the off-peak hours of demand and doing the analysis considering the demand of the whole country. Optimized charging is indicated as a way to reduce operational costs and to increase asset utilisation. However, additional gains due to V2G compared to uni-directional charging are considered as relatively marginal and a deeper analysis involving all relevant costs (such as ICT, battery value etc.) is proposed.

Indications are given about control strategies that should be flexible and adjustable to market penetration level of EVs and should be controlled including the needs and constrains of the DSOs. From environmental, social, economic points of view V2G was seen as a non-profitable business at the moment the project took place. The consideration about bi-directional strategies is that they should be reconsidered for a large penetration of EVs. It is worth pointing out that more attention has been given to costs of infrastructure and grid reinforcement like lines and transformers in this project and less to others, for example battery degradation.

4. SME project – EU

Smart Mobile Energy (SME) [6.21], a six-month Climate-KIC supported project, investigating how cities can increase energy efficiency, minimise grid impact, increase renewable contribution and generate profit by integrating smart charging and V2G technology into the existing energy infrastructure at district and city scale. Technical assessment is carried out with evaluation of the developed business models for V2G implementation across pilots in Birmingham, Berlin and Valencia. The EV projection figures indicate an increased grid loading due to EV charging, and this has to be addressed with managed charging and V2G. Other aspects that have been considered are a higher contribution of renewable which has significant impacts on the power flows across the distribution network and the important role of the aggregator. In Birmingham, Firm Frequency Response (FFR) provision with V2G and smart charging have been compared against standard charging. Generation from solar PV were also included, even though the high outlay for panel infrastructure and the diminishing Feed-in-Tariff (FiT) do not give an overall economic benefit. The aggregator takes care of the smart charging and V2G. The Net Present Value (NPV) has been found positive for smart charging, whereas by applying V2G a negative NPV is obtained. Figure 6.1-10 shows the results:

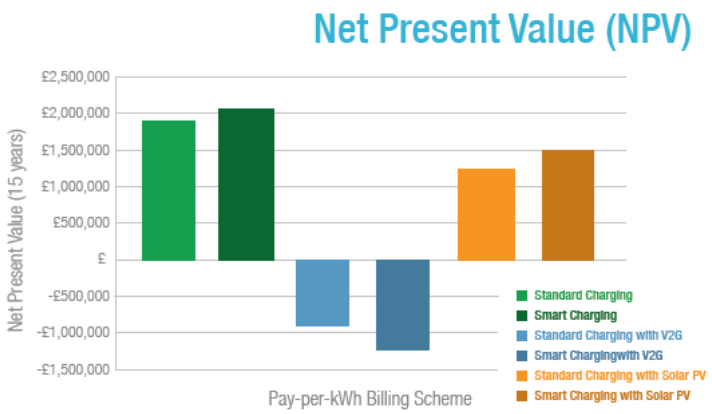

Figure 6.1-10 NPV for standard, smart and V2G charging including solar PV [6.21]

Moreover, smart charging is effective in reducing network infrastructure upgrade and increase consequently increase the profitability. It has been assumed that, because with V2G the EV must be connected to the charging point the whole day, this results in an increased need of charging points, which, along with a higher cost for a V2G capable charging point, causes higher infrastructure cost.

For Berlin, the potential of V2G in commercial transport fleets has been evaluated. Power regulation system and distribution grid capacity in Germany have been identified as the main constraints for V2G. Services such as Secondary reserve and Minute reserve have been provided, and the results in terms of potential revenues and earnings are shown in Figure 6.1-11.

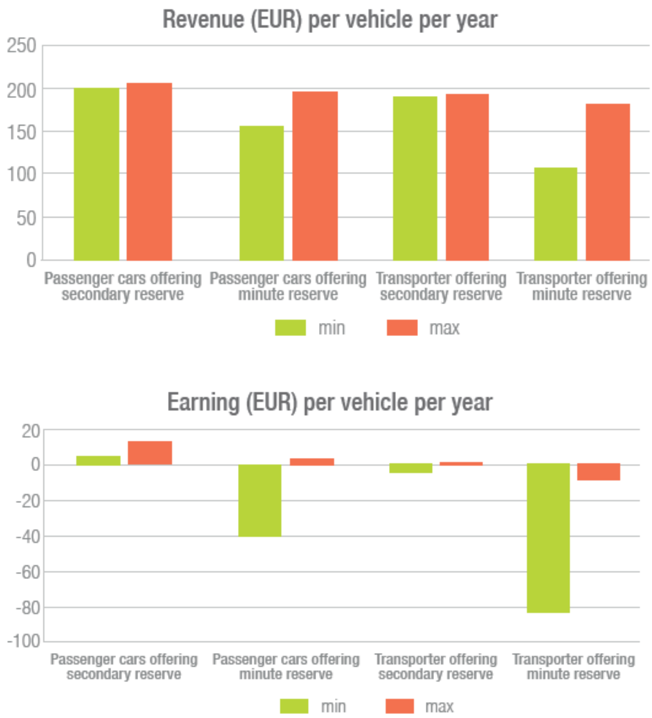

Figure 6.1-11 Revenues and earnings for different services [6.21]

The limited earnings of 13.20 €/vehicle/year does not seem appealing to attract fleet operators.

In Spain, electric regulation does not allow V2G and aggregators do not exist. The main aim was evaluating the feasibility of V2G deployment. Different aspects have been considered among which, the effect of infrastructure costs, infrastructure usage, V2G feasibility, charging session prices on the NPV and the Internal Rate of Return (IRR). The results are shown in

Figure **6.1-12**.

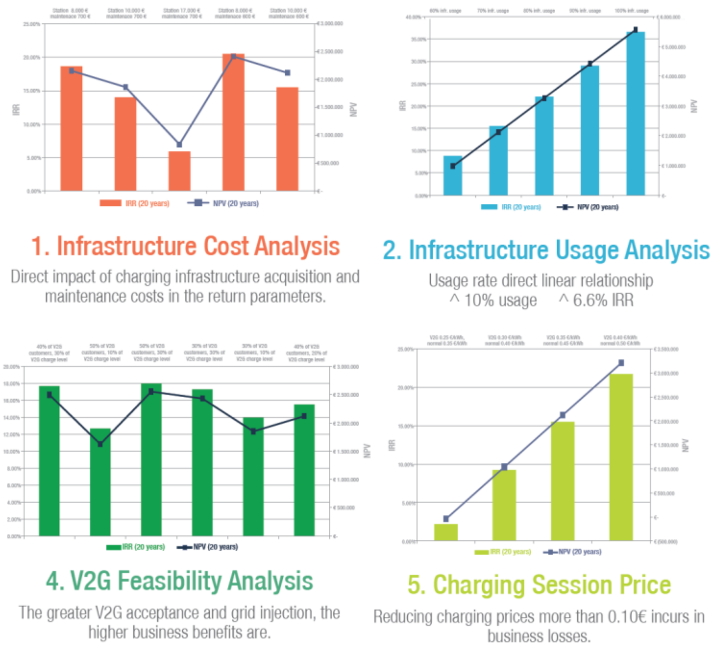

Figure 6.1-12 NPV and IRR in different scenarios [6.21]

V2G is profitable from all perspectives: with 150 V2G stations, the payback range goes from 7 to 10 years and the IRR is around 15%. Besides, V2G helps to flatten the demand curve and avoid massive charging during peak hours.

5. CENIT VERDE- Spain

CENIT VERDE [6.22] [6.23] was a Spanish program that supports technological research, in collaboration with the Ministry on Economy and Competitiveness and the Centre of Industrial Technological Development. The main goal is to create a key technology for the entire value chain of green vehicles and reduce costs by localization of main components and services. In addition, it supports the achievement of the Spain's three main objectives:

- Reduce national petrol energy dependence;
- Reduce CO_2 emissions from transportation and increase the use and business of RES;
- Assure the industrial sector and Automotive R&D activities in Spain in the future.

It started at the beginning of 2010 and ended in 2013. SEAT was the project leader, with the followed activity leaders: CeGASA, Siemens and the LEAR Corporation for the development of an Ecological Vehicle and Cobra, IBERDROLA and Endesa for the charging infrastructure and distribution side. Other private companies and public research organizations were also involved. The research field and issues addressed in this project considered 6 areas:

- Area 1: Vehicle definition and architecture. Global specification and validation;
- Area 2: Energy storing systems for PHEV/EV;
- Area 3: Electric propulsion for PHEV and EV;
- Area 4: Design of multimode bidirectional chargers for PHEV and EV;
- Area 5: Local charging infrastructure for PHEV and EV;
- Area 6: Integration of the vehicle in the electrical system which includes the following:
  - Characterisation of the vehicle as an electric load;
  - Evaluation of the impact of a massive introduction of EVs/PHEVs;
  - Definition of charging strategies that allow the integration of RES;
  - Integration of EVs/PHEVs in a Smart grid;
  - Development of operating models for an efficient and massive introduction of EVs/PHEVs.

In 2012, a sub-project of VERDE, called Prototype "VERDE" Vehicle (PVV), built a drivable plug-in hybrid vehicle including V2G technology. Some of the results are presented hereafter. Figure 6.1-13 depicts the full Life Cycle Analysis of three types of vehicles: ICE, PHEV and BEV.

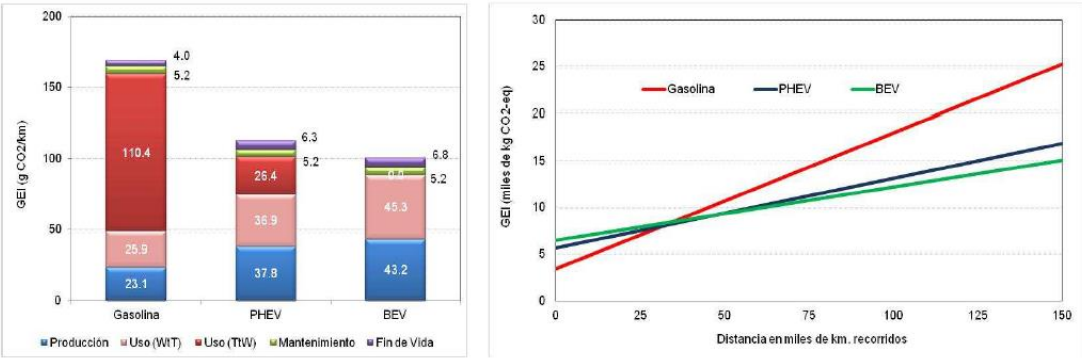

Figure 6.1-13 CO2 emissions per km considering the Lifecycle and emissions against driven distance [6.23]

The two figures show the CO_2 emitted per km and during the lifetime from the three vehicles; although PHEV and EV have significantly less emissions compared to the ICE, between these two the difference is small and as can be seen the breakeven point for PHEV/EV with the ICE vehicle in terms of CO2 emission is at around 37,000 km. Before that, ICEs emit less CO2 due to the manufacturing of PHEVs/EVs. The impact of the PHEVs/BEVs is also compared against the ICE, and shown in Figure 6.1-14.

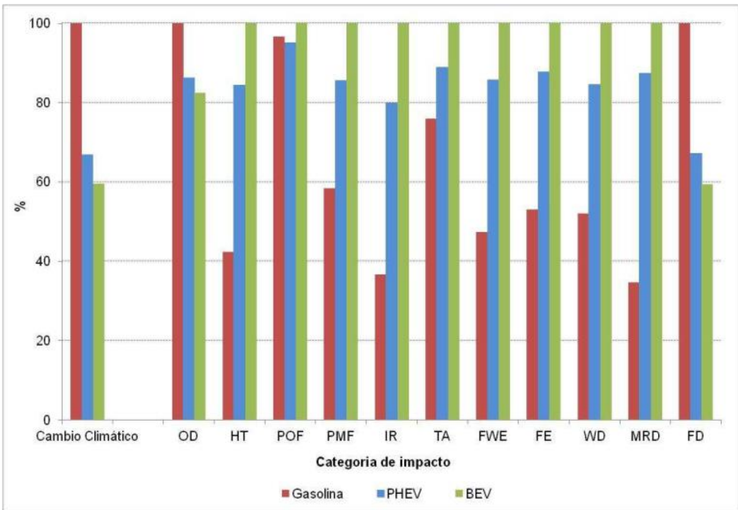

Figure 6.1-14 Environmental parameters of PHEVs and BEVs compared to ICE vehicles [6.23]

The different parameters shown for the three types of vehicles are: climate change (CC), ozone depletion (OD), human toxicity (HT), photochemical oxidant formation (POF), particulate matter formation (PMF), ionizing radiation (IR), terrestrial acidification (TA), fresh water eutrophication (FE), water depletion (WD), mineral resource depletion (MRD) and fossil depletion (FD). From the figure, it is clear that even though EVs ensure less CO_2 emissions, in terms of some of the other impact factors they are higher than that ICE vehicles. Other results that have been obtained include a central EV energy demand management system, DSM (EV demand forecasting and user consumption habits influence) models for geographical distribution of EVs and simulator for the load level at High Voltage energy transport infrastructure (14 MVE).

<u>6. Nikola – Denmark</u>

Funded by ForskEl and the Danish public service obligation (PSO) funds managed by the Danish TSO Energinet, with an active period that extends from 2013 to 2016, this project aimed at demonstrating the synergies between EVs and the power system [6.24]. The objective was to use charging strategies to minimize the operational cost of the whole power system from a societal and grid point of view. Seen from an EV owner point of view, this may be translated into operating electricity cost reduction and therefore into a more competitiveness of EVs against ICE vehicles. The “services” that EVs can offer that allow this synergy and the required technologies were investigated and demonstrated with simulations and field-testing. According to the level of the power system to which these services add value, they are classified in *System-wide services*, such as frequency regulation, *Distribution system services* - like LVN balancing - and *User-added services* which give user the information and control on the charging process. An example of the project’s experiments is shown in Figure 6.1-15.

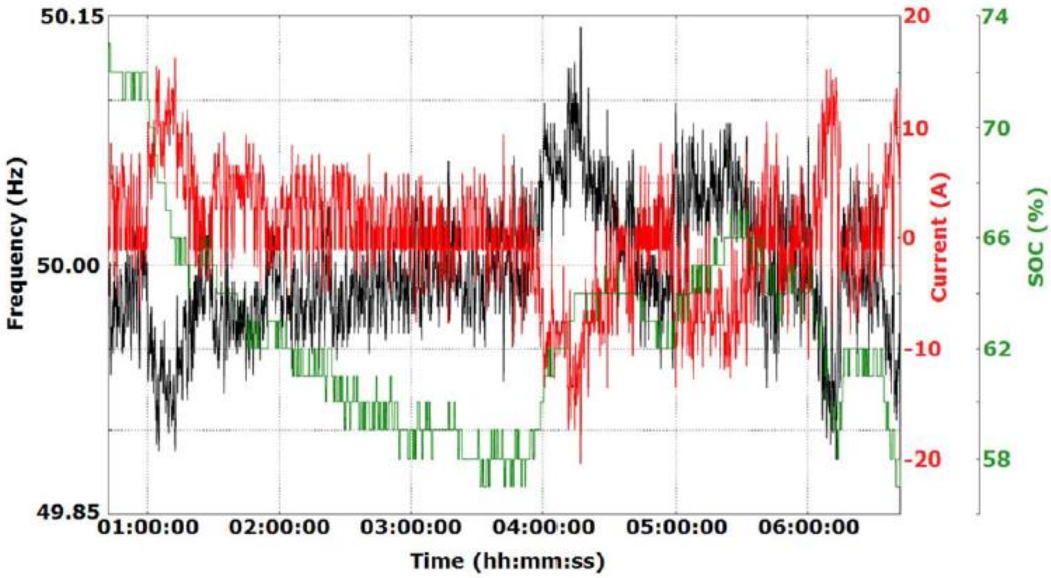

Figure 6.1-15 Experiment of frequency regulation in the Nikola project [6.24]

The black curve represents the system frequency, the red curve is the vehicle response in terms of charging/discharging (negative/positive) to the former, and the green curve is the battery SOC. As can be seen, the EV is able to adjust its charging behaviour according to the status of the system. In the seminar that signed the conclusion of the project, a Syslab test showed the operation of 6 EVs performing local voltage support once connected to the public distribution grid and when islanded, Frequency Regulation [6.25].

7. ITHECA - UK

Intelligent Transport, Heating and Control Agent (ITHECA) [6.26] wanted to prove the potential of V2G to maximise a combined heat and power (CHP) plant by showing the collaboration of transportation, frequency response, energy storage service and district heat solutions with EVs. Intelligent scheduling of EVs maximises the output. It lasted from January 2015 until June 2017, and it involved the European Bioenergy Research Institute (EBRI) at Aston University where the UK’s first V2G unit was installed as well as Cenex UK. The outcomes are a definition of the technical requirement for V2G, a business case for V2G operation, and a definition of the operational conditions for V2G implementation in real life with a fully operating V2G. A schematic of the project boundaries can be found in Figure 6.1-16.

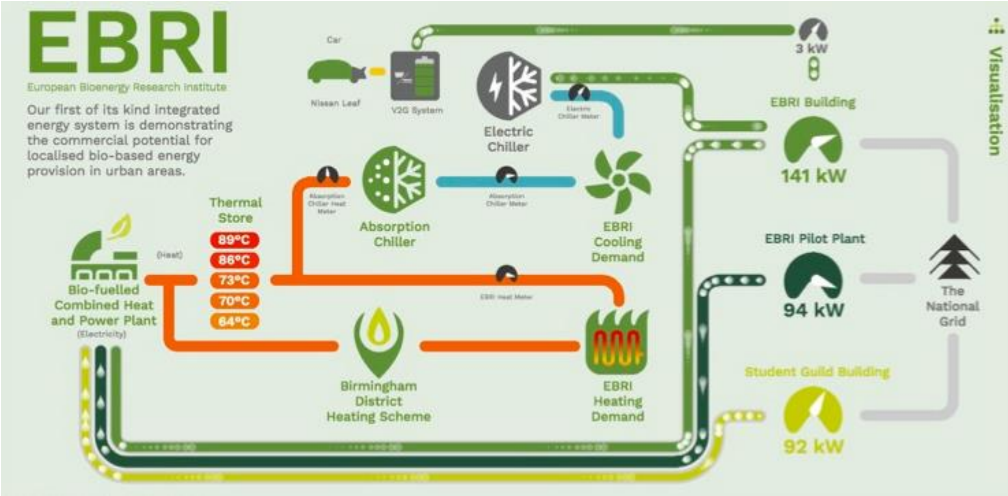

Figure 6.1-16 Schematics depicting the boundaries of ITHECA [6.26]

8. Living lab smart charging project – The Netherlands

The Living Lab Smart Charging project [6.27] runs under ElaadNL [6.28], which aims to examine and test and possibilities for smart charging with integration of EVs and renewables. The Living Lab Smart Charging project offers an open platform to support smart charging, involving charging station companies and network operators. The main focus of the project is to make the most of the renewable generations from wind and solar by controlling the charging load. By now 325 municipalities in the Netherlands (including Amsterdam, Rotterdam, Utrecht and The Hague) have participated in the projects. The municipalities represent 80% of the public chargers in The Netherlands, and now private and semi-private charging station companies such as The New Motion and EV-Box have joined. Electric vehicle owners using the stations are able to set their preferences for charging using an app, and they can also obtain revenue by responding to the grid requirements.

This project is planned for 3 steps:

1. A nation-wide deployment and upgrade of charging stations for smart charging. For example, 2500 new charging points are rolled out by the southern provinces of Noord-Brabant and Limburg;
2. Validation of the smart charging using the stations. For instance, V2G is tested in Utrecht together with Renault by using EVs as storage to coordinate with solar generation;
3. Standardization establishment based on the Dutch experience with smart charging including tests and research findings.

The project is implemented using an open market model, e-claring.net [6.29] which is a platform with the purpose to exchange roaming authorisation, charge transaction and charge point information data. The connection to e-clearing.net for interested parties is enabled by an open protocol, the Open Clearing House Protocol (OCHP) [6.30], which allows communication between the back-end system of each partners and a clearing house system in a simple way. The structure between primary stakeholders is illustrated in Figure 6.1-17, where the Electric Vehicle Service Provider (EVSP) issues the contracted EV user authorization tokens that give authorization to use the charging stations of contracted Electric Vehicle Supply Equipment (EVSE) Operators. EVSP pays the EVSE operator for the charging services received by its contracted EV users, and sets up billing processes with these EV users. The NSP offers service towards the EV user for searching, locating and routing to EVSEs of the contracted EVSE operators. It therefore may have contracts with EVSE operators or EVSPs.

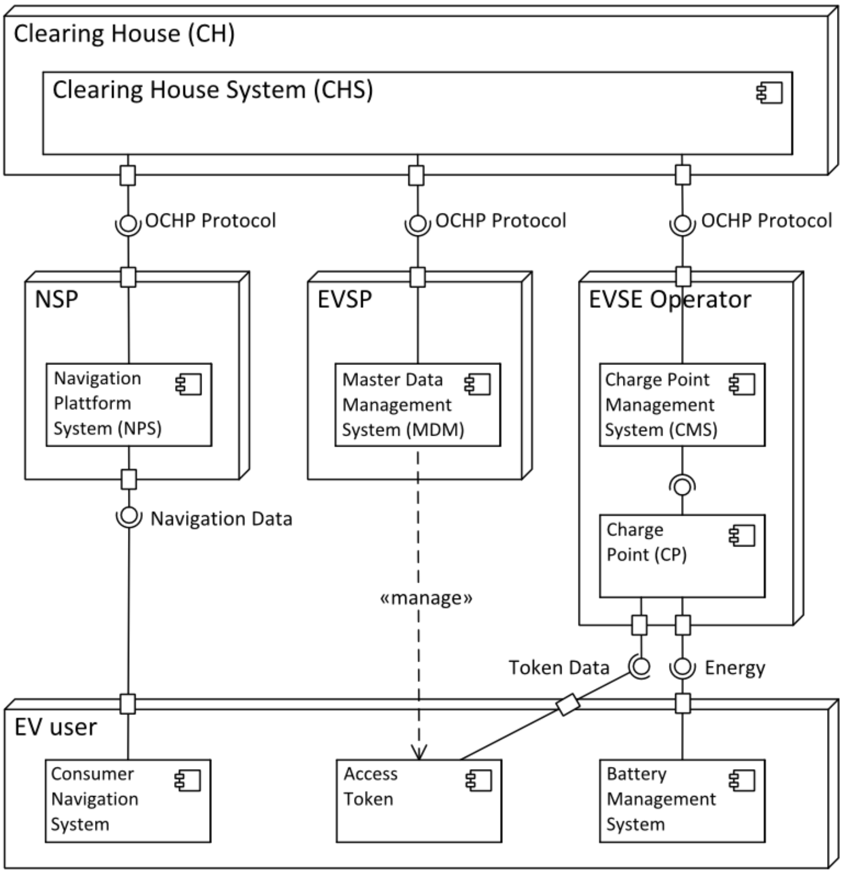

Figure 6.1-17: OCHP structure [6.30]

Project findings and conclusions (summarised in [6.31])

Consumer Behaviour

Most Dutch EVs are not used for about 90% of the time, which makes their batteries available for other purposes. A model was developed by simulating the potential value of V2G for one year. The model used settlement prices of the Dutch RRP (regulating and reserve power) market from 2014 to 2015, along with charging and driving characteristics of Dutch EV drivers. Results show substantial effects of RRP provision in terms of monetary benefits, battery throughput and SOC (state-of-charge) distribution. Provision of RRP resulted in monetary benefits in the range between €120 and €750 annually per EV owner, depending on EV and user category. This is accompanied by increased battery throughput and lower SOC distributions.

Regulatory Issues

The move from central to decentralised energy production, combined with V2G, gives some perverse incentives. For The Netherlands, the following tax barriers which hinder smart charging are identified:

- The lack of netting for charged and discharged kWh in case of bi-directional charging leads to unintended double energy taxation;
- There is no adequate energy taxation incentive for efficient use of locally generated renewable energy in combination with smart charging;

- There is no level playing field between public and private charging points; as a consequence, the incentive for smart charging, if any, varies considerably from site to site;
- The Dutch netting scheme does not provide incentives for optimising own use by means of smart charging;
- Consumption cannot be clustered, neither physically nor virtually; this complicates the free choice of energy provider and causes an additional administrative burden;
- VAT liability for EV drivers upon receiving compensation for providing an EV for bi-directional charging.

Fortunately, there are possible solutions for breaking these tax barriers. Some are short-term possible solutions. For example, storage may be interpreted in regulation as a service in respect of energy taxation in case of bi-directional charging. As such, energy taxation would only be due on net amount of charged kWh by power provider. This may provide a solution for multiple energy taxation in situations with and without netting scheme. Clarification of netting legislation is needed to the extent that netting applies in the context of smart charging that uses storage. As such, energy taxation will only be due on the net balance consumed. It is for the government to provide clarity on VAT approach of EV drivers and virtual netting. All these solutions can be fixed on a short term in the regulatory framework. Long-term solutions are also needed. One of the possible solutions for a slightly longer term includes introduction of a fixed (lower) rate, for charging EVs with renewable energy, in which the service provider can be designated as the taxable subject and the EV driver as user. This will create a more level playing field for charging electric vehicles by means of public and private charging stations. Consequently, the level of the rate will no longer depend on the site of charging. This rate may be applied to offer incentives at peak power demand hours and also provides government with better options for control and insight.

<u>9. Electric Nation Project – UK</u>

The Electric Nation Project [6.32] was funded by Western Power Distribution's Network Innovation Allowance (NIA). Launched in September 2016, this project engaged 500-700 EV drivers in the trial, which will help the Distribution Network Operators increase their understanding of the impact of EVs on their networks and how this impact could be reduced using smart chargers. The project focuses on the local electricity networks that supply homes and small businesses – the low voltage (LV) network. The trial focussed on domestic EV charging between January 2017 and December 2018. 673 smart chargers were installed at participants' homes throughout WPD's licence areas. The trial included 40 different types, makes or models of EVs. Smart Charging for the trial was provided by GreenFlux and CrowdCharge. These suppliers used different control algorithms and customer facing systems. For the purposes of the trial, EV owners were given smart chargers that were capable of reporting when an EV was plugged in and when it was actively charging the EV. Additionally, these chargers were also capable of receiving instructions to reduce or pause charging.

The project aimed to provide local electricity network operators with the tools to be able to ensure that their networks can cope with this massive new challenge, whilst avoiding replacing cables and substations. This aim is achieved by:

- Expanding the current understanding of the impact on electricity distribution networks of charging a diverse range of electric vehicles at home.
    - The My Electric Avenue project was able to build up a bank of knowledge, however this trial was confined to one type of EV with the same battery size and charging rate. This project was seeking to discover how the impact will be altered by different types of vehicles with different sizes of batteries that charge at different rates.

- Building a better understanding of how vehicle usage affects charging behaviour given diversity of charging rate and battery size.
- Evaluating the acceptability to owners of EVs of smart charging systems and the influence these have on charging behaviour. This will help to answer such questions as:
    - Would charging restrictions be acceptable to customers?
    - Can customer preference be incorporated into the system?
    - Is some form of incentive required?
    - Is such a system 'fair'?
    - Can such a system work?

Having the afore-mentioned aims in mind, each trial participant was provided a smart charger, through which their EVs is charged at home. Some trial participants had access to a mobile phone app which allows them to enter information about their journey preferences and receive information about when they've charged their car and any demand control events they've been part of. All customers had the ability to override charge control events to ensure that they can get their car fully charged when required. By the end of each charge control solution trail, the participants were required to take part in a number of online surveys regarding the EV owning and charging experience, and acceptability of the charge control solution.

In conclusion:

Data from the trial shows flexibility in charging – but without an incentive the demand in the evening peak requires management.

Demand management is technically feasible, and acceptable to the majority of trial participants.

Trial data shows that Time of Use incentives appear to be highly effective at moving demand away from the evening peak – particularly when supported by Smart Charging (with an app), which makes it simple for the user.

Smart Charging can:

- Support the introduction and management of ToU based charging; and provide a means to manage any negative consequences of mass uptake of ToU incentives;
- Data from smart chargers, similar to those used in Electric Nation, can provide a strong data source for building an evidence base for future developments.

<u>10. BaChMan Project – UK/China</u>

The UK/China research on Battery Characterisation and Management – the BaChMan project [6.33] was funded by the UK Engineering and Physical Sciences Research Council (EPSRC) and the National Natural Science Foundation of China (NSFC), involving a range of institutions and industries partners from China and UK. The project started from September 2013, and has been studying the lithium battery cell development and degradation under V2G operation and investigate grid scale energy storage. Work Package 3, focused on the V2G control where low voltage power system, to which most EVs would be connected, is modelled in details and the potential smart charging and V2G strategies are implemented on top.

The potential economic benefits that can be procured are investigated in smart charging [6.34] and V2G [6.35] in both of which the network operational limits and the user requirement for transportation are satisfied. Both cases are based on price arbitrage. A typical radial-layout distribution network with 17 households was used in the former case and the daily charging cost totals £10.92 by smart charging, in contrast to £17.64 for the uncontrolled charging case, achieving a 38% reduction of EV charging cost. The latter case further explored the value created by V2G using an IEEE30 network, and it is claimed by [6.35] that the scenario with V2G can potentially save 13.6% on charging costs in comparison to the scenario without V2G, which refers to the smart charging case.

Value creation from smart charging and V2G showed promising results using price arbitrage. However, the battery degradation cost has not been properly taken into account, though a fixed degradation rate of 0.028 £/kWh is used in [6.34] during the battery cycling.

In [6.36] control of the charging of electric vehicles located at car parks is used, without any storage, to increase the solar power generation capacity within a radial distribution network while satisfying the power system constraints and electric vehicle user requirements. A UKGDS network with solar farms and EV car parks is used as a case study, and the results show a 72.2% reduction on energy loss in the distribution network and also that the voltage constraint violation and thermal limit violations have been significantly reduced.

11. ITSES project – UK

Integrated Transport and Smart Energy for Major Urban Developments (ITSES) [6.37] was a collaborative technical feasibility study between Cenex and Costain, aiming for new technical solutions and business models for integrating V2G with urban energy and transport system, thus reducing the demand on the grid. Funded by Innovate UK, this study utilises two planned pilot sites at rail stations of old oak common and Park Royal, an area in London set to become a UK example of Smart and Integrated City, to assess the technical feasibility, commercial viability and social benefits from V2G.

Project results

Leading on the assessment of the technical, social and economic benefit of V2G within the smart city re-development, the study explored:

- The technical feasibility of installing V2G at the two pilot sites identifying electricity network infrastructure, building demand requirements and vehicle use patterns.
- The economic case by evaluating the economics relating to infrastructure installation, building demand support options and market trading opportunities.
- The social benefits to the wider community, commuters and vehicle owners using the site in order to establish a robust business case for installation of the technology at both the pilot sites and Old Oak Common.
- Unlocking new opportunities for businesses, infrastructure and the communities will provide the UK with a real-world analysis of the potential for a large scale roll out of V2G. Market research and investigations found suitable models to enable commercial viability for the technology, and the sites studied represent an ideal project for deployment.

12. EFES project – UK

Partially funded by Innovate UK and the Engineering and Physical Sciences Research Council (EPSRC) the 3-year EFES project [6.38] sought to manage, improve and reduce the electricity use of UK buildings, from single properties through to large commercial premises. This was achieved through the development of three key technologies: a virtual power plant (VPP) or aggregator, V2G unit, and V2G gateway which provides the control functionality for the V2G unit, enabling the unit to communicate with both a building and the VPP to determine the most appropriate charging or discharging option. Commercial system modelling has indicated significant economic savings for buildings with V2G provision. For example, Manchester Science Park could achieve annual savings of over £14,000; a monthly income of around £60 could be obtained for each vehicle that bid into the energy markets such as the short-term operating reserve.

13. DOD V2G Pilot Project – USA

The Department of Defence (DOD) started the project [6.39] and the aim is to develop the Plug-in Electric Vehicle (PEV) strategy, to proof the concept that PEVs can perform energy services, to show the benefits, both technical and economical and promote the integration of a large scale of PEVs in the DOD non-tactical ground fleet. One of the main objectives is to determine the Total Cost of Ownership of vehicles and infrastructure, hence among the activities that have been completed to date some relevant ones are:

- Cost-benefit analysis of V2G and PEV charging infrastructure analysis;
- Business case analysis for V2G and non-V2G fleet;
- The Los Angeles AFB, the first federal facility to have a 100 % PEV general purpose fleet;
- V2G pilot in 6 DOD sites.

Among the network services available, Frequency Regulation (FR), Spinning Reserve (SR) and Peak Power Shaving have been identified as potentially approachable and FR has been described as the best match for V2G whereas SR a good match for V2G. The case study consists of a EV Sedan Fleet in Southern California where the lease price is 200$/month, with 15 kW bidirectional chargers, 12000 miles driven a year, typical operation from 9 a.m. to 5 p.m. and participating only in the FR market of the California ISO. Some of the results of the cost-benefit analysis are presented below:

- The total value in 2011 was 2520$ a year or 210$ a month considering the markets open 24/7 for 365 days a year;
- The monthly lease price of a PEV Sedan can be reduced by 72% by providing frequency regulation, when the vehicles are used during normal business hours, from 8 a.m. to 5 p.m., Monday to Friday.

These results are further highlighted when compared against an ICE Sedan, and are shown in Figure 6.1-18.

ICE Sedan	V2G Sedan
GSA lease price: $174/month Operating cost ($.145/mile): $145/month **Net Cost: $319/month**	Base lease price: $200/month Operating cost ($.06/mile): $60/month V2G value: $150/mo **Net Cost: $110/month**
Net Savings for V2G: $209/month	

Figure 6.1-18 Cost comparison between conventional ICE car and EV with V2G technology [6.39]

As can be seen, not only have PEVs lower operating costs (mainly fuel cost) but they can provide profit from FR which allows a lower cost per month. The impact on the battery has also been addressed for driving, Peak-shaving and FR and for two types of vehicles: trucks and cars. The results in terms of extra number of cycles and the related DoDs are presented in Figure 6.1-19.

Truck				
Truck Total Energy Cycles				
Energy cycles per year				
Driving	240	cycles at	39%	% SOC/day
Peak-shaving	72	cycles at	60%	DOD/day
Frequency Regulation	61,020	cycles at	2.1%	Ave. change in SOC% /cycle
Other	24	cycles at	60%	DOD/day

Auto				
Auto Total Energy Cycles				
Energy cycles per year				
Driving	240	cycles at	50%	% SOC/day
Peak-shaving	72	cycles at	60%	DOD/day
Frequency Regulation	61,020	cycles at	2.1%	Ave. change in SOC% /cycle
Other	24	cycles at	60%	DOD/day

Figure 6.1-19 Battery cycles for different purposes including network services [6.39]

As can be seen, although V2G services cause extra cycling, resulting in additional degradation compared to driving, the number of cycles and the related DOD depends upon the service. Even though FR requires more cycles, these are much shallower than those in peak shaving, hence their effect is comparatively less. The fleet management is performed with a user interface where the participant tells when the vehicle is going to be used and where it will be travelling. The system projects the battery state upon return and determines the charging schedules for the next use and bids in the relevant market. From the findings, it can be concluded that PEVs can compete against conventional vehicles in terms of Total Cost of Ownership or be even better; bureaucratic barriers are more challenging than the technical ones in order to commercially implement V2G.

14. VEHICLE2GRID PROJECT: The Netherlands

Scope of the project [6.40] is to evaluate business models for V2G, through consumer research, in order to facilitate the adoption. The motivation for the adoption of V2G as identified by the customer research are various: financial reward for using the system that does not have to be necessarily large, a gamification element and sustainability given by the charging on green energy. The barriers are the burden of charging, the unpredictable travel patterns, the range anxiety, the limited control and the privacy of the information, A guideline for a V2X system has been defined:

- Create financial return;
- Facilitate sustainable energy charging;
- Provide control;
- Ensure ease to use;
- Consider nice to have (gamification, insight in energy use, community etc.).

Three different business models have been developed for the V2G scheme and for V2H.

In the VEHICLE-2-HOME scheme, the EV stores electricity when the prices are low andsells when the prices are high; the trading can be done automatically or manually. In case of blackout, the EV provides backup electricity to the house. The user indicates when they need the EV and what the destination is in order to schedule the charging efficiently.

One of the three V2G business models is the **Electricity bank** that gives a monthly fixed reward to the user in return of the availability. A higher number of connections and longer connections are rewarded. Figure 6.1-20 shows an overview of the scheme's reward:

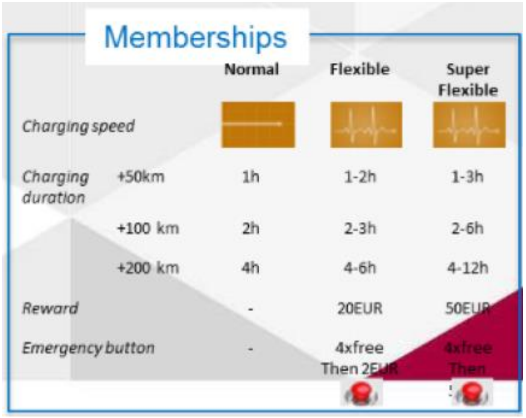

Figure 6.1-20 Example of the potential reward from the Electricity Bank [6.40]

The **Electricity Club** gives the cheapest kWh prices and credits in return of availability. The credits can be used for free charging or converted into air miles. Again, a higher number of connections and time durations of connections are rewarded more. Figure 6.1-21 shows the potential benefits.

Figure 6.1-21 Example of the potential reward from the Electricity Club [6.40]

The **Green Electricity Club** rewards flexibility with free kilometres and green reward points. The ability to compare to peers, to charge free at participating restaurants and to connect the smart meter at home further enhance the benefits of this scheme. Figure 6.1-22 shows an overview.

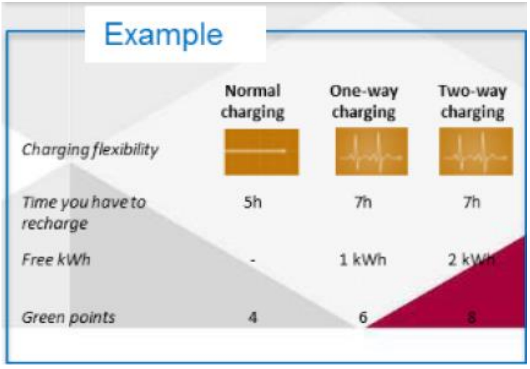

Figure 6.1-22 Example of the potential reward from the Green Electricity Club [6.40]

The Electricity Club was the most attractive scheme among the users; in fact, 42% of the respondents preferred it due to its benefits compared to the Electricity Bank, such as lower kWh prices and credits, and the simplicity as compared to the Green Electricity Club. For this option, the bi-directional charging can be offered. Furthermore, three EV charging strategies have been considered; Figure 6.1-23 shows their characteristics.

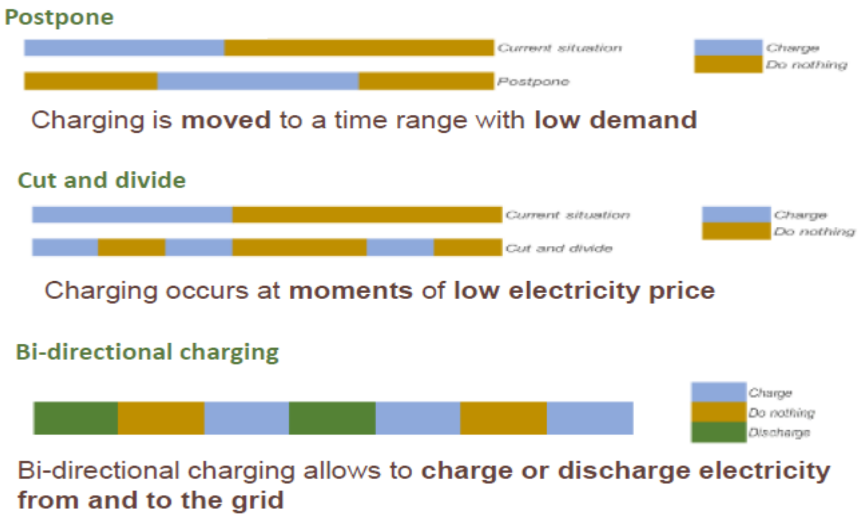

Figure 6.1-23 Different charging strategies [6.40]

Each strategy has been compared against the current situation, and the results in terms of cost reduction are shown in

Figure **6.1-24**.

Charging Strategy	Costs per average charging session		Cost reductions
Current Situation	€	0.45	n/a
Postpone	€	0.36	-20%
Cut and Divide	€	0.36	-25%
Smart Charging (Bi-directional)	€	0.35	-28%

Figure 6.1-24 Cost comparison of the different charging strategies with the current situation [6.40]

As can be seen the Bi-directional smart charging provides the highest cost reduction compared to the current situation. This can be due to the fact that the battery degradation cost has not been considered in the cost structure, which accounts for the electricity costs and marginal infrastructural cost. It was found that customers have interest in a financial reward; but it should not necessarily be a high reward. The 'Electricity club' as a 'frame' was evaluated as most attractive. Cost savings were possible for the three strategies evaluated. The cost for bi-directional charger is the most influential factor.

15. Task 28 – IREC

The project [6.41], which ended at the end of 2018, investigated on the technologies and the issues related to electric storage from PEVs for alternative uses than transportation. The objectives can be summarized as the followings:

- Analysis of the technical and economic viability of V2X;
- Synchronization and connection with different V2X research and demonstration projects;
- Issue a policy making toolbox and a technology roadmap;
- International technical information exchange;
- Promotion of new V2X technology demonstration projects.

The opportunities that have been identified for V2X are the Energy arbitrage for cost reduction, CO_2 emissions reduction, Peak Shaving, RES integration, Ancillary services and Load following. The challenges that this new technology imposes are the definition of the regulatory framework, the coordination with the grid operator, new stakeholders such aslike aggregators, the new infrastructure for bi-directional power and the standardization. A Micro grid with a 10 kW (Vehicle to Micro-grid) V2M charger has been tested in the IREC lab to analyse the technical viability of the V2M system at a household level. Figure 6.1-25 shows the framework of the test.

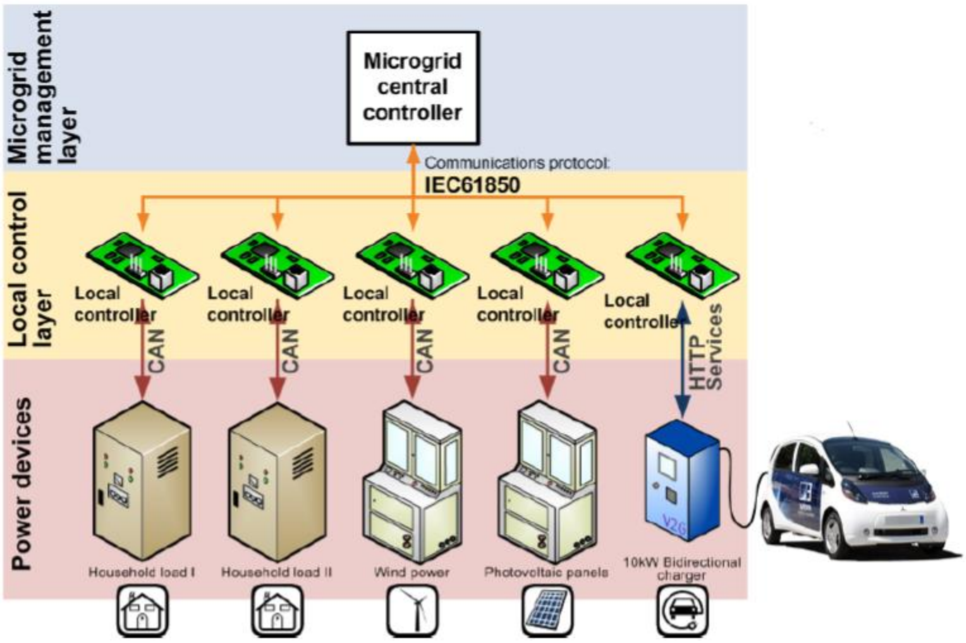

Figure 6.1-25 Micro grid tested in the Task 28 [6.41]

The system consists of two household loads, generation from wind and solar and the storage service is provided by the EV. The scenarios that have been tested are briefly mentioned below in Figure 6.1-26.

Test scenarios

Functionality	Application	Tests	ID
User	Energy Arbitrage (Cost Minimization)	No range anxiety	CM
Utilities	Average DSO Power Balancing	50% of grid tie capacity	D50
		25% of grid tie capacity	D25
	Instantaneous DSO Power Balancing	Peninsula Mode	PM

Figure 6.1-26 Different scenarios according to various test conditions [6.41]

The results from the tests are depicted in the next figures. Figure 6.1-27 shows the charging behaviour on a typical day. As can be seen the EV is discharged in two peak hours: 9 p.m. to 10 p.m. and charged in early morning from 4 a.m. to 5:30 when the price is low.

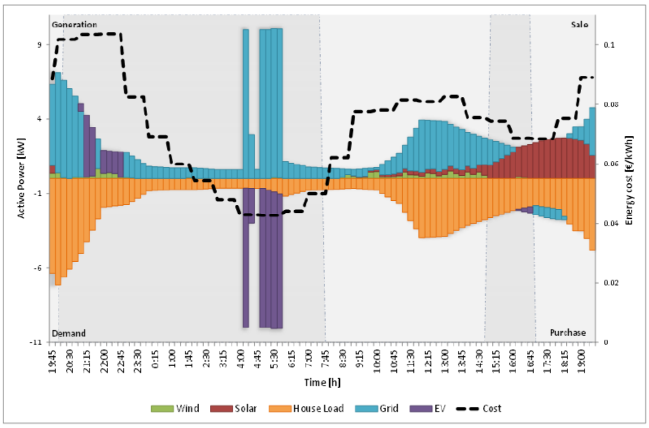

Figure 6.1-27 Charging behaviour of EV, solar production, wind, demand and grid [6.41]

Figure 6.1-28 shows how the system reacts when the network capacity is temporarily halved.

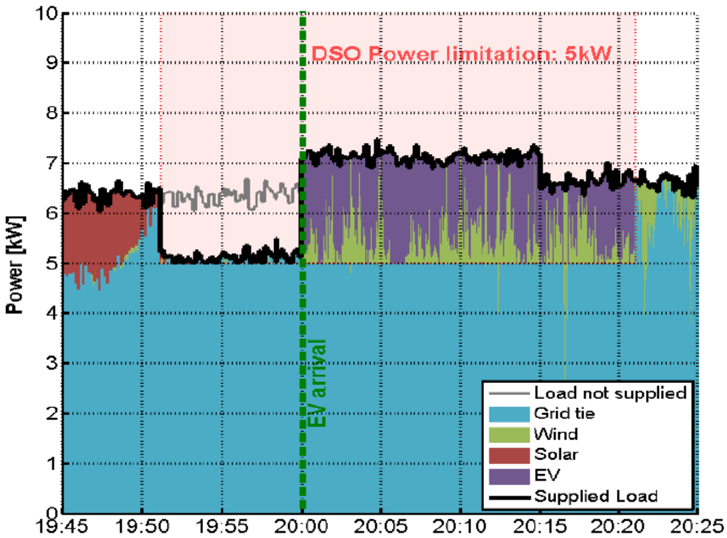

Figure 6.1-28 Results from the test once the network capacity has been halved [6.41]

As can be seen, when the EV is connected the DSO limitation is not violated anymore because the battery discharges to provide energy. At the end of the test, the SOC variation accounts for only -6%. Figure 6.1-29 shows what happens when the substation capacity is temporarily reduced to only 25% of the nominal capacity.

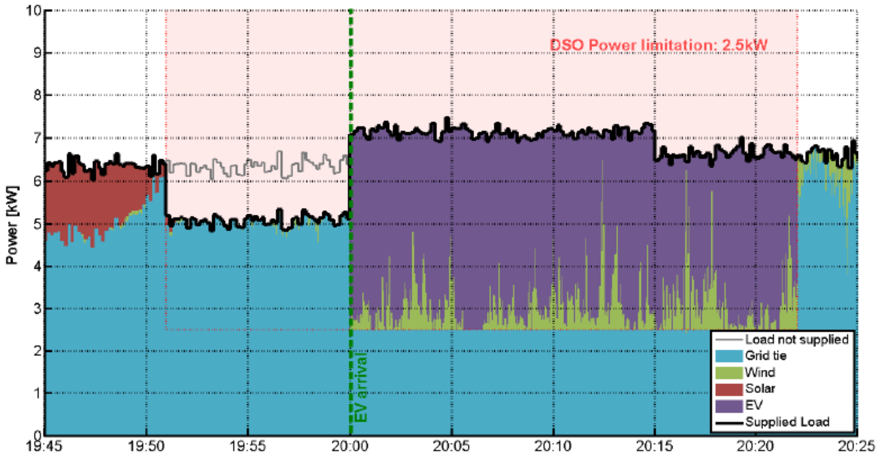

Figure 6.1-29 Results from the test when the capacity of the network is at its 25% [6.41]

It can be seen that before the arrival of the EV, the limits are not followed. The SOC variation accounts for only -13% at the end of this test. In Figure 6.1-30the simulation results for a complete lack of power for 5 minutes are shown.

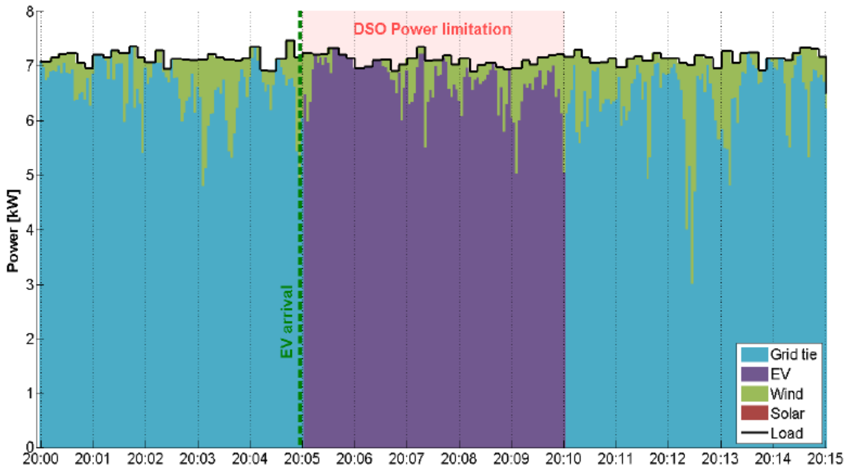

Figure 6.1-30 Results from the test when there is a complete lack of power from the grid for 5 minutes [6.41]

The EV battery is discharged for 5 minutes at 7 kW and this is enough to supply the whole household demand, with some help from wind, and at the end of the test the SOC had varied by only -5%. These results show how the 10 kW V2G system is capable to follow variations of the power set points for short periods of time, although no economic feasibility has been assessed.

<u>16. GridMotion - USA</u>

The aim of the project [6.42] which started in May 2017 - was to demonstrate how Plug-in Electric Vehicles (PEVs) can control demand response and provide ancillary services to obtain beneficial impacts on the grid and user income. This is done with smart charging, by shifting the charging times from periods when the electricity price is high to periods when electricity prices are lower and with V2G, by providing balancing services. It was a 2-year demo project, and there are two types of users:

- Uni-directional smart charging with 50 Peugeot iOn, Partner Electric, Citroën C-ZERO and Berlingo cars;
- V2G with a fleet of 15 Peugeot iOn or Citroën C-ZERO to provide balancing services.

The partners involved in this project were Groupe PSA which is the project manager and entitled to the customer recruitment, Direct Energie which performs the role of the aggregator, Nuvve which control the charging of the EVs, Enel which is the provider of the bidirectional charging stations and provides the expertise in smart grids, Proxiserve which installs the charging stations and DTU which provides the academic support and testing system.

17. Parker – Denmark

This project was funded by ForskEl with a project period from August 2016 to July 2018 [6.43]. The involved partners included OEMs such as Nissan, Mitsubishi Corporation and Mitsubishi Motors Corporation, an aggregator (NUVVE) and a charging infrastructure manufacturer (Enel), with the collaboration of the Electrical Engineering department of the Technical University of Denmark. This project aims at supporting the power grid with fleets of series-produced EVs locally and in the overall system. In this way, EV fleets become vertically integrated resources. Three pillars have been identified to focus on:

- Identification of Grid applications and technical, economic and regulatory barriers for EVs approaching these applications;
- Specification of technical parameters to be considered in Grid readiness certificates that certificate the ability of EVs to support the grid;
- Replicability and Scalability of such applications.

The project made some recommendation to support EV integration in distribution grids [6.44], and these can be found in Figure 6.1-31

Figure 6.1-31 Recommendation for EV integration in the power system [6.44]

Smart metering	• Wide-scale deployment of smart meters with standardised functionalities to ensure interoperability. • Sampling frequency in accordance with flexibility trading settlement period (maximum 5-min). • Clear pre-qualification and validation protocols.
EV/EVSE technology	• Define standards and regulation for deploying EVSEs with embedded intelligence. • Harmonise communication protocols between the EV aggregator and other participants. • Determine standardised tests for evaluating internal EV parameters (accuracy, response time, etc.).
DSO regulation	• Remove regulation which forbids aggregation and flexibility procurement. • Incentivise long-term innovation (longer regulatory period, incentives for new technologies, etc.). • Revise tariffs to include both the capacity and the energy charge. • Define new DSO tasks (active grid operation and data management). • Remunerate current DSO services to provide basis for comparing different solutions and estimating the flexibility price.
Flexibility trading	• Establish an open, transparent and fair flexibility trading platform with the corresponding roles. • Define clear and generic flexibility products. • Define technical requirements which must be included in flexibility requests/offers (power capacity, duration, direction, location, etc.). • Define the minimum bid in the kilowatt range and the settlement period of maximum 5-min to encourage EV owner participation. • Define common EV baseline (uncontrolled charging) and the corresponding measurement methodology. • Introduce capacity and energy payments, and a premium for rewarding the more reliable resources.
TSO-DSO collaboration	• Define standards for the interface and data exchange between the TSO and DSOs. • Define clear priorities between TSO and DSOs for normal operation and emergency situations. • Make local flexibility trading platform transparent to the TSO.
Consumer	• Define regulations to ensure data protection and allow sharing of sensitive data if EV user is willing. • Develop interface for providing insight into signed contracts and EV schedules. • Define standards for providing an unique ID for flexibility procurement and remuneration.

Also, a Roadmap that outlines the phases according to which the actions should be undertaken has been produced and it is presented in Figure 6.1-32.

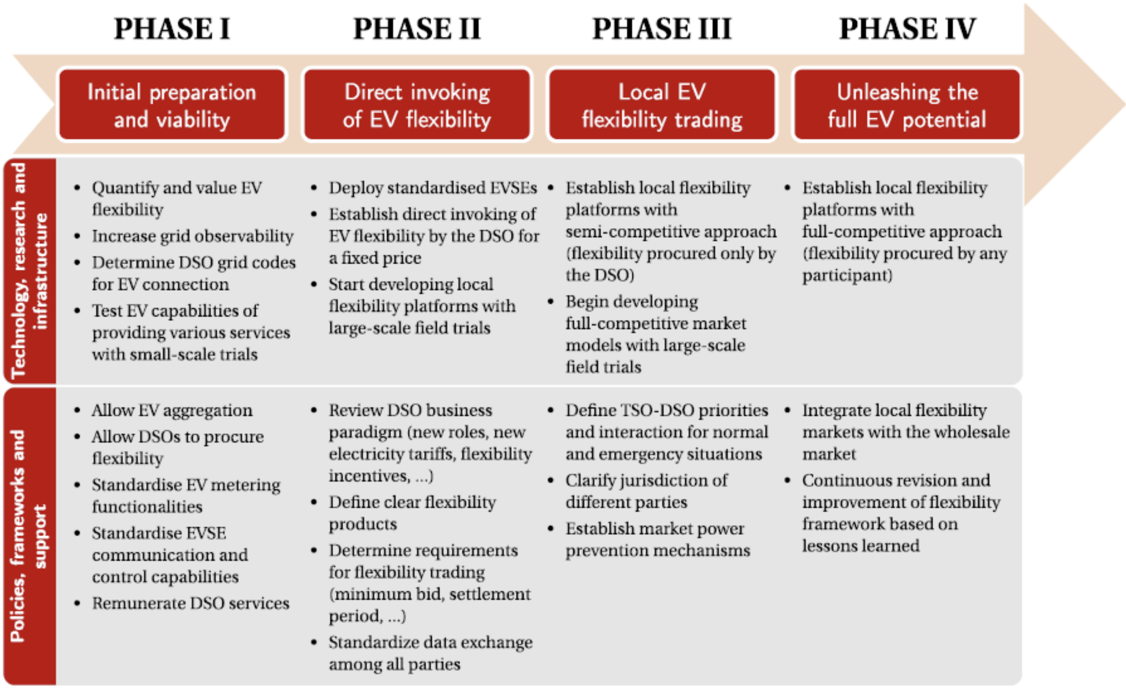

Figure 6.1-32 Roadmap for EV integration in the electricity system [6.44]

In conclusion, the project found that there are potential revenue gains in V2G markets for both the DSO and the TSO, in their respective market models. In terms of scalability, both the DSO and the TSO markets provide the option of a scalable V2G business model with an associated revenue yield. In summary, the V2G solution is scalable from a technical and a long-term financial standpoint and can provide nationwide grid stability. However, it requires a significantly larger EV fleet, the creation of a DSO market platform, and finally it requires battery and charger technology to mature to ensure a positive business case. All market models seen throughout Europe show potential for improvement, and there are definitive gains to be made if that potential is realized. Under the current framework test in the Parker Project, it has been shown that there are potential profits with a small fleet of electric vehicles. No technical limitations have been found that will limit the scalability of the business model in Denmark, and the economic gains show that the first step has now been taken towards the commercialization of V2G in a market. However, for V2G to be successful on a large scale, the industrial and political actors will have to push the agenda in terms of legislation and technology availability

18. Toyota City - Japan

The project [6.45] aims to develop a Virtual Power Plant demonstration that will regulate the electricity demand according to the generation of RES, such as, wind, solar and biomass energy, in Toyota City, in order to improve the local production and local consumption. It wants to prove the feasibility of local production and consumption of RES. This is done by combining multiple energy sources, by energy management, to operate them as a single VPP. ICT is adopted to link PHEVs, heat pumps, water heaters, storage batteries and other household loads to schedule the charging of the PHEVs and the storage batteries, to maximise the consumption of RES and make an efficient use of energy. The energy produced by the VPP can be provided to the power distributor to balance the grid. Another goal is to investigate the suitability of a centrally controlled VPP to coordinate the network voltage and the power flows and integrate RES. Toyota City has adopted an action plan to achieve a reduction of CO_2 emissions of 30% by 2020, compared to 1990. The partners of the project are: Chubu Electric Power Co., Inc, Denso Corporation, Toyota Motor Corporation and Toyota Turbine and Systems Inc. The project was due to end in March 2020.

19. UK Power Networks – UPS – UK

UPS increased the number of EVs in one of the London's biggest depots by almost 50% [6.46]: from the current 50 to 70 to more than 150 vehicles. The aim was to reduce the charging cost of freight EVs. The fleet charges during the night in order to not overload the network during peak times; the charging will stop if the demand of the local area is high. A software, developed by UK Power Networks, determined the number of EVs that can be safely charged at any one time. Also, battery storage will be utilized to charge the EVs. The project was funded by Innovate UK.

UK Power Networks Services implemented a new smart electric vehicle charging systems to power UPS's central London delivery fleet for what is believed to be the first of its kind in the world on this scale. This smart charging solution allows UPS to increase the number of 7.5-tonne electric trucks operating from its London site from the current limit of 65 to 170, without the need for an upgrade to the power supply connection. UPS is a global leader in logistics, offering a broad range of solutions including transporting packages and freight, facilitating international trade, and deploying advanced technology to more efficiently manage the world of business. As part of their sustainability strategy, UPS are growing their electric vehicle fleet at their central London depot in Kentish Town, London. Freight electric vehicles, like those used by UPS, can use up to ten times as much power as a typical home when charging. This means that charging large numbers of trucks simultaneously puts significant demand on the depot's electricity supply. Due to a capacity limitation on the local electricity network, the integration of more electric vehicles at the depot would require a significant network upgrade to ensure the demand could be met. UPS identified that traditional network reinforcement was not a viable model for deploying more electric vehicles at its Kentish Town depot, and appointed UK Power Networks Services to design, deliver and operate a smart-grid solution. UPS's requirements for the project were to allow the electrification of its 170-vehicle depot fleet whilst: Avoiding network reinforcement; ensuring business continuity; deploying a future-proof solution; being economical and sustainable.

UK Power Networks Services recommended the implementation of a smart grid system.

This solution comprises an Active Network Management system that monitors the maximum demand required by the site and controls the vehicle charging, scheduling the charge during the evening ready for the following day's delivery. An energy storage system was installed to optimise the power available for the whole site, which is particularly important during periods of high demand.

The scope of the project included:

- Upgrading of the existing charge posts on site to enable connection to the smart grid system Installation of new chargers;
- Development of a smart grid application that communicates with the connected vehicles and the energy storage system to control the overall demand;
- Installation of an energy storage system which coverts and inverts power based on tariff, network loading and vehicle specific requirements;
- Collaboration with subject matter experts to develop the specification of the requirements for a new charge post with integrated smart grid functionality.

By integrating active network management and battery storage system technologies, it was ensured that the depot's electricity demand would not exceed the network's limit. This prevented the need for significant investment in network electrical infrastructure and safeguarded UPS against the impact associated with having uncharged vehicles.

20. Vehicle to Grid Britain (V2GB):

Vehicle to Grid Britain (V2GB) [6.47] is a feasibility study, part of the UK's Vehicle-to-Grid competition, funded by the Office for Low Emission Vehicles (OLEV) and the Department for Business Energy and Industrial Strategy (BEIS), in partnership with Innovate UK.

V2G technologies are expected to play a key role in the decarbonisation of Britain's transport and energy systems. Connecting millions of EVs and coordinating their charging and discharging would minimise the costs of EV charging while allowing the grid to balance the integration of high levels of variable renewable energy sources.

Consortium members Nissan, Energy Systems Catapult, Cenex, Moixa, Western Power Distribution, National Grid ESO, and Element Energy explored both near term niches and enduring large-scale opportunities for V2G to play a role in a flexible energy system in Britain. Cenex identified a list of 16 domestic customer archetypes and 18 commercial archetypes representative of current and future customers for V2G. Each archetype was assessed for their applicability for V2G. Potential revenue streams were also identified and assessed for their suitability for V2G. Vehicle journey data was also collected for each of the archetypes to identify 'plug-in' behaviour and charging times to evaluate the value streams.; key sensitivities that would dramatically impact the potential value of V2G revenue streams were identified.

In conclusion, residential V2G charging could be economically viable in the near term, but to achieve this result will require a combination of high plug-in rates, reduction of the installation costs of high accuracy metering equipment for Firm Frequency Response, stacking of multiple revenue streams, and an agile model to move between revenue streams in a dynamic market environment.

To achieve wider uptake and contribute to energy system decarbonisation, V2G hardware cost must reduce significantly. Viable commercial models need to be developed to depreciate the assets over 10 years, and consumer concerns about range and battery impacts must be removed.

- A 7-kW residential V2G charger could capture over £400/year in revenues, but only in ideal circumstances – a typical figure would be ca. £100/year;
- Cost premium for 7 kW V2G needs to drop below £1000 by 2030 for continued viability;
- V2G could help to save £200m of cumulative distribution network investment by 2030;
- Smart Charging could generate GB energy system net savings of £180m/annum, and V2G could save an additional £40-90M annually in GB by 2030.

21. The Sciurus project:

The Sciurus project [6.48] develops and deploys a large number of V2G chargers' units with participants who own/lease a Nissan Leaf EV. It will also include the development of a grid balancing platform to provide electrical support to grid operators during peak energy demand times. Furthermore, it will explore and test commercial propositions to identify a viable long-term business model. Finally, consumer behaviour and receptiveness will be measured to provide insights into EV owners' attitudes and their response to V2G products and services. The project seeks to: demonstrate that V2G technology works at a residential level; prove the business case of residential customers participating and benefiting from V2G service provision; and demonstrate the value of V2G to vehicle manufacturers. This project brings together a unique consortium, highly skilled in their respective sectors, to deliver a first-of-a-kind large-scale demo of a truly innovative V2G proposition, with national and global exploitation potential. The partners will develop and build technologies in the UK, establish a UK supply chain and secure the position of the UK in this rapidly growing market.

The market for aggregated V2G chargers providing flexibility services is currently immature, but evolution is rapid and demand is strong, a highly competitive market is expected to develop.

Lead Participant: Ovo Energy Ltd, Bristol

Other Participants: Indra Renewable Technologies Limited, Cenex UK (Centre of Excellence for Low Carbon and Fuel Cell Technologies), Nissan Motor (GB).

6.1.1.3 Socially-oriented projects

1. ELVIRE – EU

Aim of the ELVIRE project [6.49] was to develop an on-board ICT system in order to tackle the significant problem of **range anxiety**, by locating the most appropriate charging post or battery switch station and managing the charging. This has been practically done by developing an on-board driver assistance, a good communication system and external management services. The first two collect and exchange the information between the user and the service provider while the external management services handle the data and provide information about the charging infrastructure, the optimal service and company. The main objectives can be listed as follows:

- Development of business models that allow EV deployment;
- Join the forces between OEMs (car manufacturing), utilities and research;
- Reach a higher customer awareness and user acceptance.

Within the system, the different service providers are connected with a central control system. The electric mobility services have been categorized in three different groups: driving services, energy services and generic services. Driving services are those that are necessary while driving. The energy services mainly addressed the limited range of EVs and therefore a constant monitoring of the energy level and a continuous route planning are the core of this service. The generic services are administrative processes. Upon getting in to the car the route selected by the user is analysed and in case it is considered not feasible a different guidance to the destination is provided, throughout the driving the energy level is monitored and in case of low energy a notification is provided. The most viable route to the most convenient charging point is also suggested.

Within this study, the user’s range anxiety was considered a major research scope, and therefore it has been correctly defined and addressed. The strategies that have been found to be effective are mentioned below:

- Provision of reliable information in order to reduce uncertainty;
- Immediate monitoring;
- In case a destination is not feasible, there has to be active interference;
- Ability to double check the information;
- Being flexible while presenting the relevant information.

The related ICT has been installed on board of EVs and verification, and validation has been carried out. This has showed that the application had been considered useful by 92% of the participants who trusted the information that was provided.

User perception is one of the main key factors that influence EV uptake along with policies. In previous years the lack of policy support hampered the otherwise expected EV uptake leap. However, tackling the user perception with technological development, i.e. improvement in the battery area can steadily change the trend.

2. CROME – Germany & France

Aim of the CROME project [6.50] was to develop a reliable and user-friendly electro mobility system in France and Germany and provide recommendations for EV infrastructure in a European standardization framework. In both the countries, more than 121 EVs and about 100 charging stations were deployed. The objectives can be summarized as follows:

- Cross-border field demonstration on EV mobility;
- Development of an EVSE system that is public and interoperable and ensures the access to the EVs from France and Germany;
- Evaluate how customers accept e-Mobility and their needs in terms of charging in a cross-border mobility context;
- Make charging spots availability and reservation as well as billing viable;
- Recommendation for a European standardisation for charging infrastructure.

The vehicles are sold to final consumers or leased, and can be charged in either mode 2 or 3, while some of them allow fast charging. An acceptance study was undertaken where the user responses for the developed electro-mobility system was registered through surveys and qualitative interviews. Different aspects have been evaluated in this study, and the results for both France and Germany are presented below in Figure 6.1-33.

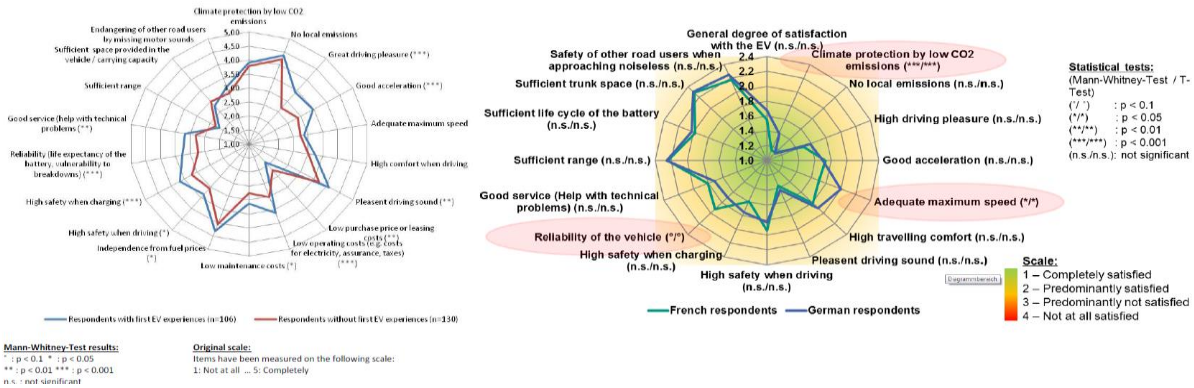

Figure 6.1-33: (a) user attitude towards different aspects concerning e-Mobility; (b) satisfaction level for different characteristics of EVs [6.50]

According to the results, 97% of the participants were completely or mostly satisfied and 76% considered EVs as a better option than a conventional car. The outcome showed that in France, users are more interested in CO_2 emission reduction and aware of the different energy mix that cause different CO_2 emissions per kWh. With moderately populated municipalities, for instance more than 20000 citizens, users are satisfied with the EV's characteristic to not emit, at least locally, and with the range and battery life cycle, more than those living in municipalities with less than 20000 citizens. In Germany, companies are found to be more interested in the public image that EVs provide than France, and prestige is one of the main reasons for EV purchase. Figure 6.1-34 shows the charging behaviours of the participants.

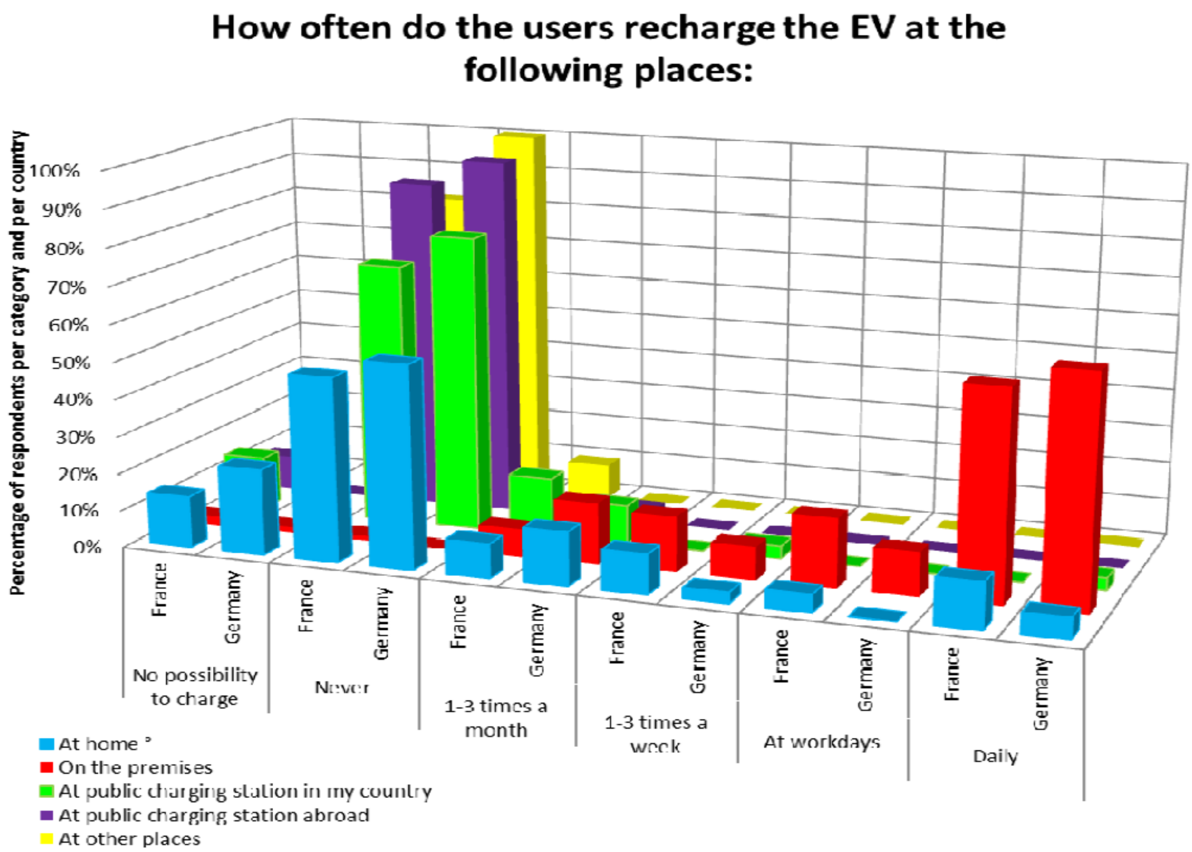

Figure 6.1-34: Percentage of charging possibilities in different places [6.50]

As can be seen, EVs were mostly charged with domestic sockets: 63% in France and 71% in Germany whereas only 10% do not charge at home. 51% of the respondents said they charge the EV after each trip, 23% when a certain SOC is reached and only 18% after the last trip of the day. The special socket usage, like type 2 and 3, account for 4% in France and 61% in Germany. Field trial participants preferred to charge the car rather than filling a car at the filling station. The data represented in Figure 6.1-34 above is related to the capacity of batteries, perhaps on the smaller side. However, when it comes to EVs with higher capacity with longer ranges, the charging options are limited by locations of corresponding charging infrastructure, which is less likely to be work and public charging, as pointed out by [6.51] - though there is an expanding network of public fast charging.

The qualitative study that consisted of face-to-face interviews with companies that adopted EVs for their services gave other results: among the motivation for participating in the project, there are, letting the customers and public know that they are involved in an e-Mobility project, pioneering the tests of new vehicles and participating to local economic development. Regional Councils represented an essential collaboration for the business development. Acceptance for different aspects were studied: the users and fleet managers were satisfied with the charging process in their own facility rather than going in a gasoline pump. The charging infrastructure was used for marketing purposes because it denotes the company's commitment to innovation, but on the other hand more information on battery and different charging plugs is required. Some businesses said that would like to extend the use of EVs beyond only mobility, and use them as electric storage for an increased self-sufficiency. Analysis on EV utilization showed that they were mainly used for short trips in an urban context, and the maximum range was hardly reached - which along with daily charging means that EVs are likely to be kept at high SOCs. Figure 6.1-35 shows the afore-mentioned results.

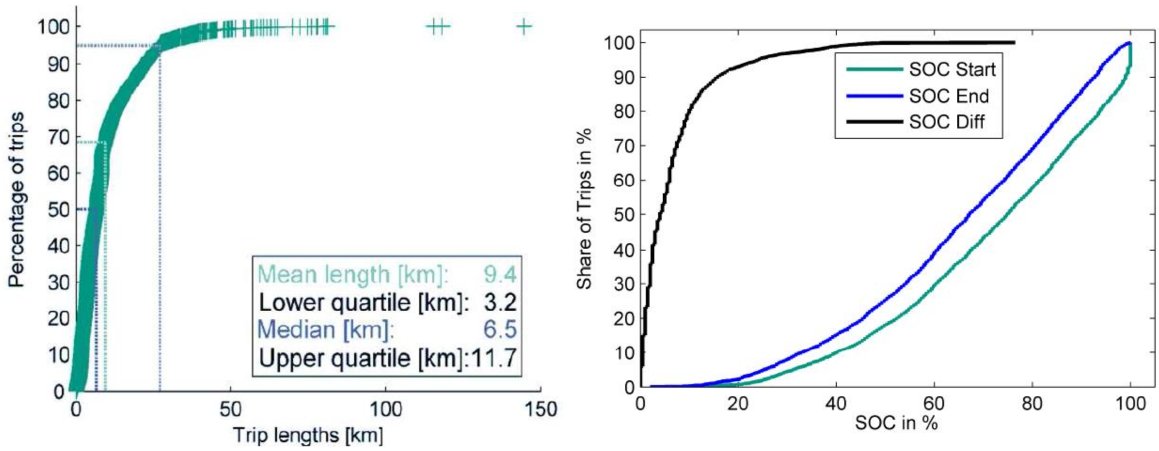

Figure 6.1-35: (a) trip lengths; (b) SoC consumption [6.50]

However, users did show concern about the low speed range which can hinder EV acceptance. As for the different services, like routing to the nearest charging point, 50 % of the participants preferred smartphones or the web to find them, 15 % the GPs system, and others preferred to ask a friend or call the service centre. Nearly 30 % of the participants wanted to know the closest charging point prior to departure, and there is demand for EVSE at shopping centres, motorways and main roads.

3. PARENT project – The Netherlands, Belgium and Norway

The aim of the project [6.52] is to reduce the electricity consumption in households with community participation and technological solutions, such as, smart meters, Home energy management systems and active participation. There are 3 pilots in Bergen, Brussels and Amsterdam, and other participants include 3 universities, 2 consultancies and 1 hardware provider. Also, local authorities, electricity providers and citizens participate. In Amsterdam, there are two phases: in the first phase 16 prosumers had been involved, where the data collections started in early March 2017 and in the second phase 100 household participated. The objectives are: increase of self-consumption levels and reduction of the grid interaction and the integration of RES at a neighbourhood level. The results from 3 connected prosumers from the first phase are presented in Figure 6.1-36.

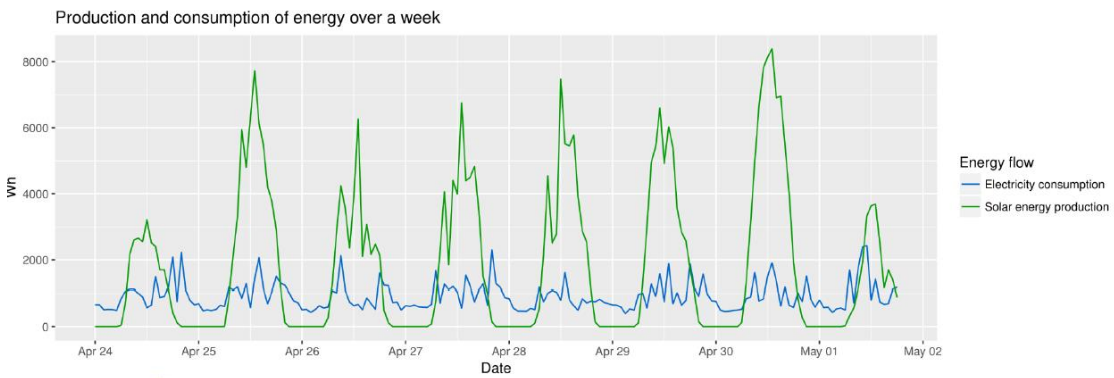

Figure 6.1-36 Solar production and energy consumption of three households [6.52]

It has been found that around 24 kWh on average has been injected in the grid between 25th - 30th April due to the surplus of the PV generation. The proposed solutions are the scheduling of shiftable load, storage, planning of EV charging stations and variable electricity pricing schemes. Among the socio-economic solutions, the electricity consumption behavioural change and engagement and active participation have been identified as the most useful. The methods consist of system design and planning, data analytics, optimization and forecasting techniques (demand, PV generation profile, driving patterns and electricity prices). Figure 6.1-37 shows the potential increase in self-consumption given by the synergy between the EV charging demand and PV energy surplus.

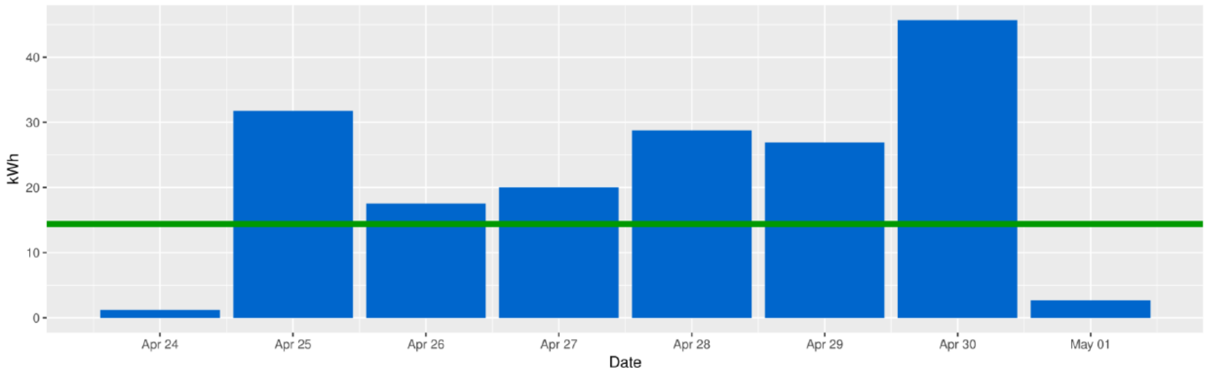

Figure 6.1-37 EV charging demand and PV production [6.52]

In conclusion, this study presents an interdisciplinary framework for residential customers' engagement and participation in energy applications. The study starts by establishing a behaviour change model for the framework, the Transtheoretical Model (TTM), that identifies the main requirements necessary to achieve the goals of the framework. To fulfill those requirements, the required technical system architecture is detailed. Then, game design elements that can be employed in the technical system are identified and classified into five categories. The value streams to different stakeholders in the energy market are identified when using the derived solution. Finally, the potential of the proposed framework in each application is examined.

6.1.1.4 ICT projects

1. ELVIIS – Sweden

The Electric Vehicle Intelligent Infrastructure (ELVIIS) project [6.53] covered the time span from 2012 to 2014. The main aim of the project was to build an open and scalable, in the sense that it can be scaled at a higher level, technical ICT platform to implement and develop new services tailored for EVs. The use of ICT and intelligent infrastructure is likely to foster EV market penetration, by weakening the potential barriers. An open infrastructure is meant to allow a common exchange of information among the various industry branches, such as, EVs, charging infrastructure, electricity provider, home appliances, communication, traffic etc. and give the possibility to third-party entities to access this information in order to develop services that increase user's and the societal benefits. A graphic representation of this platform is described in Figure 6.1-38.

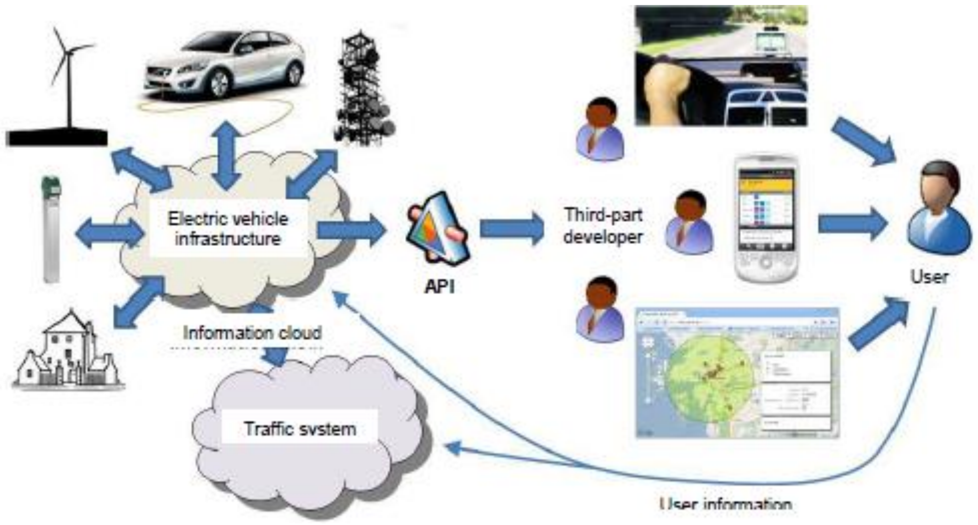

Figure 6.1-38: Open information platform for an intelligent charging infrastructure [6.53]

The EVs are connected by mean of a mobile phone network that allows to build on an existing communication infrastructure, to improve safety and to provide real time information and entertainment features to the user. This project has focused on two services: **charging** and **billing**. By letting the system know, when the charge has to be completed, the user allows flexibility that reduce accumulation of charging requests and consequent overloading. From the billing point of view, if different charging facilities are available, in order to privilege user's ease, a single billing method should be applied. It is therefore important to have the measurements on board, rather than on the charging post, to know the exact amount purchased, and have an accurate identification of the electricity user providing the charging facility. Within ELVIIS, voltage and currents are measured on-board and the electricity user is identified through a GPS system that locates the different charging posts. The goals of the project were:

- Identification of cross-industry barriers that hinder large EV penetration;
- Determination of the possibilities an intelligent infrastructure creates for user functionality;
- Identification new business cases for the car industry, power providers and telecom services;
- Development a scalable system for an intelligent EV infrastructure;
- Development of services like billing and charging and their implementation on a platform.

The aforementioned platform has been implemented on the vehicle, a smartphone app and web, with charging and billing services in five electric Volvo C30. The first pilot test performed in September-December 2011, and was followed by a survey addressed the added value of EVs in general. The second pilot operated in March-May 2013 and the effectiveness of ELVIIS has been tested with another survey.

The results can be summarized as follows:

- Realization of a scalable and open information architecture for EV charging infrastructure;
- Results from the survey related to the first pilot test are:
    - The EV product has received positive comments and it has been defined as quiet, fun to drive environment friendly and cost efficient in terms of driving but it lacks in range, charging and information aspects. The range anxiety has been the most mentioned

and as the one that destroys value, and the estimated range as the most important information.

- Results from the survey related to the second pilot are: the most commonly mentioned benefits are:
    - Check current range, remote access, easy to use, providing notification, check progress, cost information overview;
    - The sacrifices are found to be out-of-function, unsynchronized, inaccurate, amperage change only in the EV and a lack of charging spot guidance.

In conclusion, the project addressed the barriers that hamper the much awaited massive EV deployment and the importance of a smart ICT system that facilitates the user experience in terms of charging and billing emerged. Range anxiety, as well as lack of useful information on issues such as, EV state, notification in the app when SOC is low, appropriate route planning and finding the charging spots have been identified as obstacles users. The routing system that allows to change charging company has not been developed, and this is an essential scope for future work because it makes charging and billing easier for the EV user.

2. Mi Muovo Elettrico – Mi Muovo Mare – Free Carbon City – Italy

This project [6.54] [6.55] was started in 2011 and concluded in 2013 in the Emilia Romagna region of Italy, a part of the Regional Plan for the Electro Mobility and the Piano Nazionale Infrastrutturale per la Ricarica di veicoli alimentati and energia Elettrica (PNIRE), literally, the National Infrastructural Plan for the Recharge of Vehicles supplied by Electricity. In 2010, in the region there were 500 battery electric cars and buses, and this project had the following aims:

- Development of public charging points supplied by RES;
- A regional Smart Card for all the vehicles;
- Monitoring of electro mobility;
- Improvement of the access in the Limited Traffic Zone and stop in the whole region;
- Ensure interoperability among the infrastructure managed by different operators;
- Development of an infrastructure on a regional scale.

The goal of this projects is to guarantee the recharge of EVs in case of emergency and to avoid lengthy delays. The charging posts are deployed in places where usually there are numerous EVs, exchanging car park, old towns of the cities and workplaces but mainly home stations for charging during nights, as being periods of low demand. This project intended to engage public and private car fleets, logistic companies such as those for goods transportation and citizens. Therefore, in collaboration with Enel, Gruppo Hera and Iren, the project deployed more than 100 public charging points across the region that provide EV charging ensuring interoperability with a smart card which allows charging regardless of the energy distributor. The posts allowed a maximum power of 22 kW and have two plugs: SCAME, single phase 220V and MENNEKES three-phase 220-400V. They have a RFID (Radio Frequency Identity) reader to recognize the smart card. In addition, a live online digital platform provides information on the location and the availabilities of the charging posts. The project also established deals with the municipalities to allow EV circulation in Limited Traffic Zones all day long as well as free parking. This involved the city councils of Bologna, the chief town of the region, Cesena, Reggio Nell'Emilia, Ferrara, Forli, Piacenza, Parma, Imola, Ravenna and Modena.

Another project called Mi Muovo Mare deployed, by 2016, 24 charging points in 8 cities in the Region along the coast. The charging posts have been strategically deployed along the axis of the roadway known as the Via Emilia, because the main cities are roughly 30-50km away from each other, a distance that is compatible with EV ranges. The aim is to reduce air and noise pollution and at the same time ensure commuting between cities and goods transportation.

The project Free Carbon City, 2007-2014 deployed 104 EVs for the public administration and gave funds for the purchasing of 104 hybrid/ fully electric buses, for the project FICO in Bologna.

6.1.1.5 Simulations

<u>1. Sustainable Mobility-The MUTE as a Prime Example for Clean and Affordable Mobility – Germany</u>

This study [6.56] considers the effect of electric vehicle charging in the energy mix of the power plants available in Germany and in terms of environmental aspects like the CO_2 emissions. In fact, it is said that the type of power plants operating in one country is a major factor that determines the success of EVs, because they contribute to determine the electricity cost and the CO_2 emissions related to the kWh generated. The main question that the MUTE investigation wanted to answer was if EVs can be competitive against equivalent ICE vehicles and whether they can make their way towards a sustainable future by looking at a reasonable compromise between affordable and a cleaner mobility. It is important to consider the charging times of EVs in order to evaluate the impact of EVs on power generation. In order to understand the effect of EV charging on the power generation capability, the different types of plants are ranked according to the generation costs; the renewable energy sources do not have direct generation costs and therefore they are the first to supply the load. Then the base power plants, such as nuclear and lignite based, are employed followed by middle load power plants, like gas and hard coal. If there is further demand, then peak power plants are called to generate. If uncontrolled charging is employed, then, in order to satisfy EVs' demand, expensive peak power plants have to be utilized. Figure 6.1-39 shows the merit order of the different types of power plants and additional EV power demand in off-peak hours.

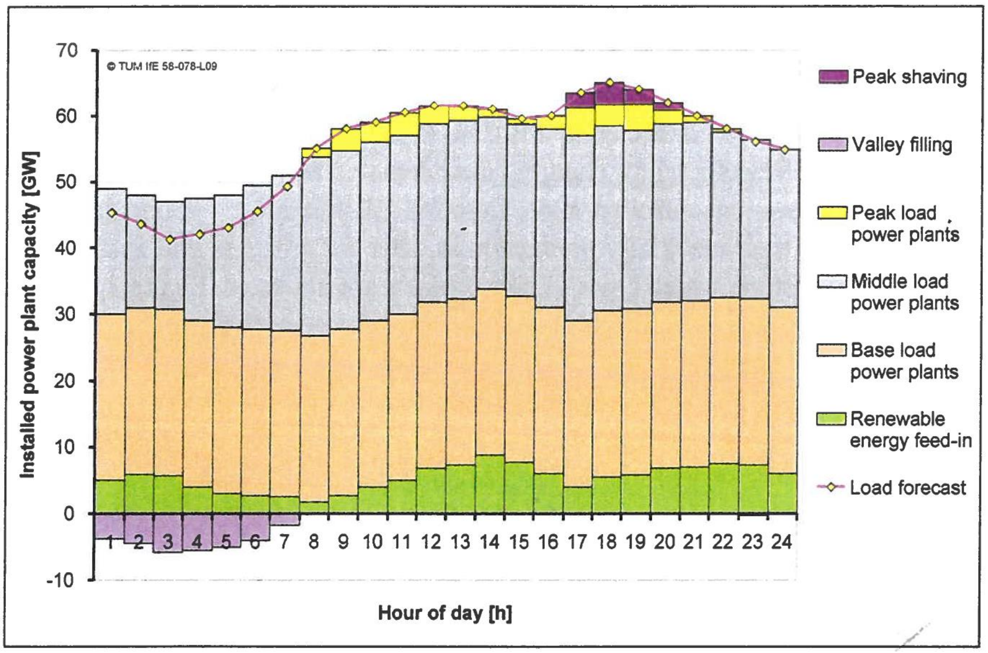

Figure 6.1-39: Utilisation of the Merit Order for covering the load curve and additional EV power demand during off-peak hours [6.56]

The core of the study is represented by three methodologies to study the charging costs and emissions of the EV: **Mix method**, **Delta method** and the **Parallel Market Method**.

Within the **Mix method,** EVs are considered as regular loads. Characteristics, such as electricity costs, CO_2 emissions and power generation efficiencies are the same for all the consumers and no specific conditions have been made for the demand times. As a consequence of this, the total generation costs and the CO_2 emissions are spread on the total generated kWh of the country. Because there is no distinction between common household loads and EVs, the impact of EVs on the power generation sector is divided on all the electricity consumers.

With the **Delta method** the EVs are treated as different loads compared to the household, ones and this scenario can be compared against a base scenario where EVs are not considered. In this way, any extra charging cost and CO_2 emissions compared to the base scenario has to be attributed to EVs. As said earlier, the supplemental demand represented by EVs has to be satisfied by extra generation which can come from those power plants that are either idle or not at full load. According to the energy mix, and to the demand time, some types of power plants may be providing power in that period; hence, this will determine a higher or lower electricity cost and CO_2 emission compared to the overall average energy mix.

The **Parallel Market method** is based on the inference that for a parallel electricity market that delivers a cleaner electricity, like the RES, electricity consumers are willing to pay a premium. This can be a separate service, provided by energy utilities along with the basic service. With this methodology, only the RES supply EVs, therefore the costs have to attributed, only to them. Within a household level, a cost optimization process for the house energy infrastructure in order to find the most advantageous solution is carried out. The devices that are considered for the energy infrastructure are, photovoltaic system, micro-wind turbine and static Li-ion batteries. Energy provision from the grid is also allowed in case of RES stagnation. The Feed-In Tariffs (FIT) are considered in this study.

Results from the different methods

Mix method: the overall German energy mix is considered, EVs are treated as generic household loads and no controlled charging is implemented. If the energy demand of the EV MUTE is considered, then the emission factor results in ***37gCO_2/km*** whereas the electricity costs account for ***2€/100 km***.

Delta method: usually in early morning, lignite and hard coal power plants are available to provide power, therefore the resulting emission factor and electricity costs, which are respectively ***71gCO2/km*** and ***1.85€/100 km***, will heavily depend on their characteristics. In fact, these power plants have a higher emission factor compared to the overall energy mix and a lower production cost. It is also reasonably said that the effect of the EVs on the electricity production will vary significantly according to the energy mix of a country and in

Figure **6.1-40** evaluations of the different impacts in various countries are depicted.

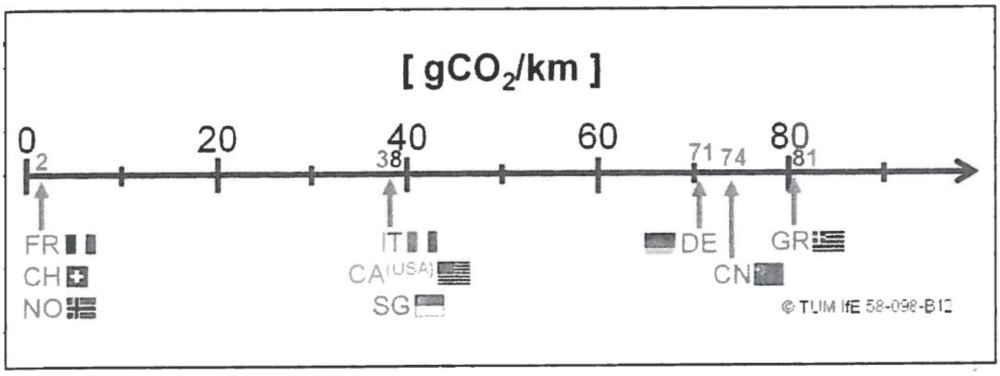

Figure 6.1-40: EV emission scale: specific CO2 emissions attributable to the MUTE in various countries for 2015 (Delta Method) [6.56]

Parallel market method: only RESs are employed to charge the EV and the house and the grid is required, if strictly necessary. The MUTE is charged with the standard socket of maximum 3.7 kW. The investment, electricity costs and the FITs are referred to 2015 and the lifetime of RES (wind and PV) are supposed to be 20 years whereas for the static storage it is 10-15 years. The investment required for the EV provision with an annual driven distance of 15.600 km and a depreciation period of RES of 15 years the new installations account for 9 kW of PV, 2 kW of wind power and 2 kWh of electric storage. Whereas in winter both the static storage and grid electricity are required as a result of low RES production.

The resulting annual driving cost of 50€ considers both the FIT, electricity purchase and the investment cost for the energy infrastructure. The energy absorption from the grid has been found to be as little as 13 kWh/year and only this has been considered to cause the emission factor of ***0.4gCO_2/km***, although for a more complete evaluation the lifetime CO_2 emissions should be considered. The energy costs are ***0.30€/100km***, as shown in Figure 6.1-41.

The results derived from the three methods have been evaluated against an equivalent ICE vehicle with a diesel consumption of 3.3l/100lm and an average diesel price in 2015 of 1.49€/l. The summarized comparison is shown in Figure 6.1-41.

Daimler Smart	MU+E		
ICE Diesel	**Mix** Method	**Delta** Method	**Parallel Market** Method
86 g CO_2/km 4.92 €/100km	37 g CO_2/km 2.00 €/100km	71 g CO_2/km 1,85 €/100km	0.4 g CO_2/km 0.30 €/100km

Figure 6.1-41: Comparison of driving costs and CO2 emissions of ICE vehicle and different methods of supplying MUTE [6.56]

Moreover, the savings against the ICE vehicle is evaluated and represented in relation to the daily kilometrage with an assumption on the vehicle usage period of 15 years in

Figure **6.1-42**.

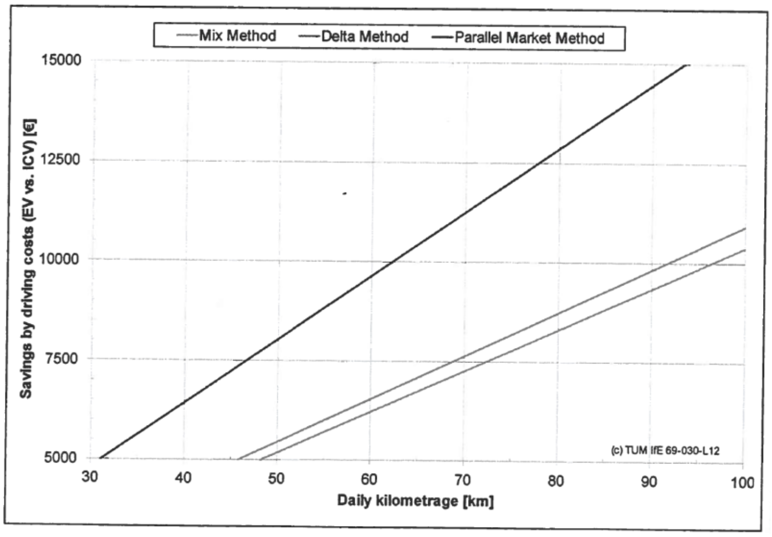

Figure 6.1-42: Savings by driving costs of EVs in contrast to conventional ICVs compared by different supply methods (assumed vehicle lifetime 15 years) [6.56]

As can be seen, a daily kilometrage of 48 km for the Mix method, 46 km for the Delta method and 31 km for the Parallel Market method is needed to achieve cost savings of €5000 compared to an ICE vehicle.

In conclusion, although the MUTE seems convenient both in terms of fuel cost and CO_2 emissions with every method seen so far, against the ICE vehicle, some critical assumptions have been made in this evaluation. At first, the investment for the MUTE has been considered as equal as the one for the equivalent ICE vehicle, which currently does not represent the reality: equivalent ICE vehicles are cheaper than EVs. Moreover, the battery degradation for the MUTE has not been considered and is replaced with a monthly battery leasing cost of 50€ as well as the V2G technology. In the Parallel Market Method, to compensate the investment made for the PV system, FITs have been considered, but currently in some countries FITs are not available anymore or are reduced and this can change the answer on the convenience of the EV over the ICE vehicle.

6.1.2. On-going projects

There are extensive on-going efforts made to improve the synergy among energy sector, transportation and environmental benefit, and the relevant projects within EU are listed here without conclusive results.

1. Smart solar charging – The Netherlands

Initiated in February 2017, the four year smart solar charging project [6.57] a successor of project “smart grid: profit for all”, is supported by the European Regional Development Fund (ERDF), aiming to develop further on coordination of renewable integration and V2G with car sharing systems, based on the Lombok experience (as from smart grid: profit for all project). Here the EV battery will be regarded as flexible storage capacity, which shifts the solar generation to periods when demand/price is high. Part of this innovation project is the deployment of 70 We Drive Solar cars which have a range of 300 km with a V2G function. This provides the opportunity to further develop Smart Solar Charging to a sustainable energy system on district level. Five linked pilot areas in the Utrecht region are used for testing, each having its own user profile, type of customer and specific market:

- Lombok: A residential area with a variety of housing and limited parking;
- Houten: A school complex in combination with a Park & Ride;

- Utrecht Science Park: De Uithof: This area is characterized by a combination of housing, education and business;
- Utrecht Central Station area: High density urban area with a mix of living, working, recreation and passers-by;
- Driebergen-Zeist: A mixed area with an important Dutch transit hub: Driebergen-Zeist (railway) station.

This project will result in:

- marketable product-service combinations for various types of districts / areas;
- new economic activity in the Utrecht region;
- A contribution to environmental sustainability, low carbon economy and social sustainability.

2. EV Energy – EU

The EV energy project [6.58] which is also known as Electric Vehicle for City Renewable Energy Supply project, is an Interreg Europe programme (1 Jan 2017 – 30 Jun 2021), aiming at creating a framework for regions and cities to improve and develop policies for the intelligent integration of electric mobility, renewable energy and smart grids (with associated ICT), which will lead to decarbonisation of the energy and mobility sector with more effective sustainable energy systems, in particular in the urban context. The policy measures include energy or mobility taxation, parking and charging issues, energy regulations and grid connection costs. The project consortium consists of Green IT Amsterdam Region (NL), Kaunas University of Technology (LT), the Province of Flevoland (NL), Barcelona Chambre of Commerce (Cat), Stockholm County Council (Se), Regional Association of Lazio Municipalities (IT) and EUR S.p.A. (IT).

The partners will first assess their local practices and improve their regional integration policies on electric mobility, smart grids and renewable energy to maximize their impact based on these assessments. Their experiences will then be documented and exchanged for inter-regional dissemination on future energy and mobility systems.

3. Share-North Project – NSR

The ongoing Interreg North Sea Region Project "SHARE-North" [6.59] or SHARE-North: Shared Mobility Solutions for a Liveable and Low-Carbon North Sea Region project, focuses on the shared mobility modes and the behavioural changes to achieve sustainable low carbon transport in the North Sea Region. The project includes activities for developing, implementing, promoting and assessing car sharing, bike sharing, ride sharing and other forms of shared mobility in urban and rural areas and employment groups. Living labs will integrate modern technology with activities to support changes in mobility behaviour.

There are multiple objectives of this project: resource efficiency, improving accessibility (including non-traditional target groups), increased efficiency in the use of transport infrastructure, reduction of space consumption for transport, improving quality of life and low carbon transport. A strong partnership of public authorities, NGOs and research institutions from the North Sea Region is supported by numerous organisations including the OECD International Transport Forum. The partnership stands for transnational cooperation, which is necessary for creating political support, and represents a high level of innovation, as shared mobility has not yet been widely employed as a part of integrated transport strategies.

4. Clean Mobile Energy project - North West Europe (NEW)

The Clean Mobile Energy (CME) [6.60] is an INTERREG NWE project which conducts research from September 2017 to March 2021, focusing on integration of renewable energy, through storage and energy management and electrical mobility. Price independence is achieved by using energy locally and at the same time sustainability can be guaranteed for EV charging. Solar and wind energy is generally generated at times when demand on the grid is low, and by integrating these renewables with the local storage and EVs, more energy efficiency could be obtained. CME will demonstrate, using different pilots in different cities, the applicability of renewable integration in European cities, from environmental, economic, and network operation aspect. As a result, it will also show if the growth of the electric drive can stimulate the growth of renewable energy.

Arnhem leads the project that involves partners including other local government bodies, such as Transport for London and the City of Nottingham, research institutes such as European Institute for Innovation (Schwabisch Gmünd) and the Luxembourg Institute for Science and Technology, and European networks such as POLIS and AVERE.

5. UC San Diego – NUVVE – USA

UC San Diego and NUVVE, a company providing V2G solutions which has been mentioned previously, will cooperate to let EV drivers in California to sell the energy in their vehicles to the grid when plugged in [6.61] [6.62]. This will be done with 50 special charging station that will be installed in the campus. EV users will receive a payment whenever the grid operator buys energy from them and at the same time the required level of charge to operate the vehicle will be guaranteed. Charging and discharging is flexible and depend on the requests of the grid operator. Solar forecasting will also be included, to predict solar power output in 15 minutes increments, so that EV charging will be matched with solar generation. The aim is to make EVs Virtual Power Plants, reduce the cost of the electricity infrastructure and reduce CO_2 emissions. The program is funded by the California Energy Commission. Nuvve Corporation, a world leader in vehicle-to-grid (V2G) – also known as vehicle grid integration (VGI) – deployments, and American Honda Motor Co. Inc. have entered into an agreement to demonstrate the benefits of electric vehicles (EVs) that are VGI-ready [6.63].

6. Nissan – Enel – UK

The project [6.64], announced in May 2016, will develop the first ever major V2G trial in the UK: private and fleet owners of Nissan LEAF and e-NV200 electric vans will play an active role in grid stability, being able to sell the stored energy in their EVs to the grid in return of a profit. This is done also to ensure that the grid is able to satisfy the demand of a future high EV penetration (they predict that, in 2020, there could be up to 700 000 EVs which will require an extra 500MW) and to integrate non-programmable RES into the grid. The EV users will charge at low-demand, cheap-tariff periods and will be able to choose whether to use the stored energy at home or at work or even to sell it to the grid. Almost 10 million pounds in funding have been earmarked by the British government for the country's largest vehicle-to-grid project to date. 1,000 [in reality, 400] V2G charging points were to be set up across the UK together with Nissan over the next three years. Nissan has been promoting electric mobility in the UK for some time. The bestselling Leaf EV is built in Sunderland. The plan was to install 1,000 vehicle-to-grid charging units across the UK over the next three years. Substantial support comes from the UK government as it wants to demonstrate the viability and also potential attractiveness of V2G solutions. The project falls back on 9.9 million pounds in funding through the Office for Low Emission Vehicles and the Department for Business, Energy and Industrial Strategy. V2G provider Nuvve, the National Grid as well as UK Power Networks and Northern Powergrid are on board as well [6.65].

6.1.3. Business applications

Different smart charging or V2G strategies have been implemented in real life with pioneering commercial applications, in the forms of either a smart device app, commercial hub/ platforms, or business trials. These will be presented in this section.

1. JEDLIX – The Netherlands

JEDLIX [6.66] offers a smart charging service via a smart device app (both IOS and Andriod version are available from early 2016), connecting over 1000 public charge stations for all BEVs and PHEVs. Jedlix manages the EV charging based on the balance between production and consumption of renewable energy. By setting the vehicle model and departure time in the app, the EVs will be charged combining owners' personal preferences and the use of the best available charging moments on the real time energy market, saving money and together increasing the share of renewable energy. For example, the EVs will be arranged at the middle of the night when the wind is still producing power but there is little demand for it (i.e. with little charging cost). EVs are ensured with full charge at the desired time and the generated financial reward is shared between Jedlix and the EV owners.

Jedlix is partner of the Living Lab Smart Charging project in The Netherlands as presented in *Section 6.1.1.2*. A Tesla platform has been developed for data exchange for Tesla users, and as of January 2017 smart charge at their home charge point has become available. The smart charging service of Jedlix is readily used at 1000 public smart charging stations across The Netherlands for Renault ZOE drivers. This service will soon be available for BMW and Renault, enabling saving of charging from domestic EV charging using the best charging moments.

2. Nuvve's GIVeTM Platform based projects

NuvveCorp. [6.67] is a San Diego based company, aiming to reduce the cost of EV ownership while supporting the integration of renewable energy sources via smart grid V2G. Nuvve GIVe™ Platform, the World's Largest Aggregator, was developed based on the work done by Prof. Willett Kempton at the University of Delaware, and has been developed worldwide to demonstrate its capabilities, flexibility of implementation and its scalability.

The world's first fully commercial V2G hub [6.68] started operating in Denmark in August 2016 thanks to Nissan's electric vehicles, dual energy flow enabled by Enel V2G chargers and Nuvve's intelligent aggregation platform, GIVe™, that controls the power flow to and from the cars. The local utility Frederiksberg Forsyning and Danish grid operator Energinet.dk have participated in the project in order to better integrate EVs and provide ancillary services to stabilise and balance the demand of the grid.

In The Netherlands, [6.69], Nuvve GIVe™ Platform participates in TenneT's Frequency Regulation Market by working closely with its local partner The New Motion, and delivers key grid services such as frequency regulation as well as provides load management services.

3. eCARSHARE – The Netherlands

eCARSHARE [6.70] is a car-sharing project at a corporate level, based in the South of The Netherlands and started by the municipality of Sittard-Geleen and the Foundation Limburd Elektrisch. It offers a bottom-up e-car sharing implementation with municipalities and employers that share their e-fleet. Businesses and private customers combine their use to optimize the occupation of the vehicles, and therefore the cost per kilometre becomes low. The relevant objectives are the intensification of the capacity utilization, the improvement of the transportation in terms of trips length, by adopting high charging speed and fast charging, and provision of extra income and cost reduction by using locally produced solar energy connected to local storages with smart charging. The main features of eCARSHARE is:

- The electric vehicle is shared with others;
- The vehicle is not owned by the user but a provider;
- The user does not have to bear the burden of the ownership of a private vehicle but only the benefits given by the use;
- The charging is slow if possible, fast if needed and always available.

This is a promising business case because of the following trends that have been noticed recently: the necessity of a car for an increasing number of people is decreasing, hence, different modes can complement each other in order to ensure mobility; status is not given by the car anymore, but gadgets, like smartphone and tablets; a continuously growing demand and urbanization need more innovative mobility solutions.

This program offers several advantages to employers (business owners): the total cost per km of EVs can be lower than ICE vehicles and can help to reduce the costs of organizations. With a combination of different vehicles, such as e-bikes and electric cars, the mobility costs can be halved. The decoupling of mobility costs and energy costs from economic growth allows to not increase the energy consumption correspondingly. The program analyses the mobility needs of the businesses and monitors the e-cars and e-bikes that are shared in order to provide an initial evaluation. After that, the electric cars and e-bikes are used for at least 12 months supported by two vehicle-sharing platforms. It can provide e-drives for 28 cents and e-bikes for 12 cents per kilometre.

4. THE MOBILITY HOUSE - Germany

The Mobility House [6.71] [6.72] is a company that offers energy facilities to private users to optimize their operation and to ensure energy self-sufficiency through integration with RES and profits for the final users. It allows EV users to make their vehicles available for some time daily, because according to their estimates EVs stand for around 23 hours a day. They have more than 30 MWh of stationary 2nd life batteries in operation or under construction, more than one fleet under controlled charging and a bidirectional V2G pilot in Germany running for more than 1.5 years. The main idea is that, if demand increases or supply decreases, the energy stored in EVs can be fed back to the grid obtaining a profit. This is done when the users specify the availability time span and the required SOC when leaving, and in this way, there are lower procurement and maintenance costs. According to TMH, EV batteries are the most competitive storage solution in the market due to their double function: at first as transportation solution and as an energy solution. Another aspect that is covered by this aggregator is the energy control in Smart Houses: clean energy consumption from PV is maximised charging the electric vehicle. Moreover, the vehicle is discharged to supply the home in the Vehicle to Home (V2H) mode. Their experience includes:

- 2014: Several electric cars have been charged in such a way that the process is optimised for fleets. This is done by developing a cost-optimised charging model with the aid of efficient communication between vehicles and grid;
- 2015: A fleet of 10 Renault Zoes is discharged on a time control basis and responds to the dynamic price of the energy market and this allows cost optimization;
- 2016: In Vehicle-to-Coffee, bi-directional charging is used to discharge Nissan Leaf and e-NV200 to satisfy the power consumption the company;
- 2017: the charging of fleets of electric commercial vehicles are intelligently controlled in order to reduce operating costs and increase fleet efficiency.

The basic idea is to implement a controlled charging or a bidirectional one instead of uncontrolled charging: this is shown in Figure 6.1-43.

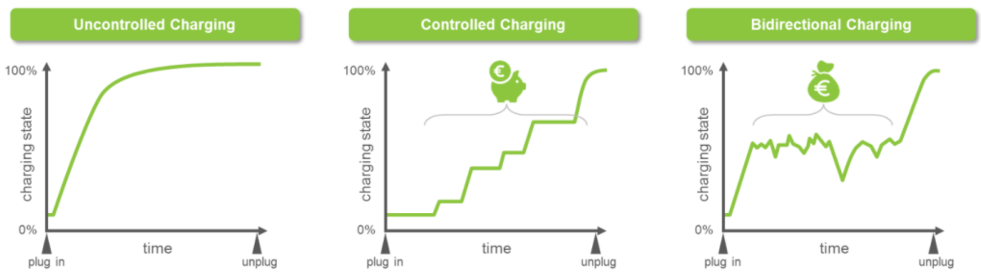

Figure 6.1-43 Different types of charging strategies [6.71]

In uncontrolled charging, as soon as the vehicle is plugged in the charging starts and the charge does not take into account the energy price on the market. Besides, the vehicle is left standing with a fully charged battery for many years. In the second mode, the vehicle is charged in a smart way: when the energy price is low and as much power possible from RES. The battery health is optimised because the optimal charging status is kept for as long as possible. The last mode allows bi-directional charging: the vehicle can be discharged when needed and provides services to the grid, the home and receives income on a day-to-day basis. It is said that also in this case the optimal charging status is maintained as long as possible although according to the literature analysed previously, V2G affects battery health because it implies extra charging. This is maybe because, the battery degradation phenomenon is not thoroughly considered and only the effect of the SOC is considered. Figure 6.1-44 shows how the system reacts to the regulation signal and how the system SOC varies accordingly.

Figure 6.1-44 (a) System frequency; (b) System power; (c) System SOC [6.72]

The products available for V2G are: from the Grid services, FFR, Frequency Control by Demand Management, Fast Reserve, STOR, Demand Turn-Up; from Industrial and Commercial Services, Peak Shaving and Uninterruptable Power Supply; from Energy Services, Intraday Arbitrage and Wind/PV buffering; and finally, for Residential Services, the TOU. In order to fetch revenues from V2G it is essential to smartly stack the most valuable products, according to the different characteristics. Figure 6.1-45 shows how the different services can be provided efficiently and in the most profitable way.

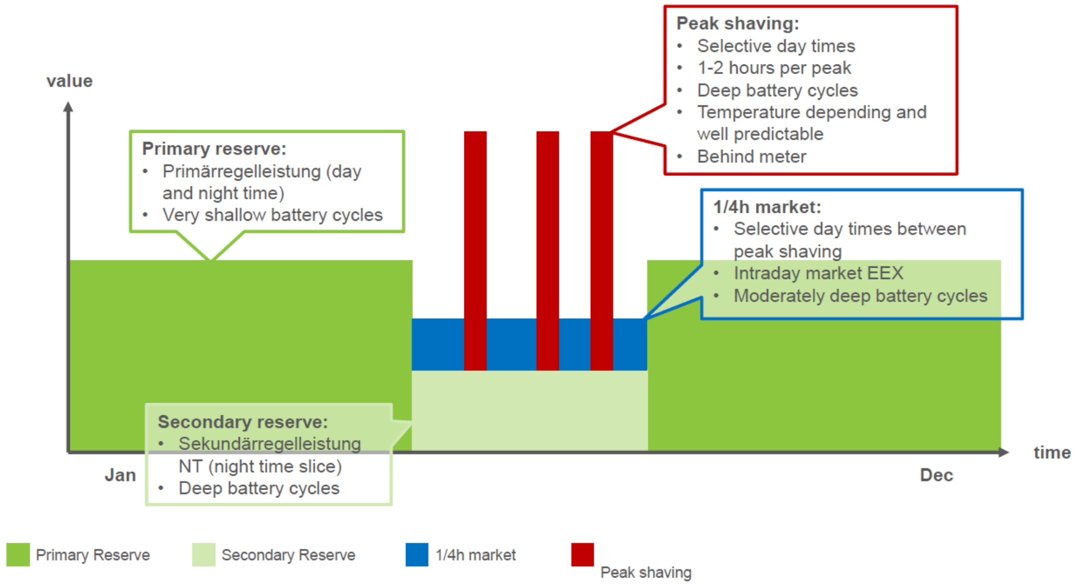

Figure 6.1-45 Stacking of different network services [6.72]

The Mobility House offers the Smartfox energy manager to the user, which optimizes the charging schedules of the EVs in order to reduce the electricity costs by maximising the PV energy consumed for household and EV charging needs. In order to provide some estimates of the potential savings to the EV user, a tool [6.73] that considers the user profile in terms of system characteristics, EV characteristics, usage patterns and energy consumption is available. The description of the PV system is given by the location (postcodes of Germany), power of the PV system and commissioning date. The EV is described by the model, which defines the battery capacity [kWh], the charging power [kW] and the consumption [kWh/100km]. The charging behaviour of the user is also considered by the average state of charge, the average daily driving distance and the availability windows in weekdays and weekends. Finally, the electricity consumption is described by the household electricity consumption and the current electricity price. Once these variables have been defined, the program gives estimates in three scenarios:

- Without PV or energy manager;
- With PV and energy manager and taking in considerations the availability given by the user;
- With PV and energy manager but maximising the self-consumption without taking in consideration the user's availability.

The program gives the achievable self-consumption rate and the savings in electricity costs by considering the energy that has not been absorbed from the grid because of the self-consumption, and the influence of the German policy with the loss of RES bonus due to self-consumption and the fee on self-consumption. At the end, the total cost per km is given for the three scenarios. Although the effect of the policy has been brought in at a later stage, it has not been considered within the optimization process; in fact, it leads sometimes to negative savings due to the so called 'energy tax' while the optimization can be programmed to obtain nil savings in the worst case.

<u>5. WE DRIVE SOLAR-LomboXnet</u>

We Drive Solar [6.74] is an electric vehicle leasing business that operates in the province of Utrecht in The Netherlands. When a reasonable number of subscribers sign up the program, the program starts in that area: a fixed parking for the car is assigned by the municipality of Utrecht to at least three regular subscribers and there is no private parking. According to the nominal mileage a year, that goes from 2500 to 5000 km, an entry fee that goes from 99€ to 196€ a month respectively must be paid; if at the end of the year a higher mileage has been reached then an extra payment of 0.12€/km has to be made. This include maintenance and insurance. For the electricity, there is a deposit per package from 12.5 to 25€ per month. Any adjustment in terms of more or less km driven is made at the end of the year. The loading costs at the charging station in public spaces are 0.3€/kWh whereas the Renault ZOE consumes 0.2 kWh/km; hence, the energy cost per km is 0.3*0.2=0.06€/km. The charging points are provided by LomboXnet and are fast smart solar charging points, which recharge an average of 100 km/h. These employ the 4000 solar panels available in the region. Besides, private solar panels can be used to charge the cars. We Drive Solar provides also businesses: the cars can be deployed as pool vehicles for the employees and can be shared in order to reduce costs. By utilizing smart charging, the car battery storage is used to maximise the use of the PV panels in the neighbourhood.

LomboXnet [6.75] is a residents' initiative in the Utrecht neighbourhood Lombok and provides internet and charging stations for EVs powered by solar energy, in the area. These are V2G enabled, hence, they can charge and discharge in order to allow more RES integration. The WDS (We Drive Solar) cars use these.

6. ENGIE

Engie Services [6.76] is a European leader in providing sustainable technological solutions for energy services and the environment. It serves companies and public organizations by providing solutions that optimize the performance of their systems in order to minimize the environmental impacts. It provides consulting, installation, management and maintenance of the charging infrastructure. For companies, there are different schemes that can bring benefits, with the only condition that the cars have to be owned by the company (they are on the balance sheet):

- MIA: 36% of deduction of the depreciation in addition to the normal one;
- KIA: for investments from 2300€ to 55248€ and additional deduction of 28% of the total depreciation;
- VAMIL: up to 75% of the investment can be recovered.

One of the projects undertaken by Engie consists in the installation of charging stations in the city of Rotterdam in The Netherlands. In fact, the Rotterdam city council is promoting electric transport in two ways:

- For citizens, with clean solutions and services that facilitate use;
- As a city, by having more than one quarter of the municipal vehicle fleet made by electric cars and nearly 3000 charging stations.

7. FlexiSolar - UK

Flexisolar [6.45] is a vertically integrated company that designs, manufactures and install solar panels and solar carports. They are able to deliver solar carports installations at less than 1£/W and these offer revenues from year one. The systems are scalable from 7.5 to 50 kW and they come with a 10 years warranty. One of their projects was an installation of a 2 bays carpark, with 10 kWp that gives 0.9 MWh at Devon Cliffs Holiday Park near Bournemouth. The co-location of two EV charging points of 7 kW and PV systems provides cost savings of over 1000£ per unit.

8. Clem '– France

Clem ' [6.77] is a French company created in 2010 which provides community car sharing programs to local authorities, businesses, collective habitats and private users. It makes available a web platform suitable for smartphone, tablet and computer, the clem.mobi platform which gives information about journeys, charging and car sharing and carpooling information. The members of partner organizations can therefore refer to it to plan their journeys. The vehicles can belong to the operators, companies, local authorities or private owners. The car sharing complements the installation of charging stations and can include many services. The most common way is through reservation, which is ideal for rural and up skirt locations where Clem ‘ has a strong expertise. The HUB allows borrowing a car from one terminal and leaving it to another; this is suitable for areas with high urban density and can be adopted by companies that have sites close to each other. The Peer-to-Peer (P2P) gives subscribers to the service (through their companies or individual subscriptions) the possibility to share their vehicles with other users in the community, by defining the time slots in which the car is made available. The Pendular scheme is or employees who want to commute to work. They book the trips for the following week and share the car between colleagues. With the Self Service, a subscriber does not have to reserve the car but s/he identifies her-/him-self upon arrival at the station if the vehicle is available. On his return, the duration of the journey is calculated and billed. The car pool is complementary to the car-sharing program. The user gives the details about their weekly schedule and receive offers for that; in order to make the meeting between car-poolers easier, every journey happens between a station and another. With “share its route” users that want to split the cost of the vehicle can post his trip to allow other users to join. The sharing cost is carried out in the portal and participants are charged for his or her fair part through their account.

From March 2017, Clem ‘ is also part of the French Energy Tech Alliance with other six partners, which aims to produce advanced technologies in the energy, eco-mobility and networks fields. Clem ‘ will develop platforms offering various information in the field of eco-mobility. The other partners are Dotvision, Luceor, Levicys, Evolution Energie and Evergaz. Their first joint project will provide global technological solutions to developers of Smart Cities worldwide.

Demonstrations of commercial applications of V2G have started blossoming worldwide. Frederiksberg in Denmark with the Parker project is the first commercial V2G hub in the world [6.43], where grid integration specialists such as Enel, Nuvve and Insero work together with car manufacturers such as Nissan, Mitsubishi and PSA Groupe. This Danish project ‘will demonstrate and define the technical capabilities, which future electric vehicles must support in order to roll out V2G worldwide. Furthermore, the project will take the first steps towards developing a Grid Integrated Vehicle (GIV) certificate that car manufacturers can apply to mark the vehicles’ ability to support the grid.’

The USEF (Universal Smart Energy Framework) foundation in The Netherlands was founded by seven key players, active across the smart energy industry, ‘with a shared goal - one integrated smart energy system which benefits all stakeholders, from energy companies to consumers.’ USEF is intended to help interested parties to understand the nature of the opportunity that the new aggregator role offers and to provide the tools to act on it, making the boundaries of an aggregator’s business model clear, without limiting opportunities. USEF sees its role in defining and delivering the related interaction models and sample technical references, which is particularly important to companies not currently active in the energy markets but that have existing retail relationships and expertise. As well as gaining early access to commercial prosumers with the highest volumes of flexibility to sell, the demonstration projects in Heerguward (a USEF-based smart energy system connecting 200 households, predicting daily electricity use, production, and smart control of appliances) and also in Hood Darlem (42 urban neighborhood households with home battery systems are combined with solar production, a smart-in-home-system, within a USEF framework) will play a role in setting the standard for the function, effectively creating a hallmark for the future which they can then apply to generate customer confidence in their brand [6.78].

6.2. ***Project approaches, methodologies and assumptions***

The projects/simulations reviewed in *Section 6.1* have been summarized in Table 6.2-1, according to various criteria including system boundary (time span and geographical scale), assumptions, methodologies/calculations, and results in terms of projections, simulations, trials/demonstrations, planned and operating, where applicable.

Table 6.2-1: Summary for selected projects

Project	Objectives	System boundaries (time and geographical)	Assumptions	Methodologies/ calculations	Key results
Network Innovation Allowance (NIA) project – UK	To assess the technical and commercial potential of EVs to support frequency response	Aggregate analyses at UK national level in the year of 2030, including both home charging EVs and EV fleet	▪ Projected EV numbers follows NG FES 2015; ▪ Division of EV charging archetype (Home of 47%, work of 3%, public of 11%, fleet of 9 %) based on DfT and UCLV data; ▪ The time available for EV charging and the daily energy requirement are assumed to be constant across archetypes; ▪ Frequency response is provided by turning on and off the charging or varying the charging rate, but excluding V2G; ▪ Holding payment of £10/MW/hr for combined low and high frequency response provision;	▪ Aggregate frequency responsive profiles are calculated by using each individual EVs to support both low and high frequency response given a signal; ▪ The calculation of CO2 emission reduction uses the figure of average increase in emission, of 0.26 tonnes of CO2 per MWh, due to capacity holding for frequency response, assuming an operation of 80%-part load; ▪ Battery degradation cost has not been considered	▪ 754 MW annual average low frequency response potential, corresponding to 52% of projected 2030 requirement, representing £66 million per year based on current prices; ▪ able to provide firm response availability over the night when combined with controlled smart charging; ▪ Potential revenues of £45/EV/year corresponding to a net annual benefit of £26/year for a home charging EV and £35/year for a fleet EV; ▪ Potential to avoid around 1 tonne CO2 /year/EV.
My Electric Avenue Project – UK	▪ To learn customer driving and EV charging habits; ▪ To trial equipment to mitigate the impact of EV charging via DSM; ▪ To develop a low-cost solution for future EV network	▪ Between January 2013 and December 2015; ▪ Over 100 people in different clusters around Britain are recruited to the trials, both households (primarily) and workplaces; ▪ 220 Nissan Leaf of 18-month lease deals;	▪ Charging rate of 3.5 kW; ▪ 24 kWh battery;	▪ Direct controls of domestic EV charging using ESPRIT by curtailing high load devices, to maintain the normal network operation; ▪ No more than five 3.5 kW chargers switched simultaneously to prevent Flicker; ▪ No more than one switch per six minutes to protect EV batteries;	▪ Esprit improve network more efficiency by shifting demand away from peak times, reducing about 9% feeders' losses; ▪ Network operation benefits from Esprit including thermal and voltage performance; ▪ 32% of low voltage (LV) feeders will require intervention for 40-70% EV penetration, based on 3.5 kW (16 amp) charging;

					▪ £2.2 billion of reinforcement costs up to 2050 could be saved by ESPRIT; ▪ 70% of EVs only charge once per day, and more than 65 % of EVs are charged until the battery is full; ▪ Most trail participants accept having their EV charging externally controlled; ▪ blueprint on contractual arrangement by third party on behalf of DNO.
Green eMotion project – EU	▪ Setting a framework for pan-European interoperable electromobility which is commonly accepted, user-friendly and scalable; ▪ Integrate smart grid developments, innovative ICT solutions and different types of EUs various urban mobility concepts; ▪ Enable a European wide market place for electromobility to allow for roaming; ▪ Providing a unique knowledge base.	The project has defined and demonstrated a European framework that connects all stakeholders.		▪ ICT systems of participating companies networked by means of a so-called Marketplace; ▪ Developed prototypes, mainly load management software and power management for distribution networks; ▪ Demonstration of combination of public charging infrastructure with other services, e.g. shopping.	▪ Proposed "Roadmap to interoperability" focused on missing standards, in particular on communication interfaces; ▪ Grid reinforcement cost costs can be reduced by so called smart charging. EVs improve integration of RES; ▪ Public charging is a difficult business case today, charging stations to be located at point of interests.
SmartCEM – EU	▪ Prove that user acceptance of electrical vehicles can be increased by at least 15% thanks to smartCEM services. ▪ Evaluate how much the efficiency of transport can be optimised, taking into	▪ From the start of 2012 to the end of 2014; ▪ Involving four European cities/regions: Barcelona, Gipuzkoa-San Sebastian, Newcastle and Reggio Emilia; ▪ Barcelona focuses on motorcycles; there are	▪ The hardware architecture will be based on the following components: ▪ On-boards units: a bidirectional onboard system, which is connected to the vehicle CAN bus and manages all internal and	▪ Five complementary services as follows are provided: ▪ EV navigation: navigation of EV charging points or charging stations; ▪ EV efficiency driving; ▪ EV trip management: existing multimodal	▪ Main factors that discourage people from buying an EV include lack of charging infrastructure, high market price and short battery range of EVs; ▪ Main factors encouraging people to buy an EV include low running cost and the

	account environmental sustainability. ▪ Develop of tools for measuring, monitoring and assessing carbon emissions. ▪ Identify and address all deployment elements such as business models, legal aspects and privacy ▪ Optimization of the energy use in the vehicle and infrastructure. ▪ Support pan-European interoperability by standardisation between operations performed by different services and facilitating the interoperability between different systems and vehicles. ▪ A complete integration of new services such as car-sharing within the public transport system. ▪ Expand the pilot to more cities, operators, or service providers	141 charging points available for 45 scooters; ▪ Gipuzkoa combines urban and interurban car-sharing facilities and a hybrid bus in the capital (San Sebastian); there are 33 charging points available for 1 hybrid bus and 30 electric vehicles; ▪ Newcastle upon Tyne develops the use of existing EVs assigned to the public; ▪ Reggio Emilia evaluate the potential of light electric vehicles' integration in the car-sharing fleet of a public administration; there are 10 vehicles in the fleet.	external data (from the back office); ▪ Back office platform: general management system that controls all vehicles, charging spots, energy and commercial transactions; ▪ Web interface: to give users access to electro mobility management and booking systems; ▪ Nomadic devices: whose use will also be studied and proposed as an alternative flexible media. ▪ The software architecture will be based on standards like web services (SOA, XML, WSDL, SOAP protocol). Standard communication channels such as GSM/UMTS will also be used and technologies like 5.9 GHz–M5 will be studied and proposals made for their use.	journey planning and potential EV sharing; ▪ EV charging station management: station operation, station energy management, power supply status, range estimator, charging point booking, payments and scheduling; ▪ EV sharing management: online and offline.	environmental benefit, such as reduction of carbon emissions, from using this type of vehicles.
MeRegioMobil – Germany	▪ Business model development; ▪ Efficient route identification; ▪ Research and demonstration of EV integration in a smart home;	▪ 2010-2011 Germany ▪ Laboratory testing with PV, EV and household load		▪ Laboratory testing; ▪ Simulations online and offline; ▪ Field tests.	

	▪ Testing of different price models; ▪ Intelligent charging strategies; ▪ RES integration; ▪ Different ICT utilization; ▪ Analysis of fast battery charging ▪ Evaluation of user acceptance of business model and pricing schemes; ▪ Evaluation of different incentives; ▪ Evaluation of the grid impact due to EV deployment; ▪ Techno-economic analysis of EV integration in the power system.				
EDISON – Denmark	▪ To develop system solutions and technologies for Electric vehicles (EVs) and Plug-in hybrid vehicles (PHEVs) which enable a sustainable, economic and reliable energy system where the properties of EVs are utilised in a power system with substantial fluctuating renewable energy. ▪ To prepare and provide a technical platform for Danish demonstrations of EVs with emphasis on the power system integration aspects.	▪ 2009-2012; ▪ Denmark.	▪ Five EV charging scenarios have been considered and these are: ▪ Charging upon plugging (dumb charging); ▪ Locally controlled charging (timer based or price signal-based charging); ▪ Aggregated and controlled charging (EV Virtual Power Plant, EVPP, as a balance responsible party); ▪ Aggregated and controlled charging (EVPP under a balance responsible party); ▪ Advanced scenario (both decentralized and aggregated control).	▪ Grid impact evaluation; ▪ Battery degradation and development of an indicative battery model; ▪ Fast charging effects on battery is also evaluated.	▪ The voltage drop along feeders is higher than the limit (5 %) with 20 % EV penetration and three-phase 16 A charging. ▪ The transformers and lines are overloaded with high EV penetration (20 %) and three-phase 16 A charging ▪ The low power charging option is more favourable in terms of loading; ▪ The voltage drop along feeders is higher than the limit (5 %) with 20 % EV penetration and three-phase 16 A charging;

	▪ To develop globally applicable standard system solutions for EVs, by utilising the Danish leading knowledge within distributed energy resources and operation of energy systems with high wind power penetration, and thereby, release the potential for Danish export of technology, system solutions, and knowledge.				▪ The dumb charging EV demands are well distributed due to the quite flat distribution of EV reaching home time. More accurate evaluations are needed.
COTEVOS - EU	▪ Asses the interoperability of the component of the e-mobility system; ▪ Determine the effect of interoperability on business models.	▪ September 2013 – February 2016	▪ The communication and function of the interfaces between the different stakeholders are tested	▪ Laboratory for interoperability testing	▪ 262 tests conducted from which 215 tests passed and 47 did not pass; ▪ More work on standardisation for energy management and grid interaction, as well as for the provision of ancillary services, smart charging and V2G need to be done; ▪ The stakeholders should adopt common standards and avoid the use of proprietary protocol; ▪ A higher security for the data management is necessary; ▪ Business models are essential to aid EV integration.
Amsterdam Vehicle 2 Grid – The Netherlands	▪ Optimization of the consumption of the local RES, to evaluate what is the behavioural change of the system with the introduction of EVs;	▪ March 2014 to March 2016; ▪ One household, e-boat, 30 m2 of PV panels.	▪ 3780 kWh/year of PV production with 3350 kWh/year of household consumption; ▪ 10 kWh of storage ▪ The EV is supposed available throughout the day.	▪ Maximisation of the energy autonomy; ▪ Minimization of the grid absorption by storing the excessive PV production in the EV storage; ▪ Reduction of the percentage of PV	▪ increase of energy autonomy of 31 % by inclusion of EV (battery); ▪ Reduction of grid injection of 33%; ▪ Grid absorption reduction; ▪ Battery degradation of 8% of the total capacity in 2 years.

	▪ Quantification of the minimum level of vehicle autonomy;			production injected in the grid; ▪ The battery degradation is evaluated only in terms of efficiency; ▪ Effect of V2G on the battery degradation is evaluated.	
Smart grid: profit for all – The Netherlands	▪ To develop and test a series of new, scalable and user-driven services related to power grids of the future; ▪ Pilot Utrecht: to integrate and use as much solar generation as possible, where participants can either consume the energy produced themselves or sell to the neighbours; ▪ Pilot Amersfoort: develop new services that allow residents to consciously deal with their energy and the electricity they produce, by using smart meters that are installed in the house.	▪ 2012-2015 ▪ Utrecht Lombok and Amersfoort Nieuwland, each with one hundred households	▪ E-car4all: Share Cars on solar power from the district ▪ Insight4all: Understanding consumption and generation per household ▪ Advice4all: Tailored advice per household ▪ Flex4all: Optimal timing by automatic control (demand side management) ▪ Profit4all: Incentives send energy behaviour (smart charging) ▪ Solar4all: Prediction of solar ▪ Storage4all: Storage of solar power (V2G) ▪ Together4all: Corporate smart energy services	▪ Eight innovative services as follows are developed in co-creation with the end-users: ▪ E-car4all ▪ Insight4all ▪ Advice4all ▪ Flex4all ▪ Profit4all ▪ Solar4allTogether4all	▪ E-car4all: 54% more solar power is utilised by coordinating with EV charging; ▪ Advice4all: advice on when to use their own generation saves an individual household 12% on average on direct cost of gas and electricity consumption; ▪ Profit4all: pilot Amersfoort achieves an energy consumption increase of more than 10% in sunny hours; ▪ Together4all: energy consumption of all the participants at night is decreased by 20%, and the associated total energy saving is 15%; ▪ Amongst the eight services E-Car4all, Insight4all, Advice4all and Flex4all foster the acceleration of the energy transition.
G4V project – EU	To develop an analytical method to evaluate the impact of a large-scale introduction of EV and PHEV on the grid infrastructure and	Distribution grids (MV and LV), data from different European countries	▪ Scenarios (different charging controls, prices, services, grid infrastructure and stakeholders);	▪ Minimisation of the costs of the total electricity production;	▪ Charging strategies should be flexible and adjustable to market penetration level of EVs;

	a visionary "road map" for the year 2020 and beyond		▪ For every scenario varying: penetration rate (0-100%), charging places, power connection (3.7-55 kW);	▪ Load flow to calculate the grid's condition and investment costs; ▪ Decentralised market-based approach.	▪ Unidirectional charge strategies should be first promoted. Bidirectional to be reconsidered for a large penetration; ▪ Cost effective deployment of EVs promoting home charging (up to 3.7 kW); ▪ ICTs do not represent a barrier.
SME project – EU	To investigate how cities can increase energy efficiency, minimize grid impact, increase renewable contribution and generate profit by integrating smart charging and V2G technology into the existing energy infrastructure at district and city scale.	▪ Supported by Climate-KIC; ▪ Pilots in Birmingham, Berlin and Valencia.	▪ The aggregator manages the charging of the fleet and provide the different services ▪ Birmingham: 5 car parks, standard, smart and V2G charging; FFR is provided; ▪ Berlin: evaluated commercial transport fleets across the city, Secondary reserve and Minute reserve provided; ▪ Valencia: household and commercial energy consumption, different servicers: daily market, secondary regulation, tertiary regulation and deviations.	▪ Evaluation of NPV, required grid infrastructure upgrade, earnings from different services, power regulation system and distribution grid constraints and IRR have been analysed.	▪ Birmingham; £975.000 potential savings in infrastructure upgrade with smart charging by 2045; ▪ Berlin: grid capacity and regulatory framework conditions are limiting factors for V2G and the maximum earning potential is 13.20€/vehicle/year is calculated ▪ Valencia: NPV 2119912.14 €, IRR 15.51% and payback time of 8 years.
CENIT VERDE – Spain	▪ To create a key technology for the entire value chain of green vehicles and reduce costs by localization of main components and services. ▪ Support Spain's three main objectives: - Reduce national petrol energy dependence;	2010-2013 Spain		▪ Vehicle definition and architecture. Global specification and validation; ▪ Energy storing systems for PHEV/EV; ▪ Electric propulsion for PHEV and EV; ▪ Design of multimode bidirectional chargers for PHEV and EV;	▪ PHEVs and BEVs emit less CO_2 than ICE although the difference between these is small; ▪ ICE emit less CO_2 due to manufacturing compared to PHEVs/BEVs.

	- Reduce CO2 emissions from transportation and increase the use and business of RES; - Assure the industrial sector and Automotive R&D activities in Spain in the future.			▪ Local charging infrastructure for PHEV and EV; ▪ Integration of the vehicle in the electrical system which includes the following: - Characterisation of the vehicle as an electric load; - Evaluation of the impact of a massive introduction of EVs/PHEVs; - Definition of charging strategies that allow the integration of RES; - Integration of EVs/PHEVs in a Smart grid; - Development of operating models for an efficient and massive introduction of EVs/PHEVs.	
Nikola - Denmark	▪ Demonstrating the synergies between EVs and the power system; ▪ Use charging strategies to minimize the operational cost of the whole power system from a societal and grid point of view.	2013-2016 Denmark	▪ EV related services are classified in three groups: - System-wide services - Distribution system services - User-added services		▪ EVs are able to change their charging behaviour according to the status of the system; ▪ 6 EVs performed local voltage support connected to the public distribution grid and frequency regulation when islanded
ITHECA – UK	Prove the potential of V2G to maximise a combined heat and power (CHP) plant by showing the collaboration of transportation, frequency response, energy storage service and district heat solutions with EVs	January 2015 – June 2017, Birmingham, UK.		▪ Intelligent scheduling of EVs to maximise the output; ▪ Definition of the technical requirement for V2G; ▪ Definition of a business case for V2G operation; ▪ Definition of the operational conditions for V2G implementation in real	

				life with a fully operating V2G.	
ELVIRE – EU	To tackle range anxiety through effective information provided by on board and external ICT	▪ January 2010 to March 2013 ▪ Partners from Belgium, France, Germany, Spain, Sweden and Israel were involved	Different services, namely, driving services, Energy services and Generic services have been defined to collect and handle the data and provide the right information.	Driver assistance, communication system and an external management system have been developed to provide the right guidance to the user	▪ 92% of the participants found the application suitable and trusted the information it showed; ▪ A ready to use technology has been developed and it can impact in many areas, such as, competitiveness of the European industry, CO2 emission reduction (by encouraging a higher adoption rate of EVs), energy security and personal data security.
CROME – Germany & France	▪ Cross-border field demonstration on EV mobility; ▪ Development of an EVSE system that is public and interoperable and ensures the access to the EVs from France and Germany; ▪ Evaluate how customers accept e-Mobility and their needs in terms of charging in a cross-border mobility context; ▪ Make charging spots availability and reservation as well as billing viable; ▪ Recommendation for a European standardisation for charging infrastructure	▪ 2011-2013; ▪ Germany-France.	▪ Level 2 and 3 charging; ▪ 121 EV sold or leased in both the countries	Surveys, face to face interviews and workshop to monitor user acceptance and response toward e-Mobility	▪ 97% of the participants are completely or mostly satisfied and 76% consider EVs as a better option than a conventional car; ▪ EV's feature of CO2 emission reduction is seen as an important aspect in France; ▪ 63% of the participants in France and 71% in Germany charge at home whereas only 10% do not charge at home – 51% of the respondents charge the EV after each trip, 23% when a certain SoC is reached and only 18 % after the last trip of the day ▪ 45% of the users in France and 61% in Germany use special sockets like type 2 and 3;

					▪ EVSE have been used for marketing purposes in businesses; ▪ The low speed is seen as a major concern; ▪ Some businesses are willing to use EVs as storage for RES integration and an increased self-sufficiency.
ELVIIS – Sweden	▪ Identification of cross-industry barriers that hinder large EV penetration; ▪ Determination of the possibilities an intelligent infrastructure creates for user functionality; ▪ Identification new business cases for the car industry, power providers and telecom services; ▪ Development a scalable system for an intelligent EV infrastructure; ▪ Development of services like billing and charging and their implementation on a platform.	▪ 2011-2013; ▪ Sweden, Gothenburg.	▪ Use of ICT for the development of services for EVs: ▪ Charging; ▪ Billing.	▪ Development of an open and scalable ICT system for EV charging; ▪ Pilot tests with 5 Volvo C30 electric and smart charging infrastructure; ▪ September-November 2011 without the ELVIIS platform and related survey; ▪ March-May 2013 with the ELVIIS platform and related survey.	▪ Open ICT platform on board, smartphone app and web; ▪ Results from the first survey address EVs as driving efficient, environmentally-friendly but range, charging and lack of information are major sacrifices; ▪ Results from the second survey indicate that ELVIIS provide useful information about EV state, costs and notification but a better identification of the charging post and routing are major lacks; ▪ Routing is perceived as an essential next step.
Mi Muovo Elettrico – Mi Muovo Mare – Free Carbon City – Italy	▪ Guaranteeing the recharge of EVs in case of emergency and to avoid lengthy stops; ▪ Reduce the air and noise pollution and at the same time ensure commuting between cities and goods transportation.	▪ Emilia-Romagna, Italy. ▪ 8 cities;	▪ Charging points with maximum 22 kW; ▪ Two plugs: SCAME, single phase 220 V and MENNEKES three-phase 220-400 V; ▪ RFID (Radio Frequency Identity) reader to recognize smart cards.	▪ Deployment of charging posts in strategic points; ▪ Improvement of the policies for the access of EVs in Limited Traffic Zones and free parking; ▪ Funding for EV purchasing for public administration.	▪ Deployment of more than 100 charging points across Emilia-Romagna; ▪ Deployment of 24 charging points in the axis of Via Emilia; ▪ Purchasing of 104 EVs for the public administrations and 9 hybrid/ electric buses.

Sustainable Mobility-The MUTE as a Prime Example for Clean and Affordable Mobility – Germany	To evaluate the effect of EV charging in terms of charging costs and CO_2 emissions.	German energy mix and FIT scheme in 2015.	3 different scenarios, Mix method, Delta method and Parallel Market method.	▪ Mix method: EVs are treated as common loads and no specific charging times is adopted; ▪ Delta method: EVs are particular loads with specific charging times hence not the whole energy mix is used; ▪ Parallel market method: EVs are charged only with the energy coming from the RES; ▪ All the three methods are compared against an equivalent ICE vehicle.	▪ The Mix method gives an emission factor of 37gCO2/km whereas the electricity costs are 2€/100 km; ▪ The Delta method gives an emission factor of 71gCO2/km and 1.85€/100 km charging costs; ▪ The Parallel Market method gives an emission factor of 0.4gCO2/km and a charging cost of 0.30€/100km.
Living lab smart charging project – The Netherlands	To make the most of the renewable generations from wind and solar by controlling the charging load.	▪ 325 municipalities in the Netherlands (including Amsterdam, Rotterdam, Utrecht and The Hague) have participated; ▪ Mainly public charging, have include private charging; ▪ Three steps are planned for the project: - Nation wise deployment and upgrade of charging stations for smart charging; - Validation of the smart charging using the stations; - Standardization establishment based on the Dutch experience with smart charging	Electric vehicle owners using the stations are able to set their preferences for charging using an app and they can also obtain revenue by responding to the grid requirements.	The project is implemented using an open market model, e-claring.net, which is a platform with the purpose to exchange roaming authorisation, charge transaction and charge point information data.	

		including tests and research findings.			
Electric Nation – UK	▪ To investigate the impact on electricity distribution networks of charging a diverse range of electric vehicles at home; ▪ To understand how vehicle usage affects charging behaviour given diversity of charging rate and battery size; ▪ To evaluate the acceptability to owners of EVs of smart charging systems and the influence these have on charging behavior.	▪ Launched in September 2016; ▪ This project is engaging 500-700 EV drivers trial participants from home and small business in the low voltage network.		▪ Access from a mobile phone app to enter journey preferences and receive charging information and demand control events; ▪ All customers will have the ability to override charge control events to ensure that they can get their car fully charged when required.	
BaChMan Project – UK/China WP3	▪ To maximize the cost savings from smart charging and V2G strategies while satisfying network constraints and vehicle user requirement; ▪ To increase the solar power generation capacity within a distribution network by controlling the EV charging at local car parks;	▪ UK-China project started from September 2013; ▪ Distribution grids simulation.	▪ Fixed battery degradation cost of 0.028 £/kWh in the smart charging case; ▪ IEEE30 network is used in V2Gstragegy exploration; ▪ UK Generic Distribution System is used in the PV integration with EV from local car parks; ▪ No extra storage is involved in the PV coordination with EV in the car parks.	▪ Minimize the charging cost by taking advantage of the difference between the selling and buying electricity prices by charging and discharging EVs at the appropriate time; ▪ Iterative charging scheduling to ensure the network operation within limits; ▪ In the PV penetration maximization, the maximum aggregate PV generation is used to calculate the matching PV in a car park.	▪ Cost saving of 38% due to smart charging in comparison to uncontrolled charging; ▪ V2G save 13.6% on charging costs in comparison to the scenario without V2G, which refers to the smart charging case; ▪ Integration of EVs reduces 72.2% of distribution loss; ▪ 77.9 MWh out of 104.1 MWh of daily solar energy generation is supplied to charge EVs, indicating an energy autonomy of roughly 75%.
Smart solar charging – The Netherlands	▪ Marketable product-service combinations for various types of districts / areas;	▪ Launched at February 2017 and will span over 4 years;		Deployment of 70 We Drive Soar cars with 300 km range and V2G function.	

	▪ New economic activity in the Utrecht region; ▪ A contribution to environmental sustainability, low carbon economy and social sustainability.	▪ Successor of project ”Smart Grid: Profit for All”; ▪ Five linked pilot areas in the Utrecht region including Lombok, Houten, Utrecht Science Park, Utrecht Central Station area and Driebergen-Zeist.			
EV Energy – EU	▪ To create framework for regions and cities to improve and develop policies for the intelligent integration of electric mobility, renewable energy and smart grids (with associated ICT); ▪ To decarbonise the energy and mobility sector with more effective sustainable energy systems, in the urban context.	▪ Interreg Europe programme; ▪ 1 Jan 2017 – 30 Jun 2021; ▪ Regional and inter-regional (between cities, regions and countries).		The main steps of the project are regional and inter-regional assessment and inter-regional exchanges, on policy measures and low-carbon emission strategies.	
Share-North Project – NSR	▪ To focus on the shared mobility modes and the behavioural changes to achieve sustainable low carbon transport in the North Sea Region; ▪ Resource efficiency, improving accessibility (including non-traditional target groups), increased efficiency in the use of transport infrastructure, reduction of space consumption for transport, improving quality of life and low carbon transport.	Partnership with public authorities, NGOs and research institutions from the North Sea Region;		Developing, implementing, promoting and assessing car sharing, bike sharing, ride sharing and other forms of shared mobility in urban and rural areas and employment groups.	
ITISES project – UK	To find new technical solutions and business	▪ Funded by Innovate UK, collaborative study			

	models for integrating V2G with urban energy and transport system, thus reducing the demand on the grid.	between Cenex and Costain; ▪ Pilot sites at rail stations of old oak common and Park Royal in London.			
efes project – UK	To manage, improve and reduce the electricity use of UK buildings, from single properties through to large commercial premises.	▪ Partially funded by Innovate UK and EPSRC; ▪ Manchester Science Park as trial.		▪ Virtual power plant (VPP) or aggregator; ▪ V2G unit; ▪ V2G gateway which provides the control functionality for the V2G unit, enabling the unit to communicate with both a building and the VPP to determine the most appropriate charging or discharging option.	
DOD V2G Pilot Project – USA	▪ Develop the Plug-in Electric Vehicle (PEV) strategy, to proof the concept that PEVs can perform energy services, to show the benefits, both technical and economical and promote the integration of a large scale of PEVs in the DOD non-tactical ground fleet; ▪ Determine the Total cost of Ownership of vehicles and infrastructure.	EV Sedan Fleet in Southern California	▪ Car leasing scheme with the lease price of 200$/month, with 15 kW bidirectional chargers, 12000 miles driven a year, typical operation from 9 a.m. to 5 p.m. and participating only in the FR market of the California ISO; ▪ Two types of vehicles: trucks and cars.		▪ The total value in 2011 was 2520$ a year or 210$ a month considering the markets open 24/7 for 365 days a year; ▪ The monthly lease price of a PEV Sedan can be reduced by 72% by providing frequency regulation; ▪ When the vehicles are used during normal business hours, from 8 a.m. to 5 p.m., Monday to Friday; ▪ Net savings of 209$/month with V2G compared to conventional ICE.
VEHICLE2GRID PROJECT – The Netherlands	Evaluate business models for V2G through consumer research in order to facilitate the adoption.	The Netherlands.	▪ Creation of financial return; ▪ Sustainable energy charging; ▪ Controlled charging; ▪ Easy to use;	▪ V2H business model and 3 V2G models (Electricity Bank, Electricity Club and the Green Electricity club); ▪ 3 charging strategies for EVs (postponed, cut and	▪ The Electricity club is the most preferred solution for its benefits and the relative simplicity;

			▪ Gamification.	divide and bi-directional charging).	▪ Bi-directional charging provides the highest cost savings.
Task 28 - IREC	▪ Investigate on the technologies and the issues related to electric storage from PEVs for alternative uses than transportation through: - Analysis of the technical and economic viability of V2X; - Synchronization and connection with different V2X research and demonstration projects; - Issue a policy making toolbox and a technology roadmap; - International technical information exchange; - Promotion of new V2X technology demonstration projects.	▪ Spain, Switzerland, France, Republic of Korea, Germany, the USA, Ireland, Canada, Denmark and possibly the Netherlands and the UK joining; ▪ 2016-2018.	▪ Energy arbitrage for cost reduction; ▪ CO2 emissions reduction; ▪ Peak shaving; ▪ RES integration; ▪ Ancillary services; ▪ Load following.	Test on a Micro grid with a 10 kW (Vehicle to Microgrid) V2M charger to analyse the technical viability of the V2M system at a household level.	The 10 kW V2G system is capable to follow variations of the power set points for short period of times.
PARENT project – The Netherlands, Belgium and Norway	▪ Reduce the electricity consumption in households with community participation and technological solutions, such as, smart meters, Home energy management systems and active participation; ▪ Increase self-consumption and reduce grid interaction; ▪ Improve RES integration at a neighbourhood level.	▪ 3 pilots: Bergen, Brussels and Amsterdam; ▪ 3 universities, 2 consultancies and 1 hardware providers; ▪ Local authorities, electricity providers and citizens.	Two phases: - 1st phase with 15 prosumers - 2nd phase with 100 households	▪ System design and planning; ▪ Data analytics; ▪ Optimization; ▪ Forecasting (demand and PV generation profile, driving patterns and electricity prices).	There is potential increase in self-consumption given by the synergy between the EV charging demand and PV energy surplus.
GridMotion	Demonstrate how Plug-in Electric Vehicles (PEVs) can	▪ 2017-2019 demo project;	▪ Smart charging;	▪ Unidirectional smart charging with 50 Peugeot	

	control demand response and provide ancillary services to obtain beneficial impacts on the grid and user income.	▪ The user participating to the project should be based in France.	▪ V2G.	iOn, Partner Electric, Citroën C-ZERO and Berlingo cars; ▪ V2G with a fleet of 15 Peugeot iOn or Citroën C-ZERO to provide balancing services.	
Parker – Denmark	Support the power grid with fleets of series-produced EVs locally and in the overall system.	August 2016 – July 2018 Denmark		Three pillars have been identified to focus on: ▪ Grid applications and technical Grid readiness certificates. ▪ Replicability and Scalability of such applications	
JEDLIX – The Netherlands	▪ To manage the EV charging based on the balance between production and consumption of renewable energy; ▪ To save money for EV users and to increase the share of renewable energy.	▪ Readily used at 1000 public smart charging stations across the Netherlands for Renault ZOE drivers; ▪ The Living Lab Smart Charging project in The Netherlands is a partner.		▪ Smart charging service via a smart device app; ▪ By setting the vehicle model and departure time in the app, the EVs will be charged combining owners' personal preferences and the use of the best available charging moments on the real time energy market.	
Nuvve's GIVeTM Platform based projects	To reduce the cost of EV ownership while supporting the integration of renewable energy sources via smart grid V2G	▪ In Denmark: the world's first fully commercial V2G hub started operating in Denmark in August 2016, involving Nissan EVs, Enel V2G charger and Nuvve's GIVe™ Platform; ▪ In The Netherlands, GIVe™ Platform participates in TenneT's Frequency Regulation Market.		Nuvve GIVe™ Platform aggregates the energy from EV battery and delivers grid ancillary services.	
eCARSHARE	Bottom-up e-carsharing implementation with	In the South of the Netherlands and started by	▪ The electric vehicle is shared with others;		

	municipalities and employers that share their e-fleet	the municipality of Sittard-Geleen and the Foundation Limburd Elektrisch.	▪ The vehicle is not owned by the user but a provider; ▪ The user does not have to bear the burden of the ownership of a private vehicle but only the benefits given by the use.		
The Mobility House-Germany	Provision of energy facilities to private users to optimize their operation and ensure energy self-sufficiency through integration with RES and profits for the final users.	▪ Germany; ▪ Aggregator.		Smartfox energy manager that control the charging of EVs in order to maximise the PV production consumption and minimise the charging costs.	
We Drive Solar & LomboXnet - The Netherlands	EV charging with solar energy from the PV system installed.	Utrecht, The Netherlands	The vehicles are shared in order to minimize the costs	▪ Monthly entry fee according to the nominal mileage + incremental payment for extra miles; ▪ Monthly deposit for the energy cost and any adjustment at the end of the year	
Engie	Solutions that optimize the performance of user systems in order to minimize the environmental impacts.	Aimed at companies and public organizations.		With EV-Box manages, maintains and operates of the charging stations. The two companies will operate the charging stations for 12 years and will provide the energy.	Rotterdam: installation of nearly 3000 charging stations
Flexisolar - UK	Vertically integrated company that designs, manufactures and install solar panels and solar carports	UK	EV charging with solar energy from the co-located PV system	The systems are scalable from 7.5 kW to 50 kW	
Clem '	▪ Provide modern, more economical and ecological mobility; ▪ Provide Shared eco-mobility for ecological, economic, technological and social mobility.	French car sharing platform for local authorities, businesses, collective habitats and private users	▪ Reservation car sharing ▪ Car pool ▪ The HUB ▪ The P2P ▪ The Pendular ▪ The Self Service	Web platform which provides information about car sharing, charging, carpooling and route information	

Clean Mobile Energy project – NWE	To integrate renewable energy, through storage and energy management and electrical mobility.	▪ Research conducted from September 2017 to March 2021; ▪ Arnhem leads the project, partners include Transport for London and the City of Nottingham, the European Institute for Innovation (Schwabisch Gmünd), the Luxembourg Institute for Science and Technology, and POLIS and AVERE.		▪ Price independence is achieved by using energy locally; ▪ Energy efficiency is obtained by integrating renewables with the local storage and EVs.	
Toyota City – Japan	▪ VPP demonstration ▪ Regulate electricity demand according to the RES generation; ▪ Prove the feasibility of local consumption and generation; ▪ The action plan aims to reduce the CO_2 emissions of 30% by 2020, compared to 1990.	Toyota City in Japan.	▪ Self-consumption optimization; ▪ Provision of balancing services to the grid.	The energy management system and ICT connect multiple energy sources together to control them as a unique power plant.	
Nissan – Enel – UK	▪ Provide grid services with the first major V2G trial in the UK ▪ Guarantee future EV charging demand satisfaction with high penetration ▪ Integrate non-programmable RES in the grid	100 V2G units provided by Enel.	Nissan EV users can sell the energy stored in their vehicles to the grid and receive a payment.	Creation of mobile energy hubs by integrating the EVs in the grid through the advanced V2G units.	
UK Power Networks – UPS – UK	Reduce the charging cost of freight EVs	▪ 70 EVs and possibly 150 in future ▪ Battery energy storage to support EV charging	Charging the vehicles during nights with cheap prices and the battery storage will step in when the local electricity demand is high.	Software developed by UK power networks to control the number of EV charging according to the local electricity demand	

UK Call for V2G – UK	To award three types of V2G projects that will help to develop a smarter energy system while increasing EV uptake: ▪ Feasibility studies on V2G; ▪ Industrial research or experimental development; i.e. development of advance charging infrastructure; ▪ Demonstration trials of V2G.

6.3. ***Summary***

The projects reviewed in this chapter cover various aspects relevant to SEEV4–City project, including technical, social, economic and environmental factors, as well as energy autonomy as applied to households, street, community within neighbourhood, city and national level. Generally, technical development is not regarded as a limiting factor in facilitating smart charging and V2G. Conversely, the upfront cost of EV, uncertainty about its residual value and lack of public charging infrastructure are at the moment the main factors that are considered to discourage people from buying an EV. It is found that user acceptance of electrical vehicles can be increased by introducing energy management systems under a smart grid communication framework. Regulations to reinforce standardization are required to enable interoperability between different systems and EVs.

A main potential barrier for EV adoption is the high initial cost and the limited revenue currently achievable from Vehicle-to-Grid services. Both [6.9] and [6.73] have pointed out the importance of incentives, such as grants or tax credits which reduce the initial payment, on the consumer's willingness-to-pay (WTP) for EVs, and this relies on national/local government policy, which will be discussed in Chapter 8. It should be pointed out that the battery cost under current market conditions still accounts for a significant part of the EV initial investment, and the cycling patterns would determine the rate of battery degradation.

The associated EV battery cost and potential impact of charging/discharging patterns on the battery life time, however, have not yet been properly accounted for by the previous projects. The introduction of EVs as energy storage will support self-sufficiency from local solar power generation which has generally shown a noticeable increase. However, evaluation of environmental benefits, such as the CO_2 emission reduction, and energy autonomy need to be clarified to create a common ground for energy and market scenario case comparisons. As for the economic benefits from smart charging and V2G, various opinions have been put forward in the presented projects, depending on the project scale, assumptions made and methodologies used. The key to optimal synergy is the development of efficient business models. The presented business applications, however, only take into account a subset of all the listed aspects involved in EV integration. SEEV4-City project seeks for the optimal synergy among all the factors of concerns, in various scales from household to city level.

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7. Business Models

In order to answer the research questions of 'what business models could be developed for different OPs at various implantation scales, as required by the SEV4-City project' and 'what are the economic benefits of smart charging and V2G', three business model structures are classified in this chapter according to the type of EV ownership, i.e. private ownership, car leasing and car sharing. The economics of smart charging and V2G are investigated by analysing the Total Cost of Ownership (TCO) and Total Cost of Use (TCU) of EVs, as well as the potential revenue streams by using EVs to provide various energy services. The potential stakeholders involved in the entire value chain are also examined, ranging from EV manufacturers to transmission system operators.

7.1. *Introduction*

The existing automotive business model for ICE vehicles in the form of value chain is outlined in

Figure **7.1-1**, where different parties capture different parts of the value chain and have been able to derive a profit out of these activities. This can be compared with the value chain adapted for EV business, as shown in Figure 7.1-2, and the principal difference between the BEV and the ICE value chains is due to the vehicle drive train and power source. The battery pack, and its associated energy exchange unit, i.e. the charging/discharging infrastructure, and the energy supplier are the new components brought in by the EV business model.

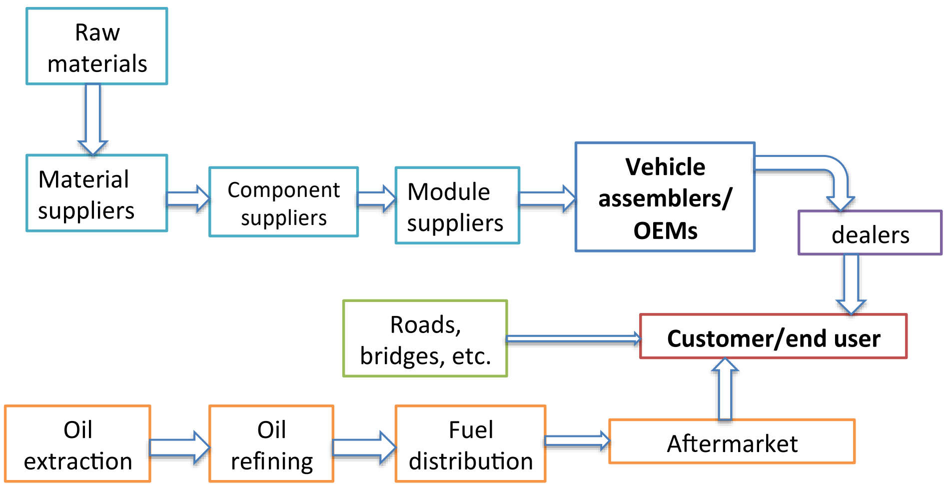

Figure 7.1-1: Value chain of the ICE automotive business model [7.1]

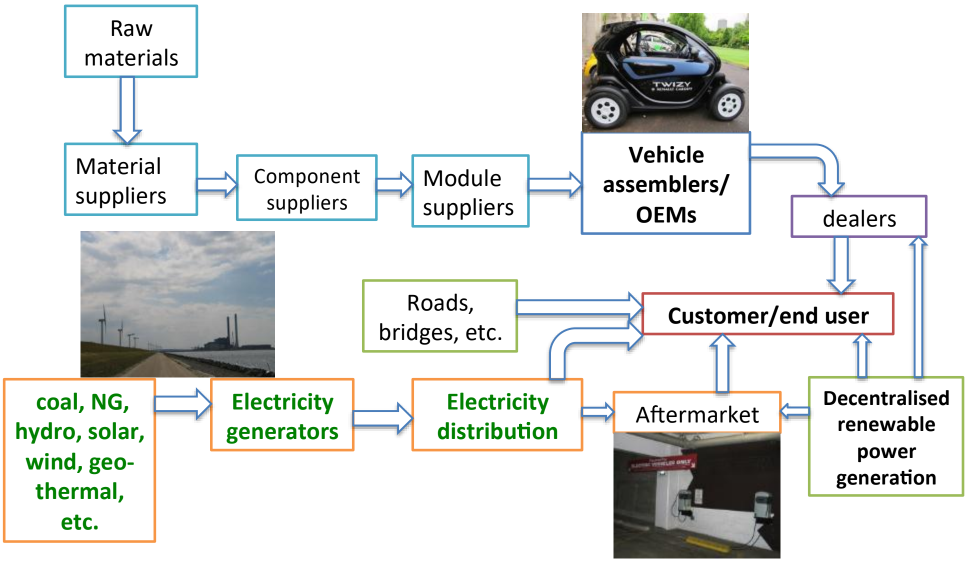

Figure 7.1-2: Value chain of the EVs business model [7.1]

A major barrier for EV take-up is the battery cost [7.2]. According to [7.1], the battery cost accounts for over 50% of the total EV initial payment. This figure would be brought down by mass production and further battery technology maturity. It has been shown in [7.3] that the industry-wide cost estimates of Li-ion battery packs declined by approximately 14 % annually between 2007 and 2014, from above US$1,000 per kWh to around US$410 per kWh, and that the cost of battery packs used by market-leading BEV manufacturers are even lower, at US$300 per kWh, and has declined by 8% annually. Transforms in the EV ownership, such as leasing and renting, could potentially relieve the battery cost issue and increase EV owners' acceptance. According to [7.4], around 76% of newly registered private vehicle in 2015 is via Personal Contract Purchase (PCP), i.e. renting/leasing. The high cost of charging infrastructure is another potential battier for EV adoption. Four key questions, as follows, are identified with respect to infrastructure provision by NPC (2012) [7.5]:

1. Who owns and pays for the initial investment in the charge point?
2. Who installs, operates and maintains that point?
3. Who provides the charging and billing from that point to the customer?
4. How does the customer pay for access to the point and the electricity consumed?

[7.6] and [7.7] have pointed out the importance of incentives, such as grant or tax credits which reduce the initial payment on vehicle and charging infrastructure, on the consumer willingness-to-pay for EVs, and this will be elaborated in details in

In the context of smart charging and V2G, further opportunities for value creation and capture could be realized by applying business models. [7.2] states that the EV business models must provide value for service provider and service user. The 'Electric Nation' project [7.8] on consumer acceptance of smart charging and V2G has also pointed out that the essence to successful EV adoption lies in the benefits procurement for EV customers. [7.9] [7.10] identify four distinct scenarios in which they examine the cost structures, revenue streams and profitability of EV charging infrastructures, but it is precisely here that the main problems emerge. While it is entirely possible to describe and enumerate a given scenario under which investments make good sense and offer competitive rates of return, investors still have no real way of knowing which out of the countless possible scenarios will actually come to pass. In other words, all of these forecasts suffer from the same fundamental problem in that the error margin is not known.

The uncertainty in social acceptance of V2G and the inconclusive net value creation capability of the current business models gives rise to the investigations of EV business model structures with feasible scenarios that could potentially be applied to the various EV scales as required in this SEEV4-Cityproject. Some of the projects mentioned in the previous section have proposed business models with various degrees of completion; a more comprehensive consideration for business models with a systematic structure is presented here.

7.1.1. Introducing 'transport4energyservices' business models

The smart integration of EVs into the grid should always consider the synergy from social, technical, economic and environmental aspects. Taking these points into account, a generic business model concept is illustrated in Figure 7.1-3, where the core model in the centre represents the coordination between EVs and the relevant participants, including the grid, local demand, storage and renewable energy sources. Outside the core model, other economic factors (such as infrastructure investment) that contribute to the business models for the house, or higher-level developers/investors are also considered. Possible opportunities for EV owners/users to procure revenue benefits are identified through network services provision and interaction with renewable generation and storage. Environmental incentives and battery life optimization can be understood as economic gains to offset purchasing or depreciation use costs of EVs. The associated variables may be scaled accordingly as the business model is applied to different Vehicle for Energy Services (V4ES) levels, i.e. V2House, V2Street, V2Neighbourhood and V2City.

The generic business model includes the commercial relationship between the stakeholders, which is listed in Figure 7.1-3, and the direction of energy flow. The output from the business model should cover the economic savings in Total Cost of Ownership (TCO) and/or Total Cost of Use (TCU) (as, for instance, leasing or vehicle sharing becomes more prevalent), the environmental benefits in terms of CO2 emission reduction, clean kilometres achieved and the improvement in local energy autonomy.

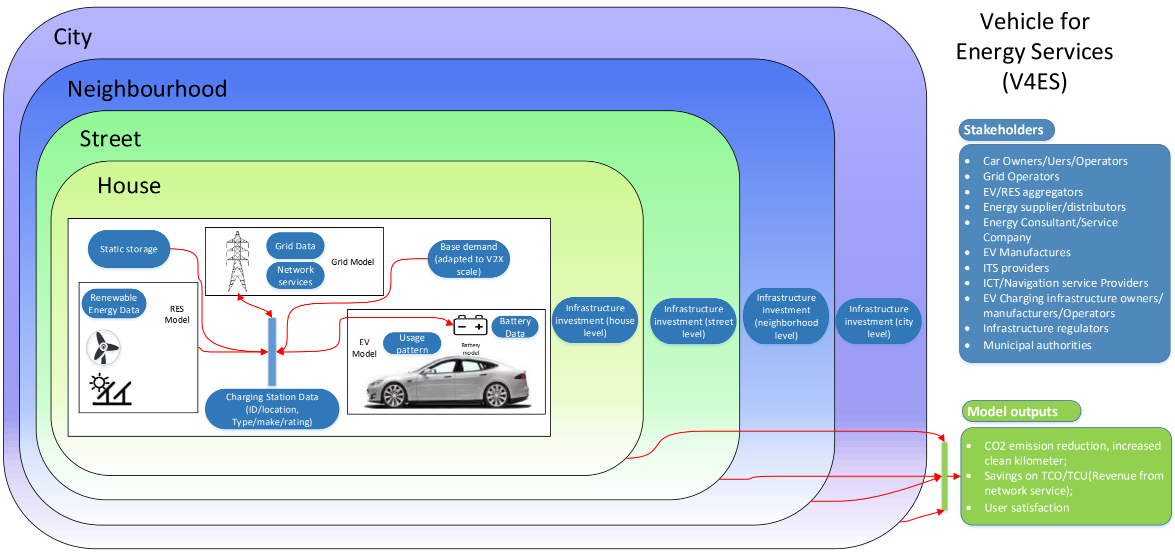

Figure 7.1-3: Generic business model concept illustration

As mentioned in the previous chapter, the EV charging vehicle archetype can be broken down into home (47%), work (33%), public (11%) and fleet (9%) according to 2014 statistics from the UK's Department for Transport and the Ultra Low Carbon Vehicle Demonstrator Programme. There is also an interaction that can be considered between the vehicle ownership and the EV charging vehicle archetype, though this is by no means strainghtforward.

In terms of vehicle ownership, the UK's Office of National Statistics' Vehicle Licensing Statistics Annual Reports for 2019 that 'during 2019, 59% of cars registered for the first time had a company keeper. However, the proportion of licensed cars at the end of 2019 kept by companies was much lower at only 9%. This illustrates that company-kept cars registered for the first time become privately-kept within a few years. The proportion of company-kept cars in the fleet has remained relatively stable between 8-10%

since 1994. Over the last 10 years, the number of female registered keepers of licensed cars had increased by 17%, compared with an increase of only 9% in male keepers. Women now account for 35% of registered car keepers with men accounting for 50%. For privately-kept vehicles where the keeper's gender is recorded, 59% are male and 41% are female at the end of 2019. Overall, privately-kept cars, including those where the gender is unknown, accounted for 89% of all cars at the end of 2019, with those between keepers [pooled, shared] accounting for 2% [7.11].

EV charging archetypes could be fitted into various categories of business model applications, as shown in Figure 7.1-4. Smart charging and V2G are potentially beneficial for domestic EV charging through DSM and network service provision, and these services could have business opportunities for traffic hotspots such as shopping centres. Fleet operation and car rental/leasing allows the optimal EV scheduling in terms of vehicle usage and revenue capture. Highway charging, however, is not suitable for smart charging or V2G provision due to its nature in travel pattern.

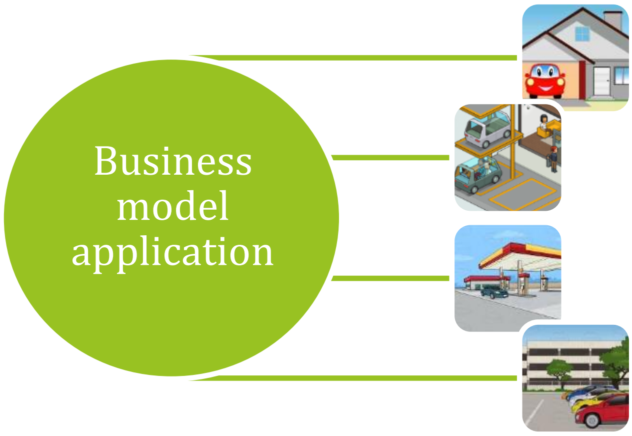

Figure 7.1-4: Category of business model application

7.2. ***Overview of different business model structures, applications, pros & cons***

7.2.1. EV Private ownership

Private ownership is the most common vehicle ownership, where the vehicle user is also the vehicle owner. This archetype in the context of EV however might hinder the uptake of EV due to the high initial battery cost under the current battery market. As mentioned earlier, an efficient business model with value creation capability is essential for potential EV owner with private ownership.

As introduced in *Section 6.1.2*, Nuvve GIVe™ Platform, the World's Largest Aggregator, was developed for the private EV ownership based on the work done by Prof. Willett Kempton at the University of Delaware. Huge economic potentials have been shown in Kempton's work. For instance, a Toyota RAV4 EV under the 2003 California Independent System Operator (CAISO) market [7.12] in the US was estimated with to have an annual revenue of $2554 by providing regulation services [7.13]. Here the net revenue is calculated as the difference between the gross revenue, which takes into account the capacity payment and energy payment with a dispatch to contract ratio of 0.1, and the cost of providing regulation, which covers capital cost, purchased energy and wear due to V2G. The V2G structure used by the Nuvve GIVe™ Platform is illustrated in Figure 7.2-1, where the energy flows (green solid line) bi-directionally between the network and the charger, and between the charger and individual EVs; and the aggregation server takes care of the commercial relationships through commutation link (red dotted line). A much more detailed structure defining the physical and commercial connections between possible elements involved in the business model is presented in [7.14] and [7.15].

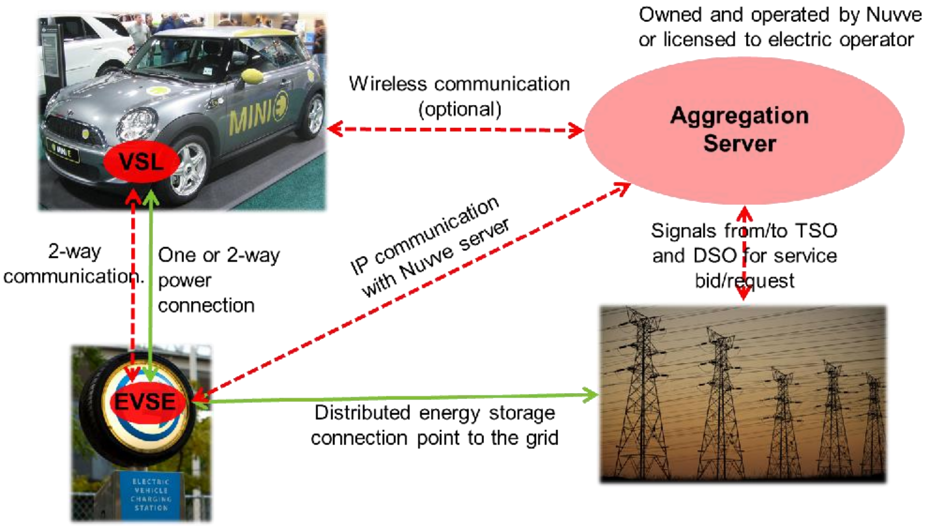

Figure 7.2-1: V2G structure for NUVVE's GIVeTM Platform [7.20]

The physical connection between various entities in a typical end customer with directed energy flow is illustrated in Figure 7.2-2, where the source is from the solar generation; the sink is due to either local energy demand or EV driving consumption; and the two storage blocks represent the static energy storage (green) and the EV battery pack (blue). The power network outside the customer's system is modelled as an aggregate entity. Energy flow between blocks is possible, apart from the EV consumption sink that can be regarded as an appendix of the EV battery storage block. On top of this, the business structure for mobility provision, infrastructure provision and energy provision has been clarified, as shown in Figure 7.2-3. The energy provider introduces time-of-use energy prices and feed-in tariff to customer, and settles the transactions through an intermediate energy management agent. The mobility provider takes care of the purchasing and leasing of the vehicle and battery, and the infrastructure provider is responsible for the charging device and solar panel.

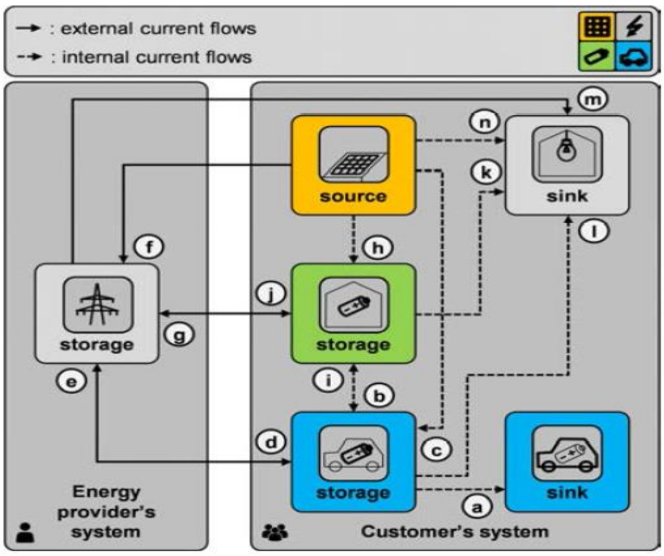

Figure 7.2-2: Energy flow between physical entities [7.14]

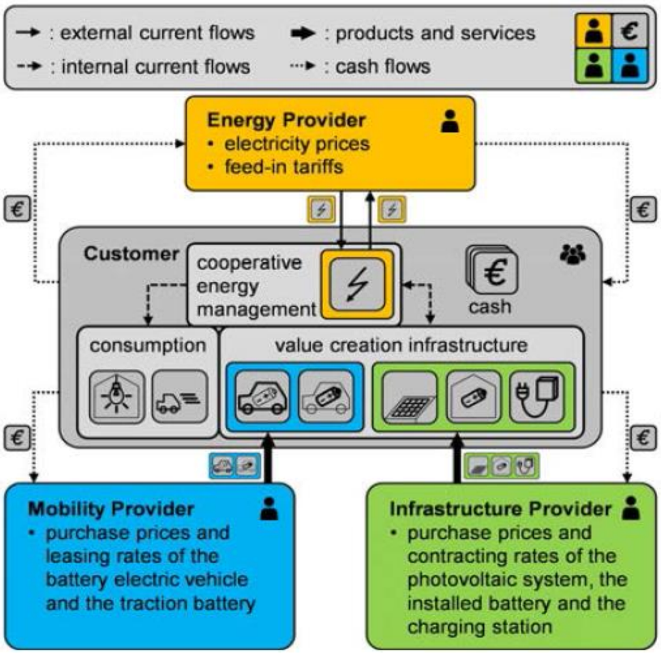

Figure 7.2-3: Value proposition for mobility and energy [7.14]

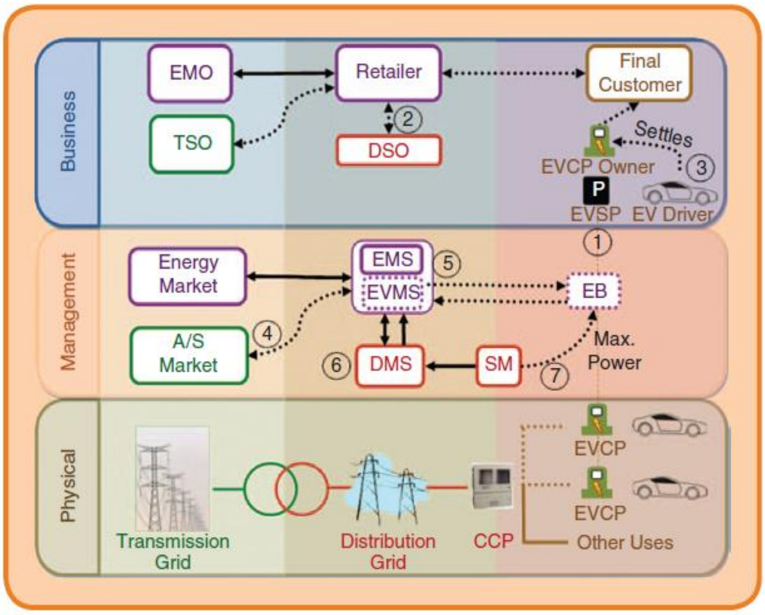

Figure 7.2-4: Retailer to charging point business model [7.15]

A three-layer business model framework is proposed in [7.15], where the stakeholders and their commercial relations are depicted in the business layer, and the management layer includes the necessary information flow between the stakeholders. Finally, the required infrastructure with physical connection is shown in the physical layer. Unlike the work in [7.14], which includes the physical elements such as PV and energy storage, this work only considers EV and its charging unit in the end customer. For the existing power network with associated physical elements connection, final customer settles its transaction with the retailer who purchases electricity from the generators via the energy market, and the ancillary services market is the market through which generators sell ancillary services to the TSO to ensure system security. Based on this framework the proposed business model introduces new commercial connections that are brought in by the EV/EV charging point, which signs contracts with the retailer for service provision as well as energy use due to vehicle charging.

With the collected energy from EV/EV charging point, retailers could then enter the ancillary service market for value creation, which is then settled with the service provider, i.e. EV/EV charging point. The description could be matched up with Figure 7.2-4, where the framework for retailor-to-charging-point business model is illustrated. A similar three-layer structure has also been proposed in [7.16], as introduced in chapter 6, and the function of various stakeholders have been discussed.

The energy flow between various physical elements inside the final customer as well as the connection with the mobility and infrastructure providers, as presented in [7.14], and the commercial relationships between EV/EV charger and the energy provider/management agent, and associated ICT on top of the physical layer, as presented in [7.15], are combined to provide a broader coverage of the stakeholders involved in a EV business model and the structure is shown in Figure 7.2-5. The physical entities consist of the base load, PV, energy storage, EV charger and EV, all of which are then connected to the higher-level network including distribution and transmission grid, and these are illustrated in black box with directed energy flow. The existing contracts signed between the final customer and retailer, which then links with the energy market, are denoted in green colour. And those introduced by the new component of EV/EV charger are coloured in red, with solid and dashed blocks indicating the commercial relationship and associated ICT connections, respectively.

Detailed commercial connections with ICT have been discussed as for [7.15], and a few differences between the structure in Figure 7.2-5 and the one in [7.15] need to be pointed out. Firstly, the contractor/coordinator of EV energy in [7.15] is the energy retailer, which has been replaced by a dedicated aggregator here, and the energy retailer in this case is only responsible for settling the transaction with final customer for base load. The mobility and infrastructure supplier as introduced in 7.14] have been merged into the structure; and the OEM of EV is also included in the value chain. Last but not least, policies of energy, transportation and environment could have direct or indirect impact on the EV energy scheduling scenarios and thus being included here. It should also be pointed out that the services provided by different stakeholders could be combined or partially combined to achieve certain objectives of these stakeholders. For example, 'The EV White Label' business model archetype proposed in [7.19] forged a partnership between the automobile industry and energy suppliers to provide both the vehicles and the electricity to the final customers, via a special branded EV tariff. In this case, the EV OEM is responsible for both battery warranty and energy service provision.

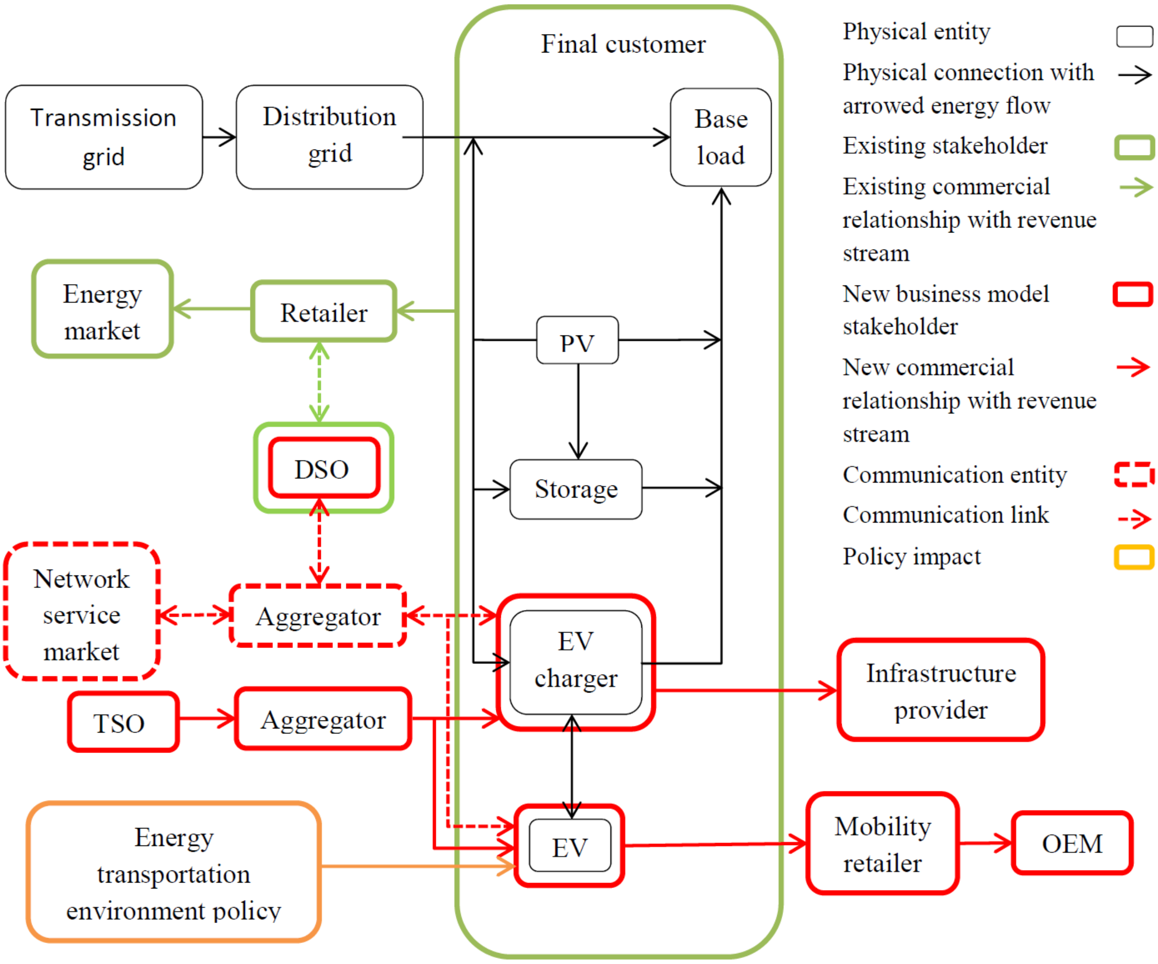

Figure 7.2-5: EV business model structure

7.2.2. EV Car leasing

Private vehicle purchase via Personal Contract Purchase (PCP), i.e. leasing/renting, has been gaining popularity in recent years; around 76% of newly registered private vehicle in 2015 in the UK was via PCP [7.4]. The issues of higher price and shorter driving range compared to conventional ICE vehicles, plus the uncertainty of battery life, create more hesitance for private ownership of EVs. According to [7.17], *"personal leasing consists of an upfront payment followed by regular monthly payments over a fixed period of time. It is usually cheaper than financing a vehicle outright as you are effectively renting the vehicle, and it doesn't belong to you. The agreement is based on a fixed term and mileage. Charges will occur if you exceed the mileage stated on your contract so it is important to take a contract based on a mileage that will best suit your personal needs. The vehicle belongs to the finance company so at the end of your contract you hand the vehicle back to them."* Also, from a behavioural economics point of view, a high initial price with low future operating cost is often perceived as less attractive than a lower initial cost but higher operating cost, even when the total economic impact is exactly the same [7.21]. Taking these points into account, Renault sells BEV without battery and instead sigh up on monthly lease to change the temporal distribution of financing. In other words, the risk of battery life is taken by OEMs under car leasing service by shifting the private EV ownership.

A similar level of EV ownership is proposed as 'the EV White Label' in [7.21], where the OEM take responsibility for both battery warranty and energy service provision by forging a partnership with the energy utilities and creating a specially branded EV tariff. Under this proposal, private and commercial customers purchase both the vehicle and the electricity from the same company.

7.2.3. EV Car sharing

By sharing cars, the vehicle ownership is completely given up, which is supported by the general trend where the interest in owning a car is decreasing [7.18]. The car sharing service provides personal mobility as flexible and as private as a personal vehicle, to both private and business use, but with more convenience and less hassle than private car ownership in a city [7.22]. The idea is going by taxi but you are the driver, and the service could be charged either by minute of use or through subscription, which often involves monthly fee at a contracted level. And this payment covers electric bill, maintenance, and road tolls, etc. This service could be accessed online or through smart phones or tablets, and service vehicles should be accessible at any public parking spot within a designated city zone. Free parking is suggested by [7.19] for all electric cars in the car sharing service due to their contribution to air pollution prevention and car density reduction; according to [7.21] 9-13 privately-owned cars are replaced by one shared car.

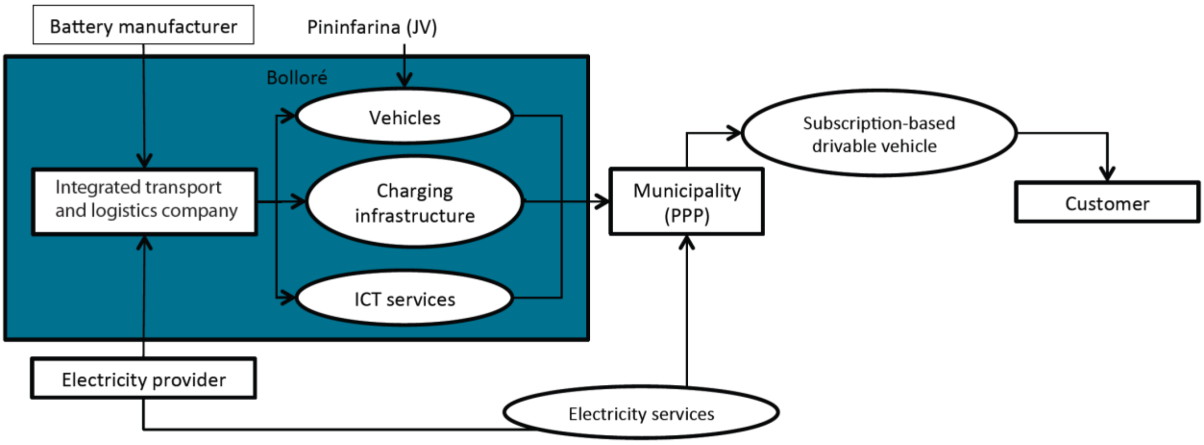

Figure 7.2-6: The Autolib's scheme for a public integrated EV sharing service [7.23]

Launched in the City of Paris and 45 of its adjacent communities in December 2011, the Autolib's initiative is the second largest EV sharing service in the world [7.23], after the Hangzhou case in China. Autolib' was managed by a municipal syndicate in the Paris metropolitan area and is operated by the Bolloré company; following a EV sharing scheme as depicted in Figure 7.2-6. This service offers a 3-door EV, the Bluecar, in the greater Paris area, where EVs are available for short term leasing to any public members via a subscription that include fuel (electricity) cost, as well as other cost of driving, i.e. insurance, maintenance, repairs and parking. Table 7.2-1 lists the subscription and rental rate for Autolib'. The program grew from the initial 250 vehicles in 2011 to 1,750 EVs and more than 5,000 charge points at 710 stations in 2012 in the Paris metropolitan area, including 45 surrounding communes [7.24]. In the final stage, Autolib' was expected to provide 3,000 vehicles and 6,600 charging stations. However, Autolib' closed on July 31st 2018.

Table 7.2-1: Autolib's subscription and rental rates [7.23]

	Year	Month	7 days	24 hours	Shared sub-scription for 4 users (16h/ month)
Subscription	€12/ month	€30	€15	€10	€165/month
1st half hour	€5	€6	€7	€7	€7,5 beyond the 16th
2nd half hour (pre-June 2012)	€4	€5	€6	€6	-

Kaplan et al [7.25] estimated annual cost savings for Autolib' drivers of about €7,000 compared with buying a car in Paris, and a total of €315 million over all users per year. Local incentives such as preferential parking, road tax exemption, registration tax exemption, and access to bus lanes also add to the value proposition. However, the revenue structure of Autolib' was dependent on public financing. The single most expensive component is the initial investment on the Bluecar, the cost of which comes between €18,600 and €23,250 for the 150-250 km range. The region Ile-de-France subsidized the project for €4 million at its debut, and the European Investment Bank provided a €130 million loan for R&D in early 2011 [7.24]. By late September 2012, Autolib's fleet reached the milestone of 500,000 rentals since its launch, and the scheme's vehicles had been driven a cumulative total of 15,000,000 km by February 2013. By mid-October 2013, the service had provided over 3 million rentals, with an average of 10,000 rentals per day. By July 2014, Autolib' had 2,500 operational vehicles and over 150,000 subscribers, and its cars had covered a cumulative mileage of over 30,000,000 km since the scheme's introduction.

In December 2009, the car-rental company Europcar brought the City of Paris to court, arguing that the Autolib' name was a plagiarism and unfair competition by the city. Europcar is the trademark owner of the rental car subscription service 'Autoliberté', which has been in operation since 2001.The case was dismissed in March 2011 by the High Court of Paris, and Europcar decided to appeal. On 30 June 2012, the Paris Court of Appeal set aside the judgment of the Paris High Court, and ruled that within a month Autolib' had to change its name because it breached trademark laws. The ruling implied that the name had to be changed on all 1,800 Autolib' cars, docking stations and subscriber cards, and also required that all of the scheme's advertising to be rewritten. After the ruling, the City of Paris and Europcar began negotiating an agreement to solve the brand name conflict. In November 2012, an agreement was reached to keep the Autolib' brand name. Europcar agreed to waive the enforcement of the court decision on the condition that the City of Paris would be the owner of the Autolib' brand, and in exchange for free advertising for Europcar's Autoliberté service. The agreement was signed for three years.

In July 2018 the Autolib' scheme in the Paris metropolitan areas ceased to operate.

Following the success (in terms of rising subscriptions and especially displaced/substituted ICEs) of this service in Paris, Autolib by 2015 had expanded to Lyon and Bordeaux in France (though under a different brand name, and at no cost to the public authorities of those cities), London in UK and as a small-scale service in Indianapolis in the USA. It had also signed deals to start off-shoots in Turin in 2016 and Singapore in 2017 [7.26].

Two main changes to the business model of private transport have been claimed by [7.24]. The first is the shift of ownership from the end-users to the service provision company. Secondly, the revenue and cost has been restructured in a way that the end-users pay a subscription fee covering the afore-mentioned ancillary costs, and thus the service-provision company bears all of the upstream and downstream risks. The ease of use and hassle-free use of an EV based car sharing service would bring new driving experience for the users, and the more efficient use of the shared vehicles than the privately-owned ones help to reduce the car density and traffic congestion. The air pollution issue is also prevented due to the use of all-electric cars.

From the investor point of view, however, the drawback of such service is the business risk involved in the significant initial investment. Hundreds of vehicles are required at launch to provide reasonable car density within reasonable designation area. Also, the current battery warranty condition for EVs might be another financial constraint. In addition, the use of a single car model limits innovation and competition-driven improvements in design and technology which could promote further use and success of the service, though it is the most efficient economic solution for a specific car sharing system [7.24].

7.3. *Economics of smart charging and V2G*

As is shown in Chapter 6, various economic results for smart charging and V2G have been achieved from previous projects, ranging from a negligible net income of £26/EV/year and £35/EV/year for home charging EVs and fleet EVs, respectively, in a national grid report where smart charging for frequency regulation is evaluated, to an extremely optimistic estimate of V2G with an annual revenue of $2554 by providing regulation services in the US market.

In previous work in relation to smart charging and V2G, different network services such as Peak Power Provision, Frequency Regulation and Spinning Reserve have been explored. According to Kempton et al., as shown in Figure 7.3-1, frequency regulation has been identified as the most profitable application of V2G for battery vehicles, followed by spinning reserves and peak power [7.27]. The revenues for V2G depend on the payment structure for the different services: for Regulation services it usually consists of a fixed payment to reflect the power which the EV can provide in support of the Grid (usually limited by the charger capacity ('capacity payment') and an energy payment for the actual energy supplied in up regulation and absorbed in down regulation. The different (and differing by country) network service provisions available in the NSR countries have been discussed in detail in Chapter 3.

	Peak power	Spinning reserves	Regulation services
Battery, full function	$267 (510 – 243)	$720 (775 – 55)	$3,162 (4479 – 1317)
Battery, city car	$75 (230 – 155)	$311 (349 – 38)	$2,573 (4479 – 1906)
Fuel cell, on-board H_2	$-50 (loss) to $1,226 (2200 – 974 to 2250)	$2,430 to $2,685 (3342 – 657 to 912)	$-2,984 (loss) to $811 (2567 – 1756 to 5551)
Hybrid, gasoline	$322 (1500 – 1178)	$1,581 (2279 – 698)	$-759 (loss) (2567 – 3326)

Figure 7.3-1: Network service profits using V2G for different types of EVs [7.27]

Costs induced by smart charging and V2G include (dis)charging infrastructure cost, energy payment and battery degradation cost due to additional ware of EV, in particular when V2G is involved. Energy payment depends on the EV driven kilometres and the price tariff involved. The cost reduction of the charging device relies on the grants and subsidies. In most scenarios, aggregators are needed to combine EVs into economically viable blocks with enough capacity to enter the market for ancillary services. The aggregators will no doubt charge for their services, so a part of the calculation of profitability involves determining how profit would be shared between aggregator and EV owner.

The main variables that accelerate battery degradation are [7.28]:

(i) **Battery cell temperature**; Operating at a cell temperature of about 20 ^{0}C gives least degradation. Operation at battery cell temperatures higher or lower than 20 ^{0}C tends to reduce battery lifetime. Charging/discharging at a low C rate (see below) does not significantly raise the temperature of the battery.

(ii) **State of Charge (SOC)** The SOC is the ratio of the actual charge stored in a battery compared to that stored when the battery is fully charged. SoC is usually expressed as a percentage. The lower the average SOC, the lower the battery degradation in a given time.

(iii) **Depth of Discharge (DOD)/amount of charge transferred**; The DOD is the percentage of a battery's full charge transferred during a charge or discharge operation. Thus, for a 10-kWh battery, if it is initially fully charged and it provides 3 kWh then the DoD is then 0.3 or 30%. The more charge transferred during cycling (i.e. the greater the DOD per cycle and the greater the number of cycles), the greater is the battery degradation.

(iv) Current rate (C-rate). The C rate for a battery is the ratio of the charging or discharging power to the capacity of the battery. Thus, a battery with capacity of 7 kWh being charged at a power of 3.5 kW is being charged at a rate of C/2. Increasing the C rate accelerates degradation and this factor is linear at rates under 1C. Domestic chargers provide power at either 3 kW or 7 kW (i.e. under 1C for passenger EVs), so for an EV with a battery capacity of 21 kWh the corresponding C rates would be C/7 and C/3 respectively.

The largest domestic chargers are level 2 (7 kW), which corresponds to a charging rate of C/3 or below for a contemporary EV. As such, the impact of temperature increases due to charging rate at this level on battery degradation can be assumed to be negligible.

The study in [7.29] considers energy arbitrage and performs a cost minimization for three different charging approaches: As Fast As Possible (AFAP), Smart charging and V2G. The battery degradation model considers two different costs, related to energy throughput and the charging power. 4 types of user profiles are considered but mainly costs for the employees and retired are compared. Smart charging and V2G show significant cost reduction compared to the AFAP approach, but the difference between the two accounts only for 10 percentage points. For retired, the cost reduction is higher because the low mileage driven and the consequent higher EV availability. This interesting finding highlights the effect of the different driving profiles in the benefits.

Frequency regulation is carried out in [7.30a] and a system that involves an EV fleet of 50.000 vehicles with Solar and Wind generation is employed. The costs consider capital investment, degradation of the battery (in terms of DOD cycling) and electricity used for driving. The revenues consist of the regulation price obtained from the energy supplied from the EVs and the price of the electricity provided by the RES. Cost of the electricity and the regulation price are kept constant and with a difference of 2 cents between them; this will not be the case always. The net profit varies in the year going from a minimum of 1$/EV/day to 5$/EV/day according to the RES production. The resulting profits are always positive because it is said that the revenues obtained from the RES production compensate the costs related to battery degradation, capital and the electricity for driving.

To implement smart charging, a suitable charger must be adopted; these usually provide some kind of flexibility for EV charging, regarding charging level and time, in order to reduce the charging costs for instance by shifting the charging when the electricity cost is lower or when there is abundance of PV generation. An appropriate communication link must be established between the charger and the energy manager. In Smart charging ready chargers an intelligent charging algorithm may be inbuilt or the charging scheduling is dictated by an energy management system if these are Smart charging compatible. Table 7.3-1 shows the smart charging systems currently available in the market.

Table 7.3-1 Smart charging solutions available in the market

Type of smart charging system	Energy management system	Charging point	Charging point price
Smart charging compatible (the energy management system is combined with a charging point)	Maxem Energy Manager (from 148€ ex. VAT to 4495€ plus 4€/socket/month, according to the number of controlled sockets [7.31])	Tesla Wall Connector, up to 16.5 kW [7.32]	£460 or €528 [7.33]
		ICU EVe mini, 22 kW [7.34]	€1222
		ICU EVe mini, 22 kW [7.34]	€1222

	Smartfox energy manager (938€ [7.35])	NRGkick mobile charging station, 22 kW [7.36]	€1119
		KEBA KeContact P30, 22 kW [7.37]	€935
		ABL eMH1, 3.7 kW [7.38]	€789
Smart charging ready (the control is inbuilt)	Not required	Newmotion Home standard, 3.7 kW [7.39]	£639
		Kraftriket Smart Total, 22 kW, [7.40]	Kr22,990 or €2388 [7.41]

As for the V2G enabled chargers, from the user point of view, the cost of V2G equipment can also present an obstacle, in view of the limited profitability of V2G, discussed elsewhere in this report. Beyond the V2G chargers, qualification costs (e.g. with TenneT), communication costs (special requirements by the TSO) and metering costs (special meter needed) also need to be considered. However, in all these considerations, the costs of an AC charger including installation (1,5-2k Euros) and perhaps even an inverter (1-2k Euros) could be saved if a domestic PV installation is involved, and this can be considered in the equation. Satisfactory revenue streams from V2G service provision may offset these costs. Besides, commercial V2G ready chargers are available which is an indication that the technology is mature and with a higher roll-out costs will be further taken down.

An initial cost estimate by Kempton et al. for the entire technical V2G installation set was at $2000 [7.42]. The initial system cost of ‘Leaf to Home’ unit in Japan is 567,000 Yen ($7118), which is brought down to 327,000 Yen ($4104) excluding installation, by taking into account the government incentive of 240,000 Yen ($3012), [7.43]. Enel tagged the cost of a V2G charger at around £600 [7.44], which would be a good demonstrator of V2G feasibility and affordability for V2G unit, considering the promising price and the huge amount of V2G projects in which Enel is involved. It is important to note that the AC charger vs DC charger aspect is very important here in terms of costs – a DC unit has a higher cost due to the power electronics needed in the charger.

Nissan, together with Eaton, has launched its xStorage for a home/business energy storage solution, [7.45]. The base system starts from €3,500 excl. VAT and installation costs for the 4.2 kWh system with second life batteries, €3,900 for a 6-kWh system with new or used batteries, and €5,580 ($5,950 USD) for a 9.6 kWh unit (with new cells). According to [7.46], xStorage forms a central part of its home V2G solution. The UK price for the competing Tesla Powerwall 2 storage system is listed as £5,400 for a single 14 kWh Powerwall battery. The supporting hardware costs £500 (including VAT) Additionally, each Powerwall 2 has typical installation costs range from £800 to £2,000 [7.44].

The Net Present Value, considering a 10-year cash flow, is considered in [7.47]: the minimization of the ownership costs is attempted. These include: capital costs, infrastructure costs and operating costs and these are compared against the revenues coming from the frequency regulation. It is worth to mention that the investment costs for the fleet of 250 trucks is the initial purchasing cost which has been set equal for the three types: ICE, PHEV and EV (BEV). Besides, PHEVs and EVs enjoy different subsidies that were available in the US context. The revenues consist of capacity payment and energy payment. Two scenarios have been adopted: ramp down and ramp up and down. Although it has been proven that EVs and PHEVs reduce the ownership costs of the vehicle compared to the ICE, in both the scenarios, the revenues are not able to overrule and overcome the ownership costs, mainly because the initial investment costs are too big. The sensitivity analysis shows that the capacity of the battery affects the revenues because it determines the energy that can be absorbed and provided, but it is the charger rating that has the most significant effect; in fact, variations of the charger rate are reflected in nearly proportional variations in profit.

Frequency regulation is provided by a single EV in [7.48] with a new policy introduced: the performance payment that awards fast ramping systems uses a fast regulation signal that contains the oscillatory part. In this example, it is found to be energy neutral in the sense that, while doing regulation up and down, the amount of energy that is discharger is roughly the same as the amount of the energy absorbed. It can be argued that this depends on case by case and the energy neutrality can be associated more to the contract that is stipulated with the Network operator (for instance, assuming a range of maximum [-2MW, 2MW]). The performance payment awards the ability to follow the fast regulation signal and therefore the variations of the fast regulations signal are compared against the variations of the conventional regulation signal. The profits that have been found are in line with what has been found before (maximum $4.34/day). Moreover, revenues from unidirectional V2G, or in other words, smart charging, depend on the initial SOC level upon plugging: the lower the SOC, higher is the capacity available for Regulation-Down and the higher is the potential revenue.

PJM Interconnection is a USA based regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia. Three business cases are evaluated in [7.49]: profitability evaluation of different ancillary services in the PJM context economic benefits from loss reduction due to V2G and economic benefits given by different parameters, such as, location of the fleet, capacity injected and load distribution in the feeder. The ancillary services that have been considered are: baseload power provision, peak provision, frequency regulation and spinning reserve. The costs and the prices that shape the revenue structure have been carried out from Kempton's work and the analysis shows that peak provision and frequency regulation are the most profitable in that context at that time. This can be partly caused by the values used for the different payments for the services. V2G provision on the spot allows a lower feeder loading which gives loss reduction. The higher the loss reduction, the higher are the economic benefits deriving from it (as reducing losses represents a saving of money). According to the capacity and the load distribution, there is an ideal location in terms of optimal profit. The more distributed the feeder load is, the lower are the losses. Generally, it has been found that the optimal situation is when the feeder load is low and there is high injected capacity.

As a general rule, V2G may be most cost effective for EV owners who participate in the short-duration, high-value power market of ancillary services, preferably with both capacity payment and energy payment [7.13]. The user type of EVs will affect the EV availability, and therefore make a difference to the associated revenues. Litmited previous work takes into account national and local energy policy, grants and subsidies to EV owners. Policy can play a role as key drivers for EV user behaviour and should therefore be considered in the V2G economics analyses. Taxes, penalties and other forms of actions to promote clean transportation also should be included.

Significant gaps exist in previous studies, and the scope of SEEV4-City is to develop a comprehensive economic approach that provides a detailed evaluation of smart charging and V2G by considering the relevant business models, together with their effects on household PV generation, energy autonomy and grid support.

The authors of [7.50] conclude that, under current cost structures, batteries that provide only one ancillary service generally do not provide a net economic benefit. However, it is argued that in most of the cases, the economics can be turned in favour of the EV battery storage by providing multiple services, given that the primary service is delivered by using only a limited part of the battery's lifetime capacity. It is done through **four cost-benefit analysis studies** where different services were provided. Of course, the characteristics of the energy storage system has to comply with the requirements of the different services. The cases are summarized below.

Commercial demand-charge management in San Francisco

The primary scope of the case study is to reduce the demand charge due to the commercial rate structures and secondarily to provide ISO/RTO services such as Load Following, Regulation and Spinning Reserve and Resource Adequacy to the California grid. The number of hours that the various services are provided for depend on the average hourly market-clearing prices for the services, the availability and the SoC of the battery. The involved building is a hotel with 140 kW and 560 kWh. This case results in positive profit although each service is provided by different behind-the-meter energy storage systems.

Figure 7.3-2 shows provides some insight on the results; the revenues and costs of the fleet is calculated over a 20-year project time and includes battery replacement in the years seven and fourteen.

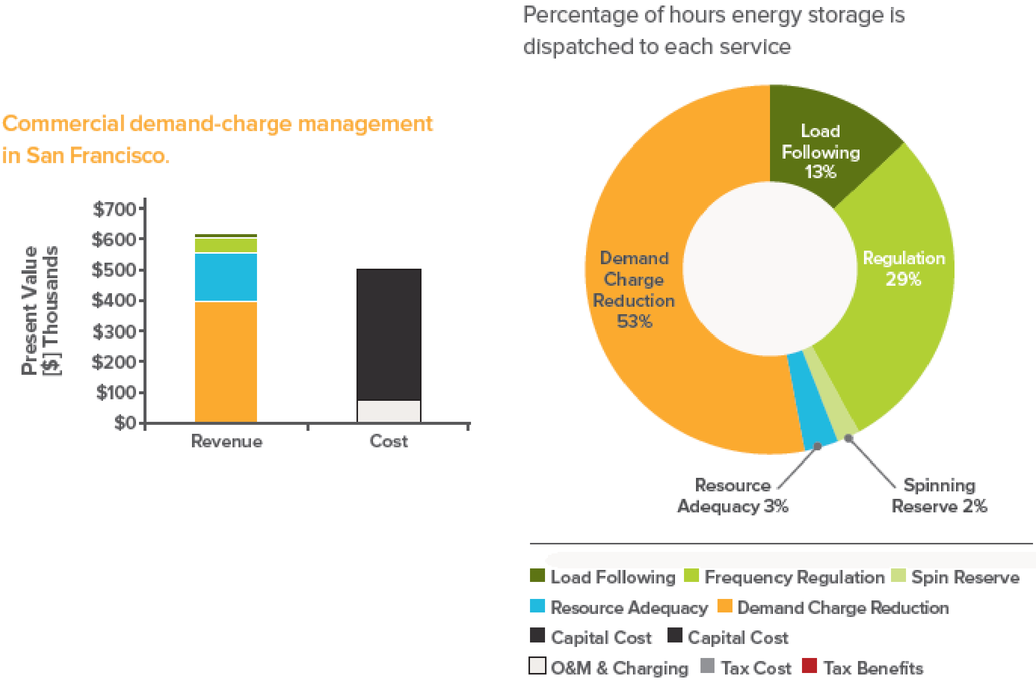

Figure 7.3-2 Cost and benefits of the Commercial demand-charge management in San Francisco [7.50]

Distribution upgrade deferral in New York

Investment of $1 billion for two substations in Brooklyn and Queens were deferred spending $200 million on behind-the-meter load management and another $300 million on traditional substation upgrades in order to reduce or rearrange the timing of 52 MW of load by 2018 in order to not overload the substations. Demand response and energy efficiency are employed to mitigate the effects of the first 26 MW and a fleet of residential and commercial behind-the-meter energy storage systems avoid the other 26 MW of peak load. The batteries are used for 120 hours each year and are used to participate in the New York Independent System Operator's (NYISO's) ancillary service market and to provide, frequency regulation, spinning and non-spinning reserve and black start services. Moreover, other services, such as, energy arbitrage and resource adequacy are also provided. In this case, the costs are greater than the revenues, as can be seen in Figure 7.3-3 Cost and benefits from the Distribution upgrade in New York [7.50] and it is asserted that this is because no customer-facing service is provided.

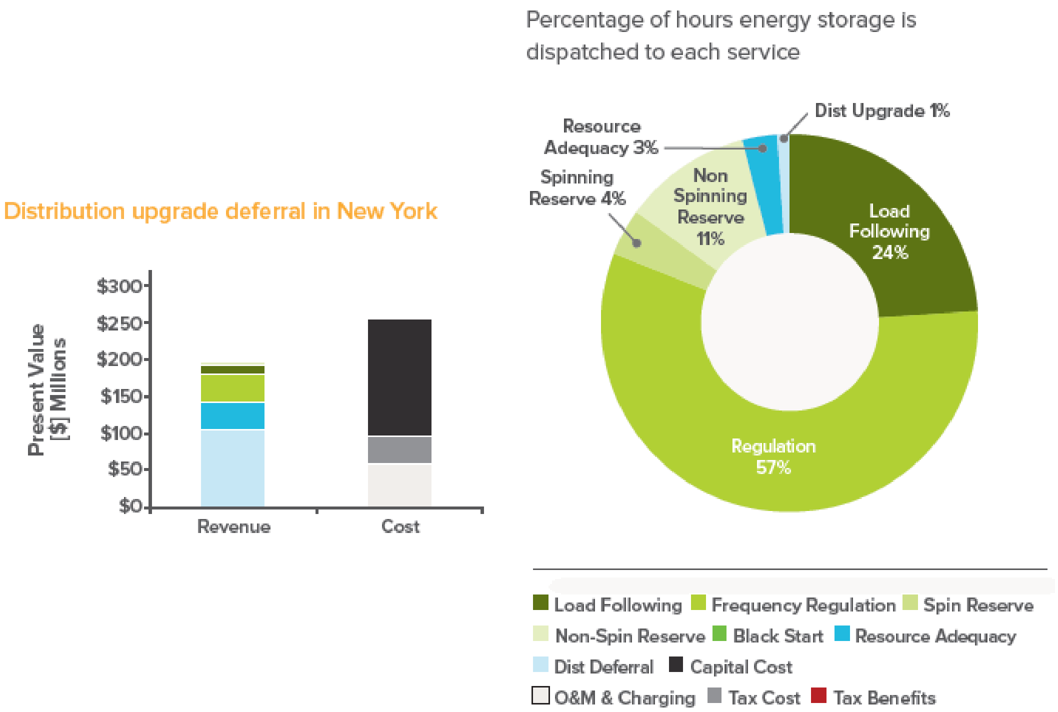

Figure 7.3-3 Cost and benefits from the Distribution upgrade in New York [7.50]

Residential bill management in Phoenix, Arizona

In this case, the storage system is used to reduce demand charges and minimize grid purchases during TOU peak periods by shifting residential demand. This is done due to a newly increased tariff for those who install rooftop PV systems. All storage systems are paired with a rooftop PV system. The ensemble of secondary services include regulation, spinning-non-spinning reserve, resource adequacy and load following. The results show a bill saving of nearly 20 % a year with a storage utilization, in terms of lifetime, of 10% a year. Customers that have peaky loads have obtained greater benefits compared to those with relatively flat loads. But if the investment tax credit goes to zero, in order to make sense of the investment, the cost of the energy storage need to be less than $300/kWh and $1111/kW. This seems a very promising prospect, considering that, as discussed in Chapter 3, the current cost for EV batteries are below $300/kWh, the ownership of the car is likely to be of the users, hence the only cost left to the aggregator, if there is one, is the charging infrastructure and management cost. Figure 7.3-4 shows the results from this study

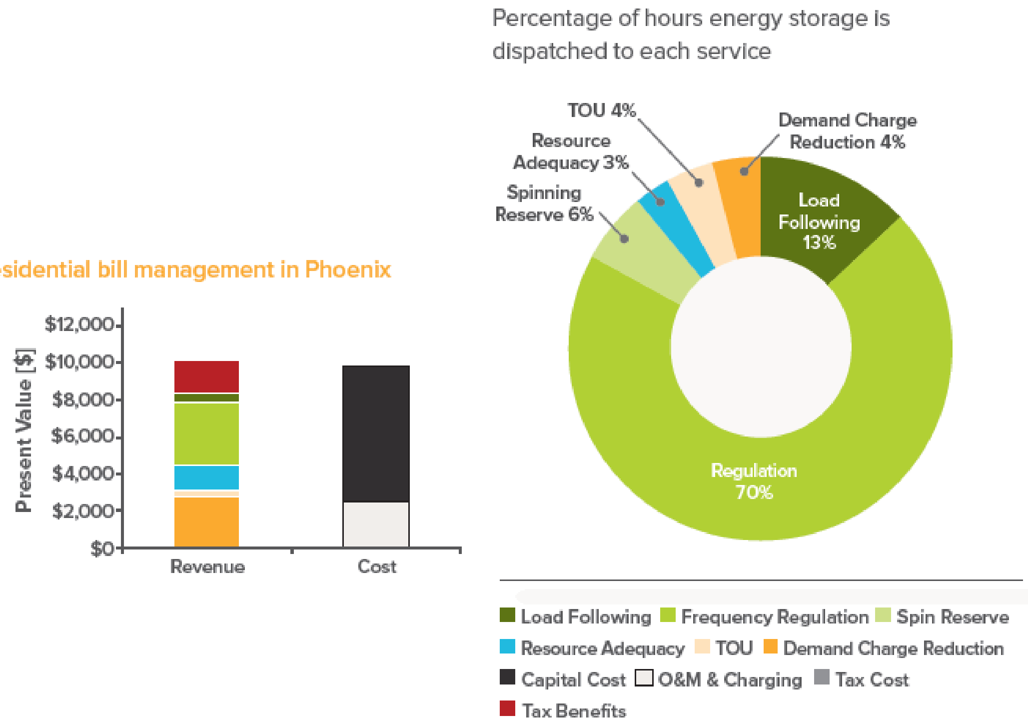

Figure 7.3-4 Cost and benefits from the Residential bill management in Phoenix [7.50]

Solar self-consumption in San Francisco

For this study, Net Energy Metering (NEM) is replaced with a modified tariff with which the solar PV produced but not consumed is fed into the grid at a value of 3.5 cents/kWh, which is much lower than the retail value. Hence, the aim is to maximise the PV self-consumption, by charging a battery with the excess energy and only once this is fully charged, export to the grid. The value for the customer is represented by the difference in the bill with and without the storage. Additionally, the customer benefits of TOU tariffs. Secondary services that are provided include regulation, spinning/non-spinning reserve, resource adequacy and energy arbitrage. The results show that the storage, after performing self-consumption, is available for roughly two-thirds of the year to provide other services. Because these are static battery storages their only use is the service they are employed for, but in case of EVs, the main function of their batteries is the transportation. The afore-mentioned result proves that transportation is not affected by the service provision. The case studied here makes sense without any NEM, whereas in the eventuality this is in place, the business case is not economically viable anymore. The results are shown in Figure 7.3-5.

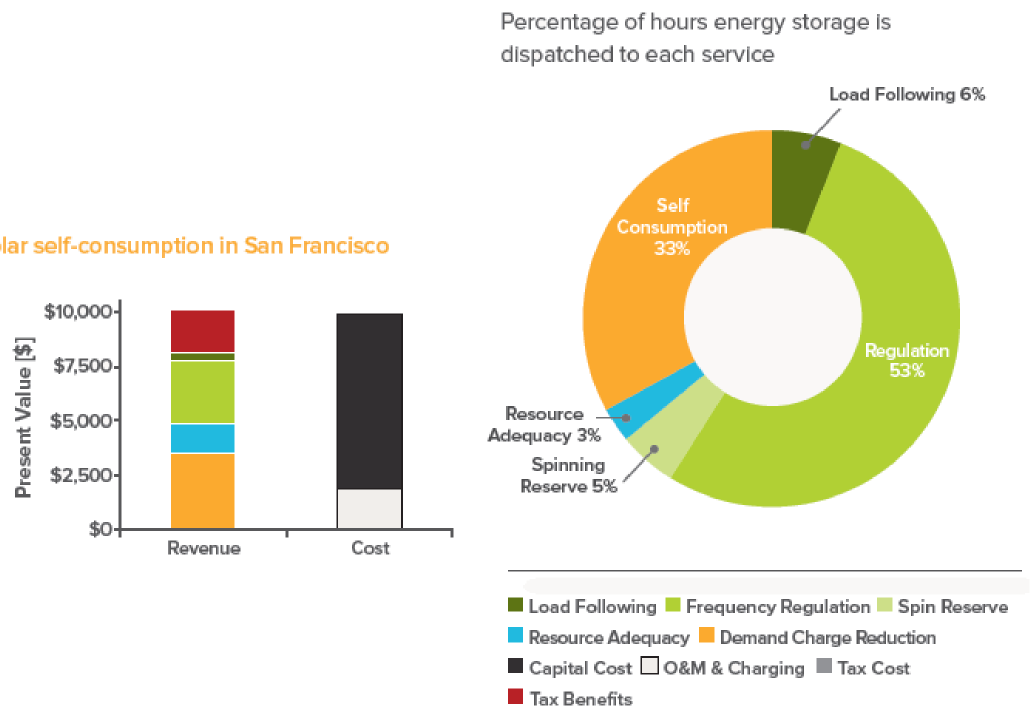

Figure 7.3-5 Cost and benefits from the Solar self-consumption in San Francisco [7.50]

As can be seen, in the majority of the cases use of V2G results in a profitable outcome, when a stack of different ancillary services is provided with a particular attention for customer-facing services which give more value. This points out once again that business models should allocate a major role to the user who is put at the centre.

7.4. ***Summary***

Three different business model structures have been presented and these are classified by the degree of EV ownership. Compared to private ownership, the ease of use and hassle-free use of an EV within a car sharing service would bring new driving experience for the users, and the more efficient use of the shared vehicles compared to the privately-owned ones will help to reduce car density and traffic congestion. Air pollution issues will also be resolved by the use of all-electric cars that are charged from RES. However, the business risk involved in the significant initial investment for the car sharing services poses a challenge for the investors. The current battery warranty condition for EVs might also be another financial constraint. It is therefore essential to have policy as a driver in early days of EV markets, either directly subsidising pilot projects that will lead the market by example, or incentivizing future behaviours in the market from aspects of transport, energy and environment; as well as reinforcing regulations to enable interoperability.

Once EV ownership is defined, the business model is developed by identifying the stakeholders within the system boundary, clarifying the communication link and the commercial relationship with revenue flows among the identified stakeholders, which is based on the physical connection of the involved entities. This is the approach adopted by the SEEV4-City project to develop the business models for different OPs with various implementation scales.

Regarding the economics of smart charging and V2G, the sources of the various costs and the potential revenue streams have been identified and analysed. The associated costs involved in smart charging and V2G include charging energy payment, charging infrastructure cost and battery degradation cost. The revenue streams are mainly due to network service provision. It has been shown that smart charging and V2G would be most cost effective for EV owners who participate in the short-duration, high-value power market of ancillary services, preferably with both capacity payment and energy payment. In general, frequency regulation services generate the most profits, followed by spinning reserve provision and possibly peak shaving. The type of usage expected of the EVs will also affect their availability and therefore make a difference on the associated revenues.

Policies of energy, transportation and environment could also have a direct or an indirect impact on the EV energy scheduling scenarios. Policies can play a major role as key drivers for EV user behaviour and should therefore be considered in the V2G economic analysis. Taxes, penalties and other forms of actions (incentives) to promote clean transportation should also be included. Not much previous work considers these aspects when developing business models, and the SEEV4-City project contributes by taking into account the national and local energy policies, grants and subsidies to relevant stakeholders that are involved in the value chain.

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8. Policies and Incentives for EV Adoption in EU and NSR

To answer the research question of 'what incentives and supportive policies for EVs are available in the NSR and EU, and what are the impact of these policies on the EV adoption', this chapter reviews a number of areas that are important to the take-up of EVs. The first area is that of energy and transport policies in Europe. The second area is focused on measures being implemented in Europe to support EVs. There are various incentives for EVs and support equipment such as charging infrastructures. The third area deals with the environmental impact of EVs throughout their lifecycle. The final area covers EV users' behaviour, and includes preference studies to investigate the interests and intention of EV purchasing.

8.1. *Transport and energy policies for EVs*

Transport policy comprise policies for road, rail, air and waterways including marine shipping. Energy policy covers electricity production and distribution, nuclear power, renewable technologies and energy efficiency measures. Not all transport and energy policy will be applicable to EVs. This means that there has to be a focus on those policy areas that will have an impact on EVs. These may be commercial (logistics) EVs (vans or even trucks), buses, cars / taxis, motorbikes, scooters and electric bicycles. Light duty vehicles, both cars and vans, are the focus of the report here, alongside buses in the heavy-duty vehicle section.

Transport is an important issue for all countries. In the EU, transport enables the movement of people and goods around the region. Transport also contributes to leisure activities. In 2014, the EU transport sector consumed some 350 Mtoe. Almost half (49%) of this is attributed to cars – that is about 175 Mtoe [8.1]. Figure 8.1-1 shows the percentage of energy for all transport sectors. This compares to an overall consumption of 1104 Mtoe (EU Energy in Figures, 2014). Almost 16% of energy used in the EU is by cars. Not only are vehicles a major energy user but they also emit pollution (harmful to the biotic environment, and harmful – directly, or indirectly through bioaccumulation - to human health), as well as greenhouse gases.

Road transport is accountable for about one-fifth of the EU's total emissions of carbon dioxide (CO_2), the main greenhouse gas. Transport is the only major sector in the EU where greenhouse gas emissions are still rising. EU legislation sets binding emission targets for new car and van fleets (i.e. by Original Equipment Manufacturers of Automobiles). As the automotive industry works towards meeting these targets, average emissions are falling each year. The targets for 2015 (for cars) and 2017 (for vans) were achieved already in 2013, according to the European Commission [8.2], though some of the actual emission performances need to be re-evaluated, certainly for diesel vehicles and also some other ICEs, based on recent critical studies. The academic literature has been sceptical for some time of the New European Drive Cycle and how accurately it represents actual road conditions.

In the EU, car manufacturers are required to reduce the average CO_2 emissions of new passenger cars to 95g CO_2/km until 2021. After 2021, a new EU regulation will need to be established. [8.3] argues that policies combining an emissions / energy consumption standard with an upstream or mid-stream emissions trading scheme are worth considering. These combinations could provide a promising approach to allow greater flexibility for the car manufacturers and to enhance efficiency and effectiveness of the regulation, whilst at the same time respecting political objectives and consumers' interests.

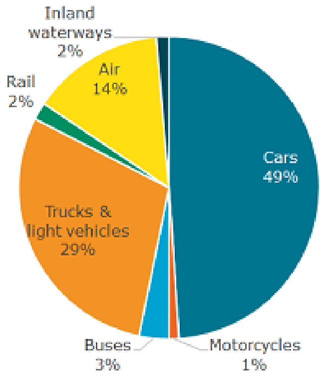

Figure 8.1-1: Decomposition of transport energy consumption by mode [8.1]

There are some energy policies that are not directly linked with EVs, but would have a potential impact on EV usage. The years 2012 and 2013 have seen a significant increase in Belgian residential PV installation due to renewable subsidies and incentives, such as net metering and feed-in tariff which have been discussed in *Chapter 2*. This massive PV installation made it increasing difficult for grid operators to balance supply and demand. Some changes have been made to alleviate the imbalance in the system. For example, Flanders introduced the prosumer tariff which requires a payment of €88.44/kwh/year from household PV to inject power back to the grid [8.4]. This incurred fee would encourage local renewable consumption from domestic base/flexible load as well as EV charging where applicable. Other regulations such as the energy tax, as enforced by Dutch energy law, requires payment when using energy from battery [8.4]. This would discourage the EV users from providing V2G.

8.2. *Incentives for EVs – both fiscal and non-fiscal*

There are a number of measures available to encourage the uptake of electric vehicles at the EU, national and sub-national levels. According to [8.5] these levels range from EU legislation that provides a framework promoting low-emission vehicles, through to national measures such as introducing lower taxes for electric vehicles and to local incentives such as free inner-city parking and use of road lanes normally reserved for public transport. [8.5] have developed a framework of financial incentives in Europe shown in Figure 8.2-1.

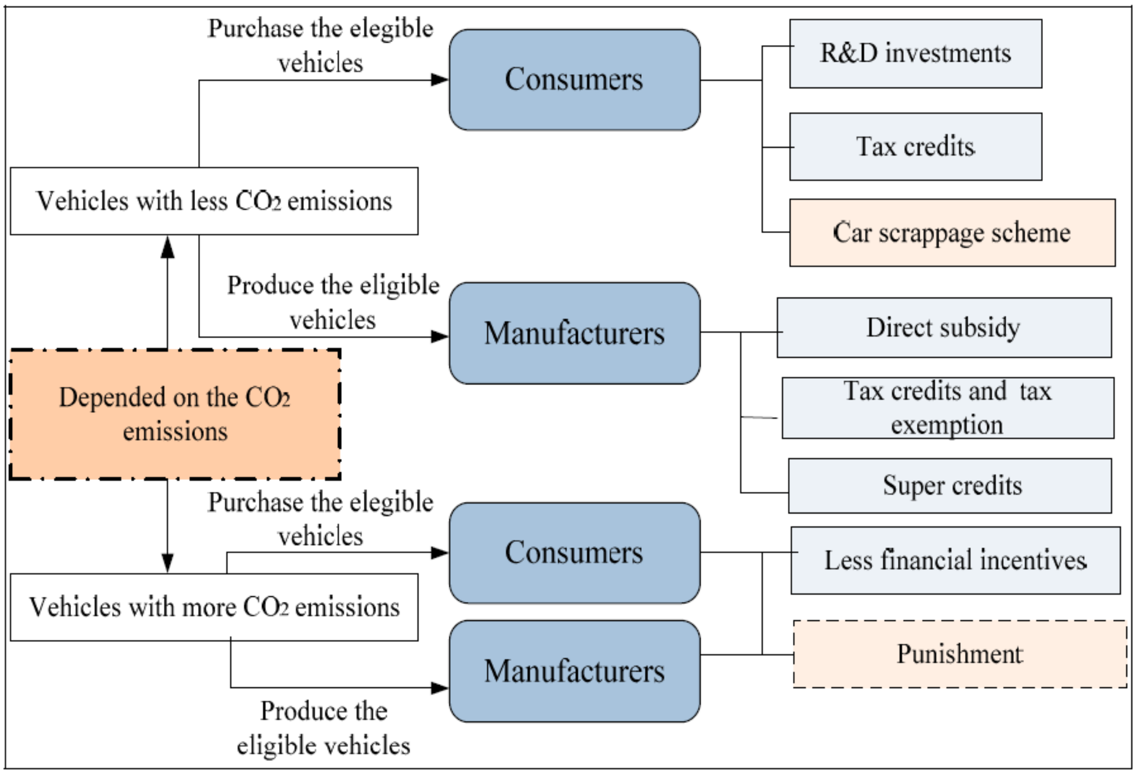

Figure 8.2-1: Framework of financial incentives in Europe [8.5]

It is not clear exactly what are the right sets of incentives for EVs, but research reported by [8.6] suggests that direct tax reductions are effective, more practical and better appreciated by customers than other instruments provided they are applied at time of purchase. As shown in Figure 8.2-2 there is a wide range of incentives for EVs ranging from Purchase Subsidies, Ownership Benefits, Business and Infrastructure Support and Local Incentives.

There is now a very considerable literature on how, or even if, incentives – such as scrappage schemes and subsidies, taxation benefits and no road taxes – and a range of other measures such as, at least in some circumstances, free public electricity for charging and / or free parking, affect vehicle purchasing, or leasing, decisions.

[8.6] researched the views of 875 people, using questionnaires, on the impact of incentives for EVs. The tested incentives are direct subsidies, free parking, a separate CO2 tax, an increase of fuel costs by tax elevation, and an increase of available charging infrastructure. Analysis of the date showed that those with a low CO2-emission rate regarding their daily transportation routines (cyclists and public transport users) will exploit these incentives. They show a significantly higher likelihood of choosing alternatively propelled cars than conventional car users. Consumers that usually use a passenger car for their daily mobility routines are mostly unwilling to change to ZEV even when incentives are given.

	PURCHASE SUBSIDIES (purchase-related tax exemptions or reductions, registration tax, import tax, co-funding or other finantial purchase support)	OWNERSHIP BENEFITS (annual tax exemption, reduction of electricity or energy costs)	BUSINESS AND INFRASTRUCTURE SUPPORT (business development or infrastructure support)	LOCAL INCENTIVES (free parking, access to bus lanes, no toll fees, free charging, access to restricted areas in city centres)
AUSTRIA	✔	✔	✔	✔
BELGIUM	✔	✔	✔	
BULGARIA	✔	✔		✔
CROATIA	✔		✔	
CYPRUS		✔		✔
CZECH REPUBLIC	✔	✔	✔	
DENMARK	✔	✔	✔	✔
ESTONIA			✔	✔
FINLAND	✔	✔	✔	
FRANCE	✔	✔	✔	✔
GREECE	✔	✔		✔
GERMANY	✔	✔	✔	✔
HUNGARY	✔	✔		✔
ICELAND	✔	✔	✔	✔
IRELAND	✔	✔	✔	✔
ITALY	✔	✔	✔	✔
LATVIA	✔	✔		✔
LIECHTENSTEIN				
LITHUANIA	✔			✔
LUXEMBOURG	✔		✔	
MALTA	✔	✔	✔	✔
NETHERLANDS	✔	✔	✔	✔
NORWAY	✔	✔	✔	✔
POLAND		✔		
PORTUGAL	✔	✔	✔	✔
ROMANIA	✔	✔		
SLOVAKIA		✔		
SLOVENIA	✔			✔
SPAIN	✔	✔	✔	✔
SWEDEN	✔	✔	✔	✔
SWITZERLAND	✔	✔	✔	✔
TURKEY	✔	✔	✔	
UNITED KINGDOM	✔	✔	✔	✔

Figure 8.2-2: Use of Incentives for electric cars across Europe [8.8]

8.2.1. The EU

The EU does not have a system of direct remuneration, but the policies discussed below can encourage EV take-up as they set out a path designed to make it more difficult for conventional vehicles. At the EU level, legislation encourages the development of low-CO_2 technologies in transport, such as electric vehicles and advanced biofuels. There are two EU regulations that set mandatory targets for average CO_2 emissions for new passenger vehicles and vans [8.9]. These regulations establish effective CO_2 emission targets for each manufacturer, depending on vehicle weights and types. The targets for new passenger vehicles and vans were both met several years before the deadlines (2015 and 2017 respectively). However, there is a growing discrepancy between the official test measurements and real-world emission measurements [8.8]. This means that in recent years actual on-road vehicles have reduced their emissions more slowly.

From 2021 onwards, the average target for the entire new car passenger fleet will be 95 g CO2/km. However, this takes only exhaust (or tailpipe) emissions into account in this context, so it treats BEVs as zero emitters. As an incentive to manufacturers, so called 'super credits' were introduced for vehicles with emissions lower than 50g CO_2/km, giving such vehicles extra weighting when calculating average emissions. Electric vehicles, as well as low-emitting hybrids, are therefore helping manufacturers achieve their targets. This approach, according to [8.10], helps to reduce policy uncertainty as this shows that the EU is committed to carbon reduction.

According to [8.8], the 2021 target of 95g CO_2/km is not sufficient in itself to help electric vehicles penetrate the market at a high rate, but rather designed to help improve vehicle efficiency in general.

Other examples of EU legislation include the Fuel Quality Directive [8.9], and the Renewable Energy Directive [8.11], which require respectively a reduction of the GHG intensity of fuels used in vehicles and a 10% share of renewables in the transport sector by 2020. Both EU Directives focus on the deployment of biofuels, but they can support electric vehicles indirectly as Member States can credit energy use by electric vehicles toward their targets.

The Alternative Fuels Infrastructure Directive [8.12] requires Member States to set targets for recharging points accessible to the public, to be built by 2020, to ensure that electric vehicles can circulate at least in urban and suburban areas. Targets should ideally include a minimum of one recharging point per 10 electric vehicles. The recently published European Strategy for Low-Emission Mobility highlights the need of moving towards low and zero-emission vehicles and scaling up the use of renewable electricity for transport and removing obstacles to the electrification of transport. It stresses the need for a further rollout of recharging infrastructure, interoperability and also EU-wide standardisation for electro-mobility. The objective is to allow a car journey across Europe, making electric vehicle charging as easy as filling the tank [8.13].

Among the measures that foster EV deployment, one of the most effective is support for research and development in innovative technologies. This allows achieving cost reduction and performance improvements and it is best exploited when coupled with other measures to scale-up the production. An example of this is the R&D in the field of batteries for EVs where the costs have been reduced by a factor of 80% in eight years as mentioned in *Chapter 3.3*.

There is evidence that the EU approach (along with national and local measures) has encouraged the take-up of EVs in a number of EU member states. Reference [8.14] shows that The Netherlands and Norway had surpassed their goals for registered EVs whilst Denmark, Germany and Sweden were close to meeting their targets.

8.2.2. National actions to support electric vehicle use

A combination of supporting incentives and coordinated policy is key in accelerating electric vehicle market development. There are many examples of ways in which national governments provide subsidies to consumers who purchase or use new electric vehicles. These include purchase tax exemptions, one-off grants or increasing taxes on fossil fuel use (which makes electricity a more attractive fuel). The level at which incentives are implemented and the amount of subsidy paid may differ greatly between countries.

8.2.3. One-off purchasing subsidies

Certain countries have used various types of one-off subsidies to encourage the purchase of electric vehicles. Reducing registration tax or exempting new vehicles is common. Reductions can range from 100% of the normal registration tax, i.e. full exemption (in Belgium/Flanders, Greece, Hungary, Latvia, The Netherlands and Portugal among others), to a more limited reduction (e.g. Denmark, Finland). Some countries reduce the tax by a defined amount (e.g. Ireland). Reducing registration tax is not the only way in which tax elements are being used to reduce the financial cost for customers who wish to purchase electric vehicles. Norway has for example exempted electric vehicles from value added tax (VAT). Several countries, including Norway and Iceland, exempt electric vehicles from import tax [8.15]. A number of governments co-fund purchases (including for public and local authorities). Such schemes generally consist of grants or premiums given by national governments to those customers who purchase electric vehicles. The method used to define the amount of the grant or premium differs between countries. Some countries, such as Sweden and Romania, apply co-funding to all purchases of cars with low CO_2 emissions. In France, Germany, Spain or the United Kingdom, the subsidies depend on the technology and category of vehicle. A number of Member States also offer additional means of financial support. In France and Portugal, a fixed grant is available for replacing an end-of-life vehicle with a new electric car. In Belgium, the government of Flanders gives grants only to individuals purchasing electric vehicles; leasing and company cars are not eligible [8.16]. However, in some countries tax reductions apply to companies as well (e.g. France, The Netherlands – where a combination of tax measures have resulted in a very high share of PHEVs that are company cars, Portugal and Sweden).

8.2.4. Reduced ownership costs

Drivers in many countries must pay an annual circulation tax that is required to drive a vehicle on a public road. Yearly tax exemptions or reductions usually focus on this cost element. Exemptions to circulation tax differ between countries, including by:

- The amount and/or the percentage of circulation tax reduction/exemption;
- The type and size of the electric vehicle;
- Ownership (private individual or company);
- The period of the exemption or reduction.

Some examples of time limits are found in Germany, Italy and Sweden. Circulation tax exemptions for electric vehicles in Italy and Sweden apply only during the first 5 years of ownership and during the first 10 years in Germany. Belgium, Cyprus, Greece, Hungary, The Netherlands, Portugal, Slovakia, Sweden or United Kingdom have also introduced exemptions from the annual circulation tax. In Latvia, owners of electric vehicles are exempt from car and motorcycle tax and from vehicle operation tax. The Austrian government exempts electric vehicle owners from monthly vehicle taxes.

Belgium and Portugal also offer the opportunity to deduct tax from corporate income if companies use low-emission cars. Portugal created incentives for battery electric and plug-in hybrid vehicles by increasing the maximum amount of depreciation acceptable as tax expenses and reducing separate tax rates on individuals' and companies' income taxes. Ownership benefits in Denmark to support fuel-efficient cars include tax reduction for electric vehicles and for hydrogen fuel cell vehicles full exemption (annual as well as purchase).

Some Member States have introduced incentives for the purchase of electric vehicles by reducing energy and/or electricity costs. At least six EU Member States (the Czech Republic, Finland, France, Germany, Poland and Spain) provide discounts for charging electric vehicles based on peak and off-peak prices. Such demand-responsive charging, or 'smart charging', provides an opportunity to reward consumers financially if they reduce their electricity usage or shift it to cheaper off-peak periods.

In 20 EU member states, and other countries like Brazil, Canada, China and South Africa, there are differentiated taxes on vehicle registration and/or circulation which depend on the fuel economy or the CO_2 performance of the vehicles [8.17].

8.2.5. Financial support to the electric vehicle industry

Many countries support research and development to encourage technological innovation for low-emission vehicles. For example, in Finland the government launched a 5-year Electric Vehicle Systems Programme (EVE) in 2011 with a total budget of around EUR 100 million. Its main aim was to create the financial conditions necessary to support and grow the electric mobility technology and service sector. From the beginning, the focus was on encouraging companies to develop international business opportunities. Pilot, test and demonstration projects were seen as important, as well as collaboration with partners from different areas of the electric vehicles industry.

A number of governments, as well as regional or local authorities, have financially supported the installation of electric vehicle charging infrastructure. As one example, since 2012 the French Environment & Energy Management Agency (ADEME) has allocated funds to a charging infrastructure support fund. It does this through its Future Investment Programme (PIA). In 2015, this fund supported the installation of more than 5000 charging points in France. Many other governments promote deployment of charging infrastructure for electric vehicles. These include Belgium, Croatia, Denmark, Estonia, Germany, Ireland, Italy, Luxembourg, Malta, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom. However, the investment funds and the targets differ significantly among countries.

In Sweden, individuals who would like to install a charging point for an electrical vehicle in their homes may get a tax reduction for the associated labour cost.

8.2.6. Other incentives

Local authorities across Europe have implemented a range of different measures designed to encourage uptake of electric vehicles. Often developed in conjunction with national authorities, to ensure that the appropriate legal basis for their implementation is in place, local measures are often (but not necessarily) non-financial. Examples of such measures include the case where municipal authorities use vehicles for many purposes including public transport, transport for the elderly and service cars for municipal workers. Local authorities are increasingly ensuring that electric vehicles are part of their public procurement contracts. One third of local councils in the United Kingdom, for example, now operate at least one electric vehicle (Intelligent Car Leasing, 2016). In the Czech Republic, municipalities, regions and local government agencies receive about 20-30% subsidy when purchasing a car with alternative technology. Public procurement and use of electric vehicles can be important factors in increasing public awareness of electric vehicles as a potential option within urban areas and it can reduce the environmental footprint of authorities.

Other examples include the provision of free parking places for electric vehicles. As part of its National Action Plan for the promotion and uptake of green vehicles for 2012-2014, Bulgaria gave electric vehicles free parking throughout all of its cities [8.18]. The German government similarly gives municipalities the option of offering various benefits to electric vehicle drivers, including free parking, [8.19]. From July 2016, electric vehicles can park free of charge in Latvia. Free public parking has also been introduced in Cyprus.

In Amsterdam, residents with an electric car have priority over other residents when applying for a parking permit.

Other incentives include the Provision of free charging at public stations. Certain countries, including Bulgaria, the Czech Republic and Denmark have introduced free charging at public stations. This scheme is also being piloted in Portugal. Some countries, such as Estonia, Germany, Latvia, Norway and the United Kingdom, permit municipalities to open individual bus lanes to labelled electric vehicles. In Italy and Greece, electric vehicles have access to restricted areas, such as city centres. In Germany, the Electric Mobility Act has also exempted (full) electric vehicles from certain restrictions.

Further measures include exemption from some driving restrictions within urban areas [8.17]: only vehicles that comply with given emission standards can freely circulate in the city centres while the others are not allowed. New EV models are likely to be exempted. A variation of this scheme is the requirement of a usage fee for portions of the road network and a good example is the Ultra-Low Emission Zone (ULEZ) in London which is applied from April 2019. Vehicles that do not meet the exhaust emission standards must pay a day charge to enter in the ULEZ zone. Naturally, full EVs are exempted from this. In Norway, battery and fuel cell electric vehicles are exempted from road tolls. These vehicles are also exempted from fees on national ferries [8.20]. The regional government of Catalonia in Spain has newly developed car labelling, and exempts electric vehicles from road tolls. It has developed a zero category for electric vehicles, REEVs and PHEVs with electric ranges of more than 40 km.

The Belgian Platform on Electric Vehicles (BPEV) was launched in 2010 [8.19]. The goal is to promote and disseminate information about electric vehicles. The platform includes all of the principal stakeholders involved in the field of electric transport in Belgium (Belgian Platform on Electric Vehicles, 2011). The Netherlands support the use of electric vehicles with consultancy, education and promotion [8.22]. The Hague has for example introduced subsidies for new and second-hand completely electric cars (EUR 5,000 and EUR 3,000 respectively) for its inhabitants. The City of Amsterdam also subsidises the purchase of electric vehicles (cars, vans, taxis, trucks) if they are to be used frequently in Amsterdam.

In January 2016, four cities in the United Kingdom (Nottingham, Bristol, Milton Keynes and London) were awarded significant funds (GBP 40 million in total) to promote green vehicle technology. These cities will deliver an increase in cutting-edge technology, such as fast-charging hubs and streetlights that double as charge points, along with a range of innovative proposals that will give electric car (battery and plug-in hybrid) owners extra local privileges such as access to bus lanes in city centres. They will also open up around 25,000 parking spaces for electric car owners, saving commuters as much as GBP 1300 a year [8.23].

Waivers on regulations that limit the availability of licence plates for ICE vehicles is also a policy that can be applied to favour the value proposition of EVs. With this approach, there is partial or no control that restricts the availability of EV licence plates in urban clusters; this has been adopted in major cities in China [8.17]. In 2016, there had been considerable changes in the financial support mechanism for EV purchases in different countries. shows the effects of this measures.

Table 8.2-1 Incentives developments for EVs in different countries [8.21]

Country	2015 vs. 2016 policy developments		2015 vs. 2016 sales growth		2016 sales	
	BEV	PHEV	BEV	PHEV	BEV	PHEV
China	~		75%	30%	257 000	79 000
United States	~		22%	70%	86 731	72 885
Norway	~	↗	6%	164%	29 520	20 660
United Kingdom	~		4%	42%	10 509	27 403
France	~		26%	36%	21 758	7 749
Japan	~		48%	-34%	15 461	9 390
Germany	~		-6%	20%	11 322	13 290
Netherlands	~	↘	47%	-50%	3 737	20 740
Sweden	~	↘	0%	86%	2 951	10 464
Canada	~		19%	147%	5 220	6 360
Denmark	↘		-71%	-49%	1 218	182
Korea	~		75%	-40%	5 099	164

In Norway, EVs are exempted from acquisition tax, which is 100,000 NOK, BEVs are exempted from 25% of the Value-Added Tax (VAT) on car purchases and there are waivers on road tolls and ferry charges. In 2016, PHEVs policy was altered compared to 2015, where higher purchase discounts and tax waivers had been introduced and this favoured the growth in PHEV registrations. However, free parking for EVs was not applicable anymore.

Significant changes have been made in the Dutch policy framework where a differentiated CO_2 emission taxation has been increased in 2020. This affects PHEVs; in 2016, they were subject to 6€/gCO_2/km which will be increased to 20€/gCO_2/km. On the other hand, taxation for Zero Emission Vehicles (ZEV) such as BEVs will remain unchanged. It is likely that these changes will contribute to a further relative decrease in PHEV sales (from 10% in 2015 to 5% in 2016).

The purchase rebates for PHEVs in Sweden had been halved in 2016, from SEK 40,000 to SEK 20,000, but PHEV sales have increased perhaps because of the large share of PHEVs sold as company cars and because the incentives is given by a reduction in value of the ‘fringe benefits’ allowed for plug-in cars compared to ICE cars of the same class.

In Denmark, new registration taxes for EVs have been introduced for the first time in 2016: EVs must pay 20% of the full registration tax applied for ICE vehicles and this was applied to the next 5,000 electric cars sold or until 2018. This tax will be increased until 2022, when the full amount will be applied also to EVs. This is likely to have contributed to the significant drop of -68 % in car sales in 2016. From 2017, a purchase tax rebate for battery based EVs of 225 $/kWh will be applied for a maximum of 45 kWh (which corresponds to $10,000).

As can be seen, policies, mainly involving financial incentives, represent a major driver regarding EV deployment and when sufficient support is missing, drop in sales is often experienced. However, financial incentives can aid EV sales by lowering the TCO compared to ICE vehicles for the short term but these are not sustainable for the medium, and even less so for the long term. Evidence of this is the reduction in financial support seen in some of the leading countries in the field of electro-mobility. This shows once again that, as the cost gap between EVs and ICE vehicles keeps narrowing, governments will be able to phase out incentives but differentiated environmental and health taxes will have to stay in place and other new measures such as differentiated access to urban areas will need to continue supporting EVs.

8.2.7. EVSE (Electric Vehicle Supply Equipment)

There are two points to consider. The first is the availability of EV charging points and the second is the financial support provided.

8.2.7.1. EVSE availability

The availability of charging stations is essential to promote a wide adoption of EVs, as this increase the benefits of e-mobility against conventional vehicles (and addresses the so-called 'range anxiety').
According to [8.24] in 2015, there were 1.45 million EVSE outlets (there can be more outlets in one charger, i.e. AC and DC) globally available, increasing from the 0.82 million in 2014 and only roughly 20,000 in 2010. By 2018 there were 5.2 million available globally. The share of publicly available EVSE outlets was 13% of the total in 2013, falling to 10.4% in 2018. In 2013 there were 50,000 publicly available EVSE outlets, 110,000 in 2014, rising to 190,000 in 2015, 330,000 in 2016, 440,000 in 2017 and 540,000 in 2018.

In 2015, the growth of the publicly accessible charging infrastructure (71%) almost paralleled the growth of the global EV stock (78%). The number of publicly available slow chargers increased by 73%, while fast chargers increased by 63%. Both slow-charging and fast-charging outlets more than doubled on an annual basis in the five preceding years. By 2018 the annual rate of increase had fallen to some 23%.

In 2015, in China, the number of fast charging outlets represented the 44% of the global stock for the same, while it was 53% one year earlier. The number of fast-charging outlets in France quadrupled in 2015 while in Norway it tripled. The availability of fast chargers more than doubled in Canada, Germany, Japan, Sweden and the United Kingdom. In 2015, yearly increases of slow chargers were weaker, except in China, Spain and France, where the growth was far more rapid than fast-charging outlets. In 2018, there were 150,000 fast chargers globally,78% of which were in China.

As on 14 April 2020, the number of publicly available 'normal' charging stations in the UK account for 11,321 'locations', which include 18,222 'devices' and 31,625 'connectors' (according to ZAP Map, charging stations are referred to as 'locations', where each location includes charging devices which may have up to three connectors). Charging stations (likely to be number of 'connectors') in other EU countries are estimated at 40,830 in The Netherlands, 10,377 in Norway, 6,070 in Belgium, 34,203 in Germany, 2,244 in Denmark and 4,036 in Sweden. As for high power charging stations, these are (as on 14 April 2020) 2,637 (connectors) in the UK [8.25], 1,300 in The Netherlands [8.26], 3,426 in Norway, 359 in Belgium, 5,088 in Germany, 449 in Denmark and 1,030 in Sweden [8.27].

The ratio between EVs and charging outlets varies across countries. Globally, the ratio between electric cars to each publicly available fast-charging outlet was 36 in 2018. Globally, there are more EVs per fast chargers [4] than per slow chargers [5] (the ratio of EV/Fast EVSE was 2.9 times the ratio EV/Slow EVSE in 2018). Fast charging infrastructure is diversified across countries. In 2018 China possessed 78% of the total supply of fast chargers, with only 45% of the global EV stock. In China in 2018 there were with 2.3 million EVs, corresponding to 19 EVs per fast charger.

- In 2015, the fast-charging outlets installed in Japan and China accounted for more than three-quarters of those installed globally and there were 21 EVs (in Japan) and 25 EVs (in China) per fast-charging outlet (Japan had 12 and China had 19 for BEVs/fast EVSE outlets;
- In Sweden and the United Kingdom there were 40 EVs per fast-charging outlet (14 in Sweden and 19 in the United Kingdom for BEVs/fast EVSE outlets), and 60 in Germany (39 for BEVs/fast EVSE outlets);
- For Canada, France, Norway and the United States, the same ratio ranges between 100 and 130 (60 and 90 for BEVs/fast EVSE outlets);

[4] According to [8.24b] fast chargers include AC 43 kW chargers, DC chargers, Tesla Superchargers and inductive chargers.
[5] According to [8.24b] slow chargers include AC level 1 (≤ 3.7 kW) and AC level 2 chargers (> 3.7 kW and ≤ 22 kW)

- In The Netherlands there were 188 electric cars per fast-charging outlet (and 20 BEVs).

8.2.7.2. EVSE financial incentives

Nearly all countries with an EV market share above 0.5% (in 2015, this was the case for China, Denmark, France, Germany, Japan, The Netherlands, Norway, Portugal, Sweden, the United Kingdom and the United States) provided either direct or fiscal incentives at the national level to install private charging outlets. The Danish government, for instance, offers a tax rebate on the installation of home chargers up to DKK 18,000 (USD 2,700) [8.24] and the United Kingdom is supporting electric car home chargers by financing up to 75% or GBP 500 (USD 700) for the installation of a charging point, [8.28]. Some countries (e.g. France) also require that all newly built residential buildings and workspaces include EV charging points [8.29].

Some countries implemented national framework programmes enabling EVSE subsidy or fiscal credits to favour the deployment of publicly accessible EVSE. In the United States, a federal funding programme that contributed to 36,500 publicly accessible charging outlets was in place in 2015 [8.30]. In France, fiscal deductions are in place for private operators investing in, maintaining or operating charging outlets in public spaces in at least two different regions, with the goal of having a national charging network [8.31]. In Denmark, a scheme administered by the Danish Energy Agency supports the deployment of new public charging stations. In Japan, a partnership with a retailer for the installation of 500 fast chargers and 650 standard chargers at its stores, providing two-thirds of the funding [8.32].

The support for publicly accessible EVSE is often developed with initiatives at the city or region-level through local EV and EVSE support programmes, such as, public or private initiatives aiming to develop countrywide charging networks, in order to expand EV availability and adoption to a wider public, for non-metropolis dwellers or long-distance travellers. Examples include the Ecotricity electric highway in the United Kingdom [8.33], and Enova's requirement of two chargers per 50 km along the main road network in Norway [8.34]. Further, there are public or private initiatives aiming to develop office chargers (e.g. the "switched on @work") initiative in the United Kingdom [8.35]. Figure 8.2-3 gives an overview of support measures [8.36].

	Direct investment		Fiscal advantages		Total EVSE stock per million inhabitants	Publicly accessible EVSE stock per million inhabitants
	Publicly accessible chargers	Private chargers	Publicly accessible chargers	Private chargers		
Canada	Targeted policy	Targeted policy	No policy	No policy	612	98
China	Nationwide policy	Nationwide policy	No policy	No policy	265	42
Denmark	Nationwide policy	No policy	Nationwide policy	Nationwide policy	1 732	309
France	Nationwide policy	Nationwide policy	Nationwide policy	Nationwide policy	970	159
Germany	Nationwide policy	No policy	No policy	No policy	664	67
India	Targeted policy	Targeted policy	No policy	No policy	5	0.3
Italy	Targeted policy	No policy	No policy	No policy	129	29
Japan	Nationwide policy	Nationwide policy	No policy	No policy	1 171	174
Netherlands	Nationwide policy	No policy	No policy	Nationwide policy	6 280	1 084
Norway	Nationwide policy	Targeted policy	No policy	No policy	15 143	1 372
Portugal	No policy	No policy	No policy	No policy	302	114
South Korea	Targeted policy	Nationwide policy	Targeted policy	Widespread policy	113	26
Spain	Targeted policy	Nationwide policy	No policy	No policy	161	35
Sweden	Targeted policy	No policy	No policy	No policy	1 674	175
United Kingdom	Targeted policy	Nationwide policy	No policy	No policy	933	155
United States	Nationwide policy	No policy	Nationwide policy	Nationwide policy	1 340	97

Legend:
No policy
Targeted policy *
Widespread policy**
Nationwide policy

Notes: * Policy implemented in certain geographical areas (e.g. specific states/regions/municipalities), affecting less than 50% of the country's inhabitants.
** Policy implemented in certain geographical areas (e.g. specific states/regions/municipalities), affecting more than 50% of the country's inhabitants.

Key point • Countries with a high EVSE rate per capita have typically deployed attractive EVSE implementation incentives.

Figure 8.2-3: Summary of Policy Support Measures for EVSE Deployment [8.36]

EVSE deployment targets [8.17] include:

- In China, the deployment of 4.3 million private EVSE, 0.5 million public chargers for cars and 850 intercity quick chargers by 2020 and other targets for buses and taxis;
- EU member states had defined national electric charging points targets for 2020 by November 2016 (with the exception of a few countries only, which had not at that point submitted those national targets), as for the EU Directive on the Deployment of Alternative Fuels Infrastructure. France has set the target of 7 million chargers by 2030.

Financial incentives are the other effective measure that benefits EVSE deployment:

- China supports municipalities for the construction of public charging infrastructure;
- A tax credit of 30% of the price of a home charger or subsidies for the deployment of residential or workplace chargers are available in France;
- The Green Deal in The Netherlands is a governmental contribution for the deployment of public EVSE by municipalities in collaboration with a third party. There is also a tax incentive for businesses that invest in EVSE;
- In Norway, public funding is provided of fast chargers every 50km on main roads and others for public chargers;
- Financial support for the deployment of EVSE is also present in Sweden and in 2015, these amounted to 130 million SEK;

- In the UK, a subsidy of £500 is given for the installation of a home charger and £300 per socket and tax breaks (for large EVSE deployment) are given to businesses that invest in charge points for fleets and/or employees. Besides, local authorities are refunded for the installation of roadside charge points in residential areas;
- In the US there is state level support dedicated to EVSE.

Along with the financial incentives, there must be other strategies that improve EVSE deployment; among these, there are regulations and permits:

- According to the French legislation, 50-75% of the parking bays in new or renovated residential buildings must allow the easy installation of EVSE with a capacity between 7 and 22 kW. As for commercial buildings, 5-10% of the parking bays must allow the easy installation of EVSE rated at least 22 kW.
- Property laws in countries like France, Portugal, Spain and the US, are being adapted to simplify and accelerate the approval process for the deployment of EVSE in rented and/or owned multi-unit dwellings.

A fundamental part of the policies aimed to support the development of EVSE is direct investment and public-private partnerships:

- More than 60 fast-charging stations have already been built in the Netherlands, by the company Fastned, and 14 more will be built in Germany and others in the UK. Elaad, bringing together seven network operators, and Clever, a company owned by Scandinavian energy companies, want to create Europe's first ultra-fast charging network;
- Washington, Oregon and California, in the US, have organized together a large-scale network of DC fast-charging stations, deployed on the major roadways every 40-80 km, named the West Coast Electric Highway. The costs have been divided among the public sector, the private sector and users;
- The State Corporation of China and China Southern Power Grid have opened together more than 27,000 charging stations;
- Among the OEMs, Tesla's supercharger network is noteworthy; it consists of more than 5,000 fast-charging stations deployed at dedicated locations on highways and it is aiming to double the charging stations to 9,000 in destinations such as hotels, resorts and restaurants. In addition, BMW, Daimler, Ford and Volkswagen have announced jointly their plan to develop a European fast-charging network along major highway;
- Because the majority of EVs are concentrated in urban areas, the steps undertaken by cities in the context of electro mobility represent a major driver for the deployment of EVSE: the Autolib electric car-sharing program from the municipality of Paris allowed (until its closure in 2018) all electric cars to use the chargers and there are other benefits, such as free parking and dedicated parking spots;
- In Amsterdam, there is the demand-based deployment of EVSE; only when there is a user demand for the charger, and there is no other private or off-street alternative, this is deployed. It is an efficient way to build a network of EVSE because it is done in parallel with the deployment of EVs. In Utrecht, the municipality gives €500 per charging point and €1,500 per semi-public charging point;
- The municipality of Beijing has established an upper limit for the fee that users need to pay to utilize the public charging network, at 15% of the price of gasoline. The municipality of Shanghai has set the aim to build 210,000 charging point by 2020. Several cities in China have strong

requirements regarding the installation of chargers in a percentage of the available parking spaces for new building construction or renovation.

- In Vancouver, Canada, there is the requirement that new single-family dwelling has to support a Level 2 infrastructure and 20% of the parking places in multifamily buildings must allow EVSE outlets;
- Source London is a citywide electric-vehicle charge point network, which was started by the integrated transport authority of London, Transport for London. It is now managed by a private operator and it provided more than 850 charge points in London and planned the installation of another 4,500 by 2018.

The deployment of EVSE is aimed to foster the deployment of EVs therefore the prospects for future EVSE deployment is strictly dependent on the future targets for EVs. Public EVSE will need to grow by a factor between 8, for the "Reference Technology" Scenario (RTS) and 25, for the "Beyond Two Degree" Scenario (B2DS), which corresponds to between 4 million and 14 million outlets by 2030, globally. Moreover, 0.1 million fast chargers will need to be deployed by 2025, under RTS and 0.6 million under B2DS; for 2030 the figures under RTS are 0.2 million whereas 0.7 million are required to satisfy B2DS. The prospects are shown in Figure 8.2-4.

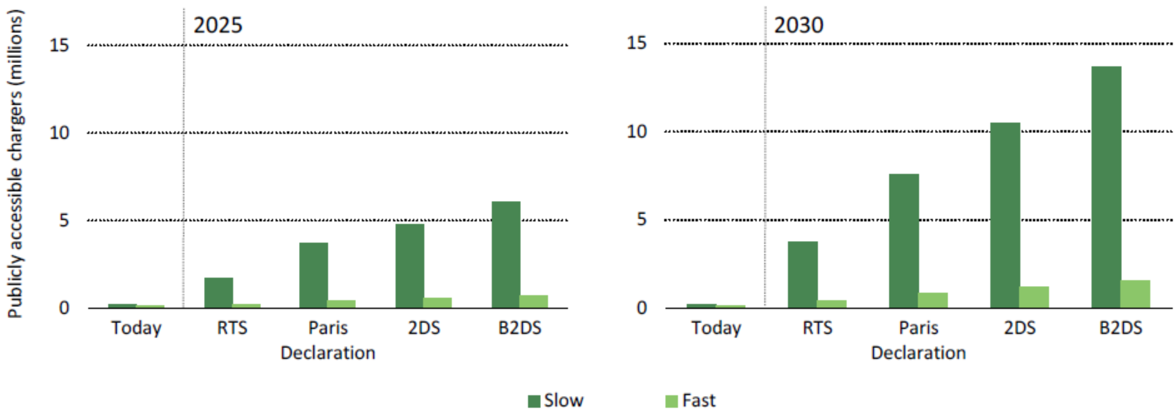

Figure 8.2-4 Future prospects for EVSE [8.18]

8.3. *Environmental impact of EV production, use and decommissioning*

EVs offer considerable potential for environmental improvement. However, like all developments they do have the potential of adverse impacts. One of the best methods for understanding impacts is through a Life Cycle Assessment. According to the International Standards Organisation (ISO), this is defined as:

A systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle.

'Life Cycle' is defined as:

Consecutive and interlinked stages of a product or service system, from the extraction of natural resources to the final disposal. [8.37]

As the following shows, there are a range of views on the life cycle of EVs.

A Life Cycle Analysis report commissioned by the Energy Efficiency and Conservation Authority (EECA) has found that EVs are better for the New Zealand environment than petrol or diesel-powered vehicles, across the lifecycle of the vehicle as well as in use. The report addresses two urban myths around EVs. The analysis found that there was no significant difference in the depletion of rare earth metals between EVs and petrol or diesel vehicles. Moreover, the lithium used in lithium-ion batteries for EVs, actually present in the form of salts, is neither a rare-earth nor even a precious metal (but there are concerns – see *Section 8.3.2*). The analysis also found that there are no significant differences across the vehicle types with regard to resource depletion, air acidification, human-toxicity and eco-toxicity lifecycle indicators [8.38].

[8.39] researched into the environmental life cycles of both electric and conventional vehicles and found that EVs powered by the present European electricity mix offer a 10% to 24% decrease in global warming potential (GWP) relative to conventional diesel or gasoline vehicles assuming lifetimes of 150,000 km. However, the researchers found that EVs exhibit the potential for significant increases in human toxicity, freshwater eco-toxicity, freshwater eutrophication, and metal depletion impacts, largely emanating from the vehicle supply chain. The researchers go to point out that in regions where fossil fuels are the main sources of power, electric cars offer no benefits and may even cause more harm.

Reference [8.40] reports on a study undertaken University of Minnesota that the environmental and human health costs of operating an electric vehicle using electricity generated from coal may be as much as 80% greater than driving a gasoline-powered vehicle. However, the study shows that environmental health cost of driving an electric vehicle using electricity from solar or wind generators could be as much as 50% less than the environmental and health toll of using gasoline.

Research by [8.41] shows the complexity of conducting an LCA for something as complex as an EV. Their research shows the impact of EVs in use depends on a range of factors such topography, driving style and electricity mix. Research by [8.39] and [8.42] provided comprehensive reviews on LCAs of EVs. They identified 55 and 79 relevant studies, respectively, including full reports, journal papers and conference papers. They both report widely diverging results. To address this problem a project supported by the EU Seventh Framework Programme, to develop guidelines for conducting an LCA on EVs [8.43]. The output of this report is entitled the E-Mobility Life Cycle Assessment Recommendations [8.44]. The output provides a comprehensive approach to the LCA of EVs. However, it should be noted that the EV sector is evolving. At present, most EV users charge at home. In the future with V2G coming more into use the impacts of EVs will change. V2G will help with managing the grid. But additional hardware will be needed and that will need to be considered. In addition, high speed and inductive charging will have impacts. It is clear that there will to be a watchful eye kept on the Life Cycle impacts of EVs and associated infrastructure.

8.3.1. Environmental impacts of EVs

According to the European Environment Agency [8.8], the major environmental impacts of vehicles are:

Greenhouse gases

GHG emissions include CO_2, CH_4 and N_2O. GHG emissions from all other major economic sectors have fallen in recent decades. Those from transport have increased. In the EU, road transport's emissions are today around 17 percent above 1990 levels, while the contribution of road transport to total EU GHG emissions has increased by around half — from 13 percent of the total in 1990 to almost 20 percent in 2014.

According to the European Environmental Agency Transport GHG indicator, published in December 2016:

- “In 2014, the transport sector contributed 25.5% of total EU-28 greenhouse gas emissions. The figure decreases to 21%, if international aviation and maritime emissions are excluded.
- Emissions from transport (including aviation) in 2014 were 20.1% above 1990 levels, despite a decline between 2008 and 2013. Emissions increased by 0.7% compared with the previous year. International aviation experienced the largest percentage increase in greenhouse gas emissions over 1990 levels (+97%), followed by international shipping (+24%) and road transport (+17%).
- Emissions need to fall by around two thirds by 2050, compared with 1990 levels, in order to meet the long-term 60 % greenhouse gas emissions reduction target as set out in the 2011 Transport White Paper” [8.45].

Air pollution

Road transport remains an important source of harmful air pollutants such as NOX and PM – the smaller are more harmful as they penetrate deeper into the respiratory system. Pollution released by vehicles is particularly important for health, as these emissions generally occur close to the ground and in areas where many people live and work, such as cities and towns, and along major trunk road networks.

Noise

Road traffic is by far the main source of traffic noise in Europe, both inside and outside urban areas. High levels of noise harm human health and well-being. In 2012, almost 90 million people living in cities, were exposed to traffic noise. At least 125 million people, or one in four Europeans, were exposed to daily traffic noise levels exceeding EU assessments threshold specified in the European Noise Directive (END) [8.46].

Resource use and waste

Manufacturing vehicles, both conventional and electric, requires significant amounts of raw materials and energy, much of which is imported. Though the European Environment Agency is clear that the ICE has adverse impacts, it still dominates the transport sector. This is despite efforts by the European Commission to promote measures to reduce the emission of GHGs by the transport sector. In the 2011 Transport White Paper [8.47] the European Commission outlined a roadmap for the transport sector to achieve, by 2050, a 60% reduction in its GHG emission levels compared with those of 1990. It describes goals for a competitive and resource-efficient transport system, including benchmarks such as:

- Halving the use of conventionally fuelled cars in urban transport by 2030 and phasing them out entirely in cities by 2050;
- Setting a 40% requirement for the use of sustainable low-carbon fuels in aviation;
- Shifting the amount of freight transported by road to other transport modes, 30 % by 2030 and 50% by 2050, for distances over 300 km.

In 2016 the EU Commission published its strategy for low-emission mobility [8.48]. The main elements of the strategy are:

- Increasing the efficiency of the transport system by making the most of digital technologies, smart pricing and further encouraging the shift to lower emission transport modes;
- Speeding up the deployment of low-emission alternative energy for transport, such as advanced biofuels, electricity, hydrogen and renewable synthetic fuels and removing obstacles to the electrification of transport;
- Moving towards zero-emission vehicles. While further improvements to the ICE will be needed, Europe needs to accelerate the transition towards low- and zero-emission vehicles.

The European Commission hopes that by 2030 EVs and low-emission vehicles will have a significant market share. There are those that think that the ICE will disappear much quicker. It is argued by [8.49] that transport by 2030 will be all electric and mostly autonomous. The car market will shrink by 80% and will need 80% less road and car parking spaces. Craig Cole writing in Autoguide [8.50] suggests that EVs will not be in a position to take over from ICEs until 2025 – he cities the range problem and costs as the two largest barriers. He also argues that car makers will push for new developments to improve fuel efficiency. However, a number of other EU countries have taken Norway's lead and are proposing to ban cars in city centres (Pedestrian Observations 2016). If this move strengthens then it is likely that we will see the move to electric vehicles sometime in the next decade. Perhaps Seba will be right and ICEs will be redundant by 2030.

8.3.2. Lithium mining

Though there are clear environmental advantages to EVs, concerns have been expressed about certain aspects of EVs; namely the batteries on which we focus here. Also, Cobalt is a major discussion point, which we will address in the next update of this draft report. Lithium is used in the manufacture of batteries used in EVs. According to [8.51] about 75% of the global reserves of lithium are found in the salt lakes of Uyuni in Bolivia, Atacama in Chile and Hombre Muerto in Argentina: the 'lithium triangle'. This desert expanse in the high Andes provides the raw material that moves the world of information technology and communications. Though the salt lakes do not have much flora or fauna, they do provide a home for flamingos. [8.52] points out that the flamingos feed on cyanobacteria, which is food for the birds but lethal to humans and other plants and animals. There are a number of concerns about mining lithium in this area. The impact of mining lithium is devastating, particularly on water supplies. Though lakes exist despite low rainfall, there is concern that more mining will disrupt water supplies for people and agriculture. In addition, crops can be affected by run-off of saline solution from which the lithium salts are gathered [8.53]. Traditionally, gathering salt has been part of local livelihoods. However, this becomes impossible as the salt ponds are contaminated by lithium mining.

There is also concern that regulation designed to minimise the adverse environmental impacts of lithium mining will not be effectively enforced. None of the governments of the lithium triangle have a good history of environmental regulation, and there is evidence that poorly paid officials often take bribes. There are fears that in the long run lithium mining will make the area unfit for its indigenous inhabitants [8.51] [8.54] [8.55].

The demand for lithium is increasingly driven by the push for electric vehicles. These should solve the urban air quality issue, but their batteries are causing environmental degradation in both their production and disposal.

And yet another issue must be raised: Lithium extraction requires a considerable amount of water [8.56].

8.3.3. Lithium recycling

There are 2 types of batteries used for electric and hybrid vehicles. Hybrid vehicles initially used nickel-metal hydride batteries. However, there is now a trend towards using lithium-ion batteries. Electric vehicles use lithium ion batteries.

Lithium-ion batteries and lithium iron phosphate (LiFePO4) batteries often contain other useful metals such as high-grade Copper and Aluminum in addition to, depending on the active material, metals such as Cobalt and Nickel as well as rare earths. To prevent a future shortage of Cobalt, Nickel, and Lithium and to enable a sustainable life cycle of these technologies, recycling processes for Lithium batteries are needed. As EVs have started to become more popular it was initially thought that recycling was a non-starter as the price of elements such as Lithium were still quite low and supplies were plentiful. However, it was thought that re-use as storage capacity was the most likely solution for dealing with batteries from EVs [8.57]. However, thought has now also been given to the process of recycling lithium-ion batteries. [8.58] describes a working system for recycling lithium ion batteries, using lead–acid battery recycling as a model. The author notes that the recycling of automotive lithium-ion batteries is more complicated and not yet established. The author also notes that it will be about another decade before there are large numbers of end-of-life batteries that make recycling more commercially attractive. There is thus the opportunity now to obviate some of the technical, economic, and institutional roadblocks that might arise.

In 2012, about 27% of the global lithium consumption came from rechargeable batteries while it was only 15% in 2007 and only 8% in 2002. The world lithium consumption from 2000 to 2008 had a steady 10% rate increase. The demand for energy storage and transportation is expected to grow by 20% per annum until 2025 [8.59].

In 2009, the US government awarded a US$9.5 million grant to a recycling company to boost its capacity for dealing with lithium-ion batteries [8.60]. In 2006, the EU established the Battery Directive. The purpose of the Battery Directive is to ensure that EU member states to contribute to the protection, preservation and improvement of the quality of the environment by minimizing the negative impact of waste batteries. Among them, waste Lithium ion batteries are part of this responsibility [8.61]. This legislation has driven the capacity of the battery recycling industry. The European Battery Recycling Association has a membership of some 15 companies that are actively involved in recycling batteries [8.62]. In the longer term, it is likely that there will sufficient European capacity for recycling Lithium-ion batteries.

Nickel metal hydride batteries are not used in EVs. However, research by BASF suggests that the capacity of these batteries could be considerably higher that than that of Lithium ion batteries. Nickel metal hydride batteries are considerable lighter that Lithium ion ones, which means that there will be a price advantage [8.63]. **Nickel** is a naturally occurring, lustrous, silvery-white metallic element. It constitutes the 73% of the cathode of a Lithium-ion battery and it is the fifth most common element on earth (0.009%) with estimate reserves of some 78 million tons. Nickel occurs extensively in the earth's crust. However, most of the Nickel is inaccessible in the core of the earth. Nickel is found naturally in food and water, but the human body is able to remove absorbed nickel so it is not a threat to people. Nickel metal on the other hand is classified as a suspect carcinogen. Nickel compounds are classified as human carcinogens. Places that process nickel have legal limits set. These limits are meant to ensure (if adhered to) that those that work in the sector are not harmed [8.64].

Cobalt makes 14% of the cathode and is a chemical element that is found in the Earth's crust only in chemically combined form, save for small deposits found in alloys of natural meteoric iron. The free element, produced by reductive smelting is a hard, lustrous, silver-gray metal. The main source of cobalt is as a by-product of copper and nickel mining. The copper belt in the Democratic Republic of Congo (DRC), the Central African Republic and Zambia yields most of the cobalt mined worldwide. The DRC alone accounted for more than 50% of 2016 world production (123,000 tonnes), according to Natural Resources Canada [8.65]. In October 2017 it was reported that Volkswagen failed in a tender with the supply chain to lock stocks of the metal in the future at prices they wanted to pay in the future [8.66].

Two-thirds of the global production of Cobalt comes from the Congo, processed in China. Companies have been accused of exploiting resources and workers [8.56]

A compound of cobalt, Lithium cobalt oxide ($LiCoO2$), is widely used in Lithium ion battery cathodes for mobile devices. More recently cobalt is being used in the rechargeable batteries for electric cars. This industry has helped create 5-times increase in the demand for cobalt, with consequent need to find additional sources in stable areas of the world. Cobalt is an essential element for life in minute amounts. However, chronic Cobalt ingestion has caused serious health problems. With regard to this all places that process cobalt have legal limits for exposure [8.67]. Global automotive companies, however, have some Corporate Social Responsibilities (CSR) headaches when sourcing from some locations, such as the Democratic Republic of Congo (DRC), the Central African Republic and Zambia, sourcing from global mining giants, such as Glencore [8.68].

Aluminium constitutes 2% of the cathode and is a silvery-white, soft, nonmagnetic ductile metal. By mass, Aluminium makes up about 8% of the Earth’s crust. Aluminium has many uses both domestic and commercial. Further, it is non-toxic and does not appear to cause harm to people.

Graphite is unique in that it has properties of both a metal and a non-metal and it is the only material for the anode. It is flexible but not elastic, has a high thermal and electrical conductivity, and is highly refractory and chemically inert. The use of graphite in batteries has been increasing in the last 30 years. Natural and synthetic graphite are used to construct the anode of all major battery technologies. The lithium-ion battery utilizes roughly twice the amount of graphite than lithium carbonate. A lithium-ion battery in a fully electric Nissan Leaf contains nearly 40 kg of graphite.

Rare Earth Elements: electric motors include a group of 17 Rare Earth Elements (REE). Though the REE implies there are very small amounts of these substances, the reality is they are not especially scarce resources but are available in only small amounts dispersed on the Earth’s crust. For example, Neodymium, used to make magnets, is no rarer than Cobalt or Nickel. Most electric vehicles (with the exception of Tesla) use Neodymium Iron Boron permanent magnets (NdFeB), which are essential to produce high-performance electric motors. Such magnets contain Neodymium (Nd), Praseodymium (Pr), and Dysprosium (Dy) Rare Earth Elements. But availability varies depending on the type of rare earth: based on known geologic reserves and security of supply issues, the US Department of Energy identified a risk of supply constraints for Neodymium and Dysprosium, two of the main components of electric magnet rotors. In 2015, half of the global demand for REE originated from magnets built into permanent electric motors, which are used in most electric vehicles [8.69].

Toxic materials and acids are used in the mining of rare earths. According to VW, complete transparency about the origins of the raw materials and the conditions of extraction is not yet possible. But there are now initiatives such as Drive Sustainability [8.70] and the Responsible Raw Materials Initiative whose mission it is to change that [8.71].

8.4. *EV user behaviour*

How people use EVs is important to understand, for manufacturers or lease companies for EVSE providers/operators as well as grid operators. But of growing importance is the impact of charging behaviour. This will impact the grid. In the longer term as vehicle to grid charging becomes more commonplace then understanding behaviour will be important to the energy companies. Research by [8.72] on 11 EV users in Western Australia found that almost all users charged their vehicles at night in their homes. Some started charging as soon as they arrived home, whilst others charged later in the evening when prices were lower. The researchers point out that this does have implications for the electricity generators and there is a need to understand what factors, for example financial incentives, could influence charging behaviour.

However, charging behaviour is not the only aspect of EV behaviour that needs to be understood. A long-term study was developed by [8.73] to evaluate user's satisfaction and adaptation to EV, in terms of driving behaviour, mobility, comfort, charging routines, interaction with the charging infrastructure. User's energy consumption and CO_2 emissions were also estimated. The presented data include information and concerns collected throgh interviews with eleven EV drivers and on-board diaries, including km travelled, kWh charged, number of trips per day. The information was gathered over a period of 5 months, and comprises a total of 1,772 trips, 18,524 km travelled, and a total electricity consumption of 3252 kWh related to approximately 220 charges. Results indicate that the adoption of the EV impacted everyday routines on 36% of the participants and 73% observed changes on their driving style. In comparison to conventional ICE vehicles running on gasoline or diesel, EV reveals considerable reductions in both energy consumption and CO2 emissions in a Well-to-Wheel life cycle approach, with 1.30 MJ/km and 63 g/km, respectively.

It is also important to for manufacturers to understand why people buy EVs. Research conducted in Norway showed most Norwegians who buy an electric car buy it as an addition to their household's car fleet. Only relatively few people substitute their conventional car. However, once bought, an electric car is used for a large proportion of all trips. This behaviour is driven by the incentive structure in Norway, and that owning an electric car reduces attitudes, intentions and perceived moral obligation to reduce car use [8.74].

Reference [8.75] sampled 308 respondents on the streets of Macau. The results demonstrate that environmental concerns and the perception of environmental policy are antecedent factors of the perception of full electric vehicles, which influences the behavioural intention to purchase full electric vehicles. The researchers also found that the perception of economic benefit is one of the key factors influencing the adoption of full electric vehicles. Vehicle operators seek economic benefits from future long-term fuel savings, high energy efficiency, and cheap electricity. They conclude that a government striving to promote low-carbon transportation needs to scale up its efforts to enhance citizens' environmental concerns and establish proper environmental policy as well as to provide long-term financial and strategic support for electric vehicles.

Modelling Consumer Preferences for Electric Vehicles

There is a clear need to understand what policies effectively encourage the take-up of EVs. [8.76] point out that many governments have initiated and implemented policies to stimulate and encourage both EV production and adoption. There is an expectation that better knowledge of consumer preferences for EV can make policy more effective and efficient.

Many empirical studies on consumer preferences for EV have been published over the last decades, and a comprehensive literature review would be helpful to synthesise the findings and facilitate a more well-rounded understanding of this topic. [8.37] gives an overview of EV adoption studies. However, according to [8.41] they only focus on individual-specific psychological factors that influence people's intention for EV adoption and only select some representative studies. Their review complements it in the following ways: first, they review a wider range of influential factors in EV adoption other than psychological constructs only; second, they present a comprehensive picture of current research by collecting all the available academic EV preference studies. They find that the impact of financial and technical attributes of EV on its utility is generally found to be significant, including its purchase and operating cost, driving range, charging duration, vehicle performance and brand diversity on the market. The density of charging stations also positively affects the utility of EV, which demonstrates the importance of charging infrastructure development in promoting EV. As for the impact of incentive policies, tax reduction (either purchase tax or road tax) is most likely effective, while there is not yet evidence supporting the effectiveness of other usage cost reduction such as free parking and toll reduction. The findings regarding giving EV access to priority lane vary for studies conducted in different regions. The preferences for the above attributes are mostly heterogeneous and can partially be accounted for by various individual-specific characteristics. The authors conclude by saying that the uncertainties associated with EVs needs further research so that a greater understanding of the behaviour towards EVs can be gained.

8.4.1. EV preference studies

Various studies have been carried out to investigate the interests and intention to purchase EVs of survey participants that are selected with various backgrounds, such as socio-economic, socio-geographical, educational, and income and property type based. The studies also looked into the impact of financial incentives, environmental policies and technical development on the attitude of these potential EV adopters.

[8.42] carried out a discrete choice study investigating the ecological impact and transport modal shift due to five different German Federal incentives for buyers of zero emissions vehicles, such as battery electric vehicles, plug-in hybrid electric vehicles and fuel cell and hydrogen electric vehicles. These tested incentives were direct subsidies, free parking, a separate CO_2 tax, an increase of fuel costs by tax elevation, and an increase in available charging infrastructure. Based on 825 completed questionnaires from an online survey conducted in the metropolitan area of Hamburg (both inner city and rural areas within the city boundary), where respondents were only selected by their socio-economic and socio-geographical attributes (not according to whether they were about to purchase a car in the near future).

[8.42] argues that besides the knowledge of the preferred propulsion technology and the importance of the different incentives, it is necessary to know the mobility patterns of the respondents to draw conclusions from their decisions to their future mobility. Therefore, he asked respondents about their daily mobility routines (i.e. yearly mileage), possession of an annual public transport transit pass, use frequency of bicycles, and use frequency of public transport – thereby clustering different mobility patters as: car users, public transport users, multimodal users with a car affinity, and multimodal users with a public transport affinity. Simulation results (random utility model, mixed logit) showed that mostly people with a low CO_2 emission rate regarding their daily transportation routines (cyclists and public transport users) would exploit these incentives. They show a significantly higher likelihood of choosing alternatively propelled cars than conventional car users. Consumers that usually use a passenger car for their daily mobility routines are mostly unwilling to change to zero-emission vehicles even when incentives are provided in this stated preferences simulation.

A relatively recent survey amongst German electric car owners by the German Centre for Aerospace and Aviation [8.43] shows that particularly well-educated people working in full-time jobs, gaining an above average income and living in detached houses in small- or medium-sized towns have bought electric cars. Many of these private users are ecologically aware and nearly half of them own a photovoltaic system.

[8.44] took this further with a computer-based interview survey study of 167 house owners (sampled only from those who have built their houses since 2009, whose houses were under construction or who were going to buy their houses within the next months) in North-Rhine Westphalia Germany during November 2013 and February 2015 as potential adopters of electric cars. Respondents were divided, with the help of energy efficiency standards for new constructions, into two groups: owners of energy-efficient houses and owners of conventional homes. Both groups were asked to choose between a conventional car, a plug-in hybrid electric car and a battery electric car in different hypothetical choice experiment situations. Results showed that both groups would prefer to replace their current car with a larger and more powerful car, with a tendency also for both groups also to choose a car with less fuel consumption. The results of the discrete choice experiment indicate that owners of energy-efficient houses have a statistically significant higher willingness to pay for plug-in hybrid electric cars (amounting to around €4,500) and for battery electric cars (amounting to around €5,600) with or without a range extender.

One of the recent studies and analyses on battery electric vehicle adoption research over the past (two) decades(s) gathered insights from 340 adopters of BEVs targeted towards North American owners of BENs but open to BEV owners all over the world via fora associated with Tesla and Nissan Leaf in particular but not exclusively to test assumptions made about early adopters based mostly on studies that have sampled members of the general population and not actual adopters of BEVs [8.77]. Based on this, [8.77] makes a distinction between two groups of adopters: high-end adopters and low-end adopters, finding that each group has a different socio-economic profile and that there are also some psychographic differences. Furthermore, high-end adopters view their BEVs more preferentially. Results show that overall high-end adopters are more likely to continue with BEVs in subsequent purchases. As for reasons of differences in the two groups, the meta study suggests that time to refuel and range for low-end BEVs should be improved in order to increase chances of drivers continuing with BEV ownership.

A Dutch internet-based questionnaire study [8.78], conducted among a large Dutch sample (n=2974) drawn from a commercial panel (*Panel Inzicht*) during June 2012 stratified to be representative of the Dutch population overall, gathered data including on individual evaluations of various attributes of electric cars, the likelihood of adopting a full electric car, and the adoption stage regarding innovative cars. Participants first indicated which adopter segment, then read a brief description of BEVs and subsequently filled out a questionnaire including questions of the attributes of an electric car, and two indicators reflecting adoption likelihood (interest in an electric car, and intention to buy an electric car). The results revealed that potential adopters of innovative cars evaluated the attributes of BEVs, but not the instrumental and environmental attributes, more favourably than later adopters. Evaluations of these BEV car attributes predicted the adoption likelihood of potential early and later adopters in a similar way. However, potential earlier adopters' evaluations of symbolic attributes predicted their interest (but not their intention to purchase) in a BEV more strongly when they perceived more instrumental drawbacks. Apparently, instrumental drawbacks, typical in the introduction stage of innovative technology, are not only a barrier for earlier adopters, but can enhance interest in a BEV because of what the car can say about the users. According to [8.78], this suggests that attributes of sustainable innovations should be stressed as this is likely to promote adoption.

As for Norway, in 2013 the new vehicle market share of electric vehicles was 5.8%, and 80% of those were owned by private users. [8.79] explore some possible explanations to the Norwegian development by detailing the electro-mobility story, the incentives provided and the attitudes amongst users. Overall, they point to a long lasting positive re-enforcing interaction between private enterprises, public authorities and non-governmental organisations combined with a taxation system that allows authorities to influence the opportunity to influence vehicle purchase via compensating for some of the purchasing price differences related to BEVs and thus marketing of those BEVs (which have been sold at a much higher rate in Norway than in any comparable country) with new models coming on-stream with continued economic incentives for now. Positive environmental effects of EVs are taken for granted, since some 96% of Norwegian electricity is produced from renewable sources. Norway also differs, other than from Denmark, with its automotive tax system which heavily taxed cars, The tax is progressive, resulting in extremely high taxes for an luxury vehicles, and is levied on four components: engine power, weight, CO_2 and NOX emissions, plus at VAT tax of 25% of the value of the car at the point of sale (not registration).

Automotive ownership and use are subject to several taxes: a) fuel tax; b) vehicle purchase tax including VAT; c) annual registration tax; d) road tax; e) scrap deposit tax; and f) income tax on company cars. Based on low costs of electricity in Norway (2014 figures), a BEV driving 15,000 km and consuming 3,000 kwh/year would have costed Norwegian consumers 276 Euros/year less than the average EU27 consumer, contributing to a more rapid diffusion of EVS in Norway. The Norwegian incentives for EVs (both fiscal incentives, direct subsidies, fuel cost savings and others such as free toll roads, reduced rates on ferries, access to bus lanes, free parking, and financial support for charging stations) have been added one at a time until the market finally responded with increased sales. Furthermore, Norwegian consumers are aware of early test phase vehicles (1970-1990) with attempts to commercialise Norwegian- (and Danish) made BEVs, with enterprises and organisations as the first users. An early market phase (1999-2009) was related to US (Ford) Foreign Direct Investment in the Norwegian BEV production, though later pulling out, and with second-hand French EVS filling the demand from 1998-2002, with the main BEV market in the greater Oslo region. The market introduction phase (2009-2012) started with a new, revised Norwegian BEV model. These were outcompeted, to the point of bankruptcy, by Mitsubishi, Peugeot, Citroen and Nissan launching their BEVs in 2010/11, resulting in a huge increase in dealerships selling BEVs. The Norwegian BEV market expanded rapidly to about 3% of new vehicle sales at the end of 2012 and the first half of 2013. Impatient investors and a price competition resulting in rapidly falling prices contributed to bankruptcy among Norwegian BEV manufacturers. The Norwegian EV Association (NEVA) was also important since the test phase in lobbying government to effect incentives, supporting their members in their BEV use, facilitated knowledge transfer between and to users. A governmental agency, Transnova, was also established in 2009 as a tool to support testing and demonstration of new GHG reduction technologies, and tit supported the establishment of charging stations on a larger scale financially. Transnova also supports 'GreenCar/Gronn bill', an organisation supporting promoting EV usage in municipalities and fleets, and originating from the energy sector (Energy Norway) and the Norwegian Association of local and Regional Authorities.

A recent survey of 3,400 BEV owners in Norway provides some insights into the role of incentives for promoting BEVs in Norway, and what incentives are critical for influencing buying decisions of BEVs and what groups of buyers respond to what types of incentives. Results by [8.80] show that exemptions from purchase tax and VAT are critical incentives for more than 80% of their respondents, in line with previous research. Suggesting that up-front price reduction (a combined exemption of both purchase tax and VAT stated as critical by 66% of respondents) is the most powerful incentive in promoting EV adoption. To a substantial number of BEV owners in Norway, however, exemption from rad tolling or bus lane access is the only decisive factor. Income is a less prominent predictor than age, gender (reduced fix costs sated as more critical by men, and also by respondents above 45 years of age) and education (with incentives that reduce use costs more likely to influence respondents with a college / university degree, and those living in or near the city of Trondheim), probably reflecting the competitive price of BEVs in the Norwegian market. The model shows that responding to priority incentives (access to bus lanes) is more likely in respondents with an elementary education and respondents living in neighbouring communities to Oslo, bus less so men, respondents older than 45 years, and respondents with low incomes, Tesla owners and respondents having bought their BEV within the last year of the survey. There is an assumed relation between the incentives and the character of transport systems the respondents engage in.

8.5. *Summary*

The available literature shows that the current policies for EVs in the early days of the EV market are generally supportive, though some energy policies might have an indirect adverse influence on EV adoption. EVs are shown to be considerably better to the environment when compared with conventional ICE vehicles, though there are some adverse impacts, particularly associated with batteries. The preference studies carried out show the critical impact of financial incentives, environmental policies and technical development on the attitude of the potential EV adopters, the degree of which depends on the socio-economic, socio-geographical, educational, income and property type of the survey participants. It can be also be seen that some policies in some countries have been favouring PHEVs more than BEVs, though this has begun to change more recently.

Alhough the policies, mentioned in this chapter, are either supportive or potentially discouraging, they could all influence the buying decision of people in respect of EVs to some extent; there has not been a holistic picture that consider all the factors. By integrating EVs into a smart grid with local renewables, the SEEV4-City project investigates how these different factors affect the results in an economic and ecological way, under various OPs scales with different types of EV users. The results will be provided to policy makers as guidelines to help achieve a sustainable increase in EV adoption.

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9. Data Acquisition and Analysis

The global target of decarbonisation, together with the prospect of limited (or finite) fossil fuel, has led to the extensive research and development of the Electric Vehicles (EV), Renewable Energy sources (RES) and smart grid technology over the past decades. As the EV uptake starts to kick off, one common issue of energy mismatch appears for the home charging EVs, i.e. EV charging creates energy demand peak when renewable production (from rooftop PV) is low but renewable energy production peaks when charging demand is low. This results in EVs not being charging on renewable energy sources and high grid investments needed for electric vehicle charging. These limitations restrict the type of service the EV can effectively provide. Furthermore, from the viewpoint of EVs, the EVs now in use have five interrelated areas which limit their acceptance: (1) Limited driving range; (2) Long refuelling (charging) time; (3) Short battery cycle lives; and (4) high costs to replace the battery.

EV and RES improvements can be accomplished in many interrelated ways, two of which are:

1. **Advanced manufacturing technologies to reduce the manufacturing and ownership costs.** Development of advanced manufacturing technologies requires considerable time and capital before production. Business models defines how users, service providers and operators interact with each other to create and capture value from product or service offerings, with particular attention to how they their activities with partners and suppliers are configured and how value are delivered to a customer [9.2].

2. **Development of innovative business model and restructuring the EV-RES-Grid system in a way to improve the operation efficiency and reduced usage costs.** Business model innovation often makes the difference between innovations that are successfully commercialised, vs. those that stay on the shelf [9.2] [9.3]. Different business models that commercialise the same technology can yield different outcomes. A good business model may be just as valuable as a good new technology, and "a mediocre technology pursued within a great business model may be more valuable than a great technology exploited via a mediocre business model." [9.4] However, in the emerging EV industry, a number of these elements of the business model are still unclear: the value proposition, the target customer segment, and the relationships and roles within the value network.

The second approach (business model innovation) is particularly interesting from the perspective of both users and service providers. Compared to the manufacturing technologies, business innovation-based EV-RES-Grid improvement can be achieved at lowest R&D investment and implemented faster. A good business model, once synthesized and verified, is used to promote the gains resulting from new technology.

However, synthesis and verification of a business model requires actual measurement from a running EV, RES systems and grids in order to show that model prediction follow the behaviour of actual systems under varying operation conditions and scenarios. The introduction of ICT in electricity networks is the primary enabler of these new business models at the interface of energy and private transport sectors. It is expected that advanced ICT systems can turn these existing barriers and the negative side effects of EV and RES into chances for future zero emission electrical vehicle expansion [9.5]. ICT-enabled data acquisition and telematics system have become a research focus in recent years. There is an increasing demand for remote monitoring and diagnostic system as the further research of EV, RES and grid go on. ICT and data acquisition will add synergy and harmonic interplay to the building blocks of the business model of EV-RES-Grid such that the problems of today's technologies can be mitigated and eventually solved. The role of ICT and data acquisition can be summarized as promoting the EVs and improving the EV-RES-Grid operating efficiencies:

- By providing aware, caring and robust means of power and energy routing between EVs, RESs and Grids;
- By applying data-driven business model optimization to EVs, RESs and Grids;

- By guiding the users, EV/RES owners, service providers and grid operators to a new level of energy-aware behaviours.

The rest of this the state-of-the-art reviewi of data acquisition technologies is organized as follows: An overview of data acquisition for SEEV4-City is presented together with related work. The first section reviews the data acquisition technologies, including technologies of on-board data loggers, retrieving public sources or deriving from pilot data log. Section 9.2 reviews the database technologies and platforms for data sharing among partners and compares the state-of the-art of data analysis technologies; Section 9.3 is an example of the existing data acquisition and analysis system. The following research questions need to be addressed:

- Which data needs to be collected from the OPs to feed the business and energy models?
- What is the data collection method that should be adopted in order to meet the objectives for SEEV4City and how is the data collection system built?
- How should the data be accessed and interfaced with the models?

This chapter will focus on a very practical and crucial part of SEEV4-City because the business and energy models and their results depend on what kind of data can be collected and how to access it.

9.1. ***Data acquisition***

9.1.1. Overview of data acquisition

ICT and data acquisition technologies have been well understood as an innovation to improve the efficiency of EVs, RESs and Grid operations. Many projects have been carried out in the last two decades. For example, the European project ICT4EVEU [9.6], studied the deployment of an innovative set of ICT services for electric vehicles (EV) in different and complementary pilots across Europe. The report [9.5] submitted to the European Commission's Directorate-General for Communications Networks, Content and Technology (DGCONNECT) AEA analyses the conditions preventing electric vehicles being deployed more early in Europe. Four cross-cutting impacts have been identified: industrial competitiveness, value creation/growth, market development and sustainability. The report [9.7] provides an insight into the benefits, technological challenges and the role of ICT for Fully Electric Vehicles, and depicts a roadmap for industrially driven research in the EV sector. An overview of the projects resulting from the first three calls for proposals under this objective was summarized. Among particularly considered issues are hurdles in terms of research, development and commercialization of the enabling ICT architectures for smart EVs, as well as environmental and the socio-economic assessments of EVs.

In the ICT-enabled integration of renewable energy with grids, several related projects have been identified.

GREEN2STORE [6] (Germany, 11/2012 – 10/2016): Integrative usage of storage capacity in the 'Cloud' for developing renewable energies. The project aimed to ensure that a greater proportion of renewable energy generation can be integrated into the distribution networks by the integrative usage of local storage units centrally managed. Various stakeholders along the electricity value chain were involved so as to address technical, industrial, economic and regulatory issues. Demonstrations took place in Lower Saxony and Baden-Württemberg with a network of batteries, managed through the cloud and used by different players.

[6] GREEN2STORE project www.green2store.de

NETFFICIENT [7] (01/2015-12/2018): developed ICT tools to exploit the synergies between the storage units, the smart grid and the consumers. The real-life demonstrations were implemented for different use cases (homes, buildings, and public lighting) in low voltage and medium voltage networks, and for a wide range of applications and functionalities. Viable business models will be defined for the use cases, and recommendations for possible changes in regulations will be made.

RealValue [8] (Realising Value from Local Electricity Markets with Smart Electric Thermal Storage Technology). The project develops a cloud hosted aggregation platform to allow consumer engagement through development of aps and Internet of Things (IOT). The demonstrations, with more than 1250 homes in Germany, Ireland and Latvia (representing 8 MW of installed capacity) showed how local small-scale energy storage, optimised across the EU energy system with advanced ICT, could bring benefits to all market participants.

ELSA [9] (Energy Local Storage Advanced system, 4/2015 – 4/2018). This project implemented and demonstrated an innovative demand-side management solution, integrating low-cost second-life EV Li-ion batteries. The core idea was to consider Storage as a Service towards building and district managers for local energy management optimization, and towards DSO for enhanced network operations. ELSA adapted, built upon, and integrated close-to-mature storage technologies and related ICT-based energy management systems for the management and control of local loads, generation and single or aggregated real or virtual storage resources, including demand response in buildings, districts and distribution grids.

Life Factory Microgrid [10] (07/2014 – 06/2017, Electric vehicles to grid, renewable generation and Zn-Br flow battery to storage in industry). As a demonstration project of the LIFE+ 2013 program, this project's main objective was to demonstrate with the implementation of a full-scale industrial smartgrid that microgrids can become one of the most appropriate solutions for energy generation and management in factories willing to minimize their environmental impact.

These ICT-enabled renewable energy integration and energy storage projects show that small-scale battery storage devices could also be used with efficient ICT technologies for a better integration of RES into grid.

The concept of data acquisition system for SEEV4-City project is illustrated in Figure 9.1-1, which shows (a) the physical interactions between EVs, RESs and Grids through the charging infrastructure; and (b) how the business model to be developed in SEEV4-City is supported by the collected data. As represented by two boxes in the diagram, the whole business model consists of two sub-models: the top one is the high-level business model for energy and stakeholder interaction at different V4ES (Vehicle for Energy Services) scales, namely, V2House, V2Street, V2Neighbourhood and V2City, and the bottom one is the low-level technical model for EVs-RESs-Grid interactions at individual EV level.

The blue boxes in Figure 9.1-1 represents the data required for model implementation and validation purpose. For example, 'grid data' covers the network layout, base load, standard rate of use, network services (with price), power quality; the battery degradation model requires inputs from battery SOC, charging/discharging rate, depth of discharge and battery temperature. More details of data to be collected will be discussed in the following sections.

[7] NETFFICIENT project http://cordis.europa.eu/project/rcn/194443_en.html
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[9] ELSA project http://cordis.europa.eu/project/rcn/194415_en.html
[10] **Life Factory Microgrid project** www.factorymicrogrid.com/en/index.aspx

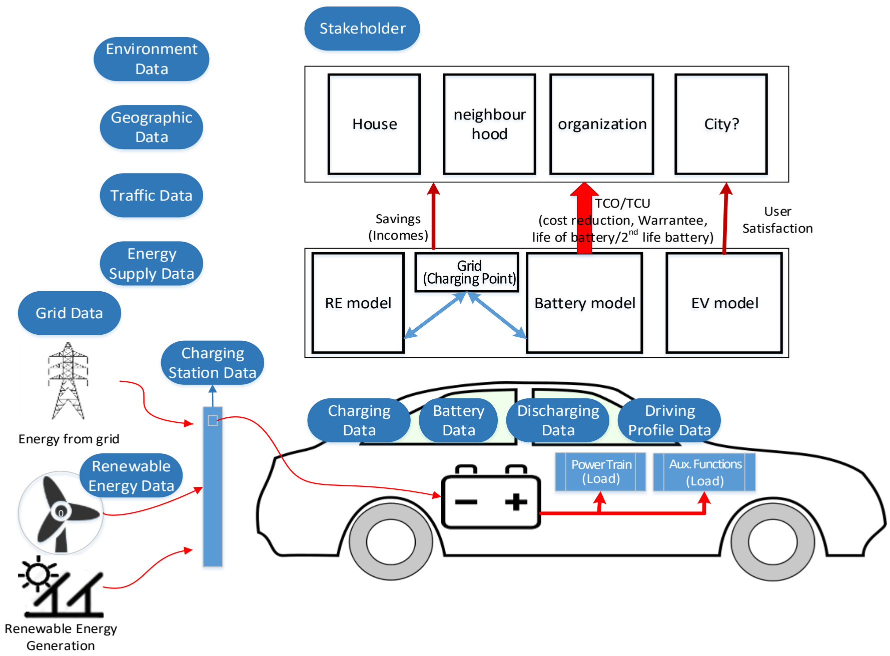

Figure 9.1-1 Concept of data acquisition for SEEV4-City project

The data acquisition is divided into two categories according to the collection method:

- Data to be collected from a logger. This is the first-hand data, is unique and thus will make a key contribution to the SEEV4-City project so that this project will stand out;
- Data may be derived from the data collected by the logger or it can also be retrieved from public sources (e.g. weathers, geographic data, grid's operational metrics and costs, prices, etc.).

9.1.2. Data acquisition by data logger

Data acquisition by data logger technologies has been proven a useful tool for gathering real-world data to develop various models of dynamic systems. Valuable information contained in the collected data are provided to study EV, RES and Grid's conditions. When used jointly with the simulation model, this data is extremely useful in analysing vehicle battery use and performance, aiding in the design of more efficient business model. Many data acquisition technologies have been employed in condition monitoring of EV, RES and Grids. The GPS-aided on-board data acquisition and logging systems have rapidly become one of the more popular methods for collecting real-world operating information of EV, RES and Grids [9.8] [9.9]. A feasibility study of the remote data acquisition system on vehicles was reported in [9.10], in which a data acquisition system was developed to connect the remote centre and the vehicle via the wireless network. The experiments showed that the developed system is able to collect all CAN data frames under the test condition using the six different types of CAN-ID.

Table 9.1-1 lists the data to be collected by using a data logger on the vehicle. These parameters are organized in groups under 'category' and are classified as Essential (E) or Desirable (D). Almost all of these data need continuous recording. The sampling rate for each parameter would be in either 1-minute resolution or event-based intervals. On-board diagnose data loggers are used to record the battery's parameters.

Table 9.1-1: Data acquisition via EV on-board data loggers

Category	Parameters	Importance	Unit	Sampling rate	Available Technology
Battery	State of charge (SOC)	E	%	1 min	OBD
	State of Health (SOH)	E		1 min or EB	OBD
	Battery temperature	D	°C	1 min	OBD
	Ambient temperature	E	°C	1 min	OBD
	Voltage on battery side	E	Volts	1 min or EB	OBD
	Current on battery side	E	Amps	1 min or EB	OBD
	Charging/discharging power on grid side	E	kW	1 min or EB	OBD
	Number of charge/discharge cycles	D	--	Event based	OBD
	Type of V2X support, Desired. The following type of V2X support should be identified and recorded (1) Frequency Support; (2) Direct Power Support (3) Reactive power compensation (4) Power quality improvement (Harmonics Control)			Event based	Customised
Driving info	EV use patterns with vehicle ID	E	--	1 min in driving or event based in other cases	GPS logger

The battery associated data here are required for the battery SOH model construction. The results of the model would ideally be cost of battery per SOC (for both charging and discharging processes), and would thus directly contribute to the business model. SOC is the main data that identifies the energy consumption of the EV (e.g. kilometres driven) and also the exchange of energy with the grid when the EV is parked, whether it is charging or contributing to V4ES. In order to determine the battery degradation model (SOH) and miles driven by an EV, the battery temperature and the ambient temperature are required. SOH may also be provided by the battery monitoring tools. It would be good to have an additional source to measure the SOH parameters, which can be used to validate the SOH model to be developed in this project.

The EV use patterns are essential to track individual vehicles' clean kilometres and the associated CO_2 emission reduction, where vehicle ID is assigned to each monitored vehicle. Both of the clean kilometre achieved and the CO_2 emission reduction from EV usage are calculated from two aspects, i.e. the substitution of the conventional ICE based vehicles from the point of view of transport, and the energy mix for EV charging. In the latter case, the more renewable energy used for the EV charging, the higher amount clean kilometres would be achieved (or more CO_2 emission reduction). These will directly contribute to the OPs as environmental indicators. An example questionnaire of event-based travel survey is the UK national Travel Survey [11], where the time and location were recorded at the beginning and end of each journeys in the time format of HH:MM (equivalent time resolution of 1 min). This survey method was used for the UK national travel survey and the US national household travel survey, and this could be adapted to EV travel survey for the OPs in this project.

Whilst some preliminary results (under controlled environment) are available, these are not conclusive and do not give a good representation of real life EV operational scenarios. The interactions among the factors under different working conditions or battery chemistries are still unclear, e.g. the impact of fast charging/discharging on the battery temperature. The battery related parameters allow for a better

[11] https://www.gov.uk/government/collections/national-travel-survey-statistics

understanding of these facts, and would thus enable the development of a more accurate business model. Unless such a battery degradation model could be provided, we think it is necessary to collect the relevant parameters. Similarly, the usage of 2nd life battery (as storage) would also be transferred into monetary term (here reflected by the requested parameter of 'operational cost'). As for other parameters such as those related to RES and power grid (demand data), they directly interact with the EVs in various V2X scales and they would enable the analysis of business model performance and financial validity check as required by WP 5.3.

Sampling Technologies

A combination of time based and event-based (EB) data logging approach is suggested. Event-based logging method is more effective for actions with a trigger, such as the frequency response (thus frequency response signal), and EV use pattern (see footnote 7). Other parameters such as battery SOC, the grid (with potentially fast response time requirement for network service provision) and RES (with fast variation in generated power, e.g. solar, wind), require a regular recording. Except of in the case of frequency support, a sampling interval of 1 min is suggested to allow accurate tracking of these parameters for realistic business model evaluation. For some parameters, EB data acquisition can be adopted. In the Frequency support mode, the sampling rate may be as high as 1 second. It is desired that the data will be always collected continuously when the car is in use (including driving, charging/discharging). Internal resistance and overall capacity are indicators of battery SOH. In order to determine these and their variation throughout battery life, voltage and current measurements are essential. Charging and discharging power should be measured at the grid side to be differentiated from the battery side measurements due to the non-unity battery efficiency.

On-board diagnostics (OBD) compatible devices have been widely used to collect the vehicle's data for the implementation of vehicle's fault diagnostic and reporting capability. Modern OBD implementations use a standardized digital communications port to provide real-time data in addition to a standardized series of diagnostic trouble codes (DTCs), which allow one to rapidly identify and remedy malfunctions within the vehicle.

Commercial data logger

There have been huge number of manufactures worldwide that make OBD data loggers, such as the one installed on the Nissan Leaf on Loughborough polit[12]. In addition, there are the DAWN OBD Mini Logger by HEM Data [13], [9.11], and the DashDyno SPD by Auterraweb [14] and the AGPtek® Super Mini ELM327 OBDII scanner [9.12], as shown in Figure 9.1-2.

Figure 9.1-2 Commercial OBD-II compatible data acquisition products

[12] https://www.viriciti.com/
[13] http://www.hemdata.com/products/dawn/obd-mini-logger
[14] http://www.auterraweb.com/dashdynopropackgps.html

The data collected by the OBDII data logger can be transmitted to a computer or tablet through a wire link (e.g. a USB-RS232 cable) or wireless link (e.g. Bluetooth, WiFi). Figure 9.1-3 illustrates the wired connection through a USB-RS232 cable.

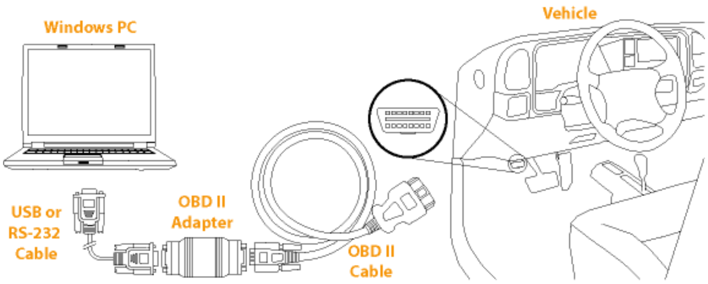

Figure 9.1-3 Connection to a vehicle's OBD interface [9.13].

Typical Features of OBD loggers:

High-end product (DAWN OBD Mini Logger, price > $1495**).** The DAWN mini logger is a compact, low-cost data logger to acquire CAN bus data from cars and light trucks. The logger installation is simple since it snaps directly on the J1962 OBD connector. DAWN comes standard with a generic OBD-II database which defines almost 100 parameters according to the SAE J1979 standard; 40 being available on a typical car. The companion DawnEdit™ software determines which parameters are available on the vehicle to create a unique database for each vehicle model. The user can select which parameters are acquired. Also, the user can add custom messages and parameters in DawnEdit to acquire proprietary messages. The integrated data logger in DashDyno SPD has 2GB storage, which is enough for recording the data for a quite long time. The price for a DAWN OBD Mini Logger including software is $1495. Optional components can also be added to enhance the data logging, for example, GPS at additional cost of $199, WiFi at additional cost of $99 and Cellur+GPS at additional cost of $499. The manufacturer HEM data also provides the battery cell database information, so that all battery-related messages can be captured and interpreted for further processing. Logging during charging depends on if the vehicle responds to OBD requests while charging (assuming the ignition will be off). It depends on the vehicle. This would be a limitation of the vehicle, not the logger if it does not respond to the requests.

Medium-end product (Dyno-Scan, price about $371.99**):** DashDyno SPD is an exciting new in-vehicle mounted device for the automotive enthusiast. It measures instant and average fuel economy, data logs engine sensors and GPS position, measures horsepower and torque, triggers alarms lights, and diagnoses that pesky Check Engine light. Using a PC, watch a synchronized playback of sensor and GPS data with Google Earth flying above the terrain you just travelled. DashDyno can do this and a whole lot more. DashDyno can be handheld or mounted inside a vehicle. A windshield suction cup mount with a quick release feature makes installation a snap. It easily connects to any 1996 or newer vehicle using the OBD II diagnostic port located under the dashboard - no hard wiring is required. The diagnostic port powers the device and offers access to over a hundred different vehicle parameters; such as engine RPM, oxygen sensors, fuel economy, and air-fuel ratio. The associated data collection and analysis software tool Dyno-Scan is also included in the unit price of $371.99. It supports "Europe and UK (gas/petrol) 2000/01 and newer" and "Europe and UK (diesel) 2003/04 and newer".

Low-end product (AGPtek® Super Mini ELM327, price a few US dollars): The AGPtek Super Mini ELM327 is a low-cost product. It is just a compact device converter the CAN interface into a RS232 communication. The reason why it is cheap is because no data analysis software is provided and no technical support either.

Non-commercial data logger

There are also some ongoing projects on developing cost-effective OBD data loggers for monitoring Electrical Vehicles. An on-board diagnostics II autocross/Track data logger for BMWE36M3 is developed at Cornell University [9.14]. In [9.15] an OBD device connecting to the OBDII port in a Nissan Leaf is used to

collect the battery's information and a Bluetooth module is attached to the OBD device to transmit the data to a smartphone. An Android app is created to interface with the Bluetooth module to receive OBD data. Battery pack voltage, battery pack current, motor RPM, and state of charge can be collected. A smart phone-based gadget, 'LeafSpy' [9.16] provides a good example of collecting the various parameters from the manufacturer installed sensors on board and transmitting the real-time reads using an OBDII scanner plugged into the Nissan Leaf's OBD port. A Bluetooth or WiFi connection is used to connect the smart device. Data that can be collected via the OBD interface includes the battery SoC, cell voltage, battery pack temperature, remained kWh, etc.
In [9.17], a remote controller area network bus (CAN-Bus) data monitor and diagnostic system for HEV is presented using on board diagnostic version-II (OBD-II) and Android-based smartphone. It is low-cost, convenient, and extensible with smartphone used in the system to realize communication with ELM327 and a remote monitoring centre wirelessly. The prototype of client and server is developed in Java language, and it is proved by the test that the system works stably and the collected data have practical values.

Comparison between commercial and non-commercial data logger

A commercial data logger is expensive, but is more powerful and combines OBDII interpreter, data logger and data processing tool into one. Commercial products also have after-sales technical support. Although the non-commercial products are much cheaper, but there is a lack of guarantee and technical support, which makes the non-commercial one suitable for budget private users and hobbies.

Table 9.1-2 lists the data to be collected by using a data logger at the premises. In order to evaluate the economic benefit of integration of RES generation with energy storage exchange, the instantaneous RES power generation, the SOC of the energy storage system and the energy supply from the grid need to be measured. Operational cost of storage would contribute to the business model. Optimal coordination among RES generation, energy storage, power grid, EV and the local demand needs to be implemented at each V2X scale, and thus the power demand at each level is required. The stability of the grid has to be monitored as stated by the Loughborough OP Baseline Specification, hence, power quality parameters that represent the stability of the grid such as voltage in a local level and frequency have to be measured and with a good resolution.

Table 9.1-2 Data acquisition via charge station data loggers

Category	Parameters		Unit	Sampling rate	Available Technology
(local) renewable generation and energy storage	PV and/or wind power generation	E	kW	1 min	
	Energy exported to the grid /household import/storage exchange	D	kWh	1 min	
	Energy storage capacity	E	kWh	--	
	Storage state of charge	E	%	1 min	
	Storage operational cost	E	£/kWh	--	
Base demand profiles for households, workplaces and commercial areas	Consumed power	E	kW	1 min	
	Power factor	E	--	1 min	
Grid power quality	Voltage	E	V	1 min	
	Frequency	E	Hz	15 s or faster	

Study [9.18] provides an insight into Information and Communication Technology (ICT) aspects with respect to managed charging of EVs in Smart Grid environments. Based on the use case of managed charging, requirements were analysed and results were derived and ICT solutions was proposed with a set of recommendations for Smart Grid architectures. In [9.19], an ICT-based Solution is proposed for V2G Scenarios by integrating Electric Vehicles in Smart Home. It studies how electric vehicles (EV) can be flexibly integrated into the energy management of a smart home both in forms of consumer loads and electrical storage systems. Based on a draft for ISO 15118, an advanced smart charge communication protocol is developed to enable to flexibly control the charging and discharging processes of an EV in a sophisticated way, so that the domestic load demand and the fluctuating RES supply (e.g. photovoltaic panels or a combined heat and power plant with the energy stored in the battery) are matched. In the EcoGrid EU project, launching a Smart Grid pilot with demonstration on the Danish island of Bornholm [9.20], information and communication technology (ICT) is investigated to collect the data and to monitor and balance the system, and potentially involve individual consumers to deliver demand-response.

9.1.3. Data acquisition by retrieving public sources or deriving from pilot data log

Table 9.1-3 lists the data that is retrieved from public sources, surveys (to be designed) or derived from data recorded in the pilot data log. Wind speed is only required when the wind power generation needs to be considered but not available. Location data determines the grid connection point of EV and hence is crucial. Type of charger refer to single/three phase, uni-/bi-directional charger; charger make indicates the charger manufacturer; charging rate can be 3 kW/7 kW or higher level.

Table 9.1-3 Data from public sources or survey

Category	Parameters	Importance	Unit	Data source
Weather	Wind speed	E	m/s	Public
Charging station/post data	Location	E	--	Public or charging log
	Type/make/rating	E	--	
	Operational/charging cost	E	£/kWh	
Grid service	Standard rate	E	£/kWh	Public
	Energy market trading	E	£/kWh	
Householder/Property archetype needs	User needs description	E	--	Survey
	Expected TCO			
	Expected TCU			
	How many persons			
	Adult / youngster / kids			
	Occupational status of adults			
	Maintenance costs			
	User acceptance			
Stakeholders and higher-level business model	List of stakeholders	E	--	Public
	Infrastructure Investment			
	Regulation (subsidy)			
	Training cost	D	--	
	Insurance			
	Lease			

One of the outcomes as stated by SEEV-4 City Operational Pilot Baseline Data Guidance Document is the social acceptance evaluation, and these variables are essential. For monitoring user acceptance, a group of parameters under the category of 'Householder needs' are requested and listed here, covering various aspects of EV users from the OPs, including economic expectations, user needs description, etc. This would be a result of demonstration for the OPs with various EV implementation scales and would also bring confidence for potential EV users outside the OPs, and thus enable the scalability of EVs for wider deployment as specified in the pilot baseline. To this end, a stated and revealed survey will be provided for the pilot members at the beginning and end of the pilot, respectively.

Furthermore, the participants to the scheme and all the facilities will imply a cost:

- The training that has to be provided in order to implement the business model, and in general V2G, at an organisational or council level requires a cost;
- Insurance for the batteries might be considered for its economic value;
- The council might not or may even even be unlikely to be the owner of the EVs (if leased, for instance, or if they are private EVs) or the chargers, thus, an external company can be assessed to this area and a return can be obtained if considered profitable. The council might, however, provide charging energy for free (or at a low price) under certain conditions and in certain places;
- The investment needed to install the infrastructure has to be considered.

Related work on data acquisition by surrey and information retrieval:

The study [9.21] investigated the collection of social infrastructure data, information-control platforms also have a role in large-scale data analysis (big data). In [9.22], a framework is proposed for collecting attribute-based stated preference data on the acquisition of EVs by Canadian commercial fleet operators. The collected data will serve as an input to advanced discrete choice models that will be used to quantify the determinants of EV fleet vehicle purchases by government agencies and commercial entities. The work in [9.22] proposes a stated-preference approach to generate behavioural data. It employs scenarios with hypothetical, yet probable, situations which are generated through methodical and planned design processes. This allows the individual making the choice (i.e. decision-maker) to compare multiple alternatives encased within a single scenario, each described in terms of varying attributes, and requiring an elicited response from the decision maker. The behavioural data acquired through this method can be used to evaluate the WTP estimates of the modelled decision makers for choosing a specific alternative. Technological advancements in the manufacturing of key EV components, especially the battery components, and the heightened climate change awareness have renewed the public's interest in EV adoption. These advancements have been focused on extending the trip range, lessening the charging time and lowering the capital cost to own an EV. Governments around the globe are supporting policies that encourage the public as well as commercial entities to consider EV adoption on a more substantial scale.

The study in [9.23] examines how the different characteristics of both electric vehicles themselves and the consumers would influence the consumption behaviour on electric vehicles. Data collection is based on the questionnaire design using the orthogonal experimental method and large-scale stated preference survey covering more than 2000 households in 10 central districts of Shanghai. Three types of electric vehicles, i.e. fast charging, battery swapping and slowing charging are investigated according to a set of factors, such as acquisition costs, operation and maintenance costs, charging time and convenience, mileage, preferential policies and so on. They analyse the data with the nested-logit model. Their results suggest that the mode of battery swapping with slowing charging enjoys a relatively higher proportion in Shanghai, though there is no absolutely dominating type. By group classification analysis, the male, the young, the well-educated and the well-paid groups share relatively low proportion of selecting electric vehicles. Furthermore, consumers pay more attention to daily variable usage cost and charging time instead of acquisition costs. All these suggest the necessity for the government to adjust the current supporting policy in order to cultivate the electric vehicle market effectively.

In [9.24] a new estimation technique, namely the Contour Positioning System (CPS), has been proposed for an electric vehicle. The CPS has a better estimation on the electric vehicle battery usage because of the consideration of road elevation, regenerative energy etc. In order to perform the CPS calculation, the elevation profile of the selected destination must be known. In this paper, the technique to extract the elevation profile – i.e. latitude, longitude and altitude – has been performed and evaluated using Google Maps or Google Earth. This method enables the user to obtain the road information and compute the amount of energy needed to reach the said destination.

9.2. *Data analysis: database and tools*

The related projects and studies on databased and cloud technologies for data analysis and sharing EV, RES and Grid data are identified. A report [9.25] provides a comprehensive overview of the applications of a data processing platform for processing the big data in the field of road transport policies in Europe. This developed platform relies on datasets of driving and mobility patterns collected by means of navigation systems. Two datasets from conventional fuel vehicles collected with on-board GPS systems have been used to perform an initial pilot study and develop its core algorithms. Topics covered in are: 1) large-scale mobility statistics, 2) potential of electric vehicles in replacing conventional fuel vehicles and related modal shift, 3) energy demand coming from electric vehicles, 4) smart design of the recharge infrastructure and Vehicle-to-Grid, and 5) real-world driving and evaporative emissions assessment and mapping.

As shown in Figure 9.2-1, a research team [9.26] [9.27] at the Automotive Research & Testing Centre, Taiwan, ROC, developed a EV monitoring system by integrating the mobile communication and GPS technologies. The electric vehicle Monitoring and Service Platform consists of an on-board computer and the monitoring and service centre. The proposed platform consists of modules. Through the OBD interface, the on-board computer collects real-time vehicular data such as vehicle's locations, malfunctions, artery system and power system information. The collected data are digitally processed, encoded, and transmitted to the service centre through 3G mobile network. In addition to collecting real-time vehicular data mentioned above, the service centre displays the vehicle's locations on Google Maps using the GPS coordinates collected, allowing quick access of the development staff to the electric and power system data. When a fault or malfunction is detected, a text message is sent to alert the driver and provide a servicing recommendation, achieving monitoring and service at the same time.

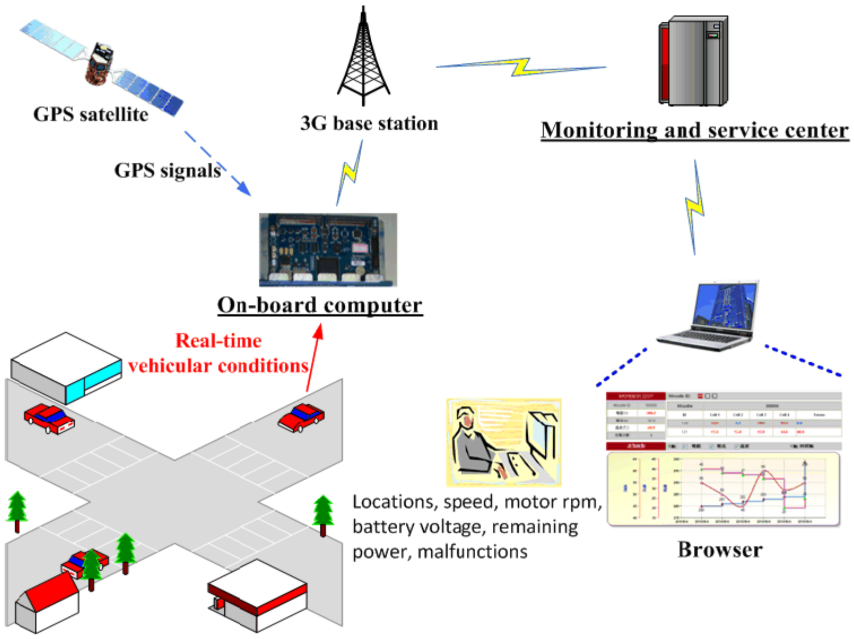

Figure 9.2-1: An example of integrated framework of EV monitoring and service platform [9.26]

In automotive industries and academia, NI's LabVIEW has been widely used for data acquisition, although it doesn't provide direct access to (the) databases. The work presented in [9.28] proposed several methods accessing to (the) databases indirectly in LabVIEW. The proposed technology adopts a user-developed database toolkit LabSQL, and communicates with Microsoft Access Database. General data operation functions of adding, query and deleting are also implemented. Hitachi is currently working on the use of information-control platforms for data collection in projects in Japan and elsewhere, and has plans to add additional functions for utilizing this data. And the Hitachi project [9.21] also investigated the analytical databases for big data analysis involving the collection and analysis of information on electric power, EV use, and equipment operation. This is to provide a means for optimizing the operation of social infrastructure through their use as a platform.

In [9.29], a Microsoft Access database structure was developed to save the data collected from a from a hybrid vehicle battery test equipment, so that the data can be saved in a structured way for better information retrieval and analysis. In addition, Matlab scripts were made with the purpose of user-friendly data processing. In the author's experiments, data was collected from late October 2010 until the beginning of July 2011 without problems.

A data-acquisition and database platform was developed in [9.30] to monitor the operation of charging stations. The platform consists of three parts: data centre, application service system and web service. The platform was deployed inside the charging station, the upper management department can access to the platform through the electric power network. The system uses a typical B/S three-layer architecture over an enterprise or VPN network. The system is developed by using the .NET platform. Each server installs Windows Server 2008 operating system. The database server deploys a SQL Server 2008 and a web server deploys IIS6.0 (Internet Information Services). A two-way wireless communication network based on Zigbee and GPRS technology was developed in [9.31] to provide data acquisition function and ensure the implement of the ordered charging strategy.

9.3. *Example of a data acquisition and analysis system*

This section reviews the present data acquisition and analysis system at the City of Amsterdam SEEV4-City operational pilot as an example of existing data acquisition and analysis system to explain the state of art in the related field.

9.3.1. Overview of Amsterdam's data collection and analysis system

The Municipality of Amsterdam has been running a number of similar projects involving electro-mobility in recent years, and there are two charging Infrastructure providers for Amsterdam: Nuon and Allego. They have already had an ICT system in place for the following purpose:

- Data collection;
- Data analysis;
- Data monitoring and storage.

The data collected at the Municipality of Amsterdam is used for the purpose of:

- Energy modelling: The data collected will be used as an input (parameters) for the Energy model of this project;
- Business modelling: Business models created for this project will require these data as an input for the business model as well. The more reliable the data, the more realistic will the business model be;
- Data Monitoring: Monitoring can be explained as 'to observe and check the progress or quality of (something) over a period of time; keep under systematic review'. One can monitor the number of charge sessions, usage of charging infrastructure, total kWh consumed, and also EV user behaviour, if required.

The data is collected from the Public Charging infrastructure (PCI) in and around Amsterdam. The charging infrastructure has an inbuilt meter to record and display essential information (meter values). On an average, each charging infrastructure system has two sockets. The data is stored in an SQL server - called a data warehouse – in the ICT department, located at HvA.

Figure 9.3-1 indicates which parameters are collected from the Public Charging Infrastructure.

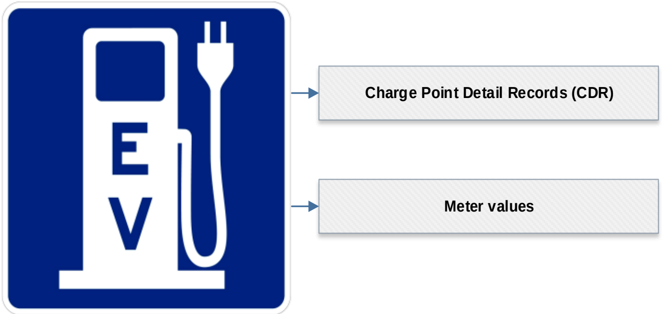

Figure 9.3-1: Nature of charging data – the two formats in which data are collected from the Public charging Infrastructure [9.32]

9.3.2. Data structure

And the data is divided into two sections: Charge Point Detail Records (CDR) and meter values. The CDR: The CDRs contain charging session-level information (Figure 9.3-1 and Table 9.3-1); this information is exchanged between charging infrastructure and electricity service providers, when a user initiates a charging session by using a contactless card. This information is required so as to enable payments to the service provider by the user (client). It must be noted that the HvA data warehouse does not receive any customer information; it only receives a unique passcode (RFID) and in some cases, the contract ID (card number).

The parameters obtained from the CDR is represented in the Table 9.3-1 below**.**

Table 9.3-1: Parameters obtained from the Charge Point Detail Records (CDR) [9.32]

Parameters	Chargepoint Detail Record
CDR_ID	Session ID
Start_datetime	Connection start date
End_datetime	Connection end date
Charge_Start_datetime	Start time of charging
Duration	Connection time of the EV
Volume	kWh (charged)
Charge_Point_Address	
Charge_Point_ZIP	
Charge_Point_City	
Charge_Point_Country	
Charge_Point_Type	
Product _Type	
Tariff_Type	
Authentication_ID	RFID contactless pass
Contract_ID	contract number / RFID by the service provider
Meter_ID	
OBIS_Code	
Charge_Point_ID	Charging pole ID
Service_Provider_ID	Service provider ID
Connection_ID	EAN code
WCD_ID	
Infra_Provider_ID	

Meter values: The meter values provide the kWh consumption of a charging station, recorded every 15 minutes; an example is given in Table 9.3-2. With these values, one can determine how many kWh have been consumed at any given point in time. The meter values are sent each month by some providers; with one provider, HvA has set a REST-server which enables real-time meter readings retrieval by HvA.

Table 9.3-2: Example of values recorded by the meter [9.32]

Meter values		
CDR_ID	**Date & time**	**Meter value**
13421455	2015-01-01 00:52:58.0	……
13421455	2015-01-01 01:57:59.0	……
13421455	2015-01-01 03:02:57.0	……
13421455	2015-01-01 04:07:59.0	……
13421455	2015-01-01 05:13:00.0	……

Thus, in summary, the HvA data warehouse receives information regarding the charging sessions, such as the location (charging pole ID), date of charging, start and end time of charging, the kWh consumed (meter reading), RFID of consumer, service provider, and so on.

9.3.3. Sampling, timing and data resolution

Meter values are collected every 15 minutes, and the cumulative data is made available to HvA on a monthly basis. This means that although the data is recorded every 15 minutes, it is updated in the server only at the end of the month. Thus, the data is real-time but historical (not dynamic). It must be noted that the data warehouse does not receive information from all infrastructure providers, and not every meter value is recorded (due to technological limitations of the meters).

9.3.4. Data access, analysis and privacy

The data can be accessed through a 'code/ R-package [15]' created in R programming language [16] . This package is already available at HvA. Based on the needs of the project (specific research questions), this package can to be modified/customised to access and analyse the data from the data warehouse.

Figure **9.3-2** represents the relationship between the data warehouse and the 'R package' (red coloured area), the significance of the blue region is explained in the next paragraph.

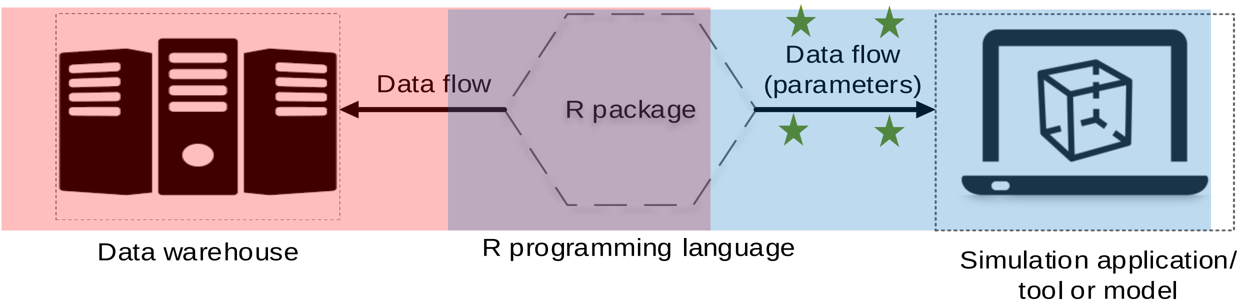

Figure 9.3-2: Accessing data using ' R package' from the Data warehouse [9.32]

This is a concept outline drawn for the City of Amsterdam SEEV4-City Operational Pilot which aims to connect the 'R package' with an energy/business model (in this case, a simulation tool). The simulation tool will be a new addition (blue coloured area) to the existing arrangement (red coloured area) (

Figure **9.3-2**). However, there is one major **restriction** in achieving this.

- The restriction is that, the nature **(format)** of the data **(parameters)** going into the 'R package' will not be of the same nature **(format)** that is coming out of the 'R package'. In simple terms, parameters that are fed into the R package (from data warehouse) will be analysed and represented merely in a graphical format (for example: Graphs, tables, figures etc.); the output of the R package will not be of any nature (format) resembling to the parameters shown in Table 9.3-1. At the moment, the R package is used merely for data analysis and not for data fetching and delivering as it is to the planned simulation tool. All the analyses happen within the R package. This is simply because of privacy and security reasons.
- However, for the planned energy and business models (the blue coloured region), we may need inputs/parameters that are similar **(format wise)** to parameters as shown in Table 9.3-1. Consequently, the major challenge now is to identify solutions to this **restriction** before proceeding with the modelling of the planned energy and business models.

It is worth pointing out the following restricts and regulations to use the data base:

- Common users, like HvA, are not allowed to store the data locally, we do not have the permission to do so. For privacy reasons, the data is kept in-house. We can only access the data via the R package;
- However, users have the flexibility to sort/simplify/ customize the search/retrieval criteria to obtain desired output. For example, if we only need user IDs of the cars having battery capacity of more than 50 kW. Users have the flexibility to sort, filter and simplify the data retrieval process

[15] **Packages** are collections of **R** functions, data, and compiled code in a well-defined format. The directory where **packages** are stored is called the library. **R** comes with a standard set of **packages**.

[16] **R** is an open source programming language and software environment for statistical computing and graphics that is supported by the **R** Foundation for Statistical Computing. The **R** language is widely used among statisticians and data miners for developing statistical software and data analysis.

from the data warehouse. The R script developed determines this functionality;

- As such, there is no particular limitation to accessing the database. The number of users of the data ware house is determined by the project requirement. As the data has to be accessed/handled directly from a server, the computational time can fluctuate depending on the complexity of the task allocated to it (the server);
- Once again, it must be mentioned that real-time dynamic data cannot be used during the simulation, since the database is only updated every month (which means we will use the historic (recorded) data of the previous months);
- Using the available data from the data warehouse, we have to first analyse the data and represent it in a manner that is instructive/informative. Some of the parameters that can be monitored are as follows:
    - Total KWh charged;
    - Number of charging sessions;
    - Connection time;
    - Connection time versus kWh;
    - Connection time based on dates.

For example, using the above information, the municipalities will be able to determine the rollout of charging stations for the coming years.

9.3.5. Data access protocol

Any access and use of data from the data warehouse requires legal and explicit permission from the Municipality of Amsterdam. Figure 9.3-3 will explain the nature of the collaboration between HvA and the municipality of Amsterdam.

The companies responsible for the charging infrastructure (Nuon and Allego, in the case of Amsterdam) collect the data and send it to the HvA data warehouse. HvA stores the information in the data warehouse, but the Municipality of Amsterdam is the owner. The data is updated every month, and available directly only to the Municipality.

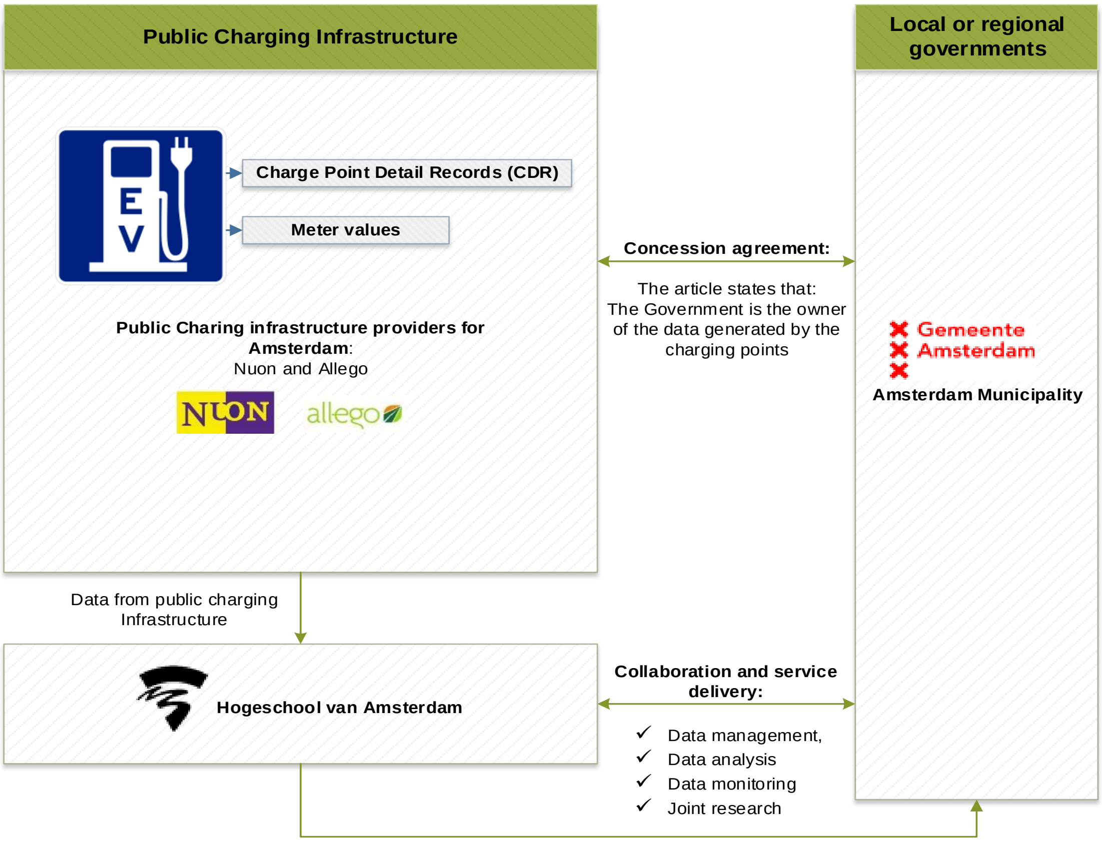

Figure 9.3-3: Collaboration between the municipality of Amsterdam, charging infrastructure providers and HvA for data acquisition and analysis [9.32]

9.4. *Summary*

In conclusion, there is already a system in place to collect, analyse and store EV charging-related data for Amsterdam via HvA. The data is stored in a data warehouse. Various parameters that are collected are shown in Table 9.3-1 and Table 9.3-2 and the presented categories are: battery, driving info, renewable generation and energy storage, base demand profiles for households, workplaces and commercial areas and grid power quality to be collected from loggers. Other information that includes weather, charging station/post data, grid services, householder and property archetype needs have to be collected from publicly available information. The involved stakeholders also need to be clearly defined. The parameters can be used in the energy & business models created for SEEV4-City; this also gives us the opportunity to monitor certain Key Performance Indicators (KPIs) by analysing this data. All data are collected in a 15-minute interval and cumulatively available only at the end of the month. This is a drawback, as it limits us from performing real-time dynamic simulation as the inputs are nearly a month old. The R package is used to access the data warehouse and necessary permission has to be obtained from the municipality before accessing the data warehouse. For SEEV4-City, one of the biggest challenges would be to create a simulation tool/energy model or business model that can link with this data warehouse seamlessly to perform simulations as desired. An example of a data collection system and how this is interfaced with the models that will be developed has been provided. It must be noted that, as of now, R language is proposed as an intermediary between the data warehouse and the simulation tool; this is subject to change, based on further deliberations with SEEV4-City knowledge and pilot partners. Moreover, the data warehouse does not receive information from all infrastructure providers, and not every meter value is recorded (due to technological limitations of the meters) – the SEEV4-City project can investigate these issues, and provide appropriate solutions.

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10. System Modelling and Optimization

This chapter focuses on the following points:

1. Energy and/or power models that have been developed over the years to analyse/evaluate and develop (alternative or new) energy systems;
2. Energy models that are available for others to model transition scenarios for projects and policy development;
3. Model-based system evaluation and optimisation.

We are especially dealing with models that combine supply and demand analysis of systems containing more than one technology (EV, PV, Energy storage and electricity gird).

Scopes for SEEV4-City

For the SEEV4-City project, we concentrate on several geographical levels of analysis:

- Pilot level;
- Regional / national level.

And different stages:

- Current situation (say 2017 - base case);
- In period of 5, 10, 20, 30 years or within policy timelines like 2020, 2030, 2050 with different scenarios.

Also, the pilots deal with fluctuating power sources (mainly PV), fluctuating demand (household and EV) and storage (EV battery). This means we need to model on timescales of an hour or even less to evaluate its performance.

The research questions that need to be answered with the energy/power modelling are:

- For the operational pilot evaluations (related to operation optimisation):
    - Is the pilot running with highest possible energy autonomy? (technologies such as PV, battery, electrical demand, and a grid connection need to be included for the given pilot lay-out);
    - Is highest energy autonomy achieved with un-controlled, smart charging, or V2G?
    - Which strategy (un-controlled, smart charging, or V2G) has lowest CO_2 emission?
    - What is the grid lay-out, does it need reinforcement and at which level? (LV, MV, HV, transformers, lines) with un-controlled, smart charging, or V2G?
    - What are the investments, operational costs and benefits that are related to these control strategies?
    - From business case evaluation, it can be derived that some technology parameters influence the business case on a large extend. If this is true, we must identify these parameters in the business model to be able to integrate with the energy/power model. For example, parameters of battery degradation;
    - Some policy options may not be suitable to model in these tools.
- From a pilot on a local scale, to regional level, it is necessary that we create scenarios forecasting the future, i.e. what will be the answers to the above questions?
- On a national level, we also need to create a market-model (load dispatch and planning) to formulate a transition scenario for all demand sectors. Importantly, to satisfy as best is possibleall

the imperative questions mentioned above. On regional and national level, what strategy gives the lowest CO_2 emission and lowest societal costs?

These questions are related to both energy flows and power (capacity) issues, and in some cases, there is a need to investigate power quality under grid impact analyses.

At this stage, we did not consider the following criteria (which may be relevant for SEEV4-City:

- Costs of the 'software tool for modelling';
- Availability of software/tools to all project partners;
- Is it an open platform/ open source?
- Representation/Communication (how is the output presented?).

This chapter is organised as follows: the existing tools for scenario modelling for local, regional, or national level is discussed, followed by modelling the pilots in the current situation. Then the model-based system evaluation and optimisation technology is reviewed. Finally, ca onclusion is drawn to see if the SEEV4-City project can use existing tools or there is the need a different approach.

10.1. ***Energy/power modelling tools***

To evaluate existing energy modelling tools, we follow the analysis and reasoning provided by [10.1] where an overview is given of commercial or public models often used for policy design, like PRIMES for the EU, or energyPRO, HOMER for other projects. In all simulation tools both an energy and economic evaluation can be done. For an comprehensive overview, we refer to [10.1] and [10.2]. Energy supply technologies in these models are mostly treated as black boxes with input and output energy & power flows and with a fixed efficiency.

As the questions raised in the SEEV4-City project are very specific technology (PV, EV and storage) related questions, a bottom up (or hybrid) model - that start from detailed energy technology and sectoral descriptions as opposed to a more macro-economic approach -seems most logical (see [10.2] and [10.3] for a discussion on this).

Since the SEEV4-City project is part of a transition towards 100% renewable systems where electrification of sectors plays a large role, we also find it important that for analysis beyond the pilot scale, more sectors (if not all) are involved in the analysis.

Although it can be argued that an approach involving only the electricity system can suffice for SEEV4-City, this must then be able to include household and EV demand, distributed electricity supply (PV) and electricity storage at the LV network level and a grid representation at least in some form of nodes and lines. As a review by [10.2] shows, most long-term energy models have a more aggregated approach and are less able to evaluate the questions coming from distributed energy systems and storage at LV or MV level. A more project-oriented model as HOMER seems to be able to include this more accurately, even up to regional scale [10.2]. Some related projects and models are reviewed as follows.

10.1.1. Energy PRO

EnergyPRO [10.4] is a modelling software package for combined techno-economic design, analysis, and optimisation, of both fossil and bio-fuelled cogeneration and trigeneration projects as well as wind power and other types of complex energy-projects. In EnergyPRO EVs and batteries can be modelled on a basic functional level as part of different strategies, such as V2G. A pricing strategy may be used to compare different operational modes. Interconnection and transmission analysis is included in the Region module of energyPRO. Battery degradation is not allowed for in energyPRO.

In energyPRO virtually any type of energy system can be modelled. Besides the many predefined production units, such as CHP, solar collectors, heat pumps, absorption chiller, etc., it is also possible set up user defined units. The flexible configuration allows you to model any type of technology from simple input/output models to very complex function-based models.

In energyPRO performing a large range of different energy system analyses can be carried out. Amongst other things the software enables you to: calculate the optimal operation of an energy plant; Make detailed investment analyses; Set up operation budgets for energy plants; Model industrial cogeneration and trigeneration; Simulate energy plants participating on different electricity markets; Conduct feasibility studies; Analyze the interaction between separate energy plants; Define a strategic energy plan.

10.1.2. HOMER

HOMER [10.5], a proprietary micropower optimization model, can help to design off-grid and grid-connected systems. It is able to perform analyses to explore a wide range of design questions such as: Which technologies are most cost-effective? What size should components be? What happens to the project's economics if costs or loads change? Is the renewable resource adequate? HOMER's optimization and sensitivity analysis capabilities helps to answer these questions.

HOMER is able to determine the least cost combination of components that meet electrical and thermal loads. HOMER can run through many system configurations, optimizing for lifecycle cost, and tabulating the results of sensitivity analyses.

The HOMER model was originally developed by the NREL in the USA. The model is designed to simulate all current low power technologies individually and in various combinations to minimise total discounted cost providing for given energy requirements. To use the tool, one enters the costs and performance characteristics of the chosen equipment, the load profile, and any available renewable resources plus energy storage facilities.

The tool can produce load and resource profiles by making energy balance calculations for all 8760 hours of the year from typical daily load profiles and averages for expected solar irradiance. Sensitivity analyses can be performed, causing the model to carry out repeated optimizations as it varies one or more of the input variables. For systems that include batteries or fuel-powered generators, HOMER also decides for each hour how to operate the generators and whether to charge or discharge the batteries. If the system meets the loads for the entire year, HOMER estimates the lifecycle cost of the system, accounting for the capital, replacement, operation and maintenance, fuel and interest costs. One may view hourly energy flows for each component as well as annual cost and performance summaries. After simulating all of the possible system configurations, HOMER displays a list of feasible systems, sorted by lifecycle cost. One can easily find the least cost system at the top of the list, or you can scan the list for other feasible systems.

Of particular interest to this project, HOMER contains a 'Modified Kinetic Battery Model' which gives the ability to model several relevant battery phenomena: Rate-dependent losses; Decreasing performance as the component degrades; Reduced capacity at cold temperatures; Cycle lifetime with depth of discharge (DOD); Increased degradation rate at high temperatures. In order to model decreasing performance of a storage device as it degrades over its lifetime, the Multi-Year Module is also required. Normally, HOMER simulates only a single year, and then extrapolates to calculate economics over an entire project lifetime. This makes HOMER fast and powerful for optimizing system architecture, but it assumes that every year will be exactly like the first one. The Multi-Year Module allows simulation all years in a project lifetime explicitly. This software will be useful in our project.

10.1.3. EnergyPLAN

EnergyPlan [10.6] is used to analyze the energy, environmental, and economic impact of various energy strategies. The key objective is to model a variety of options so that they can be compared with one another, rather than model one 'optimum' solution based on defined pre-conditions. Using this methodology, it is possible to illustrate a palette of options for the energy system, rather than one core solution. Furthermore, the aim of EnergyPLAN is to model the 'finishing point' of the energy system rather than the starting point. The focus is placed on the future energy system and how that will operate, rather than on today's energy system. Therefore, EnergyPLAN includes relatively detailed modelling of future technologies such as biomass gasification and synthetic fuels, but relatively aggregated modelling of today's technologies such as power plants. The focus is on the future rather than the present. EnergyPLAN is a deterministic model which optimizes the operation of a given energy system on the basis of inputs and outputs defined by the user. In the input, electricity for transport is divided into three options. The one is specifying a fixed electricity demand. The two other options are smart charge BEV and V2G. In both cases, the model seeks to minimise the business-economic costs of buying electricity in order to meet the annual demands. Moreover, in the V2G case, the model seeks to optimise the business-economic profit from buying and selling electricity to the grid on the basis of fluctuations in the market price.

The main purpose of the model is to assist the design of national energy planning strategies on the basis of technical and economic analyses of the consequences of different national energy systems and investments. EnergyPLAN simulates the operation of national energy systems on an hourly basis, including the electricity, heating, cooling, industry, and transport sectors. The model has also been applied to the European level as well as to a local level such as towns and/or municipalities, with a focus on the interaction between combined heat and power production (CHP) and fluctuating renewable energy sources. Moreover, the model emphasises the synergies of including the whole energy system and, through the various versions, the model includes a wide range of technologies with a focus on analysing the interaction between the electricity, gas, district heating and cooling grids.

The model is an input/output model. General inputs are demands, renewable energy sources, energy plant capacities, costs and a number of optional different simulation strategies emphasising import/export and excess electricity production. Outputs are energy balances and resulting annual productions, fuel consumption, import/exports and total costs including income from the exchange of electricity.

10.1.4. GAIA

Gaia LV Network Design [10.7] is a commercial software package for planning the most economical low voltage distribution network. Based on pre-conditions like cables costs, preferred cable types, cost of losses, loads and maximum allowed voltage drop, the program calculates the right cables for the most economical network. In other words, the total investment and operational costs are minimized. Further, Gaia LV Network Design evaluates short-circuit withstand, power quality and contact safety. The cable types are suggested by the optimization routine, taking into account the time frame, transformer tap setting and requirements concerning voltage quality, short-circuit withstand and contact safety. Unbalanced networks can be modelled. Gaia LV Network Design is designed to ensure contact safety in both TT- and TN-earthed networks. The program evaluates all neutral and sheath currents and voltages in the event of a phase-to-earth fault in the network – taking the effects of all protection devices into account. The contact safety is the result of a low contact voltage and a short exposure duration. Power quality can be assessed in terms of the voltage level and frequently occurring voltage dips. The voltage level is calculated using a stochastic load flow, evaluating expected mean values and expected extremes. The calculation is based on a full unbalanced network model. The voltage dip analysis evaluates the sensitivity for switching large loads, both balanced and unbalanced. Short-circuit analysis determines the adequacy of the network to withstand severe faults. As designed, the programme has no direct application to calculating the economics of EV use with or without renewables.

10.1.5. DigSilent Power Factory

PowerFactory by DigSilent [10.8] can model large interconnected power systems. It can be applied to any AC or DC network topology and support the simulation of new technologies such as converter-based power generation, FACTS, voltage-sourced converters (VSC), HVDC cables and overhead lines, DC breakers, filters, and various types of MW- and MVar-controllers and virtual power plants. PowerFactory is also perfectly suited to transmission system operation planning. It integrates a comprehensive set of tools to support automatic and parallel grid safety analysis such as ENTSO-E D2CF/DACF/IDCF, and outage planning.

At the distribution level, PowerFactory provides comprehensive modelling features for studying all kinds of electrical networks with different phasing technologies, meshed or radial topologies and railway supply systems connected to public distribution systems. In order to reduce network unbalance, improve quality of supply and optimise distribution networks, PowerFactory offers a large variety of functions, such as multi-phase load flow analysis, short-circuit analysis (IEC 60909, ANSI C37 and multiple fault analysis), harmonic analysis, quasi dynamic simulation, time-domain simulation, optimal power restoration and reliability assessment. Other standard features include the modelling of distributed generation and virtual power plants, voltage drop analysis, consideration of LV load diversity, daily load and generation profiles and easy-to-use protection coordination. Tie open point optimisation Optimal capacitor placement Voltage profile optimisation for bi-directional power flows Geographic diagrams (GPS-based) with background maps GIS and SCADA integration

At the industrial level, Models of generators, governors (steam, gas, diesel, water), automatic voltage regulators (AVRs) and power system stabilisers (PSSs), Voltage dependent PQ capability curves, models of motors, protection relays, power electronic converters and DC equipment. The software can carry out calculation of short-circuit currents in AC grids according to IEC 60909 (VDE 0102) and ANSI in DC auxiliary supply grids according to IEC 61660 and ANSI/IEEE 946 Stability and EMT simulation. Modelling can be done for system behaviour during short-circuits and load changes. The software can model frequency control transient stability sub synchronous resonances and transformer inrush.

In conclusion, this software could be very useful for technical analysis of power networks, but will not address the economic aspects of our project.

10.1.6. Software selection

In Table 10.1-1 we summarize the criteria set up for the SEEV4city project per category and list the models that fulfil all the criteria. From [10.1], the more extensive overview provided on EnergyPLAN, and without our own SEEV4-City experience we made this table from a list of over 25 energy/power simulation models.

Table 10.1-1 Criteria for the software selection [10.1]

		Pilot	Regional scenario's	National scenario's
Criteria	**Time scale**	Hour	Hour	Hour
	Project/region/national	Project	Regional	National
	Demand sectors	Buildings+transport	Regional	All
	Supply options	Local PV+grid	Regional options+grid	All
	Storage	At LV / MV level	At LV / MV level	At all network levels
	Battery degradation or other specifics coming from business model Fast charging			
	Network analysis	Local	General	General
	Energy market modelling	None	Electricity market simulation	Electricity market simulation
	Strategies for charging	Included	Included	Included
	Costs / benefits	Included	Included	Included
Models	**From Lund (2014)** [10.1]	energyPRO HOMER	EnergyPlan HOMER	EnergyPlan Ramses (Nordic countries)
			EMT	EMT

In all models, scenarios on the time development of demand and supply must be created separately (scenario development). This is often done from the literature (using other scenarios as reference) such as policy studies or market development studies from organisations/institutes such as the IEA or national institutes like PBL (The Netherlands).

On the cost side, it is relevant that an investment and O&M cost database is updated regularly or can be adapted and is referenced, since costs can be specific per project or region/country and change over time. All models in the table include investments and OM costs.

Models discussed here focus on societal costs or project costs. Questions related to business modelling from different stakeholder's perspective is discussed. For example, if willingness to pay is needed, a more agent based or goal seeking approach is often used.

On a project level, both energyPRO and Homer seem suited (they are both licenced software tools).

The models listed in the table above can fulfil all criteria. Another option is to use separate models per sub-system and combine outputs. This is often done with, for example, energy prices. They are either coming from a separate model or from literature. Also, the grid modelling is often done in a separate model like for example GAIA LV network design (from Phase-to-Phase) and is used by Dutch network operators (DSO). In this model full coverage of renewables, heat pumps and small-scale storage is not included. However, this can lower the consistency of values used with energy system modelled when the same parameters can not be used in both models.

Table 10.1-2 and Table 10.1-3 provide an overview on software packages that can be used to model a local electricity grid on specific network issues (steady state and dynamic analysis, harmonics, etc.) and an example of evaluation matrix. Table 10.1-2 lists the existing open source software (OSS) for power system analyses, covering power flow or optimal power flow on LV or/and MV levels, AC and DC systems, with static and dynamic analysis. Additional modelling features include distributed generation integration (e.g. OpenDSS), wholesale power system market modelling (e.g. AMES), and potential industry applications (e.g. InterPSS). These features address most of the criteria listed above for energy and system modelling. Although these OSSs are free and open source, some of them run on software which requires a license, such as those Matlab based ones. At this stage, it is not investigated how and if these software packages can model loads, PV, or storage option on LV or MV level.

Table 10.1-2 : Existing OSS for power system analyses [10.9]

Name	Language	Purpose	Interface	License
UWPFLOW	C	Continuation power flow	UNIX-like command line	Open license
TEFTS	C	Transient stability	UNIX-like command line	Open license
MatPower	MATLAB	Optimal power flow	MATLAB functions	Open license
PSAT	MATLAB, GNU Octave, Perl	Static and dynamic stability analysis	MATLAB GUIs and Simulink	GNU GPL
VST	MATLAB	Voltage stability	MATLAB GUIs	Open license
InterPSS	Java	Power system analysis for industry applications	Java GUI	GNU GPL
AMES	Java	Whole sale power markets	Java command line	GNU GPL
DCOPFJ	Java	Dc optimal power flow	Java command line	GNU GPL
Pylon	Python	Dc and ac power flow and dc optimal power flow	Graphviz and Chaco	GNU GPL
OpenDSS	Delphi	Distribution system planning	Delphi GUIs	BSD license

Table 10.1-3 Evaluation criteria for modelling software

Packages	Steady State Analysis	Dynamic Analysis	Stability Analysis	Harmonics Analysis	Fault level Calculation	Protection analysis (Coordination)	Ease of fault current limiter modelling	Ease of creating new Model	Ease of interfacing with hardware	Post processing analysis	Control Elements
Spreadsheet	OK	Not Available	Not Available	Not Available	OK	Not Available	Not Available	Not Available	Not Available	Poor	Not Available
ATP-EMTP	Good	OK	OK	OK	Good	Poor	Poor	OK	Poor	OK	Poor
PSCAD-EMTDC	Good	OK	OK	OK	Good	OK	OK	OK	OK	OK	OK
MATLAB	Good	Good	Good	Good	Good	Not Available	Good	Good	Good	Good	Good
Simplorer	Good	Good	OK	Good	Good	Not Available	Good	Good	Good	Good	OK
ERACS	Good	Poor	OK	OK	Good	Good	Not Available	Not Available	Not Available	Poor	Not Available
IPSA	Good	Poor	OK	OK	Good	Good	Poor	OK	Poor	Poor	Poor
Eurostag	Good	OK	OK	OK	Good	Good	OK	OK	OK	OK	OK

Good
OK
Poor
Not Available

To conclude, several existing models can be used for scenario studies on regional and national level for SEEV4City. ETM [10.10] can be used for the Netherlands and the UK and EnergyPlan can be used for all countries. For the pilot level scenario simulation, HOMER and energyPRO seem to be suited.

10.2. *Modelling the pilots in the current situation*

As mentioned above, the requirements for the modelling of the pilots in the current situation are met by HOMER and energyPRO. However, they have built in strategies for using EV battery as storage which do not give full flexibility and therefore may not be suited. Also, there may not be enough flexibility to define the technologies like the battery (degradation).

Besides modelling, we also want to compare the results with the analysis of data provided by the pilots on the CO_2 reduction, the energy autonomy and grid investment reduction compared to a reference.

This can be done in several ways:

a) Compare simulation results with calculations from pilot data;
b) Use pilot data as input for simulation.

Option a) is always possible, but to be able to do b) models need to be able to use input data on energy flows of the pilot. Both energyPRO and HOMER can import time series of loads on an hourly basis.

As a test case, we look at the Flexpower project conducted in Amsterdam, which is a first step of the smart charging case in the SEEV4-City project. In this project, fast charging is provided in a fixed timeframe (in this case coinciding with high demand period). This situation cannot be simulated in energyPRO, or HOMER. Both fast charging and a fixed timeframe cannot be included [10.11]

So, in conclusion existing simulation tools for energy systems cannot simulate all the cases in the pilots. Thus, we will follow a different route and construct a suite of models that can interact, accept input form pilot data or other models, and can simulate all pilot cases. As discussed before, we must make sure models are consistent.

The regional and national models (ETM and or EnergyPlan) can be used as inputs on pricing in the pilot evaluation or for other parameters outside the modelling scope.

10.2.1. Conceptual energy model for SEEV4-City

Table 10.2-1, Table 10.2-2, Table 10.2-3 and Table 10.2-4 present the conceptual energy model for the SEEV4City project. A modular approach is adopted to realise the objectives of the energy model and this is graphically illustrated in Figure 10.2-1.

By adopting this modular approach, it is possible to clearly represent and understand (making it less complex) each step of the energy model. The flow of I/O between each module is represented in red lines. Each module contains parameters that can either be an input or an output for other modules or within the module. Parameters are divided into two categories (essential and desirable), based on the importance for the primary objectives of the energy module.

There are 4 modules within the energy model and they are as follows:

1. Parameter module

The parameter module contains sub-modules, and they are:

Electric vehicle

Under the electric vehicle parameter module, these are some of the inputs that are essential from the Electric vehicle and EVSE. Almost all desired parameter can be obtained from EVSE; this is dealt with in greater detail in Chapter 9,

Table 10.2-1: Inputs related to EV and EVSE for the energy model

Submodule	Inputs required	Parameters	Unit	Resolution	Parameter category
Electric vehicle & Charging infrastructure	EVSE data (from charging point operator)	RFID – user ID	-	-	E
		EV type	-	-	D
		User driving pattern	-	-	E
		Battery capacity	kWh	-	E
		Start & end time of charging	t	1-5 mins	E
		Parking time	min	-	E
		Energy charged	kW	1-5 mins	E
		Charging location	-	-	E
		Charging rate	kW	1-5 mins	E
	EV battery data (from EVSE)	State of charge (SOC)	%	1-5 mins	E
		Battery current	I	1-5 mins	E
		Battery voltage	V	1-5 mins	E
		Charge/discharge cycle	-	-	D

Photovoltaic System

Table 10.2-2: Inputs related to PV for the energy model

Submodule	Inputs required	Parameters	unit	Resolution	Parameter category
Photovoltaic system	PV characteristics	Number of panels	-	-	E
		Efficiency	-	-	D
		PV power generation profiles	kWh	1-5 mins	E
		PV location	-	-	E

Electricity grid

Table 10.2-3: Inputs related to the electricity grid for the energy model

Submodule	Inputs required	Parameters	Unit	Resolution	Parameter category
Electricity grid	Grid characteristics	Topology	-	-	E
		Power system components (Transformers & Cables)	-	-	E
		Voltage levels	V	1-5 mins	E
		Frequency	Hz	15 s or faster	E
		Power levels	kW	-	E
		Power factor	-		E

Miscellaneous

Table 10.2-4: Miscellaneous inputs for the energy model

Submodule	Inputs required	Parameters	unit	Resolution	Parameter category
Miscellaneous	Energy storage (at the location)	Energy storage capacity	kWh	-	E
		State of charge (SOC)	%	1-5 mins	E
		Battery current	I	1-5 mins	E
		Battery voltage	V	1-5 mins	E
		Charge/discharge cycle	-	-	D
	Property/household	Location	-	1 min	E
		Seasonal load profiles	kWh	1-5 mins	E
		Property archetype	-	-	-

2. Data analysis module

The Data Analysis module receives information from the various sub-modules of the parameter module. The function of the module is to inspect, cleanse, and transform the collected information to provide relevant information for decision-making.

The output of the Data Analysis module will be sent to the Optimisation module for further analysis.

Optimisation module

It consists of the Energy Management System, which is capable of forecasting PV power production and optimizing power flows between the PV system, EVs and residential loads.

The data received from the Data Analysis module will be processed based on certain objective functions and constraints. Appropriate optimization techniques will be employed to:

- Maximize the number of EVs charged with PV energy;
- Reduce the impacts of EV charging on the power grid;
- Minimize the cost of charging EVs from the grid;
- Provide appropriate V2G ancillary services to the grid;
- Reduce emissions, and increase clean kilometers.

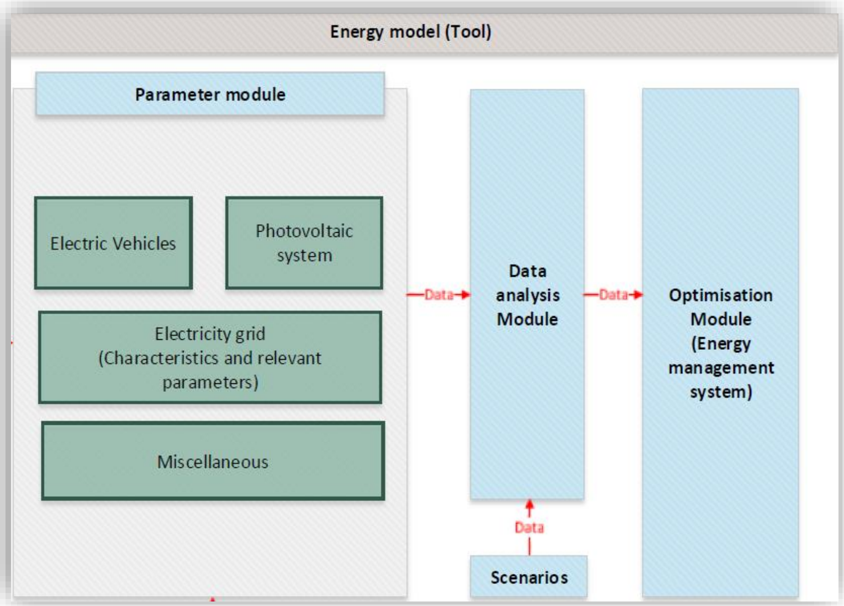

Figure 10.2-1 Conceptual Energy model for SEEV4City

Scenario module

This module consists of various scenarios and cases framed for each pilot for the future (until 2030). These scenarios will be compared with the Base case of each SEEV4-City operational pilot (2017). The objective of this module is to forecast the possible impacts of growth in population, EVs and PVs, on the electricity grid and recommend possible solutions.

10.3. *System modelling example*

In recent research funded by project partner CENEX UK [10.12] [10.13], work was carried out to create a platform from which to evaluate the investment opportunity of Vehicle-to-Grid in a local services case study for future energy scenarios, using data acquired with a view to studying V2G. As such, a MATLAB simulation was created to ascertain the economic benefit accruing to the owners of buildings and EVs owners if they implement V2G. The simulation created can model most types of situation arising from varying parameters for buildings, EVs, PV or market demand for power. Various energy scenarios were explored within the model including evaluating building peak shaving, tariff demand reduction, PV demand shifting and energy market provision. The model could estimate infrastructure provision requirements and related costs by variation of the number of vehicles within the model.

Once the MATLAB model was created and verified, it could then be used to analyse the economics of V2G for a local services case study under various future energy scenarios. The developed model was capable of handling much information related to V2G energy support scenarios. It is known as the Vehicle-to-Grid Feasibility Analysis Environment (V2GFAE) and can be used to quantify benefits arising from the use of EVs for energy storage.

The V2GFAE takes data relating to variables such as buildings, vehicles and energy markets to evaluate the economic return and viability of V2G within in a local services context for various energy scenarios. The developed model allows for considering six different energy scenarios for EV battery utilisation for building demand reduction and also power market support. One may specify or calculate the number of EVs for which would be required for building support and then analyse grid support options including peak shaving, tariff support, load shifting using PV, provision of short-term operating reserve (STOR) and capacity market support with wholesale market trading.

The industrial sponsor of the work [10.12] was CENEX UK, who wished to provide consultancy services for customers requiring evaluating the suitability of their EV fleet and /or buildings for potential provision of V2G services. The modelling tool created in [10.12] enables the study of the investment opportunities for V2G as managed by a Virtual Power Plant (VPP) within a local services scenario under various future energy scenarios. The economic return is assessed in terms of two key performance indicators; firstly, the anticipated local economic savings involving clusters of buildings using the techniques of peak shaving, time of use tariff support and PV charging integration; and secondly the suitability of EVs with V2G capability to provide power for STOR and to enter the Capacity Market. By separately defining these two areas the model can quantify the suitability of EVs for provision of electrical support to buildings within a local network, such as a street of houses or an industrial park. In addition, the suitability of the same EVs aggregated by a VPP to provide power for energy markets can be independently assessed. The model allows one to find the best application for the EVs within the energy environment being explored. This information is shown in a context diagram in Figure 10.3-1.

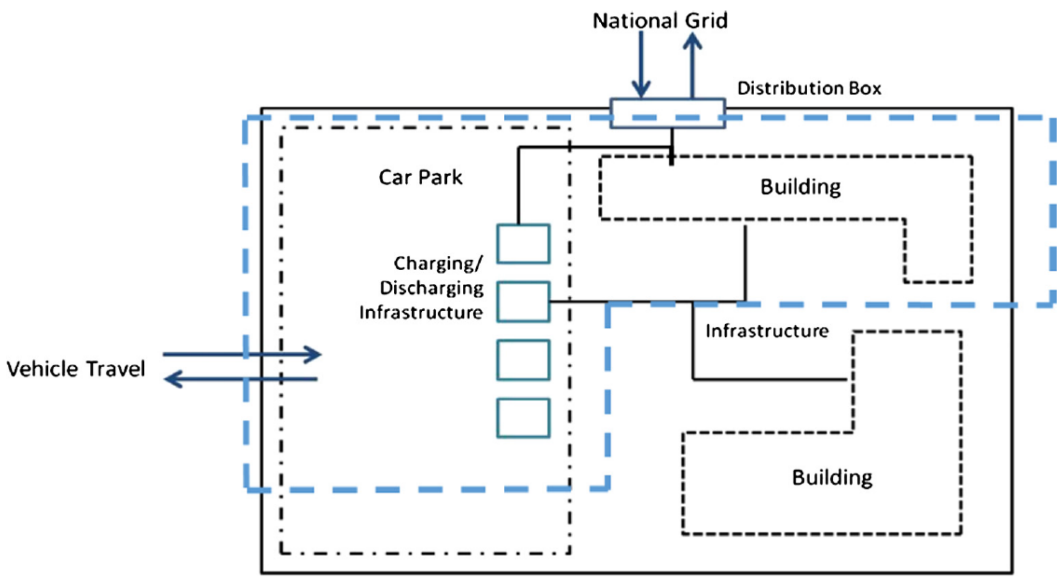

Figure 10.3-1: V2GFAE context diagram [10.12]

As mentioned, the V2GFAE software can model scenarios relating to the use of V2G with buildings, EVs, PV and energy markets. The output of the model comprises a report detailing the assumptions made in terms of the specified technical and cost related variables, and the resulting estimate for economic viability for the scenario being considered. The management of this is conducted through a central control strategy that links inputs for buildings, EVs, PV and market models to the evaluation scenarios.

The Model Elements used in [10.12] are as follows:

- **Control Strategy** - The management of the simulation is conducted through a central control strategy that links inputs for buildings, EVs, PV and market models to the evaluation scenarios. The control strategy is the overarching model that enables the user to select which energy scenario they wish to evaluate. The control system must consider multiple actors (vehicles, energy markets, buildings and economics) to produce outputs based upon the optimisation criteria.
- **Vehicle Model** – This simulates the vehicle information including battery capacity and usage profiles. It also provides demand profiles (charging and usage) and availability profiles (when the vehicle is available for discharging to support either the grid or a building). V2G information includes the rate of charge and discharge of the vehicle batteries and its efficiency based upon the rates of charge/ discharge.
- **Building Model** – This includes information relating to demand profiles and economic information. The control system will use the information to establish how the building deficit should be met (if demand exceeds generation) or used (if generation exceeds demand) and income generated from V2G provision.
- **PV Model** – This model provides a PV generation curve specific to the building being evaluated.
- **Market Model** – This model gives information on the demand profile of STOR and the capacity market to simulate energy provision requirements of the vehicles simulated.
- **Cost Model** – Two functions are performed by this model; a) assessment of the costs associated with the vehicles providing V2G services to either buildings or through the simulated energy markets and b) evaluating the savings made by the building through deployment of EVs with V2G. Savings to buildings are calculated with and without infrastructure costs, as well as the degradation cost to the vehicle in providing V2G services. VPP income for market trading scenarios is also calculated to establish which scenario has the greatest economic benefit. Figure 10.3-2 presents the operational requirements of V2GFAE.

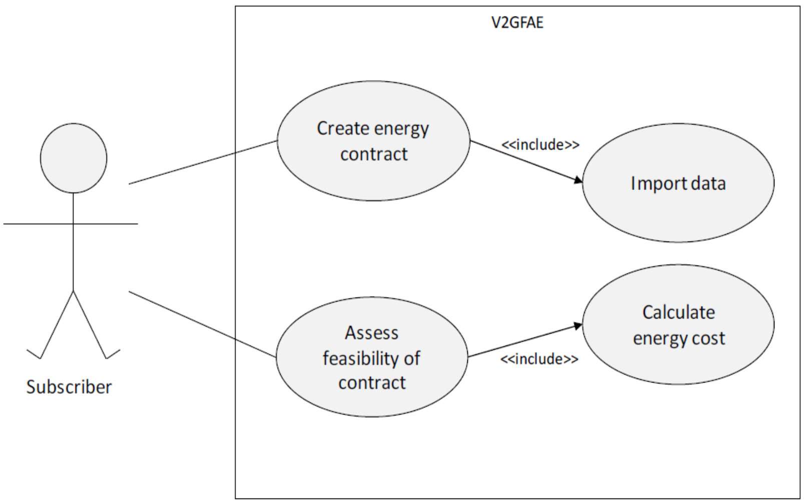

Figure 10.3-2: V2GFAE operational requirement [10.12]

The control strategy enables selection of the energy scenario and the number of vehicles to feed information into the building, vehicle and market models. If a PV related scenario is selected, the building model sends a control signal to the PV model, which provides generation information to the building model, to calculate the new building demand profile. The vehicle model uses the arrival and departure, journey and charge /discharge information to create a vehicle charge and discharge profile which is then provided to either the building or market model. These provide feedback to the vehicle model to indicate if the required limit has been reached or if another iteration is required. Once the conditions of the building or market model have been satisfied, the information is passed into the cost model, where financial information relating to the selected scenario is evaluated and output into a report format. A diagram of the interrelationships between the various sub models forming the overall structure is given in Figure 10.3-3.

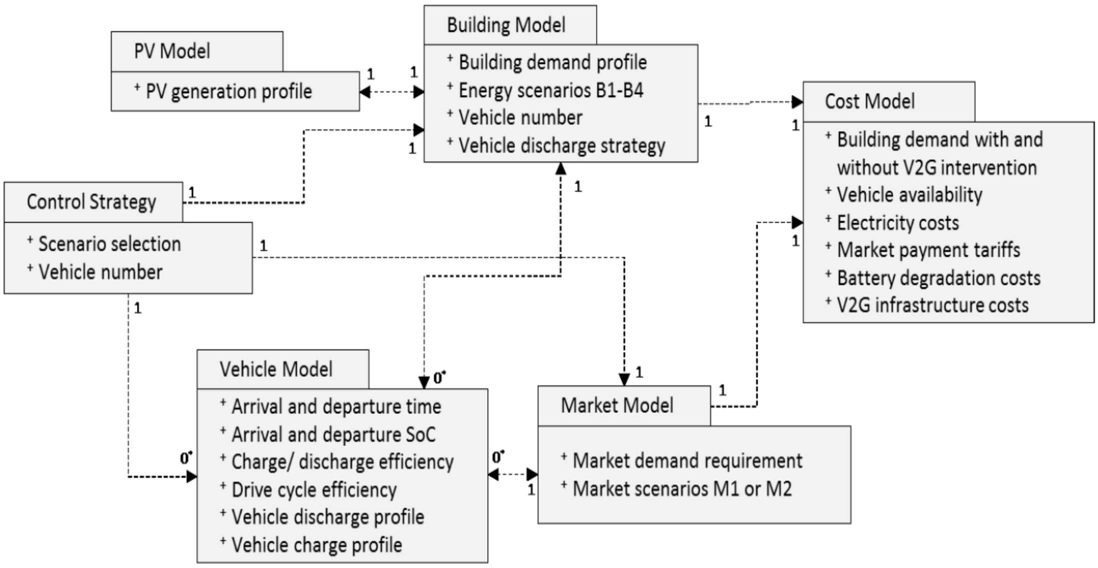

Figure 10.3-3: V2GFAE class diagram [10.12]

Highly useful model outputs are obtained, such as in Figure 10.3-4 in which energy savings obtainable from V2G are predicted.

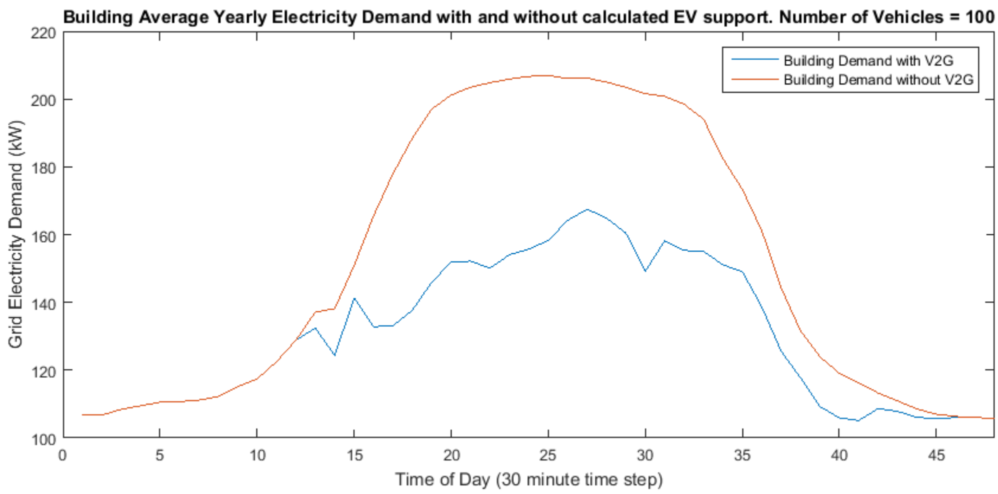

Figure 10.3-4: Building energy savings using V2G [10.12]

This work possesses considerable synergy with the work done at UNN on Battery Degradation. The modelling described in [10.12] and [10.13] do not take into account the effect of the various interventions modelled on battery SOH, and is assuming that the battery has variable DOD and a fixed capacity. As a result, the financial outcomes predicted by the model [10.12] may be made more accurate if the UNN work feeds into it.

10.4. *Optimization techniques and tools*

Once a model is developed, optimisation technologies can be adopted to maximise both the economic and environmental benefits to EV, RES, house/building owners and grid operators. Considering the complexity of the interaction among EV, chargers, RES, grid, building demands, users, owners, service provides, operators and governors, optimal operation is achieved by various modelling and optimisation methods at various level, including optimized battery and EV usage, optimised charging profile, optimized RES integration, optimized energy autonomy and optimized grid operation. The battery life and usage can be optimized by adopting advanced smart charging and discharging methods, such as the globally optimal scheduling scheme and a locally optimal scheduling scheme for EV charging and discharging [10.14]. Optimising EV usage for personal users and business organizers (e.g. EV fleet) [10.15] is investigated as the known Vehicle Routing Problem (VRP) and various optimisation methods have been proposed, such as capacitated VRP, time-windowed VRP and Multi-attribute VRPs. Optimal charging for EV fleets was studied by linear approximation and quadratic Approximation methods to recued the charging costs [10.15]. In the business model level, non-cooperative game theory is applied to minimise their costs converge to a Nash equilibrium [10.17] [10.18].

10.4.1. Smart charging optimization

Charging are usually modelled as the product of electricity price and the amount of electricity drawn; another type of cost due to battery aging is more difficult to model. Fast battery aging will lower the payback of an EV customer, since the cost of Li-ion batteries comprises a significant percentage of today's EV prices. Therefore, battery aging is an important factor that should be taken into consideration when design coordinated charging.

10.4.2. V2G optimization

Optimising V2G operation is to achieve objectives of flattening loads [10.19], minimizing electricity cost [10.14] [10.20], maximizing overall welfare [10.21] etc.

(1) Flattening loads is to flatten the load fluctuation caused by uncertain EV charging demands, while managing to fulfil these charging demands. The common optimization objectives consist of minimizing the aggregated loads, minimizing load variances, minimizing energy costs for charging EVs, etc. Below are two kinds of load flattening objective function:

1. Minimizing the aggregated loads over a certain time horizon;
2. Minimizing load variance.

For the first objective, [10.19] solve this problem with gradient projection. This is extended with probability distribution for all potential feasible charging profiles. For the second objective, two online heuristic approaches are separately proposed. Instantaneous information can be utilized to make a 'myopic' decision at each time step, and implement the allocation only for current step. The variance of the loads is minimized within the rest of the time horizon at each time slot, then the allocation of charging power is implemented through a Model Predictive Control (MPC) approach.

In the literature, no models have taken battery aging into consideration.

10.4.3. Communication framework in EV charging optimization

In general, whenever an EV on the road requires charging (contribution from route optimization), it needs to communicate with the grid or other third party who is interested in charging management, in order to be aware of its charging plan. The setting of EV charging use case in smart grid also introduces some unique security challenges, e.g. in public smart charging of EVs, where the sudden availability of charge details introduces a new incentive for attacks. This requires a design of more secure, resilient, scalable, and flexible than conventional information systems.

As reviewed by a recent survey [10.22], fruitful literature works have addressed 'charging scheduling' via regulating the EV charging, such as minimizing peak load/cost, flattening aggregated demands or reducing frequency fluctuations. In recent few years, the 'CS-selection' problem has gained interest from industrial communities thanks to the popularity of EVs. This cannot be overlooked as it is the most important feature of a vehicle in future smart city, especially for fast charging. The works in [10.23] [10.24] implement charging plans for all EVs based on the minimized queuing time at the CS, outperforms that considering the distance to the CS, and particularly the former scheme achieves a shorter charging waiting time given high EVs density. In [10.25], the CS with a higher capability to accept EVs' charging requests will advertise this service with a higher frequency. While EVs sense this service with a decreasing function of their current battery level, means that a frequent sensing is required given low electricity status. The pricing [10.26] can be considered for business model. Further to these, enabling the EV's charging reservation [10.27] is brought into system, in order to further improve performance.

The communication is essential for information exchange within the charging on-the-move. [10.29] proposes a Publish/Subscribe (P/S) enabled communication mode, in which different stakeholders in the ecosystem (e.g. EVs, CSs and the centralized controller implementing charging management) can exchange information based on dedicated topics depending on their interest for information subscription, instead of relying on the conventional point-to-point communication system. Also, due to decoupling between publishers and subscribers through the P/S paradigm, the end-to-end connections between CSs and EVs are avoided. As a result, the system benefits from scalability (i.e. the number of connections at CS sides does not depend on the number of EVs) and efficiency (i.e. fast connection establishment and reduced bandwidth usage), as the benefits of P/S based communication between CSs and EVs against point-to-point communication. The Intelligent Transportation System (ITS) supported fixed entities, such as Road Side Units (RSUs) has been deployed to enable the task.

Furthermore, it is known that Vehicular Ad hoc NETworks (VANETs) have been still receiving attention, primarily due to their potential in various applications, ranging from road safety and ITSs to on-board Internet access. Up to now, new mechanisms have been proposed for reducing the information dissemination delay and improving the reliability for data transfer, via either Vehicle-to-Infrastructure (V2I) or Vehicle-to-Vehicle (V2V) communication. In comparison, the V2I communication requires additional cost to deploy and maintain stationary infrastructures, and in particular it is limited in terms of practicality and stability to deploy the stationary infrastructure on every intersection in VANETs. In real city scenario, many intersections do not have to be with stationary infrastructures, and some of them such as RSUs are generally located on road sides rather than at intersections. Particularly, how to optimally deploy stationary RSUs is very rigid and inflexible. Instead, because of the mobility bringing more communication opportunity, the V2V communication is a more flexible and viable alternative in near future, which enables real-time exchange of basic, anonymous based speed/location information, and provides crash avoidance capability between vehicles, buses and even pedestrians, motorcycles etc. A mobility aware framework by enabling the public transportation bus has been proposed in [10.29] to behave the information broker for EVs on-the-move, deemed as a much flexible framework than [10.28].

10.5. ***Summary***

In this chapter, the criteria for the selection of software for modelling purposes to allow energy modelling with existing models as well as optimization processes have been discussed. The available software, such as Energy PRO, HOMER, EnergyPLAN, GAIA, DigSilent Power Factory and ETM, have been considered. Energy PRO allows techno-economic and design analysis and optimisation; for instance, the optimal operation of an energy plant or investment analysis can be assessed.

HOMER can develop power optimization models and undertake cost optimization and lifecycle analysis. Both are suitable for project level analysis. EnergyPLAN allows evaluating energy, environmental and economic impacts of energy strategies, it is ideal for future technologies while it lacks some abilities in dealing with current technologies. It is suitable when the aim is to design national energy planning strategies. GAIA allows calculation of the economy of low voltage networks. DigSilent Power Factory can represent distributed generation, large and industrial networks. Software like EnergyPLAN is appropriate for national level analysis, whereas EnergyPLAN and ETM are suitable at a regional level. Whilst ETM can be adopted for The Netherlands and the UK, EnergyPLAN can be used for any other country.

Each software package presented in this chapter has pros and cons and it is not possible to carry out all the analysis required in this project with a single product, i.e. some compromises in terms of different scales need to be made. The final decision will depend on the requirements and boundaries of the OPs. The possibility of dividing a large model into a number of sub models should be considered, because in this way different parts can be singularly modelled. The idea of the energy model has been presented: a parameter module that defines the proper energy models of the different parts of the system, a data analysis module that feeds the data mentioned in Chapter 9 into the model and the optimization part that considers different scenarios and objective. According to these, the correct combination of the involved variables may be decided.

A model currently available within the project consortium has also been presented and discussed. It models the parts of the system according to the data available and assesses cost-benefit analysis for different scenarios. Although this work is compatible with SEEV4-City, it lacks the accurate evaluation of battery degradation. In conclusion, different software packages can be employed in order to implement the model structure provided in this chapter and an example in Matlab is already available. The considerations from the previous chapter must be merged in the aforementioned structure and combined with compatible data and implemented in a simulation environment to develop energy and business models for SEEV4-City.

10.6. ***References***

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