Summary of the State-of-the-Art report

Authors:

Ghanim Putrus, Richard Kotter, Yue Wang, Ridoy Das, Geoff Obrien, Xuewu Dai, Edward Bentley and Yue Cao (University of Northumbria at Newcastle - UNN),

Renee Heller and Ramesh Prateek (Amsterdam University of Applied Sciences - HvA),

Becky Gough (Cenex)

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This is a working document and is subject to continuous changes

TABLE OF CONTENTS

BEV	Battery electric vehicle
BM	Balancing mechanism
CAN	Communication area network
CAPEX	Capital expenditure
CFD	Contract for difference
CPF	Carbon price floor
CPO	Charging point operator
DNO	Distribution network operator
DOD	Depth of discharge
DOE	Department of energy
DSM	Demand side management
DSO	Distribution system operator
EEA	European economic area
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
FCDM	Frequency control by demand management
FCR	Frequency containment reserve
FIT	Feed-in Tariff
ICE	Internal combustion engine
ICT	Information and communication technology
LCOE	Levelised cost of electricity
LVN	Low Voltage Network
NSR	North Sea Region
O&M	Operation and management
OBD	On-board diagnostics
OEM	Original equipment manufacturer
OCPP	Open charge point protocol
OP	Operational pilot
OPEX	Operating expenditure
OSCP	Open smart charging protocol
PCR	Primary control reserve
PHEV	Plug-in hybrid electric vehicle
PV	Photovoltaic
RE	Renewable energy
RES	Renewable energy source
SOC	Sate of charge
SOH	State of health
STOR	Short time operating reserve
SUMEP	Sustainable urban mobility and energy plan
TCO/TCU	Total cost of ownership / Use
TOU	Time-of-use
TSO	Transmission system operator
V4ES	Vehicle for energy service

1. Introduction

This report summarizes the state-of-the-art on plug-in and full battery electric vehicles (EVs), smart charging and vehicle to grid (V2G) charging. This is in relation to the technology development, the role of EVs in CO_2 reduction, their impact on the energy system as a whole, plus potential business models, services and policies to further promote the use of EV smart charging and V2G, relevant to the SEEV4-City project. EVs are a cleaner alternative to conventional internal combustion engine (ICE) vehicles, for the following reasons:

(i) Environmental improvements: CO_2 emission reduction, air pollution reduction, noise level reduction [1];

(ii) Increased energy autonomy given by smart charging (SC) and V2G and the possibility of achieving network stress alleviation (i.e. reduced need for grid infrastructure reinforcement which may be needed for high EV penetration but with appropriate SC and V2G this can be avoided with consequent cost savings) [2];

(iii) Higher efficiency both as a better transportation system and with a lower global carbon footprint than ICE based vehicles, particularly when EVs are charged from renewable energy sources (RES) [3, 4].

The North Sea Region (NSR) is at the forefront in the adoption of both EVs and RES. Increasing numbers of EVs and the amount of energy produced from RES creates a challenge, which is to match the increasing production of renewable energy and the growing energy demand for EV charging. When properly executed, it can mitigate CO_2 emissions, increase clean kilometres driven and result in less impact on the grid, which may consequently reduce otherwise needed grid investments, increase the matching of energy demand-supply and improve energy autonomy.

The implementation of Smart Charging (where the timing of EV charging is controlled to benefit network operation), V2G (where EVs are used as energy stores, enabling a better balance to be achieved between energy supply and demand) and the other ‘ancillary’ services they can provide are collectively known as ‘Vehicle4Energy Services’ or V4ES.

The main aim of SEEV4-City is to develop this concept into sustainable (commercially and socially viable) business models to integrate EVs and renewable energy in a Sustainable Urban Mobility and Energy Plan (SUMEP).

According to [5], Sustainable Urban Mobility Plan (SUMP) is defined as “a strategic plan designed to satisfy the mobility needs of people and businesses in cities and their surroundings for a better quality of life. It builds on existing planning practices and takes due consideration of integration, participation and evaluation principles”. On top of this, the electrification of transportation brings challenges and opportunities to the new picture of mobility plan, i.e. SUMEP, which SEEV4-City project will address. Both plans share the same aim of a safe, environmentally sustainable and cost-effective transportation to all citizens, with SUMEP being more capable of achieving these aims by integrating the energy from EV batteries into the electricity network. Smart integration of the charging/discharging energy into the current and future energy network is key to the success of SUMEP, as well as user acceptability and participation. Under the SUMEP framework, approaches can be developed to coordinate the energy between EVs and local renewables, or to provide power network services by gathering energy from the battery of EVs. This allows an integrated, sustainable and cost-effective mobility and energy plan to be achieved, and encourages user participation (and therefore ownership) at the same time.

In SEEV4-City, smart charging is applied by coordinating EV charging demand with the varying output of locally generated renewable energy, with the aim of minimising grid impacts and battery degradation, whilst maximising energy autonomy and economic benefits. Along with smart charging, the concept of using EVs as energy storage via V2G will be translated into operational, real-life, pilots in cities.

The pilots have different operational environments and levels of smart charging or V2G integration: Vehicle2Home (V2H), Vehicle2Street (V2S), Vehicle2Neighbourhood (V2N) and Vehicle2Business (V2B).

To summarize, the specific Key Performance Indicators (KPIs) of SEEV4-City are:

(i) Increase energy autonomy in the Operational Pilots (OPs) by 25% overall, as compared to the collective baseline, by increasing the utilization of existing local renewable energy sources through energy storage or smart charging and V2G.

(ii) Within the pilots, reduce greenhouse gas emissions by 150 Tons annually and achieve low emission kilometres.

(iii) Avoid grid-related investments (100 M Euros in 10 years) by introducing smart charging and storage services on a large scale, and make existing electrical grids more compatible with an increase in electro-mobility and local renewable energy production.

This project will consider full battery electric vehicles, plug-in hybrid electric vehicles with smart charging and V2G capability, including ICT technologies, such as the charging equipment (i.e. converters) and PV and static batteries.

The scope of SEEV4-City project is as follows:

(i) PV is considered as local renewable energy source for analysis, energy & business modelling, and simulation. Other renewable energy sources are excluded, except in the pilots, which buy electricity generated from wind and hydroelectric grid-connected plants.

(ii) Battery swapping, induction charging and other non-conventional technologies are not within the scope of the study.

(iii) Investment for upscaling PV is not within the scope of the OPs.

(iv) Micro-wind is also out of scope for SEEV4-City.

The project implementation methodology is illustrated in Figure 1-1, where work package 3 (Amsterdam University of Applied Sciences - HvA), 4 (Cenex) and 5 (University of Northumbria at Newcastle - UNN) work closely together to achieve the targets for economic, environmental and social aspects. Cenex oversees the data collection from the OPs in order for HvA to develop an energy model and for UNN to develop power and business models. UNN will provide various smart charging/V2G scenarios at different scales (household, street, neighbourhood and city), and together with HvA evaluate these scenarios for the OPs and jointly with Cenex for model improvement and validation, as well as suggested improvements to the OP running in terms of optimisation.

The main research objectives of this project are:

Optimise EV charging costs, increase PV self-consumption, and reduce stress on the grid, while avoiding significant increases in peak demand by implementing ICT and V4ES.

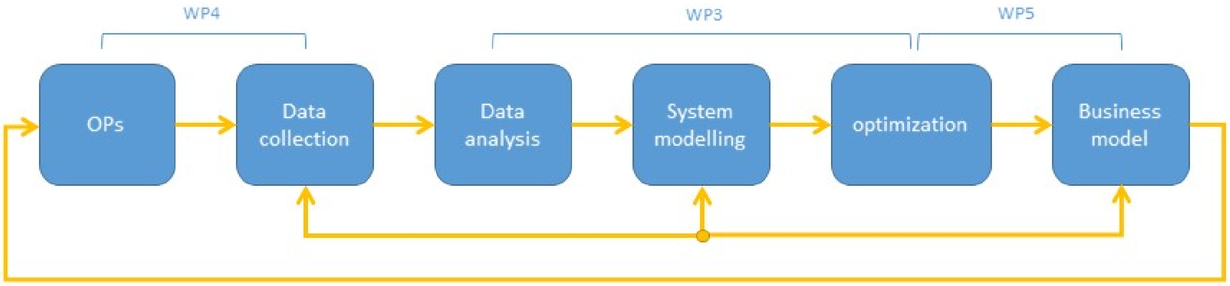

Figure 1-1 Project implementation methodology

2. Electric Vehicles, Photovoltaic and V2G technologies

2.1 Electric Vehicles (EVs)

Together with Renewable Energy Sources (RES), EVs represent the core of SEEV4-City as with optimal management they can be the basis of viable SUMEPs. There are two main types of battery-powered electric vehicles: PHEVs and BEVs. The key differences between PHEVs and BEVs are presented in Table 2-1.

Table 2-1 Type of battery-powered electrical vehicle [6]

Powertrain portfolio	Definition	Fuel
Plug-in Hybrid Electric Vehicle (PHEV)	Driving with combustion engine and /or electric motor, plug-in to recharge the battery (the higher the level of hybridisation the more interesting here).	Gasoline/diesel and battery pack
Battery Electric Vehicle (BEV)	Driving with electric motor only and plug-in to recharge the battery	Battery pack

There are three ways in which batteries can be charged: Conductive, Inductive and Battery swapping. Only conductive charging, being currently the most widely adopted method, is utilised in the SEEV4-City pilots.

The energy source in EVs is the battery and this represents a critical aspect in dictating the success of EV business models. The most important technical features of EV batteries are – energy density, power density, charging and discharging characteristics, degradation characteristics, round trip efficiencies, and operating temperature range. Important environmental and economic features are high safety, low cost, and low weight, with key technical challenges, especially battery degradation and stability over time [7]. Therefore, effective battery management (including battery temperate control) is crucial for EVs (and battery life span), as battery performance determines vehicle performance.

Electric Vehicle Supply Equipment (EVSE) is the term given to systems that recharge EVs, which usually include a converter (AC/DC or AC/AC) 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 [9]. 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; http://www.eurelectric.org/EVDeclaration/Declaration.html. In particular, there have been 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 is 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.

There are three general power levels (rates) available for EV charging (based on 1-phase and 3-phase supplies), at European level as specified by IEC 61851; these are slow charging, quick or semi-fast charging and fast charging. They are listed in Table 2-2, along with their main characteristics.

Table 2-2 Electrical ratings of different EVs charge methods in Europe and the NSR countries [10]

Charge method	Connection	Power (kW)	Max current (A)	Location
Normal power or slow charging	1-phase AC connection	3.7	10-16	Domestic
Medium power or semi-fast	1-phase or 3-phase AC connection	3.7 - 22	16 - 32	Semi-public
High power or fast charging	3-phase AC or DC connection	>22	>32	Public

According to IEC61851-1, there are 4 charging modes of conductive charging, [6] [11], as described in Table 2-3. The modes describe the safety communication protocols between the EV and the charging station; these standards are identical throughout Europe. However, charging power available may vary from 10 to 350 kW for public and semi-public charging options with significant impacts on the grid.

Table 2-3 Modes of EV charging

Mode 1 (AC)	Slow charging from a standard household-type socket-outlet supplying up to 16 A (1-phase). The supply circuit is provided with an RCD (Residual Current Device).
Mode 2 (AC)	Slow charging from a standard household-type socket-outlet (1- or 3-phase) with AC up to 32 A per phase. The charging cable is equipped with an in-cable control box (IC-CPD) which includes control and safety related functionalities such as restriction of the charging current and protection device (RCD).
Mode 3 (AC)	Basic (fast) charging using a specific 1- or 3-phase AC socket-outlet or EV connector with up to 1*70 A or 3*63 A. Extended safety functionalities are provided including continuous protective earth conductor and continuity checking; lack of a proper connection results in no voltage. Extended control possibilities exist, such as controlling the charging current.
Mode 4 (DC)	Fast (power) DC charging from an external charger. There is a fixed charging cable and protection and control are installed in the infrastructure. This system enables flexible and controllable charging power up to 120-170 kW.

The availability of charging stations is essential to promote a wide spreading of EVs as this increase the benefits of e-mobility against conventional vehicles. Currently, the number of publicly available normal charging stations in the UK (according ZAP Map, these are referred to as ‘locations’, where each location includes charging devices which may have up to three connectors) account for 4963 ‘locations’ which includes 8155 ‘devices’ and 14,118 ‘connectors’ (as on 18/12/2017). Charging stations (likely to be number of ‘connectors’) in other EU countries are estimated at 29,813 in The Netherlands, 7,947 in Norway, 1,485 in Belgium, 11.689 in Germany, 2,114 in Denmark and 1,955 in Sweden. As for high power charging stations, these are 2,637 (connectors) in the UK [12], 665 in the Netherlands [13], 1,669 in Norway, 166 in Belgium, 1,961 in Germany, 432 in Denmark and 1,764 in Sweden [14].

Electric vehicle trends

Currently, EVs are on the edge of mass adoption and many future scenarios depend on the availability of large numbers of EVs and PHEVs. This is an important factor in order to achieve significant benefits, both economic and environmental. The higher the number of EVs, in a national fleet, the higher are the possibilities for development of a SUMEP. In fact, national and European policies are developed in order to foster the uptake of EVs. Table 2-4 shows the global situation regarding EV deployment trends [15].

Table 2-4 Global EV market penetration [15]

Country	EV Stock 2016	Market penetration 2016	New BEV registration 2016	New PHEV registration 2016
UK	86420	1.41%	10510	27400
The Netherlands	112010	6.39%	3740	20740
Norway	133260	28.76%	29520	20660
Germany	72730	0.73%	11320	13290
Sweden	29330	3.41%	2950	10460
France	84000	1.46%	21760	7750
China	648770	1.37%	257000	79000
USA	563710	0.91%	86730	72890
Japan	151250	0.59%	15460	9390

As can be seen, in countries such as Norway and The Netherlands, both PHEVs and BEVs make up significant part of the vehicle fleet, and this is evidence for the success of effective policies in fostering EV uptake. In fact, in 2015, 462000 users bought an electric car worldwide, notably in China, representing an increase of 59% compared to the previous year. In the UK, electric cars represent 1.5% of the total new car market in the first three months of 2017 [16]. The market penetration for PHEVs and EVs in 2016 and 2017 for the NSR countries are presented in Table 2-5.

Table 2-5 BEV and PHEV market penetration in 2016 and 2017[1] [15]

Country	BEV market penetration 2016	PHEV market penetration 2016	BEV market penetration 2017	PHEV market penetration 2017
UK	0.38%	1.07%	0.55%	1.17%
The Netherlands	1.05%	4.92%	1.41%	0.27%
Norway	15.67%	13.37%	18.56%	16.16%
Belgium	0.38%	1.36%	0.42%	1.87%
Germany	0.34%	0.4%	0.56%	0.7%

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[1] This data for 2017 is up to the end of quarter 3, as of when the report was written. The annual figure is expected to increase.

Denmark	0.55%	0.08%	0.11%	0.01%
Sweden	0.79%	2.81%	1.09%	3.22%

As can be seen, the market penetration for 2017 for BEVs and PHEVs have increased in 2017 compared to 2016 for most of the countries a part from the singular cases like the Netherlands and Denmark. In fact, in the Netherlands, the penetration of PHEVs have seen a plunge perhaps because of the new taxation system introduced, whilst in Denmark possibly for the introduction of new registration taxes [15]. The future scenarios for EV deployment in different countries are summarised below and listed in Table 2-6.

Table 2-6 EV future scenarios

Study	Outlook
National Grid FES - United Kingdom [17]	• In the UK, there are projected to be between 1.9 and 9.3 million of EVs by 2030; • Four scenarios are presented: Two Degrees, Slow Progression, Steady State and Consumer power • By 2050, BEVs will be more numerous than PHEVs in all scenarios except the Steady State one
ECOFYS scenarios - The Netherlands [18]	• In The Netherlands, BEVs are cost effective for business users for their high annual mileage • For private drivers, EVs expected to be cost effective between 2019 and 2023 • In a positive scenario, there can be 327 000 EVs in the Netherlands by 2020; • By 2025, between 40% and 70% of all passenger vehicles and vans will be electrified • In all scenarios, business drivers are the first to move to electric because of their high mileage
Expansion of Electric Vehicles in Europe: Status and Outlook [19]	• In Norway, the number of annual sales will be at least 90 000, whilst the cumulative total will exceed 400 000 EVs in 2020.
Global EV Outlook [20]	• 100 million of EVs by 2030 • 13 million of EVs in China, India, the US, the UK, The Netherlands, Japan, France, Germany, South Korea, Denmark, Austria, Ireland, Portugal and Spain, by 2020 • Considering OEM targets, the EV stock would reach between 9 million and 20 million of units by 2020 • 40-70 million of cars could be deployed by 2025, in the Reference Technology Scenario
Bloomberg New Energy Finance – Vehicle Outlook 2017 [21]	• EV sales will surpass those of ICE vehicles by 2038 • Unsubsidized electric cars will be as cheap as gasoline models by 2025 • China, the US and Europe will represent the 40% of the global EV market • After 2025 BEVs will overtake PHEVs
OPEC World Oil Outlook 2016 [25]	• By 2040, BEVs would account for 7.2% of the global passenger car fleet
EA Energy Analysis - Promotion of electric vehicles EU Incentives & Measures seen in a Danish Context – Denmark [26]	• BEVs will provide 5% of the km driven by new vehicles by 2020, 20% by 2030 and 40% by 2050 whereas PHEVs will represent 5%, 25% and 45% respectively, in the High Scenario; • In a slow scenario, BEVs will represent only 1%, 4% and 10% of the km driven by new cars in 2020, 2030 and 2050 respectively, whilst for PHEVs the numbers will be 2%, 10% and 31%, respectively
World Energy Perspectives E-Mobility 2016 – World Energy Council [27]	• Projection of 1 350 000 EV sales in Europe, by 2020
BEVs and PHEVs in France: Market trends and key drivers of their short-term development - France [28]	• National EV stock of 206 739, 659 089 and 1 918 000 EVs in France by 2020 for annual growth rates of 20%, 60% and 100% respectively
Europe: Electrification and Beyond A market outlook on emissions and electro mobility [29]	• All Electric Vehicles stock in the European Union and European Free Trade Association to be 2 229 thousands by 2021
Scenarios for a Low Carbon Belgium by 2050 – Final Report – Belgium [30]	• BEV stock account for 231 thousand vehicles by 2020 and 1 336 thousands by 2050, whereas, PHEV stock have 191 thousand vehicles by 2020 and 1104 thousand vehicles by 2050

Table 2-6 gives an overview of the views of different bodies in the growth of EVs. It is impossible to forecast accurately the growth of EVs as there are a number of factors that will determine actual numbers. This forecast depends on the number of EVs that are set as a target (which for some countries may mean more of an aspiration than a very firm target) for the respective future years. It is also not taking into account other public policy objectives such as car sharing or pooling, e-motorbikes / electric bicycles for metropolitan commuting, or transport modal shift towards public transport, and electrification of this (particularly buses). The EV targets above do however not help much regarding forecasting the number of EVs manufactured in those years, if this information is not combined with the expected automotive battery sizes (and supply of key ingredients from supply chains for those). To this end, future projections are not straightforward, as battery prices are expected to 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 [23]. According to the authors of [24], the annual manufacturing capacity of Li ion cells in the world that are fully commissioned is 44.953 GWh in 2016. This is expected to increase to around 125 GWh in 2021 (http://www.visualcapitalist.com/the-lithium-ion-megafactories-are-coming-chart/). The estimated EV battery global demand (excluding buses and stationary applications) in 2025 is 150-400 GWh, depending on EV uptake. This shows how various forecasts can be obtained as results of different assumptions and that the actual situation will be influenced by a multitude of factors. This also demonstrates that EV manufacturing capacity which is needed to meet expected future EV demand may be hindered by the world capacity to produce battery cells, unless of course a breakthrough in battery technology occurs. The determinant of EV numbers is the world capacity to produce cells and not cars or batteries. The next factor is the number of cells per car battery.

Figure 2-1 gives an indication of the growth of EV. It is forecast that by 2040, Europe will be increasing the EV fleet by some 12 million vehicles as battery prices and hence vehicle prices fall (21). What is worth noting on Figure 2-2 Annual global EV sales by vehicle class [21]the growth of Intelligent Mobility or Autonomous Mobility. It is highly likely that this type of mobility will be focused on travel within cities.

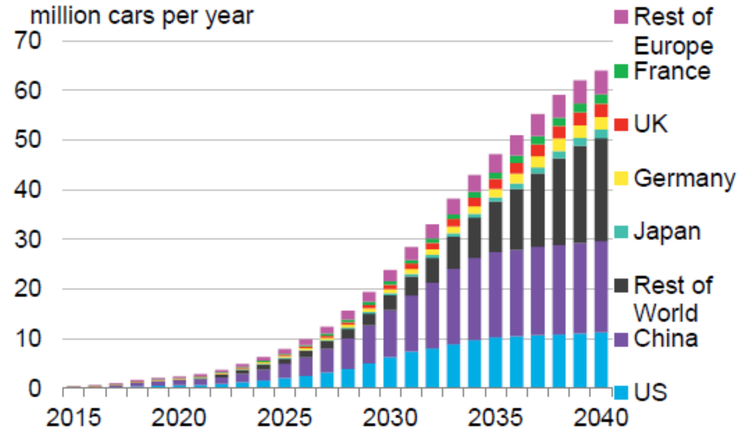


Figure 2-1 Global EV outlook [21]

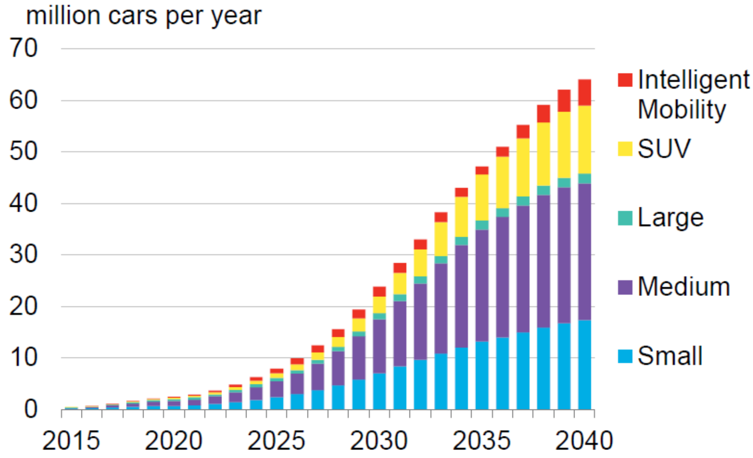


Figure 2-2 Annual global EV sales by vehicle class [21]

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 also depends on the battery manufacturing capacity. Figure 2-3 shows the forecast for the demand of automotive lithium ion batteries for 2020, 2025 and 2030.

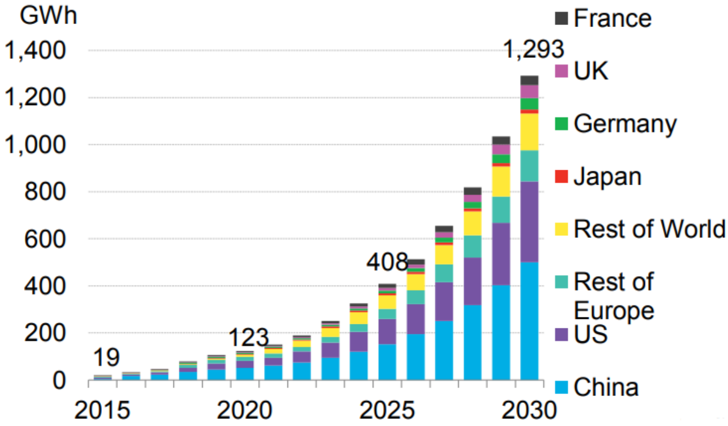


Figure 2-3 Forecasted demand for Lithium-ion batteries for EVs, 2010-2030 (GWh) [22]

2.2 Photovoltaic systems

One of the most prominent Renewable Energy Sources (RES) is Photovoltaic (PV), which has experienced a significant growth in the recent years. A study by Global Market Outlook, 2016, [31] estimated that the global installed capacity of solar PV will reach 700 GW by the year 2020 and predicted that solar PV will then be among the top 3 electricity sources in Europe. Europe reached the 100 GW milestone for installed PV capacity in 2016 and it is estimated that solar power in Europe will provide up to 15% of electricity demand by 2030, [31]. The global output of PV generated electricity grew by about 25.6% in 2016 as compared to 2015. 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 [32]. PV is becoming increasingly cost competitive as compared to fossil fuels and onshore wind power. Crystalline silicon remains the most employed (90% of all PV installations) solar module material in the world, [33; 34].

The growth of installed solar capacity is as the result of national policies regarding solar installations (i.e. feed-in tariff), a fast decline in the cost of PV panels, an increase in PV cell and module efficiency, promotion of the technology by utility companies and the active participation of prosumers [31]. The uptake projection of solar PV in Europe (medium growth scenario in 2020), according to GMO, is shown in Table 2-7 [31]:

Table 2-7 Projection of solar PV capacity for various European countries [31]

Country	2015 Total installed capacity (MW)	2020 Total installed capacity (MW) – Medium scenario 2020	2016-2020 New installed capacity	2016-2020 Compound annual growth (%)
Germany	39,696	48,396	8700	4%
United Kingdom	9,149	14,147	5,025	9%
Netherlands	1394	5044	3650	29%
Belgium	3241	3966	725	4%
Rest of Europe	5670	10,393	4720	13%

The national situation of PV uptake, as with EVs, is influenced by the support system in the respective countries, which will be presented in Chapter 5. The concept of Levelised Cost of Electricity (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 [36]. 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.

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad [35]$$

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, it has the biggest influence on the variations of the LCOE [36]. The LCOE can vary drastically according to different markets and this is shown in Figure 2-4 where the situation in 2015 for countries like 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, [38]. Furthermore, Figure 2-5 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.

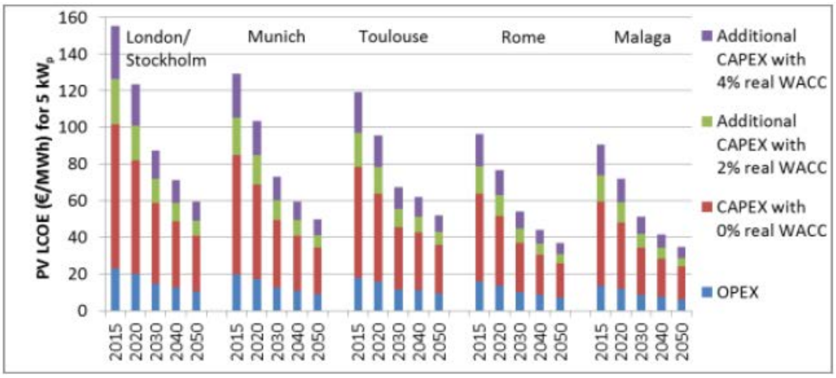


Figure 2-4 LCOE in different European countries / cities [36]

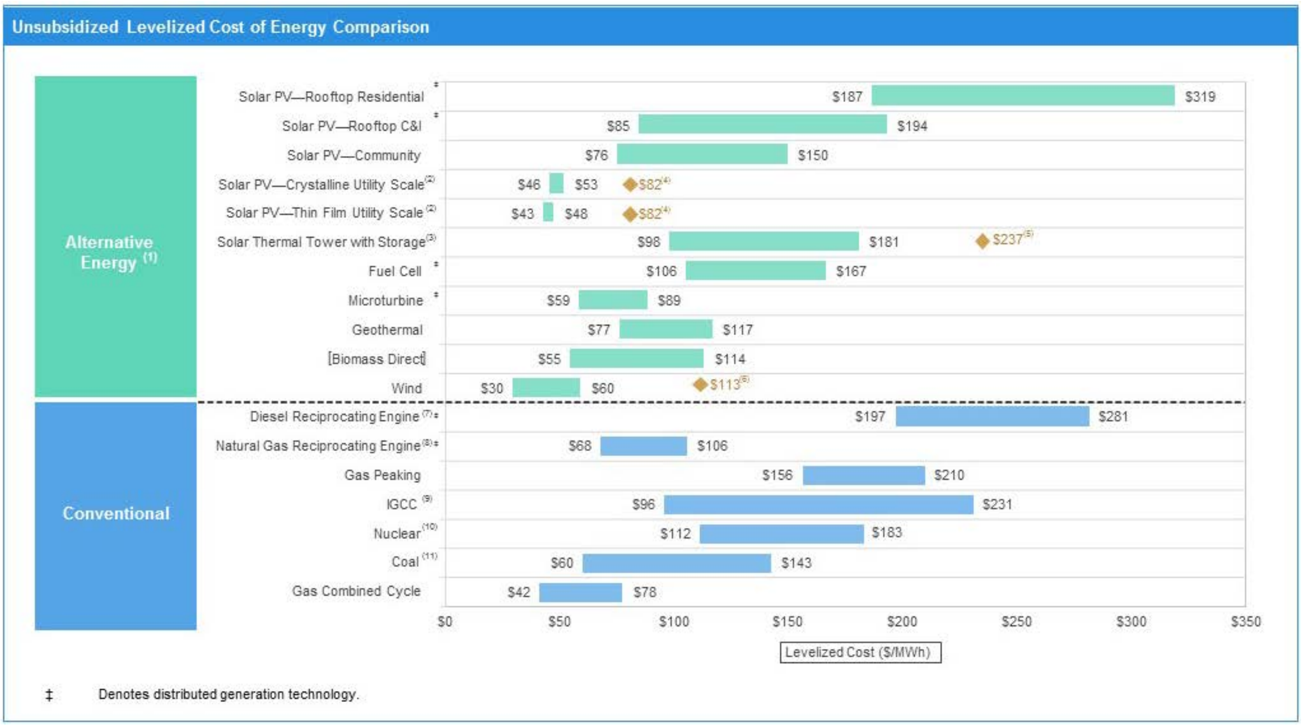


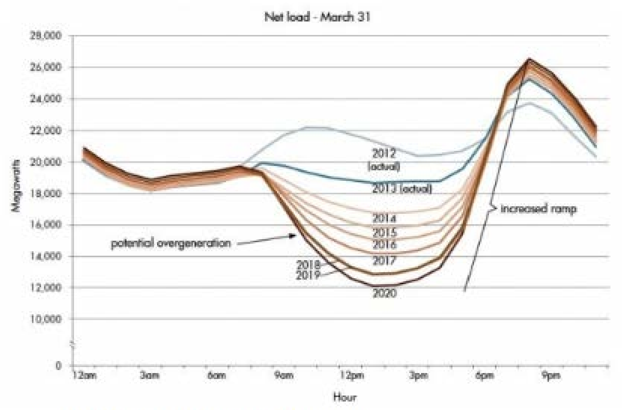
Figure 2-5 LCOE of different tedchnologies [37]

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) [35]. Despite continuous improvement in PV manufacturing technology and significant scaling up of PV production, a fairly constant price at roughly USD 4 to 4.5/Wp remained between 2004 and 2008 due to the expanding markets in Germany and Spain with profitable FITs for the developers [35]. Year 2008 to 2012 saw a massive drop of 80% in PV module price, [35, 36], as a result of the ambitious investment and huge overcapacities between 2005 and 2011.

As for the installation of residential grid-connected PV system, the price has dropped from nearly €$_{2016}$ 10-8/Wp (in 2000) to €$_{2016}$ 3-1/Wp (in 2016). In September 2016, residential systems had a worldwide average price, without tax of € 1.67/Wp, whereas in Europe there was a 25% cheaper price of €1.21/Wp. However, currently there are countries where parity with retail electricity and oil-based fuels has already been reached [36]. In order to make PV technology overall profitable, some solutions, such as increase of self-consumption or combination with a battery storage system, must be adopted. To this end, the price of the storage and other factors, such as efficiency and the Depth of Discharge (DOD) influence the total LCOE of the comprehensive system. Therefore, PV integration in the grid must be handled from different aspects in order to add value to a future smart grid.

2.2.1 Impacts of PV on the electricity grid

The considerable PV deployment expected for the upcoming years has serious impacts on the electric networks. These depend on the size of the PV system concerned. Small and medium sized PV systems are usually connected to the Low Voltage (LV) network, and therefore their effects will be mostly felt locally whilst large PV systems tend to impact the High Voltage (HV) network as well, mainly 11 kV [39]. Residential PV systems may not have noticeable effect individually but their cumulative size may be large enough to cause problems. In the SEEV4-City project, the Amsterdam and Oslo pilots will be operated alongside either a medium or large PV system whilst the rest of the pilots have small PV installations. As well as the intermittence issue, the adverse impact of PV on the grid also lies in the mismatch between its dominant generating time and the period of peak demand of the day, the difference of which can be typically shown by Figure 2-6, known as the 'Duck curve'. This mismatch creates a challenge for electricity generators to quickly ramp up energy production when the sun sets, in order to compensate the PV generation falls. Another drawback with excessive PV penetration is the curtailment of PV generation, which would significantly reduce the economic and environment benefits of PV.



California Independent System Operator

Figure 2-6 Duck curve example of the California power system [40]

Large PV systems (which could arise from the aggregation of a number of smaller LV systems) can affect grid performance in respect of power and frequency, and can cause voltage fluctuations and even instability of electric power systems. The most common impacts of PV systems are potential reverse power flow (which causes voltage control problems), increased power loss in the system, phase unbalance and power quality issues such as harmonic distortion, [39]. If optimally sized and placed on the grid, PV systems are found to reduce losses in the distribution feeders (those working at low and medium voltages). However, voltage fluctuations do happen more frequently with high penetrations of PV systems during cloud transients [39, 41]. Large PV systems increase ancillary services requirements that may provide new possibilities for EVs to provide energy services to the grid within SEEV4-City [41].

PV systems are becoming more and more integrated into European electric systems and this can make the energy mix of a country more environmentally benign. However, PV systems and EVs, acting in the capacity of energy stores, must be combined to minimize the adverse impact on the electricity grid from high penetration of both technologies, and to maximize the environmental benefits to the stakeholders.

2.3 Smart Charging and V2G

2.3.1 Impacts of EVs on the electricity grid

With many advantages the EVs can bring in, there is also a drawback: it is the impact of the charging of EV fleets especially when there is high EV penetration in the national/regional/local stocks. Uncontrolled EV charging refers to charging without any optimal scheduling, which may occur at any time, but the effect of charging in the early evening is particularly adverse, this being when people tend to return home from work, corresponding to the domestic evening peak in demand. Uncoordinated charging of EVs can lead to power losses, voltage deviations and power quality issues [42]. In [43] transformer overload at a distribution level was found to be possible with as few as 20% of the households having EVs connected at this time. Uncontrolled charging may also affect the voltage profile: 30% of the households having EVs with 3kWchargers could bring the network voltage below the statutory minimum if connected at 6 p.m. [43]. Other results obtained by the same authors [44] show that if 7 kW home chargers are used, then only 10% of the households having EVs can cause this effect. It is reported [Ref] that in Denmark, in a private house, one can (without upgrades) obtain 10 kW charging, and at an additional cost of some 8,000 EURO – up to 43 kW. Therefore, grid impacts from domestic charging may be more severe than anticipated. To resolve these issues significant grid reinforcements are required. To mitigate this problem, EVs can actually support the electricity grid by charging only when the grid has sufficient capacity, such as during the early hours of the morning when other demand for power is low. Each Low Voltage Network (LVN) will be affected differently when additional EV charging loads are added depending on the existing loads on the system, local RE generation and available capacity on the network. This means that planning of large-scale EV uptake must be done on a case by case basis when looking at system loading [45-51]. In response to this, SEEV4-City will use grid models specific to each pilot site to evaluate the impact of EV operation on that particular grid.

2.3.2 Smart Charging

An innovative charging method that can be considered to mitigate the impact of bulk EV charging is Smart Charging, which "… is when the charging cycle can be altered by external events, allowing for adaptive charging habits, providing the EV with the ability to integrate into the whole power system in a grid- and user-friendly way. Smart Charging must facilitate the security (reliability) of supply and while meeting the mobility constraints and requirements of the user. To achieve those goals in a safe, secure, reliable, sustainable and efficient manner, information needs to be exchanged between different stakeholders" [63]. The charging is managed in a way to control the demand to shift the energy from peak periods (around 9am and 6pm) to off-peak periods; this is called load shifting. This procedure will tend to even out the demand for power over a 24-hour cycle. If arranged carefully, load shifting improves energy efficiency and reduces CO_2 emissions, by smoothing the daily peaks and valleys of energy use and optimising the use of generation plant. Smart charging allows the system to charge more EVs without the need for substantial network upgrade as charging can be distributed, thus avoiding short-term overloads. Controlled charging can mitigate the consequences of a bulk EV charging as shown in some projects and case studies, such as the PlanGridEV project and the Grid4Vehicles (G4V) project [45; 46; 47].

There are further possibilities for smart charging. To accommodate renewable energy sources such as wind and solar PV in a power system, sudden peaks of excess generation need to be accepted. EV charging time can be varied to align with periods of surplus power and through Time-of-Use (TOU) rates technique can mitigate peak load demands in distribution grid and reduce transformer overloading. Time-of-Use (TOU) pricing is a demand-side management (DSM) technique, which encourages EV charging during off peak hours when rates are lower. An optimal Smart Charging algorithm can be designed to maximize either utility benefits or customer benefits, as needed, [10].

Additionally, smart charging can provide system frequency 'down regulation', within the frequency regulation services. This term describes the following scenario: if the mains frequency of a power network rises about the nominal value, indicating an excess of generation over consumption, and if large numbers of EVs are aggregated together, then the charging of the resulting block can be controlled via signals from the aggregator to increase demand for power to the correct level to bring it into equilibrium with supply.

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 2-8 shows the smart charging systems currently 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, [52])	Tesla Wall Connector, up to 16.5kW [53]	460£ or 528€ [54]
		ICU EVe mini, 22kW [55]	1249€
	Smartfox energy manager (839€, [56])	ICU EVe mini, 22kW [55]	1249€
		NRGkick mobile charging station, 22kW [57]	949€
		KEBA KeContact P30, 22kW, [58]	939€
		ABL eMH1, 3.7kW, [59]	699€
Smart charging ready (the control is inbuilt)	Not required	Newmotion Home standard, 3.7kW, [60]	714€
		Kraftriket Smart Total, 22kW, [61]	22,990kr, or 2388€ [62]

Table 2-8 Smart charging systems available in the market

2.3.3 Vehicle-to-Grid (V2G)

EVs cannot only be managed to cause a low impact on the grid but if controlled properly and with the adequate Electric Vehicle Supply Equipment (EVSE), they can supply power to the grid in a concept known as Vehicle to Grid [33]. EVs have a high capacity storage battery to supply power for vehicle operation. Normally the battery would be connected to the grid for charging purposes, when it behaves as a load corresponding to the charger capacity, e.g. 3kW or 7kW. However, when the battery is not fully discharged it contains energy, and it is possible to use this stored energy, if the EV is stationary and its charger is connected, to supply power to the grid. 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 [64]. To make V2G possible, a special bi-directional charger is required which could be either DC or AC (which could be installed on-board, as in the BYD e6 used in Utrecht [65]) and also pursued within the new 15118 standard (especially by Renault) at present, which can act as an inverter to supply power back to the. The V2G procedure, however, should not sacrifice the main function of a vehicle as transportation.

In order to facilitate V2G adoption related standards are essential to ensure interoperability. For this purpose, the standards to refer to are ISO/IEC 15118 and IEC 61851. In the ISO / IEC 15118 protocol the communication standard between a charge point and an EV is discussed and it is High Level Communication; this means the EV can communicate with a charging point with the intervention of the EV user. This is implemented in EVs that are equipped with CHAdeMO - though with the new 15118 standard also in the Combined Charging System (CCS) - but it is not used in many charging points yet and the market adoption is still low [66]. The IEC 61851-1 edition 2 describes the four charging modes. It is the standard for EV charging in Europe and has been discussed earlier in this report. The connectors that could be used for bidirectional power flow and communication fall within in the IEC 62196-2 [67] and these are SAE J1772 or Yazaki (Northern America), Mennekes (Europe), and JEVS G105-1993 or CHAdeMO (Japan) [68, 69]. Currently only CHAdeMO allows a suitable bidirectional connection that could support V2G, for the others, the required communication protocol still needs to be adapted to suit bi-directionality, such as with the new 15118 standard also in CCS. Additional standards for the communication between EVSE and the Grid Operator are required, such as the IEC61850-90-8, and between the aggregator and the EVSE or the Grid Operator, such as the OCPP, OSC/OpenADr etc. As can be seen the standards have just started to be adopted and interoperability is yet in its infancy; this is another barrier for a wide scale adoption of V2G.

From the user point of view, also the cost of V2G equipment can 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, [70]. 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), [71]. Enel tagged the cost of a V2G charger at around £600 [72], 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 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, [73]. 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 [74], 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 [74].

As well as simply providing power to support the Grid when it may require it, such as during the 6pm evening demand peak, or to facilitate the use of fluctuating RES, when the EV battery may be charged when the RES generation is excessive, and discharged when it is insufficient other services can be provided. The EV battery can also be utilized for additional services such as market trading (energy arbitrage) where energy may be bought when it is cheap to charge the battery and sold back to the grid when energy prices are higher. Frequency regulation services may also be provided: in a power system when the instantaneous power generated exceeds the instantaneous demand for power, the surplus power from e.g. steam turbines ends up accelerating the rotating machinery, causing a rise in frequency. Frequency regulation can then involve absorbing the excess power to bring the system frequency back to nominal. EVs are well suited to this application, having a very fast response time. This part of the process is known as down regulation. In an analogous way, if the instantaneous demand for power exceeds the supply, the kinetic energy in the system rotating machinery will be consumed as the rotational speed falls and the system frequency falls as a result. To solve this issue real power can be injected into the system (up regulation) to remove the power deficit. Again, aggregated EVs can supply the necessary power. Using EVs in this way there is no need to absorb much power overall, as the down regulation and up regulation functions tend to average out. In utilizing the full capability of the battery resource when the EV is stationary, the V2G controller can communicate with a management system (or aggregator), which will perform techno-economic calculations to determine how best to utilize the battery. Depending upon the complexity of the system, this could be a very simple charge/ discharge calculation or involve much more complex market trading algorithms and analysis. This is beneficial in both an economic sense for the EV owner, who could be paid for providing these ancillary services and thus make an income from V2G operations with their vehicle. From the perspective of the network operator, the use of V2G can provide the opportunity to improve the sustainability and reliability of the power system [75], especially as it is decentralized and closer to the local network.

In a conventional power grid, if the amount of power demanded changes very suddenly then the stable operation of the turbine powered synchronous generators used may become hard to achieve. Some of these technical issues concerning the stability ('transient' and 'dynamic' stability) of the grid can be alleviated by the use of V2G, since EV batteries and battery management systems are able to respond to a control signal in approximately 1 second , [76], which lies well within the requirement from IEC 61851 standards of 5 seconds, [77]. However, it is worth pointing out that the communication time between the EV and EVSE may take longer due to communication protocol stages and handshakes between vehicle and charger, in the best case 5s if the car is constantly awake.

V2G can thus be used to promote the stable operation of a power system. To this end, in the future, it will be necessary to use detailed and realistic models of EV batteries when simulating their use to maintain system stability. Even now, in Denmark, a dynamic simulation model for the entire battery plant must be submitted to the transmission system operator, if plant rated power exceeds 10MW [141]. In order to provide the aforementioned services, precise forecasting of the availability of EVs for the estimation of V2G capacity is important. Improper forecasting will have negative consequences, actually reducing system stability, giving problems for both EV fleet managers and grid operators. Only limited research has been carried out so far with real-time V2G systems incorporating RES, [78].

V2G technology is still in its infancy, with few hardware systems available for the European market. As the business cases for the technology develop and issues around the impact of V2G on battery degradation and social barriers improve, uptake will begin to increase. With increasing numbers of grid connected EVs, the system becomes very complex and grid constraints become an issue. It becomes a complicated unit-commitment problem with many constraints and conflicting objectives [78]. Proper V2G management systems as well as accurate business models that consider various network service provision and other energy services, along with appropriate policies, are essential for a successful implementation of V2G technologies [64]. Section 4.3 provides more insight on this aspect.

2.3.4 EV battery technology

The battery is the most vital part of an EV with relation to energy service offerings. Its cost accounts for a big part of the vehicle's cost, influencing the Total Cost of Ownership (TCO), so battery life has to be considered and maximized in order to allow a coherent cost-benefit analysis in an EV related business model that employs Smart Charging and V2G for Vehicle for Energy Services (V4ES). The effect of V2G on battery life is discussed in Section 4.2.

Lithium-Ion batteries are considered here as all the major EVs currently use them. Owing to developments in battery technology, manufacturing costs of EV batteries have fallen very significantly in the recent years; at the same time, the specific energy has increased [15]. Although the specific power delivered by a Li-Ion battery is comparable to that provided by an ICE, in terms of specific energy, EVs are still well behind as compared to the energy density of fossil fuels. However, the situation is improving; in [15] the energy density or specific energy of Li-ion batteries is reported to have reached near 300Wh/l in 2015 and according to the US Department of Energy (DOE) more than 330Wh/l for PHEVs in 2016 (for gasoline this accounts for more than 10000Wh/l [79]). The situation regarding battery costs can also be found in the same study: in fact, battery costs have dropped from 1000$/kWh in 2008 to under 300$/kWh in 2016 achieving a reduction of almost 80%. Market leaders as Tesla and Nissan may have reached battery costs lower than 300$/kWh [80] and this is consistent with [81] where the average battery pack price is depicted well below $300/kWh. As for future projections, battery pack prices will have a price below $/190/kWh by 2020 and below 100$/kWh by 2030 [81]. Developments in battery technology is leading to battery costs falling even faster than initially predicted. This enables cost reductions in the price of EVs that will help increase their penetration into the global vehicle fleet. Battery prices decreased by 35% in 2015 alone and it is predicted that by 2040 long-range electric cars will have a cost that is below $22000 and that 35% of the new cars will be EVs [82].

Original Equipment Manufacturers (OEMs) of EVs are always involved with battery technologies and their commercialization and according to recent studies [83], they will join forces with cell manufacturers to promote and 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 long term, when the technologies will be mature; hence, OEMs will establish alliances with suppliers.

3. Energy autonomy

A higher utilization of local RES by using EVs for energy storage to even out the peaks and troughs of the highly variable supply [84] is possible with one of the services in V4ES denominated as Energy Autonomy. This may stimulate further EV adoption, reduce the need for grid reinforcement, and provide other techno- economic advantages such as a reduction in CO_2 and urban air pollutants. The key elements required to achieve local energy autonomy are a local generation system and a storage system to match demand and supply. EVs can act as the storage system (instead of conventional storage systems such as Battery Energy Storage Systems and Pumped Hydroelectric Storage), using their batteries to store and provide the energy, as required, which means that the EV becomes an integral part of the smart energy system.

Energy autonomy is considered in several studies, from the use of local resources to fully islanded (or 'stand-alone') operations (independent from an outside electricity grid). Different definitions exist in literature for energy autonomy and it is also referred to as 'energy autarky', 'energy self-sufficiency' or 'energy self-reliance'. A clear definition is essential as it decides the elements that must be considered in the equation and this influences the economy in the business model. Various definitions of energy autonomy are summarised in Table 3-1:

Terms	Definitions
Self-sufficiency	Locally consumed energy generation / Local energy demand
Self-consumption	Locally consumed energy generation / Local energy generation
Degree of electrical autonomy	Self-sufficiency / Self-consumption

Table 3-1 Definitions of energy autonomy derived from literature [84]

From the studies conducted to date, some interesting conclusions can be drawn. If PV is combined with storage systems, a higher grid independency is achieved [85], but the capacity of the battery will determine how much improvement can be made in terms of autonomy [86]. A general trend of increasing CO_2 emission reduction and savings in electricity bills with higher investments in terms of PV and battery sizing is perceived [85]. Autonomy and battery utilization cannot be maximized simultaneously in most cases [86]. The optimum level of self-sufficiency increases with the number of involved households [87]. A way to achieve a higher energy autonomy is to apply the DSM: the charging of EVs and if applicable the base load, with a required change in user behaviour can be managed in order to eliminate the mismatch with the PV generation [88]. Depending on the economic regulation (mostly resulting from national policies), this can be an economic and easy solution. When EVs (or stationary 2nd life batteries) are used for smart charging and/or V2G the batteries present in the city are used optimally, avoiding excessive battery production.

Research shows there are multiple definitions of energy autonomy found in the literature review. For the purposes of the SEEV4-City project, Self-sufficiency as listed in Table 3-1 is adopted for energy autonomy calculation as follows.

$$EnergyAutonomy = \frac{SelfConsumption}{TotalEnergydemand}$$

Where Self-Consumption is the locally consumed energy generation including those shifted by stationary storage or EVs. This definition will be adapted for each SEEV4-City pilot, depending on the local boundaries and operational variations.

4. Business models and Economics of Smart charging and V2G

4.1 Business models

As well as the cost of the necessary V2G bidirectional charger, there will be further costs in order to enable V2G. One will need to provide a bidirectional communication channel with the TSO or Aggregator as the case may be, and an additional energy meter so that the financial impacts of V2G may be measured. As will be discussed in Section 4.2, further opportunities for value creation could be realized by applying business models; that is, EV business models must provide value for both service providers and service users [89]. Positive drivers for V2G could include market oriented regulations/tariffs, for example dynamic pricing of energy and grid usage.

It is essential to undertake an economic evaluation within the SEEV4-City project to quantify the costs/benefits of Smart Charging and V2G in order to help in developing reliable business models and promote SUMEPs. Of course, the characteristics of the energy storage system has to comply with the requirements of the different services. Different services with different calling times and frequency can be stacked and provided with the same vehicles and most importantly the same charging infrastructure to keep the costs low. The services that can be provided together are frequency regulation, demand management, distribution/transmission investment deferral, solar self -sufficiency (autonomy) and others.

According to the Department for Transport vehicle licensing statistics for 2014, [90], and the Ultra-Low Carbon Vehicle Demonstrator Programme, [91], the EV archetype can be broken down into private domestic (47%), private commercial (33%), public (11%) and fleet (9%) for the UK.

The generic EV business model includes the commercial relationship between the associated stakeholders, based on the direction of energy flow. With ICT and smart grid infrastructure in place, the aggregator is responsible for collecting the available power from EVs that are involved in the smart charging/V2G activities, providing the network service such as frequency regulation or spinning reserves provision, and settling the transactions with EVs based on the energy provision and the capacity provision for some of the available schemes. An aggregator is an intermediary between EV users, the electricity market, the distribution system operator (DSO) and the transmission system operator (TSO) [92]. The role of the aggregator is that of an agent that acts in behalf of many EV users to establish business relationships that otherwise would not have been possible, given the small size of an EV battery, compared to the grid requirements. 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 it role in defining the role and delivers the related interaction models and sample technical references, which is particularly important where the role is of interest 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, with reference demonstration projects in Heerguward (a USEF-based smart energy system connecting 200 households, predicting daily electricity use and production, and smart control of appliances; and also in Hood Darlem (42 urban neighbourhood households with home battery systems are combined with solar production, a smart-in-home-system, within a USEF framework) and in the first aggregators to adopt USEF-based smart energy system) 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. https://www.usef.energy/general-benefits/aggregator/

The uncertainty in social acceptance of V2G together with the inconclusive net value creation capability of the current business models, urge investigations on EV business model structures with feasible scenarios that could potentially be applied to the various scales, such as household level, street level, neighbourhood level, and city level. Some available examples of smart charging and V2G schemes are presented in chapter 6 of the SEEV4-City Full State-of-the-Art report.

Different stakeholders (such as network operator, energy market operator, mobility provider etc.) exist in all forms of business models, which are developed based on the various revenue streams from network service provision, DSM, price arbitrage, etc., or a combination of these. EV ownership clarification provides the basis for the commercial relationship definition of the business models, i.e. under a certain form of EV ownership, which stakeholders are more directly related to what energy scenarios, and with whom the contract are signed with. There are 3 main types of business model structures, depending on ownership, as listed in Table 4-1.

Type	Definition
EV Private ownership	- The vehicle user is also the vehicle owner. - The energy provider introduces time-of-use energy prices and feed-in tariff to the customer, and settles the transactions through an intermediate energy management agent. [93]

	- The customer must purchase the vehicle and the battery from the mobility provider and the infrastructure provider is responsible for the charging device.
EV Car leasing	- Private vehicle purchased via a Personal Contract Purchase (PCP), i.e. leasing/renting. - A personal lease consists of an upfront payment followed by regular monthly payments over a fixed period of time. [94] - It is usually cheaper than financing a vehicle outright as the individual is effectively renting the vehicle, but they do not own it. - The risk of battery life is taken by OEMs under leasing service by shifting the private EV ownership.
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. [95] - Advantages: shift of car ownership together with associated upstream and downstream risks to the service provision company; - Disadvantages: high initial investment for purchasing the vehicles, e.g. the revenue structure of Autolib in Paris, [96], which is one of the largest EV sharing services in the world, is dependent on public financing. [97]

Table 4-1 Ownership based business model structures

The output from the business model should cover the economic and environmental savings, as well as performance related rewards, in the TCO and/or TCU, the environmental benefits in terms of CO_2 emission reduction, clean kilometres achieved, and improvement in local energy autonomy.

In conclusion, EV ownership is under transformation from being purely private to a sharing form. By shifting from private EV ownership partially the risk of battery life is taken by OEMs under the leasing service, or when the ownership is fully given up, the service provision company under car sharing would completely take the upstream and downstream risk. In the latter case, the significant initial investment would be a financial challenge. In early days of EV markets, it is essential to have policy as a driver 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. The regulation needs to be tailored to support EVs: the owners should be given a market to trade energy and an appropriate taxing should be adopted. Low user acceptance may as well hinder V2G adoption and this is discussed in Section 6. With higher EV deployment, these barriers will be overcome.

4.2 Economics of Smart Charging and V2G

Although small compared to the fuel cost of a conventional vehicle, electricity charging cost of an EV is still an expenditure. An example of charging costs in the UK is around £400 for an average annual mileage of 10 000 miles [98]. The average domestic charging cost for EVs in the Netherlands is 22 c€/kWh [99]. As for public charging in the Netherlands, it was free until the end of 2012, whereas from June 2014 the fees are determined by the Charging Point Operators (CPOs). The CPO pricing mechanism can include a combination of energy cost per kWh, per-connection time fee (i.e. duration of use), and per-use fee. On average, the per-use fee and the energy fee can be 42c€ and 32c€/kWh, respectively, [100]. These prices can vary significantly depending on the operator. According to the Dutch Knowledge Platform in 2016, the average price per kWh excluding VAT was of 28 c€/kWh [101]. Rates for fast charging in the Netherlands vary in the range of 59-70 c€/kWh [102]. According to [103], EV electricity charging costs in other NSR countries such as Belgium, Germany, and Denmark range from a minimum of 25 c€/kWh to 56 c€/kWh. Per minute rates as much as 10 c€/min are also available. In Norway, running 100% on renewable energy, the slow charging is free whereas the recent fast charging infrastructure costs about NOK 2.5/min [104].

This, and other costs such as battery degradation, must be evened out or exceeded by the revenues from the different energy services to provide benefits to the user. The basic idea to consider is that supplying V2G based ancillary services to the Grid will cause additional wear to the EV battery, reducing its potential future life to a greater or lesser degree. This phenomenon is known as battery degradation. Battery life can be divided in calendar life and cycle life and while V2G may impact the cycle life, it does not influence calendar life, as batteries degrade with time whether they are used or not. The costs of battery degradation have been estimated: a simple but reasonable approach is to find the cost of replacing the EV battery divided by the total energy provided by the battery during its life cycle in kWh. The costs of battery degradation can then be measured in terms of Euros /Pounds per kWh throughput. [105]

In previous work in relation to V2G, different network services such as baseload provision, peak power provision, frequency regulation and spinning reserve have been explored. Frequency regulation has been identified as the most profitable application of V2G [106]. However, the economic feasibility must be carried out within the boundaries of each country or even region in terms of policy, technology advancement and availability, therefore some services may be more profitable in one country but not bring any value in others, just because it is put in a different context. It may be found that PV self-consumption turns out to be (much) better, once all cost components and the regulatory regime (such as the set bidding period are considered.

For example, under PJM in the US, there is already a compensation for fast responsive systems providing frequency regulation, and currently the Electric BMW Minis in the University of Delaware is earning $100 by responding to the PJM frequency regulation signal [107]. 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 actual energy costs to the EV owner for regulation services tend to balance out. The main costs are, energy cost (not to be considered for frequency regulation), battery degradation cost and the infrastructure cost for V2G charging. A possible barrier for EVs participating in frequency regulation services is when the difference between the payment and the cost of the energy provided per kWh is not satisfactory enough. In the Danish case, the aggregator NUVVE is starting a trial with 30 vehicles allowing them to discharge their batteries towards a market that is accessible to utilities that want to match demand (https://venturebeat.com/2011/06/14/the-cash-back-car-danish-evs-owners-to-sell-power-back-to-the-grid/). To access this energy they currently will have to pay a tariff that is three time higher than the energy cost. Aggregators such as NUWE are lobbying the Danish tax authorities to handle the energy used for services different than ‘normal’ demand.

Balancing the revenue obtained against the costs of carrying out the V2G operation allows a calculation showing the profit accruing to the EV owner. 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. One area of uncertainty is what the usage patterns surrounding the new ultra-fast chargers may be in the future. Will this be in line with predictive patterns from so far still limited data available, and will the length of usage of these new ultra-fast chargers allow for V2G for smart charging and V2G services? However, V2G provision can represent part of a profitable business model for EVs; in fact in the Danish context, payment of 90+10 kr/MW/h is assumed for an aggregator (https://www.livogland.dk).

The costs of battery degradation depend on the battery replacement cost and the lifetime, so with advancing technology the situation will become more favourable. Battery degradation during the lifetime of the EV largely determines the Total Cost of Use (TCU) and at the end of the battery’s useful life in the EV, the battery residual value, is determined by the remaining capacity. Due to battery degradation, in order to meet automotive requirement for adequate lifetime, the batteries may be oversized; in the context of V4ES, this represents extra cost and weight whereas the minimization of the degradation, performed with Smart Charging or V2G [106] can extend battery life and thus reduce the need for expensive oversizing of the battery. In order to design comprehensive EV business models to promote SUMEPs, a battery degradation model that evaluates several aspects must be developed: the extra battery degradation, which consequently affects the Battery State of Health (SOH) and the residual value and the effect of all the main influencing variables, such as, State of Charge (SOC), Depth of Discharge (DOD), temperature and charging/discharging rate must be considered. The majority of the studies [108] [109] [110] only consider some of the relevant parameters and their effects but not all. In addition, the model should represent the widely adopted batteries and the degradation must be expressed with a cost function. At the same time the model must be computationally efficient enough to run on an embedded system for better user experiences.

Smart charging, as opposed to V2G (especially if not done properly), will not tend to cause significant extra battery degradation when compared to normal charging, since the same charge would be transferred in both cases, and the charging conditions are the same. Indeed, delaying charging until the early hours of the morning rather than charging at say 6pm, on return from work, would give less degradation since the battery is stored overnight at a lower SOC, causing a lower degradation [111]. Thus, the benefits of Smart Charging to network operators may be obtained without disadvantage to the EV owner, who might benefit themselves by charging when power was in surplus and thus cheaper. Charging when there is high RES generation can provide benefits to the network, allowing a greater degree of renewables integration. Smart charging could be used for down regulation, obtaining free energy to charge the battery whilst being paid for provision of the service.

As regards V2G, the main source of revenues procurement is via various energy services as discussed above but it may result in extra battery degradation, which however needs more investigation, as research shows that V2G reduces the average-SOC and this could actually benefit battery life similar to smart charging. The costs of the operation depend on the lifetime of the EV battery, since carrying out the balancing service involves transfer of energy to and from the battery. A major potential use of V2G is to enable the use of RES generation without the need for fossil fuel backup when the RES is not generating; the EVs if aggregated in sufficient numbers can store RES energy, releasing it when the RES generation is too small. This would contribute to a higher level of energy autonomy. This process can produce system benefits and allow high levels of RES integration with consequent CO_2 reductions through integration with EV fleets [112]. For individual EV owners, the capacity of the charger limits the potential involvement of the EV in V2G, since even a 7kW charger has a power throughput of far less than the potential throughput of the EV battery, as when used for driving. Hence, in most scenarios, aggregators are required 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, part of the calculation of profitability involves determining how profit would be shared between aggregator and EV owner.

Little previous work takes into account national and local energy policy, grants and subsidies to EV owners that 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 incentives and disincentives (such as perhaps free parking, bus lane use, or environmental exclusion zones) 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 factors that affect these together with their effects on household PV generation, energy autonomy and grid support.

4.3 Network services

Smart charging and V2G can be employed to provide energy services to the grid and this represents a potential revenue stream within V4ES, by being developed as a business model to generate extra income for the EV owner and benefits for the involved stakeholders. The chief ancillary services are the balancing services and reactive power provision, the former being employed by the network operator in order to guarantee a secure and quality service by ensuring a continuous balance between demand and supply. The main balancing services are Frequency response, Reserve and Reactive power compensation.

Frequency response: Frequency response means that the appointed generator must automatically change the active power output in response to a frequency change. The nominal frequency value in Europe is 50 Hz; the statutory frequency limit is 49.5-50.5 Hz and the operational limit is 49.8-50.2 Hz.

In the UK, Frequency Response is divided in *Primary Response*, *Secondary Response* and *High Frequency Response*.

The common technical requirement demanded by the National Grid of the UK requires generators to satisfy the following: Mandatory frequency Response, Firm Frequency Response and Frequency Control by Demand Management. The types of frequency responses are listed in Table 4-2.

Type of Frequency Response	Requirement	Can be satisfied by EV fleets (Yes/No)
Mandatory frequency Response	Minimum rating: 10-100 MW	Possibly, at city-level
Firm Frequency Response	Minimum rating: 10 MW	Yes, because of the viable requirement
Enhanced Frequency Response	React within 1s from deviation	Yes, because of the inherent ramping characteristics of the EV batteries
Frequency Control Demand Management (FCDM)	Minimum rating: 3 MW	Yes, charging schedules can be controlled within reasonable limits

Table 4-2 Types of Frequency Response [113]

Reserve: Sources of extra power in the form of either generation or demand reduction may be required to be able to deal with unforeseen demand increase and/or generation unavailability. There are five types of Reserve, listed in Table 4-3:

Type of Reserve	Requirement	Can be satisfied by EV fleets (Yes/No)
Fast Reserve	Minimum rating: 50 MW	Yes, at city-level
Short Time Operating Reserve (STOR)	Minimum rating: 3 MW Delivery time: 240 minutes, for 2 hours	Yes, at work places, with a high number of EVs
Balancing Mechanism (BM) Start Up	Prepared generator in 89 minutes	No, not optimal for EV fleets, against the short availability of EV charging.
Demand turn-up	Minimum rating: 1 MW	Yes
Others		
Black start	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	Not at present. In future, with a huge deployment of EVs and EVSE this service may be viable.

Table 4-3 Types of Reserve [113]

Reactive Power: Voltage levels in the electric power grid are influenced by reactive power flows. If the right amount of reactive power is provided, then the network voltage can be controlled. There are various types of reactive power service, which EV may or may not be able to provide (depending on technical constraints), and are listed in Table 4-4.

Type of Reactive Power service	Description
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. EV fleets have not yet been aggregated to enable a combined output as large as 50 MW, so do not have the required rating to be applicable for this service, as yet.
Enhanced reactive power service	This service is for those generators that are not required to supply the obligatory reactive power service. EVs can be utilized to provide reactive power when idle, and when no other balancing service is provided; this can result in extra profit.

	Importantly, it should be noted, that this service does not absorb much real power from the battery, because no active power is provided; only the charger and battery losses will be present.

Table 4-4 Types of Reactive Power Service [113]

In Denmark, control of reactive power is a requirement for any battery storage system connected to the grid [141]. In the Netherlands, Belgium Germany, Austria and Switzerland, the market for the Primary Control Reserve (PCR), responsible for frequency regulation has been unified in 2015. The PCR is employed to limit and stabilise frequency disruptions in the entire synchronously connected high-voltage grid [114] [115]. This service is procured through auctions where the technical unit can bid after prequalifying in accordance with the prequalification requirements. The technical requirements for this service are listed in Table 4-5.

Requirement	Value
Minimum bid size	1MW up and down
Accuracy of the frequency measurement	10mHz or less
Insensitivity range for the frequency control	Max 10mHz
Full activation time	30s for the whole bid
Full activation frequency deviation	±200 MHz
Real time operating power measurement	In MW within 4-10 s

Table 4-5 Technical requirement for the frequency regulation [115]

A PCR provider must, for a 24-hour period with a different target frequency, regulate the output power according to a set point correction on the basis of the contractual commitment. For example, a contractual commitment of 50 MW (at 200 MHz) requires a correction to the set points of -2.5 MW at 49.99 Hz or +2.5 MW at 50.01 Hz target frequency. There is only the capacity payment. Batteries fall within the category of limited sources; hence, there are specific requirements: they must able to provide constant support to the frequency within the "standard frequency range" of 49.95-50.05 Hz. If, in case of a larger deviation in frequency, the "alert state" is reached, the limited source must be able to continuously supply the full quantity of primary reserve contracted for not less than 15 minutes (30 minutes in Germany) at a deviation of 200 MHz or more, or to supply partial delivery for a proportionately longer period in case of frequency deviations lower than 200 MHz After these 15 minutes (or proportionately longer period), the limited source must have the energy fully available again as soon as possible, but at the most within 2 hours after reaching "standard frequency range".

The different Ancillary Services available in the NSR countries and their requirements, as asked by the Network operators, are presented in the following tables. 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.

Frequency Containment Reserve (FCR)

This is normally activated in order to stabilize the System Frequency after an imbalance in all the NSR countries. Table 4-6 defines the characteristics of this service, such as the providers, the product resolution, the procurement scheme, the price types and others.

Characteristic	**Options**	**UK**	**Netherlands**	**Belgium**	**Norway**	**Germany**	**Denmark**	**Sweden**
Capacity - Procurement schemes	Hybrid				☒			
	Mandatory offers	☒						
	Organised market		☒	☒		☒	☒	☒
Capacity – minimum bidding quantity (MW)	x≤1MW			☒	☒	☒	☒	☒
	1MW≤x≤5MW		☒					
Capacity – maximum bidding time	Month(s)			☒				
	Week(s)		☒			☒		
	Hour(s)				☒		☒	☒
Capacity - Provider	Generators only		☒		☒			☒
	Generators + load						☒	
	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				☒		☒	
Energy - Provider	Generators only							☒
	Generators + Load						☒	
	Generators + Load + Pump Storage units pumping	☒						
Energy – minimum bidding quantity (MW)	No minimum bid size						☒	
	x≤1MW							☒
	5MW≤x≤10MW	☒						
Energy – settlement rule	Pay as bid	☒						
	Marginal pricing							☒

Table 4-6 Frequency Containment Reserve in the NSR countries [116]

Replacement Reserve

This service is used to restore/support the required level of frequency. It includes operating reserves that imply times from those necessary to restore frequency to hours. Amongst the NSR countries only the UK has this service. For the capacity part, the minimum bidding quantity has to be between 1MW and 5MW, 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 5MW, the providers are generators, loads and pump storage units pumping, the settlements rule is set pay as bid for, the monitoring is a hybrid system and the activation time, that 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 depends on the unit.

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 1MW and 5MW, 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.

Voltage control

Voltage control is part of the ancillary services for every NSR country except Denmark, and the characteristics are summarised in Table 4-7:

Characteristic	Options	UK	Netherlands	Belgium	Norway	Germany	Denmark	Sweden
If a power plant is able to provide voltage control, which grid it should be connected to	Transmission grid			☒			☒	
	Transmission grid or distribution grid	☒	☒		☒	☒		☒
Is it a service paid by the TSO?	Yes	☒		☒	☒			
	No							☒
	Partly		☒			☒	☒	
Settlement rule	Pay as bid	☒						
	Regulated price				☒			

	Free					☒		
	Hybrid						☒	
	Pay as bid + Free		☒	☒				
Does the TSO own reactive power compensation systems?	Yes	☒	☒	☒	☒	☒	☒	☒
	Inductance	☒	☒	☒	☒	☒	☒	☒
	Capacitor banks	☒	☒	☒	☒	☒	☒	☒
	SVC	☒			☒		☒	☒
	Synchronous compensator	☒			☒	☒	☒	☒

Table 4-7 Voltage control in the NSR countries [116]

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 these service vary. The characteristics are represented in Table 4-8.

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			☒	☒	☒	☒	☒
	Transmission grid or distribution grid	☒	☒					
Is it a service paid by the TSO?	Yes	☒	☒	☒		☒	☒	☒
	No				☒			
Settlement rule	Pay as bid	☒	☒				☒	☒
	Free					☒		
	Pay as bid + Free			☒				
Does the TSO own units for Black start service?	Yes						☒	
	No	☒	☒	☒	☒	☒		☒
Should be the Black start provided by a single unit or it is allowed to be part of a power plant?	Yes							
	No, it has to be a single unit	☒	☒	☒		☒	☒	☒
Is there a regulated gradient for the BS unit	No	☒		☒		☒		
	Yes, 0-100MW/15min						☒	

Table 4-8 Black start in the NSR countries [116]

As can be seen, the characteristics of the different services change according to the country that is considered, which means that one service can bring profit in one country but maybe not as profitable in another one, even though the structure of the business model does not change. This is why every business model must be designed according to the nation that is referred to while considering the different services available. Most probably, different services have to be combined in each country to make an acceptable to attractive overall revenue stream for EV owners.

To summarize, a diversified range of network services are available, and these are currently procured with conventional technologies whereas potentially, these could be provided by EVs. However, there is not yet a clear regulatory framework that facilitates EV fleets to enter in this market, because requirements that suit mainly large power plants are still in place and these need to be adapted for the new types of generation. SEEV4-City will include these services in business models involving different stakeholders and, at a later stage, will provide suggestions to help the involved authorities improving the regulatory framework.

5. Policies and incentives for EV adoption in EU and NSR

Alongside the various policies and incentives in EU and NSR to support the RES adoption, which has been introduced in Section 2.2, there are a number of measures available to encourage the uptake of electric vehicles at the EU, national and sub-national levels, to favour EV business models and to turn the economy in favour of EVs against ICE vehicles. They range from Purchase Subsidies, Ownership Benefits, Business and Infrastructure Support and Local Incentives. The policies combined with successful business models are essential to promote EV uptake and user engagement to make SUMEPs more fruitful. Various types of incentives for EVs and PV, classified according to four categories, at national and local level are listed in Table 5-1.

As Table 5-1 shows many EU countries have policies to support EVs. However, this should be seen against the context of the EU that has been promoting more sustainable transport systems, including road vehicles. This includes fleet vehicle emission standards, EU wide collective targets for CO_2 reduction including decarbonisation of the electricity grid, emission and air-quality standards for cities and requirements for vehicle recycling.

As can be seen from the presented policies supporting PV deployment 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. This massive PV installation made it increasingly difficult for grid operators to balance supply and demand. Some changes in policies have been made to alleviate the imbalance in the system. For example, Flanders introduced the prosumer tariff, which requires a payment of €88.44/kW/year (PV lifetime) from household PV to inject power back to the grid [126]. This incurred fee would encourage local renewable consumption from domestic base/flexible load as well as EV charging where applicable.

In conclusion, clear and strong policies and incentives are required to achieve the shift to electric vehicles, and adopt more RES in the upcoming decades. The SEEV4-City project will produce findings and policy recommendations, which will be disseminated in the final report.

E-mobility adoption is incentivized widely across the NSR countries via purchase subsidies, taxation/VAT exemption, energy pricing/regulation and others. The associated EV charging infrastructure are also under fast deployment supported by local and national governmental funds to facilitate the EV deployment. Regarding renewable integration, the quota system, FIT and Net metering are commonly adopted among the NSR countries. NSR countries share common areas along these different dimensions while at the same time showing divergence in each country, which is detailed in this table.

Policy type	UK	The Netherlands	Norway	Germany	Belgium	Denmark	Sweden
E-Mobility: purchase subsidies, taxation/VAT, energy pricing/regulations, incentives such as parking access and others	• Zero emission vehicles with at least 70 miles range get GB£4,500 grant; PHEVs under GB£60,000 receive GB£2,500 • Registration tax exemption for zero emission vehicles; low emission vehicles have reduced taxes. • Annual circulation tax exemption • Individual bus lanes opened to labelled EVs and free parking in some areas. • ULEZ in London (from 2019-2020) vehicles that do not meet the exhaust emission standards must pay a day charge to enter the ULEZ	• Full exemption from the normal registration tax for zero emission cars; for other cars there is a progressive system with 5 levels: level 1, PHEVs, 1-79 gCO_2/km and pay €6/gCO_2; level 2, 50-106 gCO_2/km and pay €69/gCO_2 and the final level, for 174 gCO_2/km or over pay €476/gCO_2. • Tax reduction to individuals and companies for EV purchasing • Zero emission cars are exempt from road taxes whereas PHEVs (<51 gCO_2/km) pay the 50% of the tax for a conventional car. • For companies investments on zero emission cars and PHEVs are	• Exemption from VAT for BEVs, and no import tax. • BEVs are exempted from acquisition tax whereas PHEVs enjoy reduced tax (up to €10,000). • In 2016 higher purchase discounts and tax waivers were introduced for PHEVs • Urban and highway toll exemption, free parking, bus lane use.	• €4,000 grant for BEVs, €3,000 for PHEVs, both for cars with a list price up to €60,000. This grant is valid for a maximum total of 400,000 cars • Circulation tax exemption for EVs in the first 10 years of ownership for cars registered until Dec 31 2015, 5 years from then until Dec 21, 2020. • Tax deduction for company cars. • Transport companies pay reduced electricity tax for electric or hybrid buses (11.42€/MWh instead of 20.5€/MWh). • Locally, BEVs benefits of free parking, reserved	• Full exemption from the normal registration tax for EVs in Flanders. • In Flanders, there are €4000 grant for individuals purchasing EVs; leasing and company cars are not eligible • Lowest annual circulation tax for EVs in all three regions (€74 instead of €1,900) • Tax deduction from corporate income 120% for zero emission vehicles and 100% for vehicles emitting 1-60 gCO_2/km; above this threshold, the deductibility rate decreases from 90% to 50%.	• Purchase subsidy up to 15,000 DKK/vehicle, limited to a total lump sum. • Energy tax: Dutch energy law requires a payment when using energy from the battery. • Limited reduction of registration tax • CO_2 emission tax for PHEVs: €6/gCO2/km in 2016 which will be increased thru 2020 to €20/gCO2/km; the taxation for EVs will remain unchanged • New registration taxes for EVs: EVs must pay 20% of the full registration tax applied for ICE vehicles and this will be applied to the next 5000 EVs sold or until 2018. The tax will be increased until 2022 when the	• “Super green car premium” of SEK40,000 for BEVs and SEK20,000 for PHEVs for new cars with maximum emissions of 50gCO_2/km. • Circulation tax exemption for the first 5 years of ownership. • Tax reduction for EV purchasing for individuals and companies. • Annual circulation tax exemption • The purchase rebates for PHEVs had been halved in 2016 from SEK 40000 to SEK 20000

	zone; EVs are exempted • Nottingham, Bristol, Milton Keynes and London employs £40 million grants to promote green vehicle technology: bus lane access in city centres and 25 000 parking spaces for EV owners	deductible from the income tax. • In Amsterdam there are subsidies for EV purchasing and residents with an electric car have priority over other residents when applying for a parking permit • Free parking in all cities		parking spots and bus lane use. • The municipalities can offer various benefits to EV drivers including free parking • The Electric Mobility Act exempts EVs from certain restrictions • Access to restricted areas such as city centres		full amount will also be applied for EVs • From 2017 a purchase tax rebate for BEVs of 225$/kWh will be applied for a maximum of 45kWh ($10,000). • Dedicated parking lots for EVs. • Fleet owners purchasing EVs can receive funding from the utility companies in the range of 2,000-4,000 DKK/vehicle.	
Urban/Spatial planning: transport plans, charging infrastructure deployment	• Installation of fast charging hubs • Financing up to 75% or £500 and £300 per socket for the installation of home charging point; subsidy up to 75% (maximum £7,500) of the cost of installing an on-street residential charge point in areas without off-street parking. • Tax breaks for businesses that	• The Green Deal 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. • More than 60 fast-charging stations have already been built by Fastned • In Amsterdam the demand-based EVSE deployment provides	• Public funding is provided for fast chargers every 50km on main roads and others for public chargers, in some cities.	• 14 fast-charging stations to be built by Fastned • There are direct investments for publicly accessible chargers	• Promotion of the deployment of EV charging infrastructure	• Tax rebate up to DKK 18 000 on the installation of home chargers. • Reduction of 50% of the connection charge for public charging stations. • The Danish Energy Agency supports the deployment of new public charging stations	• In 2015 the financial support for the EVSE deployment amounted to 130 million SEK • There are direct investment for publicly accessible chargers in some areas

	invest in charging points • Local authorities are refunded for the installation of road side charge points in residential areas • Ecotricity electric highway • In London, the company Source London provides more than 850 charging points & plans installation of 4500 by 2018	EVSE only when there is user demand and no other private or off-street alternative is available • In Utrecht, the municipality gives €500 per charging point and €1500 per semi-public charging point					

ICT – Energy system (incl. **RES production and consumption**): FIT, Net Metering and others	• FIT.
	  ◦ <5MW FIT decided by OFGEM.
	  ◦ >5MW, green certificate, from April 2017 only CFD.
	• Contracts for Difference (CFD).
	• Quota and certificate system.
	• Tax mechanism.
	• Carbon Price Floor (CPF), a tax on fossil fuels used for electricity generation
		• Loan to 'green' project with lower interest rates;
		• Net-Metering;
		• Reduction of environmental protection tax: self-consumed energy from RES is exempted from environmental protection tax;
		• Energy investment allowance: tax credit granted for investment in RES plants;
			• Quota and certificate trading system:
			• The quotas increase from 0.119 in 2016 to 0.186 in 2025, and then decrease to 0.009 in 2035.
				• FIT for small generators (capacity<100kWp) and market premium scheme through auctions for large generators.
				• Tenders for solar projects starting from 750kW
				• Consortium and low-interest loans available for PV installations.
				• For building mounted systems c€ 8.91 –
					• Brussels: quota system based on the trade of certificates, Net-metering for small prosumers and investment assistance for companies that develop environmental projects.
					• Flanders: supports electricity from RES by means of a quota system, an ecological premium and a Net-metering scheme. But there is also a prosumer
						• Premium tariff and Net-metering:
						• The bonus depends on the market price and the statutory maximum set for the sum of both the market price and the bonus.
							• Quota system
							• tax regulation mechanisms
							• subsidy scheme
							• Capital subsidy for the installation of grid-connected PV systems, which covers 35% of the installation cost. The maximum system cost of SEK37000/kWp is covered (excluding VAT).

	• 25 years for FIT	• Declaration should be applied to qualify the loan; • Net-Metering ≤ 3*80A; • Energy investment allowance: tax credit up to 57.5% of the total investments; investment between €2300 and €120 million per calendar year; • Declaration valid for 10-15 years;		12.70/kWh minus c€ 0.4/kWh	tariff of €88.44/kWh/year from household PV to inject power back to the grid • Wallonia: quota system, Qualiwatt subsidy for PV installation less or equal to 10 kW, investment assistance for companies and Net-metering are available • In Brussels and Wallonia, the quotas increase every year, from 3.5% (2013) to 14% (2025) for Brussels and from 27.7% (2015) to 37.9% (2024) in Wallonia • Investment assistance: - micro and small enterprises: 40% of eligible costs - medium enterprises: 30% of eligible costs - large enterprises: 20% of eligible costs		• Electricity produced from PV with a capacity lower than 255kW is not taxabile. • Approx. c€ 6.3/kWh of tax reduction which however cannot exceed 30000 kWh or the amount of electricity withdrawn from the grid

					- Qualiwatt: For installations up to 10 kW, the subsidy is calculated to achieve a return of the investment in 8 years with a return rate of 5%. The subsidy is calculated according to the average cost per kWp for an installation of 3kWp which is also the maximum amount allocated. Installations over 3kWp will receive the subsidies corresponding to a 3kWp installation.		
Awareness and adoption: investment in RES/Sustainable environment; transport and ICT, new jobs in low carbon economy	- One third of local council now operate at least one electric vehicle						

Table 5-1 Policy system for EVs and PV in the NSR countries [14, 15, 117-125]

6. EV user behaviour

The basis of SUMEPs is represented by the customers who show their preference to one or another commercially available technology. This determines also the level of commercialization of technologies that may have been proven at an R&D level but are still at early stage in the market deployment. Moreover, user-involvement and focus on end users and their benefits are key-factors for the success of any e-mobility plan. Therefore, it is essential to evaluate the acceptability of consumer towards EVs and associated technology, as well as their willingness for participating in demand management schemes, including smart charging and V2G.

The most important driver for the adoption of a full EV is the perception of an economic benefit, in terms of future long-time fuel savings, energy efficiency and cheap electricity [127]. In fact, users in some studies manifest the preference to change their current car from or to larger one but with less fuel consumption, but this depends on a range of consumer attributes (including whether they are owners of energy-efficient houses) [128]. Government policies may be put in place in order to promote specific technologies by making them more appealing for the users. Exemption from purchase tax and VAT are critical incentives for more than 80% of the respondents in a EV owner survey carried out in Norway [89] [129]. The upfront price reduction is the most powerful. The parking policy is a strong consumer driver in Amsterdam where parking space is very limited through the whole city [130].

The exemption from road tolling and bus lane access are perceived as substantial benefits in Norway [129]. Not only that, environmental concerns and policies are found to be in some studies to be main reasons for the purchasing a full EV, such as in Norway [127]. The density of charging station affects the perception of the usefulness of EVs, from the user point of view, hence, partly determines the user propensity towards EVs [130]. On this note, the EU project ELVIRE developed advanced ICT such as software for route and charging station selection; to tackle the range anxiety problem and 92% of the users found the application useful [131].

Apart from the above-mentioned factors, the socio-economic, socio-geographical, alongside educational backgrounds and lifestyles of potential EV adopters also play a role on their purchasing decision. People with low CO_2 emission footprint are those keener to exploit incentives for EV purchase, [132]; well educated people, working full time and with an above average income, living in detached houses and in towns are usually those who buy EVs more frequently than others. This is because they are usually ecologically aware, in fact, nearly the half of them own a PV system [133]. Studies in Germany [128] have shown that owners of energy efficient houses showed higher willingness to buy PHEVs and BEVs. Regarding this, the CROME project in Germany and France carried out an e-mobility demonstration [134]. 97% of the participants were completely or mostly satisfied of EVs and 76% considered EVs as a better option than a conventional car. With moderately populated municipalities, for instance more than 20000 citizens, users were 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 more interested in the public image that EVs provide than France and prestige is one of the main reasons for EV purchase.

About the attitude of EV owners towards third-party control of their EV charging, ‘My Electric Avenue’ project, [135], has assessed the EV drivers’ acceptability of a DNO being able to curtail their charging for managing the strain on the distribution network. No significant inconvenience or unacceptable loss of service to EV users has been shown by use of the technology. In fact, the majority participants declared themselves comfortable or very comfortable with their charging being curtailed, which shed lights to the deployment of the demand management solutions. To overcome the initial scepticism of end users, the risks and costs of different services must be minimized; this can be done through car sharing and car-rental services which can also create closed user groups or individual communities of users exploiting these services.

Besides user incentives and willingness to drive EVs and participate in smart charging/ V2G it is also important to consider plug-in patterns to understand the available flexibility and thus EV availability. In the Nikola project in Denmark, for instance, a website (EVUI.elektro.dtu.dk) was developed to demonstrate user involvement.

Modern electric power systems will face new operational challenges due to the influence of a high penetration of electric vehicles (EVs). In this context, power system operators may take advantage of EVs equipped with vehicle-to-grid (V2G) technologies to deal with network congestion management issues. One challenge is to make V2G attractive to an EV user. This can be done by making it financially attractive.

In addition, consumer apprehension is reduced by providing useful information and clarification Gamification is another way to increase user involvement [89].

In summary, well-planned policies, both in terms of optimal subsidy scheme and targeted users, with accurate business models must be implemented to promote EVs and SUMEPs by winning consumer’s confidence.

7. Projects in NSR and EU

Successful demonstration of the viability of e-mobility can lead the way for a prolific EV adoption. Significant numbers of projects have been undertaken to investigate the integration of EVs and RES into future smart grids. A thorough review of 47 projects and business applications have been undertaken, covering areas include technical, social, economic and environmental factors, as well as energy autonomy as applied to households, street, community within neighbourhood, city and national level; the comprehensive review can be found in the full SEEV4City State-of-the-Art report. 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 now the main factors that discourage people from buying an EV. It is found that user acceptance of EVs 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 from potential service provisions. Consequently, incentives have a significant role in promoting e-mobility. In fact, in both in the project Green Motion [136] and Kempton et al. [137] the importance of incentives, such as grants or tax credits which reduce the initial payment, has been pointed out on the consumer's willingness-to-pay for EVs, and this relies on national/local government policy. Government incentives are a major driver for the spread of EVs in many countries, in fact, when this kind of support becomes less the EV sales see a decline. Therefore, the phasing out of incentives should be followed by steps to convince the users of the benefits of e-mobility even without the incentive system. To this end, services are seen as good approaches to ensure user involvement and satisfaction, because they increase reliability and convenience and reduce risks and uncertainties of e-mobility plans. Different approaches could be adopted: with state-funded research programs, a real-life trial of specific services offered to the end user or a combination of both i.e. the incentives to increase the demand and services to improve the supply side. The most important services to spread EVs are, charging, IT-based services, car sharing and car rental, route planner and other information services. IT services are particularly important to support EV uptake. An efficient and extensive charging infrastructure at a national, regional or at a local level is essential to complement EV uptake [89]. 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 lifetime, 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. The SEEV4-City project seeks for the optimal synergy among all the factors of concerns, in various scales from household to city level.

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 Parker: (www.parker-project.com), where grid integration specialists such as Enel, Nuvve and Insero, car manufacturers 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.'

Nissan sets up a partnership with Enel, using 100 V2G units to provide network service in the UK, [138]; Toyota City will demonstrate a Virtual Power Plant, with EVs, that will regulate the electricity demand according to the generation of RES, such as, wind, solar and biomass energy [139]; UCC San Diego and NUVVE will cooperate to let EV drivers in California to sell the energy in their vehicles to the grid when plugged with 50 special charging station that will be installed in the campus of the university [140] [141]. The UK call for V2G projects, as of July 2017 [142], with an overall £20 million budget, has opened the way for practical demonstrations, feasibility studies and ICT prototype development for V2G applications. A comprehensive review of smart charging and V2G projects in the NSR and beyond has been carried out. Please refer to the SEEV4-City State-of-the-Art full report for more details.

8. Data acquisition, modelling and analysis

To apply Smart charging and V2G, Information Communication Technology (ICT) for data acquisition, monitoring and analysis purpose are essential. To enable the control of EV charging to achieve different objectives data from EVs must be collected and elaborated to issue optimal charging schedules. Data acquisition can be divided into two categories according to the collection method: from a data logger, and from other sources or surveys.

On-board data logger has been proven as a useful tool for gethering real-word data for the purpose of monitoring, modelling and evaluation. For EVs, On-board diagnostics (OBD)-compatible data loggers have been widely used to collect the vehicle's real-time data (such as location, speed, acceleration, motor speed, wheel speed, battery voltage, current, temperature, state of charge, etc) through a standardized Control Area Network (CAN) communications port. In order to control EV charging, EV chargers must communicate with the management system and other chargers from different vendors. Various communication protocols for charging have been proposed, such as DIN70121 [143], and ISO15118 [144]. 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.

For this, an Open Smart Charging Protocol (OSCP) [145], and the Open Charge Point Protocol (OCPP), [146] can be used. A database must be accessible for data collection and analysis. Apart from Smart charging and V2G scheduling purpose, the collected data is also used to bill the user and analyse the use of chargers, charging behaviours and roll-out strategies [147].

Within SEEV4-City, the collected data is employed to be interfaced with a business and energy model. The latter can consider geographical levels of analysis (pilot level, and regional/national level) and different stages (Base case 2017 and the coming years, or within policy timelines like 2020, 2030, 2050 with different scenarios).Commercial or public models mostly treat energy supply technologies as black boxes with input and output energy & power flows and with a fixed efficiency. The SEEV4-City project involves very specific technology (PV, EV and storage); hence, a bottom-up (or hybrid) model - that starts from detailed energy technology and sectoral descriptions, as opposed to a more macro-economic approach - is suggested by Després et al. [148] and Van Vuuren et. al [149]. The system model can be optimised to maximise both the economic and environmental benefits of the stakeholders. Considering the complexity of the interaction among them 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.

In conclusion, data collection, modelling and optimization tools can be adopted to depict different real cases, such as Operational Pilots OPs), and future scenarios, and this enables the application of business models.

9. Summary

Based on the systematic review presented, the key points attained are summarised below with associated research questions/gaps.

An overview of EVs and their associated charging infrastructure, power levels and modes as well as the trends regarding the deployment of EVs and PV systems is presented. Although EVs and PV are technologies that can provide compelling benefits, their impacts on the electricity grid, such as, increased peak load and transformer overloading for the former and voltage fluctuations and reverse power flows for the latter, influence the economy and operation of the system. An important question is therefore, *what are the impacts in the different OPs according to their physiology*?

The two modes, namely Smart Charging and V2G are introduced as solutions for the integration of EVs and RES in the grid and the related impacts and as new practices to achieve higher benefits. However, this highlights a fundamental research question: *Is it economically beneficial to adopt V2G, or is smart charging alone more viable for the OPs*? To this end, 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. Frequency regulation has been shown as the most profitable among the approachable ancillary services followed by spinning reserve and peak shaving. At the moment, conventional generators provide these services, and it is important to study their working, characteristics, and constraints. Thus, perhaps in the future, EVs can replace conventional generators by satisfying all the constraints. However, in some cases, EVs still have limitations in providing ancillary services to the same extent as conventional generators - such as minimum ratings and availability of EVs at short notice.

The economic analysis of Smart charging and V2G can be adapted to different scales (as in different OPs) with various stakeholders as structured by a business model, which can be categorised according to the EV ownership, i.e. private ownership, car leasing and car sharing. This raises the research question of *identifying all the possible stakeholders in each OP, and try to integrate them into the business model.* Moreover, since the OPs are in 5 different countries, it will be quite a challenge to come up with a unified business model suitable for all the countries. This gives rise to the question - *should it be a unified model or a separate model for each country?* It must also be kept in mind that ideally one should be able to expand and scale up business models in the future, without any problem

Extra battery degradation can be caused by providing various energy services in the V2G process. The main variables that accelerate battery degradation are: battery cell temperature, state of charge (SOC), depth of discharge (DOD)/amount of charge transferred, and current rate (C-rate). Most studies only consider some of these parameters, some neglect them with assumptions on the working conditions, while others neglect combinations of these parameters; in no case are all four parameters affecting battery degradation considered together. Thus, *how this can be addressed and linked with the battery state of health,* is one of the chief research questions of the project.

One major benefit considered in the business model will be Energy Autonomy. A most commonly adopted definition by the OPs is Energy autonomy = Self-consumption/Total Energy consumption at every moment. Some OPs are represented by different energy mix, boundary conditions and objectives, the definition would therefore be differently applied. Similarly, *a common methodology must also be defined to calculate* CO_2 *emission reductions and clean-driven kilometres.*

In order to develop a comprehensive and successful SUMEP, all the potentially fruitful factors, services and stakeholders must be considered in the business model. To this end, a thorough review of 43 applications, including projects and business exercises, aligned with the V4ES concept in the EU region has been undertaken. The analysis gives suggestions on how to proceed with the SEEV4-City business model and pointed out the importance of policy. This is because it is essential to satisfy all the regulations and policies of each country, as it can make or break a business idea.

Policies that incentivise EVs, through environmental benefits but mainly economic benefits are what are driving EV adoption from the consumer point of view. Besides, socio-economic, socio-geographical, educational backgrounds and lifestyles have an influence on the consumer willingness towards EV purchasing. In some studies, consumers have been found to be positively oriented towards third-party control of their EV charging which sheds lights on the implementation of Smart Charging and V2G.

To implement energy and business models these have to be combined with realistic data. Thus, data acquisition and analysis is not trivial. A relevant *research question would be - how is the data collected, and what type of data or parameter is required for each pilot?* For the OPs, real-time, and real-life data is essential. In SEEV4-City, this data is required to monitor the KPIs of the project, and can also provide information about user behaviour. Another research question for the OPs is – *which parameters need to be monitored, and how will it be done?* Moreover, one must obtain the data following all legal procedures, as this data is confidential. Furthermore, because each pilot is different the type of data required to model each OP must be specified for the energy and business models. A bottom-up (or hybrid) model - that starts from detailed energy technology and sectoral descriptions, as opposed to a more macro-economic approach - is suggested. In all models, scenarios for demand and supply must be created for the future.

Policy-learning should and policy convergence may occur in Europe and the NSR region, despite so far national policy being heterogeneous in many key countries despite shared overarching concerns and imperatives for decision makers (energy security, sustainable development, impact on the existing automotive sector and pressure from sub-national actors) – though not also with differences and different strategic priorities between those [150]. The EU and especially also the national state and its public policy are of crucial importance for creating an initial market for electric cars, and may – in conjunction with industry – socially create a new market for electric mobility [151]. As for municipal policy-makers, a mix of supporting citizens and businesses regarding e-mobility, supporting charging infrastructure built-up, regulatory measures, raising awareness, (local) government as lead user, and governing the transition with other levels of government has been suggested in expert workshops. Derived from this, two feasible policy mixes of overall effective and efficient measures have been suggested: On the one hand for cities that strive to be (global and European) leaders, and one as a no-regret insurance course of action that any city should adopt if it wants to develop electric mobility [152]. Case study review from electric vehicle trials and EV users conducted in the North West region of Europe, conducted under the Interreg project ENEVATE, has concluded that more policy and research attention should be given to sub-urban and rural electric vehicle application as promising niches from which wider socio-technical change may emerge [153].

References

1. EEA (2016) Electric Vehicles in Europe, EEA Report | No 20/2016, European Environment Agency, Copenhagen.
2. C. Weiller and R. Sioshansi (2014) ‘The role of plug-in electric vehicles with renewable resources in electricity systems’, *Revue d'économieindustrielle* 2014/4 (No 148), 291 – 316, 2014.
3. http://infohouse.p2ric.org/ref/40/39569.pdf
4. http://www.greencarreports.com/news/1091436_toyota-gasoline-engine-achieves-thermal-efficiency-of-38-percent
5. F. Wefering, S. Rupprecht, S. Bührmann, S. Böhler-Baedeker, “Guidelines for Developing and Implementing a Sustainable Urban Mobility Plan”, European Platform on Sustainable Urban Mobility Plans, January 2014.
6. McKinsey, “Cars, components and costs,” 2014.
7. International Energy Agency (IEA), “Technology roadmap: Electric and plug-in hybrid electric vehicles,” *Int. Energy Agency*, *Tech. Rep*, p. 52, June 2011.
8. K. Young, C. Wang, L. Y. Wang, and K. Strunz, *Electric Vehicle Integration into Modern Power Networks*. 2013.
9. A. M. M. Foley, I. J. Winning, B. P. O Gallachoir, and M. Ieee, ‘State-of-the-art in electric vehicle charging infrastructure’, in *IEEE Vehicle Power and Propulsion Conference*, 2010.
10. A. Dubey and S. Santoso, “Electric Vehicle Charging on Residential Distribution Systems: Impacts and Mitigations,” *IEEE Access*, Vol. 3, pp. 1871–1893, 2015.
11. Ir. P. Van Den Bossche, “Conductive Charging Standardisation Issues”, University of Brussel, 2003. http://etec.vub.ac.be/publications/evs17vdb.pdf
12. https://www.zap-map.com/statistics/
13. https://www.statista.com/statistics/658078/number-of-quick-charging-points-for-electric-vehicles-in-the-netherlands/
14. http://www.eafo.eu/ (Accessed 02/12/2017)
15. International Energy Agency, Clean Energy Ministerial “Global EV Outlook 2017 – Two million and counting”, Paris, France.
16. http://www.nextgreencar.com/electric-cars/statistics/
17. Future Energy Scenarios, National Grid, July 2017.
18. M. Cuijpers, M. Staats, W. Bakker, A. Hoekstra, “Eindrapport Toekomstverkenning elektrisch vervoer”, ECOFYS, December 2016.
19. Y. Yoshizawa, “Expansion of Electric Vehicles in Europe: Status and Outlook”, Mitsui Global Strategic Studies Institute Monthly Report, November 2016.
20. International Energy Agency, Clean Energy Ministerial, “Global EV Outlook 2017 - Two million and counting”, Paris, France.
21. Bloomberg Electric Vehicle Outlook 2017: “Bloomberg New Energy Finance’s annual long-term forecast of the world’s electric vehicle market.” Executive Summary, July 2017.
22. C. Curry, “Lithium-ion Battery Costs and Market”, Bloomberg New Energy Finance, June 2017. https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF-Lithium-ion-battery-costs-and-market.pdf
23. Element Energy ‘Cost and Performance of EV batteries’ Final Report for the Committee on Climate Change 21/03/2012 https://www.theccc.org.uk/archive/aws/IA&S/CCC%20battery%20cost_%20Element%20Energy%20report_March2012_Public.pdf accessed 01/12/2017.
24. N. Lebedeva, F. Di Persio, L. Boon-Brett, “Lithium ion battery value chain and related opportunities for Europe”, European Commission, Petten, 2016.
25. OPEC, “2016 World Oil Outlook”, October 2016.
26. Promotion of electric vehicles EU Incentives & Measures seen in a Danish Context, Ea Energy Analyses Copenhagen, Denmark, January 2015.
27. World Energy Perspectives, “E-MOBILITY: Closing the Emissions Gap”, 2016.
28. E. Morganti, V. Boutueil, F. Leurent, “BEVs and PHEVs in France: Market trends and key drivers of their short-term development”, Research Report, Corri-Door Consortium, 2015, pp.37.
29. PWC, “Europe: Electrification and Beyond A market outlook on emissions and electro mobility”, January 2016.
30. M. Cornet, J. Duerinck, E. Laes, P. Lodewijks, E. Meynaerts , J. Pestiaux, N. Renders, P. Vermeulen, “Scenarios for a Low Carbon Belgium by 2050, Final Report”, Climat Vito, November 2013.
31. EPIA, “Global Market Outlook for Solar Power / 2016 - 2020,” 2016.
32. J. L. Sawin, K. Seyboth and F. Sverrisson, “Renewables 2016: Global Status Report”, 2016.
33. M. Hofmann, “Energy-Only Market in 2030”, 2015.
34. Photovoltaic Power Systems Programme, “PVPS Annual Report 2015,” 2015.
35. A. Jager-Waldau, “PV Status Report 2016”, JRC Science for Policy Report, European Commission, October 2016.
36. European PV Technology Platform Steering Committee PV LCOE Working Group, “PV LCOE in Europe 2014-30 Final Report”, 23 June 2015.
37. https://www.lazard.com/perspective/levelized-cost-of-energy-2017/
38. H. Ossenbrink, T. Huld, A. Jäger Waldau, N. Taylor, “Photovoltaic Electricity Cost Maps”, JRC Scientific and Policy

Report, European Commission, 2013.

39. M. S. ElNozahy and M. M. a. Salama, “Technical impacts of grid-connected photovoltaic systems on electrical networks—A review,” *J. Renew. Sustain. Energy*, 2013.
40. https://energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy
41. D. Tobnaghi, ‘A Review on Impacts of Grid-Connected PV System on Distribution Networks’, *Int. J. Electr. Comput. Energ. Electron. Commun. Eng.*, Vol. 10, No. 1, pp. 137–142, 2016.
42. A. Dubey, S. Santoso, ‘Electric Vehicle Charging on Residential Distribution Systems: Impacts and Mitigations’, IEEE Access, Vol. 3, pp. 1871-1893, 2015.
43. G. Lacey, G.Putrus, E. Bentley, ‘Smart EV charging schedules: supporting the grid and protecting battery life’, *IET Electr. Syst. Transp.*, Vol. 7 Iss. 1, pp. 84-91, 2017.
44. E. Bentley, G. Putrus, G. Lacey: ‘A modelling tool for distribution networks to demonstrate smart grid solutions’, *2014 IEEE Vehicle Power and Propulsion Conf. (VPPC)*, 2014, pp. 1–6.
45. C. Chardonnet, C. Czajkowski, and R. R. Sanchez, ‘Impact of electric vehicles on distribution network operation’, in *CIRED Workshop*, 2016, No. 415, pp. 4–7.
46. T. Helmschrott, M. Gödde, E. Szczechowicz, C. Matrose, and A. Schnettler, ‘Methodical approach for analyzing the impact of a mass introduction of electric vehicles on the electricity networks in Europe’, *2012 IEEE Power Energy Conf. Illinois, PECI 2012*, pp. 6–11, 2012.
47. R. A. Verzijlbergh, M. O. W. Grond, Z. Lukszo, J. G. Slootweg, and M. D. Ilic, ‘Network impacts and cost savings of controlled EV charging’, *IEEE Trans. Smart Grid*, Vol. 3, No. 3, pp. 1203–1212, 2012.
48. J. Van Der Burgt, S. P. Vera, B. Wille-Haussmann, A. N. Andersen, and L. H. Tambjerg, “Grid impact of charging electric vehicles; Study cases in Denmark, Germany and the Netherlands,” *2015 IEEE Eindhoven PowerTech*, 2015.
49. D. B. Richardson, ‘Electric vehicles and the electric grid: A review of modeling approaches, impacts, and renewable energy integration’, *Renew. Sustain. Energy Rev.*, Vol. 19, pp. 247–254, 2013.
50. E. Veldman and R. A. Verzijlbergh, ‘Distribution grid impacts of smart electric vehicle charging from different perspectives’, *IEEE Trans. Smart Grid*, Vol. 6, No. 1, pp. 333–342, 2015.
51. M. Gödde, E. Szczechowicz, T. Helmschrott, C. Matrose, and A. Schnettler, ‘Approach and main results of the G4V project analyzing the impact of a mass introduction of electric vehicles on electricity networks in Europe’, *2012 IEEE Transp. Electrif. Conf. Expo, ITEC 2012*, no. 241295, pp. 0–4, 2012.
52. https://maxem.io/nl/shop
53. https://www.tesla.com/en_GB/support/home-charging-installation
54. http://www.xe.com/currencyconverter/convert/?Amount=1&From=GBP&To=EUR
55. https://shop.mobilityhouse.com/de_en/ladestationen/icu-eve-mini-rfid-904460034.html
56. https://shop.mobilityhouse.com/de_en/pv-loesung/smartfox-energiemanager.html
57. https://shop.mobilityhouse.com/de_en/nrgkick-32a-light-22kw-5m-kabel-typ2-cee-anschluss.html
58. https://shop.mobilityhouse.com/de_en/homepage-suggests/keba-kecontact-p30-98125.html
59. https://shop.mobilityhouse.com/de_en/smart-fortwo-electric-drive/abl-wall-box-emh1-basic-with-cable-evse563-22-kw-incl-5m-cable-type2.html
60. https://newmotion.com/nl_NL/laadpalen-voor-thuis/consumer-product/home-standard
61. https://www.kraftriket.no/privat/el-bil/
62. http://www.xe.com/currencyconverter/convert/?Amount=22990&From=NOK&To=EUR
63. Eurelectric, “SMART CHARGING: steering the charge, driving the change”, March 2015.
64. K. M. Tan, V. K. Ramachandaramurthy, and J. Y. Yong, ‘Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques’, *Renew. Sustain. Energy Rev.*, Vol. 53, pp. 720–732, 2016.
65. http://www.v2g.co.uk/2015/06/solar-pv-powered-public-v2g-charging-launched-in-utrecht/
66. Elaadnl,, EV Related Protocol Study – Original Study Report Version 1.1, January 2017.
67. Mercedes-Benz, „E-Mobility – Vehicle2Grid interface (Schnittstelle zwischen Fahrzeug & Infrastruktur)“, Stuttgart, December 2012.
68. http://standards.sae.org/j2847/2_201110/ 16th August 2017.
69. http://www.mennekes.de/index.php?id=vorteile_typ_2&L=1 16th August 2017.
70. Kempton, W. et al., “A Test of Vehicle-to-Grid (V2G) for Energy Storage and Frequency Regulation in the PJM System”. University of Delware, 2008.
71. http://greengears.net/v2g-becomes-a-reality/ accessed 16th August 2017.
72. http://www.yougen.co.uk/blog-entry/2688/How+much+will+V2G+cost+and+when'2C+where+and+who+will+make+it+happen'3F/, (Accessed 11/08/2017).
73. https://www.nissan.co.uk/experience-nissan/electric-vehicle-leadership/xstorage-by-nissan.html (Accessed 17th August 2017).
74. http://utilityweek.co.uk/news/grid-scale-battery-storage-is-gathering-momentum/1244582#.WZS5slWGPRY (Accessed 17th August 2017).
75. T. U. Daim, X. Wang, K. Cowan, and T. Shott, ‘Technology roadmap for smart electric vehicle-to-grid (V2G) of residential chargers’, *J. Innov. Entrep.* 5(15), 2016.
76. element energy, Frequency sensitive electric vehicle and heat pump power consumption, final report for National Grid, , July 2015.

77. http://www.iec.ch/
78. A. Damiano, G. Gatto, I. Marongiu, M. Porru, and A. Serpi, ‘Vehicle-to-Grid Technology: State-of-the-Art and Future Scenarios’,*J. Energy Power Eng.*, 8(1), pp. 152-162, 2014.
79. http://www.energyresourcefulness.org/Fuels/plug_ins.html
80. B. Nykvist, M. Nilsson, ‘Rapidly falling costs of battery packs for electric vehicles’, *Nature Climate Change*, *pp* 329–332, March 2015.
81. McKinsey&Company, “Electrifying insights: How automakers can drive electrified vehicle sales and profitability”, January 2017. http://www.mckinsey.com/industries/automotive-and-assembly/our-insights/electrifying-insights-how-automakers-can-drive-electrified-vehicle-sales-and-profitability accessed 27 March 2017
82. T. Randall, “Here’s How Electric Cars Will Cause the Next Oil Crisis”, Bloomberg, February 2016. https://www.bloomberg.com/features/2016-ev-oil-crisis/ (Accessed 27 March 2017).
83. The Boston Consulting Group, “Batteries for Electric Cars-Challenges, Opportunities, and the Outlook to 2020” ,2009. https://www.bcg.com/documents/file36615.pdf (Accessed 27 March 2017).
84. Luthander, R., Widén, J., Nilsson, D. and Palm, J., ‘Photovoltaic self-consumption in buildings: A review’, *Applied Energy*, *142*, pp. 80-94, 2015
85. M.N. Akter, M.A. Mahmud, Amanullah M.T. Oo, ‘Comprehensive economic evaluations of a residential building with solar photovoltaic and battery energy storage systems: An Australian case study’, *Energy and Buildings*, Volume 138, pp. 332-346, 2017.
86. T. Lawder , V. Viswanathan , V. R. Subramanian, ‘Balancing autonomy and utilization of solar power and battery storage for demand based microgrids’, *Journal of Power Sources*, Volume 279, pp. 645-655, April 2015,.
87. R. McKenna, E. Merkel, W. Fichtner, “Energy autonomy in residential buildings: A techno-economic model-based analysis of the scale effects”, *Applied Energy*, Volume 189, Elsevier, pp. 800-815, March 2017.
88. C. Rae and F. Bradley, ‘Energy autonomy in sustainable communities-A review of key issues’, *Renewable and Sustainable Energy Reviews*, Vol. 16, , pp. 497–6506, 2012.
89. S. Lamberth-Cocca and M. Friedrich, “Success with Electric Mobility. Case studies of user-friendly services and innovative business models”, DELFIN, June 2016
90. https://www.gov.uk/government/statistical-data-sets/veh02-licensed-cars
91. The Ultra Low Carbon Vehicle Demonstrator Programme, “Assessing the viability of EVs in daily life”, 2013.
92. R. Bessa, “Electric Vehicles Aggregation Agents: a Business Opportunity”, Lisboa, June 2012.
93. K. Laurischkat, and D. Jandt, "Business Model Prototyping for Electric Mobility and Solar Power Solutions", *Procedia CIRP*, *48*, pp.307-312, 2016.
94. https://www.whatcar.com/car-leasing/
95. R. Kalmbach, W. Bernhart, P. Kleimann, M Hoffmann, "Automotive landscape 2025: opportunities and challenges ahead", Roland Berger Strategy Consultants, Munich, 2011.
96. https://www.autolib.eu/en/
97. W. Mats and C. Stålstad. "Four business models for a fast commercialization of plug-in cars." In D. Beeton and G. Meyer (eds): *Electric Vehicle Business Models*, pp. 17-34. Springer International Publishing, 2015.
98. http://www.evchargingsolutions.co.uk/electric-vehicles/ Accessed 13/08/2017
99. http://www.ev-box.com/knowledge-center/faq/what-are-the-costs-of-charging-an-electric-car/ Accessed 13/08/2017
100. http://www.idolaad.com/shared-content/blog/rick-wolbertus/2016/charge-tarrifs.html?origin=56Kq9e2vRD6ttDv0vafU5Q
101. Nationaal Kennisplatform Laadinfrastructuur, Verslag van de workshop Benchmark Kosten Publieke Laadinfrastructuur 2016, August 2016.
102. https://fastned.nl/en/choose-your-priceplan (Accessed 29/08/2017)
103. https://my.newmotion.com/ (Accessed 13/08/2017)
104. http://newatlas.com/fortum-charge-and-drive-tesla-supercharger-nebbenes-norway/45284/ (Accessed 13/08/2017)
105. W. Kempton, J. Tomic, S. Letendre, A. Brooks, T. Lipman, T., “Vehicle-to-Grid Power:Battery, Hybrid, and Fuel Cell Vehicles as Resources for Distributed Electric Power in California”, report prepared for the California Air Resources Board and the California Environmental Protection Agency 06-01-2001.
106. K. Uddin, T. Jackson, W.D. Widanage, G. Chouchelamane, P. A. Jennings, J. Marco, ‘On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by an integrated vehicle and smart-grid system’, *Energy*, Vol 133, pp. 710-722, August 2017,.
107. https://learn.pjm.com/energy-innovations/plug-in-electric.aspx
108. A. Hoke, A. Brisette, A. Pratt, K. Smith, “Electric Vehicle Charge Optimization Including Effects of Lithium-Ion Battery Degradation”, *Vehicle Power and Propulsion Conference (VPPC*), IEEE, October 2011.
109. K. Smith, M. Earleywine, E. Wood, A. Pesaran, Battery wear from Disparate Duty-Cycles: Opportunities for Electric-Drive Vehicle Battery Health Management, American Control Conference, NREL, Canada, October 2012
110. M. Koller, T. Borsche, A. Ulbig, G. Andersson, “Defining a Degradation Cost Function for Optimal Control of a Battery Energy Storage System”, *PowerTech (POWERTECH)*, Grenoble, IEEE, 2013.
111. G. Lacey, G. Putrus, “Controlling EV Charging Schedules: Supporting the Grid and Protecting Battery Life”, *IEEE Vehicle Power and Propulsion Conference (VPPC)*, October 2015 Montreal.
112. Electric Vehicles for City Renewable Energy Supply: Ongoing EU Interreg project 1 Jan 2017 to 30 Jun 2021.
113. http://www2.nationalgrid.com/uk/services/balancing-services/

114. https://www.tennet.eu/?L=0#&panel1-1 (Accessed 13/08/2017).

115. Product Specification FCR, TenneT, February 2017.

116. Survey on Ancillary services procurement, Balancing market design 2015, ENTSO-E WGAS, May 2016.

117. EEA (2016) Electric Vehicles in Europe, EEA Report | No 20/2016, European Environment Agency, Copenhagen.

118. M. Aasness and J. Odeck, (2015) ‘The increase of electric vehicle usage in Norway: incentives and adverse effects’, *European Transport Research and Review*, 7: 34.

119. Vlaanderen, 2016, Milieuvriendelijke voertuigen — Zero-emissie premie (http://milieuvriendelijkevoertuigen.be/zero-emissiepremie) (Accessed March 2017).

120. D. Tost, (2014), “Berlin approves new incentives for electric car drivers” (http://www.euractiv.com/section/transport/news/berlin-approves-new-incentives-for-electric-car-drivers) (Accessed March 2017).

121. O. Hannisdahl, H. Malvik, G. Wensaas (2013), “The future is electric! The EV revolution in Norway — explanations and lessons learned”, EVS27 paper.

122. Nederland elektrisch, 2016 (http://nederlandelektrisch.nl/english'Nederland elektrisch) (Accessed March 2017).

123. Go Ultra Low City Scheme, 2016, '£40 million to drive green car revolution across UK cities', (https://www.gov.uk/government/news/40-million-to-drive-green-car-revolution-across-ukcities) accessed March 2017.

124. IEA, Global EV Outlook 2016: Beyond One Million Electric Cars, Paris France. Online at:- http://www.iea.org/publications/freepublications/publication/Global_EV_Outlook_2016.pdf

125. OLEV (Office for Low Emission Vehicles, UK), "Electric vehicle homecharge scheme guidance for customers: 1 March 2016". Availale at: www.gov.uk/government/uploads/system/uploads/attachment_data/file/514339/electricvehicle-homecharge-scheme-guidance-for-customers-2016.pdf.

126. V. Bareman, F. Behrends, A. Fanicchia, W. Gee, N. van Rijn, and A. Schmidt, “Future Solar Cities. A Policy Set for Amsterdam”, Resourcefully, Amsterdam.

127. C.A. Klockner, A. Naynm, M. Mehmetoglu, ‘Positive and negative spillover effects from electric car purchase to car use’,, *Transp. Res. D*, Vol. 21, pp. 32-38, 2013.

128. L. Jacobs, K.Laurenz, S.Keuchel, C. Thiel, ‘Willingness to pay for electromobility: an investigation among owners of energy-efficient houses’, *Transportation Research Procedia*, Vol. 13, pp. 40-48, 2016.

129. E. Figenbaum, T. Assum, M. Kolbenstevedt, ‘Electromobility in Norway: Experiences and Opportunities’, *Research in Transportation Economics*, Vol. 50, pp. 29-38, 2015.

130. F. Liao, E. Molin, B. Van Wee, ‘Consumer preferences for electric vehicles: A literature review’, *Transport Reviews*, 37:3, pp. 252-275, 2016

131. G. Pellischek, H. Lüttringhaus, D. Seidel, “Final Report Publishable Summary”, ELVIRE Consortium 2013, June 2013.

132. C. Rudolph, ‘How many incentives for electric cars affect purchasing decisions?’, *Transport Policy*, Vol. 52, pp. 113-120, 2016.

133. L. Frenzel, J. Jarass, S. Trommer, B. Lenz, 2015, “Erstnutzer von Elektrofahrzeugen in Deutschland. Nutzerprofile, Anschaffung, Fahrzeugnutzung“. Deutsches Zentrum für Luft-und Raumfahrt e.V., Berlin.

134. Report on the Research Project CROME (for the period 2011-2013)”, Bundesministerium für Wirtschaft und Technologie, March 2014. See also: Schäuble, P. Jochem, W. Fichtner (Eds.) (2016), *Cross-border Mobility for Electric Vehicles: Selected Results from One of the First Cross-border Field Tests in Europe*, KIT Scientific Publishing, Karlsruhe, Germany.

135. My Electric Avenue project: http://myelectricavenue.info/about-project

136. http://www.eafo.eu/sites/default/files/Final%20report%20Green%20eMotion%20project.pdf

137. W. Kempton, F. Marra, P.B. Andersen and R. Garcia-Valle, ‘Business models and control and management architectures for EV electrical grid integration’, In R. Garcia-Valle and J.A. Pecas Lopes (eds): *Electric Vehicle Integration into Modern Power Networks*. Springer: New York, 2013, pp. 87-105.

138. http://newsroom.nissan-europe.com/uk/en-gb/media/pressreleases/145248.

139. http://www.greencarcongress.com/2017/06/20170605-toyotacity.html.

140. https://timesofsandiego.com/tech/2017/06/14/electric-car-drivers-can-sell-back-electricity-in-uc-san-diego-test/

141. http://ucsdnews.ucsd.edu/pressrelease/nuvve_and_uc_san_diego_to_demonstrate_vehicle_to_grid_technology.

142. https://www.gov.uk/government/news/innovative-vehicle-to-grid-technology-to-receive-20-million

143. DIN, “Electromobility - Digital communication between a D.C. EV charging station and an electric vehicle for control of D.C. charging in the Combined Charging System (DIN SPEC 70121:2014-12)”, Dec 2014, [online] http://www.din.de/en/technical-rule/din-spec-70121/224350045

144. ISO, “Road vehicles -- Vehicle to grid communication interface -- Part 3: Physical and data link layer requirements (ISO/IEC 15118-3:2015)”, 2015, [online] http://www.iso.org/iso/catalogue_detail.htm?csnumber=55366

145. http://www.openchargealliance.org/protocols/oscp/oscp-10/

146. http://www.openchargealliance.org/protocols/ocpp/ocpp-20/

147. “IDO-laad.” [Online]. Available: http://www.idolaad.nl/.

148. J. Després, N. Hadjsaid, P. Criqui, and I. Noirot, ‘Modelling the impacts of variable renewable sources on the power sector: Reconsidering the typology of energy modelling tools’, *Energy*, Vol. 80, pp. 486-495, 2015.

149. D. P. van Vuuren, M. Hoogwijk, T. Barker, K. Riahi, S. Boeters, J. Chateau, S. Scrieciu, J. van Vliet, T. Masui, K. Blok, E. Blomen, and T. Kram, ‘Comparison of top-down and bottom-up estimates of sectoral and regional greenhouse gas emission reduction potentials’, *Energy Policy*, Vol. 37, Iss. 12, pp. 5125-5139, 2009.

150. J. Begley, N. Berkeley, T. Donnelly, D. Jarvis, ‘National policy-making and the promotion of electric vehicles’, *International Journal of Automotive Technology and Management* 16 (3), pp. 319-339, 2016.

151. A. Villreal, ‘The social construction of the market for electric cars in France: politics coming to the aid of economics’, *International Journal of Automotive Technology and Management* 11 (4), pp. 326-339, 2016.

152. S. Bakker and J.J. Trip, ‘Policy options to support the adoption of electric vehicles in the urban environment’, *Transportation Research Part D* 25, 18-23, 2013.

153. D. Newman, P. Wells, P. Niewenhuis, H. Davies, ‘Urban, sub-urban or rural: where is the best place for electric vehicles?, *International Journal of Automotive Technology and Management* 14 (3/4), pp. 306-323, 2014.

154. [https://en.energinet.dk/-/media/Energinet/El-RGD/El-PBU/Dokumenter/LVT-MDA---Tekniske-forskrifter/Engelske-tekniske-forskrifter/Engelske-tekniske-forskrifter---grid-connection/TR-3_3_1/Technical-regulation-3_3_1-for-battery-plants---revision-1.pdf?la=en accessed 18/12/2017]