Northumbria University NEWCASTLE

Interreg North Sea Region SEEV4-City
European Regional Development Fund
EUROPEAN UNION

SEEV4-City

Smart, clean Energy and Electrical Vehicles for the City

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Business models for Vehicle to Grid (V2G) and policy

The SEEV4City Challenge

- A top priority of public authorities on all levels in the North Sea Region area is stimulating clean transport solutions powered by clean renewable energy.
- Due to a difference in demand and supply of renewable energy, electric vehicles are not always charged with renewable energy and electrical grid instability is an actual concern.
- The challenge is to structure the system in such a way that **electric vehicles will be charged by locally produced renewable energy.**
- These objectives will be realized by using the EV batteries as a short term storage of renewable energy, through bidirectional chargers. This technique is known as Vehicle to Grid (V2G), and allows to balance out the curve of power demand over the day.

This means that the electricity system is able to assimilate a higher amount of renewable energies and more electric vehicles.

Project Goals and Business Model

Three goals:

- ✓ Increase ***energy autonomy***.
- ✓ Increase ***ultra-low emission kilometres (CO2 reductions)***.
- ✓ **Avoid extra grid investments** to *make existing electrical grids compatible* with an increase in electro mobility and local energy production.

The results should enable

- ✓ **Clean electric transport services** and **renewable energy generation integration**,
- ✓ ***New businesses*** for renewable energy & **ultra-low emission mobility services**,
- ✓ ***Social acceptance*** *studies, management guidelines and policy frameworks*

Need to consider the cost of Electric Vehicle ownership/usage in order to ***develop a feasible business model***.

WP5: Policy and Business Case

The **main aims** are to research the concept of '**vehicle4energy services**' and to develop **business models** to **integrate electric vehicles in** a **Sustainable Urban Mobility and Energy Plan** (SUMEP).

- ✓ **Operational Optimisation**: Evaluate charging techniques & vehicle energy management system **to extend battery life & reduce total cost of ownership and use**.
- ✓ **Planning, Business and Economic Optimisation**: Develop and analyse cost-benefit models and scenarios under actual conditions of individual use or organisation-wide operation **at home, street, neighbourhood to city level**.

Electric vehicle use – stimulation

[credit: Matteo Conti and Richard Kotter, Northumbria University]

The complexity of EV development and its business success are dependent on a large number of variables which need to trigger other prerequisites in the right sequence to bring technical progress and as a result extensive mass production as part of an EV ecosystem.

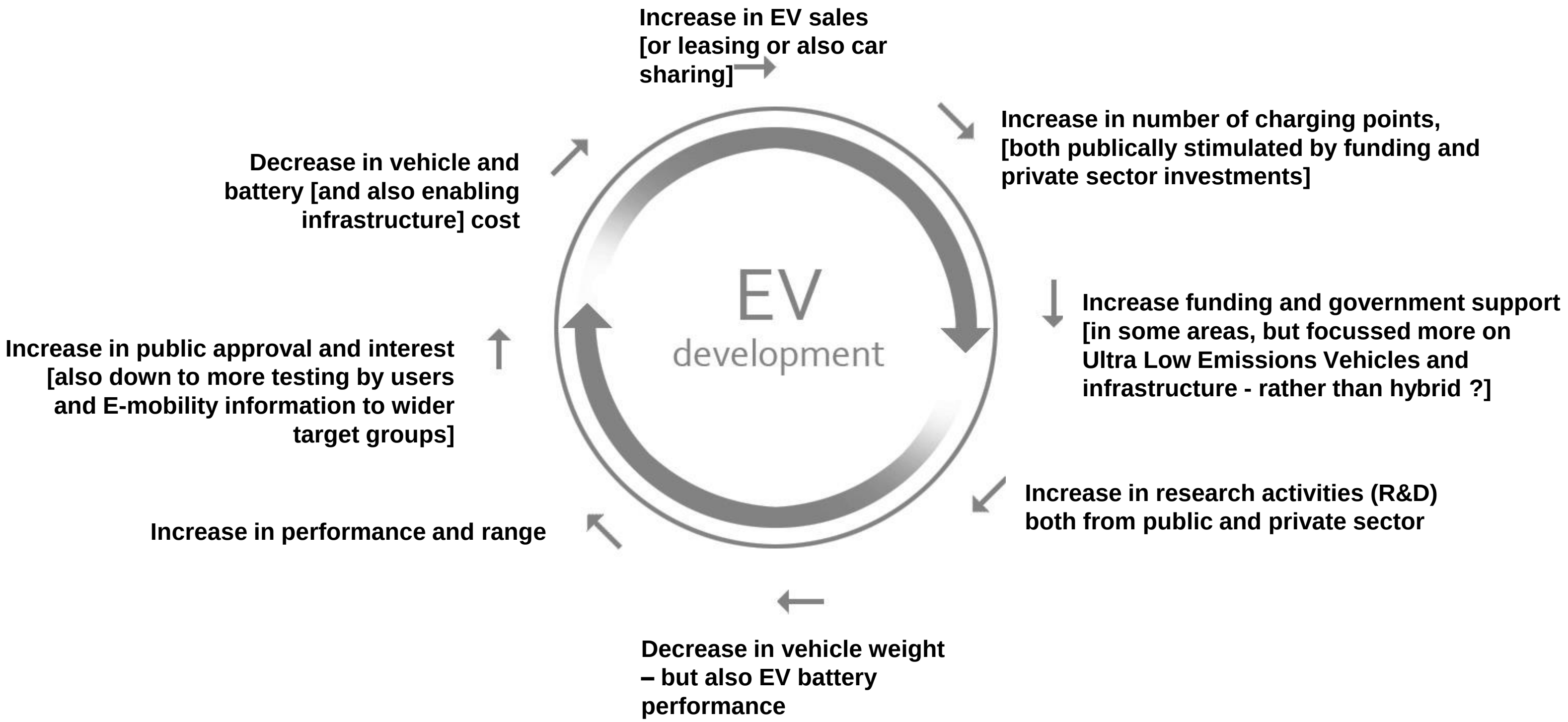


Figure: EV development cycle

Types of Electric Vehicles

Amongst a vast range of EVs these are some main types:

- BEV (Battery Electric Vehicle) *is an electric vehicle that utilises chemical energy that is stored in rechargeable battery packs.*
- HEV (Hybrid Electric Vehicle: parallel and series types) *is a vehicle that uses both an electric motor and a conventional internal combustion engine. This type of vehicle is considered to have better performance and fuel economy compared to a conventional one.*
- PHEV (Plug-in Hybrid Electric Vehicle: parallel and series types) *is a vehicle whose battery can be recharged by plugging it in to an external source of electric power as well by its on-board internal combustion engine and generator.*
- MHEV (Mild Hybrid Electric Vehicle) *is a simplified version of a PHEV where an electric motor/generator, powered by a small battery, is able to assist the internal combustion engine during hard acceleration, coasting, braking, and stop-start conditions.*
- E-REV (Extended Range Electric Vehicle) *or* REEV (Range Extended Electric Vehicle) *is a vehicle that functions as a BEV as long as the battery has charge remaining before it engages an auxiliary energy supply (normally a compact ICE) to provide additional power to recharge the battery*
- FCEV (Fuel Cell Electric Vehicle) *uses a propulsion system similar to a BEV although the vehicle is fueled by hydrogen which is turned into electricity by the fuel cell. This type of vehicle does not produce any tailpipe poisonous emissions.*

Battery Electric Vehicle (BEV)

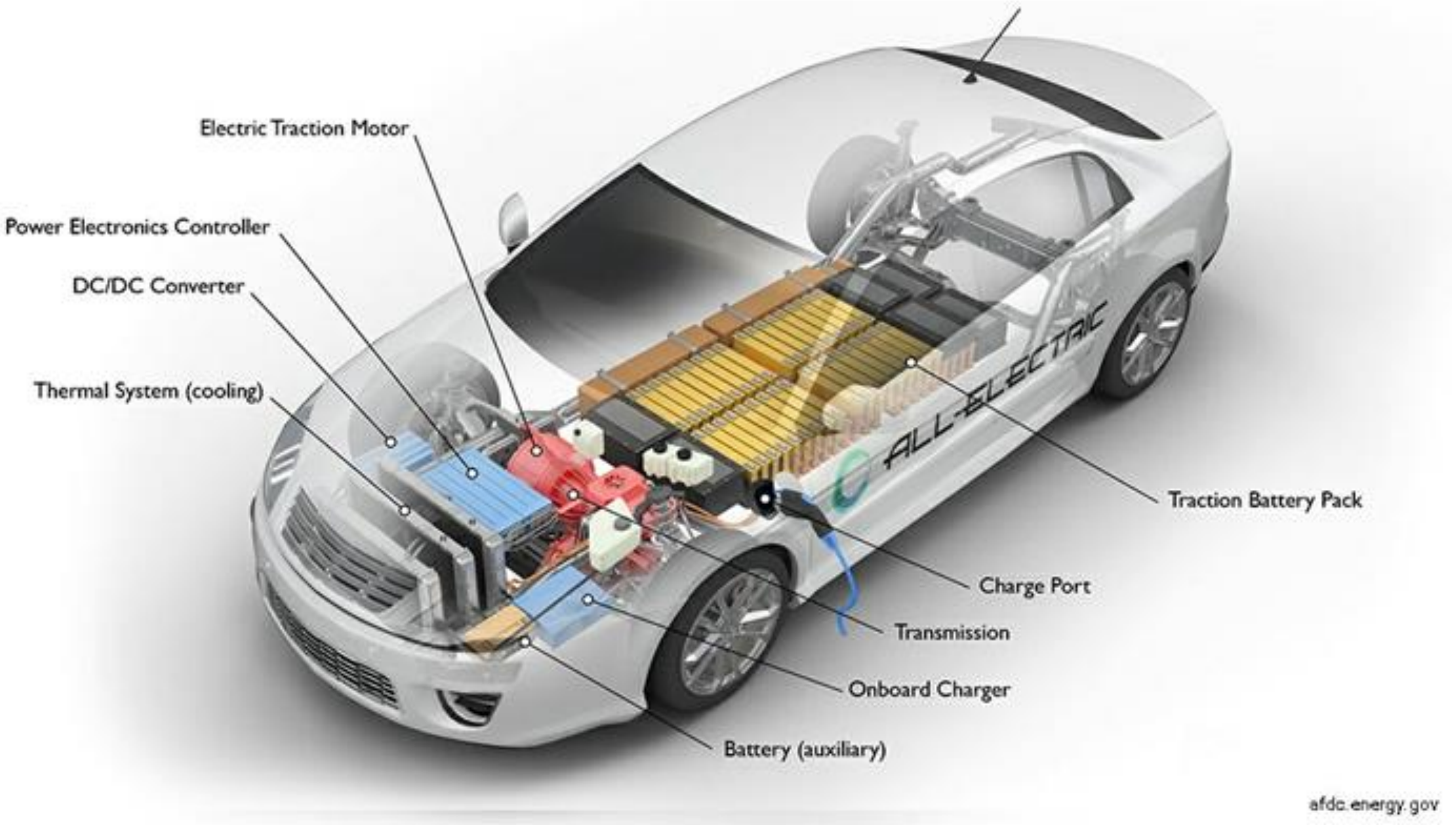


Figure 2: Battery Electric Vehicle (U.S. DOE, 2017)

Battery Electric Vehicle (BEV)

BEVs (Fig. 2) are charged through a chargeable traction battery pack to supply electric traction motors and other motors to control the vehicle propulsion.

Battery recharging can be performed using an onboard charger system or through the vehicle charge port connected to an offboard system.

- Onboard: uses AC (Alternate Current) and is capable of recharging in a few hours (EATON, 2011)
- Offboard: usually operates using DC (Direct Current) and may directly recharge the batteries in less than an hour. In addition, the offboard platforms include a more sophisticated Battery Management System (BMS) that may result in a reduction of the vehicle weight and improvement of vehicle efficiency, since this component is no longer needed in the vehicle.

According to Sakka et al. (2011), a DC-DC converter is useful to interface different components in the electric powertrain by boosting or chopping voltage levels.

A simple parallel combination of batteries / SCs may result in different voltage levels, which can be controlled by introducing a DC-DC converter.

Moreover, driving at high voltages makes for a more efficient use of the electric motor.

Battery Technology

The battery system is the key component of an electrified drive train, once it determines how an electric vehicle will be efficient.

A battery system is assembled by cells, battery management system, electrical and sensor systems, shelter elements, cooling periphery and casing.

According to Germany Trade & Invest (2015), the overall system operation and efficiency are influenced by cell chemistry and design factors.

In the early 20th century EVs were powered by lead acid batteries.

Nowadays the main battery technologies available on the market are:

- lead acid battery (Pb)
- nickel-cadmium (NiCd)
- metal hydride (NiMH)
- lithium ion (Li-ion in various chemistries)

Battery Technology and Costs

According to Berckmans et al. (2017), the average of current batteries assembled on small cars may provide 18.2 kWh (range up to 153 km) as well as medium-large cars are provided of 36.2 kWh (range up to 231 km).

On the other hand, the latest battery technologies as observed in the Tesla Model S® can delivery 60–100 kWh and may result in a range of more than 400 km, which has dramatically encouraged EV adoption.

However, the battery performance is directly influenced by the weather and user driving conditions. Vehicles such as Tesla Model S (75D) may reduce the range by 18% when the temperature drops from 21°C to -17°C and considering that the car drives at 100 km/h.

The battery cost is considered another huge challenge for e-mobility success.

About 10 years ago (BCG, 2010), the battery cost at low volumes reached USD1,220/kWh for OEM (Original Equipment Manufacturer), where approx. 65% of this price is due to the cells and components. However, the battery costs year by year have reduced the prices.

Yirka (2015) suggest that prices will fall approx. 8% per year and can reach USD 150/kWh in the next decade, due to improvements made by battery manufacturers.

In addition, Berckmans et al. (2017) suggest that the battery cost will come down to USD 131/kWh.

Both cases allowing the BEV cost to be competitive compared to ICE technologies and considering a possible rising oil prices scenario.

A tangible sign of this trend is confirmed by Tesla battery cost for Model 3 to be reduced by 35% in the new company’s Gigafactory.

Battery Technology and Recycling

- **Where is this sourced from and under what (labour, and environmental) conditions and impacts ?, which is related to OEM's Corporate Social Responsibility policies and (automotive and other) reporting initiatives**

For some, such as Cobalt, the human and labour rights record of major producing countries, such as the Democratic Republic of Congo are a major concern. Battery supplier LG Chem claims that they have stopped using conflict-sourced Cobalt.

Also, Recycling [including Second-Life battery use – i.e. non-automotive use but for energy storage for instance] can help reduce the need to search for battery materials. Cobalt for instance is fully recyclable and about 15 % of U.S. cobalt consumption is from recycled scrap today.

Nickel is also a concern, with hidden environmental and health costs in some of the key mining countries, such as Australia, Canada, Indonesia, Russia and the Phillipines (May Oprey, 2018; https://www.theguardian.com/sustainable-business/2017/aug/24/nickel-mining-hidden-environmental-cost-electric-cars-batteries)

- **How much do batteries cost?**

This relates also to the type of – developing – battery technologies and also scale of production (mass volume).

Battery technology is reported to be continuing to improve. For instance, Lithium-titanate and lithium-iron-phosphate, are growing in importance in the EV market and they also do not need Cobalt.

Different battery chemistries that rely on magnesium, sodium, or lithium-sulfur are also being focused on as they are argued to have the potential to outcompete lithium-ion batteries on energy density and cost.

Battery Technology and Automotive Battery Life (& Warranty]

- **How long do EV batteries last?**

The advanced batteries in EVs are designed for a reasonably long automotive life but will wear out eventually for automotive uses.

The convention is that this is when the battery capacity has been reduced to 80% of its original specification.

Currently, most manufacturers are offering 8-year/100,000-mile warranties for their EV batteries.

Nissan is providing additional battery capacity loss coverage for 5 years or 60,000 miles.

For the USA, manufacturers have also extended their coverage in federal states that have adopted the California emissions warranty coverage periods, which require at least 10-year coverage for batteries on partial zero-emissions vehicles (which include EVs).

https://www.ucsusa.org/clean-vehicles/electric-vehicles/electric-cars-battery-life-materials-cost#.Ww_YpS-ZNTY

Debates Over EV Lifetime CO2 Emissions

The traction battery impact as the most polluting of an EV in the vehicle lifetime. For this reason EU regulations require the battery makers to finance the costs of collecting, treating and recycling all collected batteries. Consequently, some encouraging tie-ups between carmakers and recyclers are taking place. Umicore has recently invested 25M Euros in a new plant in Antwerp to recycle Li-ion batteries and provide precious metal to car OEMs as Tesla and Toyota.

Research studies (as confirmed by Dale Hall and Nic Lutsey in ‘Effects of battery manufacturing on electric vehicle life-cycle greenhouse gas emissions’, 2018) pointed out that an EV using average European electricity is nearly 30% cleaner over its life cycle compared to even the most efficient ICE vehicle on today’s market. It follows that even if the environmental credential of EVs based on the energy production to power those vehicles is critically important, the whole debate over vehicle emissions should be based on the premise that an EV usually produces about half the greenhouse gas emissions of an average European ICE passenger car.

Therefore, key debates are around lifecycle, CO2 emissions, well-to-wheel, cradle to grave, etc.

A useful and reliable source is provided by Eurostat for the EU (data extracted in June 2017; planned article update in June 2018): ‘Electricity production, consumption and market overview’.

http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_production,_consumption_and_market_overview

The article describes the electricity market in the European Union with an analysis of electricity production / generation (the two terms are used synonymously) according to a range of different energy sources.

A national statistical office, or a relevant national agency, will have the equivalent national data for a country you are interested in.

How Clean is Your Electric Vehicle?

According to Bloomberg New Energy Finance (2016) driving an electric vehicle is 39% cleaner than using an ICE vehicle. It is predicted that by 2040 such key figure will reach 67% as solar and wind power will be increasingly playing a bigger role in the energy generation mix of many countries.

In the USA the Union of Concerned Scientists (UCS) has produced a website called "How Clean is *Your* Electric Vehicle?" which is an emissions tool designed to calculate the impact of a common vehicle and in relation to a designated area.

The UCS website states that electric cars tend to produce less carbon pollution than gas-powered ones, but just how much less? By entering the user's ZIP code it is possible to see how different types of vehicles stack up in the user's area. Entering a make, model, and year will narrow results to a specific EV model.

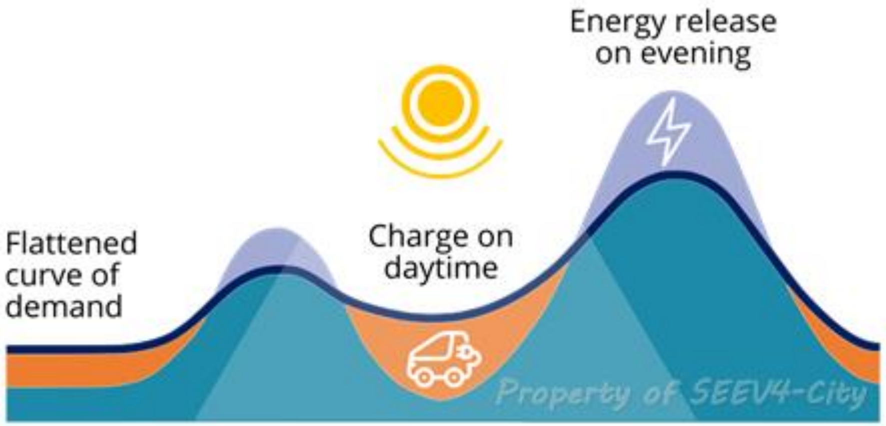
https://www.ucsusa.org/clean-vehicles/electric-vehicles/ev-emissions-tool#.Ww_ZQS-ZNTY

A dedicated website published by *The Guardian* 'How green are electric cars' provides key statistics about GreenHouseGas [GHG] emissions and the amount of energy used by the mainstream types of EVs. It also provides an interesting account of how electricity is produced in various countries across the globe showing that Norway, for instance, is the nation which relies the least on fossil fuel to generate electricity, thus making EVs a very eco-friendly mode of transport.

https://www.theguardian.com/football/ng-interactive/2017/dec/25/how-green-are-electric-cars

Without, and with, Vehicle to Grid (V2G)

[credit: SEEV4City consortium]



Electric Vehicle Charging Systems

There are a number of charging systems which cater for different users needs:

- Standard Chargers
- Quick/Rapid Chargers
- Flexible rating Chargers
- Fast Chargers
- [in the near future: Super-fast / Super-Quick Chargers]
- Pentograph (E-buses)
- Vehicle to Grid Chargers [that is, with bi-directional flow]
- And also perhaps wireless induction charging in the (near) future

The following table illustrates the charging systems currently available, their main specifications and place of installation.

Charging Systems, Levels of Charging Stations

Charging Systems available					
Source	Wikimedia commons (2017a)	Wikimedia commons (2017b)	Wikimedia commons (2016a)	Wikimedia commons (2016b)	Wikimedia commons (2017c)
Type	Universal receptacle Level 1	Level 1 charging station	Level 1 & 2 charging station	Commercial Level 2	DC Quick Charger
Input voltage	110/120V AC	110/120V AC	208/240V AC	208/240V AC	208V AC
Max Power	Up to 1.9 kW	1.9 – 3.6 kW	3.8 – 7.2 kW	7.2 – 16.8 kW	50 kW
Design					
Applications					
Installation locations	Single and multi-family homes, parking garages, university campuses, truck stops, restaurants, airports, municipalities, shopping centers, corporate offices, hotels.	Single and multi-family homes, real estate developers, builders, military bases, government city centres, schools, small offices.	Single and multi-family homes, real estate developers, builders, government city centres, schools, small offices.	Workplace, parking garages, hotels, entertainment centers, shopping centers, restaurants, amusement parks, museums, grocery stores, university campuses.	Pharmacy stores, convenience stores, off-interstate dining, rest / truck stops, university campuses.

Infrastructure Charging Requirements

In today's fast developing world of increased energy consumption and e-mobility ensuring that power demands are met at all times is not necessarily a given. This is why current charging infrastructure needs to feature the following requirements and characteristics:

- availability
- reliability
- robustness
- speed of commissioning and implementation
- mode and opportunity of access
- cost of installation and operation
- Cost of use

The Charging Infrastructure Design Guide by EV Association Scotland and OREF published in July 2016 gives a clear and structured overview of good practice for charging infrastructure as far as safety, signage and general use is concerned.

(http://www.oref.co.uk/wp-content/uploads/2016/07/20160726-Charging-Infrastructure-Design-Guide-V1.3.3.pdf)

Charging Systems – market trends

One trend is also to see how locally produced, including on site / installation, **solar energy can be integrated in the running / powering of EV charging infrastructure – so-called solar car pods**. Potentially, this could include some locally generated wind energy also**: https://electrek.co/2017/09/20/giraffe-electric-car-charging-power-solar-wind/**

The current home-charging systems such as provided by Tesla needs close to 9 h (75 kWh) or 6 h (100 kWh) to provide a full charge of the Model X, which can range up to 480 km with a single charge. However, the DC quick charger can accomplish this task in close to an hour, since the DC charger is able to connect directly to the traction pack batteries.

In the UK companies as Chargemaster (official Toyota charging partner) and podPOINT (official Nissan charging partner) provide and install chargers for home and also off-street parking. Both Japanese automotive manufacturers offer their chargers to be installed free of charge for their EV and PHEV customers respectively.

BP is taking over Chargemaster: British Petroleum, nowadays just BP, will buy one of the UK's largest electric car charging providers. Chargemaster runs about 6,500 EV charging stations in their Polar network. They did not disclose any details but the new company will be called BP Chargemaster and plans on setting up additional fast-charging stations at BP pit stops

An increasing trend are **fast or rapid chargers**. Indeed Estonia has designed it's national EV charging system on them; and they are coming more to the UK – some of them co-funded by the EU as part of the TEN European (motorway or main roads) network, such as the Rapid Charge Network project, the development of a multi-standard, rapid charge network for electric vehicles throughout the UK and Ireland. http://rapidchargenetwork.com/about.php

Even though a **DC (rapid) charger** shows an advantage regarding the short time to recharge the batteries, the International Energy Agency – IEA (2017) identified that mostly common the charge system is concentrated on private charge stations. However, the public charge stations have grown, following the increase of the number of electrical vehicles, which also makes public stations a prerequisite for making EVs successful.

There are also up-coming ultrafast charger networks: Porsche had already build its own super-fast charging station. The first two networks are Ionity, which is backed by BMW, Mercedes, Ford, and Volkswagen, and Ultra-E, which is backed by Allego, Audi, BMW, Magna, Renault, Hubject, and others such as Fortum Drive & Charge. This planned network is now also referred to as MEGA-E, which will consist of 322 Ultra-fast chargers (up to 350 kW) and 27 smart charging hubs throughout 20 European countries. Both networks aim to deploy charging stations with a charging capacity up to 350 kW, which could charge an electric vehicle faster than any charging station in operation today. EON has also launched it's own network. https://electrek.co/2018/01/24/ultra-fast-electric-vehicle-charging-network-europe/ http://www.alphr.com/cars/1007599/eon-launching-its-own-ultra-fast-ev-charging-network-in-europe

Charging System: V2G

Work at Northumbria University and elsewhere has shown that at present the economic benefits of V2G to the EV owner fall short of the costs of battery degradation for some applications such as peak shaving, with current battery prices and technology.

The adoption of a modelling tool developed to study Low Voltage (LV) networks has shown that attempting to charge too many EVs at the same time on a LV network can result in excessive voltage drops, together with cable / line and transformer overload, presenting a risk of system damage.

Uncontrolled charging increases the risk of system overload, since there is no guarantee that charging won't take place at a time of peak load such as 6.00pm.

See the Interim SEEV4City State of the Art Summary report:

http://www.northsearegion.eu/media/4384/summary-state-of-the-art-report-seev4-city.pdf

A very recent Cenex workshop (by invitation only, May 2018) report for Innovate UK into 'V2G Market Study' is also highly relevant.

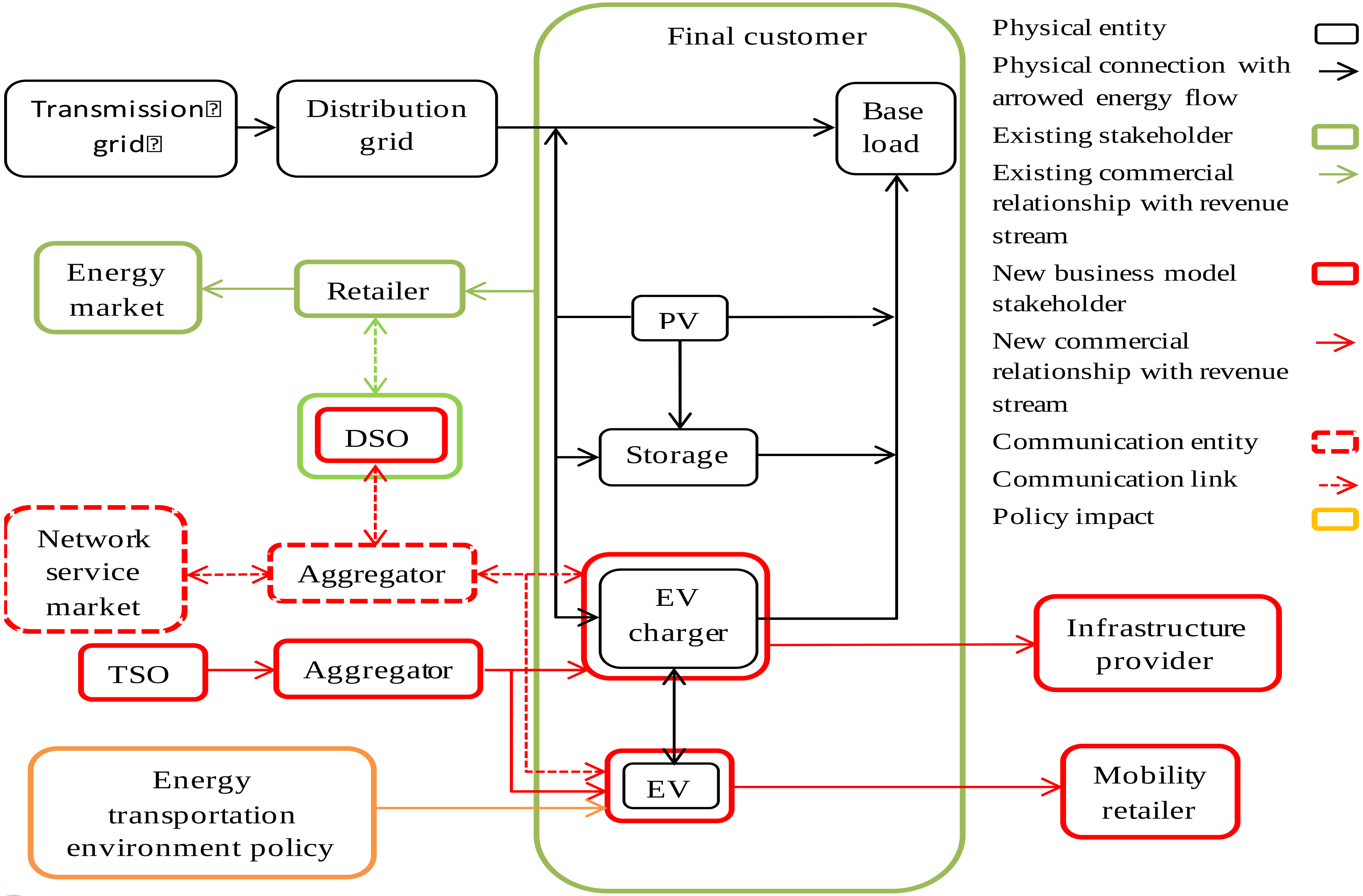
The participants gave the feedback in group discussions that, amongst other main markets, 'Vehicle to Building', 'Workplace', 'Return to base Fleets', 'Residential (Domestic)', as well as 'Community Energy Schemes' and – in the future – 'Automotive Vehicles' are promising markets, all with their specific drivers (and barriers), different potential business models and Unique Selling Points (USPs)

It is noteworthy that Innovate UK – with support from the Office of Low Emissions Vehicles (OLEV) [i.e. the UK Government] in early 2018 competitively awarded almost £30 million £ available for V2G technologies and business models https://www.gov.uk/government/news/30-million-investment-in-revolutionary-v2g-technologies

- Through the Industrial Strategy the government is committed to becoming a world leader in shaping the future of mobility and in the design and development of the clean technologies of the future. This investment will help deliver on that ambition, supporting vehicle-to-grid (V2G) technologies that could enable electric cars and other vehicles to deliver electricity back to the smart grid, to light homes and power businesses.
- The funding has been awarded to 21 V2G projects, to pay for research and design and development, with the aim of exploring and trialling both the technology itself and commercial opportunities.
- These schemes, including EDF Energy's V2GO scheme, will demonstrate how energy stored in electric vehicle batteries could be borrowed by the electricity system during peak hours, before being recharged during the off-peak in time for their drivers to set off on their next journey

Generic EV Business Model Structure

[credit: Northumbria University SEEV4City team]



Business Model Pillars

Clean

- Target: CO_2 emission minimization
- ICE (Internal Combustion Engine) substitution
- Energy mix (time dependent)
- Renewable (PV) integration

Energy Autonomy

- Target: energy autonomy maximization
- Smart charging and Demand Side Management (DSM) for load shifting
- Optimal utilization of static battery where applicable

Grid

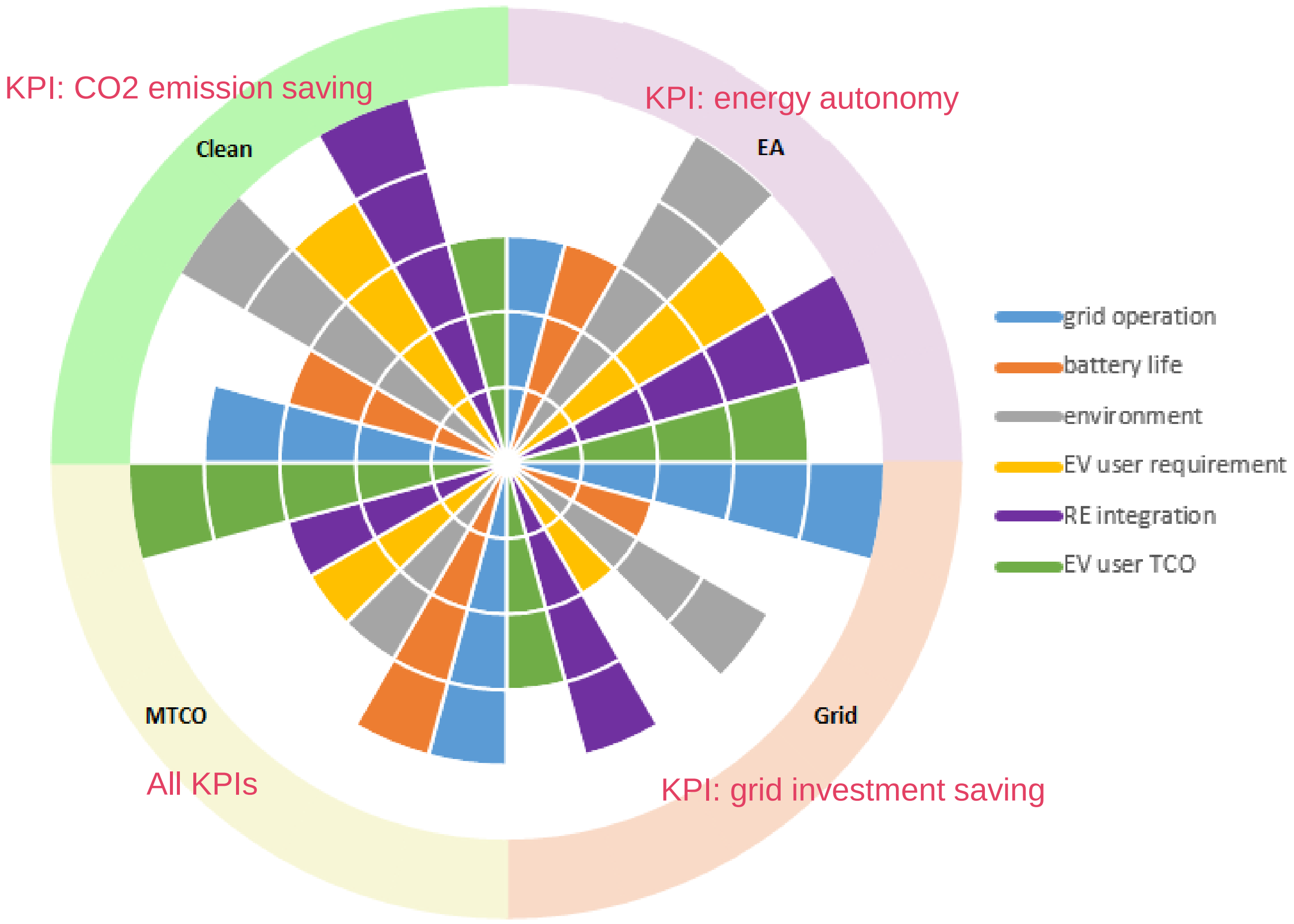
- Target: minimize the deviations between supply and demand via smart charging and V2G
- Investment savings
- Smart charging to minimize the mismatch between load and PV
- Balancing services

M-TCO/U

- Target: minimize the modified TCO (Total Cost of Ownership) and TCU (Total Cost of Use)
- Provision of services to obtain revenue stream
- Subsidies and policies
- Battery life optimization

Strength / focus of each BM Pillar

- A range of dimensions and their strengths are set based on the SEEV4City State-of-the-Art review http://www.northsearegion.eu/media/4384/summary-state-of-the-art-report-seev4-city.pdf
- There is a trade-off among the pillars for the different OPs as they have different objectives.
- The strengths will be evaluated before and after the implementation of the generic business model to the OPs



- EV user requirement should not be sacrificed in any case, and this will be taken into account as a constraint during model development and implementation.
- Policy and route mapping can increase the strength of any OP along part or all of the dimensions

Loughborough Pilot evaluation – pilot setting & assumptions

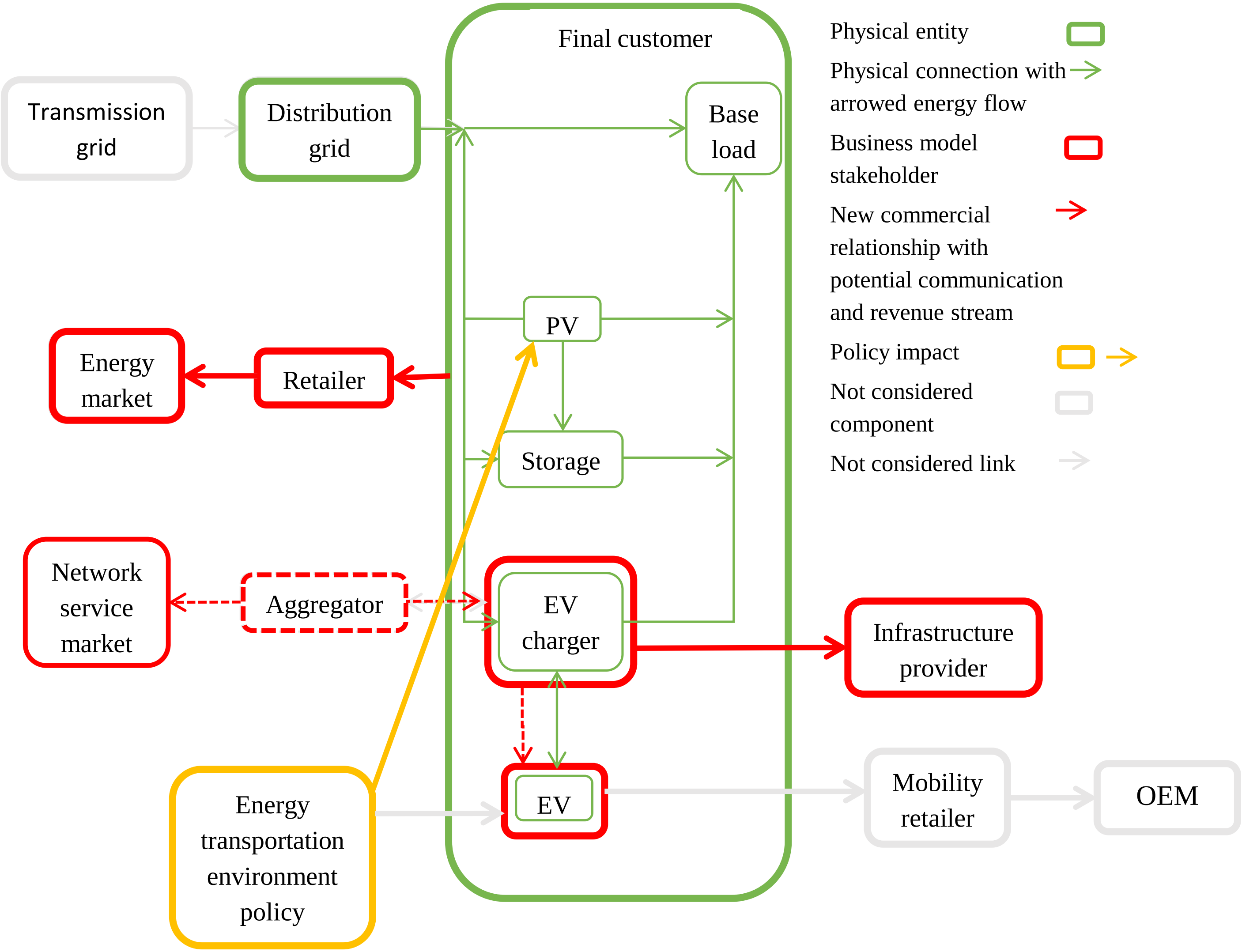
Variable	Value	Unit
EV size	24	kWh
PV size	4	kWp
Charging/V2G unit converter size	3	kW
Static battery size	4	kWh
Static battery converter size	400	W
Electricity tariff price	10	p/kWh (fixed)
PV generation tariff	13.39	p/kWh
PV export tariff	4.85	p/kWh
EV and static battery efficiency	100	%
EV departure State of Charge (SoC) requirement	50	%

- Home charging is the only charging method
- Vehicle discharges power into the home but not controlled to export to the grid
- Static battery size is 4 kWh according to the Moixa website
- The recorded operational data of the pilot is assumed to be the baseline case where Cenex's proposed scenarios are applied

Aspects considered in previous work and proposed for Loughborough Operational Pilot SEEV4-City

Considered aspects	Y. Wang, D. Infield and S. Gill	R. Gough, P. Speers and V. Lejona, C. Dickerson, P. Rowley, and C. Walsh	SEEV4-City
Renewable	✗	✓	✓ PV generation
Grid impact analysis	✓	✗	✓ (for KPI of grid infrastructure cost saving)
Simulation style	Day ahead with assumptions	Scenario base (real time)	Day ahead with assumptions
EV usage pattern	✓ Simulated data	✓✗ (✗ due to rough assumptions)	✓ (real data)
User requirement	✓	✓✗	✓
Battery degradation	£/kWh	£/cycle	£/kWh (via a more comprehensive battery degradation model)
Methodology	Price arbitrage	Price arbitrage capacity market STOR	Frequency response Price arbitrage capacity market
Scale	Domestic	Domestic Building	Domestic
Base load	Individually simulated	Data based	Real data
Optimization technique	✓	✗	✓
CO_2 emission	✗	✗	✓ (alongside with increase in energy autonomy and clean km)

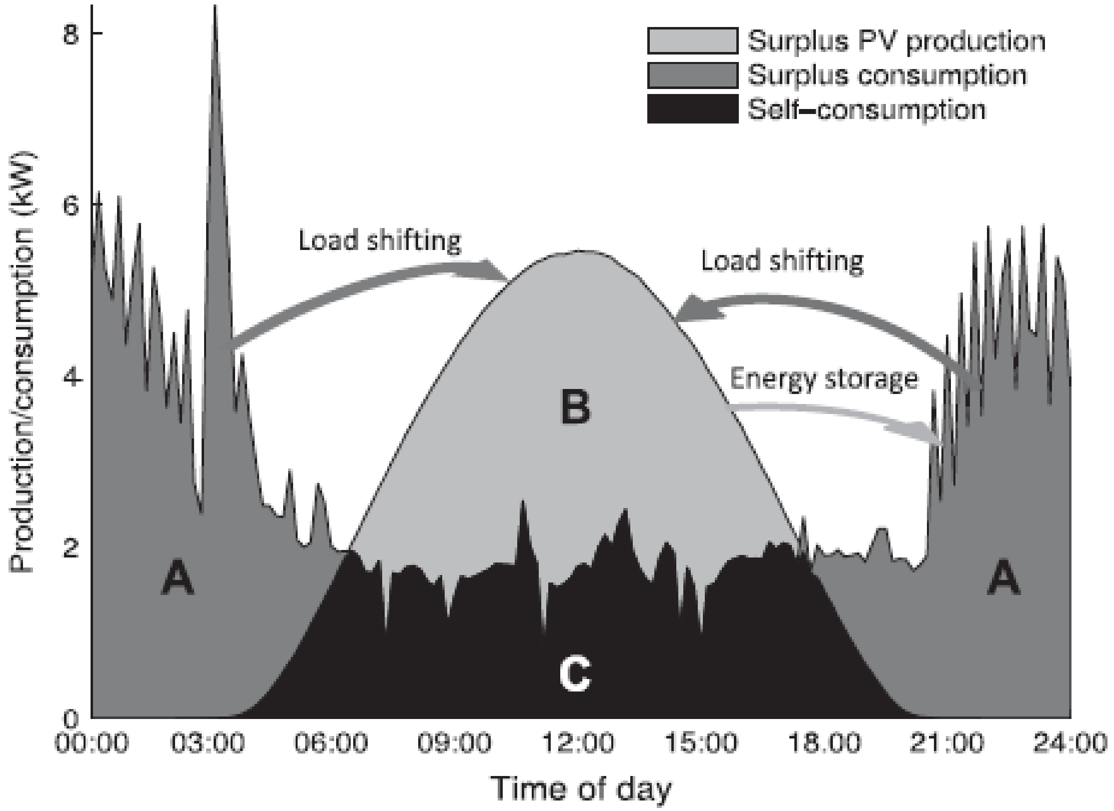
Boundary identified in generic BM – Loughborough pilot



R. Gough, C. Dickerson, P. Rowley and Chris Walsh, 'Vehicle-to-grid feasibility: A techno-economic analysis of EV-based energy storage', Applied Energy, Vol. 192, 2017, pp. 12-23

R. Gough, P. Speers and V. Lejona, 'Evaluating the Benefits of Vehicle-to-Grid in a Domestic Scenario', EVS30 Symposium, Stuttgart, October 2017

Loughborough Pilot – Energy Autonomy pillar methodology



R. Luthander, J. Widén, D. Nilsson, J. Palm, “Photovoltaic self-consumption in buildings: A review”, Applied Energy, Vol. 142, January 2015, pp. 80–94.

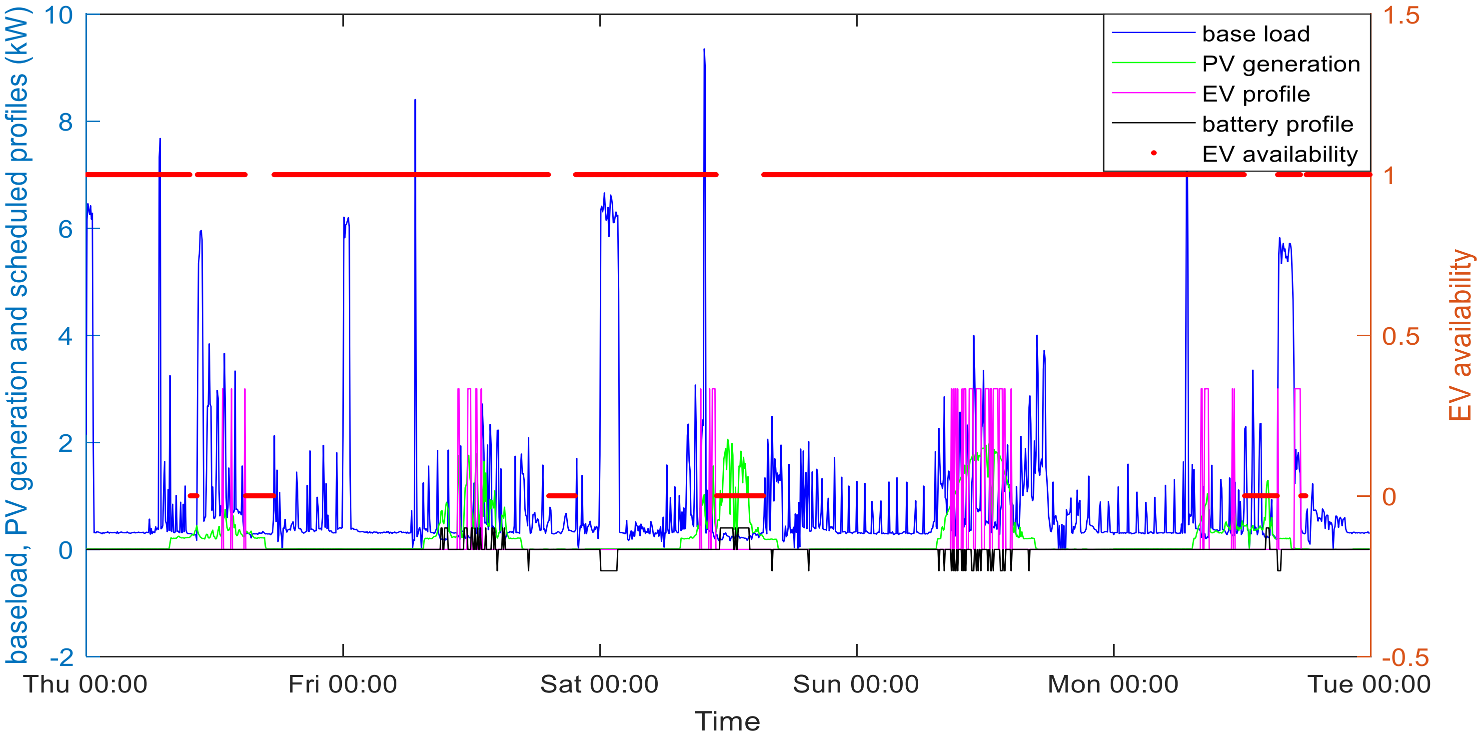
$$Self - sufficiency = \frac{Amount\ of\ local\ production\ consumed}{Total\ load} = \frac{C}{A + C}$$

Loughborough Pilot – EA pillar implementation and associated cost evaluation for a 5-day winter period 9th(Thu) – 14th(Tue) Nov 2017

- Pilot operation data (recorded)
  - Base load: household base demand
  - PV generation
  - EV availability: 1 is parking at home and 0 otherwise
- Scheduled data
  - EV profile
  - Battery profile: static battery

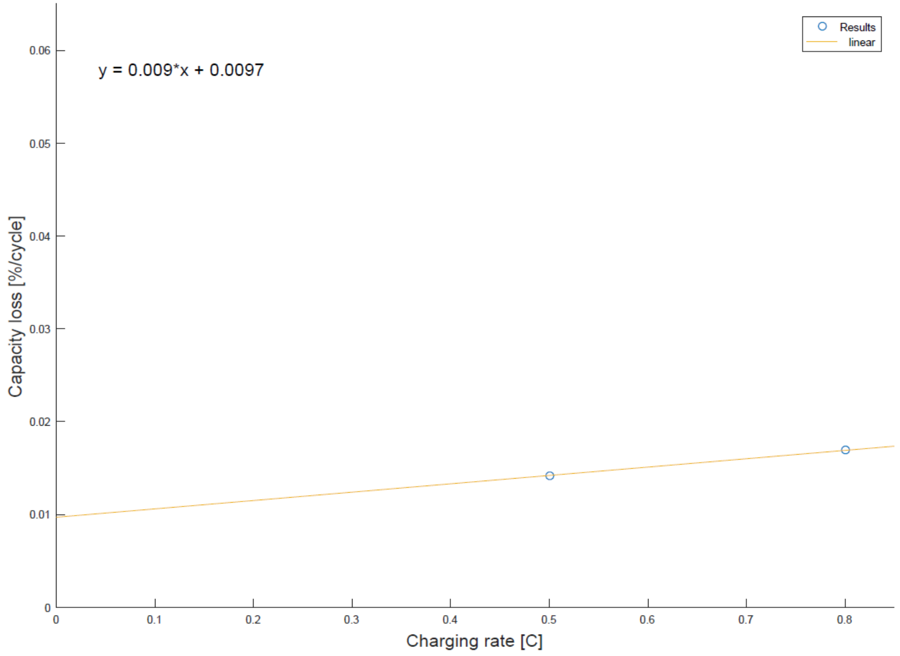
Note: The recorded operational data of the pilot is assumed to be the baseline case

- Costs:
  - Electricity cost
  - Battery degradation cost
- Profits:
  - FiT generation tariff
  - FiT export tariff



	Baseline	Energy autonomy pillar (EV charging only)	Relative difference (%)
Energy autonomy (%)	17.87	21.45	20
Energy cost (£)	8.05	5.89	- 26.8
Energy cost exclusive of battery degradation cost (£)	5.24	4.81	- 8.2

Loughborough Pilot – battery degradation cost



- Lab experiment of capacity loss per cycle @ 0.5C and 0.8C for 2.6 Ah LG Li-ion battery
- Linear extrapolation to 0.125C which corresponds to the rate in the pilot
- Same degradation profile is assumed to be transferable to the battery on Nissan Leaf
- Nissan Leaf battery cost of \$200/kWh is assumed
- Kempton's method is used to evaluate the degradation cost

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

- EV battery degradation cost @ 3 kW is 5.73 p/kWh of energy throughput

Formula for cost of degradation

$$C_D = \frac{(ES \times C_B) + (C_L \times LH)}{ES_L} = \frac{(ES \times C_B) + (C_L \times LH)}{ES \times DOD \times B_C}$$

Where ES is the battery capacity in kWh,

ES_L is the total energy stored in the battery during its life cycle in kWh,

C_B is cost of battery replacement in $/kWh,

C_L is cost of labour in $/h,

LH is labour time for battery replacement in hours, and

B_C is battery life in cycles.

It is assumed that battery replacement is determined by its cycle life, not the calendar life [1].

The battery cost used would be most appropriately the new replacement cost rather than the original cost, since EV battery prices have fallen steeply in recent years.

For modern batteries the term $DOD*B_C$ is constant for a given C rate average SOC and temperature.

If the costs of labour are ignored one gets: $C_D = C_B/(DOD*B_C)$

W. Kempton J. Tomic, S.Letendre, A. Brooks, T. Lipman, Vehicle-to-Grid Power: Battery, Hybrid, and Fuel Cell Vehicles as Resources for Distributed Electric Power in California paper prepared for the California Air Resources Board and the California Environmental Protection Agency 2001.

Firm Frequency Response 1

In the UK, on 2013 figures median compensation for energy delivered was £145 MWh^{-1} and £805 h^{-1} for committing a 50MW plant to be available for firm frequency response [14]. A minimum aggregate power level of 10MW is required for a fast reserve supplier to participate in the UK regulation scheme.

Thus an EV owner with a 7kW charger participating in a 50MW aggregate might expect to receive £0.145 per kWh supplied or £1.015 per hour at 7kW, and with a 7kW charger might receive an additional £805 *7000/50,000,000 or about £0.11 per hour for committing his EV. Total available revenue before aggregation costs = £1.13 per hour, assuming full utilisation.

[14] J. D.K. Bishop, D. Bonilla, C. J. Axon, D. Banister (2016) 'Estimating the grid payments necessary to compensate additional costs to prospective electric vehicle owners who provide vehicle-to-grid ancillary services' Energy Vol. 94, 1 January 2016 pp715-727.

Firm Frequency Response 2

The EV owner would be part of an aggregate of 50,000,000/7000 = 7143 EVs with 7kW chargers connected for the 1 hour period. The aggregator would charge fees so the net outcome would be somewhat less for the EV owner. The constitution of the aggregate would change, as some EVs were used for driving.

Given balanced supply and drawdown of power, one could ignore costs of power. Degradation costs would be £0.067 kWh^{-1} ie £0.067*7 = £0.47 per hour giving a profit of about 66p/h (£1.13-£0.47) ; approx. £13 for 20 h/day connection or about £4818 per year assuming full utilisation. Power throughput at 7kW would be 140kWh /20 hour day or 51100kWh per year. For a 24kWh EV this would represent 51100/24 =2129 cycles at 100% DOD, or 51100/24*0.75 = 2839 cycles at 75% DOD. The problem is that the EV battery would need replacing after between 1 and 2 years if its cycle life was 3500 [14].

Economics with modern batteries

If batteries could be used at a cost of $200/kWh, with a V2G lifetime of >10,000 cycles at 100% DOD at C/3,such as the A123, degradation costs would be $200/1*10000, $0.02/kWh or £0.015/kWh. This gives degradation costs of 7*£0.015 = £0.105 per hour. Income would still be £1.13 per hour giving a net profit of as much as £1.025 per hour, £20.05 per 20 hour day or £7318 per year assuming full utilisation.

Power throughput at 7kW would be 140kWh /20 hour day or 51100kWh per year. For a 24kWh EV this would represent 51100/24 =2129 cycles at 100% DOD with a modern battery. The EV battery would need replacing after about 5 years if its cycle life was over 10000. In this period a net profit of well over £30000 could be anticipated, enough to replace a Nissan Leaf even without a subsidy.

2013 National grid FFR market

Energy Payment = 145 £/MWh

Availability Payment = 805 £/h @ 50MW

7kW charger

50,000/7=7143 chargers @7kW

EP= 0.145 £/kWh ➔ £1.1015/h @7kW

+

AP= £0.11/h @7kW

=

R= £1.13/h @7kW

−

c_D = 0.067 £/kWh

C_D = 0.067*7=0.47£/h

=

66p/h

13£/day or 4818£/year @20h/day

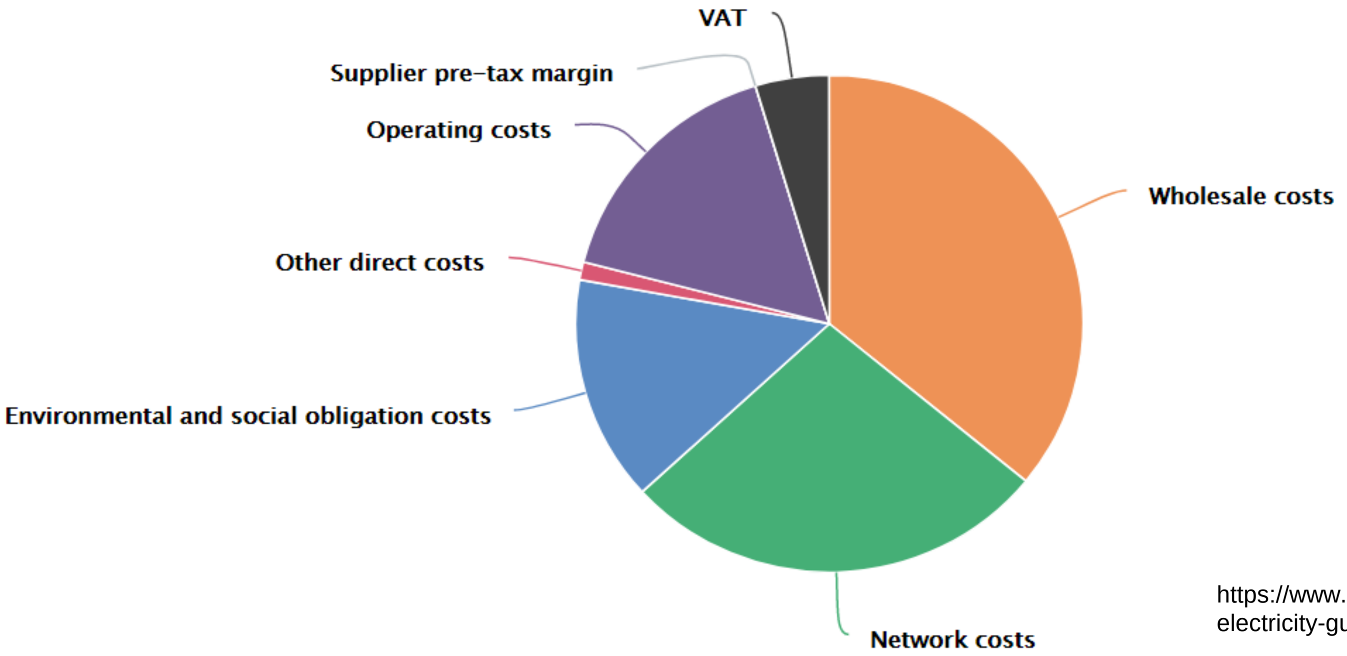
140 kWh/day @ 7kW ➔ 51,100 kWh/year

51,100/24= 2129 cycles @24kWh EV and 100% DOD

But

Dynamic pricing

- **Real-time pricing based on wholesale electricity price**
  - **Breakdown of an electricity bill (UK, information correct as of August 2017) – will change with market trends and government policy**



https://www.ofgem.gov.uk/consumers/household-gas-and-electricity-guide/understand-your-gas-and-electricity-bills

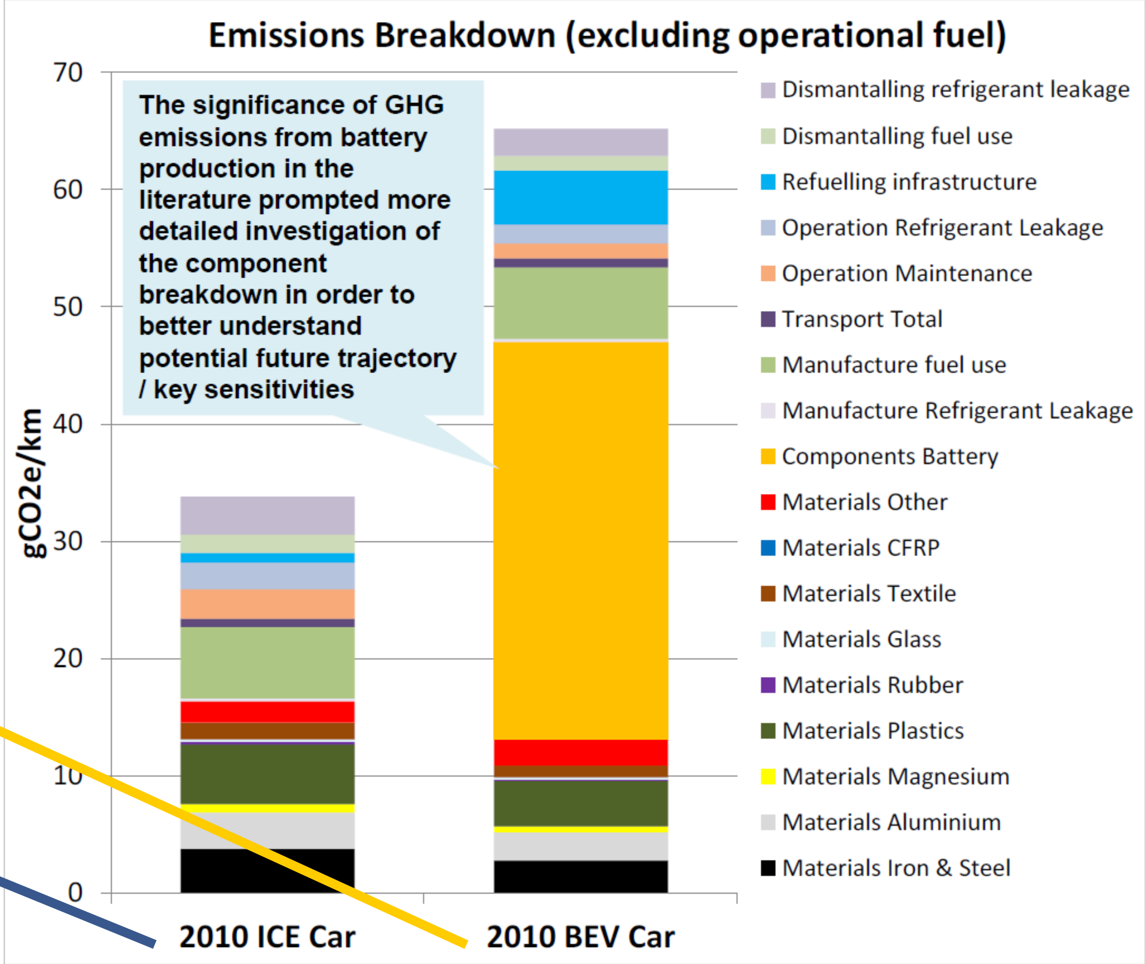
- **Potential tariff due to transformer/substation loading**

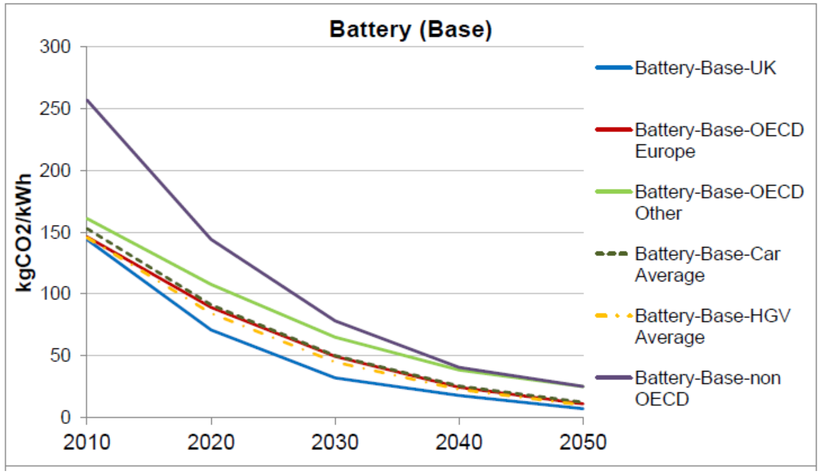
CO2 emission saving due to ICE substitution – Lifecycle Assessment

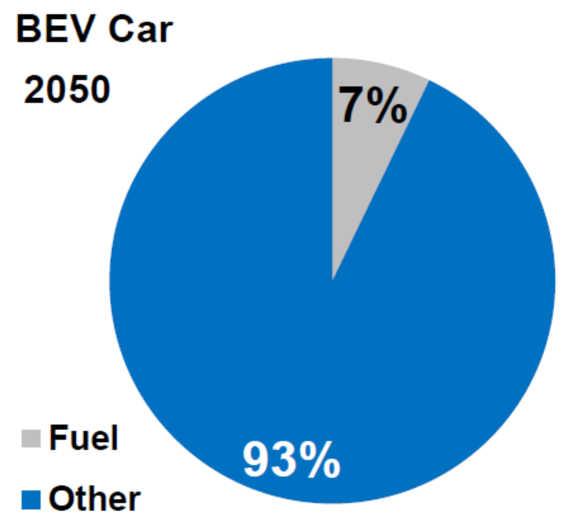
- Manufacturing
- ~~Operational cost~~
- Maintenance
- EOL (End of Life)

BEV: 65.28 g/km in 2010

ICE: 34.45 g/km in 2010





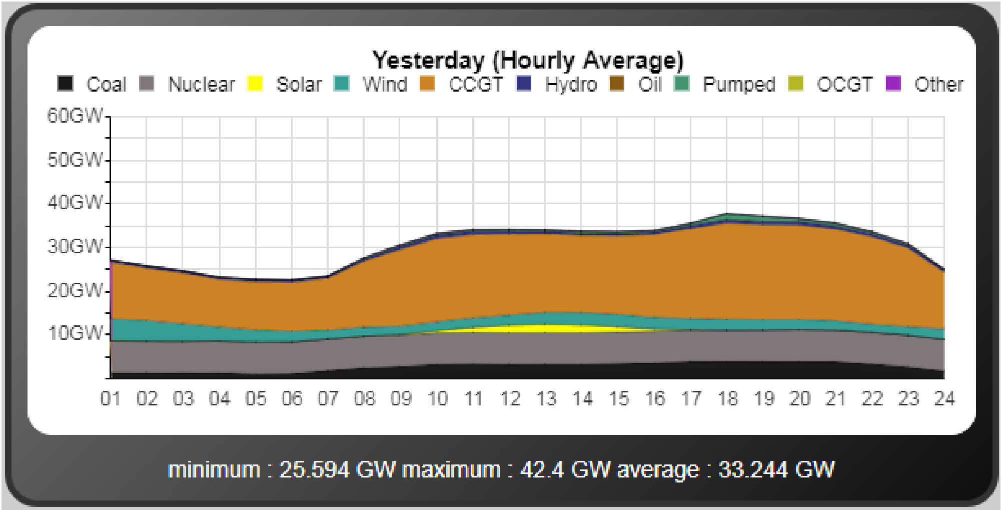


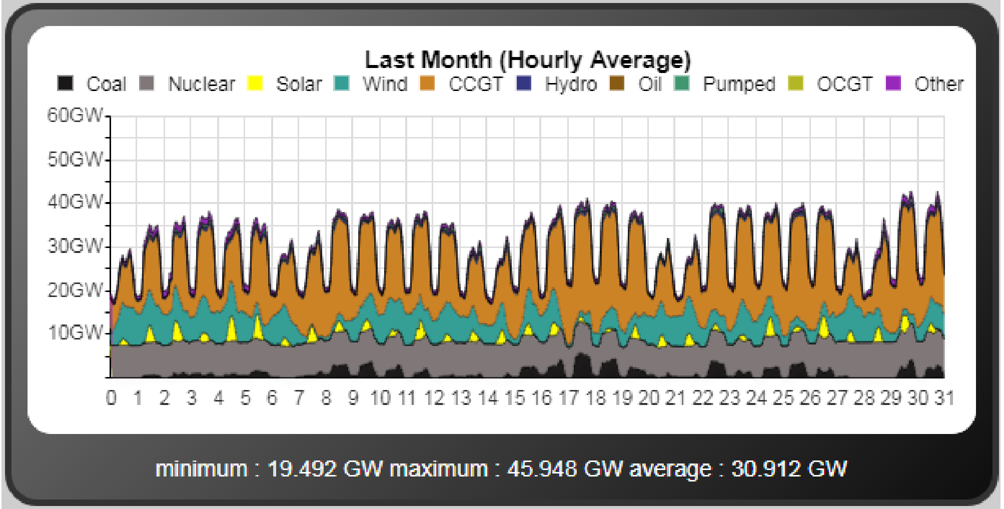
15.52 g/km in 2050 excluding fuel

N. Odeh, N. Hill and D. Forster, 'Current and Future Lifecycle Emissions of Key 'Low Carbon' Technology and Alternatives, Final Report, RICARDO-AEA, April 2013

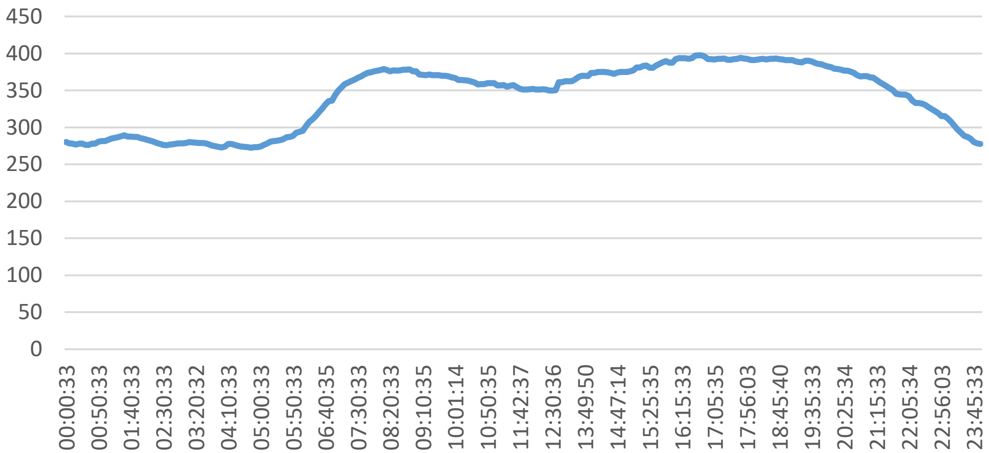
Time-dependent CO_2 emission due to energy mix

As of 12/11/2017





Energy mix based CO_2 emission for 09/11/2017 [g/kWh]



Merit order of different generation types

Generation type	Life time CO2 emission value
Wind	11
Nuclear	16
Hydro	20
PV	40
CCGT	487
OCGT	487
Oil	650
Coal	870

http://gridwatch.co.uk/co2-emissions

https://www.nrel.gov/docs/fy13osti/56487.pdf

Leicester proposed BM: Smart solar carport

EA

- Target: minimize grid interaction translated in energy autonomy maximization
- Smart charging to ensure charging at the lowest cost
- V2G to provide excess energy to the council building load

Involved Stakeholders

- Leicester City Council
- Private individuals
- Wester Power Distribution
- Chargemaster

Costs

- Energy cost
- Smart and V2G unit investment cost
- Management cost to the charge manager
- Degradation cost of the EV and static battery and replacement?
- PV annualized cost
- Parking management cost?

EA

CO_2

Grid

Further benefits: Carbon footprint reduction and local authority demonstration leadership

Benefit

The benefits are seen as **financial savings** compared to the baseline case

- Lower energy cost due to the increase in Energy Autonomy
- The grid is not under significant stress because of the increased PV utilization, hence the capacity payment for grid congestion will be lower

Amsterdam city proposed BM: Green energy

EA
CO_2
Grid

Clean

- Target: CO_2 emission minimization
- ICE substitution
- Energy mix (time dependent)
- Renewable (PV) integration

Involved Stakeholders

- Private vehicle owners
- Alliander
- NUON
- City of Amsterdam
- ElaadNL
- Province of Noord-Holland

Costs

- Energy cost
- Smart and V2G unit investment cost
- Management cost to the charge manager

Further benefits: environmental savings and local authority demonstration leadership

Benefit

The benefits are seen as **financial** compared to the baseline case

- Lower energy cost due to the increase in Energy Autonomy
- Lower environmental costs (GHG emissions and urban air pollution)

Kortrijk proposed PM: Smart Solar Carport

EA

- Target: minimize grid interaction translated in energy autonomy maximization
- Smart charging to ensure charging at the lowest cost
- V2G to provide excess energy to the depot load

Involved Stakeholders

- KBC, City of Kortrijk (Stad Kortrijk) and KU Leuven(Vehicle owners)
- City of Kortrijk (building owner)
- KBC (Leasing, PV array owner) and Eneco (PV array operator)
- Gaselwest, Vlaanderen (and Wallonie), VVSG, SmartGridsFlanders, Energyville platform and provincie West-Vlaanderen

EA
CO_2
Grid

Costs

- Energy cost
- Smart and V2G unit investment cost
- PV annualized cost
- Parking management cost

Benefit

The benefits are seen as **financial and environmental savings** compared to the baseline case

- Lower energy cost due to the increase in Energy Autonomy

ArenA proposed BM: Optimized electricity management

EA
CO2
Grid

EA

- Target: minimize grid interaction translated in energy autonomy maximization
- Smart charging and V2G for load shifting
- Peak shaving and back-up power
- Optimized use of battery (battery degradation reduction)*

Involved Stakeholders

- Amsterdam ArenA
- The Mobility House (V2G and BS management)
- Companies, employees, visitors (vehicle owners)
- Parkeergebouwen Amsterdam (Garage owner)
- Alliander
- Eaton and Nissan (Battery storage provider)

Costs

- Energy cost
- V2G unit investment cost
- Static battery investment cost
- Management cost to the V2G manager
- Degradation cost of the EV and static battery and replacement
- PV annualized cost

Benefit

The benefits are seen as **financial savings** compared to the baseline case

- Lower energy cost due to the increase in Energy Autonomy
- The grid is not under significant stress because of the increased PV utilization, hence the capacity payment for grid congestion will be lower

ArenA proposed BM: PCR provision

EA					
CO_2					
Grid					

Grid

- PCR
- Smart charging and V2G to store as much PV energy as possible to be able to provide PCR on large scale
- Target: minimizing the deviations between supply and demand via smart charging and V2G
- Investment savings
- Optimized use of battery (battery degradation reduction)*

Involved Stakeholders

- Amsterdam ArenA
- The Mobility House (V2G and BS management)
- Companies, employees, visitors (vehicle owners)
- Parkeergebouwen Amsterdam (Garage owner)
- Alliander
- Eaton and Nissan (Battery storage provider)
- TenneT

Costs

- Energy cost
- V2G unit investment cost
- Static battery investment cost
- Management cost to the V2G manager
- Degradation cost of the EV and static battery and replacement
- PV annualized cost
- Possible payment to vehicle owners to ensure reliable availability

Benefits

- Revenues from network service provision
- Improved battery performance in terms of degradation
- Reduced electricity cost from Regulation Down
- Lower impact to the grid

Requirement from the pilots – essential parameters

<table>
<tr><th>Category</th><th>Baseline Evaluation</th><th>Business model development</th></tr>
<tr><td rowspan="10">EV</td><td rowspan="4">Power/energy exchanged (time series) [kW or kWh]</td><td>Availability: - Location
- Driving status</td></tr>
<tr><td>Battery Size [kWh]</td></tr>
<tr><td>Charger rate [kW]</td></tr>
<tr><td>V2G status (currently enabled or not)</td></tr>
<tr><td colspan="2">Driving constraints (n. of journeys, energy driven or consumed)</td></tr>
<tr><td colspan="2">Number of EVs</td></tr>
<tr><td colspan="2">Number of chargers</td></tr>
<tr><td colspan="2">Possible charging locations (e.g. home only etc.)</td></tr>
<tr><td colspan="2">Operational/charging cost (if different from the archetype’s tariff) [£/kWh]</td></tr>
<tr><td colspan="2">Charging points investment [£/unit]</td></tr>
</table>

Requirement from the pilots – essential parameters

Category	Baseline Evaluation	Business model development
Archetype	Archetype baseload (power/energy, time series) [kW or kWh]	
	Electricity tariff [£/kWh] (e.g. fixed, ToU, dynamic, etc.)	
Renewable generation	PV generation (power/energy, time series) [kW or kWh]	
	Subsidies available (i.e. FIT) [£/kWh]	
	PV system investment [£]	
	PV generation to baseload [kW or kWh]	Size [kW]
	PV generation to ESS [kW or kWh]	
ESS	ESS investment [£]	
	Power/energy exchanged (time series) [kW or kWh]	Size [kWh]
		Rating of the associated inverter [kW]

Advantages and Drawbacks of V2G

Credit: Edward Bentley, Richard Kotter, Ghanim Putrus, Yue Wang, Ridoy Das, Geoff O'Brien (all Northumbria University)

Power flow (V2G)	Unidirectional (Smart Charging)	Bidirectional
Infrastructure/hardware	EV battery, communication system	EV battery and bi-directional battery charger, Communication system
Power levels	Level 1, 2 and 3	Level 1 and 2
Services	Spinning reserve, power gird power regulation	Active power support, spinning reserve, Reactive power support, Power factor correction, Improve power system stability, Harmonic filter, Frequency regulation Energy backup, Energy autonomy facilitated
Cost	Low	Expensive
Advantages/benefits	Prevent overloading of power grid, minimise emissions and maximise revenue	Further improved grid stability and load profile, maintain voltage levels, reduce renewable energy intermittency, prevent power grid overloading, failure recovery, minimise emissions and maximise revenue, reduce Carbon Dioxide emissions
Disadvantages	Limited services	Battery degradation, investment cost, complex setup, and social barriers

Loughborough OP – operational cost breakdown

		Actual value (for period of)		
		Jan–Dec 2017	May–Dec 2017	May 17–2018
Home base demand (kWh)		5663	4089	6202
Electric Vehicle (EV) driving consumption (kWh)		758	475	820
Photovoltaic (PV) generation (kWh)		3578	2344	3230
Baseline	Energy cost (£)	796	582	917
	Feed-in-Tariff - FIT (£)	-589	-382	-506
	Battery degradation cost (£)	119	105	131
Smart charging	Energy cost (£)	759	547	877
	FIT (£)	-589	-382	-506
	Battery degradation cost (£)	44	28	47

- The higher operational cost in May 2017 – May 2018 is due to the combination of higher home demand, higher EV driving consumption, and lower PV generation, when compared with Jan – Dec 2017
- Higher battery degradation in Baseline due to V2H, compared with Smart Charging
- Data is scale and extrapolated, as from January 2018 there has been construction work and the EV has not been consistently available also

Loughborough (household-level) Pilot data – further improvements sought

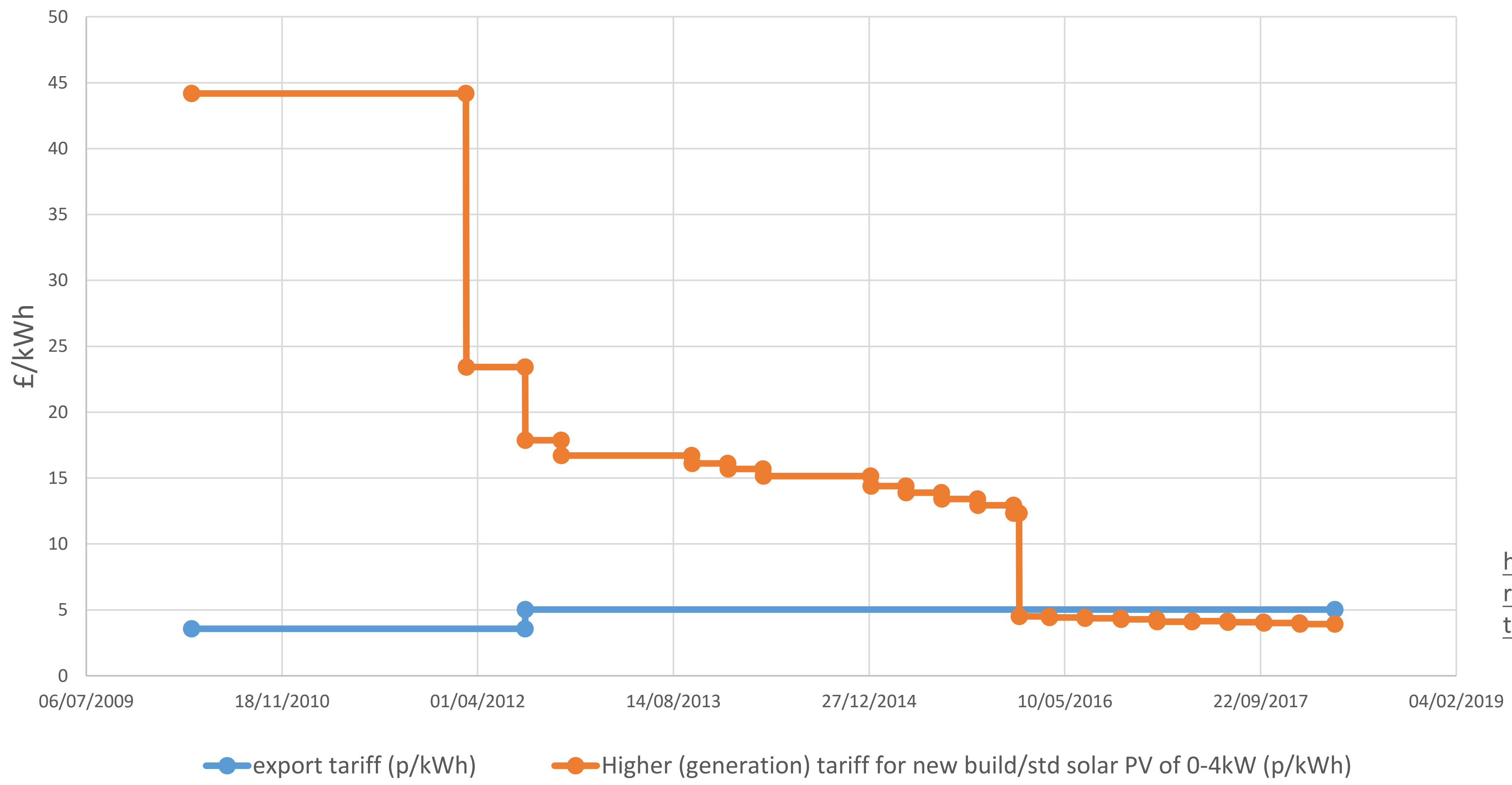
Difficulties	Suggestions for improvement
Data interpretation without dictionary	A parameter dictionary with clear explanation of measurements if needed, as well as a schematic of the pilot with the measurement location
Derivation of EV parking (availability) & EV charging using GPS and EV driving mode data	Clear indication of the period for EV availability & EV charging, e.g. Kortrijk Pilot data

Economic evaluation for domestic PV and ESS (static battery) investment

		Loughborough	Amsterdam	Flanders
PV supporting scheme (for 4kWp)		Feed-in Tariff since 2010	Net metering since 2011	Net metering with prosumer fee (since 2015) of ~€90/kW
PV cost per kWp (€)		2097 [1]	1350 [2]	1350 [2]
Electricity tariff per kWh (€/kWh)		0.172	0.22	0.2877 [4]
ESS cost per kWh (€/kWh$_{inst}$)		400, [5-7]		
Data source for year 2017	**Demand profile**	Pilot, annual 5632 kWh	From HvA, annual 3300 kWh	Synthetic data [8], annual 5023 kWh [9]
	PV generation profile	Pilot, annual 3558 kWh	From HvA, annual 4700 kWh, verified against [10]	

1. Ofgem solar cost: https://www.gov.uk/government/statistics/solar-pv-cost-data
2. A. Jager-Waldau, "PV Status Report 2016", JRC Science for Policy Report, European Commission, October 2016.
3. https://www.statista.com/statistics/418106/electricity-prices-for-households-in-netherlands/
4. https://www.statista.com/statistics/418067/electricity-prices-for-households-in-belgium/
5. https://www.bloomberg.com/news/articles/2018-03-08/the-battery-will-kill-fossil-fuels-it-s-only-a-matter-of-time
6. IRENA (2017), 'Electricity Storage and Renewables: Costs and Markets to 2030', International Renewable Energy Agency, Abu Dhabi.
7. http://www.photonicuniverse.com/en/catalog/list/page/4/category/inverters
8. http://www.synergrid.be/index.cfm?PageID=16896&language_code=NED#
9. J. Kaat, 'Energy Consumption Survey for Belgian households', VITO, 2014
10. http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#HR

Feed-in Tariff in the UK



https://www.ofgem.gov.uk/environmental-programmes/fit/fit-tariff-rates

Flanders (Belgium) case study

Value for the user

$$NPV_{PV} = €9{,}690$$

- Additional storage does not bring further benefit to the user
- **grid is used as storage.**

Value for the grid operator

- Significant time **mismatch** between **PV power** and **demand power**
- With storage, the daily **load and generation variation** is reduced ➔ the net power exchange is **flattened**, which alleviates grid stress.
- Policy suggestion: **remuneration** from the **grid operator** for ESS installation for the efficient use of the grid, i.e. **exemption from prosumer fee** (extra NPV of **€5,887** in 20 years), or PV power should be remunerated on a **market** basis if NM were to be phased out. (*'Prosumers can avoid this tariff if they ask to install a new meter that counts separately what goes out and what goes in. In that case, they won't benefit from the net metering anymore and will have to sell their excess electricity to a retailer.' [1]*)

1. G. Neubourg, 'National Survey Report of PV Power Applications in Belgium', IEA-PVPS, 2015

The Netherlands case study

Value for the user

$$NPV_{PV} = €5{,}989$$

- By considering and yearly mileage of **13,000km** [2] and a km/kWh efficiency of 5.9km/kWh ➔ **2,200kWh/year**, this NM scheme will accommodate another 1400 kWh (i.e. 63%) of the annual consumption from an EV, without any further energy cost for EV charging.

Value for the grid operator

- **Mismatch** between **PV power** and **demand power**. The subsidy does not take this into account.
- Policy suggestion: a **remuneration** from the **grid operator** for the efficient use of the grid

1. http://www.res-legal.eu/en/search-by-country/netherlands/single/s/res-e/t/promotion/aid/tax-regulation-mechanisms-ii-eia/lastp/171/
2. ‘Trends in the Netherlands 2017’, Statistics Netherlands, 2017.

Two Key UNN SEEV4City Policy Proposals

1. EV chargers should <u>not</u> be installed without the prior existence of a curtailment agreement, applying to small 3.5kW chargers and above, chargers installed having been shown to comply with the requirements of a technical control provision preventing an excessive number of chargers operating when the Low Voltage (LV) system cannot support them

2. Work at Northumbria University and elsewhere has shown that at present the economic benefits of V2G to the EV owner fall short of the costs of battery degradation for some applications such as peak shaving, with current battery prices and technology.

Therefore, a V2G Feed In Tariff (FIT) is proposed to compensate EV owners for their economic losses in carrying out V2G, until battery technology improves and prices fall enough to render the FIT superfluous.

The value of peak shaving V2G can be estimated from the level of arbitrage profit available, and the costs are determined by the value of the additional battery degradation ensuing from the V2G operation. In a recent key study [Electricity-price arbitrage with plug-in hybrid electric vehicle: Gain or loss? by Shang,D. & Sun,G., *Energy Policy* 95 (2016), 402–410] Energy Arbitrage was found to lose money with present technology using Li Ion batteries as a result of degradation costs, and a subsidy was suggested to promote adoption of the practice. As the EV battery degradation costs fall with decreasing battery cost and increased life, the FIT would be reduced in the same way as the FIT for Solar PV.

My Electric Avenue [UK project]

Between 2012 and 2015 a large scale experiment, ‘My Electric Avenue’, led by EA TECHNOLOGY, and including contributions from Nissan, Northern Powergrid, Ricardo, Scottish and Southern Electricity Network, The University of Manchester, Zero Carbon Futures, and De Montford University was carried out in the UK to determine whether EV charging curtailment in the event of LV system overload was feasible and acceptable to the trial participants.

3.5kW chargers and Mark 2 Nissan Leaf EVs were used throughout in the trial.

Project 'My Electric Avenue' 2012-2015

The project arranged ten 'electric avenues' – groups or 'clusters', with ten people or more on the same low voltage network – where each person would drive an electric car with a 3.5kW charger for 18 months to trial a new technology, 'Esprit', which would monitor and control the electricity used when their car was being charged.

Esprit defines an algorithm, based on local substation feeder load measurements and information from intelligent control boxes (ICBs) attached to car charging points on that same feeder, which reduces car charging load at times of network stress. The Esprit system is designed to avoid any potential power outages and damage to network infrastructure by temporarily curtailing EV charging to reduce the overall load on a single feeder or transformer.

Over 100 people in different clusters around Britain were successfully recruited to My Electric Avenue's Technical Trials.

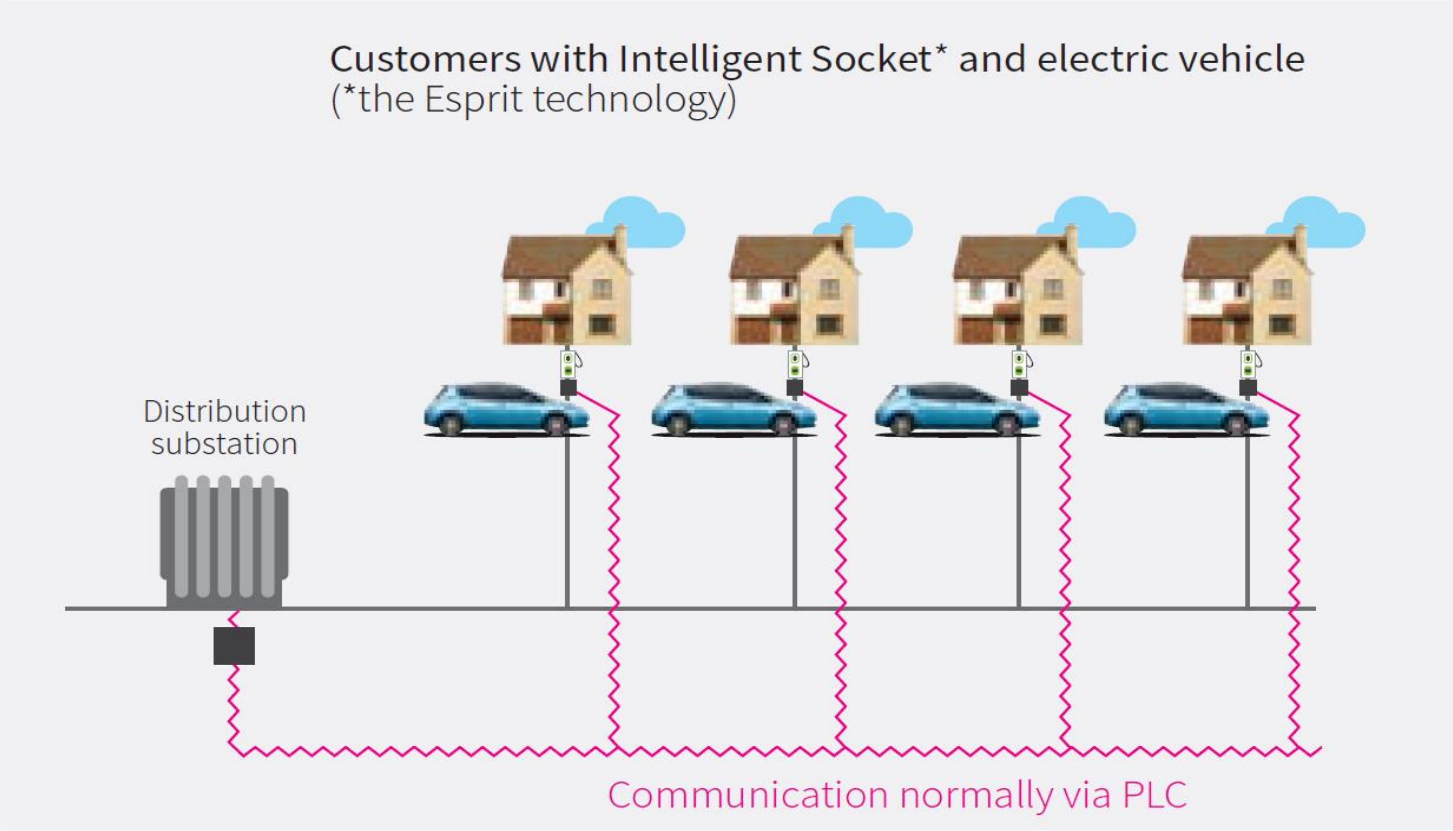
The results of the project's modelling has shown that across Britain 32% of low voltage (LV) feeders (312,000 circuits) will require intervention when 40% – 70% of customers have EVs based on 3.5 kW (16 amp) charging.

Susceptible networks are typically characterised by available capacity of less than 1.5 kW per customer.

Esprit Results

- **The Esprit system employs demand side management to protect power networks from potential overload caused by the simultaneous recharging of numerous EVs on the same substation feeder. It does so by temporary curtailment of recharging on a rolling basis (typically, in this trial, for 15 minutes each) across the local cluster of EVs.**
- The project showed that this **technology was successful in curtailing charging when necessary**, and demonstrated that **Esprit has the potential to be a means for DNOs to prevent the need for system reinforcement**.
- **By 2050 in terms of the discounted Totex network reinforcement savings compared to a world without Esprit savings were estimated at around £2.2 billion**. The figure was obtained using the 'Transform Model' developed by EA Technology with inputs from a number of Esprit Project Partners and with the full engagement of all British DNOs. It is now licensed to the DNOs, Ofgem, DECC and National Grid **and has been used as part of all DNOs' business plans for the new regulatory period (RIIO-ED1 (ends 2023)).**
- The model uses the UK's Department of Energy and Climate Change (DECC)'s Fourth Carbon Budget scenarios to look at the potential costs associated with the proliferation of new Low Carbon Technologies (LCTs) such as EVs, PV and Heat Pumps.
- Esprit also helps DNOs maintain network voltages, since large loads like EVs can reduce it, Esprit typically allows an additional 10% of customers to connect EVs before this occurs, according to modelling using the Transform Model.
- Esprit can also help make networks more efficient; by shifting demand away from peak times Esprit reduces the losses in feeders. In one network modelled, losses were reduced from some 1.9% to approximately 1.73%.
- The curtailment scheme proved acceptable to the participants in the trial.
- How to implement Esprit?
- Who pays for it ?

The Esprit Technology



The study ignored the effects of domestic heat pumps, CHP, domestic Wind power, and domestic PV. The latter could have a particularly beneficial effect on LV system operation, since by increasing energy autonomy it would offer the possibility of reducing the load on the system caused by EV charging

Policy Proposal 1 reduces the risk of LV system overload

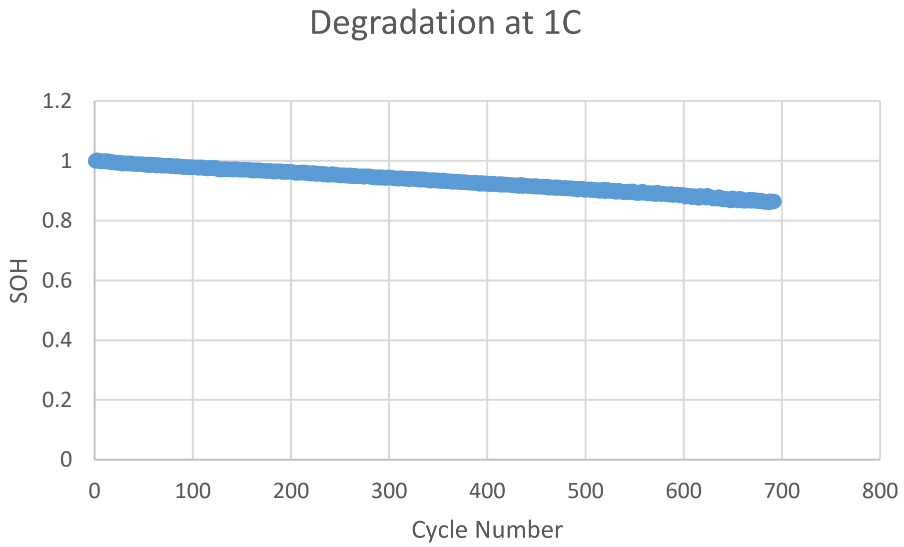
EV chargers marketed should be required to possess a Product Certification Certificate analogous to that used for PV inverters, to ensure that they were designed so that charging could be curtailed remotely by the DNO at need in the case of system overload. Given that the My Electric Avenue project found system overload using small chargers of 3.5kW, all EV chargers at this level and above should be subject to control.

In the UK, BS 7671 S.722, the electrical safety regulations applicable to EV chargers, should be modified to incorporate a requirement for an external charging control port for use by the DNO to curtail EV charging in cases where LV system overload occurs. Similar provisions should be made in other European countries. This does not represent a major change in the UK since under S2.4.8 of the IET Code of Practice for electric vehicle charging equipment installation 2015 2nd edition (IETCP) some types of EV charging equipment are already permitted to have built in communication equipment to allow data relating to energy usage and faults to be sent to the owner/operator of the equipment via wired connection such as Ethernet or wireless e.g. GPRS.

The relevant national laws should be amended to provide for an agreement between DNO and EV Charger operator prior to Grid connection permitting charging curtailment, in the event of LV system overload. The agreement might be a version of the existing grid connection agreements between Wind Farm operators and network operators, under which the output of the wind farm is curtailed at certain times when then system lacks capacity to convey all of the available energy. This is a complex issue and, to date, there is no clear policy or clearly defined structure or commercially established business models for aggregators. In the UK under S3.2 of the IETCP, load management strategies may be implemented which could entail electrical, mechanical or behavioural means of reducing simultaneous use of equipment with high current demand. If an installation interferes with the power quality of another user, the DNO under S26 of the Electricity Safety Quality and Continuity Regs 2002 may issue a notice requiring remedial works to be carried out, or as a last resort the DNO may disconnect supply. Under S10 of the IETCP, in the case of dedicated EV chargers the equipment installer must ensure that the DNO is notified of the installation; in the event that the property concerned has a maximum demand load of > 13.8kVA after installation an application for permission to connect must be made to the DNO in advance.

Feed In Tariff to encourage V2G Peak Shaving/Load Shifting

Work at Northumbria University has measured the degradation incurred by a 2016 Nissan Leaf EV cell as it was charged/discharged 100% DOD at 1C at 25^{O}C in order to measure the likely costs of V2G Peak Shaving:



Battery life was found to be 1056 cycles at 1C with 100% Depth Of Discharge(DOD) for the usual 20% decrease in State Of Health (SOH) to end of life. This is a severe test of the battery – normal use at C/3 (7kW) or C/7 (3kW) would be expected to yield a longer battery life, and we are carrying out further work to quantify this.

The Maths

The cost of Nissan Leaf cells is currently £205.2/kWh https://insideevs.com/breaking-nissan-prices-leaf-battery-replacement-5499-new-packs-heat-durable/

The cost of a 24kWh replacement battery at £205.2/kWh = £24*205.2 = £4925 which provides 1056 V2G cycles

So degradation cost of 1 cycle (24kWh) of V2G = £4925/1056 =£4.66

Degradation cost/kWh for Peak Shaving/Load Shifting V2G =£4.66/24 = £0.2

Arbitrage profits for peak shaving/load shifting V2G can be as much as £0.05/kWh

https://www.apxgroup.com/market-results/apx-power-uk/dashboard/

This suggest that there is a loss of £0.15/kWh or more in carrying out peak shaving /load shifting V2G at 1C.

Policy Proposal 2 – Level of FIT to make V2G Peak Shaving/Load Shifting marginally economic

The above calculation suggests that there is a loss of £0.15/kWh in carrying out peak shaving V2G with a Nissan Leaf battery at 1C, a relatively extreme mode. C/7 would cause less degradation.

With current cells such as those used in the Nissan Leaf, a minimum FIT of £0.2-£0.05 = £0.15/kWh would seem appropriate to defray V2G losses to encourage the uptake of Peak Shaving V2G. In the absence of V2G the economic costs of not doing peak shaving will be represented by the possible arbitrage profits of about £0.05/kWh. By analogy with the existing PV FIT, the costs of the subsidy could be 'loaded' on to the electricity bills of consumers generally. Existing arrangements do not provide an incentive to EV owners to do the socially useful thing in supporting the Grid with V2G, postponing the need for Grid reinforcement, reducing CO_2 emissions, facilitating energy autonomy and levelling out energy costs. The Flanders study demonstrates the need for such a subsidy.

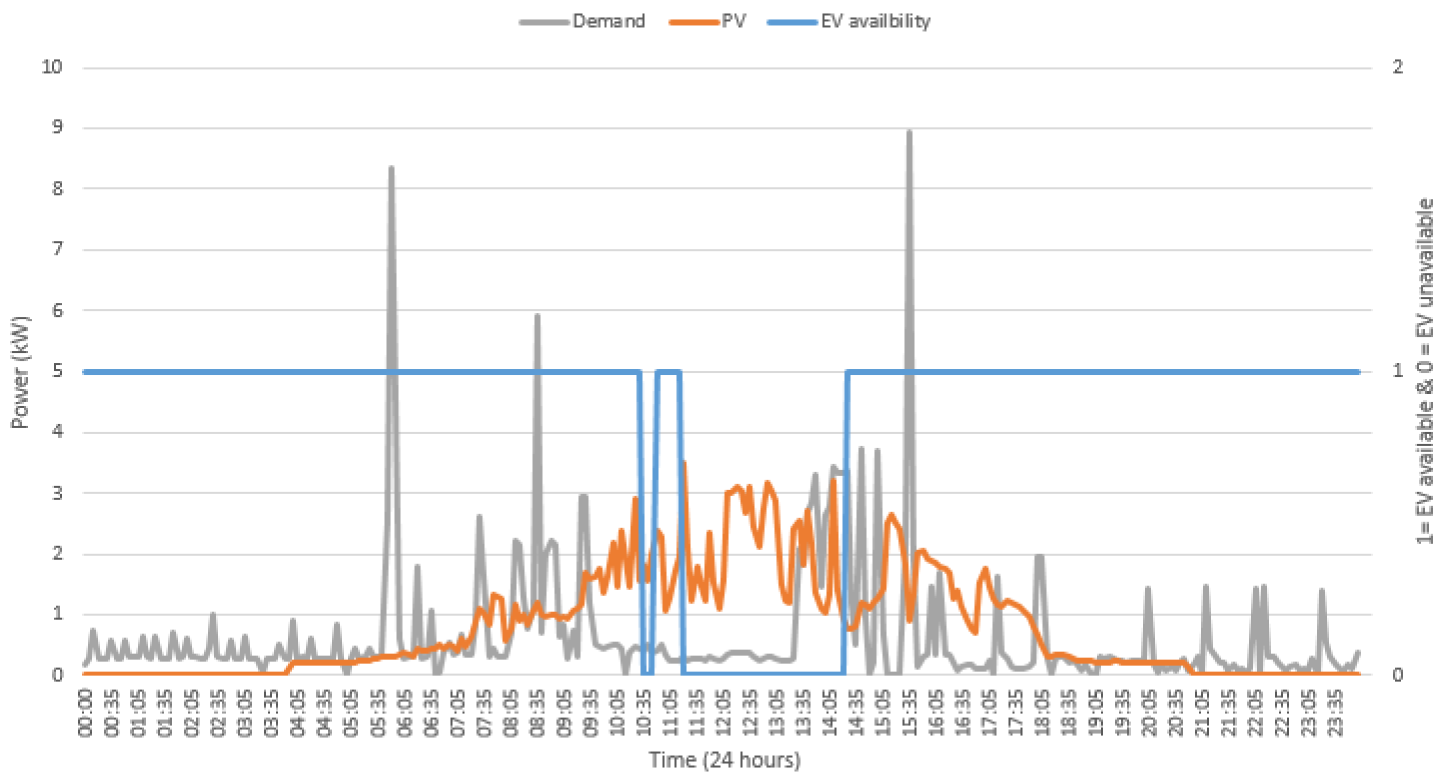
FITs have been used successfully in the past, e.g. for domestic PV, to encourage the uptake of a new technology. The initial level of FIT was set above the value of the energy produced.

Another possible approach, as used to encourage the use of EVs, would be to provide suitable V2G charger units at a subsidised price.

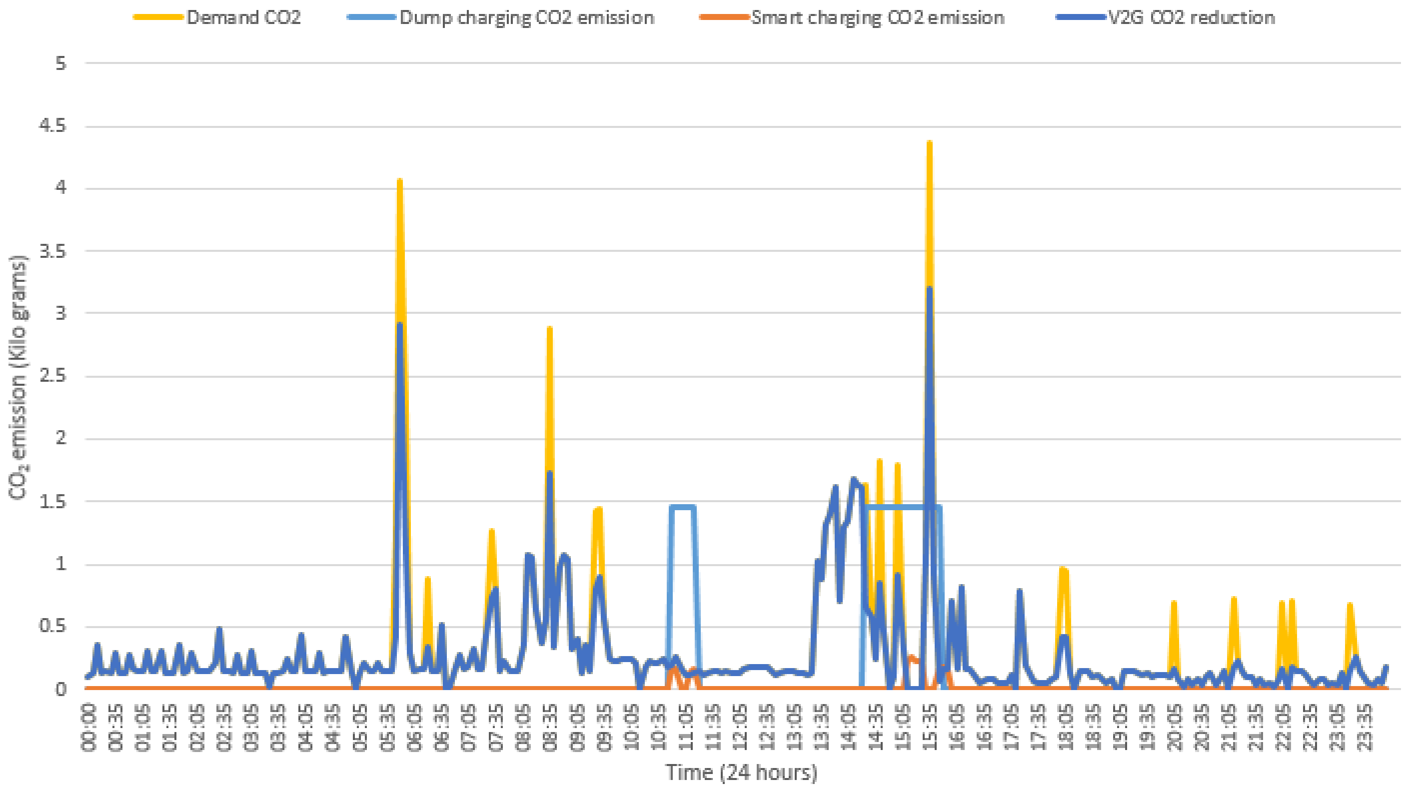
Loughborough Pilot Results

- As part of this project, a pilot study was carried out in Loughborough Leicestershire, UK. The study was based on a family household with a grid connected PV, EV and battery storage system with a V2G unit. The daily electrical consumption, PV output and battery system SOC were recorded.
- Using the data for a 2017 summer day, the impact on the daily household power demand and the increase in CO_2 emissions to charge the EV during various charging strategies were examined.

Pilot 2017 summer day household power demand, PV output and EV availability



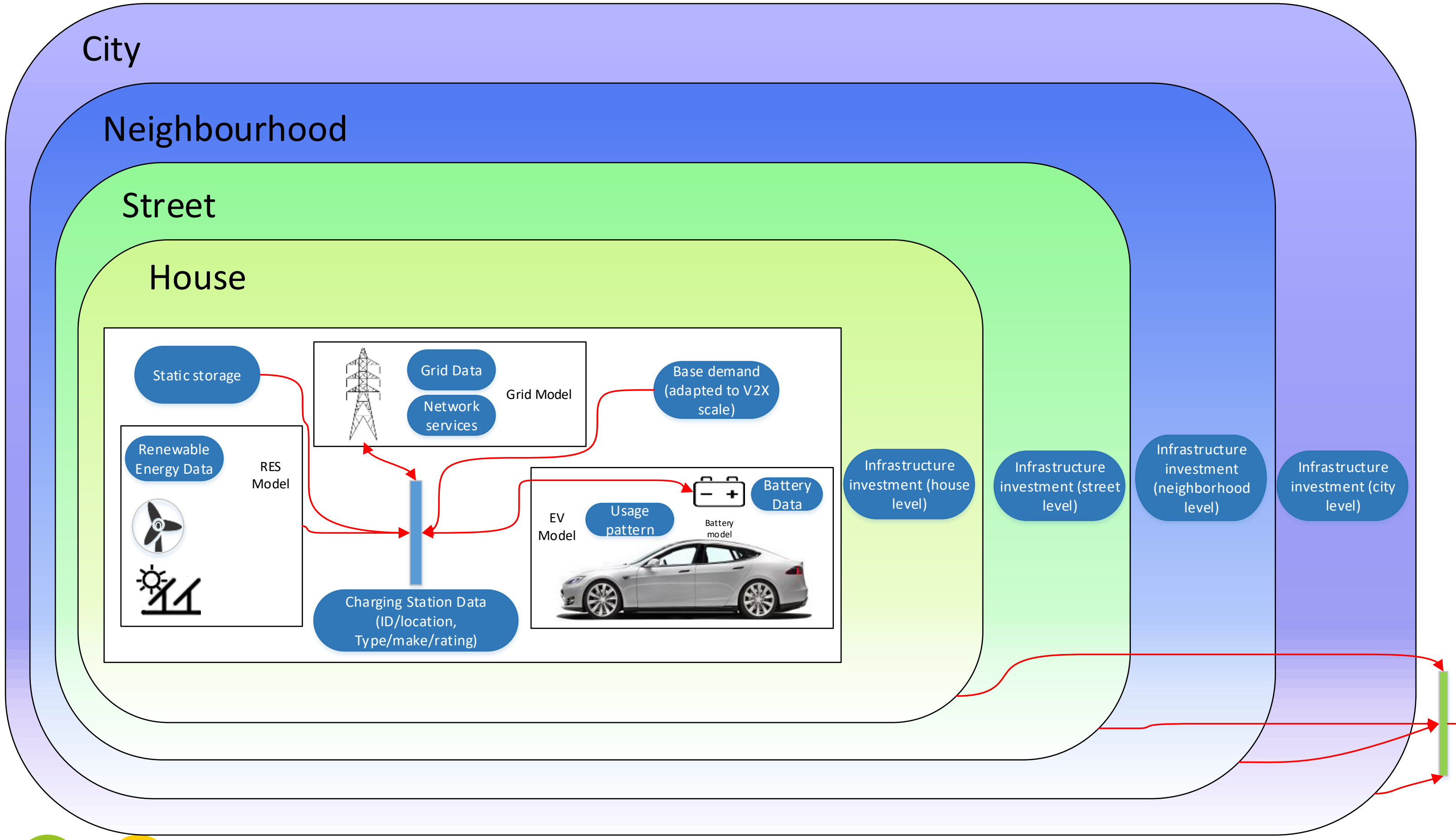
CO_2 emissions during various charging strategies on 2017 summer day



Beneficial effects of V2G on CO2 Production

- With EV uncontrolled 'dump charging' there was a rise of around 33.52% in CO2 emissions compared to CO2 emissions with no EV charging.
- With smart charging the rise in CO2 emissions was limited to 2.12% compared to the base case without EV charging. This difference in CO2 emissions is because in EV 'dump charging' the vehicle is charged upon return home whereas in EV smart charging the vehicle is charged during a time when the PV output was available to provide the charging energy
- Using V2G, there is a drop of around 14.15% in CO2 emissions compared to the base case with no EV charging because the vehicle is discharged at peak demand times when Grid generation itself produces high levels of CO2. V2G can reduce CO2 emissions very significantly.

Policy Proposal 1 postpones infrastructure upgrade costs for Street/Neighbourhood/City



Vehicle for Energy Services (V4ES)

Stakeholders

- Car Owners/Uers/Operators
- Grid Operators
- EV/RES aggregators
- Energy supplier/distributors
- Energy Consultant/Service Company
- EV Manufactures
- ITS providers
- ICT/Navigation service Providers
- EV Charging infrastructure owners/ manufacturers/Operators
- Infrastructure regulators
- Municipal authorities

Model outputs

- CO_2 emission reduction, increased clean kilometer;
- Savings on TCO/TCU(Revenue from network service);
- User satisfaction

Policies 1 and 2 strengthen all Business Model Pillars

Clean

- Target: CO2 emission minimization
- ICE substitution
- Energy mix (time dependent)
- Renewable (PV) integration
- Proposal 2 allows reduced CO2 emission via V2G without increased TCO

Energy Autonomy

- Target: energy autonomy maximization
- Smart charging and DSM for load shifting
- Optimal utilization of static battery where applicable
- Proposal 2 enhances opportunity for energy autonomy via Load Shifting V2G

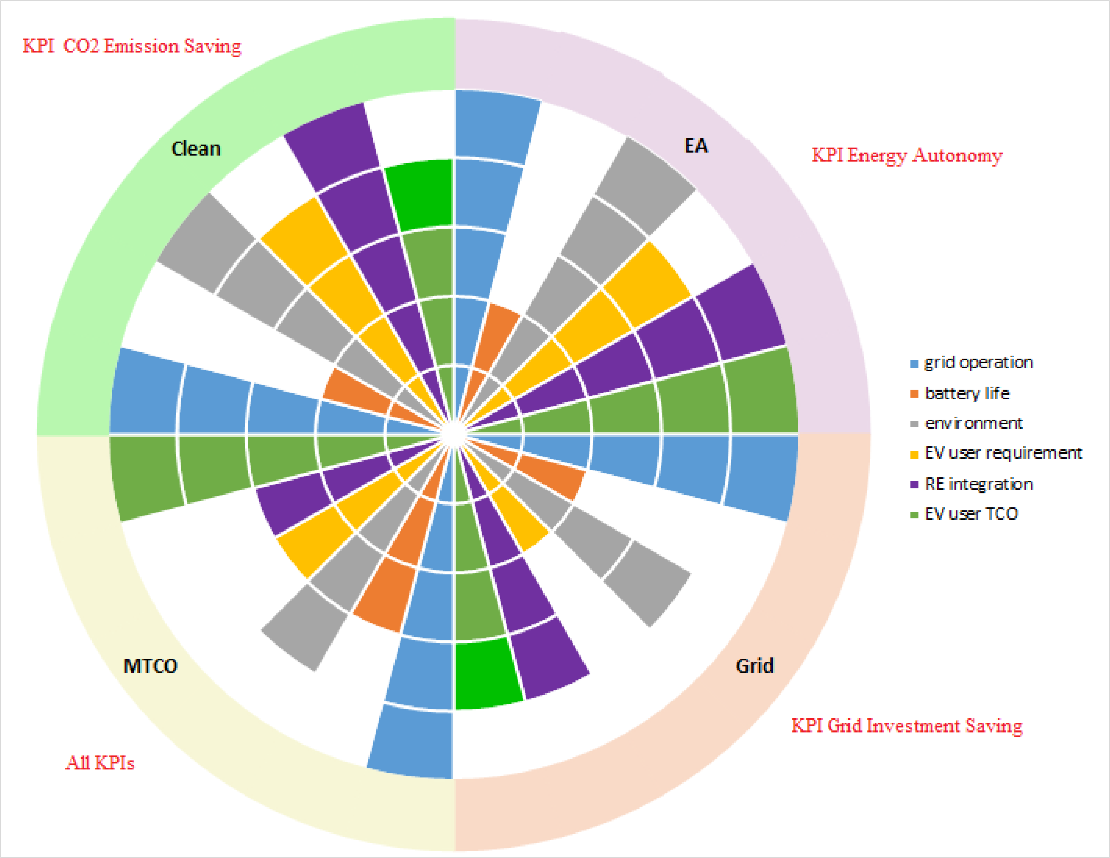
Grid

- Target: minimizing the deviations between supply and demand via smart charging and V2G
- Investment savings
- Smart charging to minimize the mismatch between load and PV
- Balancing services
- Proposal 1 postpones LV network upgrade costs

M-TCO/U

- Target: minimize the modified TCO and TCU
- Provision of services to obtain revenue stream
- Subsidies and policies
- Battery life optimization
- Proposal 2 enables V2G without increased TCO

Strength / focus of each BM Pillar with V2G FIT



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