Researcher Links UK-Russia Workshop

Scientific and technical grounds of future low-carbon propulsion

'Electrification in Transport'

November 19-20, 2018

Newcastle upon Tyne, UK

Sustainable Electric Transport

Ghanim Putrus

Professor of Electrical Power Engineering

Faculty of *Engineering and Environment*

Northumbria University

E-mail: ghanim.putrus@northumbria.ac.uk

Acknowledgement

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Presentation Outline

- Introduction
- Electric Transport and Electricity Supply
- Electric Transport and Renewable Energy
- Challenges and Opportunities
- Vision of Future Transport-Energy Supply
- Battery Controllers
- Summary

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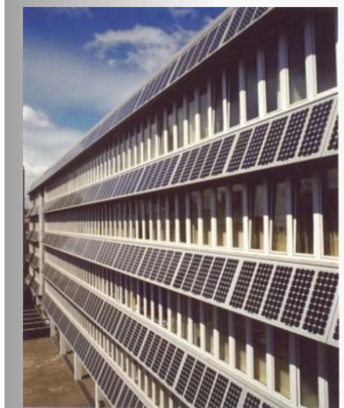
Over 35,000 students and 3,500 staff, including over 500 PhD students

Academic Faculties:

1. Faculty of Arts, Design and Social Sciences
2. Faculty of Business and Law
3. Faculty of Health and Life Sciences
4. Faculty of Engineering and Environment

16 Departments, including:

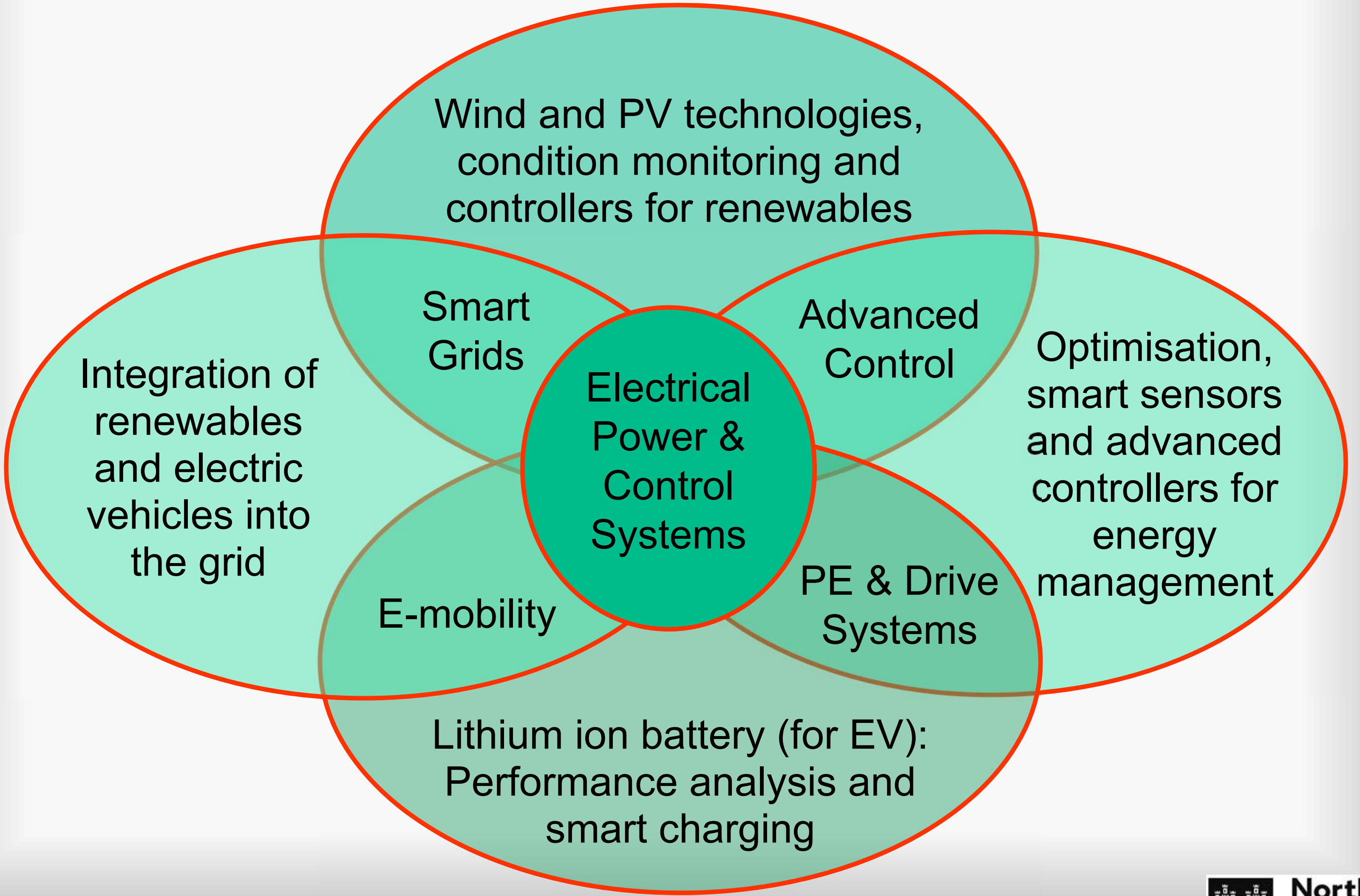
1. Mechanical and Construction Engineering
2. Maths, Physics and Electrical Engineering
   - Electrical Power and Control Systems
   - Renewable Energy Technologies and Materials
   - Optical Communications Research Group
   - Smart Materials & Surfaces Laboratory
   - Mathematics of Complex and Nonlinear Phenomena
   - Applied Statistics
   - Solar Physics



40 kWp PV Façade Northumberland Building

16 channels battery tester

Electrical Power and Control Systems Research Group



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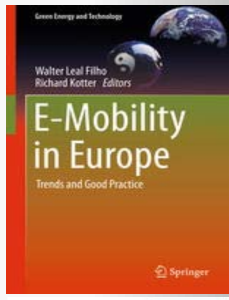
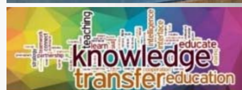
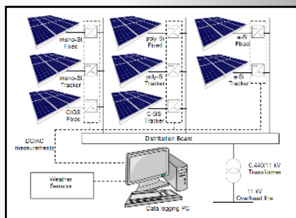
Recent Projects

- Smart, clean Energy and Electric Vehicles 4 the City (SEEV4-City); EU; 2016-2019.
- An intelligent battery charger for electric vehicles applications; KTP; Innovate UK, July 2014-2016.
- E-mobility NSR; EU; 2011-2014.
- Modelling tool to evaluate impact of EVs and V2G on the electrical supply infrastructure; CYC; UK; 2012 -2014.
- Stability and Performance of Photovoltaics (STAPP); EPSRC; UK; 2012-2015.
- Smart Grid Interface Controllers for Dynamic Energy Management; NaREC; 2009-2013.
- Performance comparison of traditional and emerging doubly-fed generator topologies for grid connected wind power applications; EPSRC; 2008-2011.



European Union





EPSRC
Engineering and Physical Sciences Research Council

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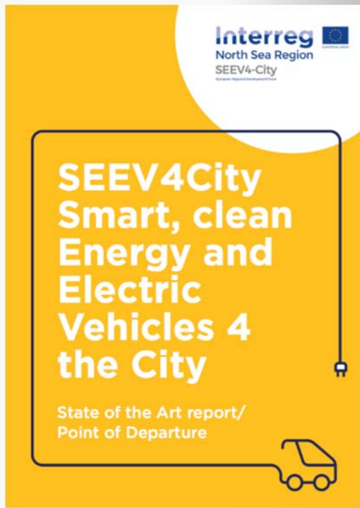
Smart, clean Energy and Electric Vehicles For the City (SEEV4-City)

- **SEEV4-City** is an EU project funded by the **Interreg North Sea Region programme with** main objective to demonstrate smart energy and electric mobility solutions.
- October 2016 to 2019 (total grant €4.313M)
- 10 partners working on 6 operational demonstration pilots.
- Focus on integration of electric transport, electricity grid and renewable energy.
- KPIs: Reduction of CO2 emission; Increased energy autonomy; Optimized grid performance.




The Amsterdam ArenA
NL


Loughborough 'Living Lab'
UK


Leicester City Hall
UK

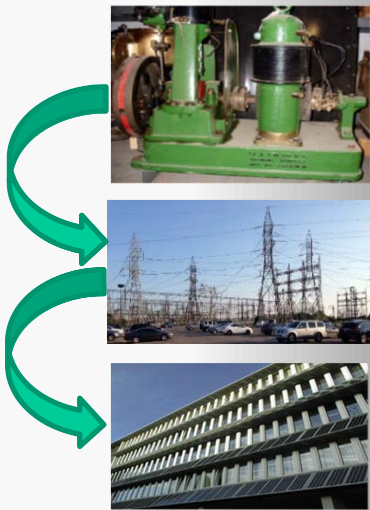

Vulkan Real Estate Building
Oslo, Norway


The city depot of Kortrijk
BE

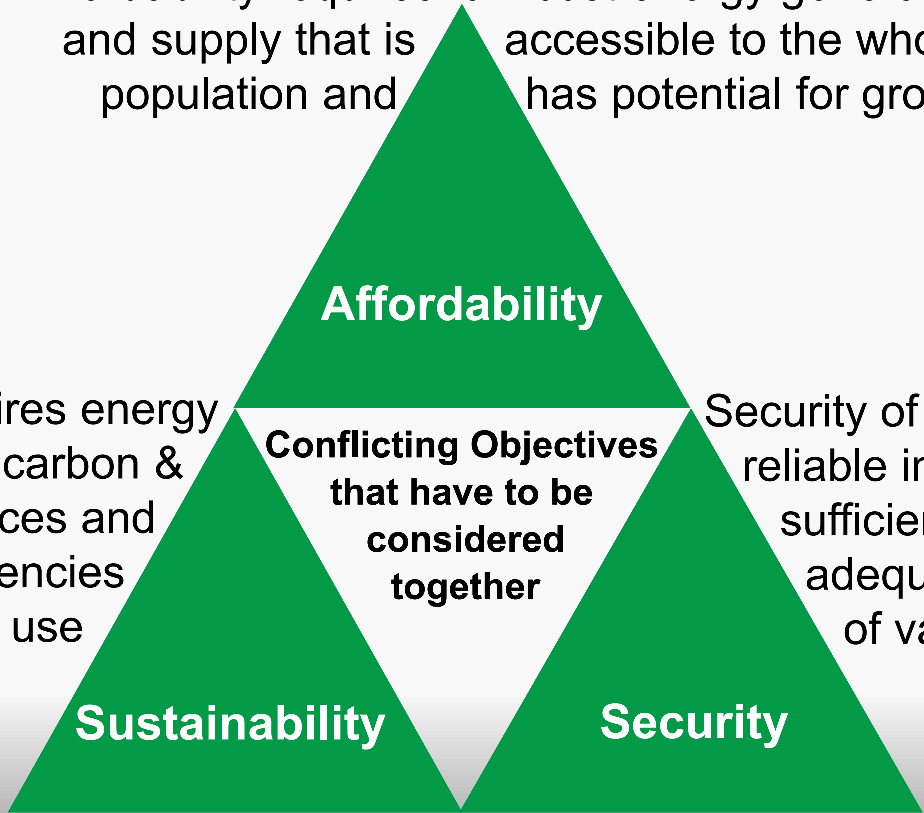

Flexpower Amsterdam
NL

The Energy Trilemma

Electricity and transport evolved throughout the 20th century to provide adequate services that our civilization now rely on.



Affordability requires low-cost energy generation and supply that is accessible to the whole population and has potential for growth



Sustainability requires energy supply from low carbon & renewable sources and energy efficiencies in supply & use

Security of supply requires reliable infrastructure, sufficient capacity and adequate management of variety of sources

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Electric Supply and Transport

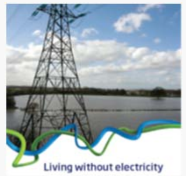
- According to UK National Grid: “The risk of blackouts this winter (2015) has increased compared with a year ago”. “The spare capacity on the system is just 1.2% - the worst for a decade”.

BBC News
15 July 2015

- According to one of Ofgem’s senior executives: “The future UK electricity system may be one where we cannot access the power we want, when we want it”.

The Journal
5 OCT 2016

- In Dec 2015, Storm Desmond brought unprecedented flooding to North Lancashire and Cumbria resulting in more than 100,000 people to be without electricity.



Royal Academy of Engineering,
May 2016

- Electric cars ‘will never’ be as cheap as petrol or suitable for our long-distances. The biggest issue is the cost of lithium-ion batteries.

Klaus Frohlich, Head of R&D BMW
NEWDAILY, 11 Oct 2018

http://www.bbc.co.uk/news/business-33527967
http://www.chroniclelive.co.uk/business/business-news/people-wont-able-use-electricity-11982536
https://www.raeng.org.uk/publications/reports/living-without-electricity
https://thenewdaily.com.au/life/auto/2018/10/11/electric-cars-petrol/

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Wide-Scale Power Outages (Blackouts)

- Not planned, affect at least 1,000 people, last at least one hour and causes at least 1,000,000 person-hours of disruption.

2017		March 1, New York and 5 other states. 10M affected.
2016		June 7, Kenya blackout (4 hrs), caused by a rogue monkey. 20M affected
2015		January 26, Pakistan blackout due to technical fault. 140M affected
2014		November 1, Bangladesh power outage for ~10 hours. 150M affected
2013		March 22, Belfast power outage caused by a technical fault during a storm.
2012		July 31, India blackout, is the biggest ever in the world, 620M affected
2011		Sept 24, north and central Chile. 9M affected.
2010		March 14, Chile blackout left 15M people (90% population) without power.
2000s		2 Major (2001 India 230M & 2005 Indonesia 100M). 1 EU (2006 15M) & 3 UK
1990s		Dec 26 1999, France 3.4M affected. One of greatest by a developed country.
1980s		Oct 16 1987 a storm interrupted UK-France d.c. link, causing outages.
1970s	6	July 13 1977, New York 9M and Sept 20, Quebec, Canada 6M affected.
1960s	2	Aug 5 1969, Florida, 2M affected.

https://en.wikipedia.org/wiki/List_of_major_power_outages

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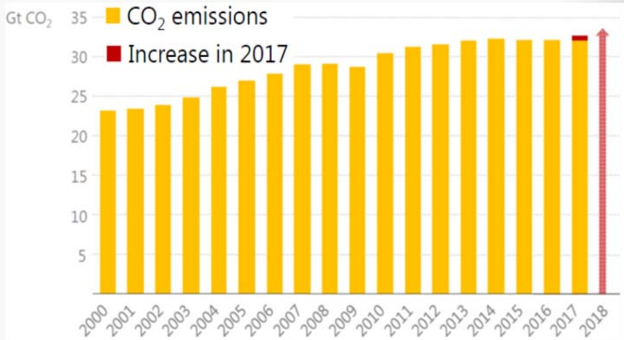
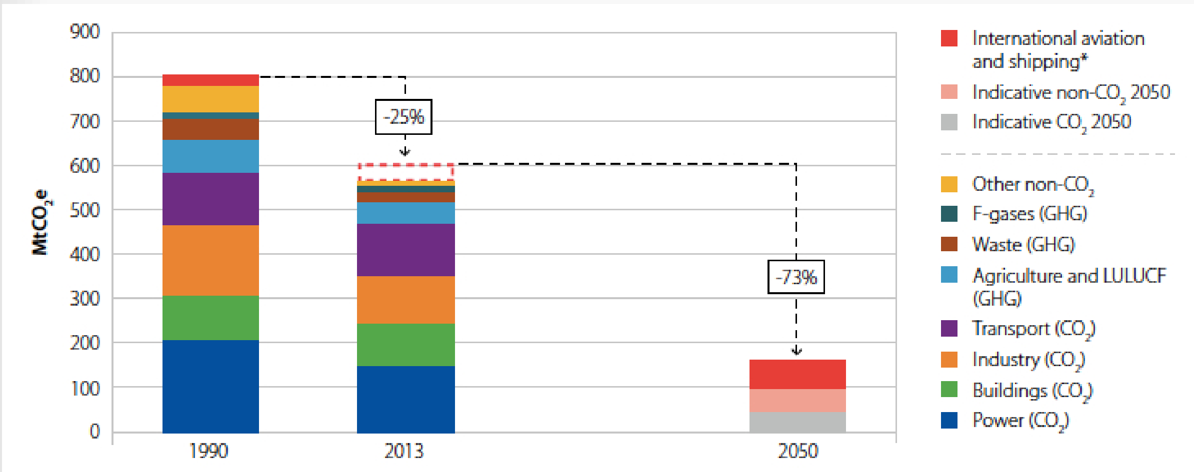
Greenhouse Gas Emissions

- The Kyoto Protocol
- The 20/20/20 energy targets for European countries
- 80% reduction of greenhouse gas emissions below 1990 levels by 2050



Global energy-related CO_2 emissions



UK CO_2 emissions by sector (1990-2050)

Sources: NAEI (2014) final Emissions estimates; CCC analysis

Low Carbon Transport: A Greener Future A Carbon Reduction Strategy for Transport, Department for Transport, July 2009

IEA, Renewables 2018; Analysis and Forecasts to 2023

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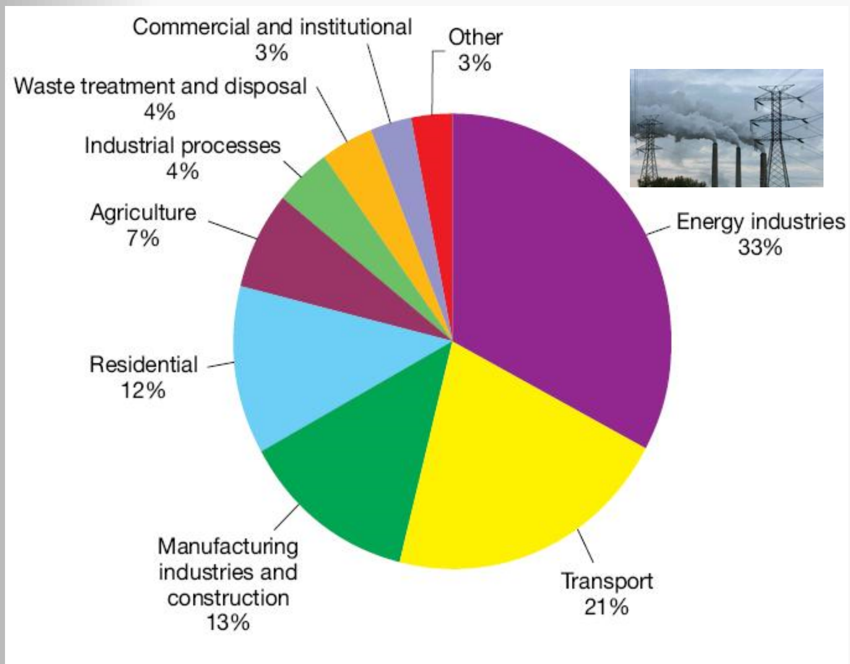
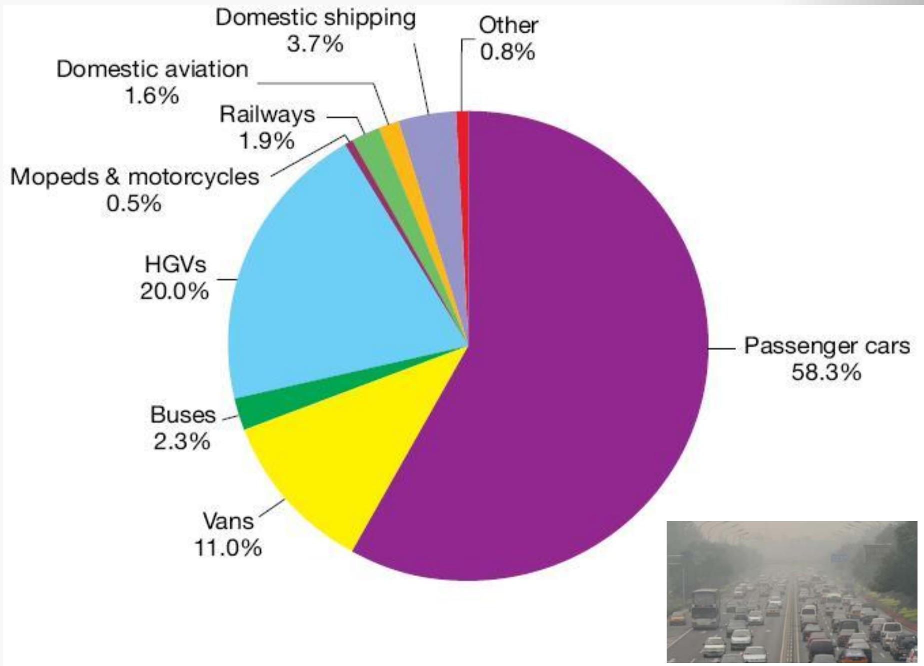
UK Transport Greenhouse Emission

- The main contributors to greenhouse gas emissions are the energy (electrical) and transport sectors
- In 2006: Transportation contributed 21% of the total gas emissions and around 90% of this came from vehicles



Due to energy consumption



Due to transportation only

Source: “Low Carbon Transport: A Greener Future A Carbon Reduction Strategy for Transport” Department for Transport July 2009

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Electric Vehicles

- First cars were electric and used rechargeable batteries.

- **Plug-in Hybrid Electric Vehicle (PHEV)**
  - 5-15 kWh battery
  - Electric range is limited, but enough for most city journeys (10-40 miles).

Toyota Prius PHEV

8.8 kWh Lithium-Ion battery
25 miles electric range

- **Electric Vehicle (EV)**
  - >15 kWh battery
  - Range is usually around 100 miles, and this will increase with development in battery technology.

Nissan Leaf EV

24 kWh Lithium-Ion battery
100 miles range

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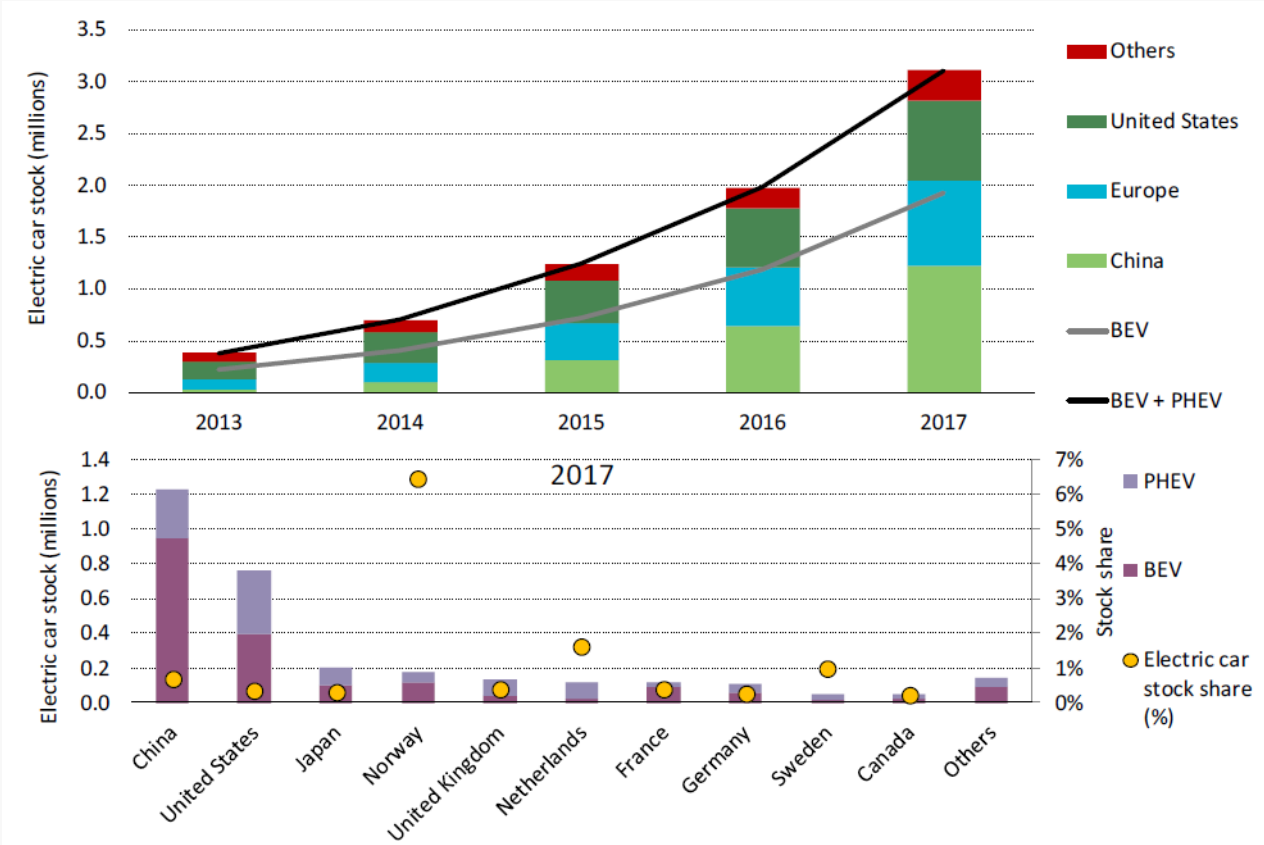
EV Development and Stock Share



Passenger electric car stock in major regions and the top-ten EV initiative countries

Source: global EV outlook 2018, IEA, 2018.

Electric Vehicles: Challenges & Opportunities

- Challenges
  - High up front cost and uncertainty about the residual value.
  - Limited battery energy/power capacity and driving range.
  - Availability of charging infrastructure and impact on the grid.

- Opportunities
  - Develop new battery technologies.
  - Smart charge from available renewable energy sources and help to deal with their intermittency and also the environment.
  - Smart control to reduce degradation and extend battery life.
  - Find additional uses for the EV by providing energy storage as part of a smart energy system or by providing ancillary services to the grid, e.g. supply-demand matching, voltage and frequency control.
  - Redeploy used EV batteries for stationary application (second life).

Electricity Supply is Changing

- Electrifying the transport system
  - Charging will increase grid demand and make system voltage, frequency and stability difficult to control.
  - EVs have high energy capacity and mass deployment.
  - As range increases, battery size increases and charging becomes more challenging.

- Power generation from renewable energy
  - Opportunities
    - Abundant and no greenhouse emissions.
    - Generation is closer to loads, thus reduced central generation capacity, network infrastructure and power losses.

  - Challenges
    - Cost.
    - Technical problems and impact on the grid performance due to variability of power generated from renewables and loss of central control.

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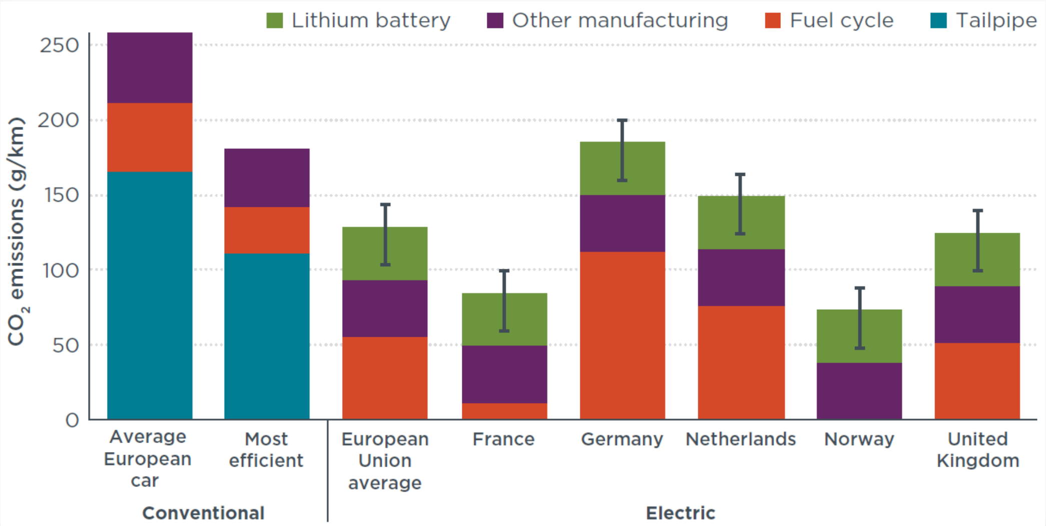
Are Electric Vehicles Really Green?

- EV needs to charge from renewable energy, otherwise it is not green transport.
- Need to exploit the synergies between RES generation and EV charging profiles. Thus, charge EVs whilst reduce the amount of curtailed renewable energy.
- Charge from local generation, so increase energy autonomy and reduce grid losses.

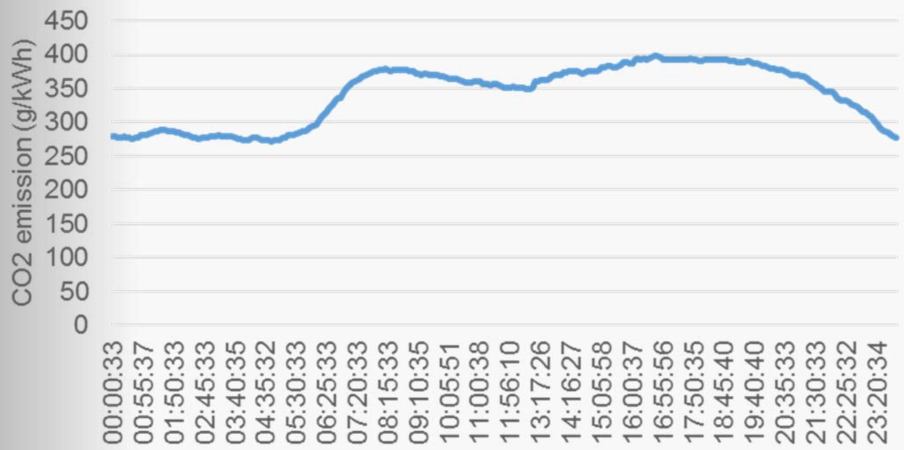


CO_2 emission due to the operation of ICE and EV in Europe

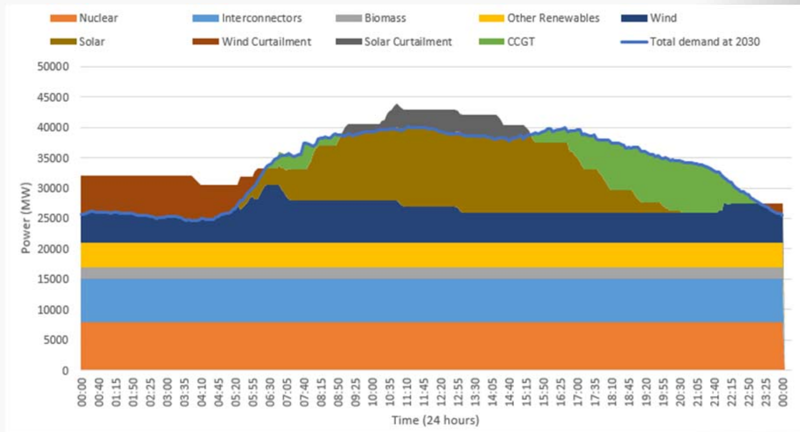
D. Hall and N. Lutsey, 'Effects of battery manufacturing on electric vehicle life-cycle greenhouse gas emissions', The International Council on Clean Transportation, February 2018.

Renewable Energy and Electric Transport

- The energy mix to charge the EV, and hence CO_2 emissions, changes during the day, week and season.
- Renewable energy installed capacity in the UK at Q2 (the end of) 2018: Wind (~13 GW onshore & ~8 GW offshore), ~13 GW Solar PV and ~8 GW others.
- ~35% is residential and commercial rooftop (PV installed capacity in UK is expected to exceed 20 GW by 2020).
- In Germany: ~90% is residential and commercial rooftops (PV installed capacity ~42 GW).



Energy mix based CO_2 emission for the UK, 09/11/2017



Generation mix and total demand, Summer day 2030

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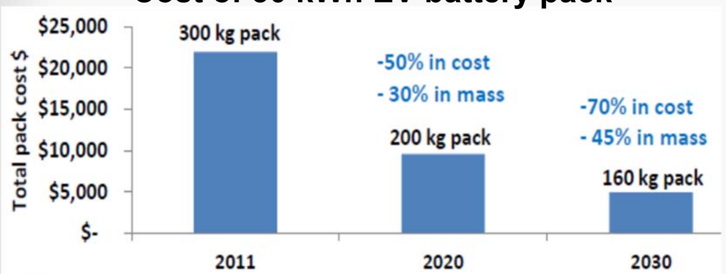
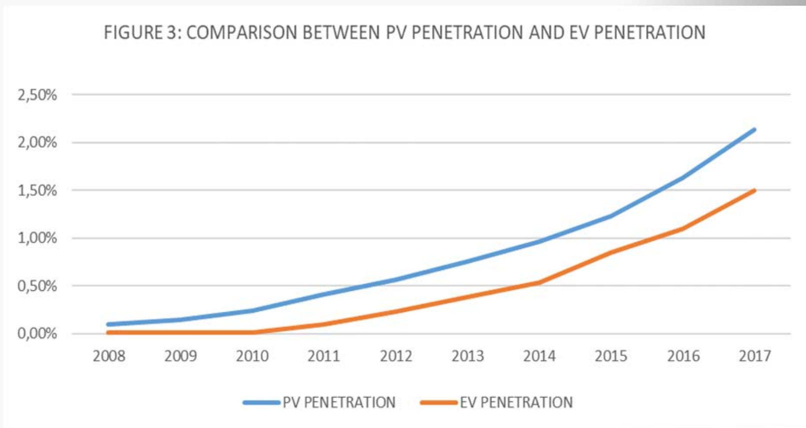
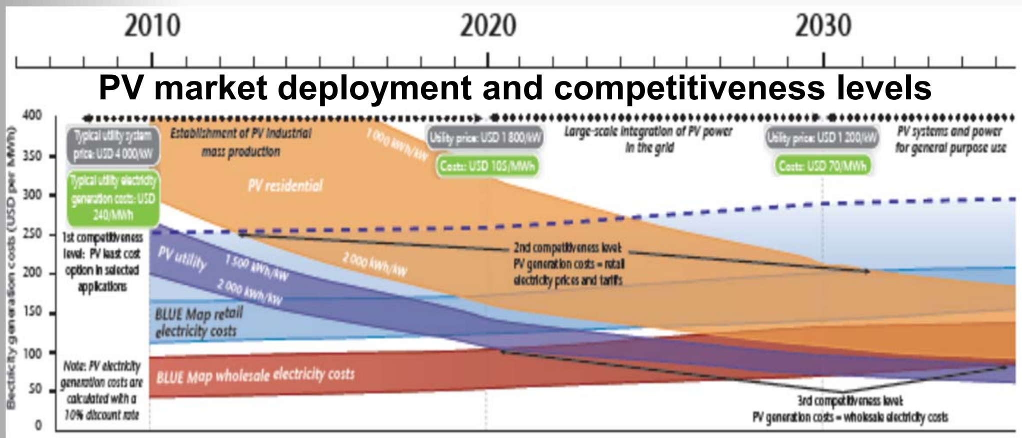
EV and PV Market Development

- The accelerated development of the EV market could be compared to the development of the PV market.
- Renewable energy: ongoing cost reductions continue.
- Need to reduce the cost of EVs. EV production costs: ~50% battery; ~30% drive system; ~20% manufacturing of the body.
- The UK is investing £246m (over 4 years) on battery development.

Cost of 30 kWh EV battery pack







Sources: IEA Publications: Technology Roadmap, Solar photovoltaic energy
elementenergy: Cost and performance of EV batteries, Axeon, Final report for The Committee on Climate Change, 21/03/2012
How to reduce EV production costs? EV Battery Tech USA, cars 21, 7th October 2011 http://www.cars21.com/news/view/670
SNAPSHOT OF GLOBAL PHOTOVOLTAIC MARKETS, Report IEA PVPS T1-33:2018

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Modelling Tool to Evaluate Impact of EVs on the Electrical Supply Infrastructure and EV Battery Degradation

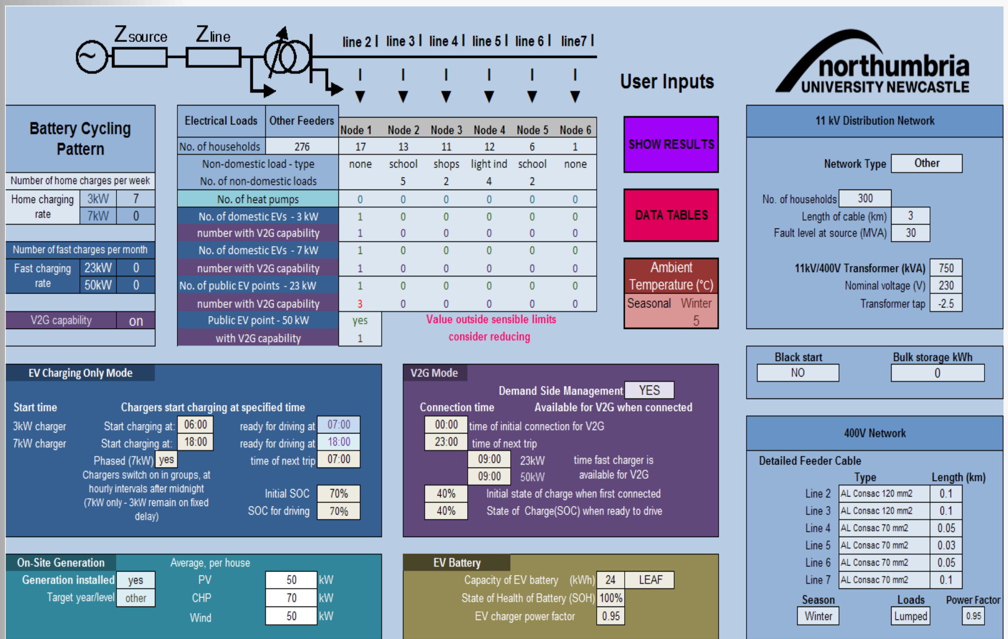
A computer model was developed to analyse performance of existing and future distribution networks (smart grids) with and without EVs, renewable energy and low carbon technologies.

The model allows evaluation of the impacts of EV charging and analysis of smart grids solutions, G2V, V2G, smart charging and the impact of battery cycling on the battery state of health.

Battery Degradation

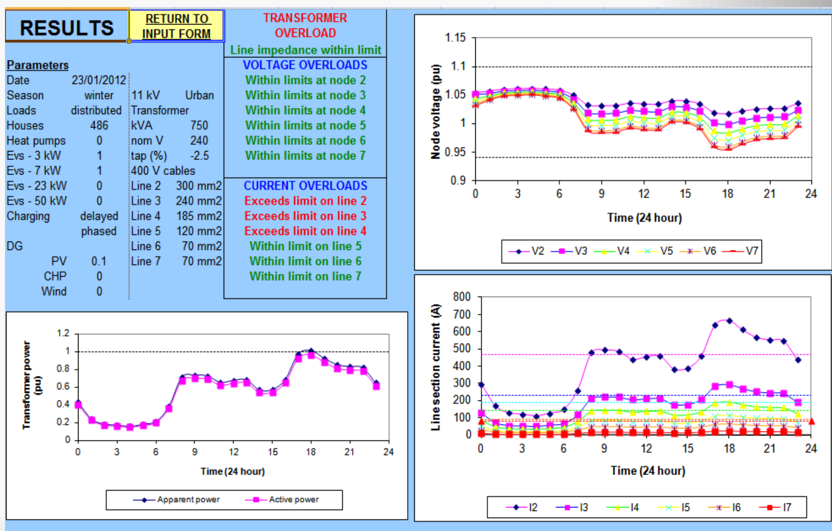
1.9%
Degradation after one year

10.77
years until capacity is 80% of new



The Data Input Page

Results Page



CHARGE YOUR CAR
PARK + PLUG + RECHARGE

The modelling tool was developed as part of a project funded by Charge Your Car North (Electric Vehicle Infrastructure).

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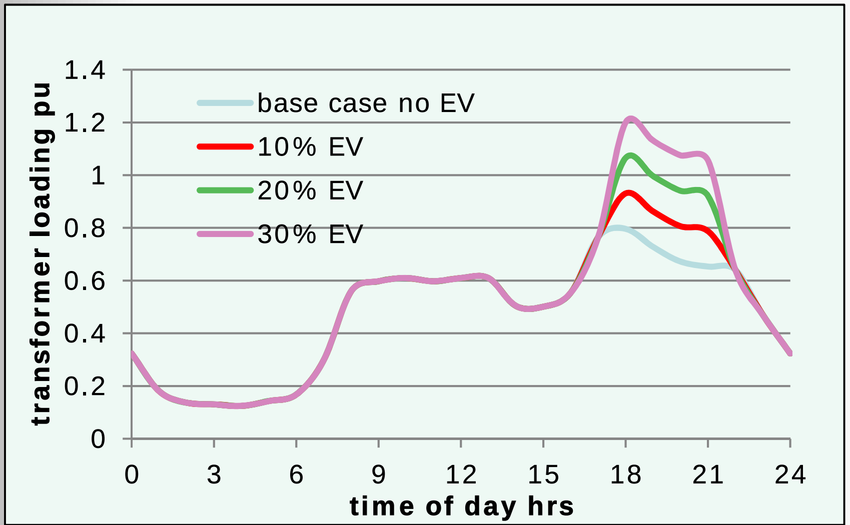
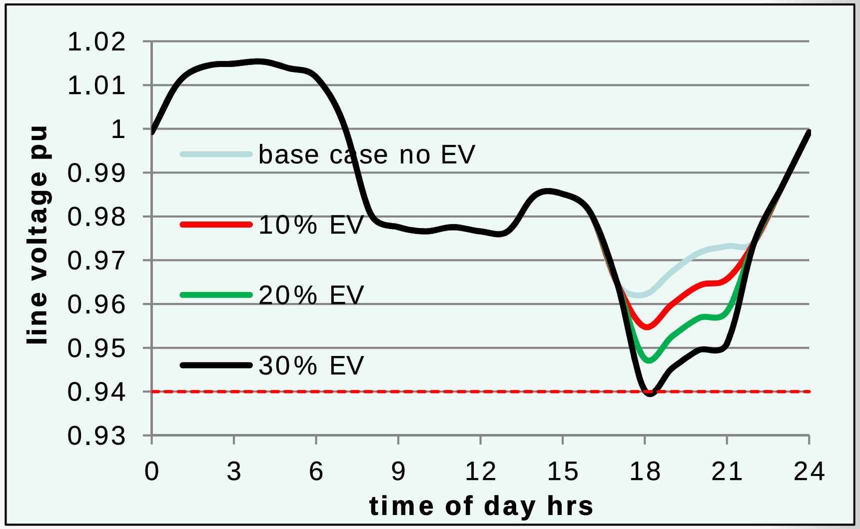
Transformer Loading and Voltage Profiles for Uncontrolled 3 kW Charging



Transformer loading

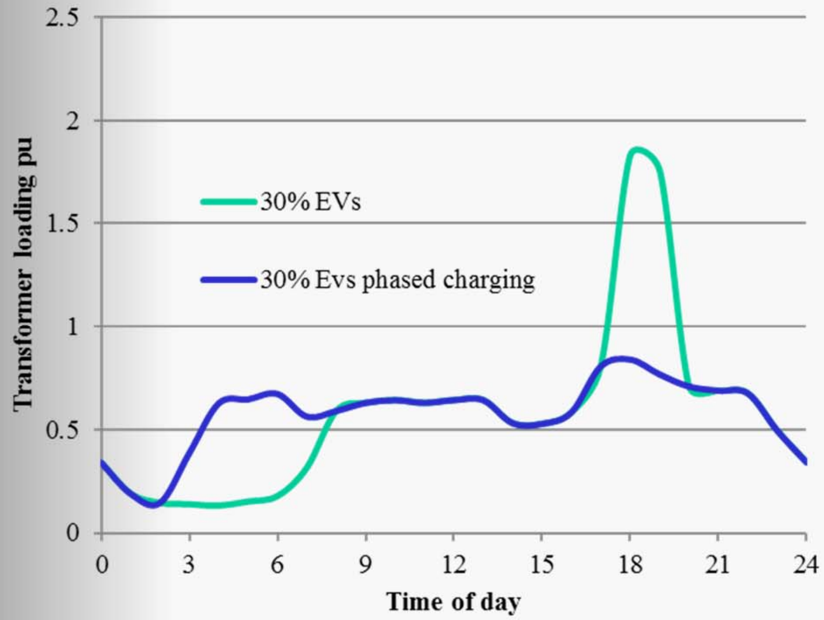


End of feeder voltage

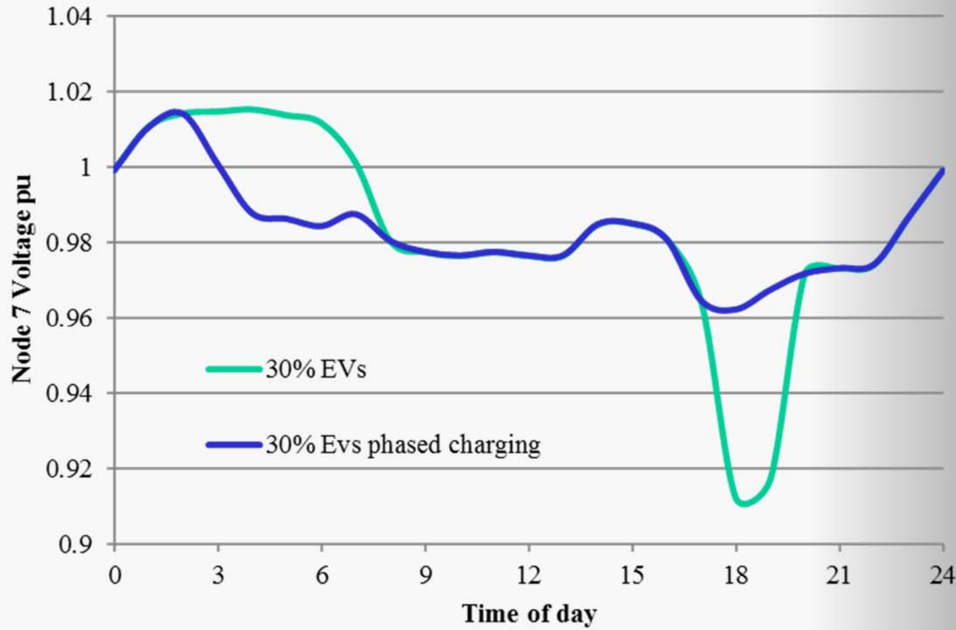
- Increase of ~14% loading for every 10% increase in houses with EVs
- EVs at 20%: Operation of the OLTC keeps the voltage within the statutory limit.
- EVs at 30%: The OLTC reaches its maximum limit and voltage levels at some points drop below the limit.
- With 7 kW chargers, the increase in loading is ~30% and the OLTC limit is reached at around 10% EV penetration level.

Putrus G., Suwanapingkarl P., et al, “Impacts of Electric Vehicles on Power Distribution Networks”, IEEE VPPC, Michigan, 2009, pp 827-831.

30% EVs with Delayed Charging to avoid overload and excessive voltage drops (7 kW)



Transformer loading



End of feeder voltage

- ‘Smart’ charging and V2G (using the right policy and incentives for customers), will reduce daily power demand, allow better use of available asset (match network capacity) and match RE generation.
- Need to consider the impact on battery degradation.

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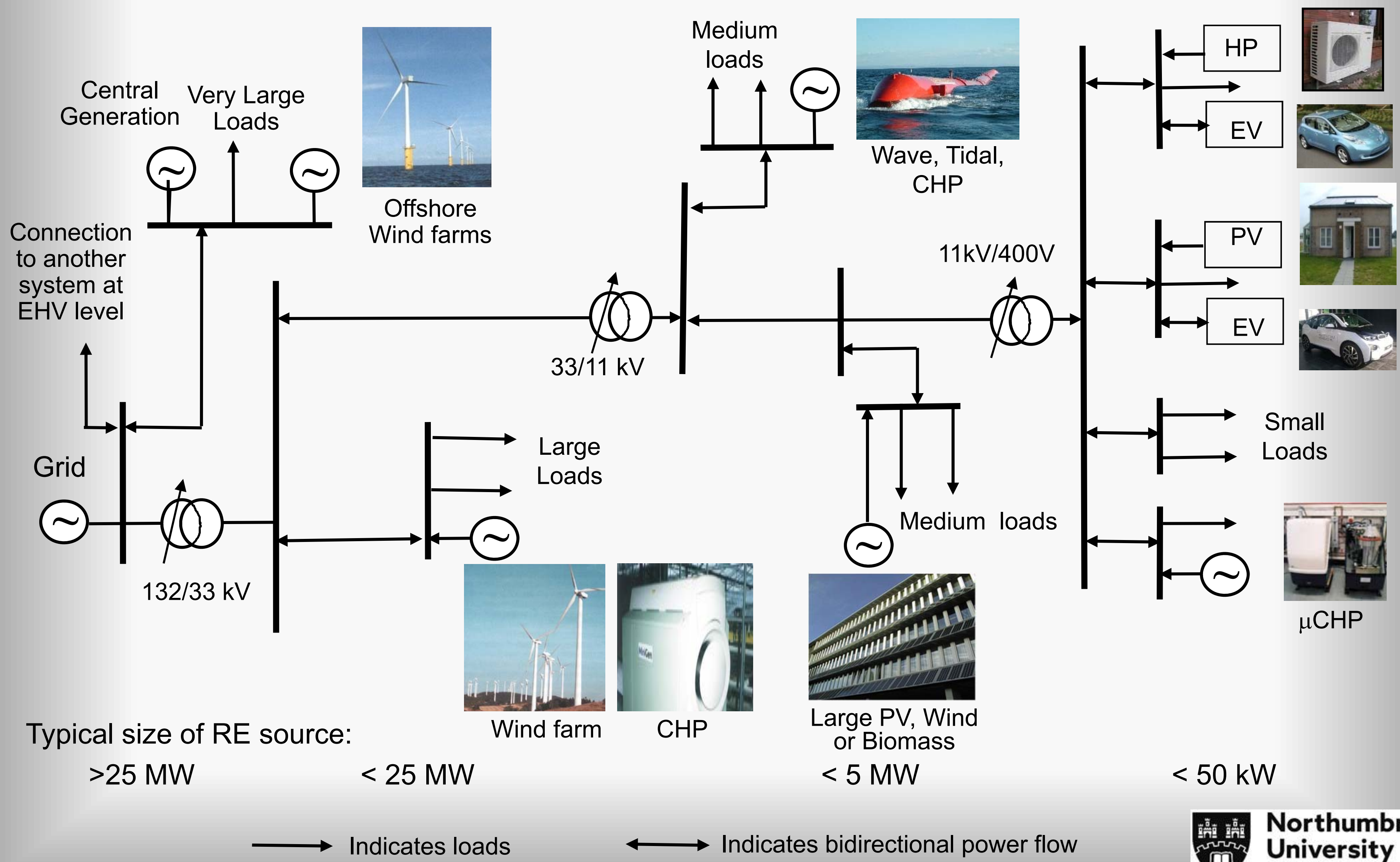
Future Power Networks



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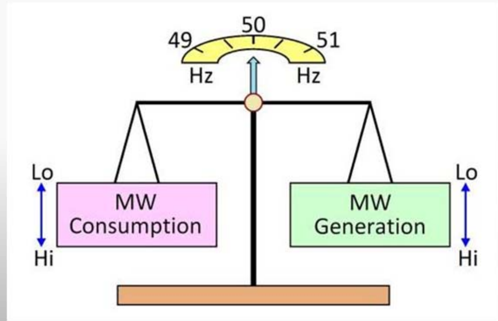
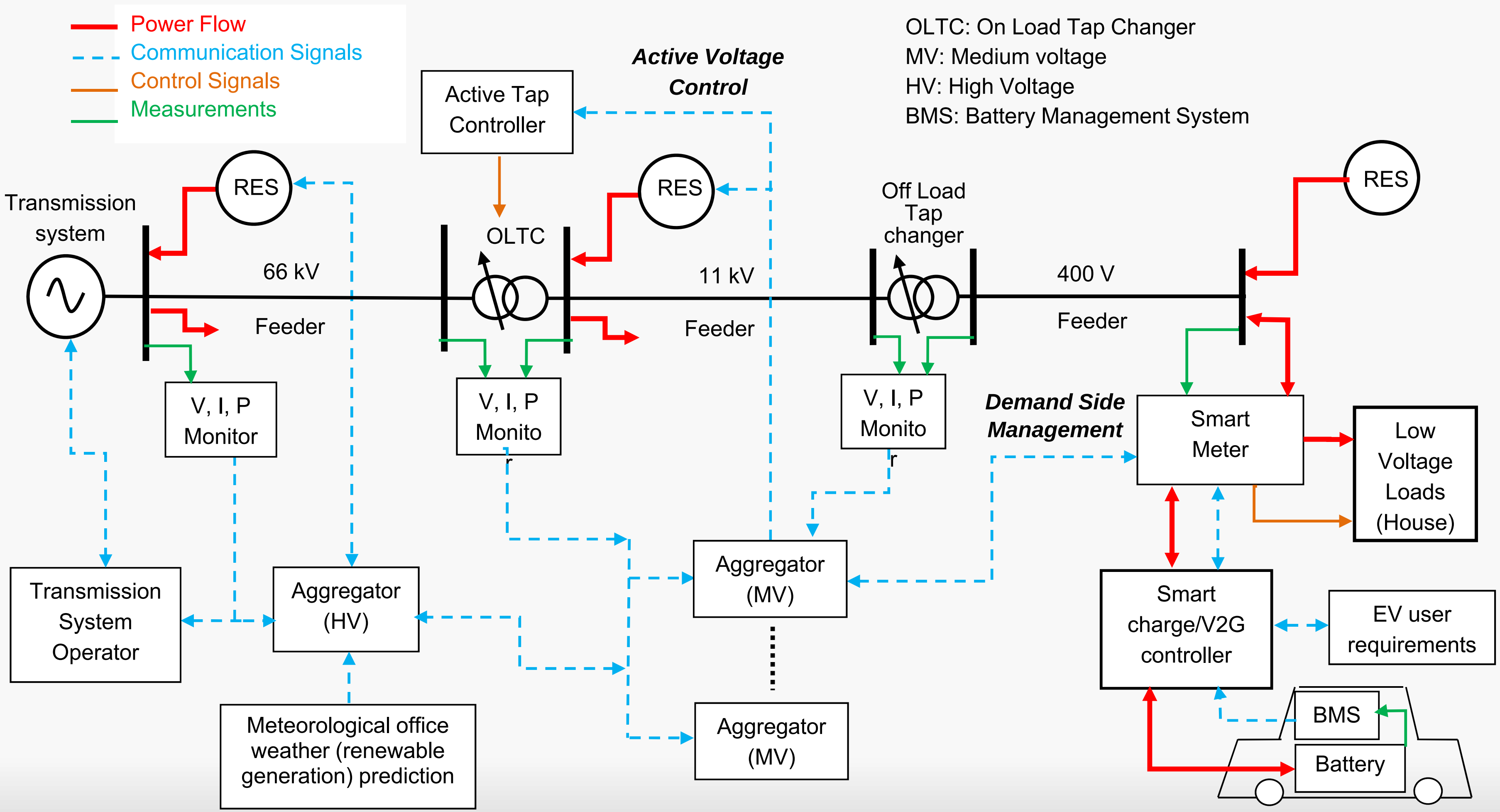
Smart Thinking

- Increased penetration of EVs and renewables will cause problems to the grid and make system voltage, frequency and stability difficult to control.
- RE generation and EV charging profiles may be made complementary and therefore provide opportunities for both the grid, EV and the user.
- Power systems need to become dynamic and grid control philosophy will have to rely on controlling the demand and storage as generation from renewables varies.



Power balance

RE and EV Part of a Smart Grid



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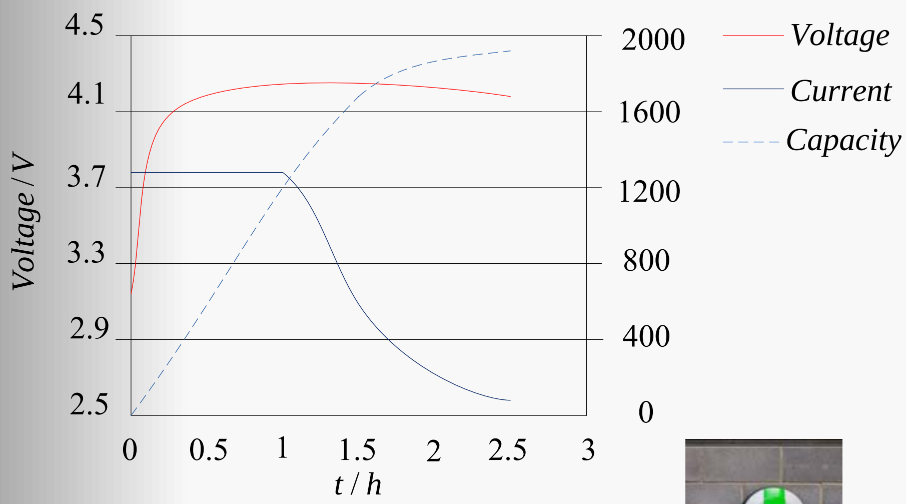
Current EV Charging Options



Existing chargers provide limited controllability regarding charging specifications **and flexibility** to the user regarding charging time and length of next journey.

New chargers are getting better but **they are not smart enough**!

	Home charging	Public charging	Fast charging
Power	3 or 7 kW	23 kW	Up to 50 kW
Time	8 or 4 hours	1 hour	20 mins (80%SOC)
Average C-Rate	0.12 or 0.25 C	1 C	3 C

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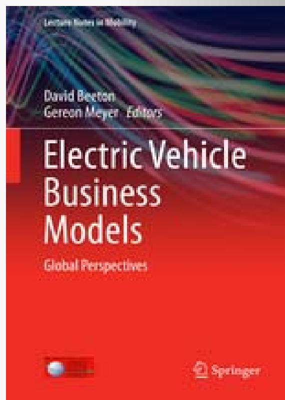
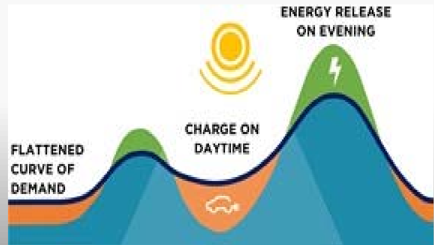
Smart Charging

- EV user requirements are defined in terms of the next journey length and the time the user is willing to wait for charging to complete.
- Charging only the necessary amount of energy required for the next journey: allow for user behaviour & driving conditions, help the grid and extend battery life.
- With smart control, EVs may be charged/discharged with minimum degradation to the battery, thus increase the residual value.
- Provide support to the grid in order to reduce the total cost of EV ownership.
- Charge from available renewable energy sources and help to deal with their intermittency and also the environment.





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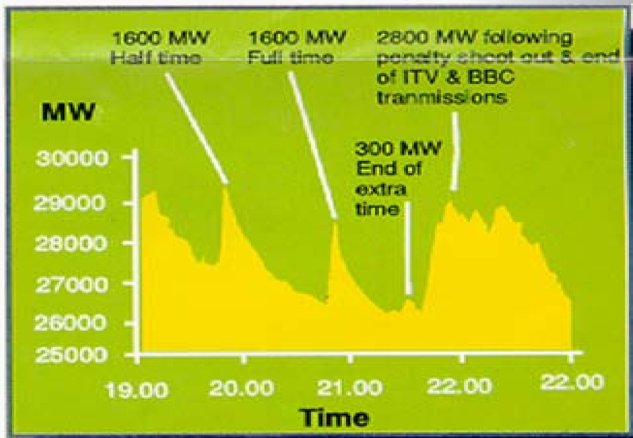
Potential Storage Capacity of EVs

- At the end of 2012, there were 34.5 million vehicles licensed for use on the roads in the UK.
- Assume 10% of existing vehicles become electric and that average battery capacity is 25 kWh. This gives a potential total battery energy capacity of 86.25 GWh.
- Assuming that 50% EVs are available for grid support and that only 40% battery capacity is used (to reduce battery degradation), there will be up to 17.25 GWh storage capacity available to support the grid.



Surges in demand of electricity during England-Germany World Cup semi-final
4th July 1990

Great Britain. Department for Transport; Vehicle Licensing Statistics; *Statistical Release* 11 April 2013

Challenges for the Battery SOH

- Battery is the most expensive part in the EV, so it is important to reduce degradation and extend battery life, especially if the battery is to be used to provide ancillary services. Currently cost of degradation varies between €0.03-0.3 per kWh.
- Battery performance and lifetime are very sensitive to internal factors (e.g. chemistry, structure) and operating conditions, (e.g. cells balancing, temperature, charging/discharging regimes).
- Need to clearly understand battery aging mechanism and factors that affect this in order to **define favourable charging/discharging profiles**, which may be achieved by using smart charging and smart BMS.

Battery Management System (BMS)

- Monitor the state of health of individual cells.
- Ensure that cells voltages and loading are balanced.
- Protect the battery from operating outside its safe operating area.
- Communicate with external environment.

- Tesla 85 kWh battery pack contains 16 modules; each contains 6 groups of 74 Li-ion 18650 type cells with a total of 7,104 cells.
- Nissan Leaf 24/30 kWh battery pack contains 48/24 modules; each contains 4/8 Li-ion NCM 622 laminate type cells with a total of 192 cells

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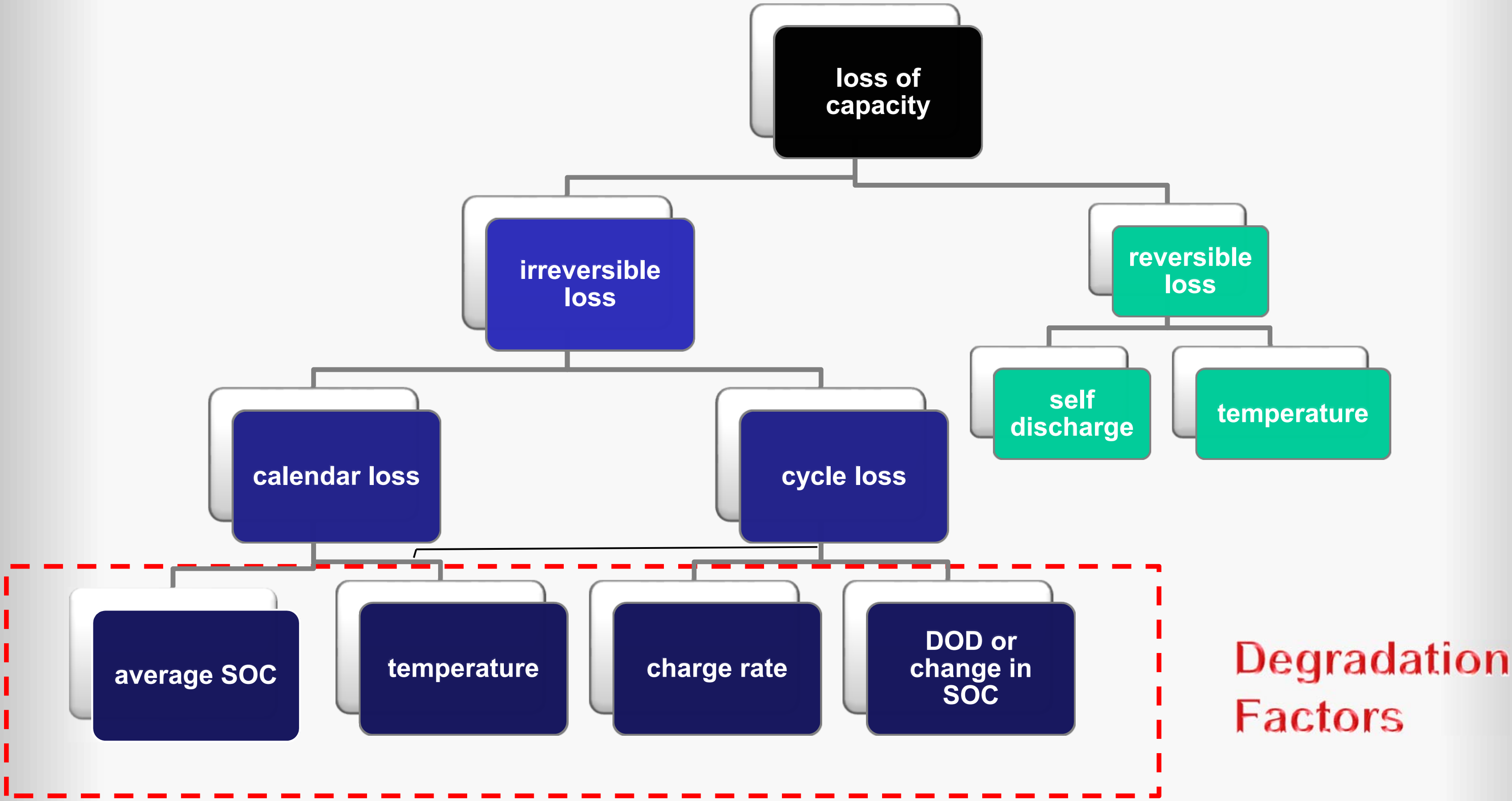
EV Battery (Li ion) Capacity Loss



Smart charging can reduce battery capacity loss

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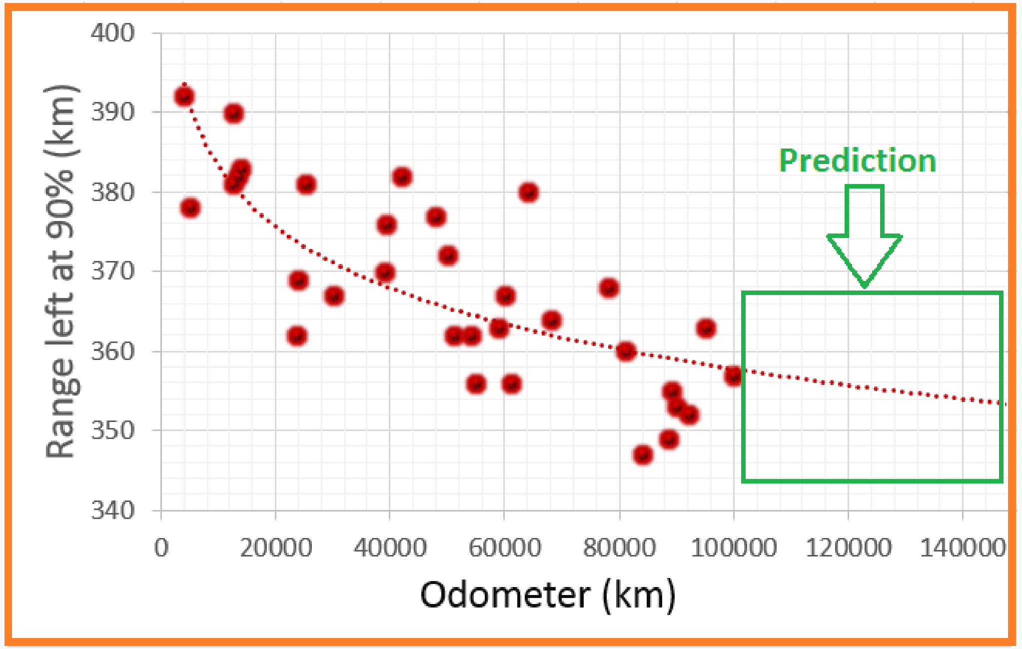
EV Battery Degrades with Time and Use

Need to understand battery ageing mechanism and minimize degradation in order to provide smart charging and economical grid support.



16 channels battery tester and environmental chamber

Source: teslamotorsclub.com

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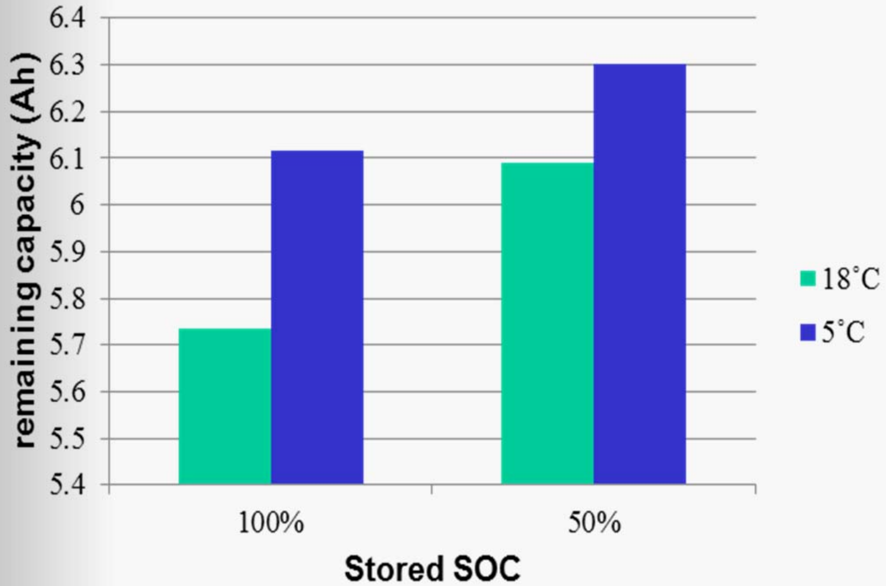
Battery Calendar-Loss

- Permanent capacity loss increases with temperature and SOC.
- Not all Li ion batteries behave the same.

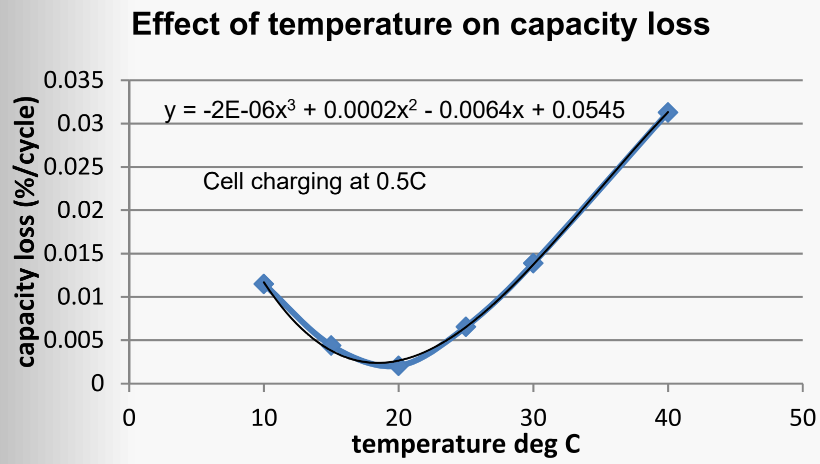


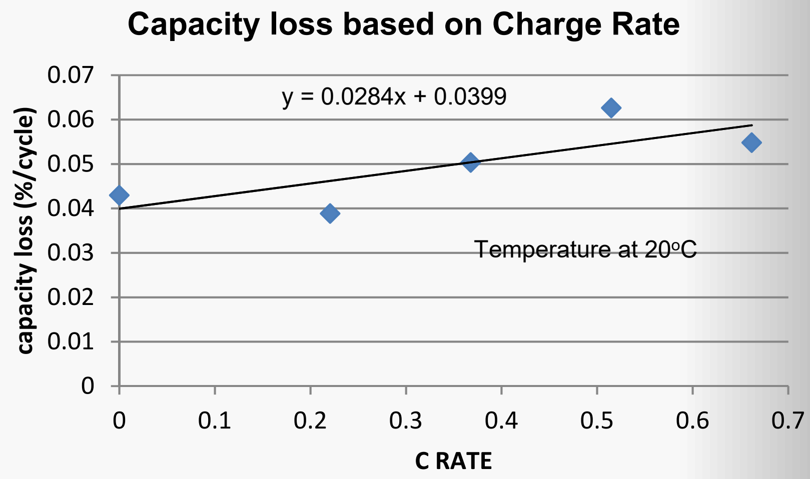
Temp.	40% charge	100% charge
0° C	98%	94%
25° C	96%	80%
40° C	85%	65%
60° C	75%	60% (after 3 months)

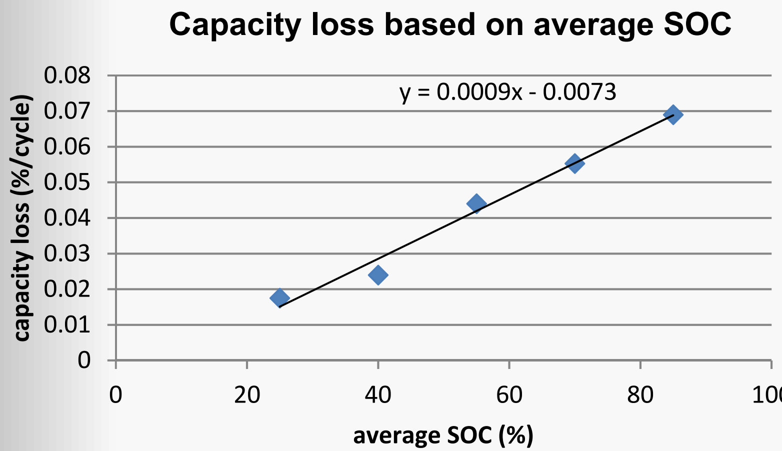
https://batteryuniversity.com/learn/article/how_to_prolong_lithium_based_batteries

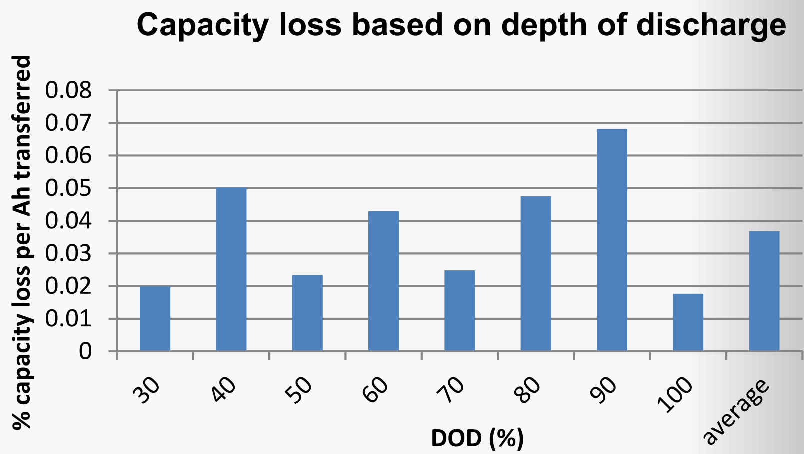
The remaining capacity in batteries stored for one year at different temperatures and SOC

Battery Cycle-Life Degradation Factors









Battery SOH is best at room temperature; Low SOC; Low DOD and Low charging/discharging current

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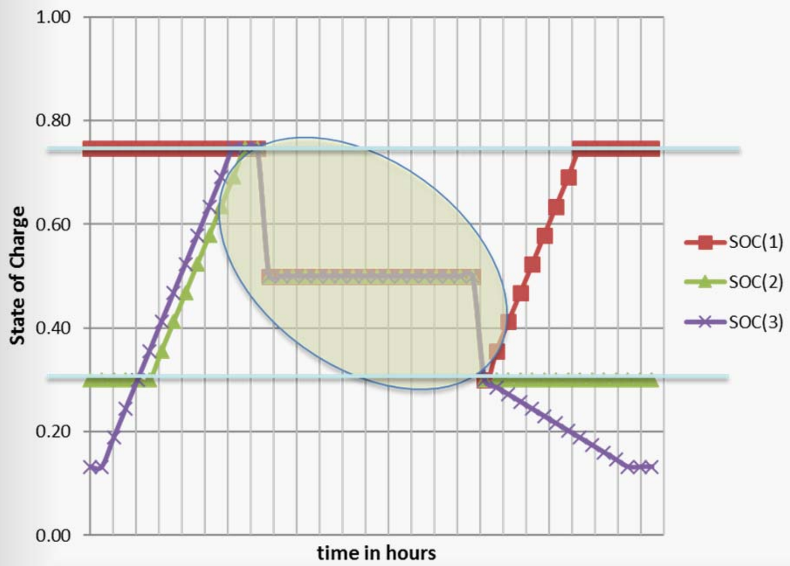
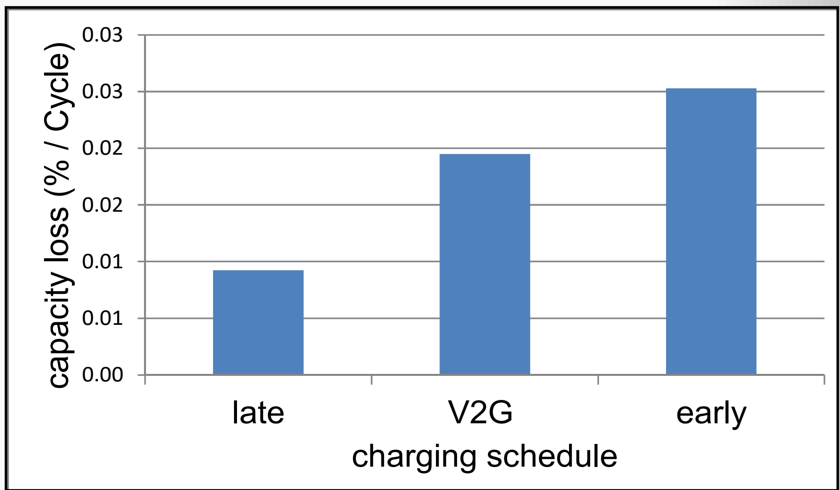
Smart Charging Extends Battery Life

- Lab tests on cells cycled over 15 months show the effect of cycling schedules on battery degradation.
- Assuming constant temperature, battery degradation is determined by the battery average SOC and charge transfer during cycling.
- Smart (late) charging and V2G result in lower average SOC and this reduces capacity loss.





Early: EV is charged immediately after driving.
Late: EV is charged immediately before driving
V2G: after driving, EV is used to support the grid and then charged.

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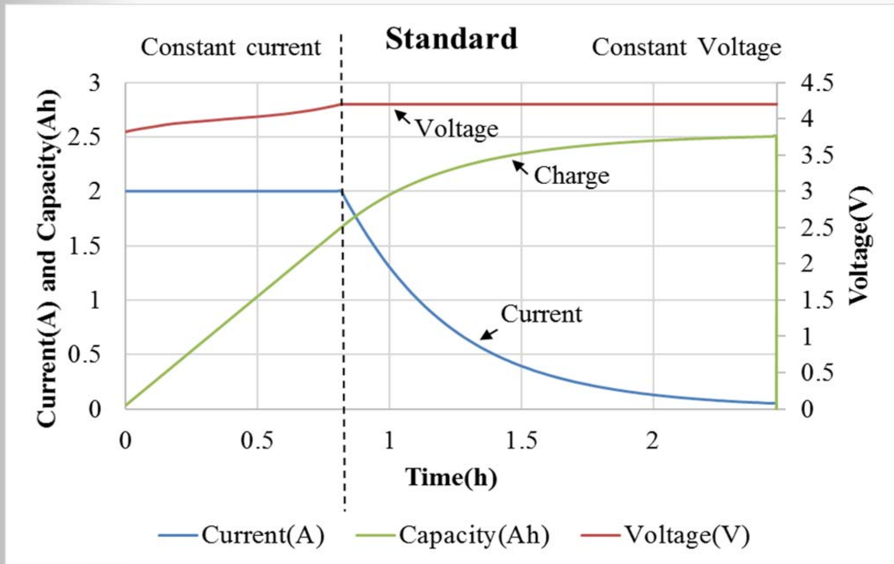
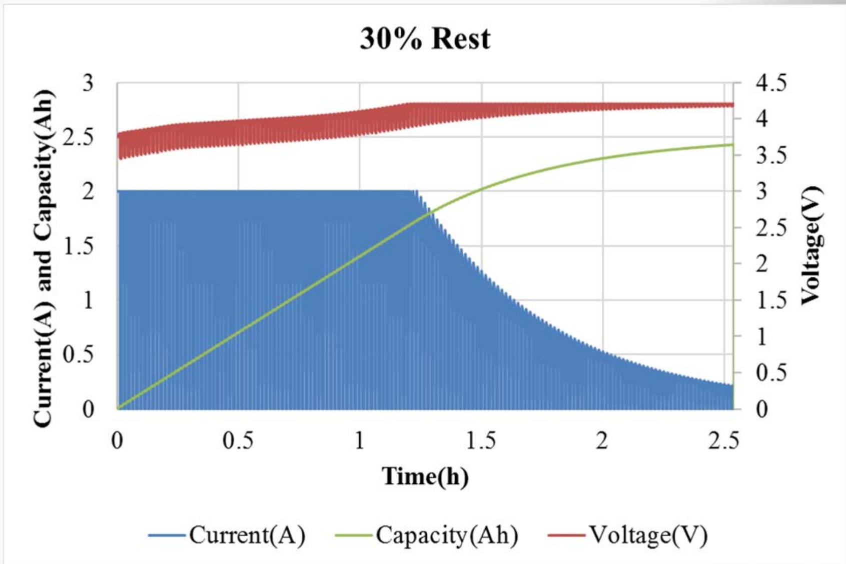
Standard and Modified Charging Profiles





Standard Constant Current - Constant Voltage (CC-CV) profile

Currently considered to be fast and better way of charging Lithium ion batteries.

Modified charging profiles

By introducing rest and/or negative pulse periods throughout the charging period.

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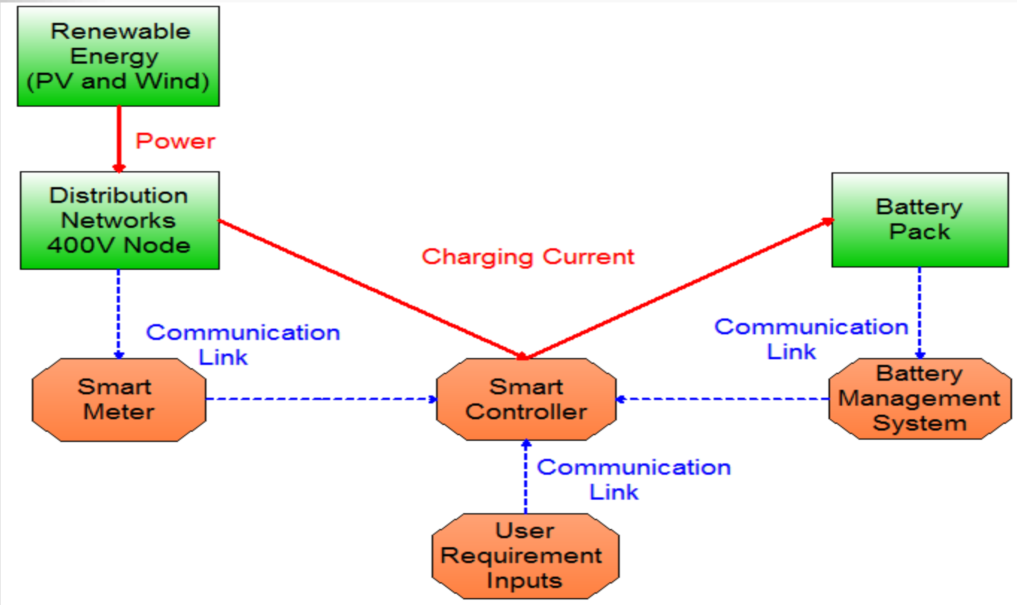
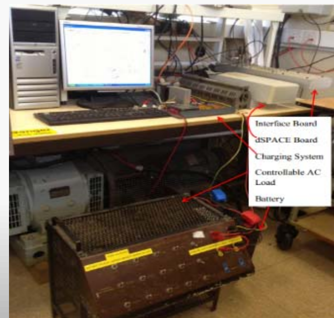
Smart EV Charger

- Meet driver requirements (e.g. charging time & length of next trip).
- Reduce battery degradation.
- Support the grid, by charging during off-peak times
- Charge from renewable energy (when possible)



This led to a Knowledge Transfer Partnership (KTP) project with SEVCON funded by Innovate UK (£137k) to develop a ready for market controller was completed in July 2016.



Jiang T., Putrus G., et al, "Development of a Decentralized Smart Charge Controller for Electric Vehicles", Elsevier Journal of Electrical Power & Energy Systems, Volume 61, October 2014, pp. 355–370.

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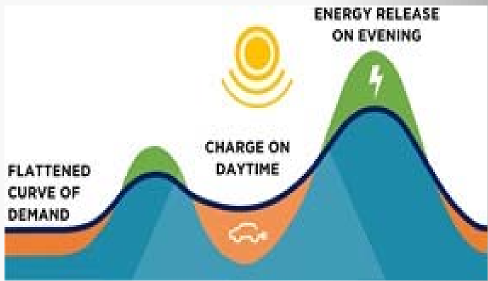
EV Battery as Energy Storage for the Grid

- Energy storage provides the missing link between renewable (intermittent) energy and grid control by providing Supply-Demand balance.



- EVs as distributed energy storage
  - ➢ EVs have high energy capacity and mass deployment
  - ➢ With smart control, EVs provide opportunities to support the grid and charge from available renewable energy with minimum degradation to the battery.

- Grid-scale storage employing used EV batteries.

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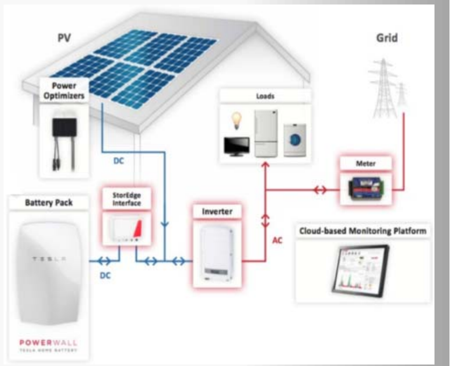
Second Life EV Battery

- Electric Vehicle batteries have sufficient energy capacity to supply energy for a typical house for up to 24 hours.
- Electric vehicle battery is replaced when its energy capacity drops to 80% of capacity when new.
- After EV use, batteries may be given a "second life" for large centralised bulk grid storage, as size and weight are immaterial.
- Use of second life EV batteries will reduce total cost of EV ownership.
- Bloomberg: "Second-life" EV battery storage will total 26 GWh by 2025.



Stationary storage using BMW i3 battery (22 or 33 kWh)

Charles Morris, "Charged Electric Vehicle Magazine", 04/09/2016.

Summary

- The 19th century saw the birth of electric vehicles and the commercialization of distributed d.c. electricity generation.
- The 20th century saw the mass production of ICE vehicles and the birth of high-voltage national centralized a.c. grids.
- What will the 21st century brings?
- EVs have high energy capacity and their mass deployment can have negative impacts on the grid and the environment **or** can provide valuable support if smart charging is used.
- Opportunities to use the EV to meet driver requirements, provide support to the grid and charge from green energy.
- Smart charging may be designed to extend battery life, allow for driving behaviour, traffic and weather conditions.
- A sustainable electric transport relies on developing successful business models for ‘vehicle for energy services’.

Sustainable Electric Transport and Supply

Thank you

Ghanim Putrus

Faculty of *Engineering and Environment*
Northumbria University
Newcastle upon Tyne NE1 8ST

E-mail: ghanim.putrus@northumbria.ac.uk

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