Electric cars: mass rollout, but when?

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http://www.eprg.group.cam.ac.uk
Outline

• **Necessity**: transport must decarbonise by 2050
• **Barriers**: Economic, technical, informational, use
• **Social cost benefit analysis**
  – Fiscal cost of subsidizing BEVs
  – Fuel costs, carbon pricing and electricity costs
• **Conclusion**:
  – favourable price developments needed for mass roll-out
  – as well as overcoming barriers

Draws on FP7 project *Green e-Motion* at [http://www.greenemotion-project.eu/](http://www.greenemotion-project.eu/)
Transport: no GHG by 2050

Source: NAEI (2014) Final emissions estimates; CCC analysis.
Notes: *Emissions from international aviation and shipping are not currently included in carbon budgets. This will be reviewed by Government in 2016.

Useful numbers

• Energy/km increases at square of speed
  – At 110kph 27kW (85% efficient motor) 0.25 kWh/km is absolute limit given frontal area (MacKay, 2013, p256)

• 0.2 kWh/km at 15,000km/yr => 3 MWh ≈ 2 x domestic cons.
  – Electricity at current av 500gm CO₂/kWh = 100 gm CO₂/km
  – At 2030 target 100 gm/kWh = 20 gm CO₂/km
  – 3.5 kW home charger = 17.5km/hr, 50 kW fast charger = 250kph

• FES Gone Green scenario 2030: 2.8 m BEVs ≈ 9% of fleet
  – 8.4 TWh ≈ 2% 2030 demand - modest
  – 2050: 30 million BEVs ≈ 90 TWh ≈ 15% of 600 TWh

• 1 gallon (Imp.) gasoline = 40 kWh. Diesel = 45.5 kWh
  – VW Polo 1.2 TSI 47.4 mpg (6L/100km) = 0.53 kWh/km = 141gm CO₂/km;
  – VW Polo 1.4 TDI 56.2 mpg (5.1L/100km) = 0.51 kWh/km = 134 gm CO₂/km
Perceived disadvantages: battery cost; slow charging + lack of charging poles => range anxiety; lack of performance, life and resale information

- 80% of TRL survey had never charged outside home
- 44% charge every day, regardless of state of charge, SOC
- 72% delayed charging until off-peak tariff (after 9pm)

Range anxiety increases with experience of use
- Depends on speed, temperature, SOC
  - But mean SOC before trips is consistently high

Perceived advantages: grant important for 85% buyers
- fuel saving decisive for 60% buyers (mainly tax subsidy)
- Annual licence saving £140 less important
Barriers: economic

• GeM D9.1: purchase cost is main barrier
  • Offsets: lower “fuel” and maintenance in Total Cost of Use
• Range anxiety – increases with experience
• Willingness to pay (WTP) for km increased range:
  • Averages: IT = €61/km; IE = €21/km; DK €98/km
    => cost penalty for BEV €3,000-14,000
  • WTP €50/km => WTP €250/kWh battery < current cost
• Characteristics: High capital, low running cost => high utilisation, but range anxiety and slow charging => barriers
  • Fast public charging: DE WTP = €§24/kWh but low demand and doubtful economics; peak charging costly
  • Off-peak controlled charging: cheap power, costly kit
Barriers: informational

• About *battery reliability*, and determinants of *life and performance*
  • also *battery replacement cost, second hand value, maintenance costs*
  • Not helped by biased information from OEMs
  • Can be addressed through warranties, battery /car lease
• **Policy implications**
  • Better on-board journey information on remaining range

*Experience reduces concerns over charging but increases concerns over mobility*
Barriers: utilisation

- **Proliferation of fast charging standards:** Japan, US and EU differ
  - Need for easy location of charging poles (signage)
  - Need for communications **standards** for charging/billing
  - Need for **roaming** options
  - Some EVSE owners/operators not allowed to **retail** electricity
  - Some countries **licence** refueling/charging stations and limit number and entry

*Given large public subsidies there is potential public leverage over solving these problems*
Social cost benefit analysis

- Economic cost requires the use of **efficient, not market prices** ⇒ **social cost benefit analysis**
  - For road fuel this is *exclusive* of road fuel excise duty (88 €¢/L for UK diesel), but *plus* the CO$_2$ and air pollutant costs
  - For electricity prices it is the nodal spot price + ΔCO$_2$ with the scarcity price of any transmission and distribution networks

⇒ Domestic **efficient** electricity prices for controllable EV charging times can be low: 5 €¢/kWh or less
  - **But** peak efficient prices might be 30 - 40€¢/kWh (**Plus** fast charging outlet cost)

- The **subsidy** is the difference between the required market price for profitability and the efficient price
Road fuel is heavily taxed

Values in EUR at 01/10/2014

Unleaded Petrol

Situation as at 1 January 2015

Minimum Excise Duty: 359 EUR per 1000 litres
Fiscal cost to 2020

• Suppose 2% penetration = 5 m BEVs in EU by 2020
  • If av purchase subsidy is €2,000/BEV => €10 billion
  • If av fuel tax is €0.6/L, av ICV does 6L/100km, 14,000 km/yr then lost revenue €500/BEV/yr => €5.5 billion
  • Total lost revenue = €15.5 billion for only 2% penetration
• IEA study => subsidy = $50,000/BEV to 2012
• UK example
  • 2% of 2020 park = 570,000 BEVs
  • Lost fuel tax revenue = €560/BEVyr => €700 million to 2020
  • Lost vehicle licence €165/BEVyr => €200 million to 2020
  • if current grant £5,000/BEV maintained => €3.36 billion
  • At €2,000/BEV => €1.14 billion, total €2 billion
### Social cost of road fuel 2015-30

#### Table 1 Calculation of social cost of road fuels excluding excise taxes, US $(2012)/litre

<table>
<thead>
<tr>
<th>Date</th>
<th>Scenario</th>
<th>Oil price US$/bbl</th>
<th>CO₂ cost US$/tonne</th>
<th>retail pre-tax prices US$/L</th>
<th>CO₂ cost US$/L</th>
<th>Pollution US $/L</th>
<th>Total US$/L</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>G</td>
<td>D</td>
<td>G</td>
<td>D</td>
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<tr>
<td>2015</td>
<td>Low</td>
<td>$91</td>
<td>$0</td>
<td>$0.70</td>
<td>$0.72</td>
<td>$0.00</td>
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<td></td>
<td>Central</td>
<td>$110</td>
<td>$9</td>
<td>$0.91</td>
<td>$0.89</td>
<td>$0.02</td>
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<td></td>
<td>High</td>
<td>$130</td>
<td>$21</td>
<td>$1.11</td>
<td>$1.06</td>
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<td>$0.06</td>
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<tr>
<td>2020</td>
<td>Low</td>
<td>$85</td>
<td>$0</td>
<td>$0.66</td>
<td>$0.68</td>
<td>$0.00</td>
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<tr>
<td></td>
<td>Central</td>
<td>$117</td>
<td>$14</td>
<td>$0.95</td>
<td>$0.94</td>
<td>$0.03</td>
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<td></td>
<td>High</td>
<td>$147</td>
<td>$28</td>
<td>$1.25</td>
<td>$1.19</td>
<td>$0.07</td>
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<td>2030</td>
<td>Low</td>
<td>$74</td>
<td>$61</td>
<td>$0.60</td>
<td>$0.62</td>
<td>$0.14</td>
<td>$0.16</td>
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<tr>
<td></td>
<td>Central</td>
<td>$132</td>
<td>$121</td>
<td>$1.09</td>
<td>$1.07</td>
<td>$0.29</td>
<td>$0.32</td>
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<td>$182</td>
<td>$1.59</td>
<td>$1.52</td>
<td>$0.43</td>
<td>$0.49</td>
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</table>

Source: DECC (2012, 2013), Newbery (2005) updated to 2012 prices, exchange rate $1.60=£1
### “Fuel” cost €¢/kWh

- 2015 efficiencies Low
- 2020 L-M; 2030 M-H

#### Table 2 Assumed conversion efficiencies

<table>
<thead>
<tr>
<th></th>
<th>Diesel</th>
<th>Gasoline</th>
<th>Battery</th>
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<tbody>
<tr>
<td><strong>Low</strong></td>
<td>30%</td>
<td>20%</td>
<td>70%</td>
</tr>
<tr>
<td><strong>Medium</strong></td>
<td>35%</td>
<td>30%</td>
<td>75%</td>
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<tr>
<td><strong>High</strong></td>
<td>41%</td>
<td>37%</td>
<td>80%</td>
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</table>

#### Table: Fuel Costs and Energy Equivalents

<table>
<thead>
<tr>
<th>Date</th>
<th>Scenario</th>
<th>total fuel energy content €¢/kWh</th>
<th>battery energy equivalent €¢/kWh</th>
<th>maintenance penalty €¢/kWh</th>
<th>total €¢/kWh</th>
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<td>G</td>
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<td>G</td>
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<tr>
<td>2015</td>
<td>Low</td>
<td>6.4</td>
<td>6.4</td>
<td>22.5</td>
<td>14.9</td>
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<td>8.5</td>
<td>8.2</td>
<td>29.7</td>
<td>19.0</td>
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<tr>
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<td>High</td>
<td>10.6</td>
<td>10.0</td>
<td>37.1</td>
<td>23.3</td>
</tr>
<tr>
<td>2020</td>
<td>Low</td>
<td>6.0</td>
<td>6.0</td>
<td>15.1</td>
<td>12.8</td>
</tr>
<tr>
<td></td>
<td>Central</td>
<td>8.9</td>
<td>8.5</td>
<td>26.8</td>
<td>18.9</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>11.9</td>
<td>10.9</td>
<td>41.5</td>
<td>25.5</td>
</tr>
<tr>
<td>2030</td>
<td>Low</td>
<td>6.7</td>
<td>6.6</td>
<td>14.4</td>
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<td>Central</td>
<td>12.3</td>
<td>11.6</td>
<td>28.8</td>
<td>23.8</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>18.0</td>
<td>16.6</td>
<td>45.1</td>
<td>35.6</td>
</tr>
</tbody>
</table>
Typical charging profile

Source: Low Carbon London Report B1
• Home charging of BEVs: most 3.5kW, some 7kW
  => increased load => impact distribution transformers
  – How much? Can investment be reduced/delayed?
• Normal domestic demand enjoys high diversity:
  – Electric hob 10kW, electric kettle 3 kW
  – Domestic demand Dec-Mar LP1 peak at 7pm 0.7kW
  – LP2 (peak/off-peak metered) peak at 1.30am 1.9 kW
• BEVs without TOU charging very peaky
  – But diversity still exists => 25% of individual EV
  **BEVs responsive to TOU charging**
Uncontrolled and optimized BEV charging: 22 HHs & EVs

Source: Low Carbon London Report B1
Impact of charging strategies on the need for conventional plant capacity and emissions and prices of electricity

- **Optimistic optimisation** – assumes could and would charge whenever stationary (which is most of the time)

Source: GeM D9.2
Carbon impact of EVs

• **Cap**: under ETS CO₂ separate caps for two sectors
  – Transport fuel only included in uncovered sector
  – If each cap binds then no saving of CO₂?
    • Surely in longer run caps would be adjusted? More like:

• **No such problem with carbon price**
  – Saving is difference in gm CO₂/km x km
  – E.g. 2015 for gasoline = 141-100 = 41gm/km = **0.62 tonnes/EVyr**
  – 2030 at 100gm/kWh = 121 gm/km = **1.82 tonnes/EVyr**
    • But ICVs may be more efficient then

• **What generation is at margin when BEV charges? Fossil?**
  *Only short run – future BEV => more low C generation*
Additional system cost per EV in UK and Ireland in 2030

“fuel” = generation variable cost

“off-peak”
Additional CO$_2$/EVyr 2030

GEM 9.2: 2.12 MWh/yr
2030 CO$_2$ and cost

- GeM D9.2 2030 with 5% EV penetration for UK:
  - 2030 CO$_2$ price: Low (L) €50/tonne, High (H) €150/tonne
  - No smart charging: 150 gm/kWh, C cost = 0.75(L) - 2.3 (H) €¢ /kWh
  - 75% smart charging: 88 gm/kWh
  - With 10% of EVs offering frequency response CO$_2$ falls by 27 gm/kWh so with 75% smart charging overall 61gm/kWh
  - C cost = 0.3(L) – 0.9 (H) €¢ /kWh
- Spain and Germany considerably higher
Prices vary from peak to off-peak

European power exchanges 2012

Euros/MWh

percent time price higher than

-€ 200
-€ 150
-€ 100
-€ 50
€ 0
€ 50
€ 100
€ 150
€ 200
€ 250
€ 300
€ 350
€ 400
€ 450
€ 500

-€ 50
-€ 100
-€ 150
-€ 200
-€ 250
-€ 300
-€ 350
-€ 400
-€ 450
-€ 500

0.0% 0.2% 0.4% 0.6% 0.8% 1.0% 1.2% 1.4% 1.6% 1.8%

UK MIP (Euros)
Germany 2012
Netherlands
France
Estimating the 2030 cost of electricity

- Germany has high renewables, better represents 2030
- 2012 EU av wholesale price excl CO₂ = €₄.2/kWh
- Take 2030 av wholesale price excl. carbon as €₄.8/kWh
- Top 25% hours 148% average price = €₇.₁/kWh
- Bottom 25% hours 75% average price = €₂.₅/kWh
- Add in CO₂ cost (€75-150/tonne) Low-High:
  - peak 0.₈-2.₃ €/kWh, smart (“off-peak”) 0.₃-0.₉ €/kWh
- Mark-up to retail (losses, contracting, margin etc.) = 50%
- T&D in 2020 €200/yr recover in top 25% hours €₂₄/kWh
- 2020 Peak hour cost = 7.₁x₁.₅+0.₈-2.₃+2₄ = 3₅-3₇ €/kWh
- 2020 Off-peak/smart cost =2.₅x₁.₅+ 0.₃-0.₉ = 4-₅ €/kWh
### Range of BEV “fuel” costs

- Battery, charger and electricity cost, per kWh

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Net battery + charger (10yr life)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low at 5%, 17,000 km/yr</td>
<td>38</td>
<td>22</td>
<td>13</td>
</tr>
<tr>
<td>High: 10%, 15,000 km/yr</td>
<td>57</td>
<td>36</td>
<td>22</td>
</tr>
<tr>
<td><strong>Electricity off-peak L</strong></td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Peak H</td>
<td>30</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td><strong>Total cost</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low + off-peak</td>
<td>42</td>
<td>26</td>
<td>17</td>
</tr>
<tr>
<td>High + peak</td>
<td>87</td>
<td>73</td>
<td>59</td>
</tr>
<tr>
<td>90% off-peak, 10% peak</td>
<td>47</td>
<td>31</td>
<td>21</td>
</tr>
</tbody>
</table>
BEVs could be competitive by 2015

With high oil prices

Build up of "fuel" costs €/kWh

- maintenance penalty
- extra for peak
- off-peak electricity
- CO2 elec offpk
- battery+other costs
- D purchase cost
- CO2
- Oil
Low Carbon London CBA

• Main issue is impact on distribution transformers

CBA findings:
• ToU tariff: NPV>0 if recruitment cost < £20/EV
  – estimated recruitment cost = £350/EV
• ANM: benefit = £6.7k, DNO cost = £307k!
  – Could be competitive for commercial fleet > 131 vans

Conclusion: ToU and ANM unlikely to be cost-effective
Conclusions

• Many important questions remain
  • On battery performance – what is the potential in power density, hence size and range, and cost/lifetime?
  • On network management – how can charging be managed to deliver cheap low-C power without more investment?
  • For the Distribution Service Operator – how to access frequency control and demand side response (LCNF projects)
  • On driving behaviour – what would reduce range anxiety? Is the BEV just the second car or can ICV rental solve problem?

Viable economic case by 2020 need high oil and carbon costs
If battery costs continue to fall, cost parity by 2020-30
Spare slides

David Newbery

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Acronyms

BEV  Battery Electric Vehicle
C    Carbon (as in CO$_2$)
D9.2 Economic and environmental impact of EV deployment on European
electricity systems; Final report by Aunedi, Strbac, Pudjianto & Djapic
GeM  Green e-Motion (FP7 project)
EV   Electric Vehicle
ETS  Emissions Trading System (of EU)
FES  Future Energy Scenarios produced by National Grid
FR   Frequency response
GHG  Greenhouse gas, mainly CO$_2$
ICV  Internal combustion vehicle
SOC  State of Charge
TOU  Time of use (charging)
WTP  Willingness to pay