Green Emotion - GEM

The Economics of Electric Vehicles

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Outline

• Statement of the problem
• Quick overview of vehicles
• Structure of Green eMotion and Imperial College activities
  • my tasks within that
  • Other activities – Low Carbon Network Project I2EV
• Business models under trial
• The economics of EVs and Plug-in Hybrids (PHVs)
  • contrasts with “Business case”
  • Links with other WPs looking at grid interactions
• Conclusions

Four year project, field trial data slow to arrive
Questions and comparisons

• What are we comparing?
  • **Cars only**: Battery Electric Vehicles (BEVs), Plug-in Hybrids (PHVs) with conventional internal combustion vehicles (ICVs)

• What are the main differences?
  • Hold car characteristics constant (size, acceleration, carrying capacity, etc.) then:
    • Battery cost and weight, refuelling time, range, fuel price
  • **Will EVs be attractive (at some scale) by, say, 2020?**
    • With future fuel, electricity and carbon prices
    • And future battery costs and ICV performance?

*Need to distinguish economic from business case*
Nissan Leaf BEV

- Motor: 80 kW; battery Li-Ion 24 kWh, 300kg, guarantee: 8ys or 160,000 km, charge time: 7 hrs @ 240 V; charger costs $2,200; DC 500V fast charge in 30 mins ($17,000) **vehicle price UK £31,000***
- Performance 4.73km/kWh = 0.21 kWh/km, 0 -100 km/h in 10 secs
- Range: 117 km (175km Euro test); 75-100km at -7to-1°C with heater and heavy traffic; typically charge 2hrs/night
- 7,500 US sample: av 60km/day; 11 km/trip

* Reuters op/ed Sep 2012: GM losing US$49,000 on each Volt built. The Volt is "over-engineered and over-priced"
Battery Pack – not just a battery

Figure 2-3 Example of a battery pack. Source: Axeon guide to batteries

Source: Element Energy (2012)
Chevy Volt 2012 PHV (Vauxhall Ampera)

- Engine: 1.4 L 63 kW; Motor: 111 kW; Battery: 16 kWh Li-Ion
  10.8 kWh available, wt 200 kg, guarantee: 8 yrs or 160,000 km
- 55 kW generator, 0–97 km/h = 9.2 secs electric, 9 secs both
- Performance 5.9 km/kWh = 0.17 kWh/km EV, 20 km/L petrol
- 4.7 L/100 km as hybrid. **UK price £34-37,000**
- Range: 55 km EV; 610 km total, charge time: 4 hrs @ 240 V
Toyota Prius 2012 PHV

- Engine: 1.8 L 73 kW; Motor: 60 kW; Battery: 4.5 kw-hr Li-Ion; 42 kW generator, 0 to 100 km/h in 10.7 secs
- Performance 5.5 km/kWh = 0.18 kWh/km
- Passenger vol 90 ft³. **Price £33,000** before subsidy
- Combined city/highway rating 4.7 L/100 km as hybrid
- Range: 20 km EV, 860 km total; charge time: 1.5 hrs @ 240 V
Experience of PHV:

Prius experience after 497,100 miles driven

• 66% of commute trips < 20 km = the expected EV range
• > 33% of participants > 100 km trip at least once a week.
• Prius PHV consumed 36% less fuel than the comparable, best-in-class diesel vehicle, and almost 50% less than the best-in-class petrol vehicle.
My relationship to the ICL WP9 Tasks

- **Task 9.1** Consumer acceptance
  - Customer preferences
  - Env. impact of electricity supply
  - Env. performance parameters
  - Economic performance indicators

- **Task 9.2** System economic performance
  - Participation in system management
  - Areas with added value

- **Task 9.3** Business models

- **Task 9.4** Environmental impacts

- **Task 9.5** Policy recommendations

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**UNIVERSITY OF CAMBRIDGE**
**Electricity Policy Research Group**
Task Objective

Identify and analyse the most promising business models for allowing a widespread adoption of electric mobility in Europe.
Considerations for Business Models Selection

WP1 Business Models (according to DoW):

- Barcelona: **e-parking**, for cars + motorbikes
- Berlin: Post payment + **roaming**, public/semi/private, for cars/commercial
- Bornholm: Monthly subscription + roaming, public, cars/bikes/taxis/commercial
- Copenhagen: Subscription + roaming, **battery switch**, cars/commercial
- Copenhague2: Free, private, cars
- Malmoe: Free + roaming, public, cars/bikes
- Ireland: Post payment, public/semi/private, cars/commercial/taxis
- Italy: **Energy retailer**, public/private, cars
- Madrid: **Car renting**, public, cars/commercial
- Malaga: Energy retailer, private, cars
- Strasbourg: Free, public/semi/private, hybrid car
- Stuttgart-Karlsruhe: Energy retailer + roaming, public/semi/private, cars/commercial
Other projects

• Low Carbon Network Project I2EV – Southern Electric Power Distribution Division
  • This project will trial a technology that will allow a cluster of electric vehicles (EVs) to re-charge without stressing the low voltage network. The aim is to test the effectiveness and acceptance by EV customers of an “intelligent socket” that is controlled from the distribution sub-station – ensuring that the load on the feeder is kept within acceptable limits. It will use the Nissan Leaf

This project explores intelligent charging to reduce the electricity cost (to the network and EV owner)
Expected Task Development

BM = Business Model

WP1

List of BM within GeM

Qualitative assessment of BM

Selection of 3-4 promising BM

BM refinement (if needed)

WP9

Evaluation of economic impact on all relevant actors

Identification of barriers

Proposal of regulatory measures to overcome them

Evaluation of economic impact of measures

T9.5

Scenarios

2015

2020

2030

WP9

WP1

BM = Business Model
Building the Business Model

- A sustainable business case for the long-term requires
  - The economy as a whole benefits
    => need to use correct prices for evaluation
  - Each agent in the value chain makes a profit
- Medium run will require subsidies
  - to overcome barriers and coordination problems
  - to stimulate demand => higher production => lower long run costs => commercialisation
  - to offset pricing distortions elsewhere:
    Carbon not adequately priced, road fuel heavily taxed
Battery exchange versus charging points

• Cost of battery exchange has three elements:
  1. the net cost of the electricity supplied,
  2. the **use cost**, interest + depreciation of battery, and
  3. the **service cost**, i.e. the cost of providing the service (including all the handling and comms charges).

• Compare with cost of owning or renting battery ($12,000)
  • but still need home charger $2,000 or access to charging points
Better Place model*

- Better Place (partner Renault) owns batteries
- Plans to install charging points in homes ($2,000 each), work places, and various public locations and offer services and DSM to DNOs.
  - Communication System provides data on battery, charging stations, battery exchange, GPS, etc

Battery Switch Stations

• Battery exchanged at Battery Switch Stations
  • Automated - change takes 4 mins (same as fueling C V).
NRG installed its first Freedom Station in Dallas/Fort Worth on **April 8, 2011**, as part of eVgoSM’s network of charging stations.

- DC Fast charger: delivers 50 miles of charge in 15 minutes
- Level 2 charger: delivers up to 25 miles per hour.
- Plans 70 Freedom Station sites in the Dallas/Fort Worth area and 50 in the Houston area, (11 already in place in Houston and six installed in Dallas/Fort Worth at **June 2012**)
- Install a Level 2 (240v) charger at home, avoid $2,000 for $59/month for single family; $69 multi-family
- at work-place from $29/month – per person, multi purpose use
Charging stations

eVgoSM "Freedom Station" with one Level 2 charger (left) and one DC fast charger (right) at a Houston supermarket

Find On the Go Plans
- Starting at $19/month
Possible EV developments

• Initially BEVs as niche product
  • second car, limited local use, range not critical
  • charging at home/work, some outlets
• Plug-in Hybrids (PHVs) as bridging technology
  • stimulates battery and control development
  • removes range anxiety as charging outlets expand
• Eventually BEVs competitive as sole vehicle
  • cost-effective against ICVs
  • adequate charging infrastructure developed
  • various business models – rental, battery swap, etc
Projecting the future

- Carbon, electricity and oil prices will change
- Scenarios consistent with decarbonising imply high C prices
- High BEV penetration requires road tax changes
  - road fuel tax very high, pays for roads
    - gives high advantage to EVs at present
  - notionally replace by road pricing for all vehicles
- ICVs will improve
  - under tightened emissions/efficiency standards
  - substantial improvements possible (weight, engine)

**BEV competitiveness is a moving target**
Social cost benefit analysis and the business model

• Social cost benefit analysis requires the use of efficient, not market prices
  • For road fuel this is *exclusive of road fuel excise duty* (88 €¢/L for UK diesel), but *plus the CO₂ and air pollutant costs*
  • For electricity prices it is the nodal spot price 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 prices might be 45 €¢/kWh (fast charging outlets)
• The *subsidy* is the difference between the required market price for profitability and the efficient price
UK average domestic electricity prices include some tax-like charges but under-estimate carbon cost.

Price is forecast to rise from 14.9p/kWh to 18.3p/kWh by 2020 and 20.1p/kWh by 2030.
Data requirements

• Need to specify oil, carbon and electricity prices
• several scenarios, take from EU Roadmap?
• Need margins from oil to pump for gasoline, diesel
• then add CO2 cost + other corrective charges => “fuel cost”
• Project fuel efficiency of ICVs in 2015, 2020, 2025
  • for comparable size and power
  • calculate “fuel cost” per km for different C prices
• Calculate break-even running cost per km of BEVs
  • electricity + battery interest + depreciation separately
  => target electricity and battery costs rel to C price
• Assumes equality of BEVs and ICVs of same size
• But BEVs and ICVs differ in other respects
  • that affect consumer willingness to pay
• For BEVs: range anxiety vs reduced maintenance costs and increased functionality
  • varies according as main or second car and driving pattern
• Balance between purchase and operating costs
  • possibly different tax treatment

*Need information on willingness to pay for different vehicle types of similar power*
Oil prices are volatile, margins less so

Real US oil and product prices

- US imported crude
- Gasoline
- Diesel
- Gasoline margin
- Diesel margin

US$ (2009) per tonne

Jan-80 Jan-82 Jan-84 Jan-86 Jan-88 Jan-90 Jan-92 Jan-94 Jan-96 Jan-98 Jan-00 Jan-02 Jan-04 Jan-06 Jan-08 Jan-10 Jan-12

$100/bbl
Impact of carbon pricing

• 2020 DECC oil price projections $(2012)/bbl
  • Low       Med       High
  • $95       $125      $150

• energy content; D = 9.7kWh/L; G = 8.8 kWh/L

• pump prices without any taxes €¢/kWh
  • Diesel:  3.9  4.2  4.4
  • gasoline  4.8  5.0  5.3

• Add €50/tonne CO₂ and for other pollution
  • Diesel:  1.38 €¢/kWh  1.48 €¢/kWh
  • Gasoline: 1.35 €¢/kWh  0.56 €¢/kWh
**Efficiency estimates**

- IC vehicles where Low is current and high is possible
  
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<td>35%</td>
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<tr>
<td>Gasoline</td>
<td>20%</td>
<td>30%</td>
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- BEVs efficiency allowing for losses in battery
  
  |       | 70%  | 75%  | 80%  |

Allows us to estimate target electricity plus battery cost at which BEV running cost = ICV fuel cost

- to which should be added differential maintenance cost
Varying oil and C price *together* and assuming all efficiencies are *negatively correlated* with fossil fuel costs and 2020 pollution costs are 50%, 75% and 100% of 2000 levels *2012 prices*:

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<td>Oil price $/bbl</td>
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<td>$150</td>
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<tr>
<td>CO$_2$ €/EUA</td>
<td>25</td>
<td>50</td>
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*Target electricity plus battery cost €¢/kWh*

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<th>Diesel:</th>
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<td>14.2</td>
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<tr>
<td>Gasoline:</td>
<td>12.4</td>
<td>17.0</td>
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Current and projected PHEV battery cost

2011: $800/kWh for pack; 100 Wh/kg, $21,000 range = 150km
2030: possibly 300Wh/kg, $6,400 for a range of 250km.

Source: Element Energy (2012)
Cell plus packing costs for various BEV types

Source: Element Energy (2012) *Cost and performance of EV batteries* for CCC at


Figure 6-2 Cell and packing cost split in 2020 for the four defined BEV types
Projected PHEV battery cost

Figure 6-4 PHEV pack cost ($/kWh) for C&D 60kW pack for various pack sizes
### Example of battery costs (revised)

- Suppose battery costs /kWh
  - 2020 L: $350
  - 2020 H: $500

- Consider three cycle lifetimes:
  - 2,000 Years: €280
  - 2,500 Years: €400
  - 3,000 Years: €400

- Ignoring discounting, this translates into €¢/kWh
  - 2020L: €¢14
  - 2020H: €¢16

Cf target electricity + battery cost €¢15 (€¢10-28)/kWh
Impact of charging strategies on the need for conventional plant capacity and emissions and prices of electricity

- Calculate delivered electricity price (including same price of carbon) assuming efficient charging strategy
  - Including cost of extra generation, transmission, distribution assets
    - which with efficient charging could be zero
    - and spot price of power, lower if wind at the margin
Preliminary conclusions (revised)

- BEV Economics depend on battery cost, carbon & fuel cost and the local price of electricity at CP
  - Carbon + pollution tax element < current fuel excises
  - Battery cost and life are critical determinants
- At 2,500 cycles battery should last 10 years and might cost €11-16/kWh by 2020
- At $125/bbl, CO₂ at €50/EUA, modest ICV efficiency gain, possibly competitive at €14-17/kWh (D or G)
- So could pay €1-6/kWh for charging

BEVs viable only with higher oil and carbon prices or cheaper batteries?
• *If* there is a **viable economic case** for BEVs by e.g. 2020
  • examine existing support via road fuel tax exemption
    • correct for efficient pricing of electricity
    • may need extra support until pricing improves
    • Is this sufficient to cover difference in BEV – ICV cost?
  • estimate support needed to make vehicles viable at some earlier date – e.g. 2015?
    • offer this as capital rebate on battery? Subsidies to charging points (including in home)
    • Then compute business case with these subsidies
Policy implications

- BEV economics depend on costs of battery, carbon & road fuel and local cost of electricity at CP
  - Carbon + pollution tax element < current fuel excises
  - Battery costs and cycle lives are critical determinants

⇒ conduct all SCBAs at efficient prices
⇒ Main corrections to fuel, carbon and electricity prices
⇒ Economics look doubtful even by 2020 without subsidy or much higher C and oil price

- Consider possible contract designs between DSOs, aggregators and EV owners
Conclusions

• Many interesting questions to research
  • On battery performance – what is the potential in power density, hence size and range, and cost?
  • 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)
  • On driving behaviour – what would reduce range anxiety? Or is the BEV just the second car?
  • On business models – own or rent/lease; own or swap battery?
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Experience of PHV: