UNIVERSITY OF CAMBRIDGE | Energy Policy Research Group

CEEPR

MIT Center for Energy and Environmental Policy Research

Electric cars: mass rollout, but when?

David Newbery

University of Cambridge

EPRG-CEEPR European Energy Policy Conference

London, 10th July 2014

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

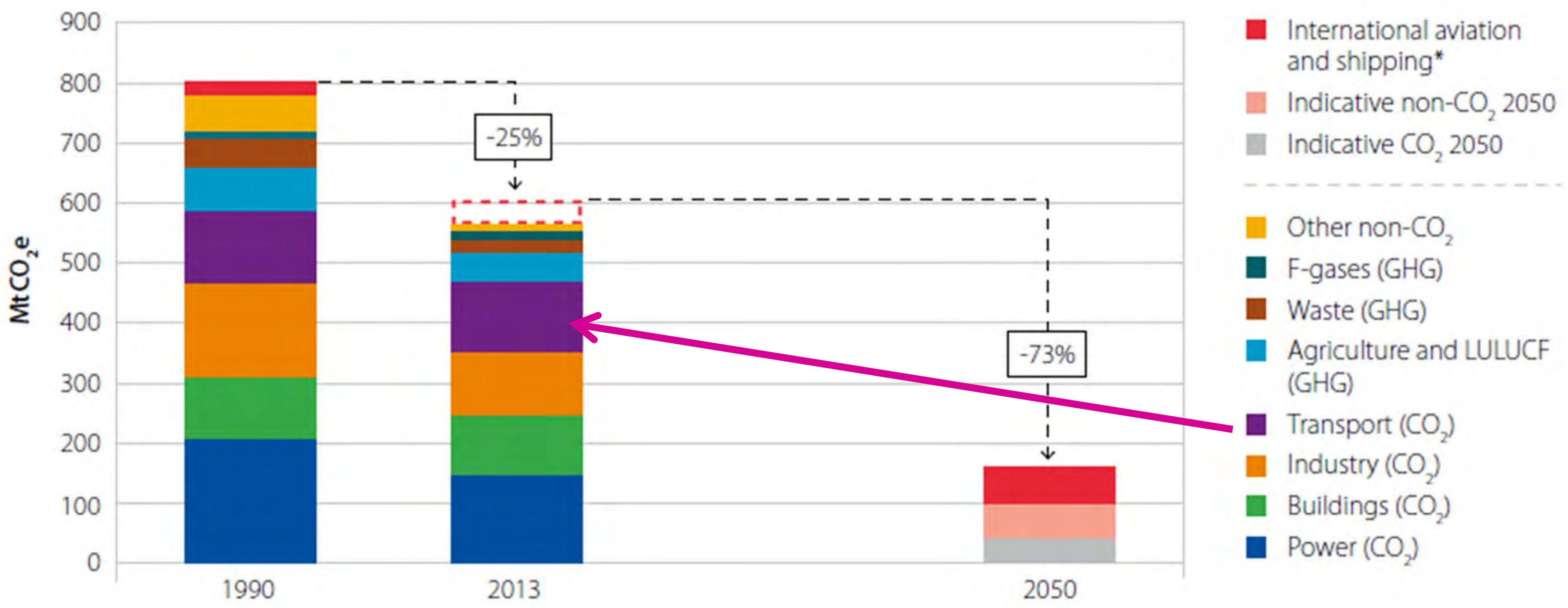
Outline

- 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/*

Transport: no GHG by 2050

UNIVERSITY OF CAMBRIDGE | Energy Policy Research Group



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.

CCC 2014) at http://www.theccc.org.uk/wp-content/uploads/2014/07/2014-Progress-report-presentation.pdf

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 CO_2 /kWh = **100 gm CO_2 /km**
  - At 2030 target 100 gm/kWh = **20 gm CO_2 /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 CO_2 /km**;
  - VW Polo 1.4 TDI 56.2 mpg (5.1L/100km) = 0.51 kWh/km = **134 gm CO_2 /km**

Perceptions from *UK survey*

- **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

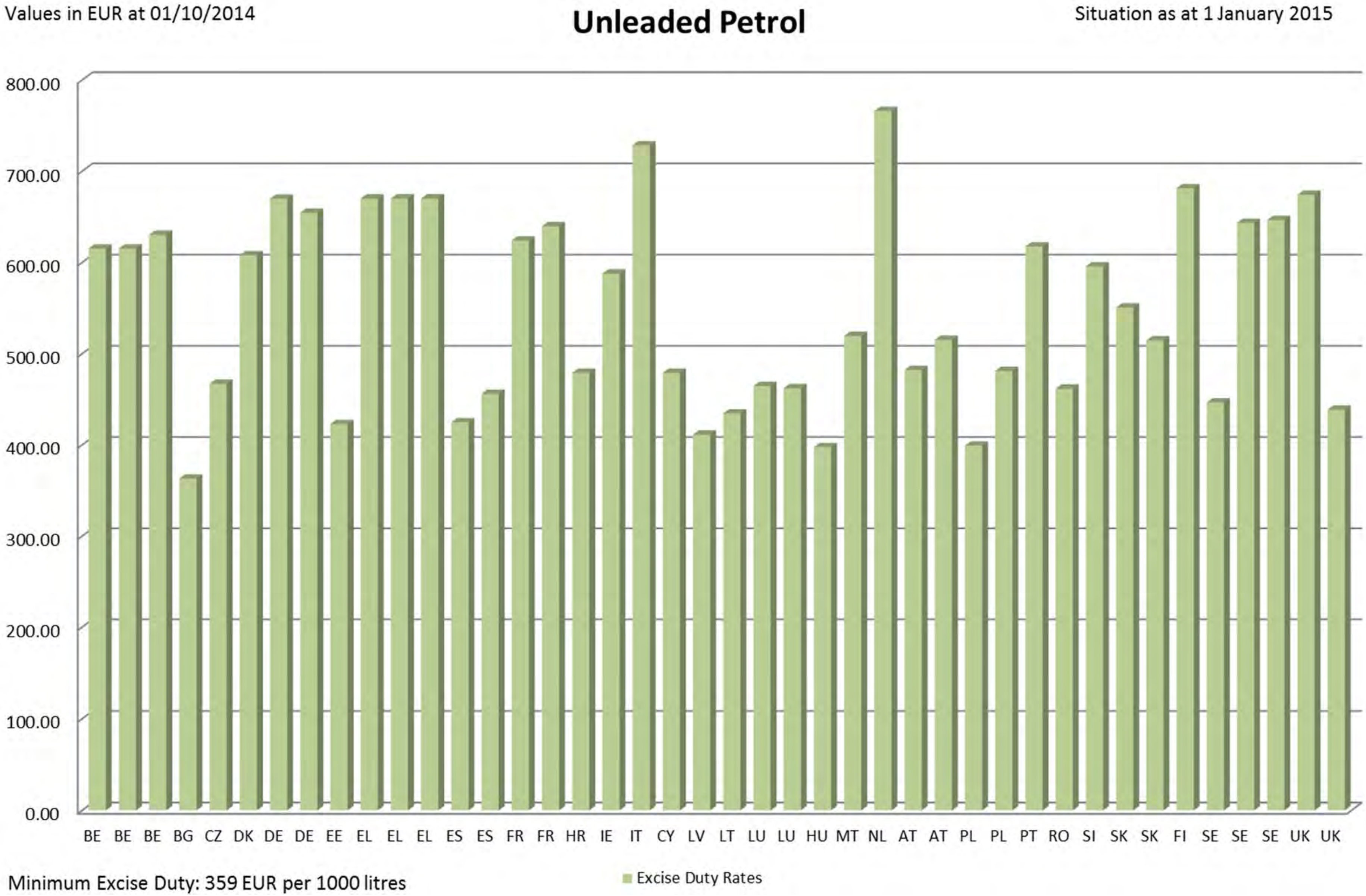
- Economic cost requires the use of **efficient, not market prices => social cost benefit analysis**
  - For road fuel this is *exclusive* of road fuel excise duty (88 €₵/L for UK diesel), but *plus* the CO_2 and air pollutant costs
  - For electricity prices it is the nodal spot price + ΔCO_2 with the 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



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

Date	Scenario	Oil price US$/bbl	CO_2 cost US$ /tonne	retail pre-tax prices US$/L G	retail pre-tax prices US$/L D	CO_2 cost US$/L G	CO_2 cost US$/L D	Pollution US $/L G	Pollution US $/L D	Total US$/L G	Total US$/L D
2015	Low	$91	$0	$0.70	$0.72	$0.00	$0.00	$0.03	$0.08	$0.73	$0.81
	Central	$110	$9	$0.91	$0.89	$0.02	$0.02	$0.04	$0.11	$0.97	$1.03
	High	$130	$21	$1.11	$1.06	$0.05	$0.06	$0.05	$0.14	$1.21	$1.26
2020	Low	$85	$0	$0.66	$0.68	$0.00	$0.00	$0.02	$0.07	$0.69	$0.75
	Central	$117	$14	$0.95	$0.94	$0.03	$0.04	$0.03	$0.09	$1.02	$1.07
	High	$147	$28	$1.25	$1.19	$0.07	$0.07	$0.04	$0.11	$1.35	$1.38
2030	Low	$74	$61	$0.60	$0.62	$0.14	$0.16	$0.02	$0.06	$0.76	$0.83
	Central	$132	$121	$1.09	$1.07	$0.29	$0.32	$0.03	$0.07	$1.41	$1.46
	High	$191	$182	$1.59	$1.52	$0.43	$0.49	$0.03	$0.09	$2.05	$2.10

Source: DECC (2012, 2013), Newbery (2005) updated to 2012 prices, exchange rate $1.60=£1

"Fuel" cost €¢/kWh

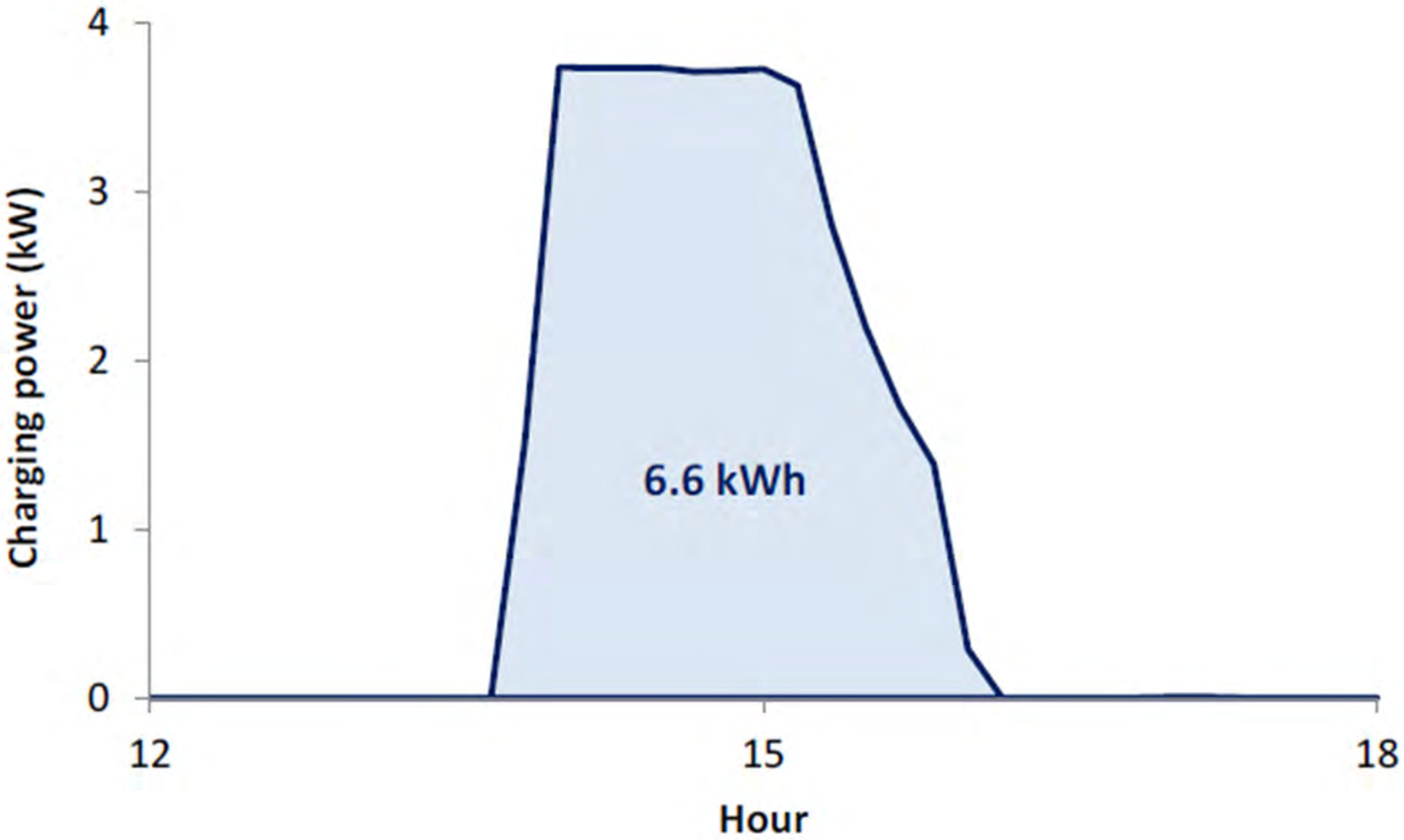
- 2015 efficiencies Low
- 2020 L-M; 2030 M-H

Table 2 Assumed conversion efficiencies

	Diesel	Gasoline	Battery
Low	30%	20%	70%
Medium	35%	30%	75%
High	41%	37%	80%

		total fuel energy content €¢/kWh		battery energy equivalent €¢/kWh		maintenance penalty €¢/kWh		total €¢/kWh	
Date	Scenario	G	D	G	D	G	D	G	D
2015	Low	6.4	6.4	22.5	14.9	8.0	16.2	30.5	31.1
	Central	8.5	8.2	29.7	19.0	9.5	19.5	39.2	38.5
	High	10.6	10.0	37.1	23.3	11.0	22.8	48.1	46.1
2020	Low	6.0	6.0	15.1	12.8	8.0	16.2	23.1	29.0
	Central	8.9	8.5	26.8	18.9	9.5	19.5	36.3	38.4
	High	11.9	10.9	41.5	25.5	11.0	22.8	52.5	48.3
2030	Low	6.7	6.6	14.4	12.9	8.0	16.2	22.4	29.1
	Central	12.3	11.6	28.8	23.8	9.5	19.5	38.3	43.3
	High	18.0	16.6	45.1	35.6	11.0	22.8	56.1	58.4

Typical charging profile



Source: Low Carbon London Report B1

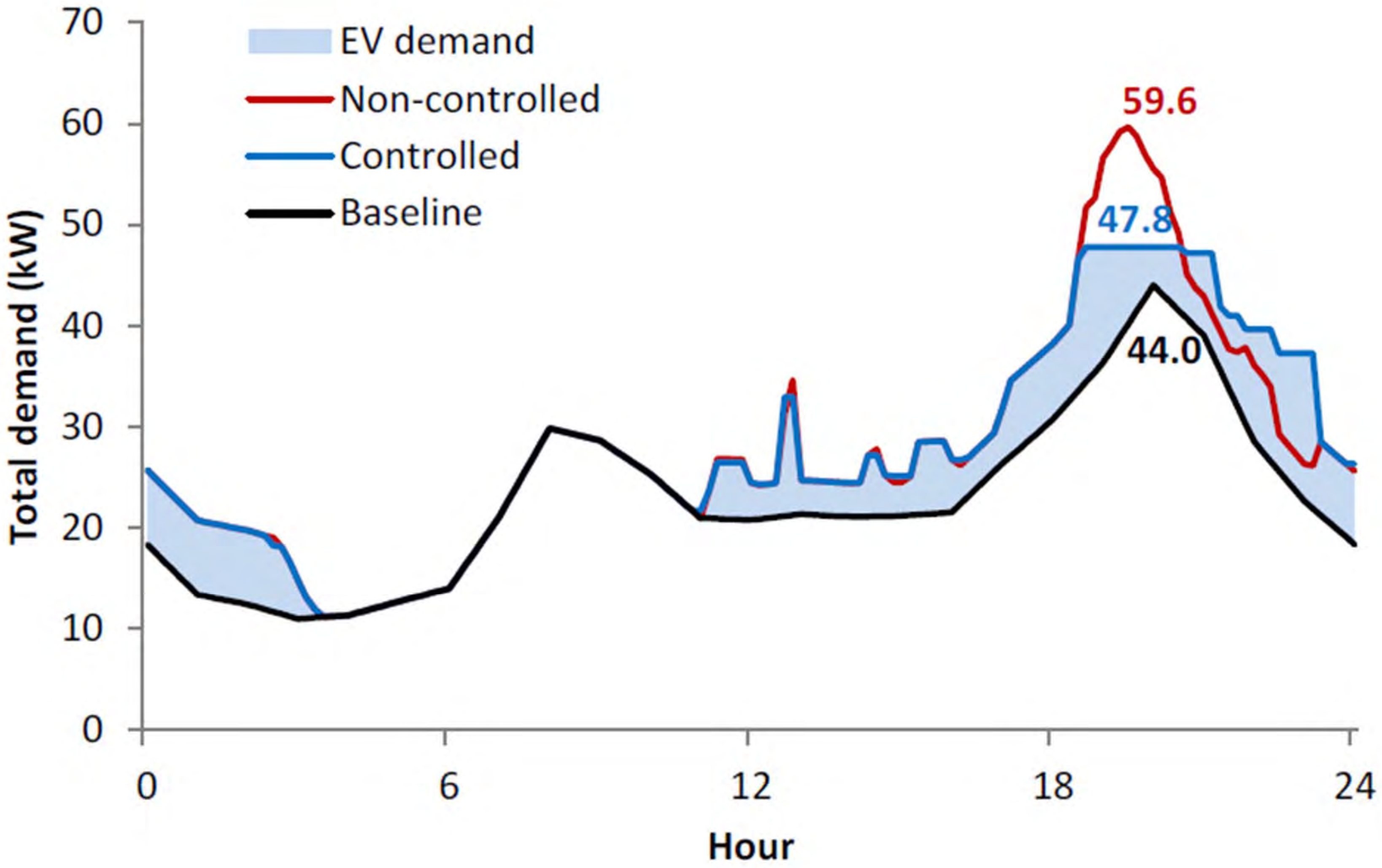
Problem for DNOs

- 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

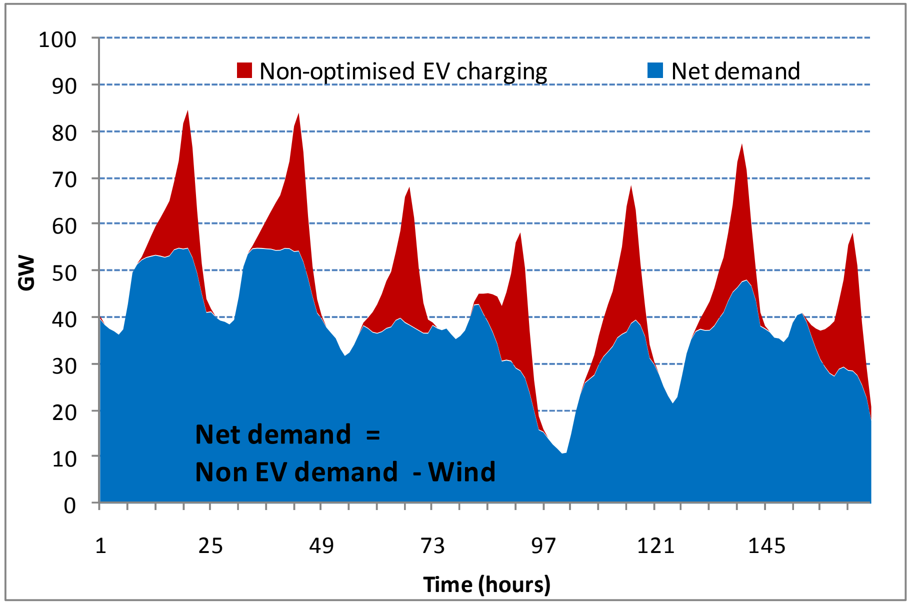
BEVs responsive to TOU charging

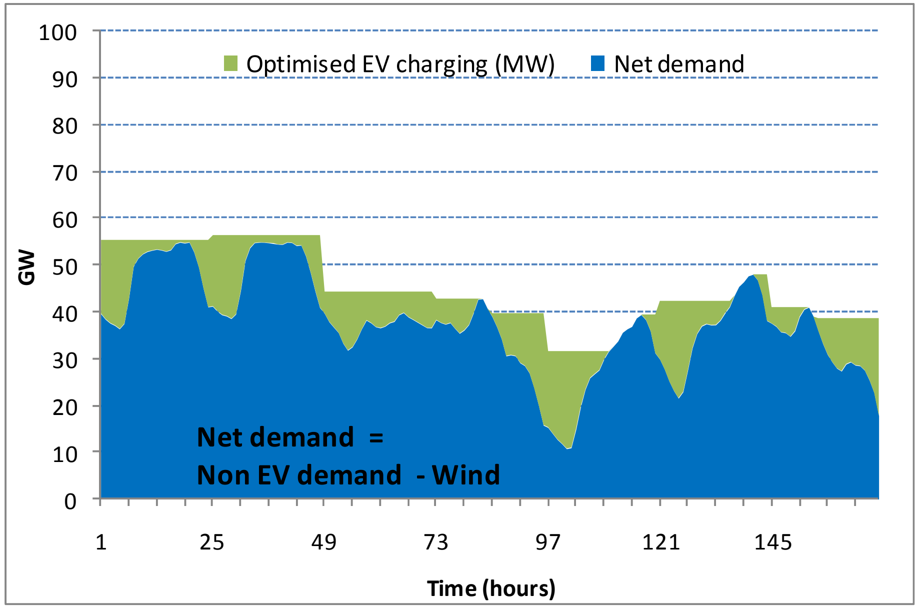
Uncontrolled and optimized BEV charging: 22 HHs & EVs



Source: Low Carbon London Report B1

Impact of charging strategies on the need for conventional plant capacity and emissions and prices of electricity





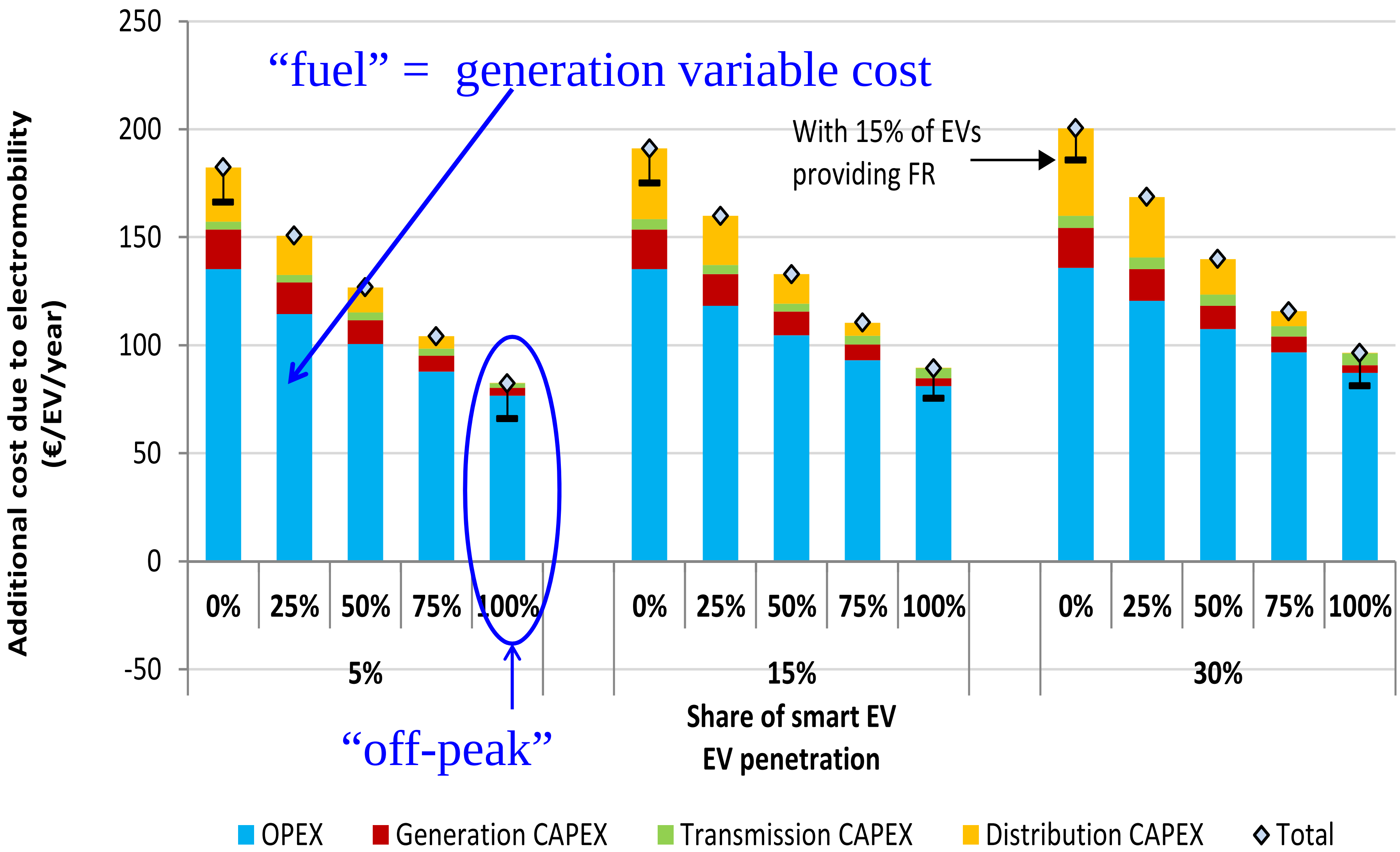
- **Optimistic optimisation** – assumes could and would charge whenever stationary (which is most of the time)

Source: GeM D9.2

Carbon impact of EVs

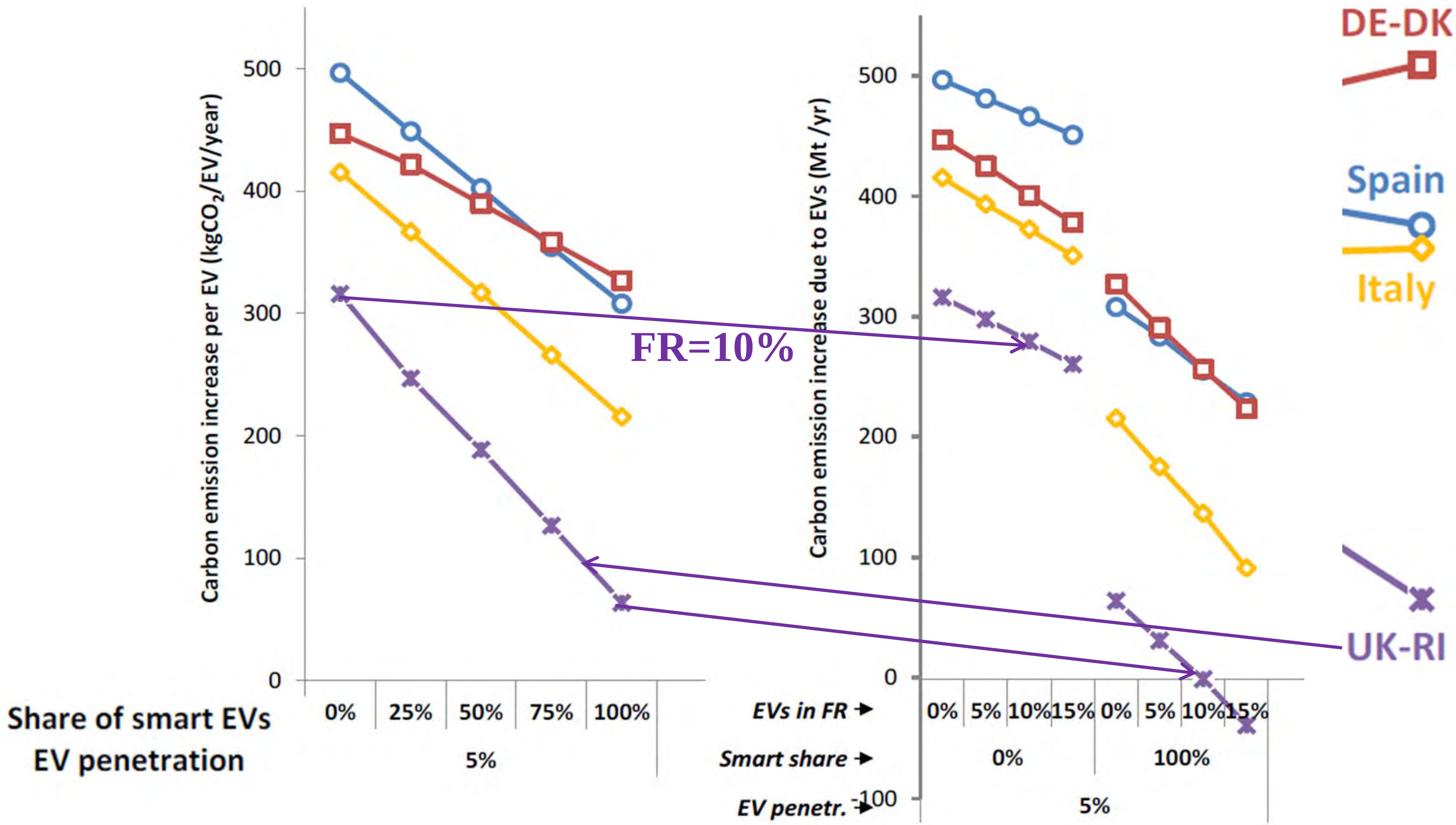
- Cap: under ETS CO_2 separate caps for two sectors
  - Transport fuel only included in uncovered sector
  - If each cap binds then no saving of CO_2?
    - Surely in longer run caps would be adjusted? More like:
- No such problem with carbon price
  - Saving is difference in gm CO_2/km x km
  - E.g. 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



UNIVERSITY OF CAMBRIDGE | Energy Policy Research Group

Additional CO_2/EVyr 2030

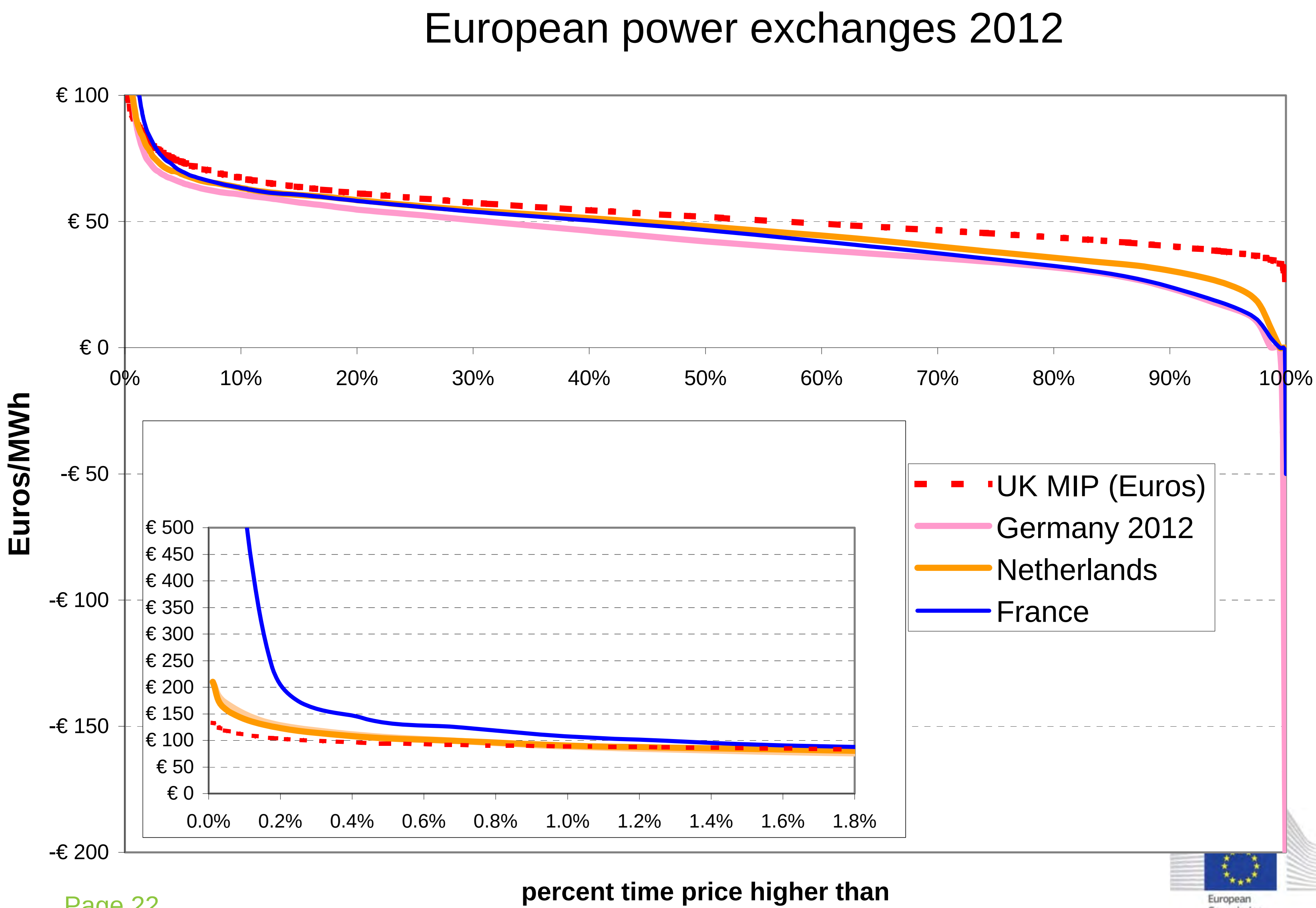


GEM 9.2: **2.12 MWh/yr**

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



Estimating the 2030 cost of electricity

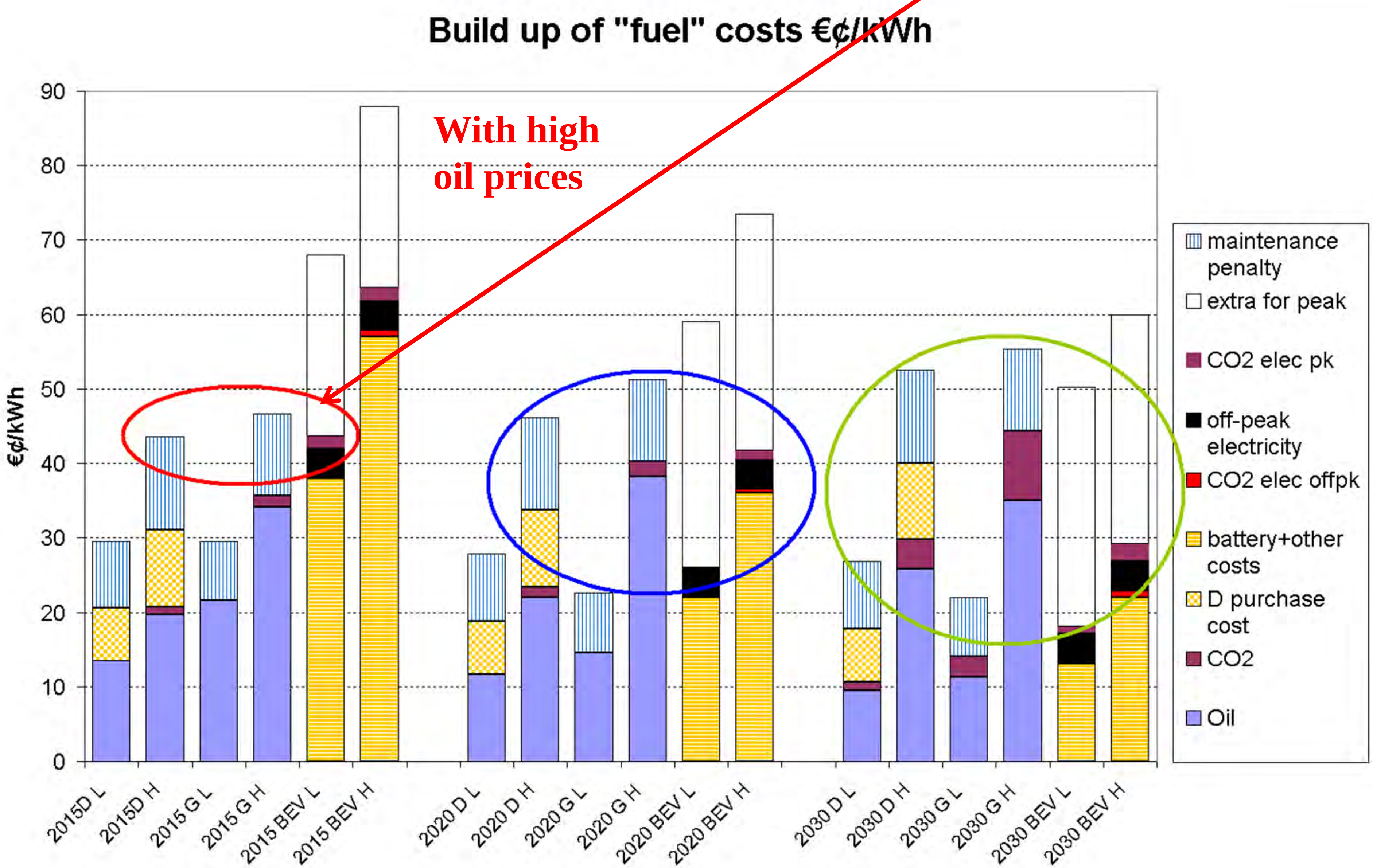
- Germany has high renewables, better represents **2030**
- 2012 EU av wholesale price excl CO_2 = €¢4.2/kWh
- Take 2030 av wholesale price excl. carbon as €¢4.8/kWh
- Top 25% hours 148% average price = €¢**7.1**/kWh
- Bottom 25% hours 75% average price = €¢2.5/kWh
- Add in CO_2 cost (€75-150/tonne) 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**

	2015	2020	2030
Net battery + charger (10yr life)		cost €¢(2012) per kW	
Low at 5%, 17,000 km/yr	38	22	13
High: 10%, 15,000 km/yr	57	36	22
Electricity off-peak L	4	4	4
peak H	30	37	37
Total cost			
Low + off-peak	42	26	17
High + peak	87	73	59
90% off-peak, 10% peak	47	31	21

BEVs *could* be competitive by 2015



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

UNIVERSITY OF CAMBRIDGE | Energy Policy Research Group

MIT Center for Energy and Environmental Policy Research

Spare slides

David Newbery

University of Cambridge

EPRG-CEEPR European Energy Policy Conference

London, 10th July 2014

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

References

DECC 2012. Updated short-term traded carbon values used for UK public policy appraisal, at https.//www.gov.uk/government/uploads/system/uploads/attachment_data/file/245385/6667-update-short-term-traded-carbon-values-for-uk-publ.pdf

DECC 2013. Fossil Fuel Price Projections, at https.//www.gov.uk/government/publications/fossil-fuel-price-projections-2013

GeM D9.2 at http://www.greenemotion-project.eu/upload/pdf/deliverables/D9_2-Smart-and-less-smart-large-scale-integration_submitted_2.pdf

Newbery, D.M. and G. Strbac, 2015. Barriers, gaps, and commercial and regulatory framework for broad rollout of e-mobility, Final Report, at http://www.greenemotion-project.eu/upload/pdf/deliverables/D9_6-Barriers-gaps-and-commercial-and-regulatory-framework-V2_1_submitted.pdf

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