The e-mobility revolution: impact of electric vehicles on the GB power system and emerging utility business models

January 2018

Agenda

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Electrification is one of 4 key trends that will shape the future of mobility

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Connected

- Current status: basic connectivity e.g. navigation, telephony
- Future: voice control, vehicle condition and driver fatigue monitoring, hazard alerts

Electric

- Current status: internal combustion engine (ICE) is dominant technology
- Future: shift towards a mix of plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs)

Autonomous

- Current status: basic autonomous features (self parking, cruise control, ABS[1])
- Future: further autonomous features e.g. adaptive cruise control, blind spot monitoring, automatic emergency braking, 'pontooning' – eventually leading to fully autonomous vehicles

Shared

- Current status: most vehicles are either privately owned or operated as part of company fleet
- Future: decline in car ownership, with users switching to E-hailing (e.g. Uber), ride sharing (UberPool), or car clubs/short term rental (Zip car)

1. Anti-lock braking system.

Sources: Aurora Energy Research

Electric cars are likely to become the dominant technology in the long run for six key reasons

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EVs will become increasingly attractive for consumers …

A Price parity
- EVs will become cost competitive with combustion engines within next decade
- Driven by production scale and battery cost decline

B Range
- Range will become sufficient as battery size increases
- Consumers will increasingly get used to range as EV penetration increases

C Charging access
- Charging access will not be an obstacle in the long term
- Consumers, government and industry have incentive to invest in infrastructure

… and Government is supporting the shift

D Local pollution
- Governments rely on EVs to address air pollution, especially in cities
- Concerns over air quality and adverse impacts on health will lead national and city Governments to promote EVs over ICEs

E Global warming
- Electric vehicles can be used to cut emissions from the transport sector
- EVs have lower emissions than ICEs, even at current grid carbon intensity

F Industrial Strategy
- UK Government has identified mobility as one of 4 ‘Grand Challenges’
- Government hopes to transform public transport, and capitalise on the UK’s existing strengths in the automotive and wider transport sector

Source: Aurora Energy Research

Purchase price parity unlikely before 2030s; but EVs become competitive on total cost of ownership basis in the 2020s

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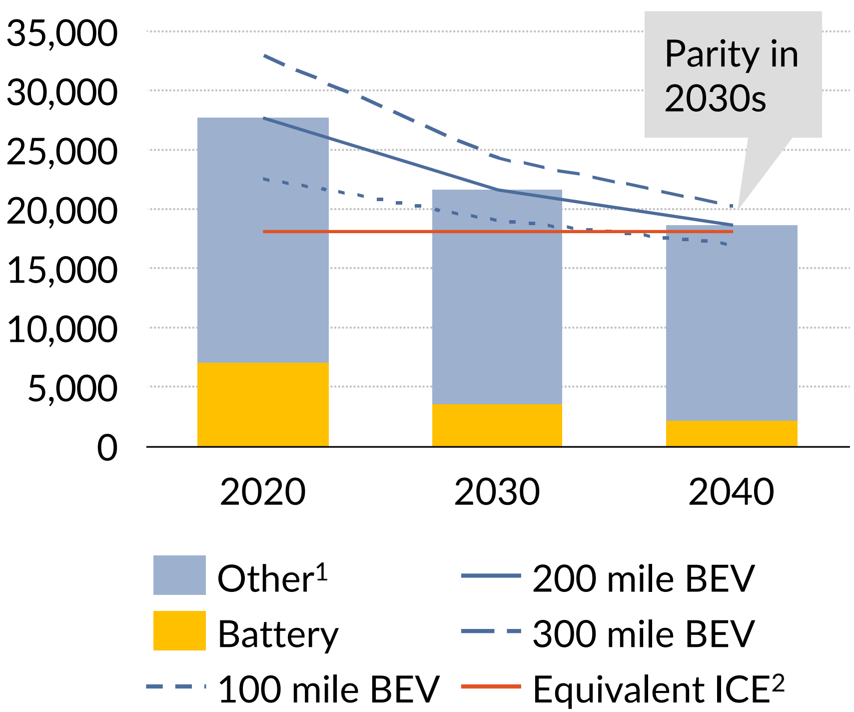
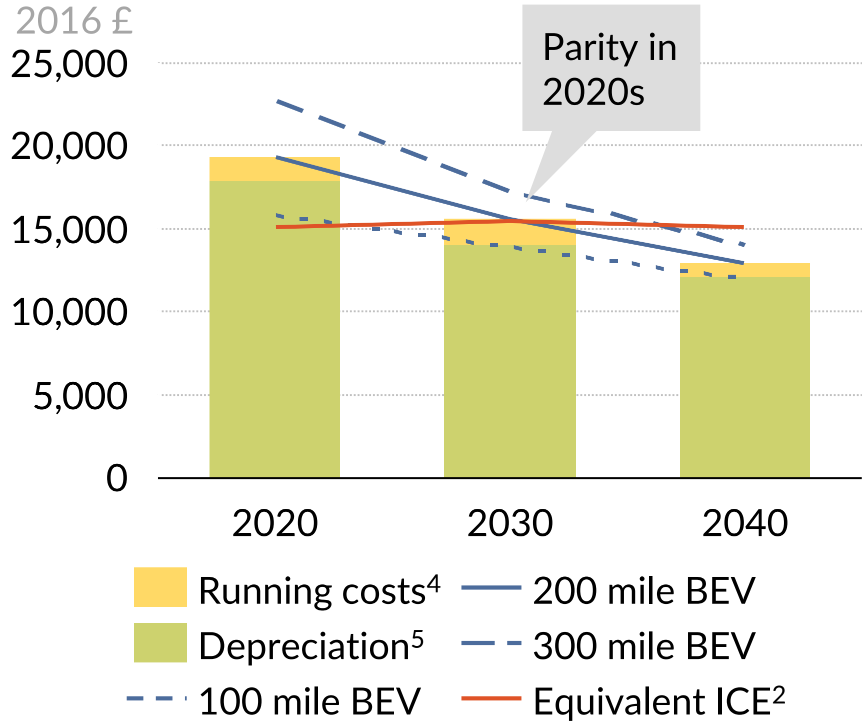
Unsubsidised purchase price for 200 mile medium-size BEV,
2016 £



- EV price decline driven by falling battery cost
- Slower cost decline for PHEVs due to smaller battery

Unsubsidised 3 year TCO[3] for 200 mile medium-size BEV,
2016 £



- EVs save on running costs due to cheaper 'fuel' and simpler powertrain reducing maintenance costs

1. Includes other manufacturing costs, margin and VAT. 2. ICE is equivalent in terms of power and vehicle size. ICE costs assumed constant. 3. Total Cost of Ownership. Assumes annual mileage of 8,000 miles. Greater mileage will favour BEVs due to lower fuel and maintenance costs. Discounted at 6%. 4. Running costs considered include fuel, maintenance and road tax but not insurance. 5. Depreciation is calculated as purchase price minus resale value at the end of a 3 year ownership, discounted to present value.

Sources: Aurora Energy Research

Increasing range and roll out of charging infrastructure will alleviate range anxiety

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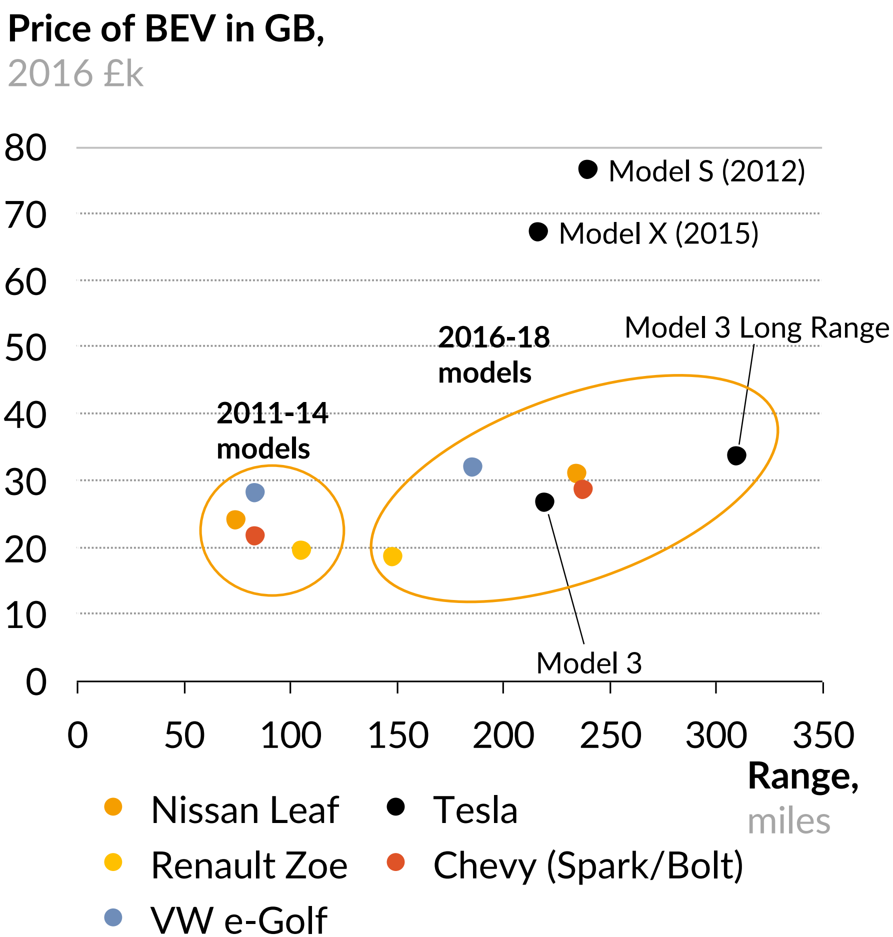
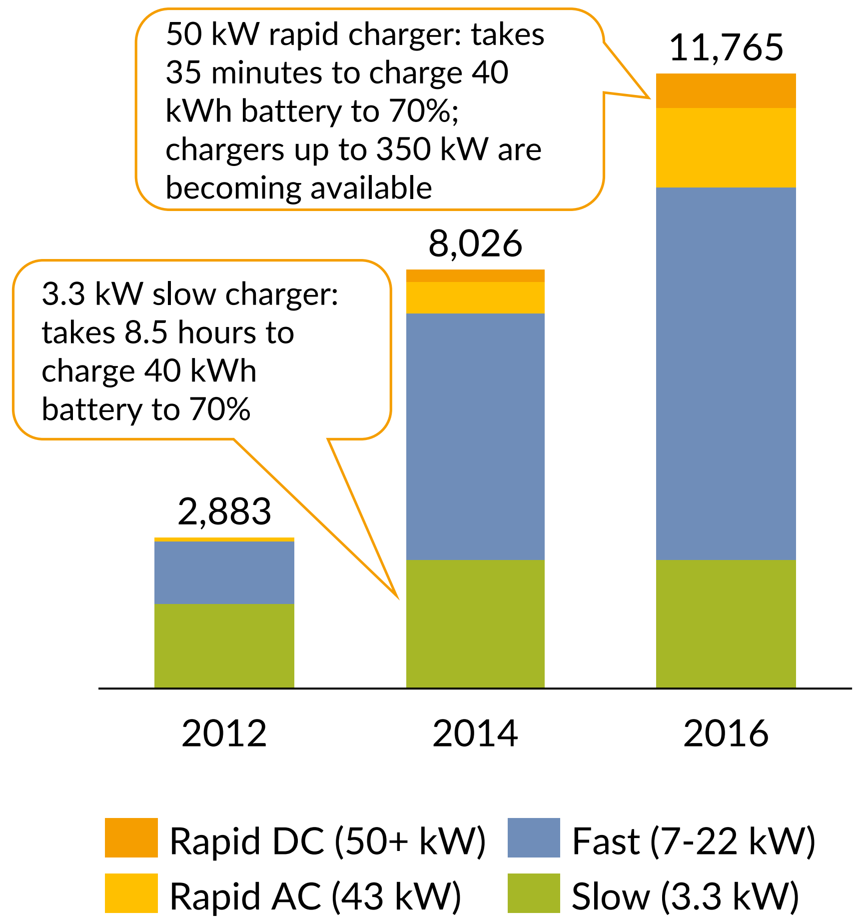
New EVs have higher range at similar prices

Fast chargers are becoming widely available





Sources: Aurora Energy Research, Zap-Map, National Charge Registry, UBS, Goldman Sachs, Tesla, Nissan, Next Green Car

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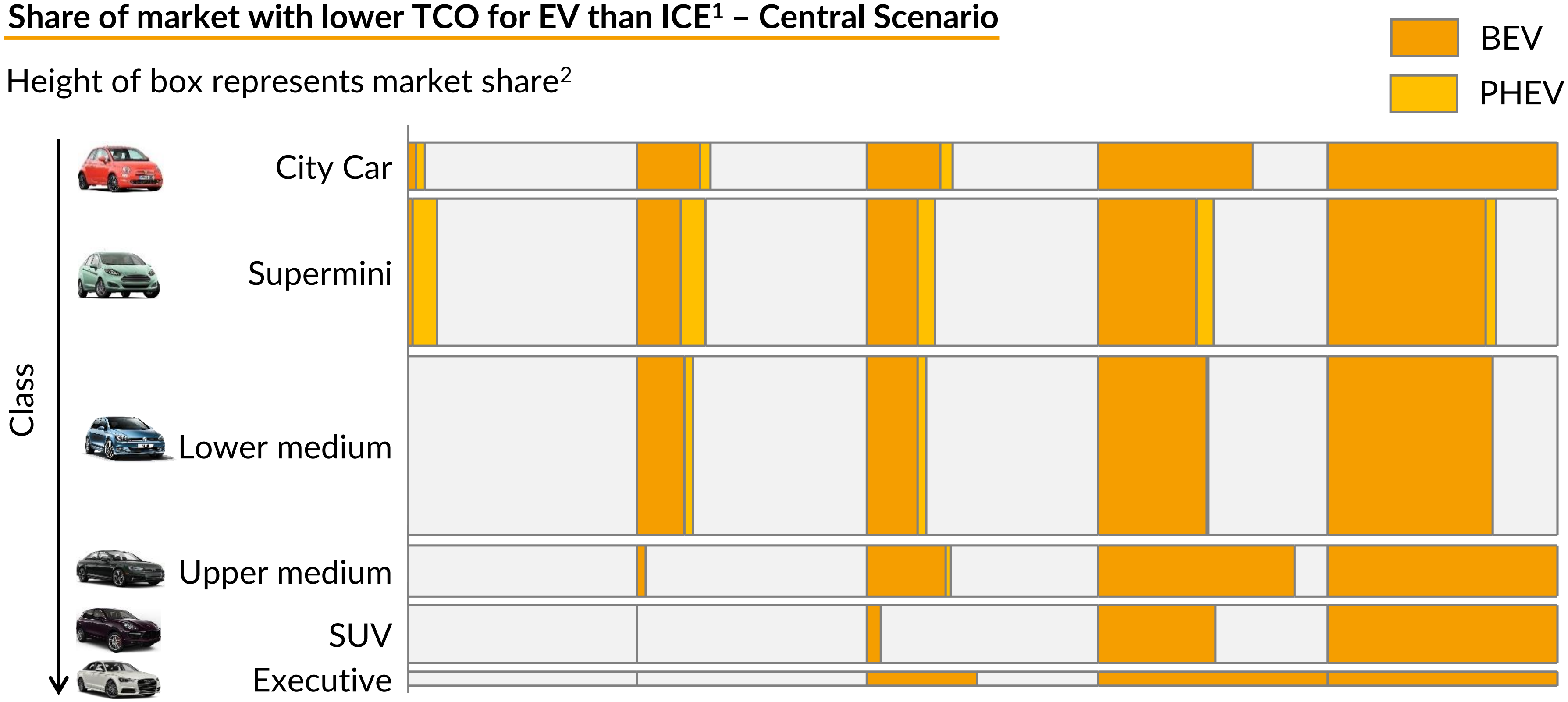
Majority of consumers switch from ICEs in 2030s as BEVs become the economic choice

Share of market with lower TCO for EV than ICE[1] – Central Scenario

Height of box represents market share[2]



	2020	2025	2030	2035	2040
Total market share	**5%**	**21%**	**30%**	**59%**	**81%**

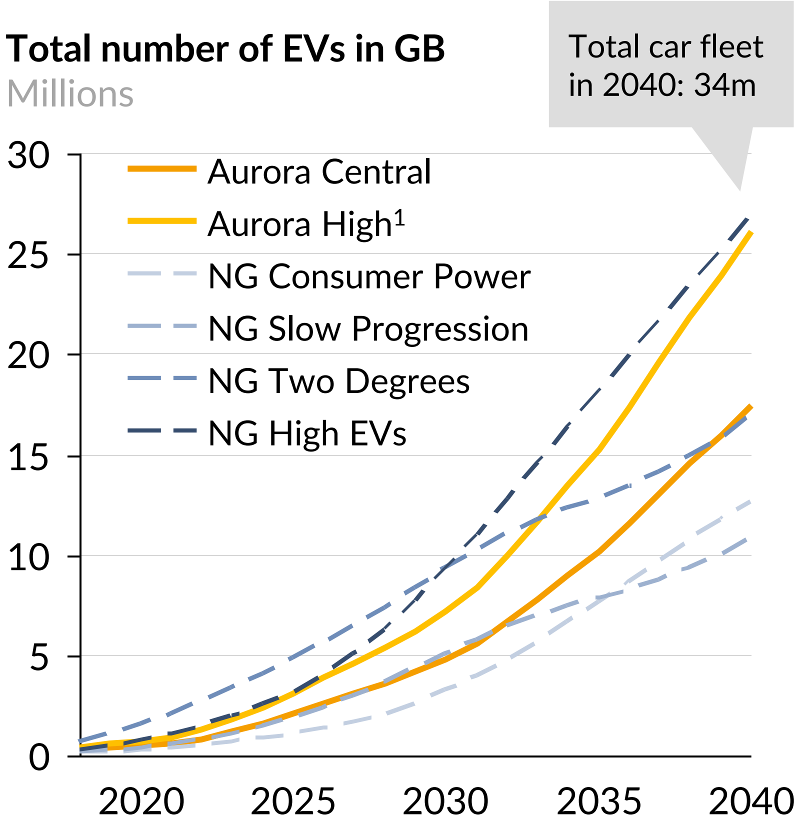
- TCO parity is reached first for consumers with lower range requirement due to lower battery cost
- PHEVs make up 65% of EV share in 2020, but BEVs dominate by 2025

1. Analysis is based on purely economic uptake (without subsidies), and does not consider policy interventions that would precipitate the phase-out of ICEs non-economically. 2. Market share of each vehicle segment is assumed constant over time.

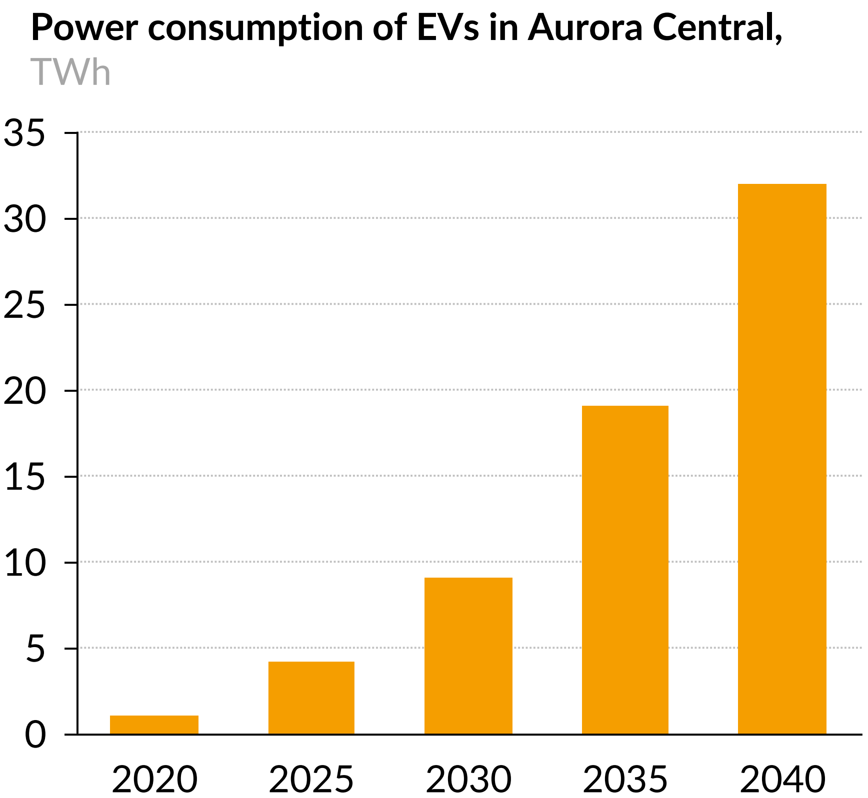
Source: Aurora Energy Research

This results in 10 million EVs on the road in GB by 2035, adding 19 TWh to annual power demand

By 2035 we expect 10m EVs on the road in GB, representing 30% of the car fleet…



… adding 19 TWh to power demand in 2035, or 6% of current demand



1. High case based on 50% increase in total number of EVs from central case, equating to 60% share of car sales in 2030.

Sources: Aurora Energy Research, National Grid, DUKES, Department for Transport

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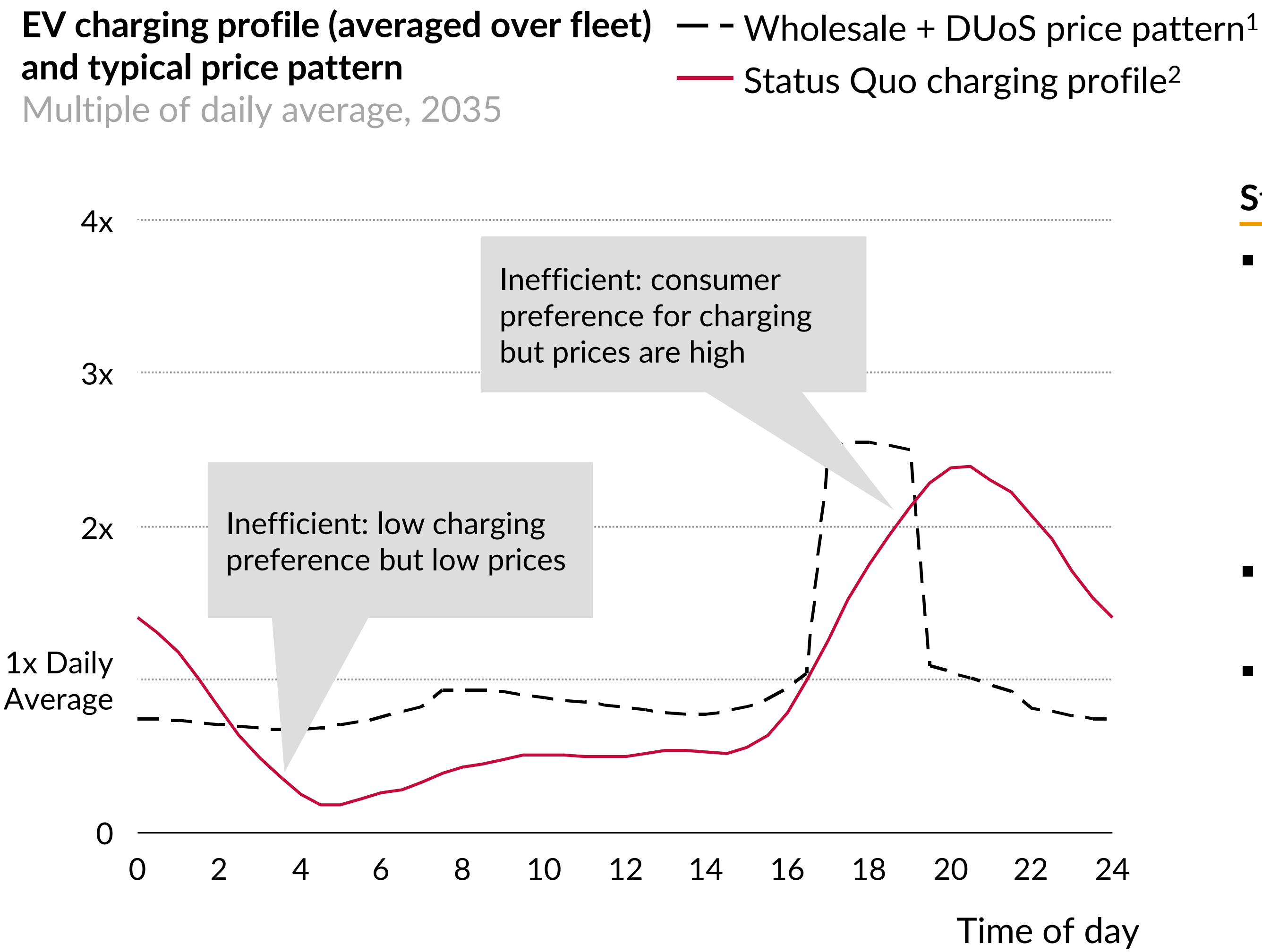
Early experience shows EV owners tend to charge in the evening when prices are high and capacity is scarce…

EV charging profile (averaged over fleet) and typical price pattern
Multiple of daily average, 2035



Status Quo charging

- Due to consumer preferences, most EV owners charge their vehicles when they get home, despite not needing the vehicle until the following morning
- This results in significant addition to peak demand
- Estimated annual charging cost per EV: £280[3]

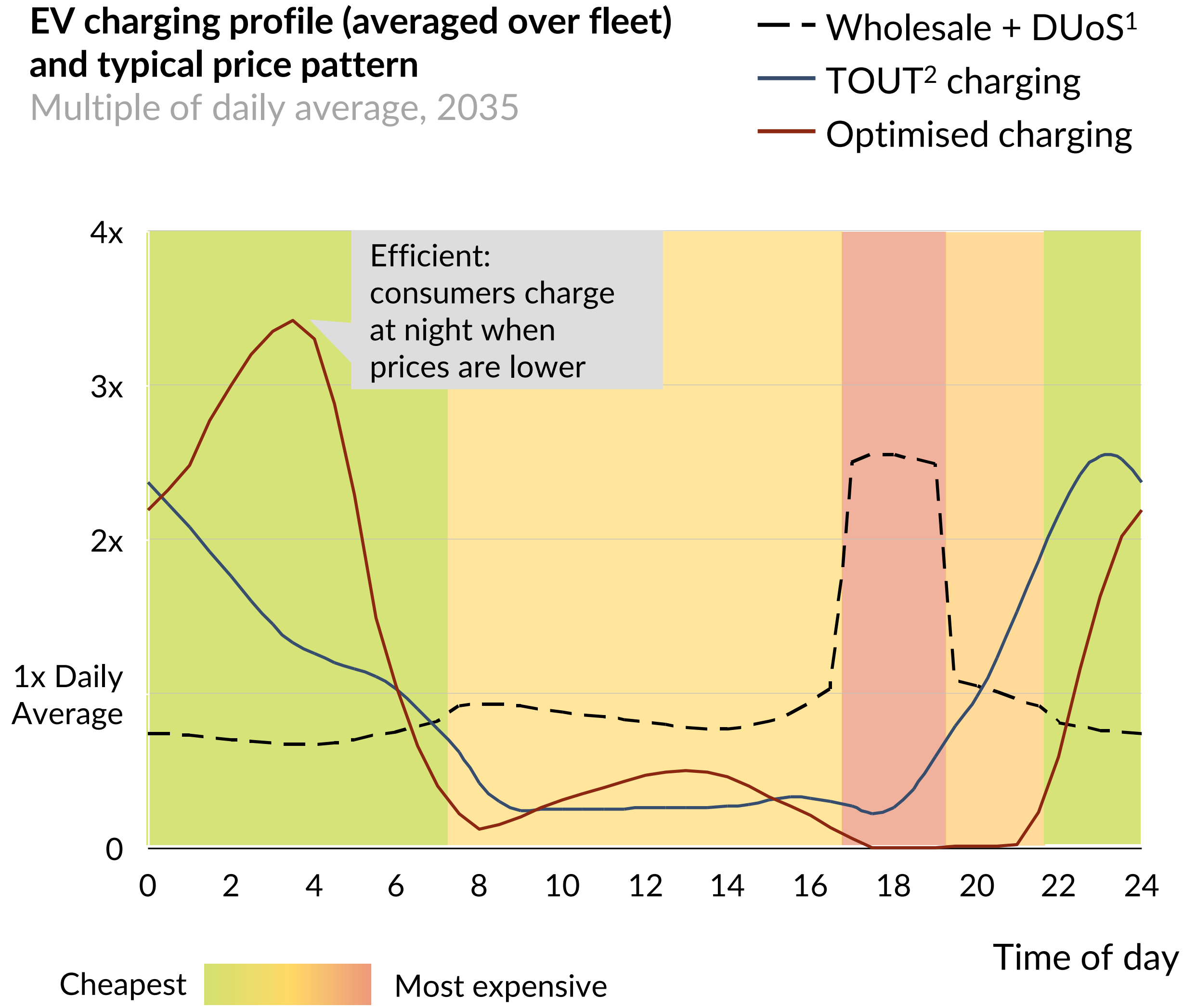
1. Distribution Use of System. Low voltage network DUoS charges used, taken as average over a number of Distribution Networks. 2. Status Quo charging pattern shows averaged profile from over 100 participants in UK Customer Led Network Revolution trial. 3. In 2018. Assumes 8,000 miles driven per year, consumption of 0.27 kWh/mile and retail electricity price of 13 p/kWh throughout the day

Source: Aurora Energy Research, UK Customer Led Network Revolution

… this could be addressed either by Time of use Tariffs or smart charging that responds dynamically to spot prices

EV charging profile (averaged over fleet) and typical price pattern

Multiple of daily average, 2035



TOUT[2] charging

- **Rationale**: 3-band TOUT incentivises EV owners to charge at non-peak times (maximum consumer saving of £170/year[3])
- **Requirements**: smart meter, half hourly settlement
- Modelled by creating an adjusted charging profile

Optimised charging

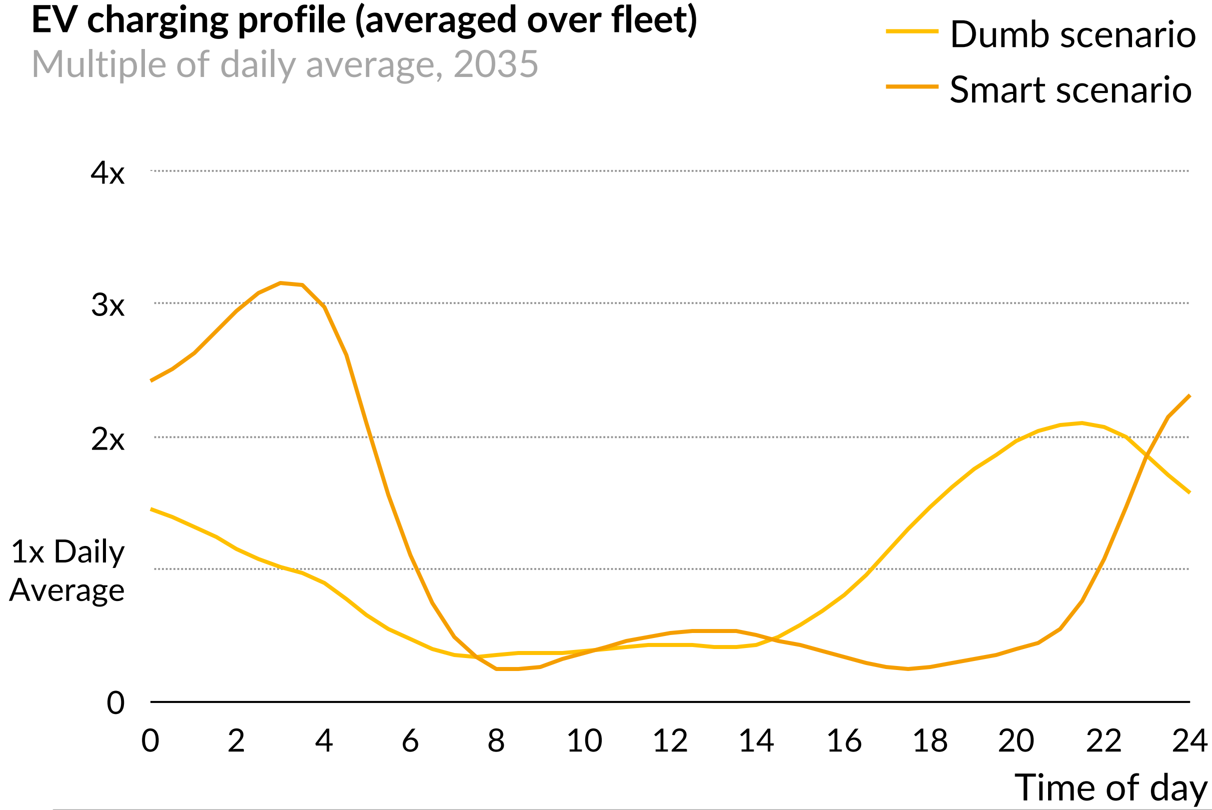
- **Rationale**: charging times are optimised to minimise price
- **Requirements**: as above plus remotely accessible charging controls and aggregators with software to control EV fleets[4]
- Modelled by allowing EV charging to respond dynamically to price (wholesale and DUoS charge)

1. Distribution Use of System. Low voltage network DUoS charges used, taken as average over a number of Distribution Networks. 2. Time of Use Tariff 3. In 2018. Status Quo charging assumes flat rate of 13p/kWh, 8,000 miles driven per year and efficiency of 0.27 kWh/mile. For maximum saving, TOUT charging assumes all charging is carried out on low tariff rate of 5 p/kWh. 4. For public charging outlets with multiple connectors, price could be optimised by combining with stationary battery storage instead of by delaying EV charging

Source: Aurora Energy Research

The charging profiles are combined to model two scenarios: dumb and smart

EV charging profile (averaged over fleet)
Multiple of daily average, 2035



Dumb scenario

- 80% status quo charging
- 10% TOUT charging
- 10% optimised charging

Smart scenario

- 10% status quo charging
- 10% TOUT charging
- 80% optimised charging

- Differences in underlying consumer preferences suggest that actual outturn will be a combination of the three different charging profiles
- We model two fairly extreme cases: one where 80% of consumers stick to status quo charging pattern, and another where 80% of EV charging is optimised to prevailing spot prices

Source: Aurora Energy Research

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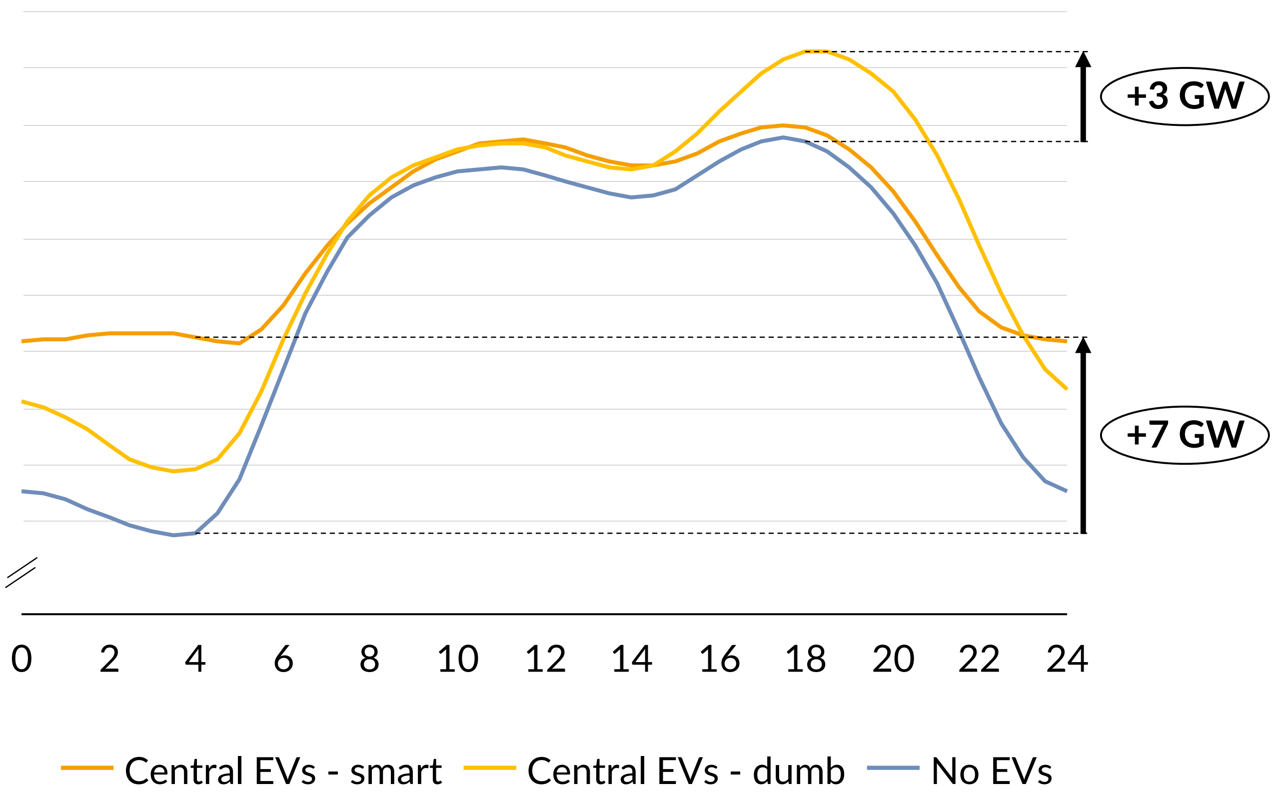
An additional 10 million EVs would result in only 0.5 GW increase in evening demand if integration is smart

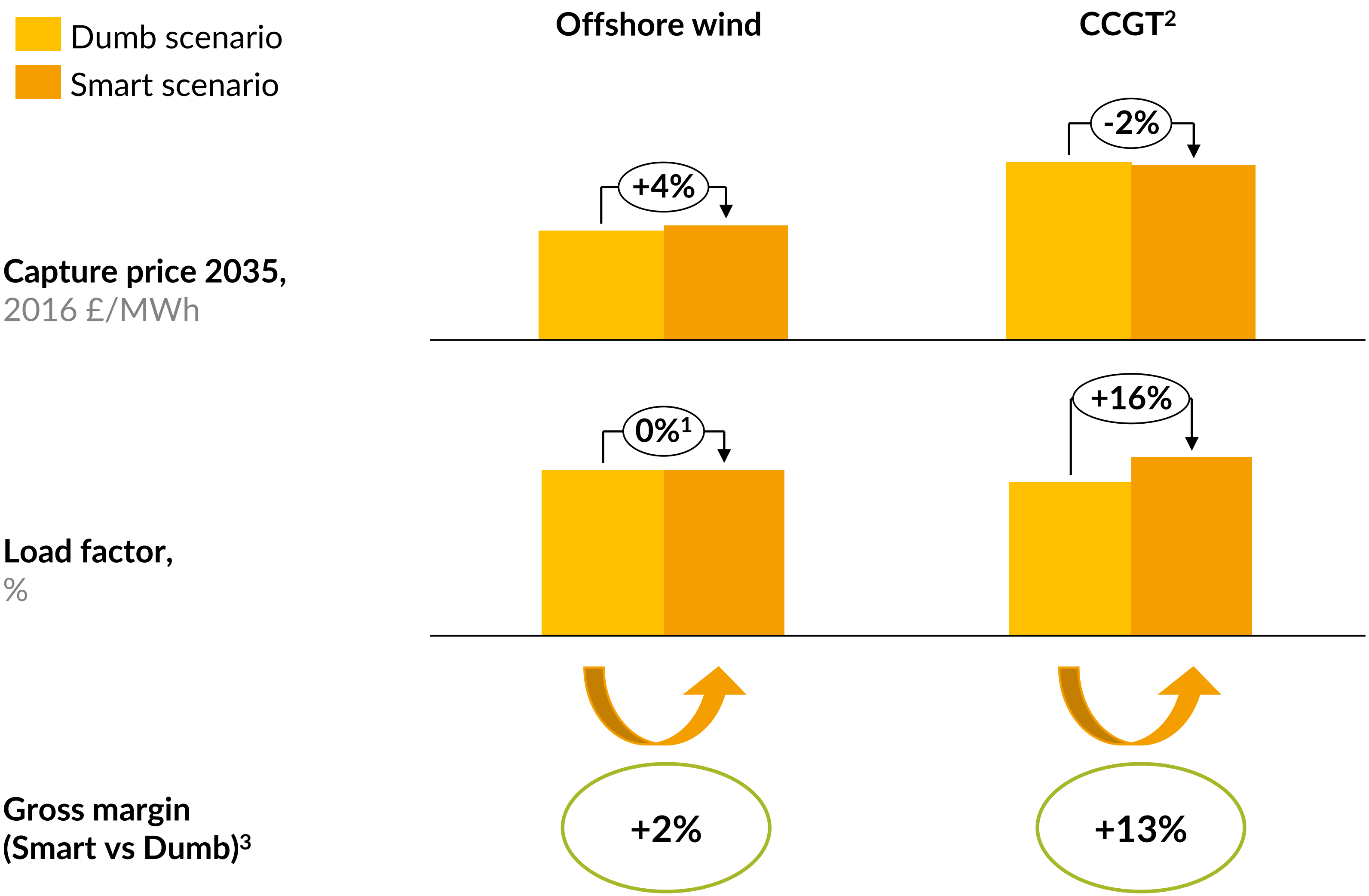
Average hourly demand 2035,
GW



- Impact on demand pattern depends critically on extent to which EV charging is smart
- With 10 million EVs on the road by 2035, evening peak demand increases by 3 GW if charging is dumb, but only 0.5 GW if charging is smart
- With smart EV charging, lowest price periods could see demand increase by 7 GW

Source: Aurora Energy Research

Renewables gain from higher capture prices, while CCGTs enjoy increase in load factors



1. Renewables load factors are assumed exogenously. 2. For a mid-merit 52.5% HHV CCGT. 3. Gross margin includes wholesale and balancing revenues.

Source: Aurora Energy Research

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New business models for utilities are emerging to capture the opportunities presented by EV charging

Value chain steps

Generation → Transmission → Retail → Charging → After sales

Power market impact				
Transmission–Retail	4	1		
Charging			2	3
After sales	5			

Business model		Description	Example
1	Time of use tariffs (TOUT)	▪ Offer TOUT to EV owner for residential charging ▪ Customers benefit from lower charging costs during off-peak hours	green energy
1 + 2	Optimised charging	▪ Aggregate and remotely control EV charging ▪ Further reduction in charging cost due to optimisation	open energi
1 + 2 + 3	Vehicle to grid (V2G)	▪ Optimise charging & discharging to grid, comparable to grid-scale battery ▪ Customer benefits from additional discount on power price due to revenues from V2G	ovo energy; NISSAN
4	Charging infrastructure	▪ Own and/or operate on-street, car park and filling station charging points capturing payments for use of infrastructure & power sales	TESLA; ecotricity; IONITY; Shell
5	Second life batteries	▪ Repurpose EV batteries for grid or home use once capacity drops too much for use in vehicle	RENAULT; POWERVAULT

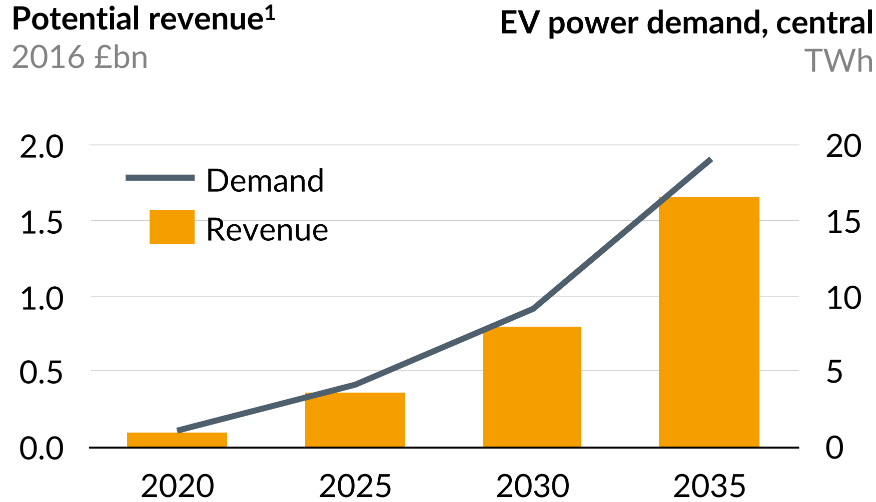
Source: Aurora Energy Research

Time of Use Tariffs match well with suppliers' capabilities, and market size looks likely to increase

Description

- Supplier provides power to EV owner with time of use tariff (TOUT) to incentivise charging at non-peak times
- Demand for TOUTs is likely to increase with EV ownership due to flexibility of charging time afforded by EVs; consumer savings could be up to £170/year
- However, tariffs must be well designed to realise gains from price discrimination
- Example: Green Energy's 3-band TOUT:
  - 11pm – 6am: 5p/kWh
  - 4pm – 7pm: 25 p/kWh
  - Other: 12p/kWh

Market potential



Competitive intensity – Porter's Five Forces

Bargaining power of 'supplier' (generator)	Low
Bargaining power of customer (EV owner)	Low
Threat of substitution (other charging)	Medium
Threat of new entrants	Medium
Competitive rivalry	Medium

Competition: Medium - Low

Capability match for utility

- Access to customers or existing customer base ✓
- Sales and marketing expertise ✓
- Smart meter and half-hourly settlement (✓)
- In-house power-trading unit ✓

Capability match: High

1. Calculated as tariff price multiplied by charging volume within each tariff band, according to TOUT charging profile detailed in slide 12.

Source: Aurora Energy Research

Key Takeaways

- Battery electric cars will become cost competitive on an unsubsidised "Total Cost of Ownership" basis in the 2020s; with 10 million EVs on the road in GB by 2035

- Charging behaviour is just as important as the number of EVs on the road in determining the impact on the power system; smart charging could limit the impact on peak demand to +0.5 GW in 2035

- Smart charging will raise off-peak demand, improving the profitability of renewables such as offshore wind by 2%

- Consumers stand to benefit from smart charging: the average EV owner could save up to £170 per annum by charging off-peak

Source: Aurora Energy Research

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