Impact Analysis of Mass EV Adoption and Low Carbon Intensity Fuels Scenarios – Summary Report

Date Issued 24 August 2018
Report RD18-001912-3
Project Q015713 – PVR 1
Confidential CONCAWE – Public Domain

Report by Dr Nick Powell, Nikolas Hill, Judith Bates, Dr Nathaniel Bottrell, Marius Biedka, Ben White, Tom Pine, Sarah Carter, Jane Patterson, Selahattin Yucel

Approved pp. N. N. Powell
Angela Johnson
Head of Knowledge and Technology Strategy
The implications of two scenarios to 2050 for Light Duty Vehicle propulsion in Europe have been studied

- Both scenarios feature electrification and use of low carbon fuels (biofuels and eFuels), but with significantly more Electric Vehicles (EVs) or low carbon fuels in each scenario respectively

- Both scenarios result in a similar and significant (~85%) reduction in total life cycle GHG emissions to 2050 at similar annual parc total costs to the end user (when adjusted to maintain Net Fiscal Revenue)
  - A combined scenario “Mixed Fleet” scenario also resulted in similar GHG reduction and costs
  - Up to 2040 the cumulative societal costs of the Low Carbon Fuels scenario are estimated to be €140bn lower than the High EV scenario, but €33bn higher by 2050

- Electricity demand from EV charging in the High EV scenario in 2050 is ~550 TWh, which represents ~17.5% of the EU’s 2015 electricity generation, and is twice that required in the Low Carbon Fuels scenario

- In the High EV scenario, the cumulative cost of a managed EV charging and network infrastructure reinforcement is estimated between €630bn & €830bn to 2050, compared to overall cumulative savings to the end-user between €1,100 & €1,600bn (1.3% - 1.8% of total end-user costs)* vs European Commission Business as Usual reference to 2050
  - In the Low Carbon Fuels scenario the network infrastructure reinforcement cost is estimated to be €326bn
Executive Summary

The modelling suggests an optimal cost-effective GHG reduction solution may lie somewhere in-between the scenarios evaluated.

Implications of two scenarios to 2050 Light Duty Vehicle propulsion in Europe continued:

- Significant risks associated with the supply of resources are highlighted, especially in the High EV scenario
  - Peak annual virgin lithium demand (~220kt) is 6 times higher than global lithium production in 2016 (35kt)
  - The Lithium resource requirements for the Low Carbon Fuels scenario are less than half of those for the High EV scenario
- The annual parc total costs to the end user (when adjusted to maintain Net Fiscal Revenue) are similar for the High EV, Low Carbon Fuels and Mixed Fleet scenarios, and below the baseline scenario
  - The estimated marginal capital costs for the High EV scenario are particularly strongly influenced by assumptions on battery prices
- Under the High EV scenario, ~15 Gigafactories (@35GWh p.a.) would be needed to supply batteries to the European EV market by 2050, compared to ~5.5 Gigafactories in the Low Carbon Fuels scenario by 2050
- Major shifts to electrified transport in the High EV scenario would certainly require alternative approaches to tax revenue generation, due to substantial (up to 66 €Billion p.a.) reductions in net fiscal revenue
- Due to the rapid rate of change in this area, there are significant uncertainties on the future evolution of battery technology and costs and on the infrastructure requirements to support a wholesale shift to BEVs
- The modelling suggests an optimal solution from the perspective of cost-effective GHG reduction and risk mitigation may lie somewhere in-between the scenarios evaluated
## Version History & Disclaimer

<table>
<thead>
<tr>
<th>Reference Number</th>
<th>Issued Date</th>
<th>Revision</th>
</tr>
</thead>
<tbody>
<tr>
<td>RD18-001912-1</td>
<td>19 June 2018</td>
<td>First issue</td>
</tr>
<tr>
<td>RD18-001912-2</td>
<td>24 July 2018</td>
<td>Societal costs added. Executive Summary updated in line with full report.</td>
</tr>
<tr>
<td>RD18-001912-3</td>
<td>24 August 2018</td>
<td>Minor plot format modifications</td>
</tr>
</tbody>
</table>

This Report has been prepared solely for use by the party which commissioned it in connection with this project and should not be used for any other purpose. Ricardo accepts no duty of care, responsibility or legal liability to any other recipient of this Report and no other person may rely on the contents. This Report is confidential and contains proprietary intellectual property. Subject to applicable law, Ricardo disclaims all and any liability whether arising in tort or contract, statute, or under any duty of care, warranty or undertaking, express or implied, to any person other than the Client in respect of this Report. In preparing this Report Ricardo may have relied on data, information or statements (Data) supplied to us by the Client or third parties, in which case we have not independently verified this Data unless expressly stated in the Report. Data is assumed to be accurate, complete, reliable and current as of the date of such information and no responsibility for any error or omission in the Report arising from errors or omissions in Data is accepted. Any forecasts presented in this Report were prepared using Data and the Report is dependent on it. Some of the assumptions used to develop any forecasts may not be realised and unanticipated events and circumstances may occur. Consequently Ricardo does not warrant the conclusions contained in this Report as there may be material differences between forecasts and actual results. Parties must rely on their own skill and judgement when making use of this Report.
Contents

- Introduction
- Key Inputs & Assumptions
- Results
- Conclusions
- Recommendations
Introduction

The impact of two scenarios: ‘High EV Adoption’ & ‘Low Carbon Fuels’ on GHG emissions, infrastructure, costs & resources are compared

- This report summarises findings from a study of the implications of two scenarios for future Light Duty Vehicle* propulsion energy to 2050 in Europe
  - The implications of each scenario have been analysed using the SULTAN** (SUstainabLe TrANsport) model, developed by Ricardo for the European Commission, and by reference to a literature search of over 400 technical publications
  - The study did not consider the implications of Connected and Autonomous Vehicles (CAV) and Mobility as a Service (MaaS) or model consumer purchase preferences

---

** SULTAN: A Ricardo tool developed for the European Commission as a transport policy modelling tool, with the ability to evaluate the medium- and long-term (to 2050) impacts of new vehicle technologies.

# Low Carbon Fuels include biofuels and eFuels generated from renewable energy sources.

---

1. What are the Green House Gas (GHG) emissions, including life cycle emissions?
2. What are the implications for energy supply and electricity infrastructure?
3. What are the cost implications?
4. What are the implications on materials and natural resources?

Note: * The scenarios consider the European light duty vehicle fleet only. L-category vehicles, buses, and medium and heavy duty trucks have not been included in the analysis.

© Ricardo plc 2018 Unclassified - Public Domain Q015713 RD18-001912-3 24 August 2018
Introduction

Both scenarios feature significant electrification and use of low carbon fuels (biofuels and eFuels)

- The scenarios examine the implications of hypothetical future vehicle fleet powertrain mixes
  - The scenarios are not intended to be forecasts of the future powertrain mix
- The energy share of each fuel uses energy/km estimates of each powertrain type based on a study* carried out by Ricardo for the European Commission and on Ricardo specialist opinion

Note: New registrations and vehicle parc profiles are calibrated to historic data and projections from European Commission modelling - Comparable scenarios were created for Light Commercial Vehicles – see full report

Source: "N. Hill et al., "Improving understanding of technology and costs for CO2 reductions from cars and LCVs in the period to 2030 and development of cost curves," 2014

© Ricardo plc 2018 Unclassified - Public Domain Q015713 RD18-001912-3 24 August 2018
Introduction

Total Life Cycle GHG emissions were estimated including vehicle production and disposal, and fuel production emissions

Vehicle life cycle

- For the purpose of this analysis, the vehicle life cycle is broken down into several key stages:
  - **Vehicle Production**: Assessment of environmental impact of producing the vehicle from raw materials to complete product
  - **Use**: - Tailpipe CO$_2$ from driving - Impacts from maintenance and servicing
  - **Disposal**: Assessment of environmental impact of “end of life” scenario, including re-using components, recycling materials and landfill

- The default LCA approach adopted for the analysis is an Avoided Burden approach (a.k.a. End-of-Life recycling, 0/100), with credits provided based on the average automotive recycling rate by material/component
- A Recycled Content approach (a.k.a. cut-off, 100/0) is used in the sensitivity analysis
Introduction

To investigate the implication for electricity network infrastructure, the study considered a series of recharging scenarios for plug-in vehicles.

Recharging Scenarios

**Home Unmanaged**
- Home charging is where users charge mainly using off-street home or on-street residential recharging infrastructure.

**Home Managed**
- Same charging type split as “Home Unmanaged”, but with longer time periods to simulate managed charging.

**Grazing Unmanaged**
- Grazing is where users charge little and often, mainly using charging points away from the home.

**Grazing Managed**
- Same charging type split as “Grazing Unmanaged”, but with longer time periods to simulate managed charging.

Current EU housing data shows 28% of households are located in rural environments, and 72% are located in urban and sub-urban environments. Therefore, Ricardo has assumed an EV electricity demand split of 28% for rural charging and 72% for urban charging, applied to all four scenarios. Urban includes both urban and sub-urban properties.

Source: Eurostat (online data code: ilc_lvho01)
Trends in key input assumptions to 2050 are based on recent studies supported by sensitivity studies on key variables

- Key input assumptions are described in the links below:

- Fleet average tailpipe CO₂
- Electricity GHG Intensity
- Battery Costs
- Liquid Fuels and Electricity price
- Low Carbon Fuel availability
- Low Carbon Fuel substitution rates

Coloured titles are clickable links to relevant pages
Clicking R-logo navigates back to this page
The trajectories for CO₂ improvement were set up to be consistent with the gCO₂/km improvements indicated by the European Parliament.

Input assumptions on Tank-to-Wheels (TTW) NEDC gCO₂/km improvement trajectory for new vehicles:

- The European Parliament indicated a range of improvement of gCO₂/km emissions that should be explored by the EC for potential post-2020 regulatory CO₂ targets for LDVs.
- The post-2020 gCO₂/km reduction trajectory for the High EV scenario has been set up to be consistent with the upper end of these recommendations, and extrapolated to 2050.
- The Tank-to-Wheels (TTW) trajectory for the Low Carbon Fuels scenario achieves an equivalent Well-to-Wheels (WTW) CO₂ emissions to the High EV scenario.

Key Inputs & Assumptions

The trajectories for CO₂ improvement were set up to be consistent with the gCO₂/km improvements indicated by the European Parliament.

Input assumptions on Tank-to-Wheels (TTW) NEDC gCO₂/km improvement trajectory for new vehicles:

- The European Parliament indicated a range of improvement of gCO₂/km emissions that should be explored by the EC for potential post-2020 regulatory CO₂ targets for LDVs.
- The post-2020 gCO₂/km reduction trajectory for the High EV scenario has been set up to be consistent with the upper end of these recommendations, and extrapolated to 2050.
- The Tank-to-Wheels (TTW) trajectory for the Low Carbon Fuels scenario achieves an equivalent Well-to-Wheels (WTW) CO₂ emissions to the High EV scenario.

Source: Ricardo Energy & Environment
The electricity GHG intensity is based on European Commission assumptions and other previous analysis

The impact of ‘High’ and ‘Low’ GHG intensity assumptions are also analysed

### European Electricity Scenario

Electricity Global Warming Potential (GWP) [kgCO₂/kWh]

- **Sensitivity “High GHG” Scenario**
- **European Electricity Scenario**
- **Sensitivity “Low GHG” Scenario**

- **Source:** S. Frank et al., "EU Reference Scenario 2016 Energy, transport and GHG emissions Trends to 2050.", 2016; Previous analysis by Ricardo Energy & Environment for the EC and other European projects

- **The baseline trajectory for electricity GHG intensity is based on the European Commission’s 2016 Reference scenario dataset.**

- **Alternative scenarios for GHG intensity were based on previous analysis for the Commission from the EU Transport GHG: Routes to 2050 (R2050) projects**
  - Low GHG intensity (93% reduction on 1990) is consistent with the low end of the range for high decarbonisation scenarios from the Commissions “Roadmap for moving to a competitive low carbon economy in 2050”
  - High GHG intensity (65% reduction on 1990) is a sensitivity from R2050 projects
Battery costs are a key component of EV costs. Cost/kWh is expected to decline by over 70% by 2030 compared to prices in 2015.

Sensitivity studies were also carried out to understand the affect of battery cost on overall costs.

### Assumed Technology Cost Trends – Battery Pack

**Battery Pack Cost [$/kWh]**

- **Sensitivity “Very High” Scenario**
- **Sensitivity “High” Scenario**
- **Typical / Central Case**
- **Sensitivity “Low” Scenario**

- Estimates for future battery pack costs (including assembly) are based on learning-based cost analysis developed as part of work for the European Commission.
- Battery costs are used together with electric range and State of Charge assumptions to calculate the costs of baseline xEV powertrain vehicles relative to conventional equivalents.
- Assembly of the battery pack into the vehicle is considered in vehicle costs.
- Sensitivity studies were carried out for ‘Low’, ‘High’ and ‘Very High’ battery cost trends.
- The average battery pack size for an EV passenger car in 2050 is assumed to be 82kWh (108kWh for an average Light Commercial Vehicle).
  - Battery pack energy density was also assumed to increase to 800Wh/kg by 2050.
Key Inputs & Assumptions

The price of liquid fuels and electricity has been based on data from published studies.

Sensitivity studies were also carried out to understand the affect of electricity and fuel price.

**Assumed Energy Cost Trends Excluding Taxes**

![Graph showing assumed energy cost trends excluding taxes](image)

- Electricity Price [€/kWh, excl. tax]
- Low Carbon Fuels Price [€/litre eq., excl. tax]

- Assumptions about energy costs are based on the references below:
  - Sensitivity “Low GHG” Scenario
  - European Electricity Scenario
  - Sensitivity “High GHG” Scenario

  - Directorate-General for Research and Innovation (European Commission), “Research and innovation perspective of the mid-and long-term potential for advanced biofuels in Europe,” 2018;

Return Homepage
Key Inputs & Assumptions

The energy available from biofuels and eFuels for European light duty vehicles has been estimated from other recent research sources.

- Availability of Low Carbon Fuels is intended to reflect a scenario where the whole biomass supply chain is optimised to maximise use of bioenergy.
- Assumptions about the availability of Low Carbon Fuels are based on the references below.
- Quantities available to LDVs allow for similar substitution levels in other road transport (e.g. HDVs) but use in other transport modes is not considered explicitly.

Key Inputs & Assumptions

Both scenarios feature substitution of conventional liquid fuels by biofuels, with a higher share in the Low Carbon Fuels scenario.

European scenarios for biofuel and other low carbon fuel uptake

- Net GHG reduction for biofuels is assumed to reach ~85% by 2050.
- After 2020 it is assumed that the share of low/no-ILUC biofuel (i.e. from waste or non-crop feedstocks) will increase to >95% share by 2050.
- For the High EV scenario, E20 is assumed to be 100% by 2040.
- For the Low carbon fuels scenario:
  - It is assumed that the majority of biodiesel used post-2025 will be drop-in fuels (including syn-diesel, eFuels and HVO) and by 2050 substitution reaches 100%.
  - Gasoline is also mainly replaced by advanced biofuels (synthetic gasoline) and substitution nears 80% by 2050.

Source: Analysis by Ricardo Energy & Environment based on previous work for the EC and other European projects, and the availability (in PJ) of low carbon fuels developed by CONCAWE and reviewed by Ricardo.
The study compares the impact of each scenario on GHG emissions, electricity infrastructure, costs & resources.

1. What are the Green House Gas (GHG) emissions, including life cycle emissions?

2. What are the implications for energy supply and electricity infrastructure?

3. What are the cost implications?

4. What are the implications on materials and natural resources?

- Selected results are shown compared to a Business as Usual (BAU) reference scenario as used by the European Commission as a baseline for quantifying the impact of future policy changes.
Both scenarios result in a similar and significant reduction in GHG emissions to 2050

- GHG emissions reduce to less than 13% of 2015 value by 2050, for both scenarios
- GHG emissions are substantially less than the European Commission Business as Usual* (BAU) reference scenario
- Well-to-Wheel (WTW) GHG savings vs 1990 are ~92%

Technologies will continue to develop to deliver “zero impact” on air quality from tailpipe but this was not considered in this analysis

The embedded emissions from production and disposal rises to ~25% by 2050 for both the Low Carbon Fuels and the High-EV scenario

Source: Ricardo Energy & Environment SULTAN modelling and analysis

* BAU scenario as used by European Commission as a baseline for quantifying the impact of future policy changes
Sensitivities on electricity GHG intensity affect which scenario results in lower GHG emissions

Sensitivities on Electricity GHG intensity vs base High EV scenario

Electricity Global Warming Potential (GWP) [kgCO₂/kWh]

Total GHG emissions

“High” electricity GHG intensity
High EV Scenario produces 33Mt CO₂ MORE than the Low Carbon Fuels Scenario

“Low” electricity GHG intensity
High EV Scenario produces 8Mt CO₂ LESS than the Low Carbon Fuels Scenario

Source: Ricardo Energy & Environment SULTAN modelling and analysis
Twice the electrical energy is required for EVs in the High EV scenario compared to the Low Carbon fuels scenario (550 TWh vs 289 TWh)

Electricity consumption from recharging by location (Home Charging Scenario)

- Electricity demand from EV charging in 2050 in the managed home charging scenario is ~550 TWh (1980 PJ)
  - This represents ~17.5% of the EU’s 2015 electricity generation
- In the ‘Home’ charging scenario, most of this energy (~60%) is expected to come from charging overnight in residential areas
- Charging requirements are ~47% lower in the Low Carbon Fuels scenario, with a higher share of charging from residential/home

Unmanaged charging would require significantly more upgrades to Low Voltage (LV) networks to support off-street and on-street charging (and therefore much higher cost – more than double the cost cumulatively to 2050)

Source: Ricardo Energy & Environment SULTAN modelling and analysis
Note: * Including EU electricity used to produce EU eFuels decreases the difference to 39% lower for Low Carbon Fuel vs High EV
Under a grazing scenario home charging accounts for 36% and 49% of consumption for High EV & Low Carbon Fuels scenarios respectively.

For all recharging scenarios, the need to replace secondary substations contributes most to infrastructure upgrade costs.

Source: Ricardo Energy & Environment SULTAN modelling and analysis
The cumulative cost of managed EV charging & network infrastructure reinforcement is estimated between €630bn and €830bn to 2050.

Comparison of cumulative electric charging (Managed) and network infrastructure costs

- For the High EV scenario, the cumulative charging and network infrastructure reinforcement costs by 2050 are:
  - ‘Home’ charging ~€630bn
  - ‘Grazing’ charging ~€830bn

- For the Low Carbon Fuel scenario, the cumulative costs, are approximately half of this
  - ‘Home’ charging ~€326bn
  - ‘Grazing’ charging ~€389bn

Source: Ricardo Energy & Environment SULTAN modelling and analysis
Increased peak power for managed home charging is 115GW (15% of currently installed peak power generation) for the High EV scenario

Additional peak power as a percentage of existing installed generation capacity

- In 2015 the EU28 had 770GW of installed peak power generation and the peak load was 528GW
  - In the managed charging at home case, by 2050 the estimated increase in peak power as a percentage of currently installed peak power generation is
    - ~15% (115GW) for High EV scenario
    - ~8% (63GW) for Low Carbon Fuels
  - Unmanaged charging doubles the peak power requirement
  - Both grazing and home charging will have similar peak power flows requiring a similar quantity of generation assets
    - Adding additional storage to the network could reduce the peak power required

In 2015, 39% of EU28 installed peak power generation was from renewable sources and 53% was from traditional generation (fossil & nuclear)

Source: Ricardo Energy & Environment SULTAN modelling and analysis
The annual parc total costs to the end user are similar for the High EV and Low Carbon Fuels scenarios if lost fuel tax revenue is considered. Taxes are applied for all energy carriers at their current and projected (BAU) levels.

- Total annual parc cost to the end user is similar for both scenarios in 2050, when adjusting to maintain Net Fiscal Revenue: ~€2,254bn & ~€2,263bn for the High EV and Low Carbon Fuels scenarios respectively.

- Net fiscal revenue loss is greater for the High EV scenario because liquid fuels have a larger proportion of tax & because the energy requirement for EVs is less due to their higher efficiency.

- Both scenarios result in overall cumulative cost savings to the end-user between ~€1,100 & €1,600bn (1.3% - 1.8% of total cumulative end user costs)* vs EC BAU** reference to 2050.

Source: Ricardo Energy & Environment SULTAN modelling and analysis
Note: *Including infrastructure costs but excluding adjustment for Net Fiscal Revenue  
**BAU scenario as used by European Commission as a baseline for quantifying the impact of future policy changes.
The estimated marginal capital costs for the High EV scenario are particularly strongly influenced by assumptions on battery prices.

The average marginal cost increases for new cars under the High EV scenario are significantly higher than those under the Low Carbon Fuels Scenario.

The average marginal cost of new cars is more strongly influenced by uncertainties in battery price in the High EV scenario than the Low Carbon Fuels scenario.
The estimated marginal capital cost increase for vans is larger than for cars, particularly for the High EV scenario.

Average marginal additional capital costs per vehicle for light commercial vehicles:

- The marginal capital costs of vans is particularly strongly affected by battery costs.

Source: Ricardo Energy & Environment SULTAN modelling and analysis.
Results - Costs

**Overall Total Cost of Ownership (TCO) to end-users, for the average vehicle, reduces in both scenarios compared to BAU**

Taxes are applied for all energy carriers at their current and projected (BAU) levels

---

**New European Passenger Car Total Cost of Ownership (TCO) – Scenario Comparison**

- Assumes lifetime 210,000 km over 15 years
- End-user perspective (including all taxes) with future costs discounted to Net Present Value (NPV)*

**Source:** Ricardo Analysis

**Note:**
- BAU: Scenario as used by European Commission as a baseline for quantifying the impact of future policy changes
- EV Infrastructure costs include only cost end-users are assumed to directly pay for – i.e. Provision of on-off-street charging units. NPV assumes 10% Discount Rate

---

![Graph showing TCO comparison between BAU, High EV, and Low Carbon Fuel scenarios.](image-url)
The net societal cumulative costs are lower for High EV scenario only in later periods

External costs (or ‘externalities’) are the monetary value attached to GHG and Air Quality emissions

**Total Parc Annual Societal Costs (excl. tax), including Externalities**

- Calculating the net societal costs for both scenarios including all cost components as well as externalities results in a significant lowering of High EV costs in the period after 2035
- Up to 2035, the total annual societal costs are slightly higher under the High EV scenario
- By 2050, total annual societal costs are 33.5 €Billion p.a. lower for the High EV scenario than for the Low carbon fuels scenario

**Cumulative Net Societal Costs (relative to High EV)**

- **Note**: Societal costs exclude all taxes
Under the High EV scenario, ~15 Gigafactories would be needed to supply batteries to the European EV market by 2050

The High EV scenario requires almost three times the total battery capacity compared to the Low Carbon Fuels scenario:

- The Tesla Gigafactory is projected to produce ~35 GWh per annum.*
- Europe will need ~15 gigafactories under the High EV Scenario, while ~5.5 such factories will be needed under the Low Carbon Fuels Scenario by 2050.


Note: Tesla Giga Factory estimates factor in anticipated battery energy density improvements per unit from 2025-2050. This output should be expected to scale with increased battery kg/Wh.
Results - Resources and Materials

The Lithium resource requirements for the Low Carbon Fuels scenario are less than half of those for the High EV scenario

Resources & Materials – Key Battery Materials [tonnes], annual demand

- Assuming current chemistry mixes the resource requirements for Lithium, Cobalt and Nickel would increase very substantially over the period to 2050, which would pose a potential availability risk
- Current global total production p.a.:
  - Li : 35 kt (with 14 Mt reserves)
  - Co : 123 kt (with 7 Mt reserves)
  - Ni : 2.25 Mt (78 Mt reserves)
- Overall resource requirements for the High EV scenario would more than double those for the Low Carbon Fuels scenario under these assumptions

The use of Cobalt and Nickel in battery chemistries is expected to be phased out between 2030 and 2040: the share after this is uncertain
Lithium extraction and recycling would have to be increased significantly to reach peak demand in 2040 in the High EV scenario.

Lithium Material Analysis – High EV scenario

- For the High-EV scenario, annual virgin lithium demand increases rapidly until a peak is reached in 2040, when EV recycling becomes significant.
- European mass EV adoption will consume a larger share of global lithium reserves than its global vehicle sales. This may result in a shortage of lithium if other regions also undergo mass EV adoption.

By 2050, extracted lithium and recycled lithium volumes are expected to be almost the same. However, it is not clear what will encourage the recycling industry to grow to that level, from current 1% recovery of Li scrap.

Source: JRC for EU Commission: L. Lebedeva, F. Di Persio, and L. Boon-Brett, "Lithium ion battery value chain and related opportunities for Europe" 2016;
The majority of lithium and cobalt is located in a few countries which is a potential risk for prices and security of supply

- The majority of lithium reserves are located in South America; Chile has over half the global lithium reserves.

- Lithium production and prices could depend heavily on the policies of the Chilean government.

- Although cobalt reserves are present in many countries, the largest reserves and current production are located in Congo (Kinshasa).

- Instability in this region is a factor in the 128% increase in the price of cobalt in 12 months*.

*Source: U.S Geological Survey (Mineral Commodity Summaries 2017); * The London Metal Exchange (Sep 2016 – Sep 2017 Values)
Finally, a scenario was created based on the “ERTRAC” mixed fleet scenario with combined xEV and Low Carbon Fuel powertrains at 2050.

Mixed Fleet Scenario – Based on “ERTRAC” Mixed Fleet Share Scenario study to be published

- The Mixed Fleet scenario assumes 64% Plug-In Vehicle (PIV) at 2050, compared to 91% and 47% for the High EV and Low Carbon Fuel scenarios respectively.
- The improvement in efficiency of Internal Combustion Engine and Hybrid vehicles was considered greater than in the High EV scenario, due to likely further development of engines in this scenario.
- The share of biofuels and eFuels, rapidly increases after 2030, reaching 100% and 75% share for diesel and gasoline respectively by 2050.

Source: Ricardo Energy & Environment; ERTRAC: European Road Transport Research Advisory study to be published.
The Mixed Fleet scenario also shows a significant and similar reduction in GHG emissions to the other scenarios.

All scenarios demonstrate broadly similar reductions in total GHG at 2050.

Source: Ricardo Energy & Environment SULTAN modelling and analysis
The annual parc total costs to the end user are similar for the High EV and Mixed Fleet Scenarios

Total Parc Annual Costs to End-user, including AFV Infrastructure and Network upgrades

- Whilst costs are higher in the period to 2035 for the High EV scenario, the net costs are ~€58bn p.a. lower than Mixed Fleet scenario by 2050.
- Including Net Fiscal Revenue (NFR) loss (vs BAU) closes the gap to €11bn p.a.
- All scenarios reduce GHG emissions/meet reduction objectives at lower overall cost to the end user, primarily due to lower fuel and energy costs than the Business as Usual (BAU) reference, which does not meet GHG reduction objectives.

Source: Ricardo Energy & Environment SULTAN modelling and analysis
Both scenarios significantly reduce GHG emissions at similar cost but require large increases in battery production or low carbon fuel supply

- All scenarios result in a similar and significant (~85%) reduction in GHG emissions to 2050
  - The key assumptions on GHG intensity of electricity supply, and low carbon fuel availability, affects whether the High EV or the Low Carbon Fuels scenario results in lower total GHG emissions

- Electricity demand from EV charging in 2050 in the managed home charging scenario is ~550 TWh
  - This represents ~17.5% of the EU’s 2015 electricity generation, and is twice that required in the Low Carbon Fuels scenario

- The cumulative cost of a managed EV charging and network infrastructure reinforcement is estimated between €630bn & €830bn to 2050, compared to overall cumulative savings to the end-user between €1,100 & €1,600bn (1.3% - 1.8% of total end-user costs)* vs European Commission Business as Usual reference to 2050
  - For all recharging scenarios, the need to replace secondary substations contributes most to network infrastructure upgrade costs

- The annual parc total costs to the end user (when adjusted to maintain Net Fiscal Revenue) are similar for the High EV, Low Carbon Fuels and Mixed Fleet scenarios, and below the baseline scenario
  - The estimated marginal capital costs for the High EV scenario are particularly strongly influenced by assumptions on battery prices

- Under the High EV scenario, ~15 Gigafactories (@35GWh p.a.) would be needed to supply batteries to the European EV market by 2050, compared to ~5.5 Gigafactories in the Low Carbon Fuels scenario by 2050

- In the High EV scenario, peak annual virgin lithium demand (~220kt) is 6 times higher than global lithium production in 2016 (35kt)
  - The Lithium requirements for the Low Carbon Fuels scenario are less than half for the High EV scenario

* Excluding adjustment for loss of Net Fiscal Revenue
Further work recommendations

- It is recommended that further work should:
  - Explore the impact of combinations of the scenarios presented here
  - Further investigate the risks associated with supply of raw materials for battery production
  - Study what framework would be required to support investment in low carbon fuel availability, alongside electrification