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A comparative life-cycle analysis of low GHG HGV powertrain technologies and fuels

Nikolas Hill, “Decarbonisation of Heavy Goods Vehicle Transport”, EC JRC Online Workshop , 28 October 2020

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meeting the challenges within the markets of Transport & Security, Energy and Scarce Natural Resources & Waste

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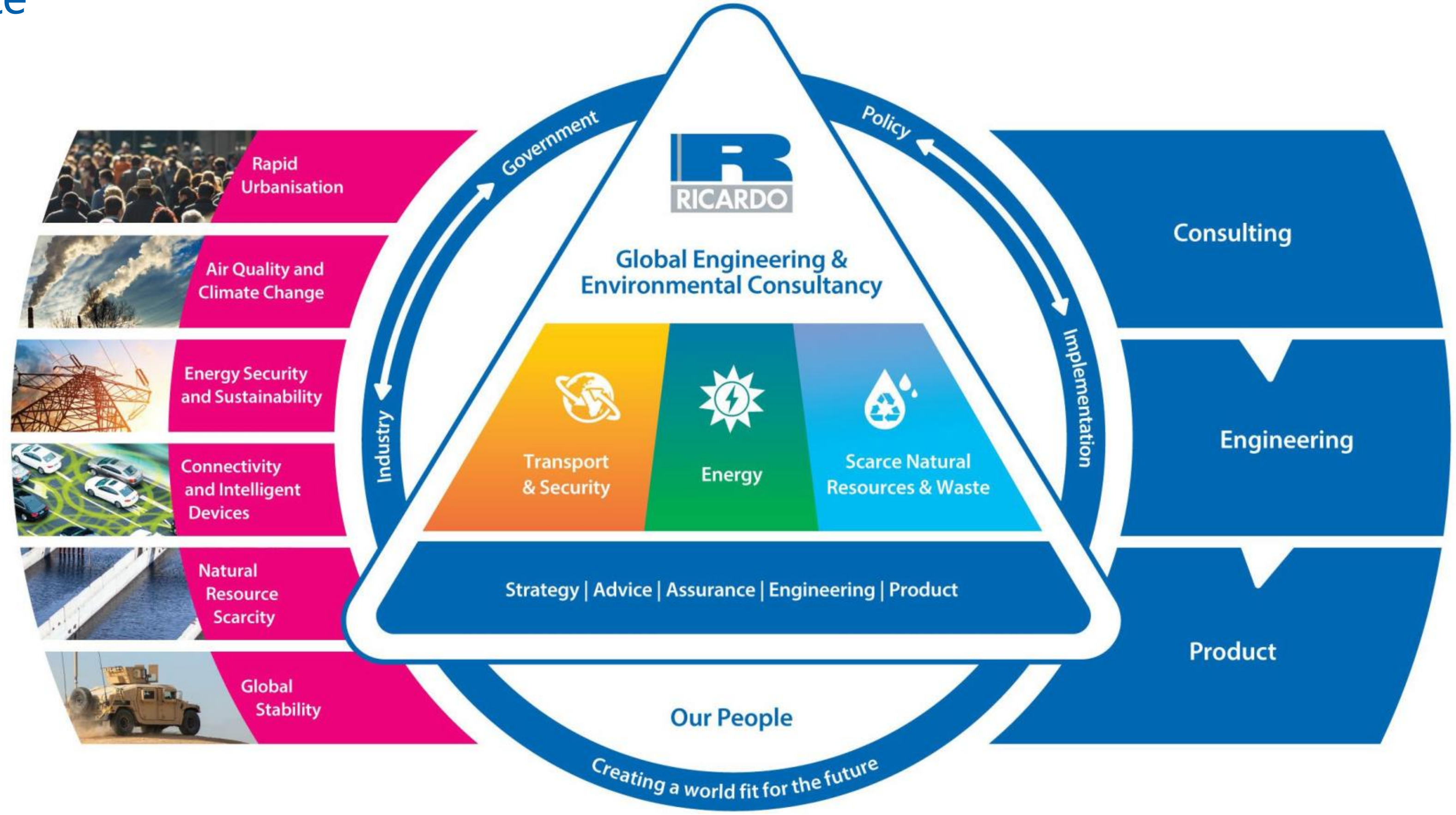

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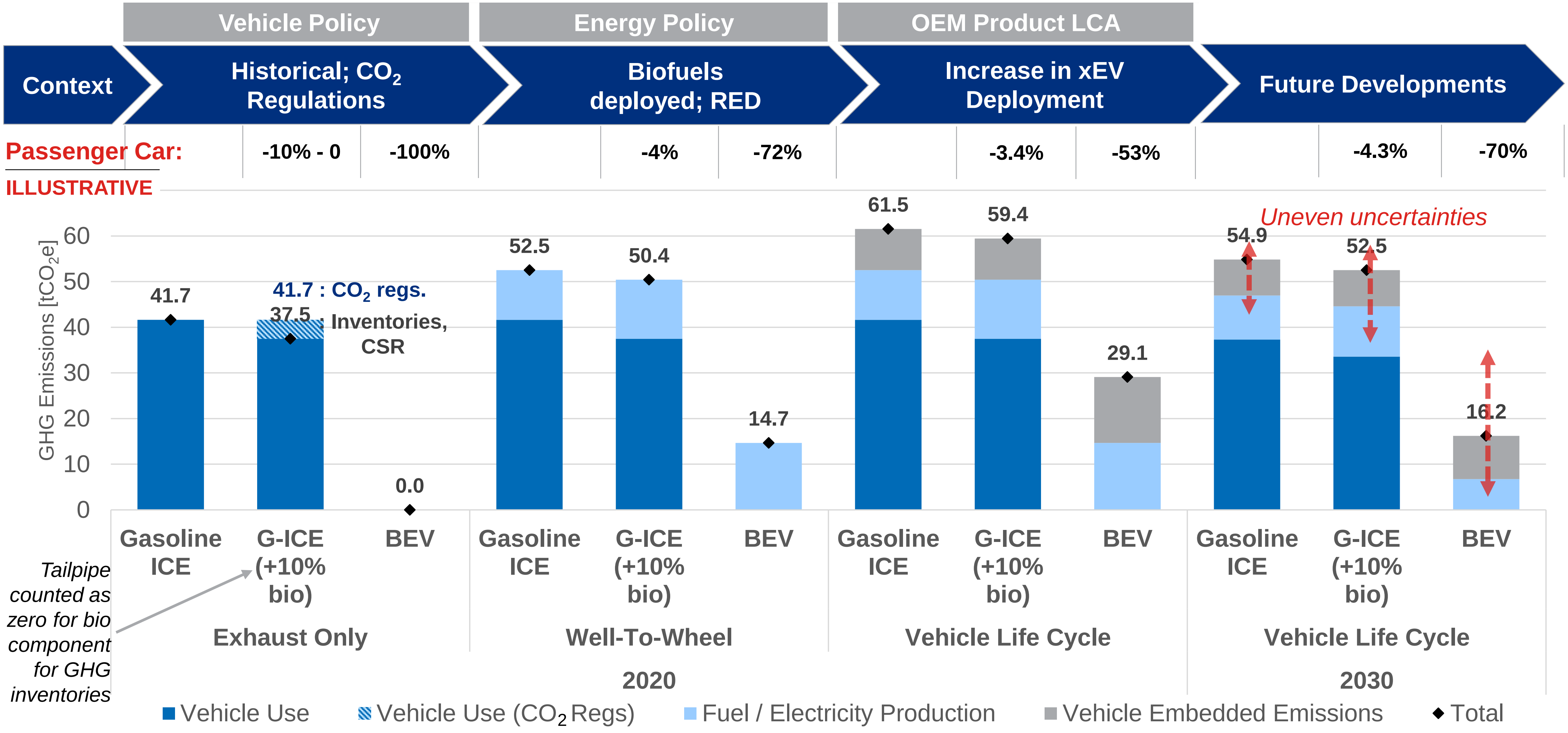
88 nationalities
51 sites in **26** countries

Contents

Why are we interested? A combination of changes in the regulatory environment, as well as the uptake of new fuels/powertrains, means many complex future scenarios



Source: Ricardo Vehicle LCA analysis (June 2020) for average EU lower-medium passenger car: Assumes lifetime 225,000 km, real-world fuel consumption. GHG from fuel/electricity consumption is based on the average fuel/grid electricity factor over the life of the vehicle (Baseline scenario); Calculated 89.0 kgCO_2e/kWh battery in 2020, 30.0 kgCO_2e/kWh in 2030. Includes EoL recycling credits

Ricardo led (with also ifeu and E4tech) a 2-year Vehicle LCA project for DG CLIMA which considered the environmental impacts over the whole life of the vehicle, to provide comparisons across a range of vehicle types, powertrains and energy chains

Vehicle Life Cycle

Well-to-Wheel (WTW) Analysis on the production of fuels and electricity, and operational emissions

Vehicle cycle "Embedded" emissions result from vehicle manufacturing, maintenance and end-of-life (EoL) disposal


Fuel & Electricity Production

Assessment of (WTT) environmental impact of producing the energy vector(s) from primary energy source, generation plants, through to distribution point

Study Boundary:
The **whole vehicle life cycle** includes embedded emissions from vehicle production, maintenance and servicing, and end-of-life activities, and WTW (WTT+TTW) emissions from fuels and electricity

Not in scope

Electricity Storage

Vehicle Manuf. Plants

Vehicle Production

Assessment of **'Cradle-to-Gate'** environmental impact of producing the vehicle, including extract of raw materials, processing, component manufacture, logistics, vehicle assembly and painting

Use/Operation

- Environmental impact of driving (TTW emissions)
- Impact from maintenance and servicing

End-of-Life

Adds assessment of environmental impact of "end of life" scenario (i.e. **-to-Grave**). Can include: **re-using** or **re-purposing** components, **recycling** materials, energy recovery and disposal to landfill

Transport Infrastructure - charging/ refuelling; roads etc.

Not in scope

The EC Vehicle LCA project has a number of unique points and has delivered significant added value compared to existing studies in this area

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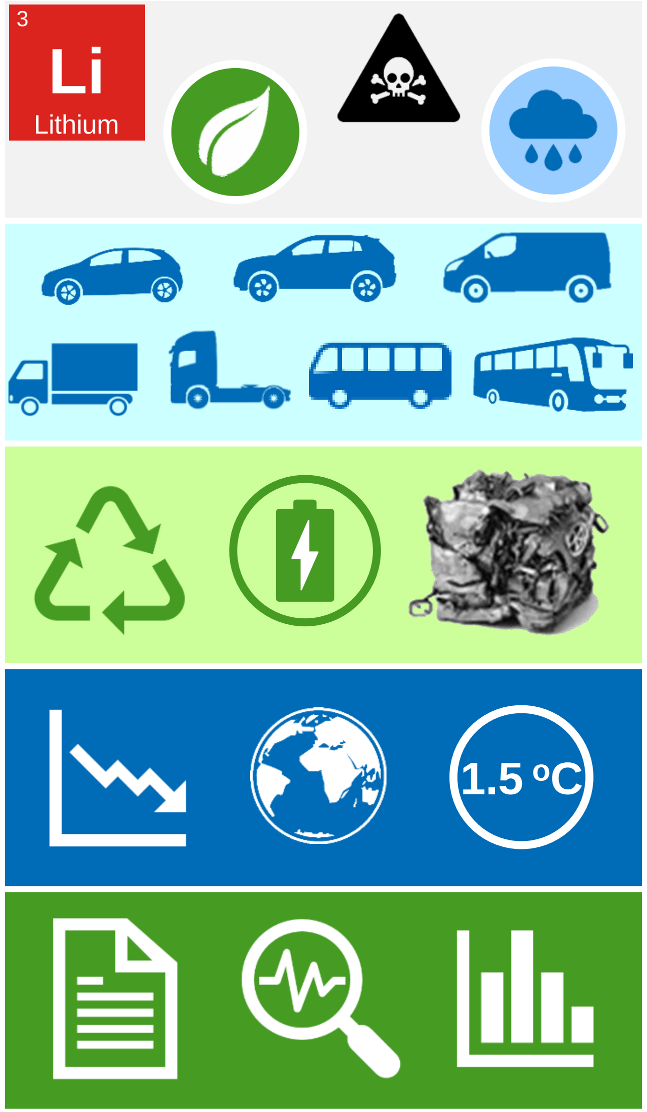
- The project covered a wide range of (14) LCA impact metrics, not just GHG emissions (GWP) and Cumulative Energy Demand (CED)
  (i.e. AP, POCP, ODP, PMF, HTP, FA ETP, IRP, ARD minerals & metals, ARD fossil energy, land use, water scarcity)

- 7 light- and heavy-duty road vehicle types, and different duty cycles were analysed using a consistent and harmonised methodology

- Accounting for end-of-life impacts: application of PEF CFF*, and estimation of benefits resulting from second-life of xEV batteries
  *Product Environmental Footprint – Circular Footprint Formula

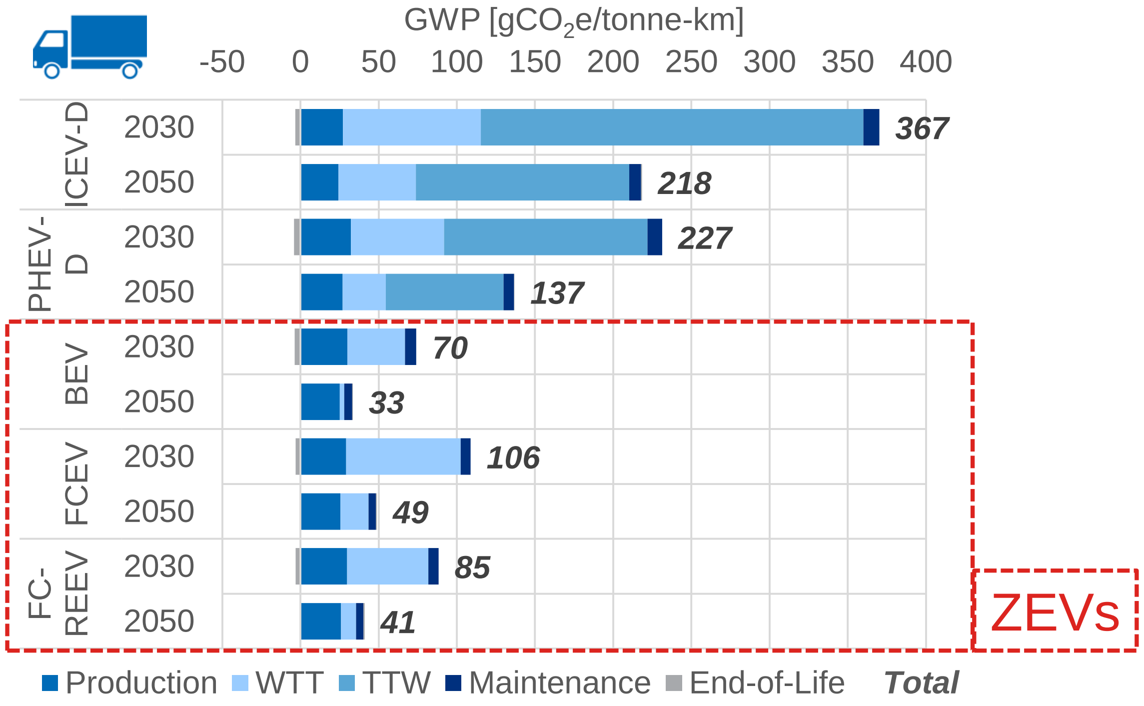
- Alignment with the EC's 1.5 Tech scenario*: Accounting for temporal effects on materials, energy carriers and vehicle characteristics
  * Long-Term Strategy to reach a climate-neutral Europe by 2050 - scenario consistent with the EU contribution to meeting the Paris Agreement objective of keeping global temperature increase to a maximum of 1.5 ºC; https://ec.europa.eu/clima/policies/strategies/2050_en

- Development and application of a new methodology, supported by testing of the results using a thorough set of sensitivity analyses

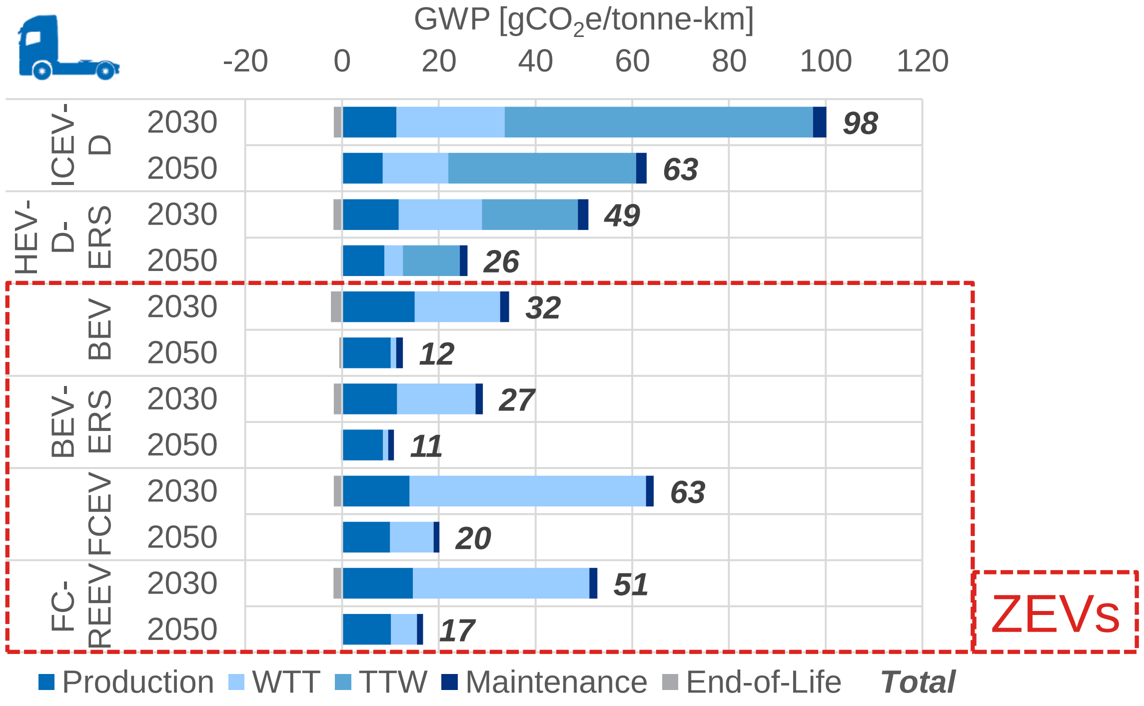


Results from the LCA modelling demonstrate the significant current and future potential benefits of xEVs over conventional powertrains for Rigid and Artic Lorries

Rigid Lorry 12t GVW, Urban Delivery – Tech1.5 Scenario



Artic Lorry 40t GVW, Long Haul – Tech1.5 Scenario



- ZEVs demonstrate significant reductions in life-cycle GWP impacts (also in 2020), particularly in Urban Delivery settings
- Benefits versus conventionally fuelled vehicles increase 2030-2050 due to various scenario, decarbonisation effects:
  - Materials and manufacturing (vehicle, batteries), EoL activities
  - Improved vehicle and battery technology (i.e. energy density)

- GWP benefits also substantial for articulated lorries, even accounting for lost loading capacity (reduces over time)
- Catenary battery electric vehicles (BEV-ERS) have the lowest impacts, however infrastructure is not included

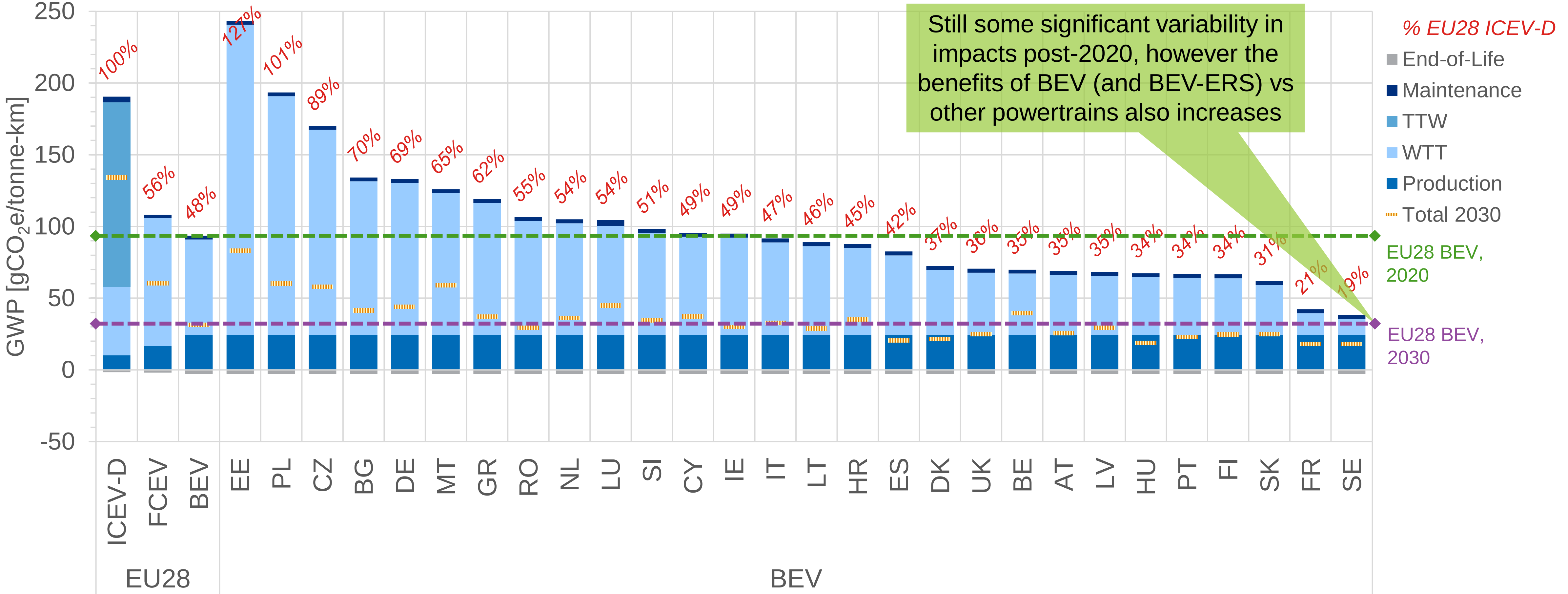
[*Note*: Some changes have been made to input data assumptions since EC Vehicle LCA project, e.g. future electric range for BEV, BEV-ERS]

Additional information: 570,000 km, 12 year lifetime. 2030/2050 BEV battery 195/226 kWh, 300/350km range, with av. lifetime EU28 fuel/electricity mix (age-dependant mileage weighted). No battery replacement calculated to be needed for xEVs.

Additional information: 800,000 km, 10 year lifetime. 2030/2050 BEV battery 958/1147 kWh, 820/1000km range, with av. lifetime EU28 fuel/electricity mix (age-dependant mileage weighted). No battery replacement calculated to be needed for xEVs.

Example – Regional variation impacts of comparison of ICEV, FCEV vs BEV shows that in the majority of EU countries BEVs could already show significant GHG benefits

Articulated Lorry

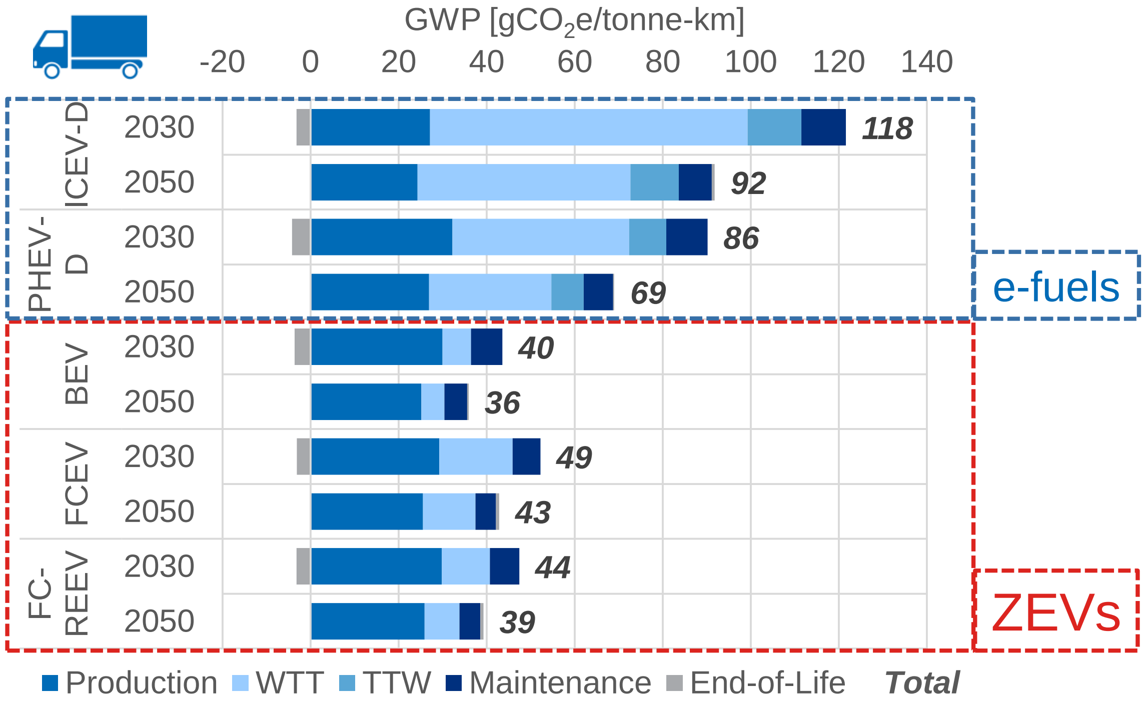


- Modelled % variation in impacts due to ICEV powertrains is lower (with a range of approx. +40%/-20% of the EU av.), but asymmetric with BEV impacts due to a combination of variation in driving shares by road type and temperature variations (other impacts not modelled)

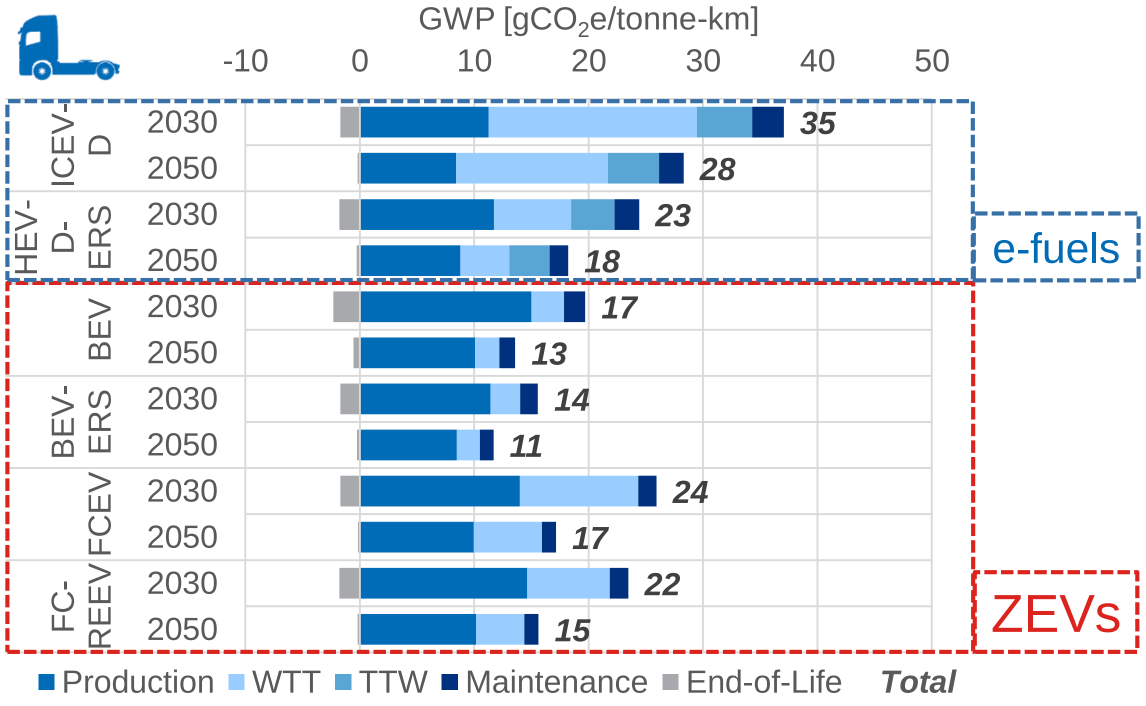
Source: Ricardo LCA modelling, October 2020. Results shown for the artic lorry 40t GVW in the Tech1.5 scenario. Production = production of raw materials, manufacturing of components and vehicle assembly; WTT = fuel/electricity production cycle; TTW = impacts due to emissions from the vehicle during operational use; Maintenance = impacts from replacement parts and consumables; End-of-Life = impacts/credits from collection, recycling, energy recovery and disposal of vehicles and batteries. Additional information on key input assumptions and derived intermediate data include the following: a lifetime activity of 800,000 km over 10 years. 2020 BEV battery has a 900 kWh, a 500km Long-Haul cycle range, and with average lifetime EU28 fuel/electricity mix (age-dependant mileage weighted). No battery replacement is calculated to be needed for BEVs, based on the assumptions on the capacity of the battery, battery cycle life and lifetime km of the vehicle.

Conventional and hybrid powertrain vehicles operating on e-fuels produced from renewable electricity have the potential to reduce GHG almost as much as xEVs

Rigid Lorry 12t GVW, Urban Delivery – Tech1.5 Scenario



Artic Lorry 40t GVW, Long Haul – Tech1.5 Scenario



- WTT impacts for e-fuels are mainly due to embedded emissions from electricity generation equipment (e.g. solar PV cell manufacturing)
- TTW impacts for vehicles using e-fuels are mainly due to N_2O emissions from NOx control/SCR aftertreatment

- Impacts for hybrid catenary electric vehicles (HEV-D-ERS) using e-fuels are similar to FCEV using hydrogen produced by electrolysis of water with (intermittent) renewable electricity
  - However catenary (ERS) infrastructure is not included in the calculations

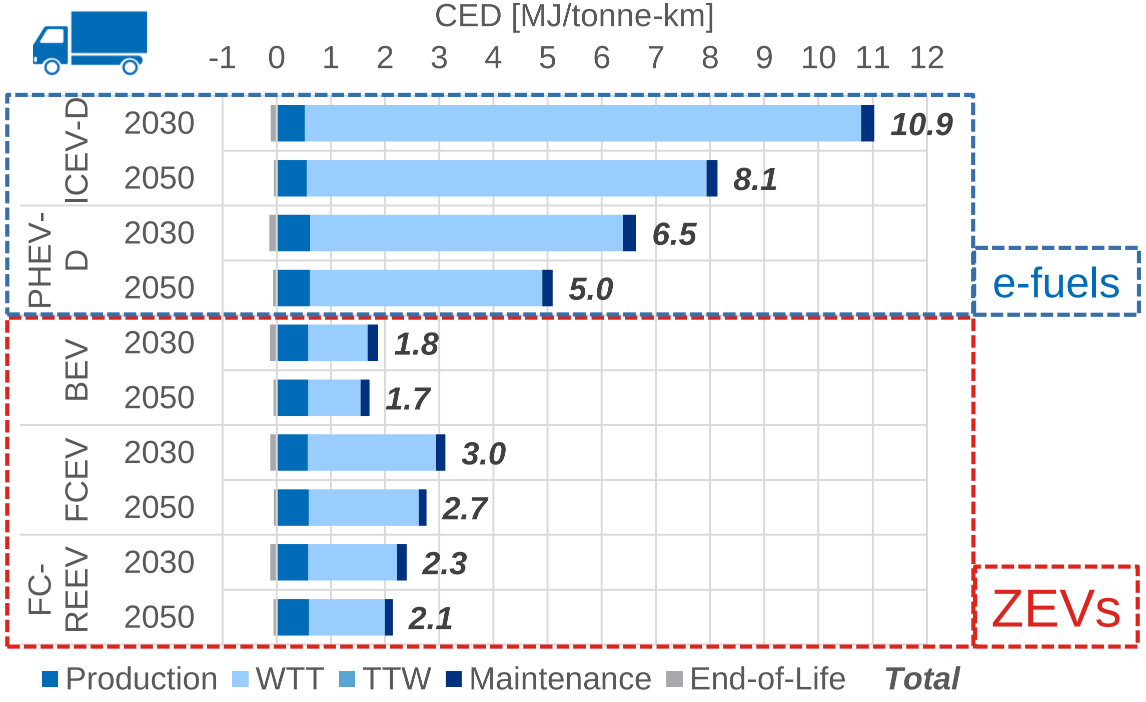
[Note: All vehicles/powertrains shown are assumed to be operating on fuels produced from (intermittent) renewable electricity]

Additional information: 570,000 km, 12 year lifetime. 2030/2050 BEV battery 195/226 kWh, 300/350km range, with av. lifetime EU28 fuel/electricity mix (age-dependant mileage weighted). No battery replacement calculated to be needed for xEVs.

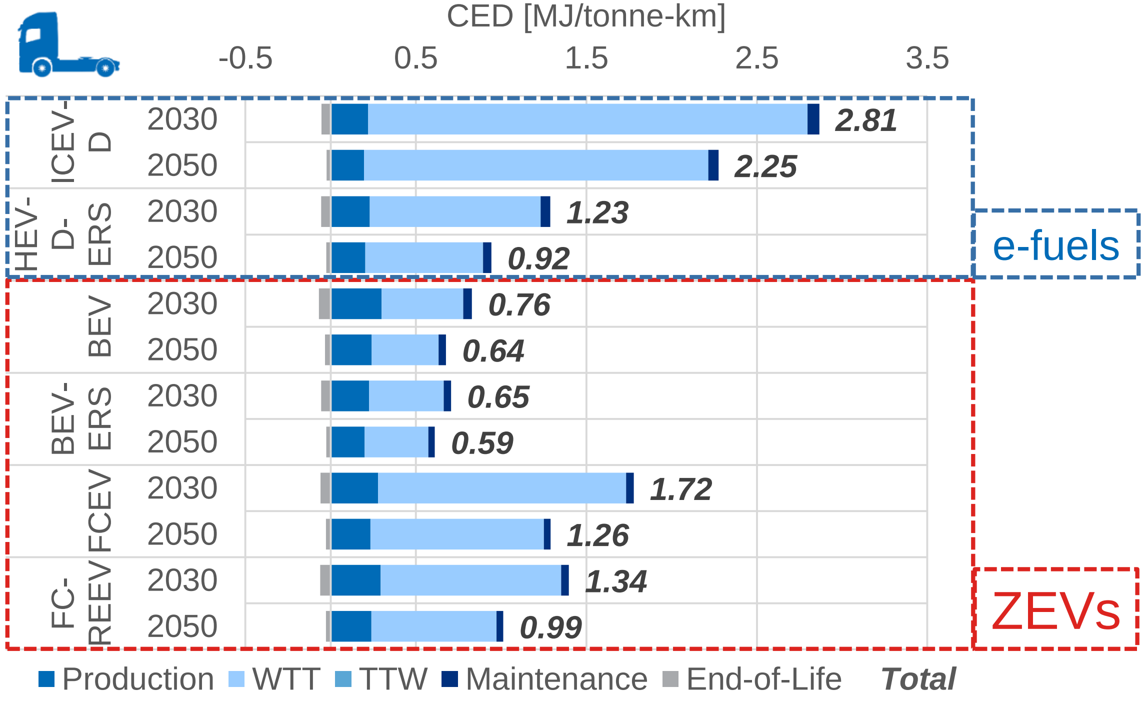
Additional information: 800,000 km, 10 year lifetime. 2030/2050 BEV battery 958/1147 kWh, 820/1000km range, with av. lifetime EU28 fuel/electricity mix (age-dependant mileage weighted). No battery replacement calculated to be needed for xEVs.

The cumulative (renewable) energy consumption for vehicles operating on e-fuels is 5-7 times higher than for BEV / Catenary BEV powertrains; 1.6-2 x higher for H2 FCEV

Rigid Lorry 12t GVW, Urban Delivery – Tech1.5 Scenario



Artic Lorry 40t GVW, Long Haul – Tech1.5 Scenario



- The cumulative energy demand across the lifecycle for use of e-fuels is extremely high compared to electric and hydrogen fuel cell electric vehicles
  - The use of these fuels is likely best reserved for applications where xEVs are less well suited
- FCEV (and FC-REEV) use significantly more energy than BEV (and BEV-ERS), but less than e-fuels
  - However, there are potential applications for hydrogen also for supporting longer-term storage (and transport) of renewable electricity

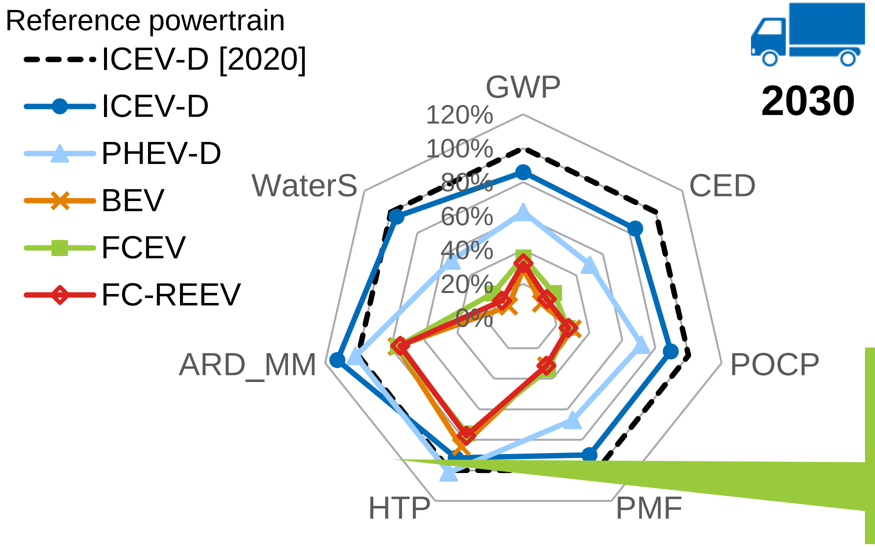
[Note: All vehicles/powertrains shown are assumed to be operating on fuels produced from (intermittent) renewable electricity]

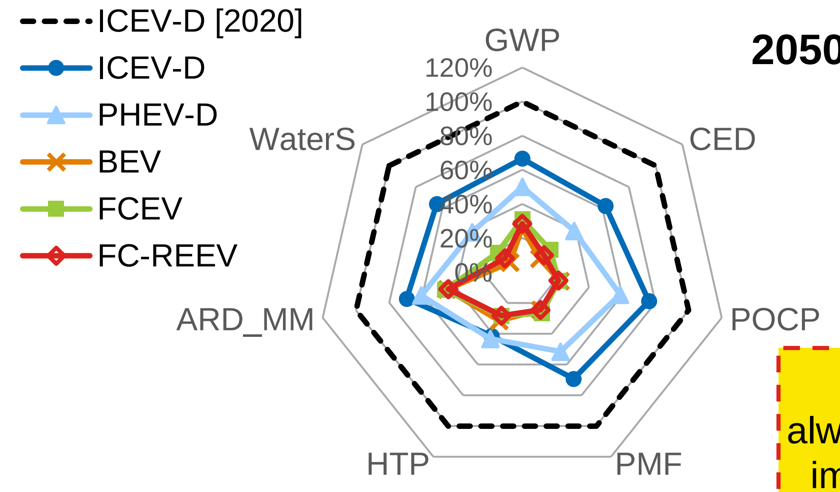
Additional information: 570,000 km, 12 year lifetime. 2030/2050 BEV battery 195/226 kWh, 300/350km range, with av. lifetime EU28 fuel/electricity mix (age-dependant mileage weighted). No battery replacement calculated to be needed for xEVs.

Additional information: 800,000 km, 10 year lifetime. 2030/2050 BEV battery 958/1147 kWh, 820/1000km range, with av. lifetime EU28 fuel/electricity mix (age-dependant mileage weighted). No battery replacement calculated to be needed for xEVs.

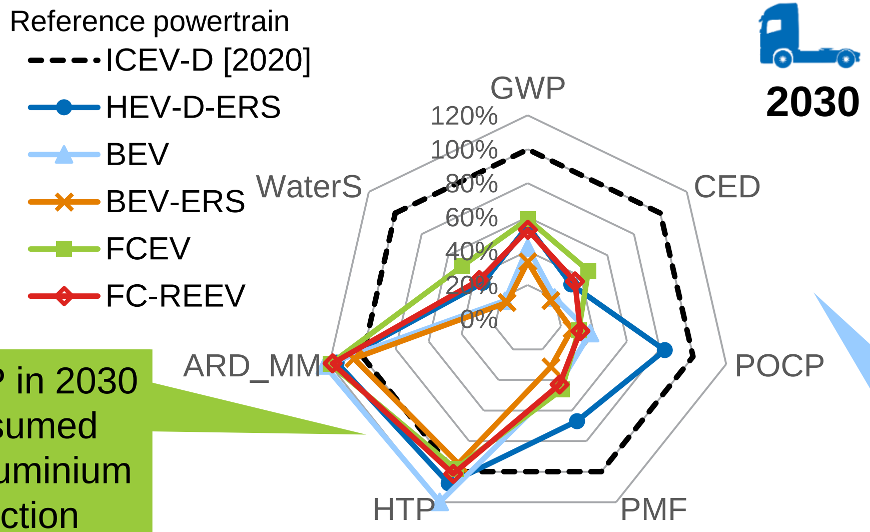
Other lifecycle impacts are also reduced by xEVs relative to powertrains using conventional diesel or e-fuels due to high lifetime activity of HGVs (vs Cars)

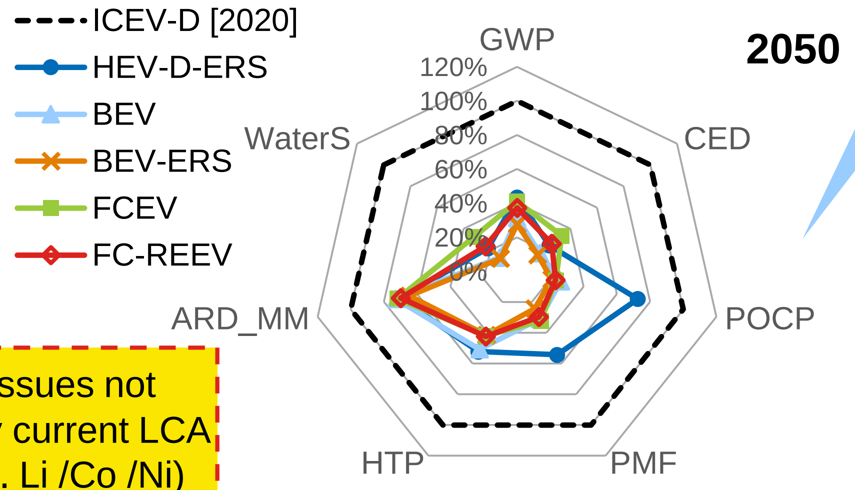
Rigid Lorry 12t GVW, Urban Delivery – Tech1.5 Scenario





Artic Lorry 40t GVW, Long Haul – Tech1.5 Scenario





Higher ARD, HTP in 2030 also due to assumed greater use of Aluminium for mass reduction

Relative trends for other impacts similar order between powertrains as for GWP and CED due to high lifetime km

‼ Certain resource issues not always captured well by current LCA impact categories (e.g. Li /Co /Ni)

Notes: GWP = Global Warming Potential; CED = Cumulative Energy Demand; POCP = Photochemical Ozone Creation Potential, PMF = Particulate Matter Formation; HPT = Human Toxicity Potential; ARD_MM = Abiotic Resource Depletion, minerals and metals; WaterS = Water Scarcity

A sensitivity on the effects of alternative powertrain mass at high %load operation show that impacts per tonne-km are actually increased for xEV powertrains vs av. load

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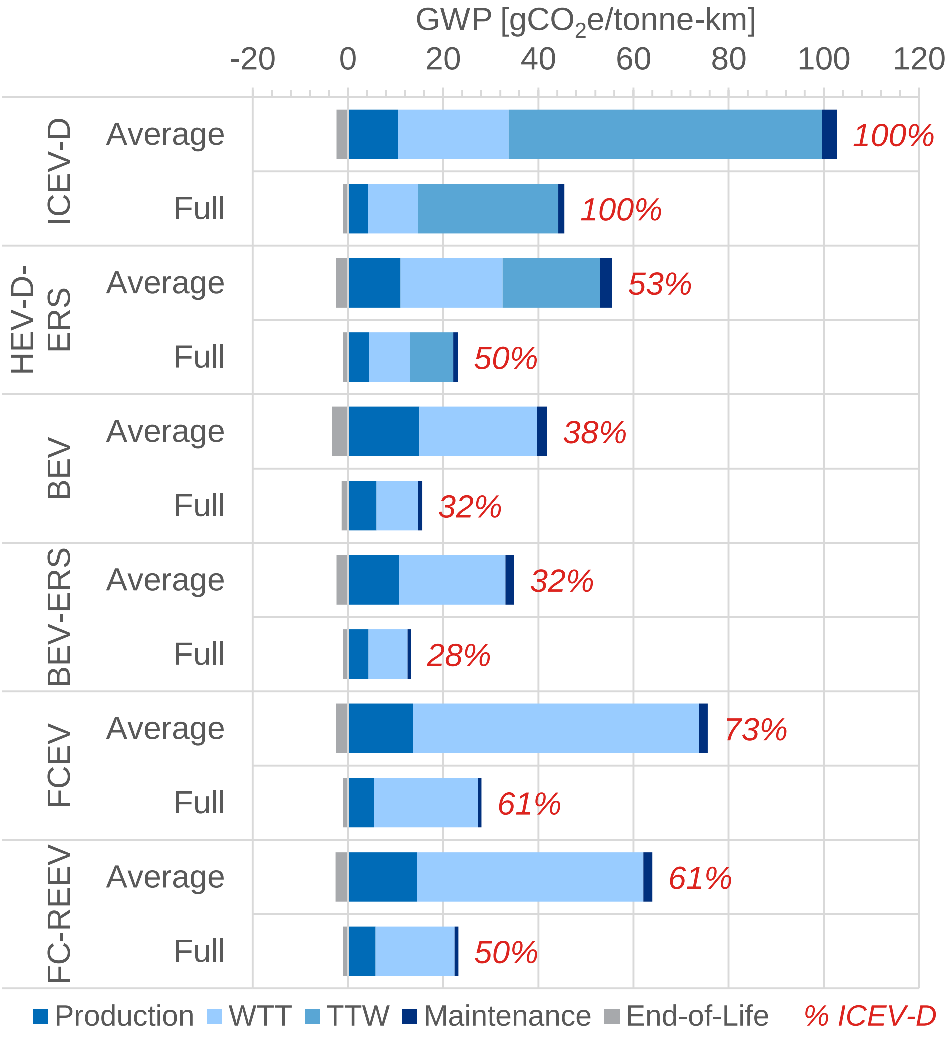
Medium Impact

Artic Lorry, Long Haul – Tech1.5 Scenario, 2030



- Av. Load Factor impacts on MJ/km (heavier vehicles use more energy) and will also have impacts per tonne-km (tkm) of freight carried
- The actual impact on lifetime tonne-km for reduced load capacity for heavier powertrains is uncertain
  - Depends on whether mass or volume-limited (vol. impacts *may* be smaller)
- The analysis suggests that a high load factor may actually *magnify* relative the benefits of xEV per vehicle-km since the WTW energy impacts are a much smaller share of the total
- For tonne-km this effect is counter-balanced to a limited extent for BEV due to the reduced load capacity

Additional information: 800,000km, 10 year lifetime. 2030 BEV battery 958 kWh, 820km range, with av. lifetime EU28 fuel/electricity mix (age-dependant mileage weighted). No battery replacement needed for BEV only.

Summary: What has / can vehicle LCA tell us about the impacts of different ZE HGV powertrain options and circular economy? What are the key challenges for LCA and areas where other complementary approaches are needed?

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Key findings and benefits of vehicle LCA

- \+ Helped to confirm significant GWP benefits for xEVs over other types of powertrain that also increase over time
  - Also helped identify the significance of key uncertainties and assumption via sensitivities
- \+ Highlighted hotspots, e.g. for xEVs due to certain materials through Abiotic Resource Depletion and Human Toxicity Potential
- \+ Cumulative energy demand is much higher for FCEVs than BEVs due to the less efficient end-to-end energy chain (more so for e-fuels)
- \+ EoL methodologies help illustrate the benefits (also for the circular economy) for vehicle recycling and battery 2nd life applications

Challenges for LCA and future improvements

- ! Highly complex; further standardisation / vehicle LCA PCR (product category rules) needed to facilitate comparisons ➲ EU policy?
  - Different methodologies and assumptions can have significant impacts on the result
- ! Resource issues not always captured well by current LCA impact categories (e.g. Li /Co /Ni)
  - Complimentary fleet/system modelling needed to capture resource flows / implications
- ! Uncertainty on future battery recycling / recovery levels and impacts
- ! Improved policy needed on 2nd life batteries, and methodologies for assessing repurposing and 2nd life impact/credits are needed

Questions & Answers

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Thank you!

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