Creating a world
fit for the future

Determining the environmental impacts of conventional and alternatively fuelled vehicles through Life Cycle Assessment

Nikolas Hill, 2020 Annual Meeting of the G20 Transport Task Group, 7 October 2020

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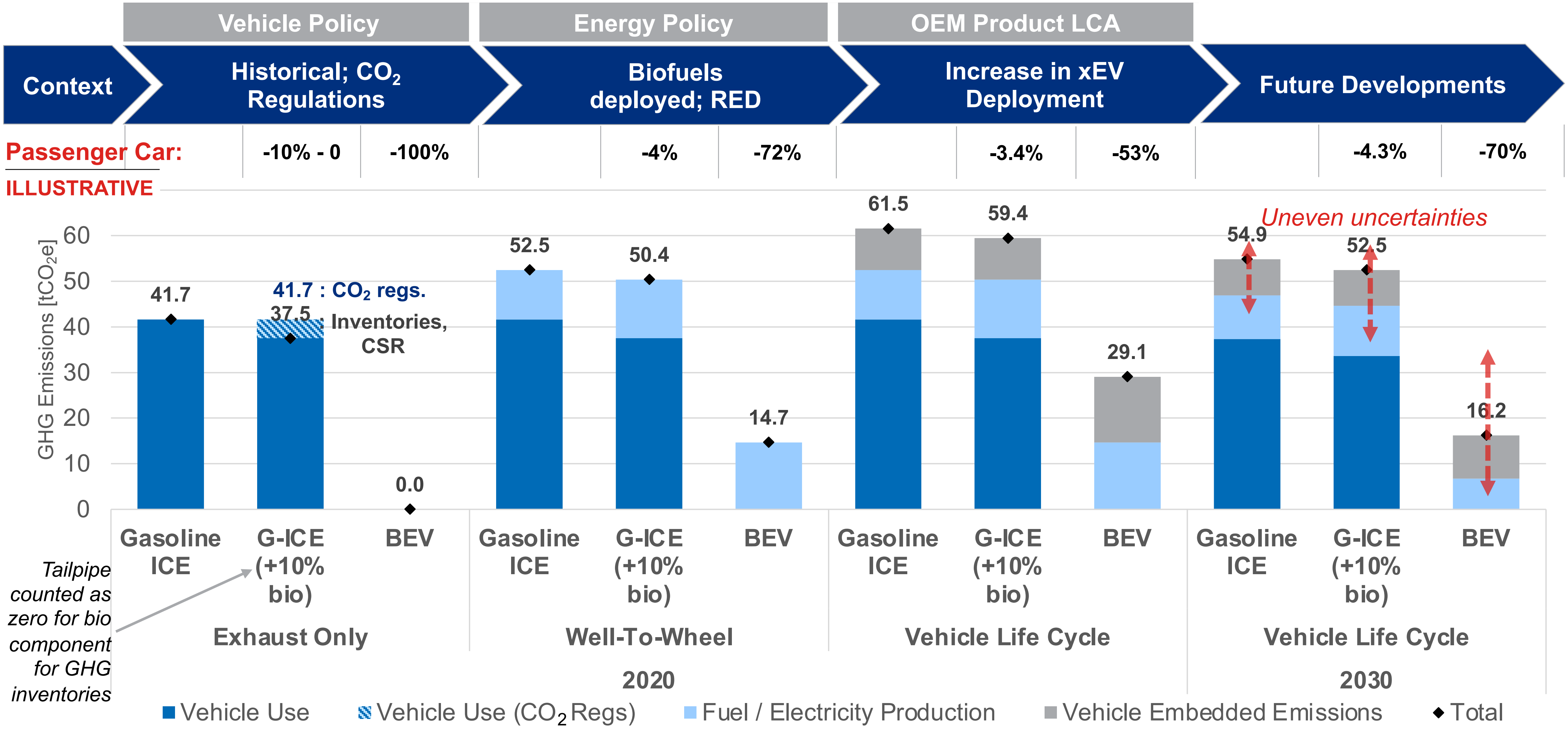
Contents

- Brief introduction to the project
- Unique selling points for the work
- Highlights of the main results
- Future research needs
- Questions & Answers

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 projects for the European Commission provide holistic insights on the impacts of different vehicles, powertrains & fuels and the circular economy

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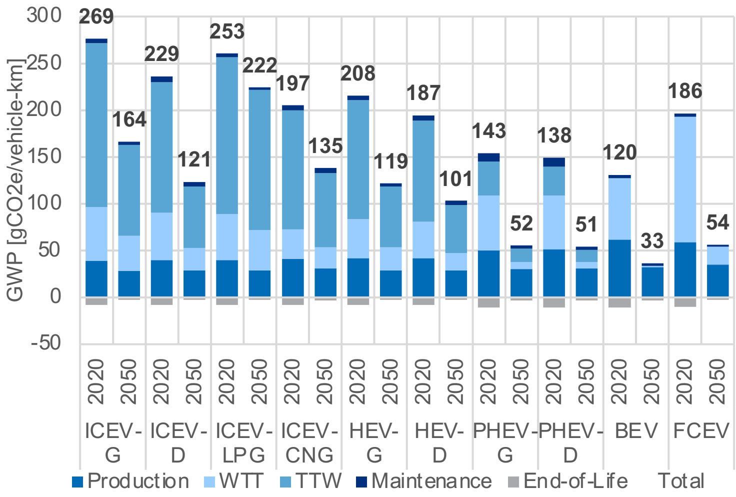

EC DG CLIMA Vehicle Policy LCA project; with E4tech, ifeu:

- Objective to develop and apply LCA methodology across a range of road vehicle types, powertrains and energy chains:
  - Literature review and data collection
  - LCA Methodological Development
  - Application of the LCA methodology to provide results, explore hotspots and key sensitivities to the outcome

Our EC Vehicle Policy LCA project considers environmental impacts over the whole life of the vehicle

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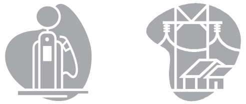
Vehicle Life Cycle

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

Electricity Storage

Vehicle Manuf. Plants

Not in scope

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 selling points and has delivered significant added value compared to existing studies in this area

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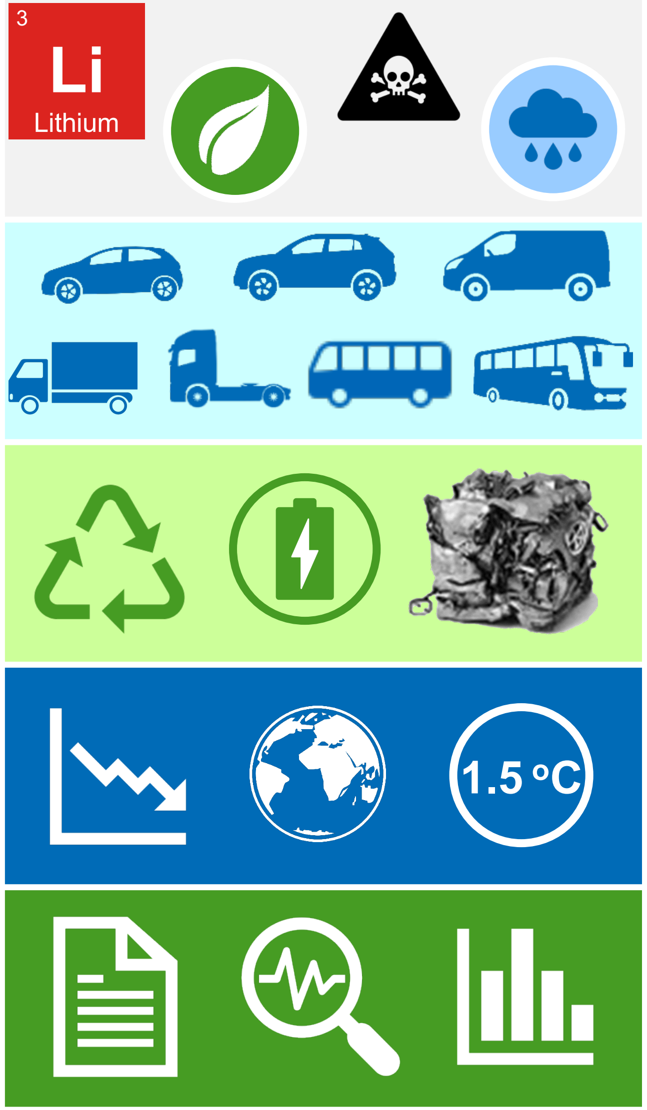
- The project covered a wide range of (14) LCA impact metrics, not just GHG emissions (GWP) and Cumulative Energy Demand (CED)
  (i.e. AP, POCP, ODP, PMF, HTP, FA ETP, IRP, ARD minerals & metals, ARD fossil energy, land use, water scarcity)
- 7 light- and heavy-duty road vehicle types, and different 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 ^{o}C; 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



The EC Vehicle Policy LCA covered many different dimensions – this required a streamlined approach for the development and application of the methodology

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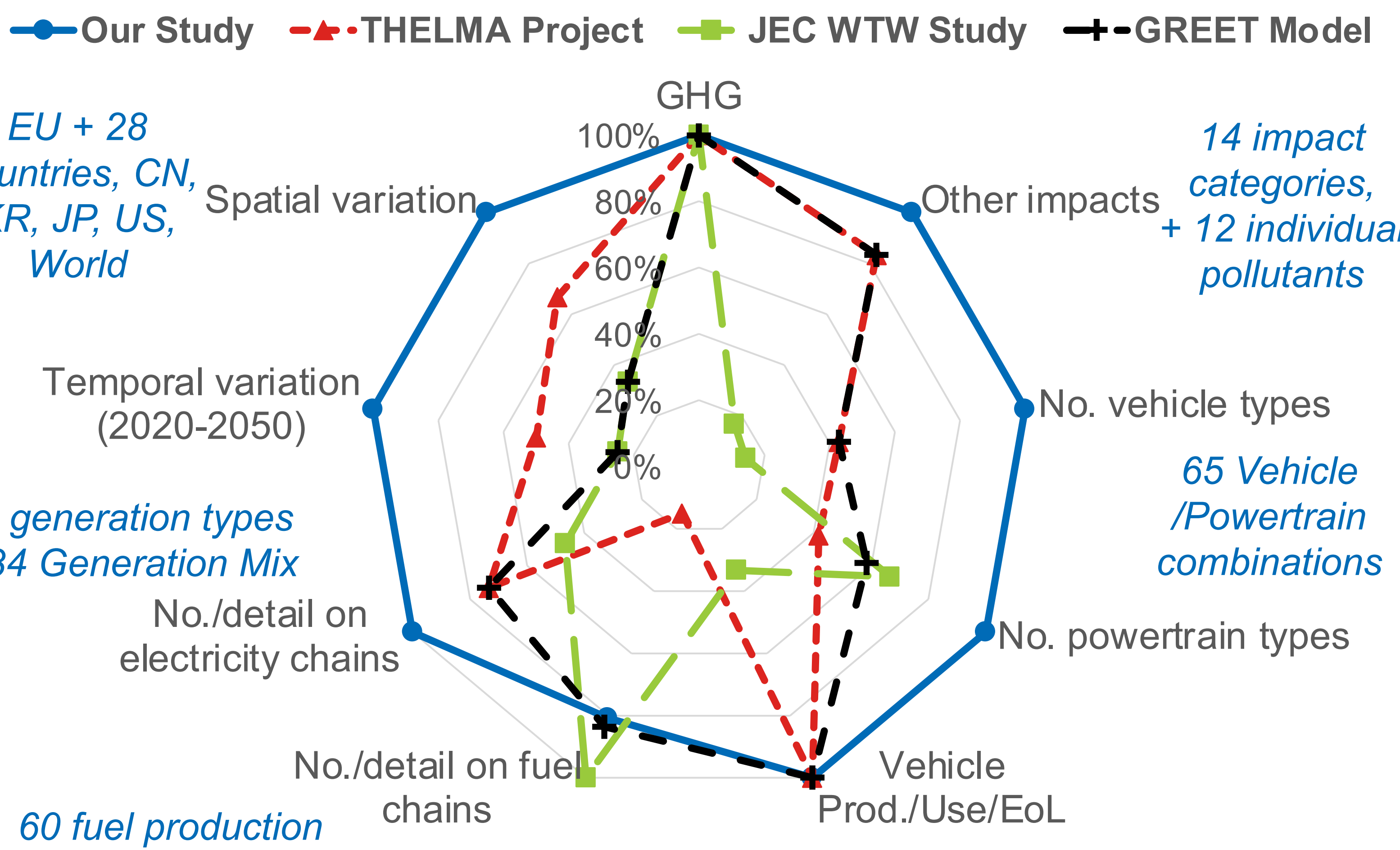
Scope of our study vis-à-vis reference studies



EU + 28 countries, CN, KR, JP, US, World

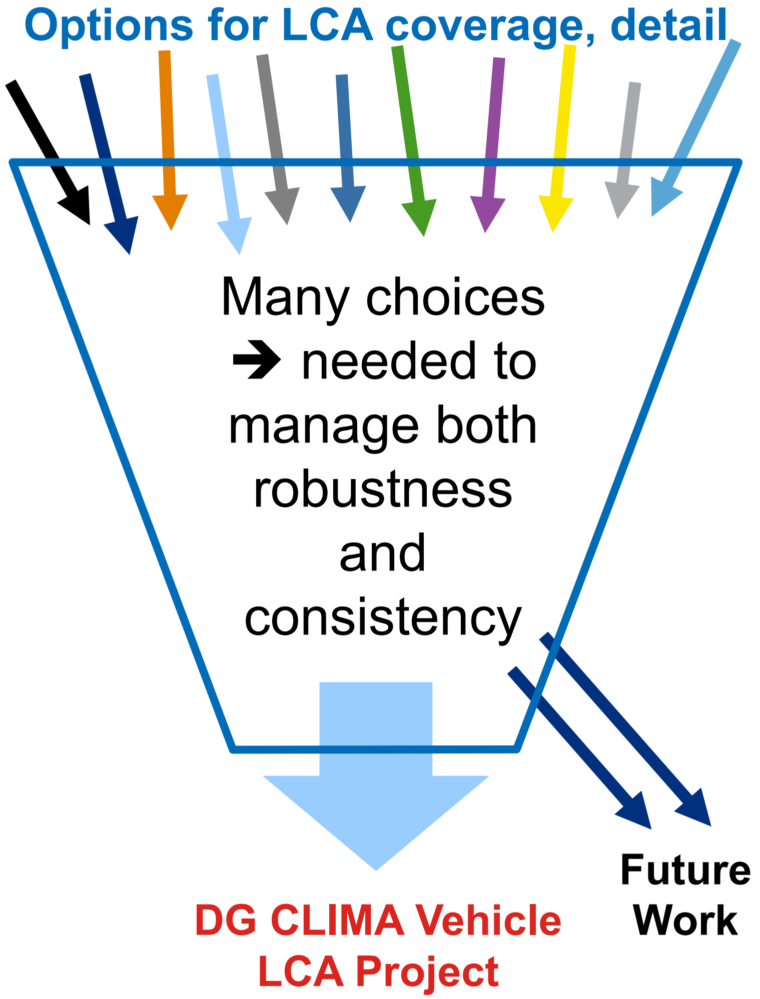
14 impact categories, + 12 individual pollutants

65 Vehicle /Powertrain combinations

14 generation types + 34 Generation Mix

60 fuel production chains + 12 Fuel Blends

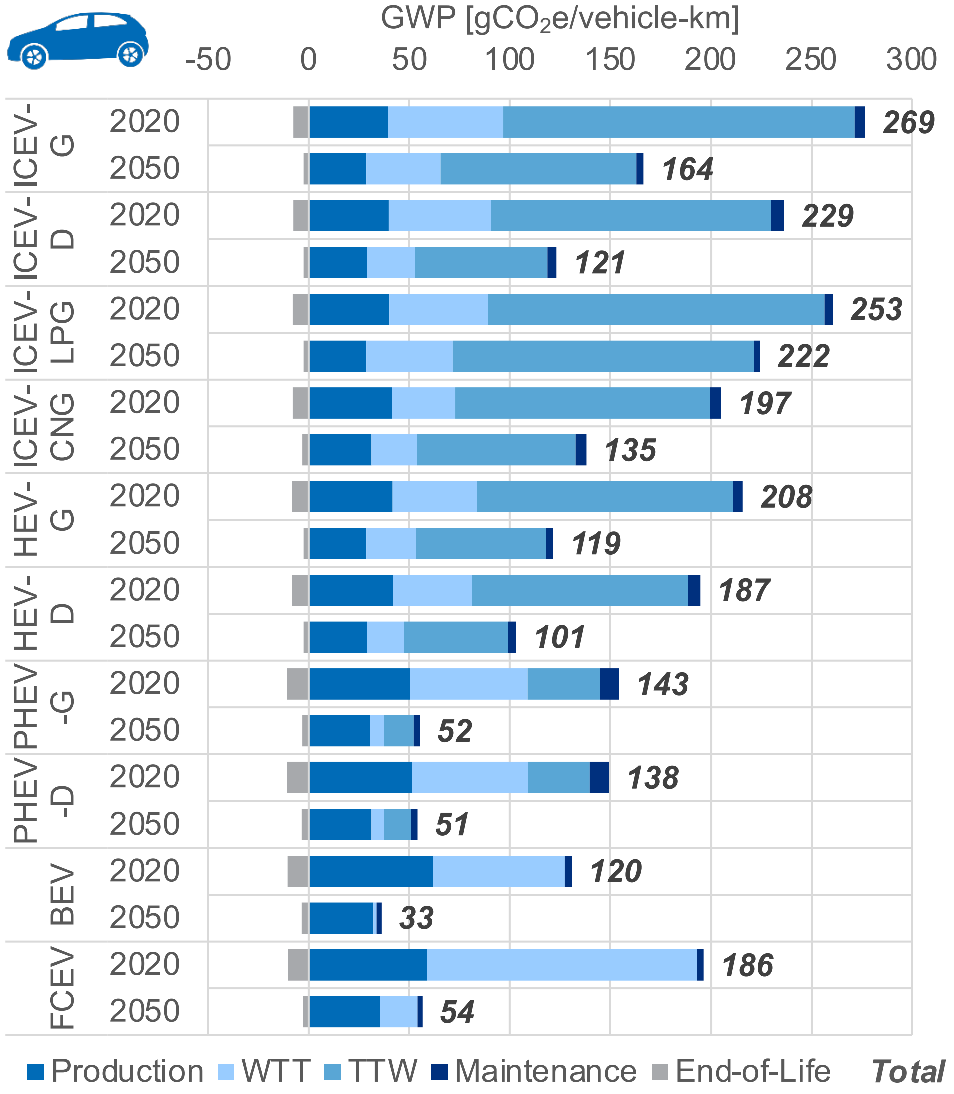
Level of coverage and detail



EC Vehicle Policy LCA results are provided for each impact category, with a wide range of sensitivities – e.g. for Lower Medium Cars (i.e. European Segment C)

Lower Medium Car – Tech1.5 Scenario

1



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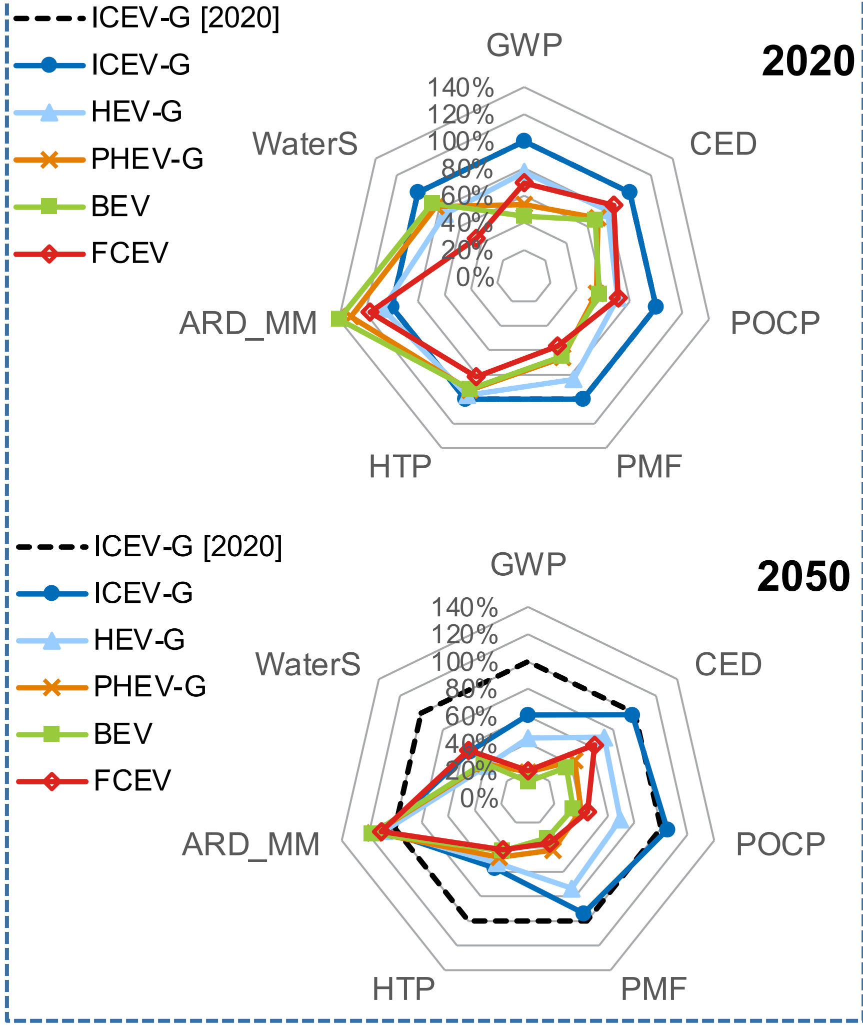


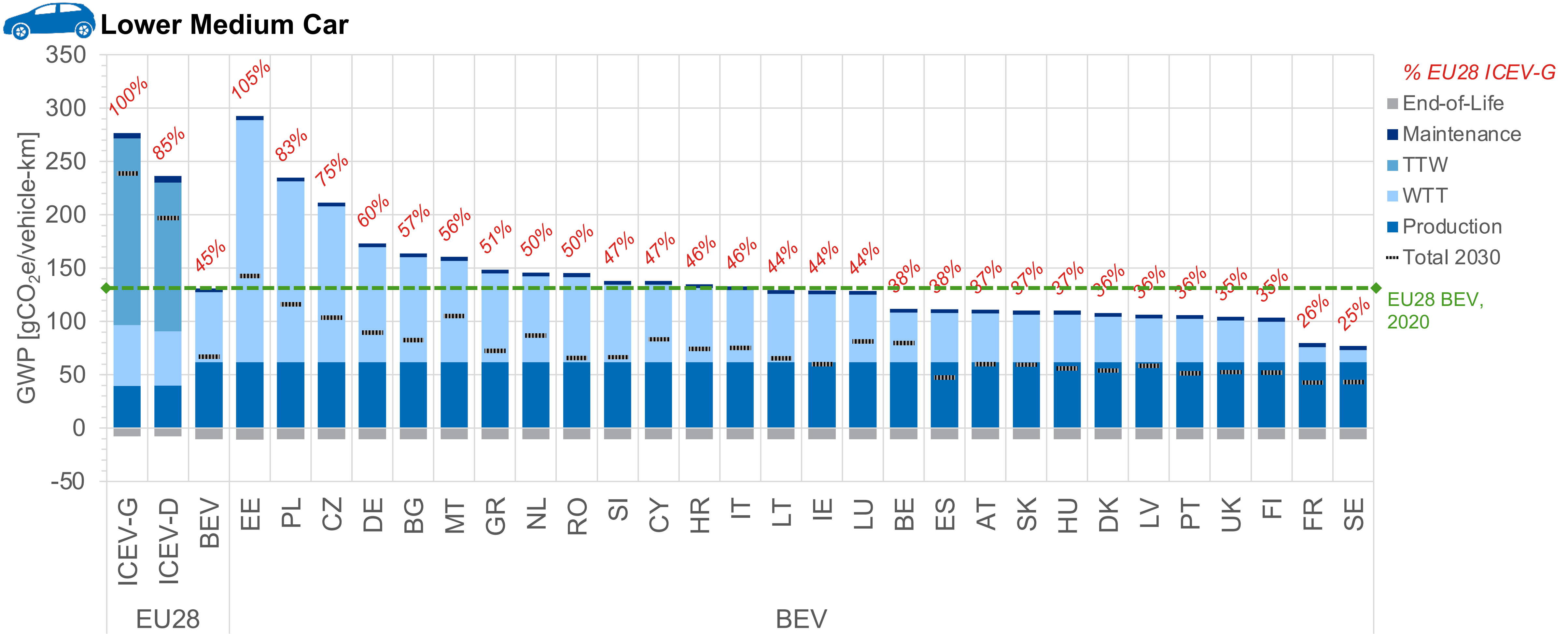
3

	#	Sensitivity	Impact
Operation	1	Regional Variation	High
	2	Lifetime km	Medium
	3	PHEV fuel share	Medium
	4	Loading	Medium
	5	Future ICE air quality plan (AQP)	Low
	6	Ambient temperature	Low
	7	Fuels methodology	Low-Mid
Veh. Spec.	8	Trajectories for glider material composition	Low
	9	Electric range	Low
	10	Battery energy density	Low
Prod. + EoL	11	Battery EU sustainable value chain	Low
	12	Battery 2nd life	Low
	13	Vehicle EU sustainable value chain	Low

Additional information: 225,000km, 15 year lifetime. 2020 BEV battery 57 kWh, 300km range, with av. lifetime EU28 fuel/electricity mix (age-dependant mileage weighted). No battery replacement calculated to be needed for xEVs.

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

Example – Regional variation impacts of comparison of ICEVs vs BEVs shows that in the vast majority of EU countries BEVs already show significant GHG benefits



- Modelled variation in impacts due to ICEV powertrains is much lower (with a range of approx. +-10% of the EU av.), due to a combination of variation in driving shares by road type and temperature variations (other impacts not modelled)

Source: Ricardo LCA modelling, July 2020. Results shown for the lower medium car in the baseline 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 225,000 km over 15 years. 2020 BEV battery has a 58 kWh, a 300km WLTP 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.

Key conclusions and achievements

Ricardo developed a bespoke and flexible LCA framework, which was used to provide results

1. A harmonised/consistent comparison of the environmental performance of vehicles has been developed for all stages of the vehicle life-cycle, with a number of unique aspects and novel approaches implemented
2. Results prove the significant potential benefits of xEVs, whilst highlighting key dependencies and hotspots:
   - Benefits increase with degree of electrification and over time
   - Production and EoL stages responsible for larger share of impacts in xEVs compared to conventional powertrains
   - Benefits vary with EU Member State
3. Results show that natural (and bio-/synthetic-) gas fuelled vehicles can provide significant benefits vs conventional alternatives
4. Conclusions shed light on key areas/factors that determine relative performance of vehicles:
   - Benefits of BEV, PHEV, FCEV significantly enhanced with decarbonised electricity/H_2, battery improvements, EU manuf.
   - Benefits increase with improved process efficiency and generation mix used in the production of key raw materials
   - Potential benefits of improved recycling material recovery rates and shift to lower carbon electricity in recycling processes (EU Circular Economy)
   - Cumulative energy demand BEV << FCEVs << e-fuels due to the less efficient end-to-end energy chain
5. Findings for low carbon fuels are less clear, need further work particularly on low carbon fuel options that are not yet commercially mature (i.e. synthetic bio- and e-fuels)

Recommendations for future work

Area	Methods	Data	Comment
Vehicle Specification			Refine current assumptions based on improved data and/or expand analysis to include other vehicle types
Vehicle / Battery Manufacturing			- Improved characterisation of battery manufacturing, particularly for newer and advanced battery chemistries. - More information / data on efficiency improvements in recent years and on effects of future improvements
Electricity Chains			- Updated input data on future electricity mix projections - Further review and enhancement of underlying datasets
Fuel Chains			- Some methodological areas need further consideration e.g. counterfactual and substitution scenarios, LUC - Development of improved datasets for new processes - particularly for synthetic fuels - Improvements in data/methodological consistency and modelling of additional fuel chains
Vehicle Operation			Further enhancement to methodologies to enable capturing of sensitivities due to other effects such as climatic impacts on energy consumption and emissions for heavy duty vehicle applications (buses and coaches)
Vehicle / Battery End-of-Life			Improved datasets for certain recycled materials; Further research on of end-of-life recycling and battery second life: LCA methodologies and data

Recommendations for future work

Area	Methods	Data	Comment
Refuelling, recharging, and ERS infrastructure (i.e. catenary)	☹	☹	***- Not covered in this study*** - Methodologies and datasets need developing to characterise existing and new infrastructure - Fleet-level modelling/assessment may be needed to appropriately allocate impacts on a vehicle-basis
Other transport infrastructure	☹	☹	***- Not covered in this study*** - Expansion of boundary to also consider other road infrastructure elements
System/Fleet impacts modelling	☹	☹	***- Not covered in this study*** - Complimentary whole vehicle fleet/system modelling is needed to capture resource flows / life-cycle impacts using outputs from this study. In particular, resource issues are not always captured well by current LCA impact categories (e.g. Li /Co /Ni)
Effects of new technologies and trends	☹	☹	***- Not covered in this study*** - Estimation of further operational effects due to new technology or trends: e.g. effects of C-ITS / ITS and autonomous vehicle technologies on (a) production/disposal of new systems added to the vehicle, (b) impacts of infrastructure, (c) impacts on vehicle operational efficiency / emissions

Questions & Answers

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Thank you!

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Additional slides

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Our ambition is to create a world fit for the future,

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

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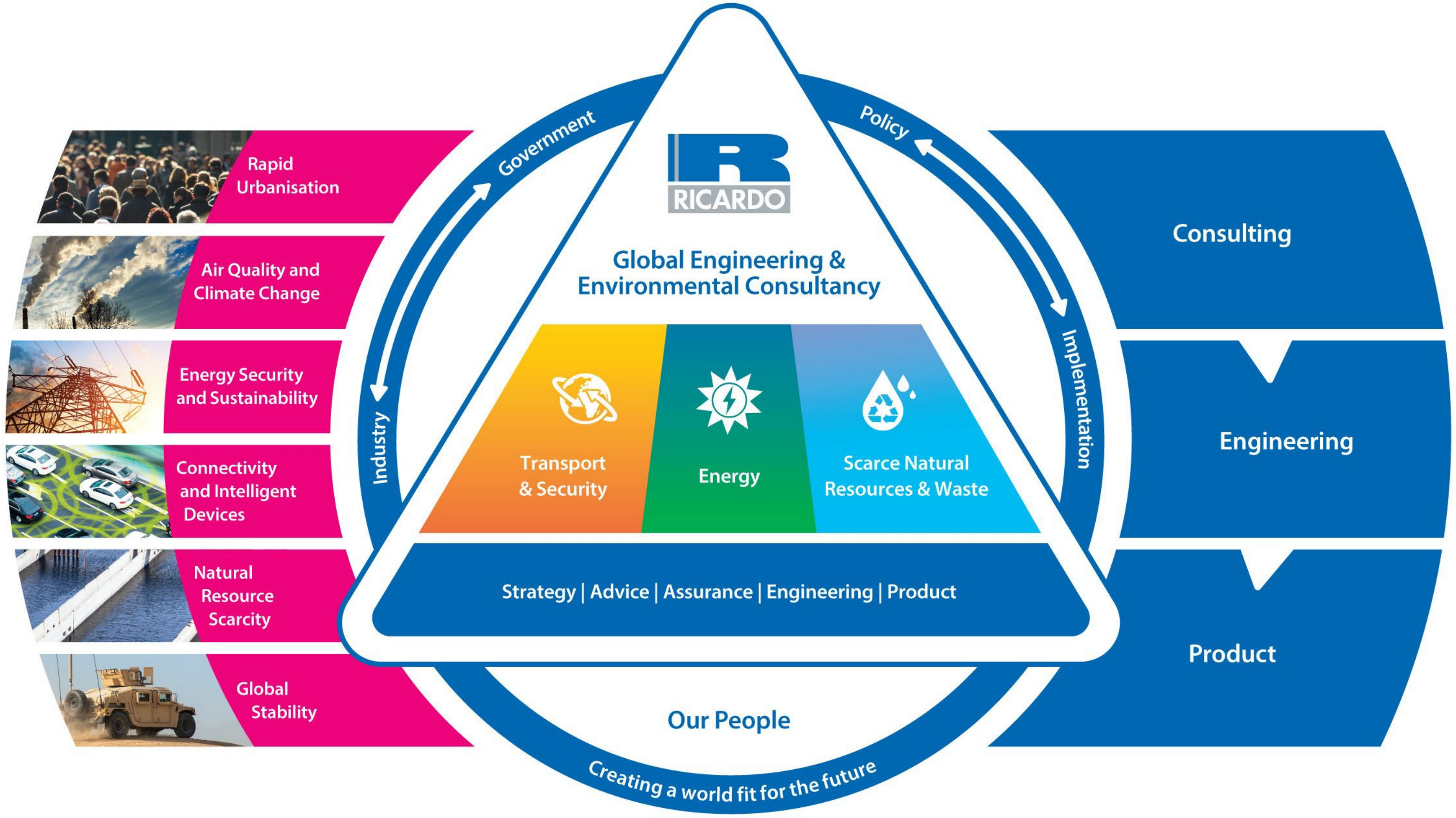
Commercial Vehicles
Defence
Energy & Environment
Motorsport
Motorcycle
Off-Highway Vehicles
Rail



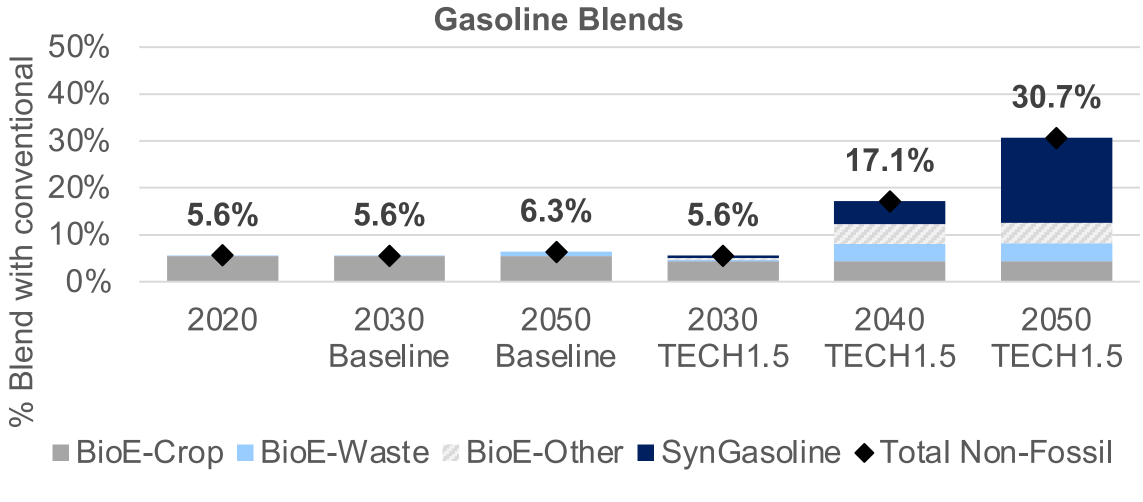
3,000+ staff
88 nationalities
51 sites in **26** countries

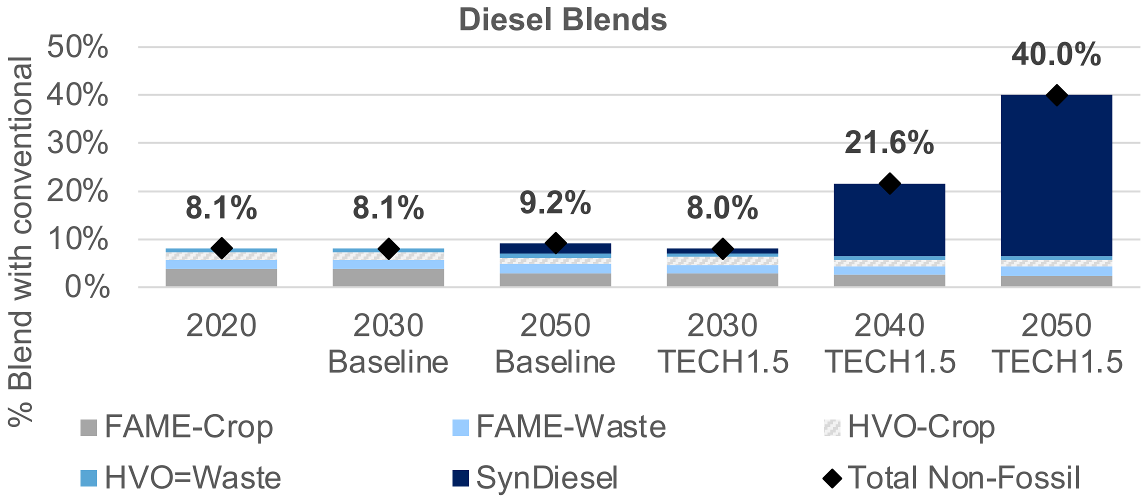
A modular approach was used to define/characterise generic vehicles and to estimate changes 2020-2050 for a wide range of vehicle types and powertrains

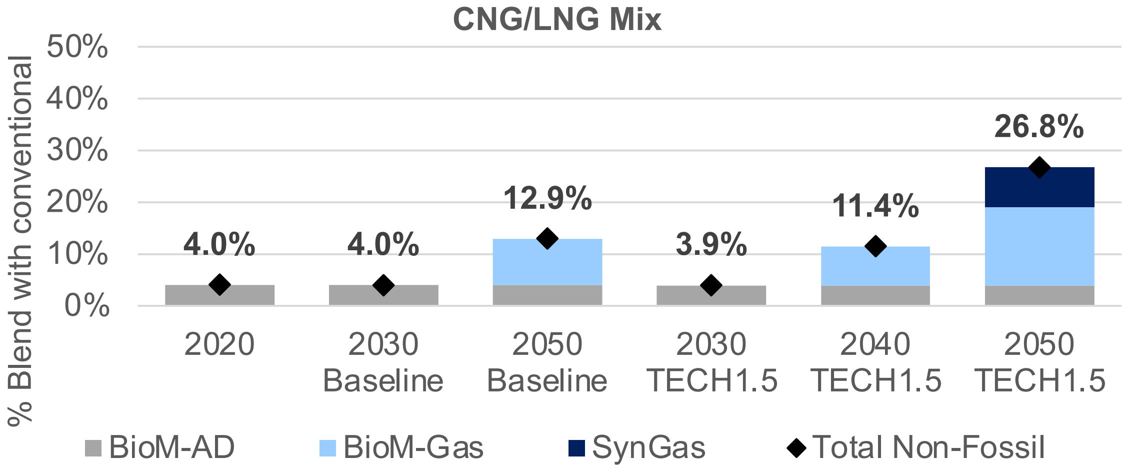
Body type:	Passenger Car	Van	Rigid Lorry	Articulated Lorry	Urban Bus	Coach
Segment/Class:	1. Lower Medium; 2. Large SUV *	N1 Class III (3.5 t GVW)	12 t GVW, Box Body	40 t GVW, Box Trailer	Full Size (12m) Single Deck	Typical Single-Deck, 24 t GVW
Gasoline ICEV	Y	Y				
Diesel ICEV	Y	Y	Y	Y	Y	Y
CNG ICEV ***	Y	Y	Y		Y	Y
LPG ICEV	Y	Y				
LNG ICEV ***			Y	Y	Y	Y
Gasoline HEV	Y	Y				
Diesel HEV	Y	Y	Y	Y	Y	Y
Gasoline PHEV	Y	Y				
Diesel PHEV	Y	Y	Y	Y	Y	Y
BEV	Y	Y	Y	Y	Y	Y
FCEV	Y	Y	Y	Y	Y	Y
FC-REEV			Y	Y		Y
Diesel HEV-ERS				Y		
BEV-ERS				Y	Y**	

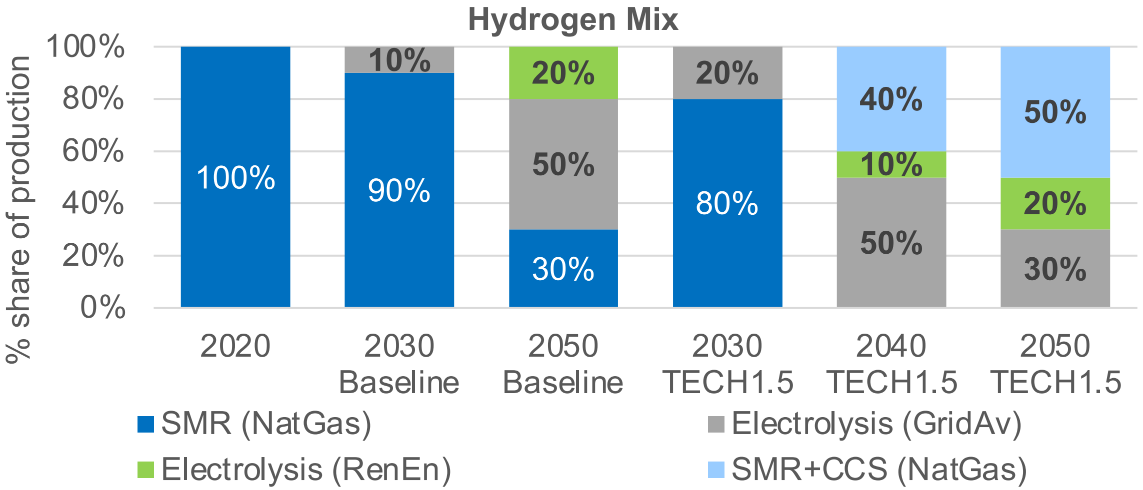
Note: * Based on EU registrations-weighted averages for: Lower Medium = defined as segment C vehicles (e.g. VW Golf) and medium SUVs (e.g. Nissan Qashqai); Large SUV = Large SUVs / Crossovers (e.g. BMW X5, Land Rover Range Rover, Volkswagen Touareg, Volvo XC90, etc.). **Urban bus using regular ultra-rapid charging via a pantograph connection at stops along its route, enabling a significantly smaller on-board battery. Not a trolleybus. *** Modelled with two variants each: -CNG and -CNG lean-burn; -LNG and -LNG/Diesel HPDI.

EU fuel blend/production mix assumptions used in the overall Vehicle LCA modelling, as a percentage of the total including conventional fossil fuels







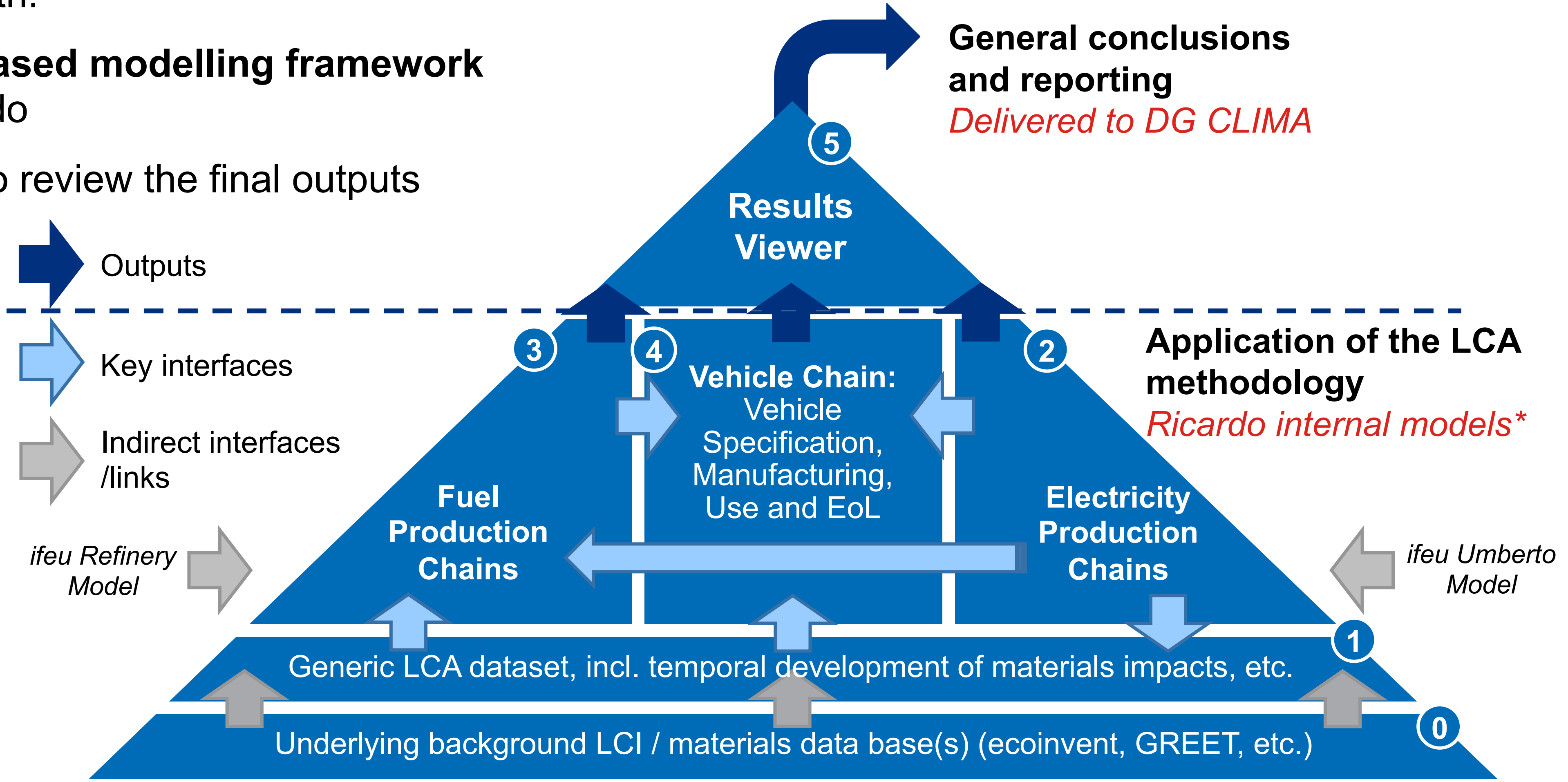


Source: The blend/mix of fuel production chains assumed are only indicative as these were limited by the subset of the currently available fuels that have been modelled as part of this project. BioE = bioethanol, BioM-AD = biomethane from anaerobic digestion process chains, BioM-Gas = biomethane from gasification process chains, SynGasoline / SynDiesel includes e-fuel / PtX chains as well as biomass-to-liquid (BtL) chains.

The EC Vehicle Policy LCA project methodology was applied in a modular framework developed by Ricardo to generate results and conclusions for the project:

The methodology has been implemented in our bespoke Vehicle LCA Model, with:

- A **Modular Excel-based modelling framework** developed by Ricardo
- A **Results Viewer** to review the final outputs



Summary: What has / can vehicle LCA tell us about the impacts of different vehicles / powertrains / fuels, 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