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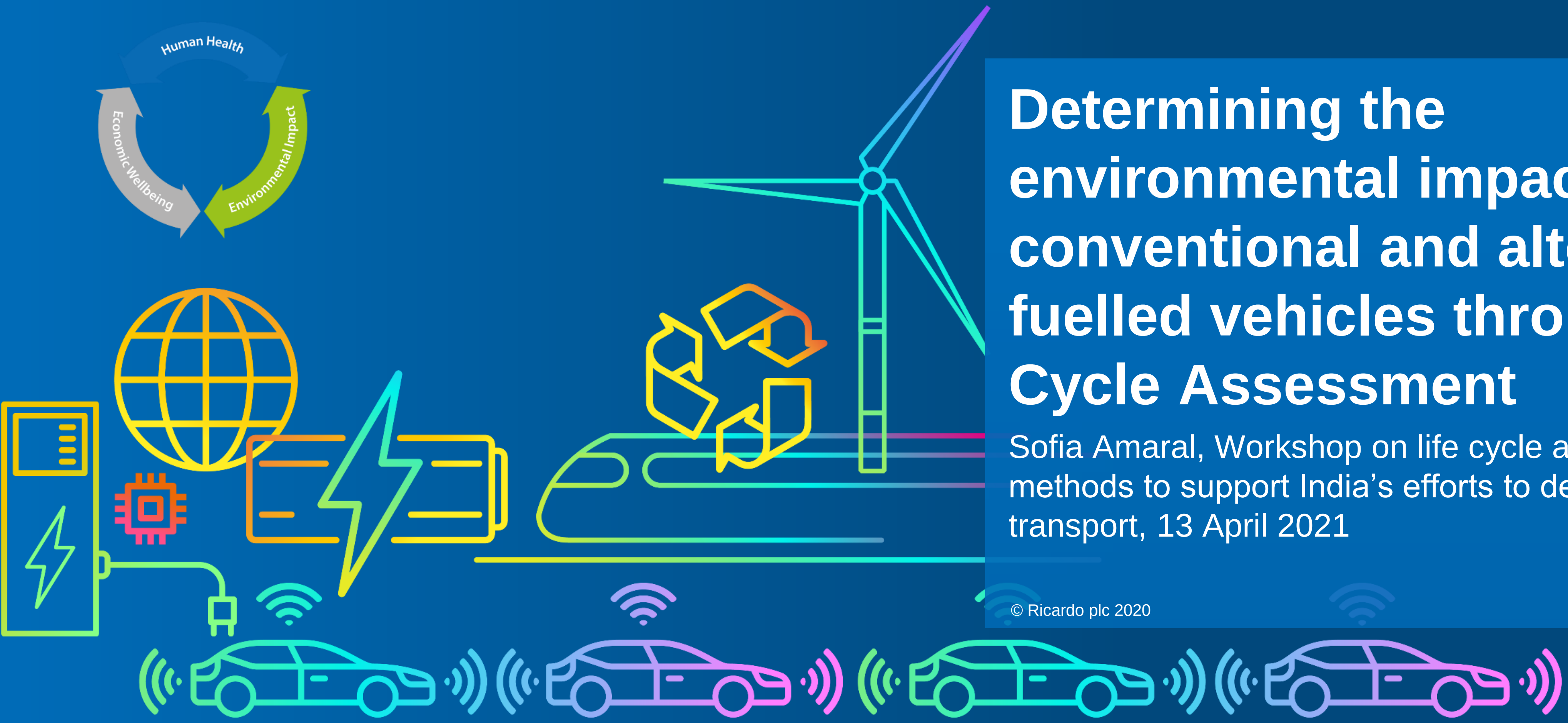


Determining the environmental impacts of conventional and alternatively fuelled vehicles through Life Cycle Assessment

Sofia Amaral, Workshop on life cycle assessment methods to support India's efforts to decarbonise transport, 13 April 2021

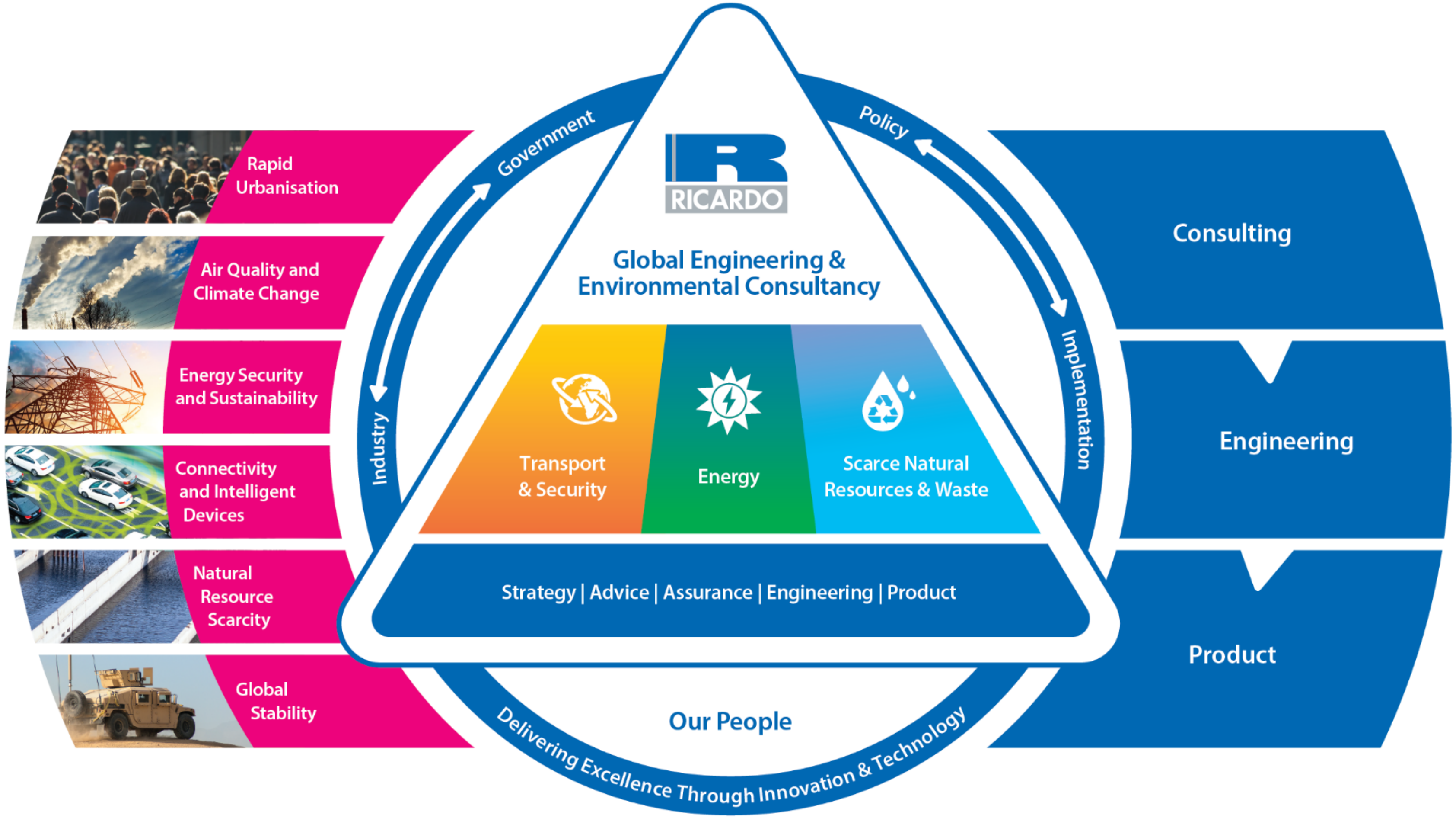
www.ricardo.com

Contents

- Brief introduction
- Why are we interested in LCA?
- The Ricardo project for the European Commission:
  - What is the scope?
  - What approaches have we applied?
  - What are the key results and conclusions?

Ricardo is a Global Engineering & Environmental Consultancy with over 3000 employees: engineers, scientists and consultants in all major regions

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



Ricardo has performed LCA studies on an extremely wide range of products

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SELECTED EXAMPLES

The entire portfolio of Green Investment Group projects

Using ammonia as an energy storage vector

New powertrains for Dutch region's rolling stock

The by-products from whisky production

Railway cable troughs made from recycled plastic

Rolling stock for Thailand

Making jet fuel from waste materials

Light-weighting a Dutch passenger train

Carpet tiles

Hybrid vs diesel powertrains for buses

The McLaren P2 engine

High thermal-efficiency wall cladding fixture

A timber building I-joist

A high-speed train

Alternative truck engine designs

Water footprint of a brick

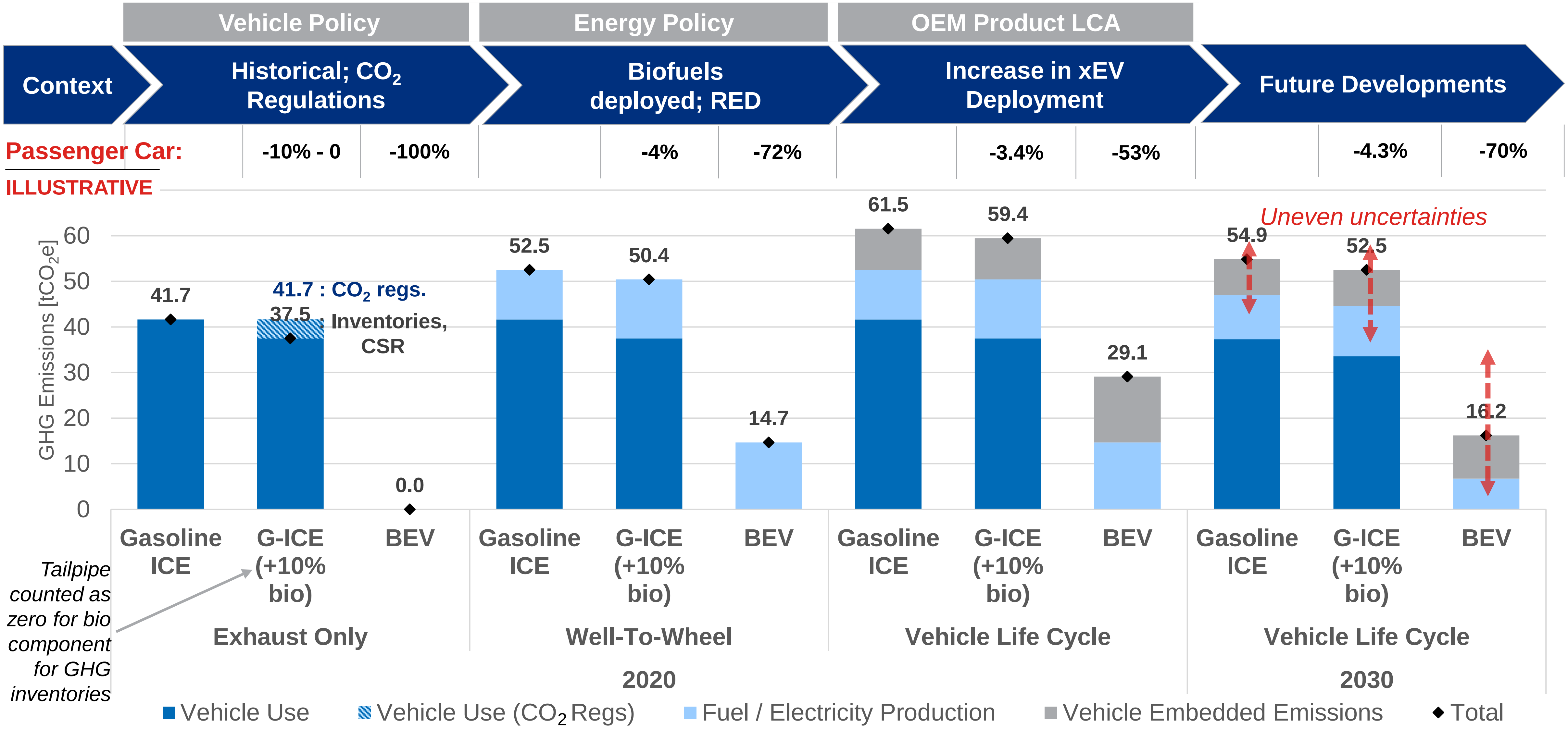
Design choices for in-line printers and their inks

Electric aircraft

The European Green Deal will transform the EU into a modern, resource efficient and competitive economy

Source: European Commission

Interest in and relevance of LCA has been building over the years driven by changes in the regulatory environment and uptake of new fuels/powertrains



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 project for the European Commission (EC) provided holistic insights on the impacts of different vehicles, powertrains & fuels and the circular economy

Vehicle Policy LCA project led by Ricardo with E4tech, ifeu for DG CLIMA (EC):

- 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
- Focus is on **LCA for policy-making/strategy**

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

Vehicle Life Cycle

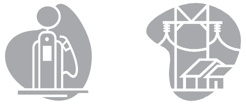
Not in scope

Electricity Storage

Vehicle Manuf. Plants

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

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

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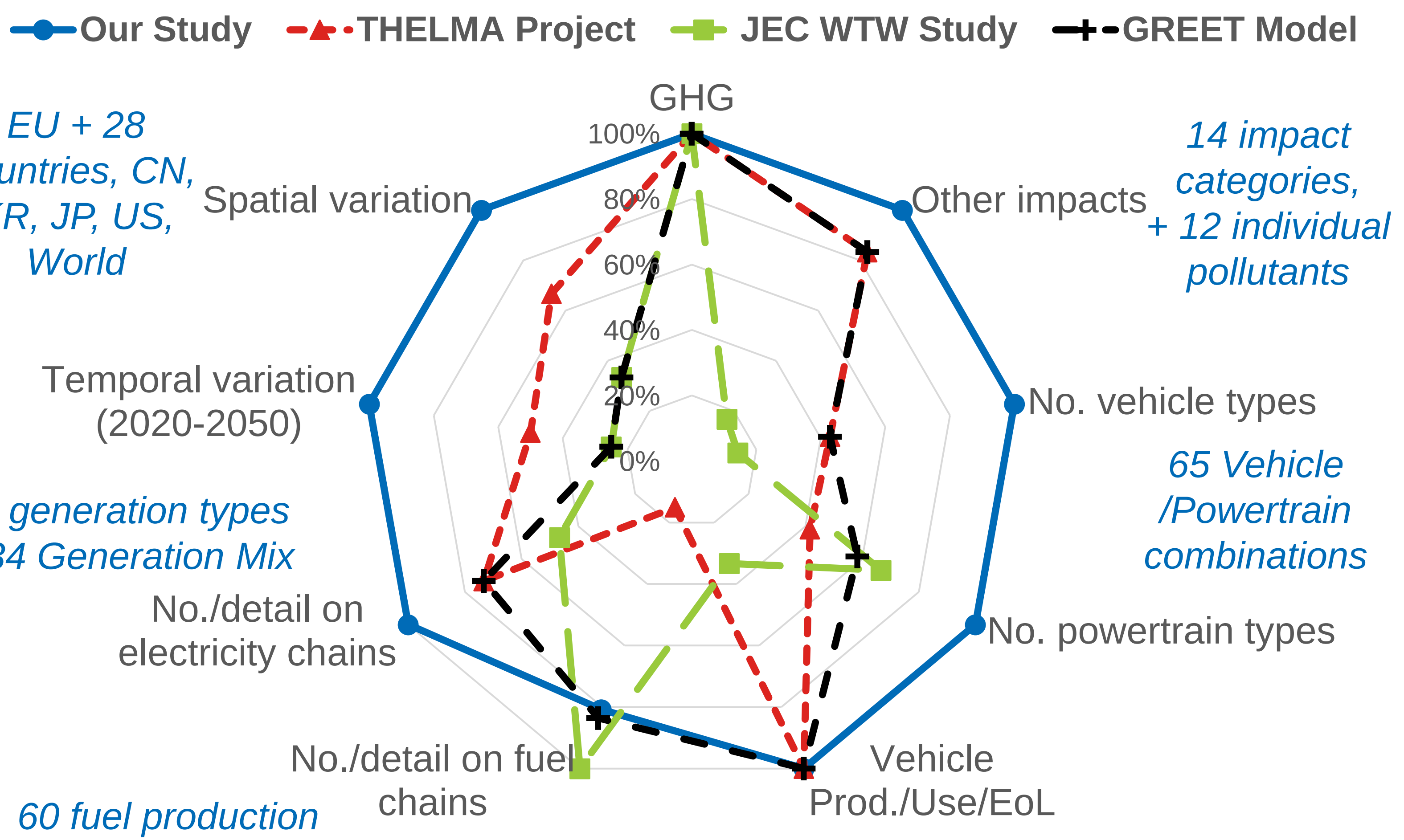
Scope of our study vis-à-vis reference studies

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

14 generation types + 34 Generation Mix

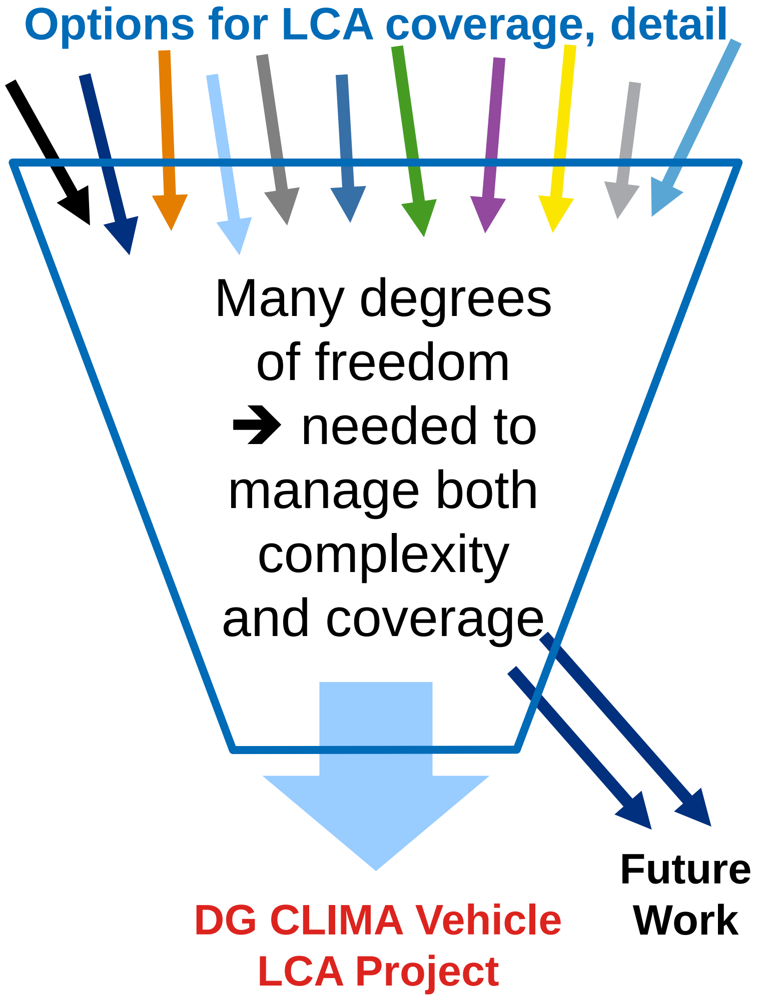
60 fuel production chains + 12 Fuel Blends



14 impact categories, + 12 individual pollutants

65 Vehicle /Powertrain combinations

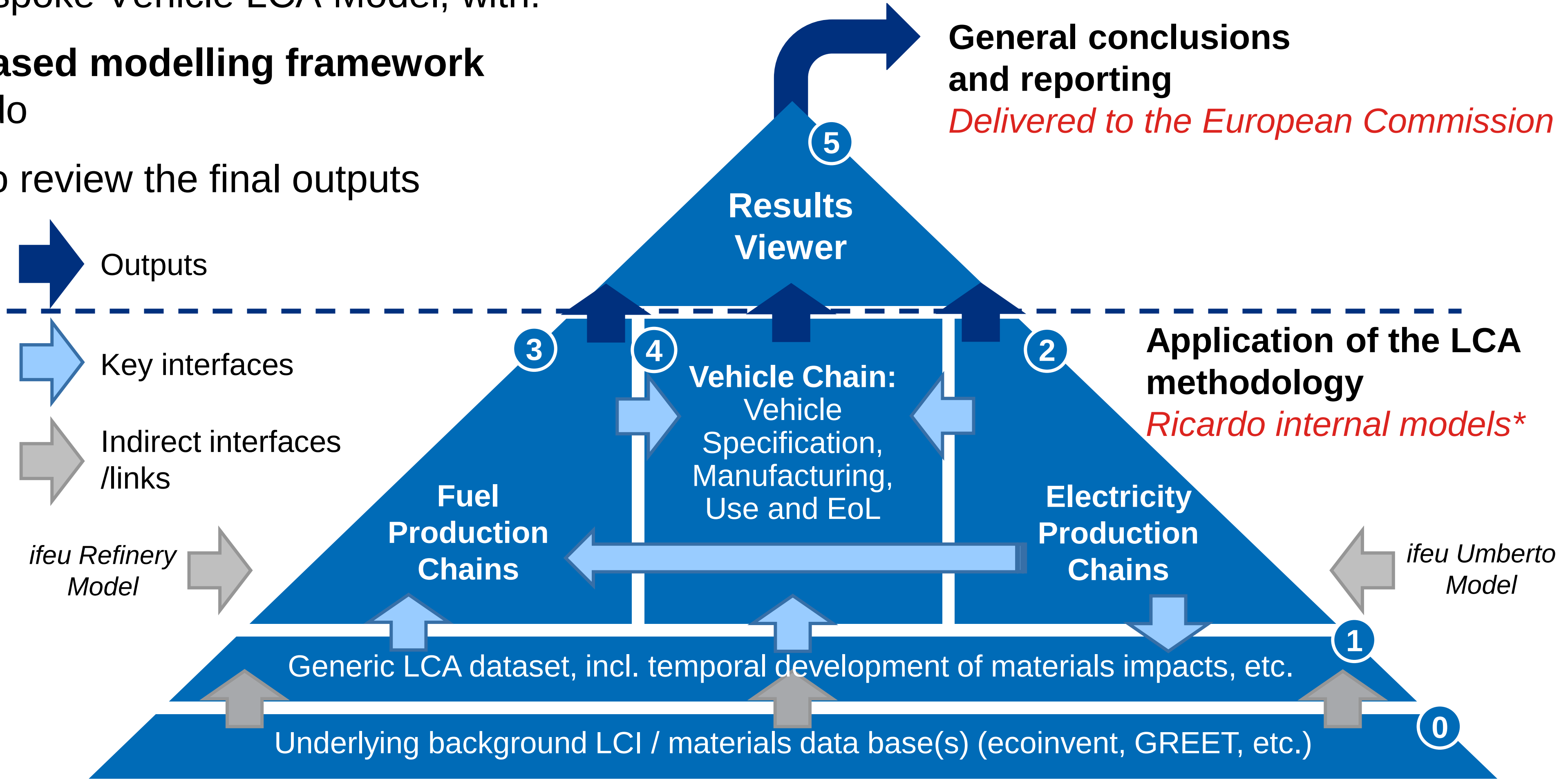
Level of coverage and detail



The Ricardo Lifecycle Protocol (RLP) was applied in a modular framework developed by Ricardo to generate results and conclusions for the project:

The **Ricardo Lifecycle Protocol (RLP)** 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



The 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

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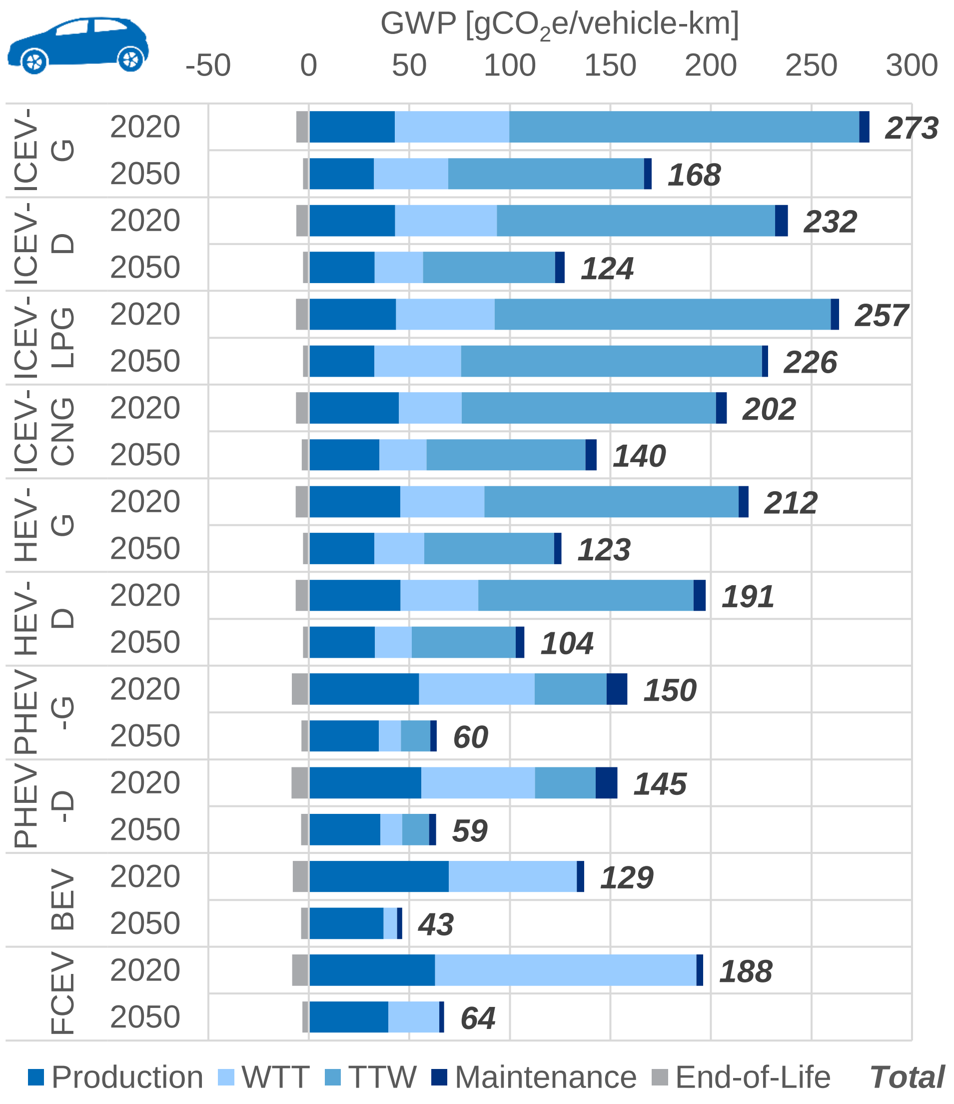

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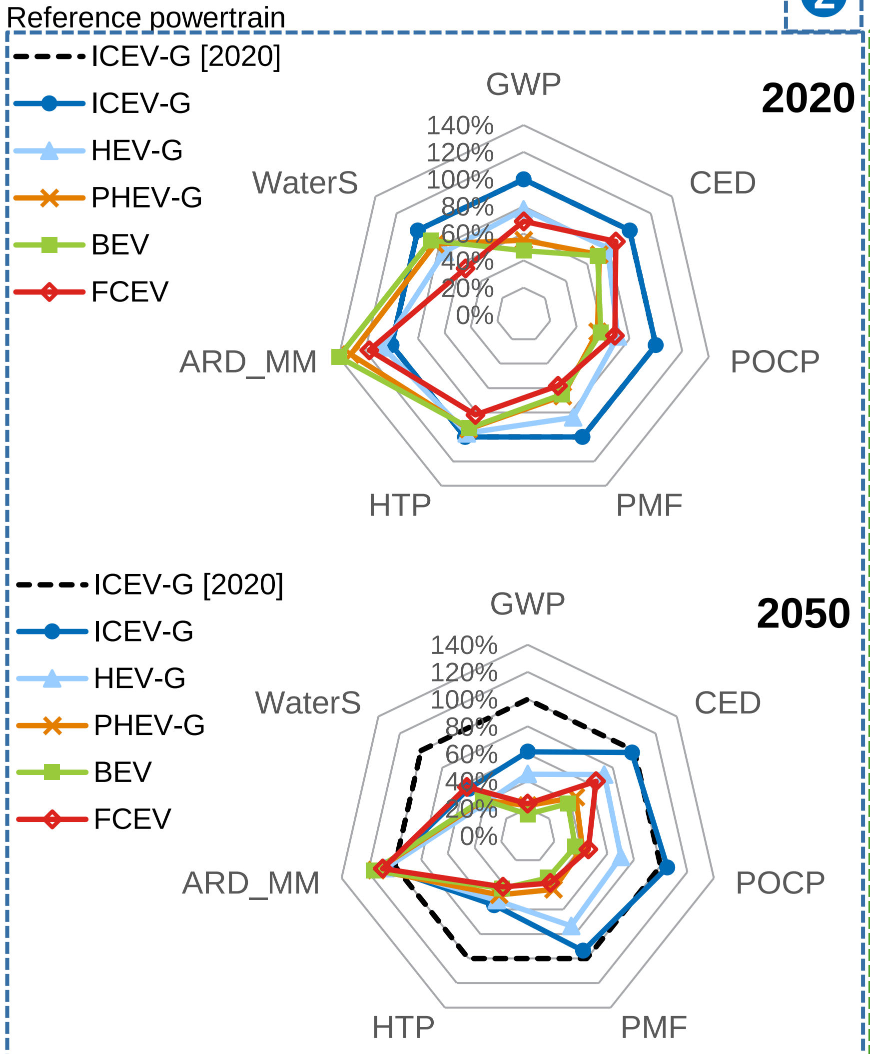

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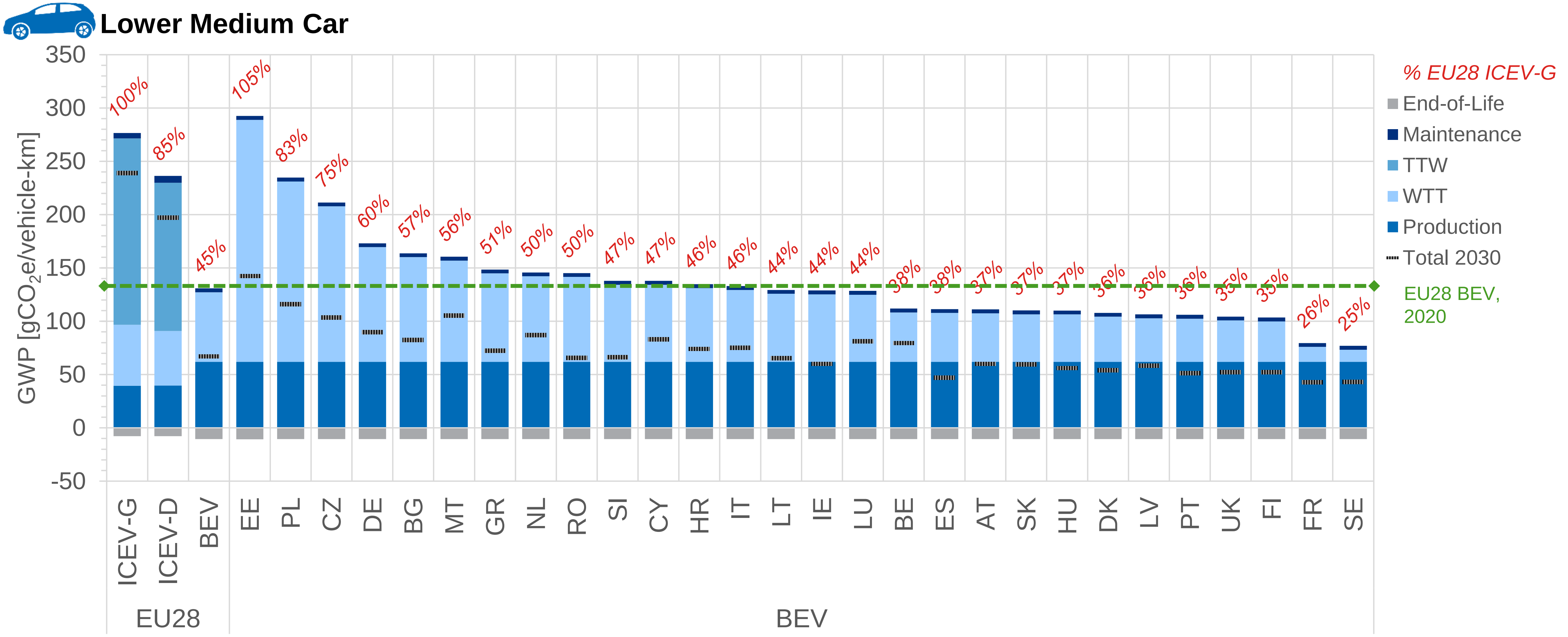
		Sensitivity	Impact
Operation	1	Regional Variation	High
Operation	2	Lifetime km	Medium
Operation	3	PHEV fuel share	Medium
Operation	4	Loading	Medium
Operation	5	Future ICE air quality plan (AQP)	Low
Operation	6	Ambient temperature	Low
Operation	7	Fuels methodology	Low-Mid
Veh. Spec.	8	Trajectories for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

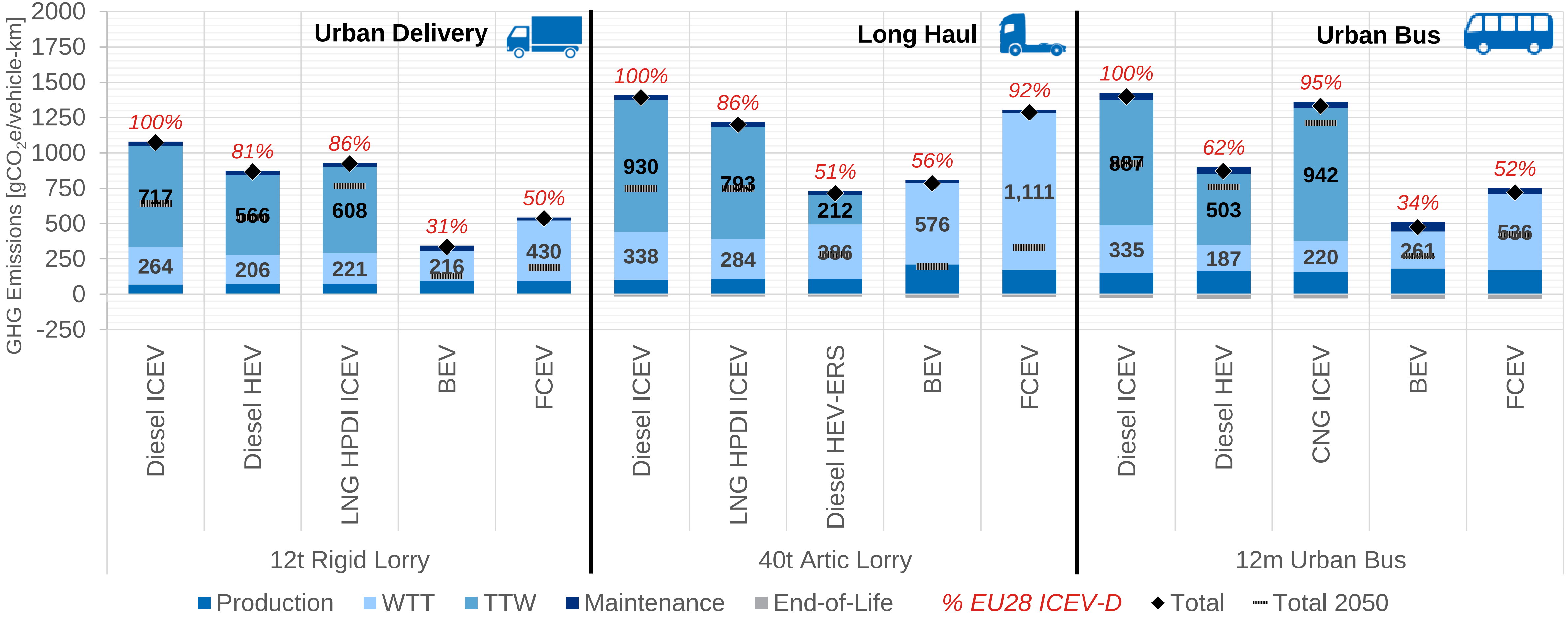
Example – Regional variation impacts of comparison of ICEVs vs BEVs shows that in the vast majority of EU countries BEVs already show significant GHG benefits



Source: Ricardo LCA modelling, June 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.

Similar trends are seen for HDVs as for passenger cars, even when accounting for lost load capacity (which particularly reduces benefits for Artic BEVs in 2020). BEVs have lowest GHG from 2030 for all HDVs

EU Av. for EC “Tech1.5” Scenario (2020 breakdown; 2050 total)



- **Rigid / Artic / Bus**: Lifetime **570,000 / 800,000 / 675,000** km. BEV electric range **200 / 500 / 250** km in 2020, **350 / 1500 / 400** km in 2050
- GHG from fuel/electricity consumption is based on the average fuel/grid electricity factor over **12 / 10 / 15** year vehicle life

Source: Ricardo vehicle LCA analysis, June 2020

What has / can vehicle LCA tell us about the impacts of different 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
+ 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 Fuel Cell Electric Vehicles (FCEVs) than Battery Electric Vehicles (BEVs) due to the less efficient end-to-end energy chain
+ 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
  - 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

Thank you!

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