

End-of-Life Impact on the Cradle-to-Grave LCA of Light-Duty Commercial Vehicles in Europe

Antonella Accardo ^{1,*}, Giovanni Dotelli ², Federico Miretti ¹, and Ezio Spessa ¹

¹ Dipartimento Energia “Galileo Ferraris”, CARS@Polito, Politecnico di Torino, c.so Duca Degli Abruzzi 24, 10129 Torino, Italy; federico.miretti@polito.it (F.M.); ezio.spessa@polito.it (E.S.)

² Dipartimento di Chimica, Materiali e Ingegneria Chimica “Giulio Natta”, Politecnico di Milano, p.zza Leonardo da Vinci 32, 20133 Milano, Italy; giovanni.dotelli@polimi.it

* Correspondence: antonella.accardo@polito.it

Abstract: A cradle-to-grave life cycle assessment focused on end-of-life (EoL) was conducted in this study for three configurations of a light-duty commercial vehicle (LDCV): diesel, compressed natural gas (CNG), and battery electric vehicle (BEV). The aim is to investigate the impact of recycling under two EoL scenarios with different allocation methods. The first is based on the traditional avoided burden method, while the second is based on the circular footprint formula (CFF) developed by the European Commission. For each configuration, a detailed multilevel waste management scheme was developed in compliance with the 2000/53/CE directive and ISO22628 standard. The results showed that the global warming potential (GWP) impact under the CFF method is significantly greater when compared to the avoided burden method because of the A-parameter, which allocates the burdens and benefits between the two connected product systems. Furthermore, in all configurations and scenarios, the benefits due to the avoided production of virgin materials compensate for the recycling burdens within GWP impact. The main drivers of GWP reduction are steel recycling for all of the considered LDCVs, platinum, palladium, and rhodium recycling for the diesel and CNG configurations, and Li-ion battery recycling for the BEV configuration. Finally, the EoL stage significantly reduces the environmental impact of those categories other than GWP.

Keywords: waste management treatment of vehicles; end-of-life (EoL) of vehicles; life cycle assessment (LCA); light duty commercial vehicles; avoided burden approach; circular footprint formula; ELVS

Table S1 Compositions of the ELVs

Materials/Components	DIE-ICEV (kg)	CNG-ICEV (kg)	BEV (kg)
Steel	1720	1724	1471
Light alloys (e.g., Aluminium, Magnesium)	21	8	48
Heavy metals (e.g., Copper, Zinc, Lead, Nickel)	40	34	74
Other metals (e.g., Tin, Silver, Gold)	0.2	0.1	0.4
Polymers (e.g., Thermoplastics, Elastomers, Polyester, Polyurethane)	227	205	302
Textiles and organic materials	11	8	12
Glass	66	65	50
Other materials and material compounds (e.g., Brass)	4.7	4.8	38
Electronics	1.8	2.3	15.6
Fuels and auxiliary means	7.7	7.7	7.8
Components (e.g., Steering wheel, Sensors, Engine, Electric Motor)	564	750	245
Lead acid battery	22	22	22

Exhaust components (DOC/DPF, sensors, Three-way catalyst)	14.8	14.3	0
Electric powertrain (w/o battery)	0	0	137
Li-ion NMC111 battery	0	0	452
Total	2700	2845	2876

Table S2 Assumed fates

Depollution		
Air bags	Reused	No Ecoinvent recycling pathway available so it was assumed to be reused
Oils	Involved in clinker production	From Ecoinvent
Fuels	Reused	
Other fluids (e.g., brake fluid, coolant)	Reused	No Ecoinvent recycling pathway available so it was assumed to be reused
Water	Wastewater treatment	From Ecoinvent.
Li-ion NMC battery	Treatment of the Li-ion NMC battery	Details in [45].
Lead Acid Battery	Treatment of scrap Lead in Lead acid battery	95% recycled (from Annex C PEF e-mobility batteries), 5% landfilled.
CNG tanks	Treatment of metal components	64% recycled, 36% reused (From [48]).
Dismantling		
30% of the total amount of plastics	Treatment of plastics and elastomers	86% recycled, 9% reused, 5% landfilled
Electric and Electronic equipment	Treatment of electric and electronic equipment	Manual dismantled, 87% recycled and 13% landfilled.
Steel and Aluminium components	Treatment of metal components	64% recycled, 36% reused (From [48]).
Plastics components	Treatment of plastic components	85% recycled, 15% reused (From [48]).
Other components (e.g., sensors, cables)	Reused	
Tires	Treatment of tires	31% incinerated, 64% recycled, 5% reused (From [48]).
Exhaust system	Underground disposal	100% landfilled.
Platinum/Rhodium/Palladium	Treatment of Platinum/Rhodium/Palladium	Following [49], in the European Automotive sector the 50% is recycled.
BEV powertrain	Treatment of electric and electronic equipment	Manual dismantled, 87% recycled and 13% landfilled.
Glass	Recycling of Glass	85% recycled, 9% reused (From [48]).
Mixed metals	Treatment of mixed metals	80% recycled, 20% landfilled.
Magnesium alloys	Recycling of Magnesium	100% recycled.
Electronic scrap from control unit	Treatment of electric and electronic equipment	Manual dismantled, 87% recycled and 13% landfilled.
Shredding and post-shredding		

Steel	Recycling of Steel	100% recycled.
Aluminium	Recycling of Aluminium	100% recycled.
Nickel alloys	Recycling of Nickel	100% recycled.
Lead	Recycling of Lead	100% recycled.
Copper	Recycling of Copper	100% recycled.
Lacquers	Incineration of non-ferrous materials	100% incinerated.
ASR polymeric fraction	Recycling of PP as proxy	100% recycled.
ASR metallic fraction	Recycling of Steel as proxy	100% recycled.
ASR non identified fraction		65% incinerated, 35% landfilled.

Table S3 Life Cycle Inventory of the three ELVs EoL scenario

Avoided products	DIE-ICEV (kg/vehicle)	CNG-ICEV (kg/vehicle)	BEV (kg/vehicle)	
Steel low-alloyed	1430	1390	1220	Recycled from Shredding and Post-shredding stage
Steel low-alloyed	274	256	135	Recycled and Reused from metal components
Aluminium cast alloy	17	6	39	Recycled from Shredding stage
Aluminium cast alloy	177	382	0.5	Recycled and Reused from metal components
Nickel	0.02	0.01	3.63	Recycled from Shredding stage
Lead	11	11	11	Recycled from Shredding stage
Copper	24	18	75	Recycled from Shredding stage
Polypropylene granulate	62	55	81	Recycled and Reused from Dismantling stage
Polypropylene granulate	151	135	198	Recycled from Post-shredding stage
Polypropylene granulate	32.2	31	20	Recycled and Reused from plastic components
Glass	50	49	36	Recycled
Reused components	39	42	42	Reused
Steel low-alloyed	3.5	3.5	3.5	Recycled from tires
Synthetic rubber	20	20	20	Recycled from tires
Nylon 6-6	0.5	0.5	0.5	Recycled from tires
Polyethylene terephthalate	1.0	1.0	1.0	Recycled from tires
Magnesium alloys	0.6	1.0	1.0	Recycled
Platinum/Rhodium/Palladium	0.02	0.03	-	Recycled
Polypropylene granulate	0.4	0.3	19	Recycled from electric and electronics equipment
Aluminium cast alloy	0.8	0.5	37	Recycled from electric and electronics equipment
Copper	0.4	0.3	17	Recycled from electric and electronics equipment
Steel low-alloyed	1.3	0.9	58	Recycled from electric and electronics equipment
Other metals	0.13	0.11	0.30	Recycled
Lead from Lead Acid Battery	13.2	13.2	13.2	Lead recycled in Lead Acid Battery
Li-ion NMC battery	-	-	407	Recycled
Waste to treatment				
Steel recycling	1363	1318	1148	Recycling of Steel from shredding stage

Steel recycling	175	164	86	Recycling of Steel from metal components
Steel recycling	64	68	68	Recycling of Steel from ASR metal fraction
Alluminium recycling	113	244	0.3	Recycling of Alluminium from metal components
Alluminium recycling	17	6	39	Recycling of Alluminium from shredding
Nickel recycling	0.02	0.01	3.6	Recycling of Nickel from shredding
Lead recycling	11	11	11	Recycling of Lead from shredding
Copper recycling	24	18	75	Recycling of Copper from shredding
Plastics and elastomers recycling	92	84	99	Recycling of plastics and elastomers from dismantling and plastic components
Plastics and elastomers recycling	151	135	198	Recycling of plastics and elastomers from ASR polymeric fraction
Lead in Lead acid battery	15	15	15	Treatment of Lead in Lead Acid battery
Li-ion NMC battery	0	0	452	Treatment of Li-ion NMC battery
Inert waste material landfill	110	125	104	Landfill of plastic components and 35% of ASR non identified fraction
Incineration of waste	201	229	187	Incineration of non-ferrous materials and 65% of ASR non identified fraction
Electric and electronic equipment	3.4	2.3	153	Treatment of electric and electronics equipment
Tires recycling	38	38	38	Recycling of tires
Tires incineration	18	18	18	Incineration of tires
Clinker production from waste oil	1	1	0.82	
Wastewater treatment	0.01	0.01	0.01	
Exhaust system	4.5	4.5	-	
Platinum/Rhodium/Palladium	0.03	0.06	-	
Glass recycling	56	55	40	
Treatment of mixed metals	0.2	0.1	0.4	
Magnesium recycling	1	1	1	

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.