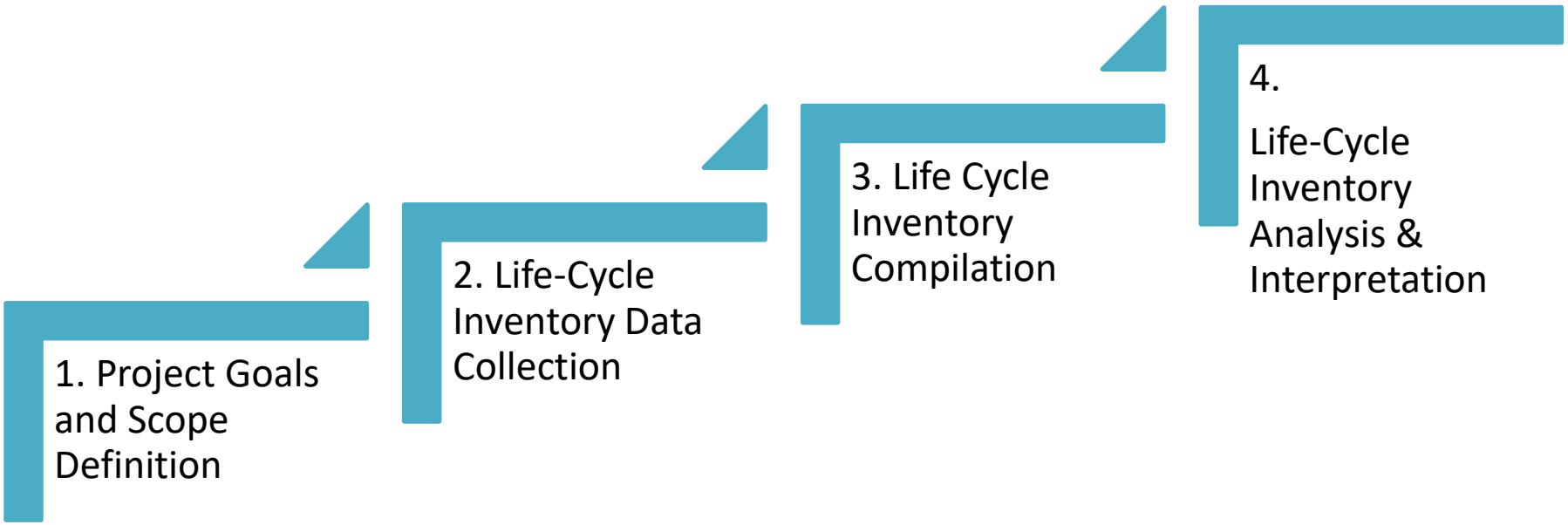
Life-Cycle Carbon and Air Pollutants Footprinting comparison between for Lithium Electric Vehicle and Diesel Passenger Car

Project: Wipro EV Study

CBALANCE
carbon ▸ cost ▸ community ▸ climate

Process Flow



Goal & Scope Definition

Goal

- Establishing baseline life cycle carbon and air pollutant footprints for diesel passenger cars
- Conducting a comparative analysis, based on primary as well as secondary research, with the life cycle footprint of ‘Lithiums’ Electric Vehicles to enable informed decision making related to mitigating environmental impacts of employee commuting activities of the organization

Goal & Scope Definition

Scope

- Conduct comparative life cycle footprint analysis between EV and Diesel Passenger Cars according to the life-cycle boundary defined below and and analyse them through ride based scenario models.

Life Cycle Stage	Sub-Stage	Included within I
Material Acquisition and Pre-Processing	Ore and other raw material mining and extraction	No
	Metal and other material processing	Yes
Production	Metal and other material (for batteries) procurement	Yes
	Transformation of metals and other materials (for batteries)	Yes
	Painting	Yes
	Assembling	Yes
Distribution and Storage	Domestic Transport for Export	No
	International Transport for Export	No
Use	Car Use & Ride Scenarios	Yes
End-of-Life	Disposal of Batteries	Yes

Goal & Scope Definition

Scope

1. PART 1: Primary Fuel Efficiency & Vehicle Research and Data Collection: Conducting primary and secondary research through site visits, literature reviews, interviews with stakeholders, web research catalogues to collate information on vehicle make, model, design and efficiency along with manufacturing and other details.
2. PART 2: Formulating Vehicle based Emission Factors: Thorough and comprehensive formulizing of vehicle-based emissions factors
3. PART 3: Conducting Life Cycle Assessments: Designing Spreadsheet models to calculate life cycle carbon and air pollutant footprint of EV and Diesel Passenger Cars using GHG Protocol's Product Life Cycle Accounting
4. PART 4: Scenario Modelling Use Case Scenarios: Sophisticated spreadsheet modelling to design and study ownership vs ride-share scenario of EV and Diesel Passenger

Protocols & Standards

International Protocols followed:

- 1996 & 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 2 – Energy for developing Scope 2 & Scope 3 Emission Factors for Indian Grid Electricity Mix.
- Greenhouse Gas Protocol's Product Life Cycle Accounting and Reporting Standard (WRI, WBCSD)

Sources

Sr. No.	Sources:
1	1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual, TABLE 1-12 SAMPLE AND DEFAULT VALUES OF SULPHUR CONTENT (S) IN FUEL
2	2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 2 - Energy
3	Aguirre, K. et al. (2012). Lifecycle Analysis Comparison of a Battery Electric Vehicle and a Conventional Gasoline Vehicle. California: The California Air Resource Board
4	All India Electricity Statistics - General Review 2011 - Central Electricity Authority - Minstry of Power - Govt. of India
5	Climate Change and India: Uncertainty Reduction in GHG Inventory Estimates, GHG Emission Measurements from Coal Combustion in Select Industries, Subhashis Biswas et. al., pp 76-79, Table 5.3 & 5.6
6	Dale, H., and Nic,L. (2016). Effects of battery manufacturing on electric vehicle life-cycle greenhouse gas emissions. Washington:The International Council on Clean Transportation, p.2 & 3
7	Eberhard,M Tarpenning,M. 2006.The 21st Century Electric Car. Tesla Motors.1-10
8	Ellingsen et al (2016)
9	Ellingsen, L. A-W., Hung, C. R. (2018). Research for TRAN Committee – Resources, energy, and lifecycle greenhouse gas emission aspects of electric vehicles, European Parliament, Policy Department for Structural and Cohesion Policies, Brussels, p.44. & 46
10	EMEP/EEA Emission Inventory Guidebook 2013, 1.A.1 Energy industries
11	Emissions Inventory of India, P.R. Shulka & A. Garg, pp125, Table 7.1
12	Establishing a National In-Use Vehicle Testing Programme in India, Authors : C Sita Lakshmi, Sumit Sharma, S Sundar (The Energy and Resources Institute, New Delhi) and B Bhanot
13	Faria, R. et al. (2012). A sustainability assessment of electric vehicles as a personal mobility system. Portugal: Energy Conversion and Management. Vol.61, pg(19-30)
14	Goel, R., et al. Assessment of motor vehicle use characteristics in three Indian cities. Transport. Res.

Sources

Sr. No.	Sources:
15	Hawkins et al.(2012).Comparative environmental life cycle assessment of conventional and electric vehicles. Journal of Industrial Ecology
16	http://www.cea.nic.in/reports/planning/cdm_co2/user_guide_ver4.pdf, Table 6, CM
17	https://www.autocarindia.com/car-news/top-10-fuel-efficient-petrol-cars-in-india-401947
18	IEA (2011). Technology Roadmaps - Electric and plug-in hybrid electric vehicles (EV/PHEV), p.29
19	Messagie, M.(2017). Life Cycle Analysis of the Climate Impact of Electric Vehicles. Brussels : Vrije Universiteit
20	Miotti, M. Supran, G. Kim, E. Trancik, J. (2016). Personal Vehicles Evaluated against Climate Change Mitigation Targets. Cambridge: American Chemical Society. p10795 -10808
21	Moro, A.et al. (2017). Electricity carbon intensity in European Member States: Impacts on GHG emissions of electric vehicles.Italy:Transportation Research Part D,pg(8)
22	Notter, D.A. et al. (2010). Contribution of Li-ion Batteries to the Environment Impact of Electric Vehicles. Environmental Science & Technology. Vol. 44
23	Odeh, N. et al. (2013). Current and Future Lifecycle Emissions of Key 'Low Carbon' Technologies and ALternatives. UK: Ricardo AEA
24	Online brochure from Mahindra website
25	Peters et al (2017)
26	Romare, M. et al. (2017). The Life Cycle Energy Consumption and Greenhouse Gas Emissions from Lithium-Ion Batteries.Sweden:IVL Swedish Environmental Research Institute, p(16,29,36)
27	Shunmugasundaram, R. et all. (2017). The Future is battery-powered. But are we overcharging the planet? Zurich: Sustainable Impact Summit, Development, p.(4)

Table 1 – Electric Vehicle

Table 1: Performance inventory of currently available electric vehicles by Mahindra Electric

Sr. No.	Vehicle Brand	Model No.	Car Weight (Kg)	Battery type	Motor Power (kW)	Storage capacity (kWh)	Battery Weight (Kg)	Fuel Efficiency (km/kWh)	Battery Life (km)	Vehicle Life (km)
1	e2o Plus	P2(48V)	937	Li-ion	19.0	15.0	112	10.9	160,934	100,000
2	e2o Plus	P4(48V)	932	Li-ion	19.0	11.0	84.0	10.9	160,934	100,000
3	e2o Plus	P6(48V)	940	Li-ion	19.0	11.0	84.0	10.9	160,934	100,000
4	eVerito	C2/C4/C6	1,225	Li-ion	31.0	13.9	-	7.7	160,934	100,000
5	eVerito	D2/D4/D6	1,265	Li-ion	31.0	18.6	-	7.3	160,934	100,000

Note: due to significant (31%) difference between low fuel efficiency of eVerito vs. high fuel efficiency of e20 Plus, the e20 Plus Model's fuel efficiency was used for further Use-Phase Emissions Analysis

Table 2 – Petrol Vehicle

Table 2: Calculated Emission Factor (EF) of air pollutants and GHGs for Indian petrol based car models

Sr. No.	Vehicle Brand	Model No.	Fuel GHG EF (kg CO2e/liter fuel)	Fuel SO2 EF (kg SO2/liter fuel)	Distance GHG EF (CO2e/km)	Distance SO2 EF (CO2e/km)	Distance NOx EF (kg NOx/km)	Distance PM EF (kg PM/km)	Vehicle Life (km)
1	Datsun Redigo	Petrol Variant - BSIII Fuel	2.30	0.00750	0.129	0.000419	0.0000900	0.00000200	100,000
2	Renault Kwid	Petrol Variant - BSIII Fuel	2.30	0.00750	0.125	0.000408	0.0000900	0.00000200	100,000
3	Maruti Alto 800	Petrol Variant - BSIII Fuel	2.30	0.00750	0.103	0.000337	0.0000900	0.00000200	100,000
4	Maruti Alto K10	Petrol Variant - BSIII Fuel	2.30	0.00750	0.148	0.000484	0.0000900	0.00000200	100,000
5	Tata Tiago	Petrol Variant - BSIII Fuel	2.30	0.00750	0.219	0.000714	0.0000900	0.00000200	100,000
6	Maruti Suzuki Dzire	Petrol Variant - BSIII Fuel	2.30	0.00750	0.144	0.000470	0.0000900	0.00000200	100,000
7	Maruti Suzuki Baleno	Petrol Variant - BSIII Fuel	2.30	0.00750	0.146	0.000476	0.0000900	0.00000200	100,000
8	Hyundai Eon	Petrol Variant - BSIII Fuel	2.30	0.00750	0.149	0.000487	0.0000900	0.00000200	100,000

Table 3 – Diesel Vehicle

Table 3: Calculated Emission Factor (EF) of air pollutants and GHGs for Indian diesel based car models

Sr. No.	Vehicle Brand	Model No.	Fuel GHG EF (kg CO2e/liter fuel)	Fuel SO2 EF (kg SO2/liter fuel)	Distance GHG EF (CO2e/ km)	Distance SO2 EF (CO2e/ km)	Distance NOx EF (kg Nox/km)	Distance PM EF (kg PM/km)	Vehicle Life (km)
1	Maruti Suzuki Dzire	Diesel Variant -BSIII Fuel	2.66	0.0166	0.167	0.00104	0.000280	0.0000150	100,000
2	Maruti Ciaz	Diesel Variant -BSIII Fuel	2.66	0.0166	0.185	0.00116	0.000280	0.0000150	100,000
3	Maruti Baleno	Diesel Variant -BSIII Fuel	2.66	0.0166	0.147	0.000915	0.000280	0.0000150	100,000
4	Honda Jazz	Diesel Variant -BSIII Fuel	2.66	0.0166	0.156	0.000971	0.000280	0.0000150	100,000
5	Tata Tiago	Diesel Variant -BSIII Fuel	2.66	0.0166	0.213	0.00133	0.000280	0.0000150	100,000
6	Maruti Ignis	Diesel Variant -BSIII Fuel	2.66	0.0166	0.150	0.000938	0.000280	0.0000150	100,000
7	Ford Figo Aspire	Diesel Variant -BSIII Fuel	2.66	0.0166	0.168	0.00105	0.000280	0.0000150	100,000
8	Honda Amaze	Diesel Variant -BSIII Fuel	2.66	0.0166	0.148	0.000922	0.000280	0.0000150	100,000
9	Honda City	Diesel Variant -BSIII Fuel	2.66	0.0166	0.158	0.000985	0.000280	0.0000150	100,000

Table 4 – Grid Electricity Emissions

Table 4: Emission Factor (EF) from Indian grid electricity consumption

Sr. No.	Parameter	Value	Units
1	GHG EF	1.19	kg CO2e/kWh
2	NOx EF	0.152	kg NOx/kWh
3	SO2 EF	0.0148	kg SO2/kWh

Table 5 – Material Acquisition and Pre-Processing

Table 5: GHG EF for Material Acquisition and Pre-Processing LCA stage, Component: Battery, Basis: Battery Unit

Parameter	EF (kg CO_2e/battery)	Lifespan (km/battery)	EF (kg CO2e/km)
Aluminum	81.0	160,934	0.000503
Carbon Black	9.00	160,934	0.0000559
Cobalt	82.5	160,934	0.000513
Copper	90.0	160,934	0.000559
Ethylene Carbonate	25.0	160,934	0.000155
Graphite	64.5	160,934	0.000401
Lithium Carbonate	49.0	160,934	0.000304
Lithium Hexafluorophosphate	78.0	160,934	0.000485
Nickel	109	160,934	0.000677
Steel	63.0	160,934	0.000391
All Components	**651**	**160,934**	**0.00405**

Table 6 – Material Acquisition and Pre-Processing

Table 6: GHG EF for Material Acquisition and Pre-Processing LCA stage, Component: Battery, Basis: Storage Capacity

Material	EF (kg CO2e/kWh storage capacity)	EF (kg CO2e/battery)	EF (kg CO2e/km)
Aluminum	3.25	45.2	0.000280705
Carbon Black	0.300	4.17	2.59112E-05
Cobalt	3.00	41.7	0.000259112
Copper	3.25	45.2	0.000280705
Ethylene Carbonate	1.00	13.9	8.63708E-05
Graphite	2.50	34.8	0.000215927
Lithium Carbonate	1.50	20.9	0.000130
Lithium Hexafluorophosphate	3.00	41.7	0.000259112
Nickel	4.00	55.6	0.000345483
Steel	2.25	31.3	0.000194334
Anode	8.70	120.9	0.000751426
Cathode	17.5	243.3	0.001511489
Electrolyte	3.00	41.7	0.000259112
All Components (Calculated)	**53.3**	**740.2**	**0.00460**
All Components (Research)	**82.2**	**1,142**	**0.00710**

Note: for battery storage capacity of 13.9 kWh & lifespan of 160,934 km

Table 7 – Material Acquisition and Pre-Processing

Table 7: GHG EF for Material Acquisition and Pre-Processing LCA stage, Component: Battery, Basis: Battery Mass Composition

Material	Mass (kg material/battery)	EF (kg CO2e/kg material)	EF (kg CO2e/battery)	EF (kg CO2e/km)
Aluminum	47	4.4	204.5	0.001270397
Carbon Black	3	2.5	7.5	4.6603E-05
Cobalt	12	49.4	592.8	0.003683498
Copper	38	2.8	104.5	0.000649335
Ethylene Carbonate	21	1.0	21.0	0.000130488
Graphite	24	-	0.0	0
Lithium Carbonate	16	-	32.0	0.000198839
Lithium Hexafluorophosphate	3	-	81.0	0.000503312
Nickel	14	-	188.1	0.001168595
Steel	34	-	57.8	0.000359153
Anode	-	-	-	0
Cathode	-	-	-	0
Electrolyte	-	-	-	0
All Components	**-**	**-**	**1,289**	**0.00801**

Note: for battery lifespan of 160,934 km

Table 8 – Material Acquisition and Pre-Processing

Table 8: Summary of GHG EFs

LCA Stage: **Material Acquisition and Pre-Processing**
Component: **Battery**

Basis	EF (kg CO2e/km)
Battery Unit	0.00405
Storage Capacity (Calculated)	0.00460
Storage Capacity (Research)	0.00710
Battery Composition Mass Basis	0.00801
Average EF (all analytical methods)	**0.00594**

Table 9 – Material Acquisition and Pre-Processing

Table 9: Summary of GHG EFs

LCA Stage: **Material Acquisition and Pre-Processing**
Component: **Vehicle Body**

Parameter	EV	ICE	Units
Vehicle Weight	1,060	1,415	kg
Battery Weight	98	-	kg
Vehicle Weight w/o Battery	962	1,415	kg
EF	1.7	1.7	kg CO2e/kg
EF	1,635	2,406	kg CO2e/vehicle
Lifespan	100,000	100,000	km
EF (Lifespan)	**0.0164**	**0.0241**	**kg CO2e/km**

Note: ICE and EV Vehicle Body assumed to be comprised of 100% steel/ferrous alloys

Table 10 – Production

Table 10a: GHG EFs for Production LCA stage, Component: Battery Body

Region	EF (kg CO2e/kWh storage capacity)	Storage Capacity (kWh)	EF (kg CO2e/battery)	EF (kg CO2e/km)
East Asia	205	13.9	2,847	0.0177
EU	161	13.9	2,231	0.0139
USA	118	13.9	1,640	0.0102

Table 10b: GHG EFs for Production LCA stage, Component: Battery Components

Other Battery Components	EF (kg CO2e/kWh storage capacity)	Storage Capacity (kWh)	EF (kg CO2e/battery)	EF (kg CO2e/km)
Cell Casing / Packaging	13.0	13.9	181	0.00112
Battery Management System	19.6	13.9	272	0.00169
Sum	32.6	13.9	452	0.00281

Note: for battery lifespan of 160,934 km

Table 11 – Production

Table 11: GHG EFs for Production LCA stage, Component: Battery Body + Components

Region	EF Battery body production (kg CO2e/km)
East Asia	0.0205
EU	0.0167
USA	0.0130

Table 12 – Production

Table 12: GHG EFs for Production LCA stage, Component: Vehicle Body

Parameter	EV	ICE	Units
Vehicle Weight	1,060	1,415	kg
Battery Weight	98.0	-	kg
Vehicle Weight w/o Battery	962	1,415	kg
EF	6,700	4,850	kg CO2e/tonne of car
EF (calculated)	6,444	6,863	kg CO2e/vehicle
EF (research)	5,233	-	kg CO2e/vehicle
Lifespan	100,000	100,000	km
EF	**0.0584**	**0.0686**	**kg CO2e/km**

Table 13 – Production

Table 13: Summary of GHG EFs

LCA Stage: **Production**
Component: **Entire Vehicle (Battery + Vehicle Body)**

Region	EV	ICE	Units
East Asia	0.0789	0.0686	kg CO2e/km
EU (Calculated)	0.0751	0.0686	kg CO2e/km
EU (Research)	0.0567	-	kg CO2e/km
USA	0.0714	0.0686	kg CO2e/km

Table 14 – Use

Table 14: Summary of GHG, NO_x and SO_2 EFs

LCA Stage: **Use**
Component: **Entire Vehicle**

Parameter	EV	Units	ICE - Petrol	ICE - Diesel	Units
Fuel Efficiency	10.9	km/kWh	16.5	16.3	km/liter
GHG EF	1.19	kg CO2e/kWh	2.30	2.66	kg CO2e/liter
NOx EF	0.152	kg NOx/kWh	-	-	-
SO2 EF	0.015	kg SO2/kWh	0.00750	0.0166	kg SO2/liter
GHG Emissions/km	**0.109**	**kg CO2e/km**	**0.140**	**0.163**	**kg CO2e/km**
NOx Emissions/km	**0.014**	**kg NOx/km**	**0.0000900**	**0.00028**	**kg NOx/km**
SO2 Emissions/km	**0.00136**	**kg SO2/km**	**0.000456**	**0.00102**	**kg SO2/km**
PM Emissions/km	**-**	**kg PM/km**	**0.00000200**	**0.0000150**	**kg PM/km**

Table 15 – End of Life

Table 15a: Summary of GHG EFs

LCA Stage: **End of Life**
Component: **Battery**

Parameter	Mass Basis	Units	Storage Capacity Basis	Units
Complete Battery Recycling - Hydrometallurgy	2.49	kg CO2e/kg-battery	185	kg CO2e/kwh
- Recycling Step - Hydrometalurgy - Cathode Separation	0.213	kg CO2e-Cathode separation/kg-battery	-	-
- Recycling Step - Hydromettalurgy - Cell Separation	0.586	kg CO2e-Cell separation/kg-battery	-	-
- Recycling Step - Hydromettalurgy - Dismantling	0.234	kg CO2e-dismantling/kg-battery	-	-
- Recycling Step - Hydromettalurgy - Hydroseparation	1.46	kg CO2e-Hydro-processing/kg-battery	-	-
EF	2.49	kg CO2e/kg-battery	-	-
Battery Specification	93.3	kg	13.9	kWh
EF	233	kg CO2e/battery	2,572	kg CO2e/battery
Lifespan	160,934	km	160,934	km
EF	**0.00145**	**kg CO2e/km**	**0.0160**	**kg CO2e/km**

Table 15 – End of Life

Table 15b: Summary of GHG EFs

LCA Stage: **End of Life**
Component: **Battery**

Parameter	Distance Basis	Units	Per Battery Basis	Units
EF	-	-	933	kg CO2e/battery
Lifespan			160,934	km
EF	**0.0510**	**kg CO2e/km**	**0.00580**	**kg CO2e/km**

Table 16 – LCA Summary

LCA Stage	GHG Emissions		NOX Emissions		SO2 Emissions		Units
	EV	ICE	EV	ICE	EV	ICE	
Material Acquisition and Pre Processing	0.0223	0.0241	-	-	-	-	kg Emissions/km
Production	0.0789	0.0686	-	-	-	-	kg Emissions/km
Use	0.109	0.152	0.0139	0.000185	0.00136	0.000738	kg Emissions/km
End of Life	0.0186	NA	-	-	-	-	kg Emissions/km
Total LCA (Including Material Acquisition & End of Life Emissions) – S1	0.229	0.244					kg Emissions/km
Total LCA (Including Material Acquisition, Excluding End of Life Emissions) – S2	0.211	0.244	0.0139	0.000185	0.00136	0.000738	kg Emissions/km
Total LCA (Excluding Material Acquisition, Including End of Life Emissions) –S3	0.207	0.220					kg Emissions/km
Avg. of S2 & S3	**0.209**	**0.232**	**0.0139**	**0.000185**	**0.00136**	**0.000738**	kg Emissions/km

Chart 1 – LCA Summary - EV

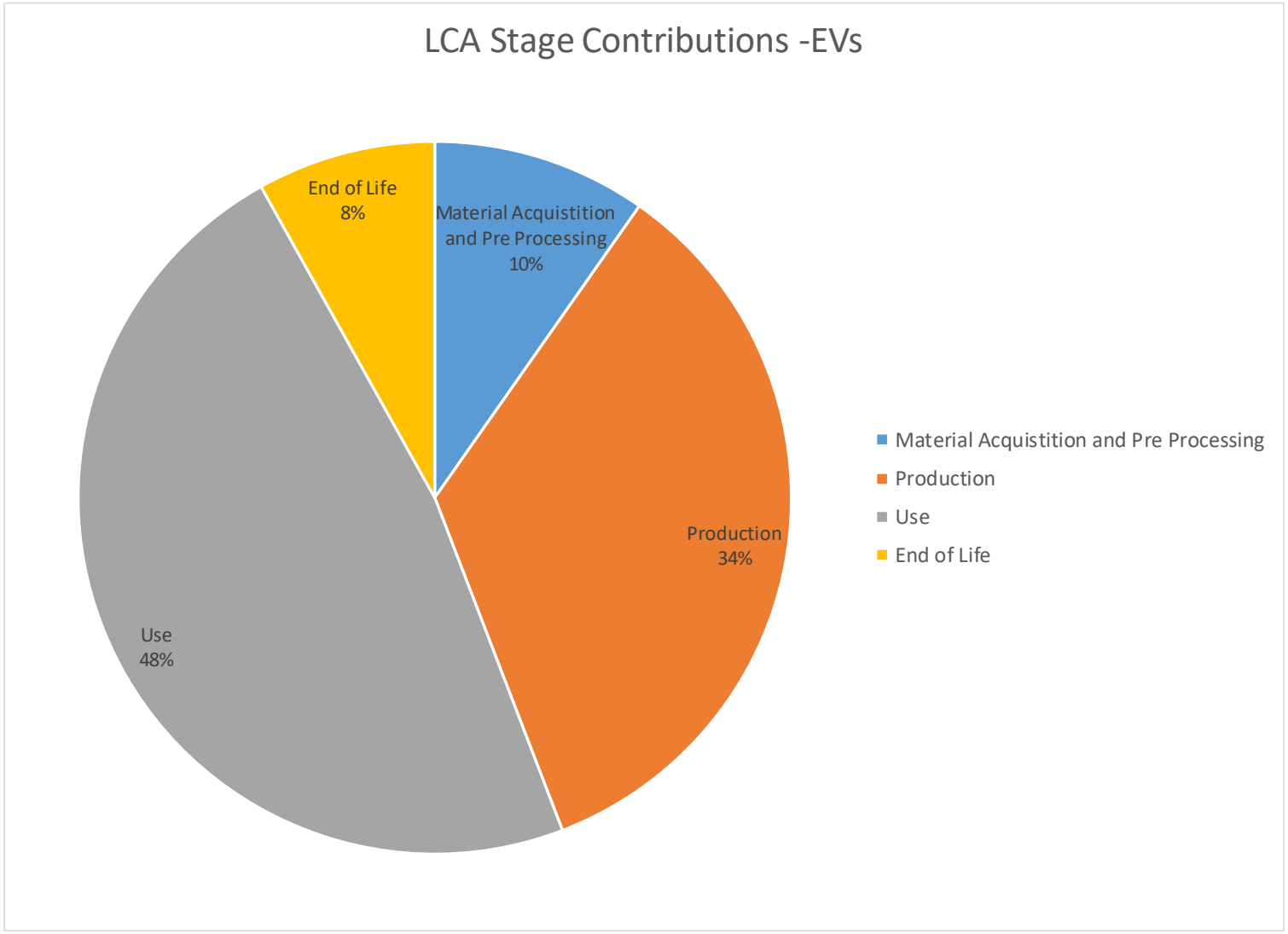


Chart 2 – LCA Summary - ICE

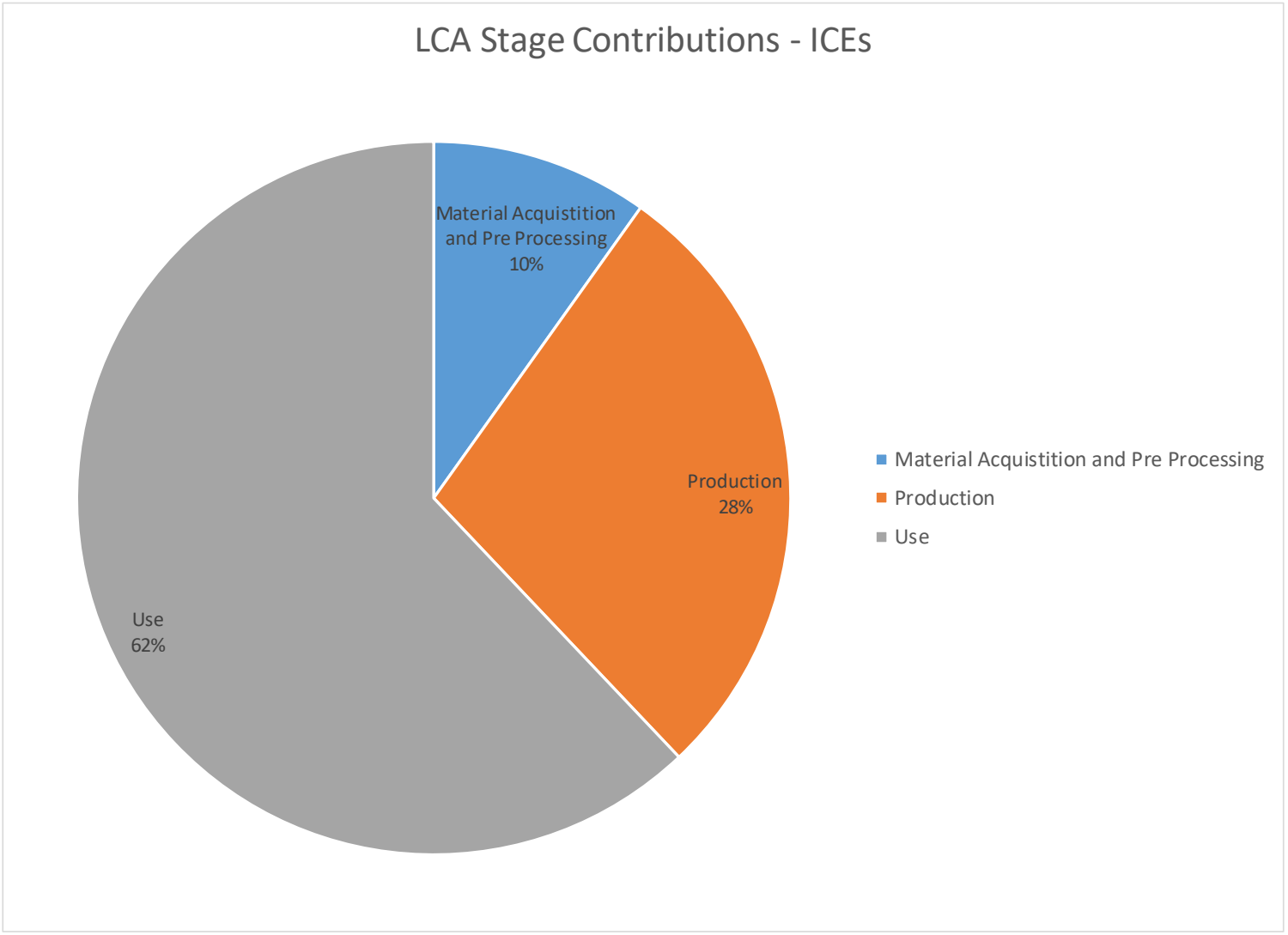


Chart 3 – Life Cycle GHG Emissions Comparison

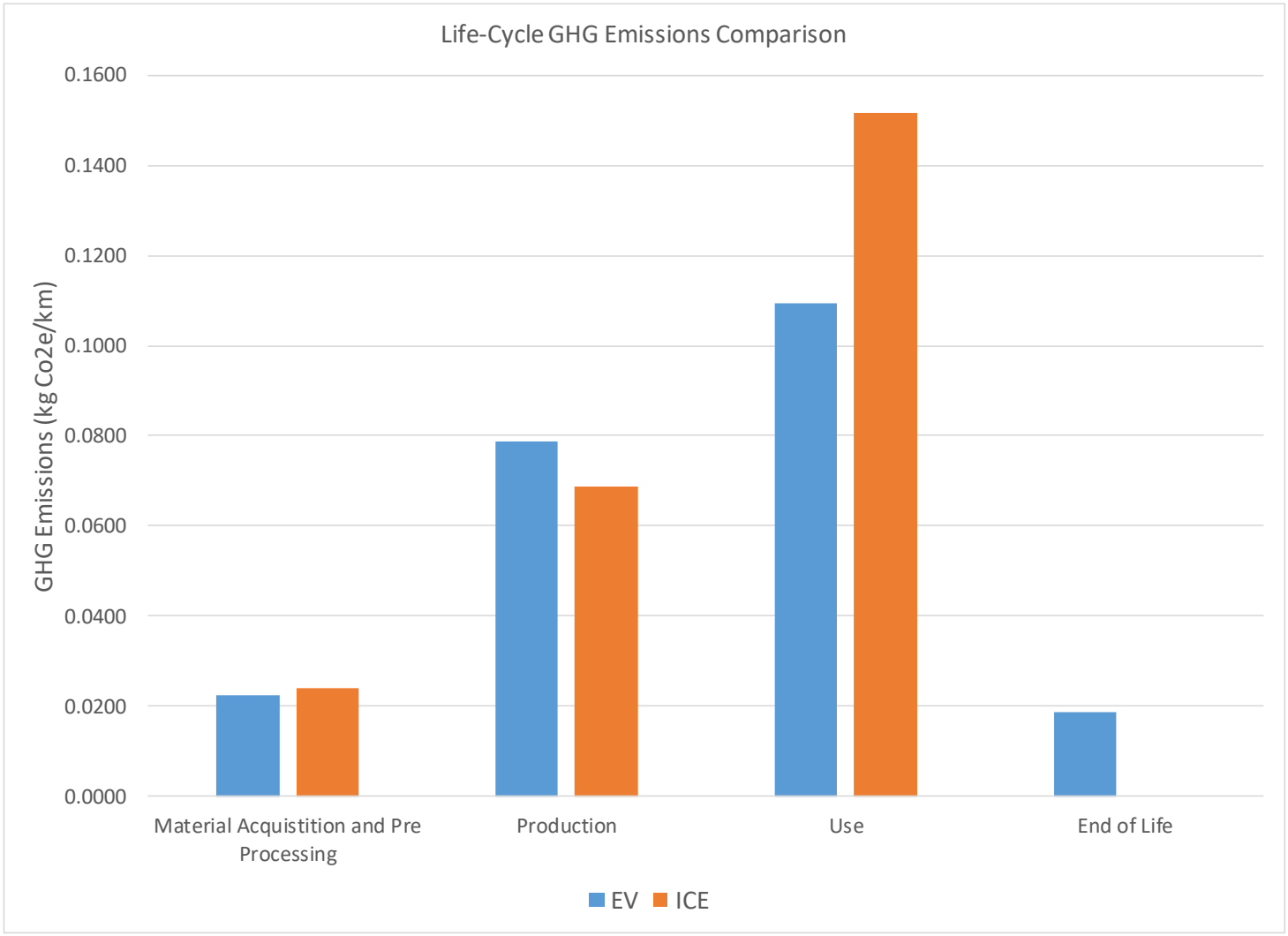


Chart 4 – Total LCA Comparison