

Methodology for Evaluating Cradle-to-Grave Environmental Impacts

By-

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TATA MOTORS PASSENGER VEHICLE LIMITED (TMPV)

Material Science, VATS,
Engineering Research Centre, Pune.

TATA TECHNOLOGIES (TTL)

OUR CULTURE CREDO

AT TATA MOTORS

We are connecting aspirations by being bold in thought and action, owning every opportunity and challenge, Solving together as one team and engaging all our stakeholders with empathy.

We are **MORE WHEN ONE!**



Agenda

- Chairman's Message on Sustainability, Project Aalingana & Sustainability Targets
- Typical LCA System Boundary
 - ✓ *Life Cycle Assessment– Challenges & Strategic Need*
- Earlier Approach: Manual Evaluation of Cradle-to-Gate Carbon Footprint
 - ✓ *Limitations of Earlier Approach*
- New Approach: Parameterised Detailed GaBi Model for Cradle-to-Grave Impact
 - ✓ *Uniqueness of New Approach*
 - ✓ *Flexibility & Replication Potential*
 - ✓ *Output: LCA with New Approach*
 - ✓ *Project Cost, Tangible & Intangible Benefits*
 - ✓ *Challenges faced during Implementation*




Delivering the inaugural address at the Tata Sustainability Conclave 2022: Mr. N. Chandrasekaran, Chairman, Tata Sons

Laying out the Group Sustainability Vision with Mr. N Chandrasekaran, Group Chairman, Tata Group

As part of the inaugural address, the Group Chairman emphasised that while sustainability is one of the biggest challenges facing corporates today, it is also a big opportunity. Comparing the sustainability journey to an ultra-marathon, the Chairman encouraged companies to sharpen their sustainability agendas, lay out their **decarbonisation** plans as the world transitions to a low-carbon economy and invest in innovative solutions.

Project Aalingana & Sustainability Targets


Driving Net-Zero



2030
25% REDUCTION IN ABSOLUTE CARBON EMISSIONS*
**From 2020 baseline (Scope 1 & 2); Tata Steel India to reduce emissions intensity by 28-30% from 2020 baseline*

2045
NET ZERO EMISSIONS ACROSS THE GROUP*
**Scope 1 & 2 across companies; scope 3 for JLR, TML, TCS, TCPL*

Pioneering Circular Economies



2025
MORE THAN DOUBLE THE CONTENT OF RENEWABLE OR RECYCLED RESOURCES IN PRODUCTS*
**Over 2020 baseline*

2030
REPLENISH FRESHWATER & ZERO WASTE TO LANDFILL*
**Freshwater target for India operations only*

2040
REPLENISH MORE FRESHWATER THAN CONSUMED

Preserving Nature & Biodiversity



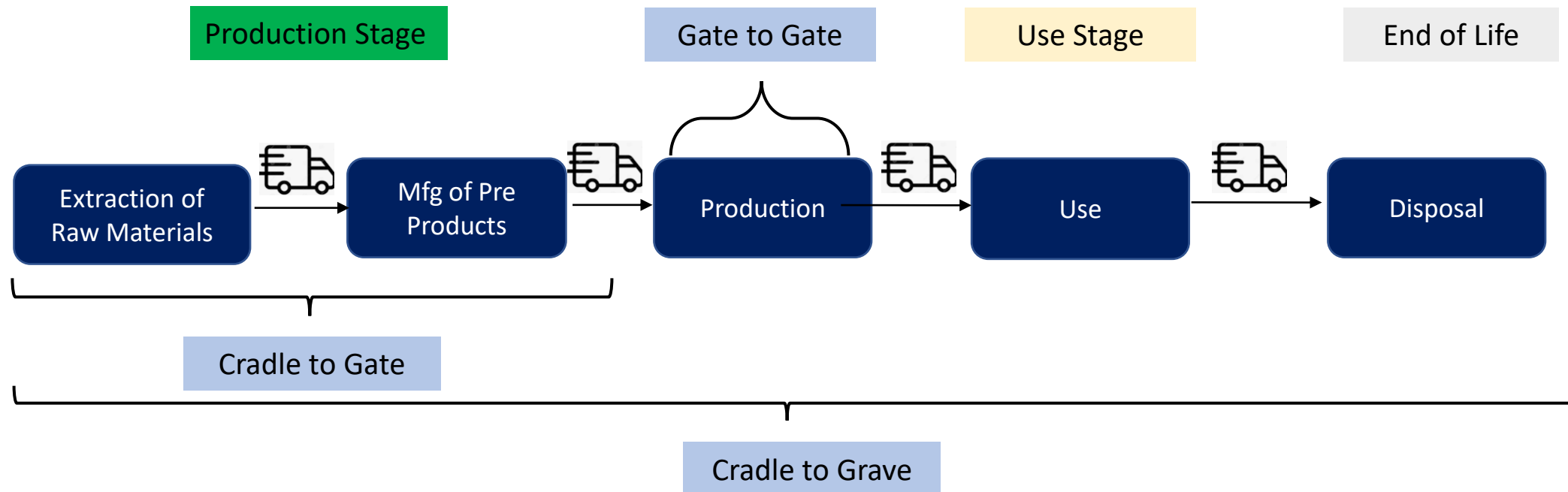
2024
ACTION PLANS FOR NET POSITIVE IMPACT

2025
INVEST IN NATURE-BASED SOLUTIONS (NBS) PROJECTS IN INDIA

2030
GROUP IS AN NBS LEADER AND HAS SUPPORTED NBS MARKET IN INDIA

Typical LCA: System Boundary

- LCA is Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.
- It is holistic environment assessment tool for sustainability assessment and strategy at product level.
- ISO 14040/44 guided process



Life Cycle Assessment– Challenges & Strategic Need

Tata Motors: A Leading Automotive Manufacturer

- Diverse portfolio with **8 models** across multiple **fuel and powertrain options**
- High product complexity: **10,000+ components per vehicle**
- Extensive supplier base: **350+ suppliers**

Current Challenges

- Carbon footprint evaluation is **time and resource intensive** due to variant diversity
- Manual calculations hinder **speed and scalability**

Strategic Need

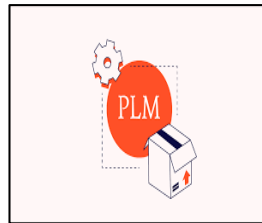
- Develop a **structured and standardized methodology** for Cradle-to-Grave carbon footprint assessment across all variants
- Ensure **integration and alignment of existing data systems** to:
 - Handle bulk data efficiently
 - Minimize manual effort
 - Accelerate result generation

Compliance Focus

- Align methodology with **ISO 14040 & ISO 14044** standards



Earlier Approach: Manual Evaluation of Cradle-to-Gate Carbon Footprint



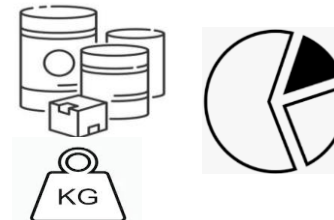
PLM



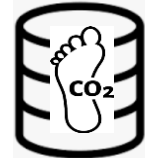
IMDS



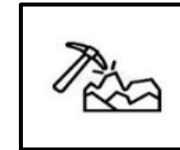
ENVIRONEXT
(In-house developed system)



PMW Breakdown
(9 material categories*)



Carbon footprint factors



Identification of relevant material & process datasets



Material Category	Material	Material Mfg Key	Part Manufacturing Plan	Weighted factor as per Indian DB
Steel	Steel - Hot rolled	ASA Steel Hot Rolled Coil	GO Steel sheet stamping and bending (DB listed to carbon)	4.07
	Steel - Billet	IN BF Steel billet_slab_bloom	(GO) Steel sheet stamping and bending (DB listed to carbon)	
	Steel - Cold rolled	Asia Steel cold rolled coil	(DE) Steel sheet deep drawing (multi-sheet to carbon)	
	Cast iron	IN BF Steel billet_slab_bloom	(DE) Cast iron part (automotive) to carbon	
Aluminum	Aluminum	ASA Steel Hot Rolled Coil	GO Steel Turning	
	Aluminum	IN BF Steel billet_slab_bloom	(GO) Steel Turning	
	Aluminum	IN Aluminum ingot	(DE) Aluminum cast machining	26.42
Copper	Copper (unrefined)	IN Aluminum sheet	(DE) Aluminum sheet deep drawing	
	Others	IN Aluminum ingot	(DE) Aluminum die cast part	6.91
Plastics	Other (non-alloy)	DE Zinc redibled mix to (no data)		1.58
	Other (alloy)	GO Nickel (Class 1, 99.99%) (CCO)		
Plastics	Plastic	EU 2B Lead primary and secondary		
	Plastic	GO Plastic injection moulding (parameterized) use to		6.95
	Plastic	DE Polyamide 6 Granulate (PA 6)	GO Plastic injection moulding (parameterized) use to	
	Plastic	IN Polyurethane granulate (PU) High	GO Plastic injection moulding (parameterized) use to	

Manual calculations for carbon footprint evaluation



Cradle-to-Gate vehicle carbon footprint

Manual excel based process to evaluate Cradle-to-Gate impacts with limited material categories

*Material categories considered: Steel, Aluminum, Plastics, Elastomers, Glass, Copper, Electronics, Fluids and Others [~30 material sub-categories & mfg. process combinations]

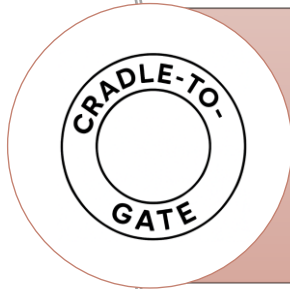
Limitations of Earlier Approach

- **Manual process with limited system boundary scope typically resulted into ~3 months to complete Cradle-to-Gate study for one model**
- **Highlights the need for a more robust, scalable, and accurate methodology to cover complete portfolio over entire life cycle impacts**



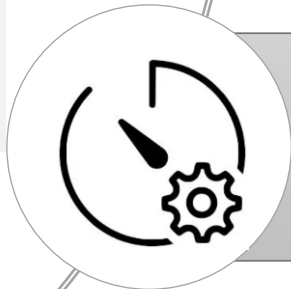
Time & resource intensive

- Replication to various models & fuel/power train variants is challenge
- Manual extraction of emission factors from LCA software



Limited scope & granularity

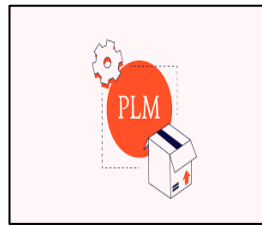
- System boundary limited to Cradle-to-Gate due to complex nature of product; does not provide insights for entire life cycle impacts
- Lack of granularity in terms of the variety of materials and manufacturing processes
- Precious metals used in the vehicle were not mapped



Lack of efficient use of LCA software functionalities

- Limitations to include other impact categories such as Acidification potential, Eutrophication Potential, Ozone depletion potential, Photochemical ozone creation etc.
- Manual update of all the factors to revise the calculations with every bi-annual database update

New Approach: Parameterised Detailed GaBi Model for Cradle-to-Grave Impact



PLM

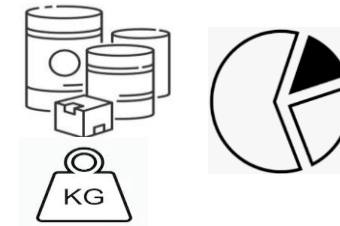


IMDS



ENVIRONEXT

(In-house developed system)



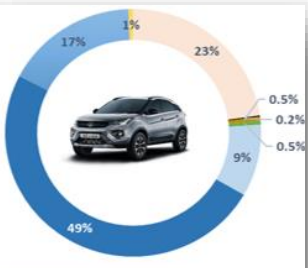
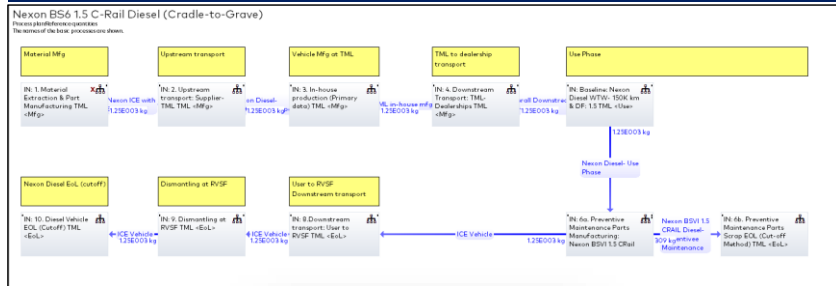
PMW Breakdown

(60+ material-process combinations)



Parameterized generic GaBi models

Cradle-to-Grave Vehicle Specific Model



Material extraction & part processing
 ■ Upstream Transportation
 ■ Vehicle manufacturing & assembly
 ■ Downstream distribution
 ■ Use phase: Well-to-Tank (WTT)
 ■ Use phase: Tank-to-Wheel (TTW)
 ■ Use Phase: Maintenance (Part Mfg.+EoL of replaced part)
 ■ End-of-Life (Cut-off approach)

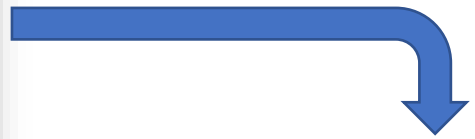
1. Material Extraction & Part Manufacturing

Process plan reference queries
The names of the base processes are shown.

Parameter	Formula	Value	Minimum	Maximum	Standard	Comment, units, defaults
in_ABS		1			0 %	[kg] Total ABS weight in vehicle
in_acid		1			0 %	[kg] Total acid weight in vehicle
in_adhe_PVC		1			0 %	[kg] Total PVC weight in vehicle
in_Al_extrusion		1			0 %	[kg] Total Al extrusion weight in vehicle
in_Al_ingot		1			0 %	[kg] Total Al ingot weight in vehicle
in_Al_sheet		1			0 %	[kg] Total Al sheet weight in vehicle
in_BIW_suppli		1			0 %	[kg] Total BIW weight in vehicle
in_cardboard		1			0 %	[kg] Total cardboard weight in vehicle
in_cast_iron		1			0 %	[kg] Total cast iron weight in vehicle
in_ceramic		1			0 %	[kg] Total ceramic weight in vehicle
in_cerium		1			0 %	[kg] Total cerium weight in vehicle
in_cold_roll_sh		1			0 %	[kg] Total cold rolled stamping bending part weight in vehicle
in_cold_roll_st		1			0 %	[kg] Total cold rolled steel sheet deep drawing part weight in vehicle
IN_copp_weig		1			0 %	[kg] Total copper weight in vehicle
in_copper		1			0 %	[kg] Total copper weight in vehicle
in_electronics		1			0 %	[kg] Total electronics weight in vehicle
in_EPDM_elast		1			0 %	[kg] Total EPDM elastomer weight in vehicle
in_EPDM_rubb		1			0 %	[kg] Total EPDM rubber weight in vehicle
in_ethylene_g		1			0 %	[kg] Total ethylene glycol weight in vehicle

New Approach: Parameterised Model for Each Phase

Generalised parameterised modelling with in each GaBi plan for material, process & life cycle plan can easily adopted for any vehicle model just by changing the weights & other resource consumption data



6a. Preventive Maintenance Parts Manufacturing: Nexon BSVI 1.5 CRail Diesel

Parameter	Formula	Value	Minimum	Maximum	Standard	Comment, units, defaults
IN_AC_filter		1		0 %		[kg] Total AC filter weight in vehicle
IN_Air_filter		1		0 %		[kg] Total Air filter weight in vehicle
IN_Brake		1		0 %		[kg] Total brake fluid weight in vehicle
IN_Coolant		1		0 %		[kg] Total coolant weight in vehicle
IN_Engine_Oil		1		0 %		[kg] Total engine oil weight in vehicle
IN_Fuel_filter		1		0 %		[kg] Total fuel filterweight in vehicle
IN_ICE_Vehide		1		0 %		[kg]Total ICE Vehide weight in vehicle
IN_LV_battery		1		0 %		[kg] Total LV battery weight in vehicle
IN_Oil_filter		1		0 %		[kg] Total oil filter weight in vehicle
IN_Timing_driv		1		0 %		[kg]Total Timing Drive weight in vehicle
IN_Transaxel		1		0 %		[kg] Total transaxel oil weight in vehicle
IN_Tyre		1		0 %		[kg] Total tyre weight in vehicle
Out_ICE_Vehide		1		0 %		[kg] Total ICE Vehide weig
OUT_Nexon_E		1		0 %		[kg] Total Nexon Diesel Pre

Parameter	Formula	Value	Minimum	Maximum	Standard	Comment, units, defaults
IN_AC_filter		0.757		0 %		[kg] Total AC filter weight in vehicle
IN_Air_filter		1.12		0 %		[kg] Total Air filter weight in vehicle
IN_Brake		1.92		0 %		[kg] Total brake fluid weight in vehicle
IN_Coolant		22		0 %		[kg] Total coolant weight in vehicle
IN_Engine_Oil		43.1		0 %		[kg] Total engine oil weight in vehicle
IN_Fuel_filter		0.544		0 %		[kg] Total fuel filterweight in vehicle
IN_ICE_Vehide		1.25E003		0 %		[kg]Total ICE Vehide weight in vehicle
IN_LV_battery		57.2		0 %		[kg] Total LV battery weight in vehicle
IN_Oil_filter		6.69		0 %		[kg] Total oil filter weight in vehicle
IN_Timing_drive		0.747		0 %		[kg]Total Timing Drive weight in vehicle
IN_Transaxel		4.8		0 %		[kg] Total transaxel oil weight in vehicle
IN_Tyre		170		0 %		[kg] Total tyre weight in vehicle
Out_ICE_Vehide		1.25E003		0 %		[kg] Total ICE Vehide weight in vehicle
OUT_Nexon_Diese		309		0 %		[kg] Total Nexon Diesel Preventivee maintenance parts weight in vehicle

New approach not only streamline the process but also reduces the LCA impact evaluation time from ~3 months to ~2 weeks per model

Increased granularity for enhanced accuracy

- Finalized vehicle level material categories with increased scope covering 60+ material-process combinations
- Separate consideration of precious metals and rare earth elements
- Mapping & consideration of HV battery related materials

Effective use of software functionalities for streamlining & scaling

- Generalized parameterization modelling approach followed to map all phases of vehicle's life cycle
- This has simplified the process & can be replicated & scaled to evaluate the impacts for any vehicle variant simply by adjusting material weights & other phase parameters
- Consistent & streamlined approach in modelling with minimal manual intervention & efforts

Methodology to cover extended system boundary across multiple impact categories with 3rd party verification

- Detailed methodology developed to evaluate Cradle-to-Grave lifecycle of the vehicle across various impact categories
- Extensive scenario analysis can be easily performed [Extension of life, material change/weight reduction, change in battery capacity, variation in grid mix etc.]
- Approach is used to evaluate ISO 14040/44 compliant Cradle-to-Grave impact of Nexon ICE & EV model which is externally verified by TUV Rheinland

Within Company

With Parametrized modelling approach, phase-wise & life cycle impacts can easily adopted for all the current models as well as new designs & configuration by varying the input data in parameterized models.

Within Auto Sector

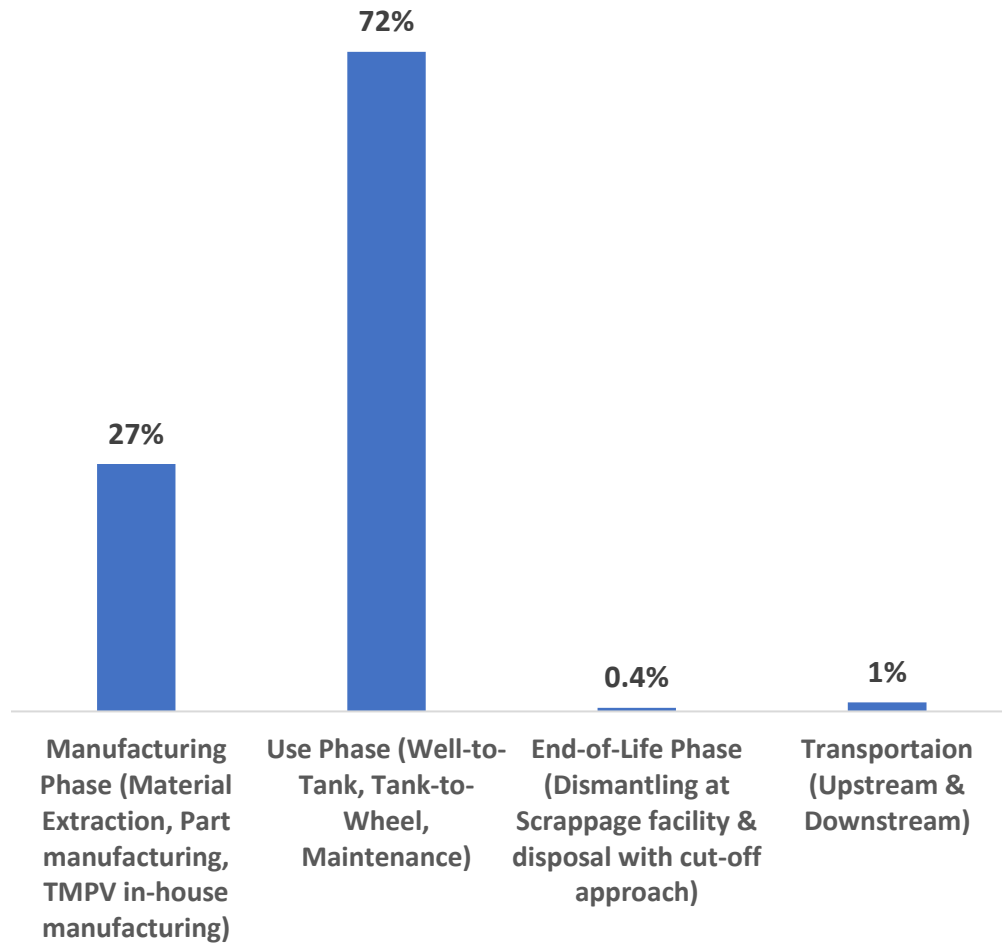
This methodology can be easily applied to all automotive manufacturers for streamlining the evaluation of life cycle emission impacts

Across Industry

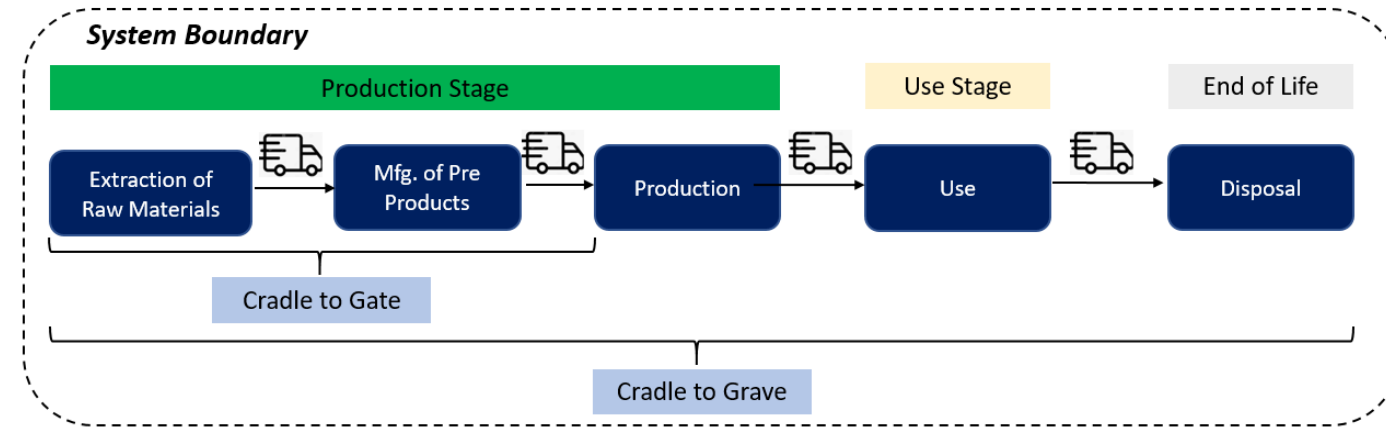
This approach can also other complex products like data centers, heavy consumer electronic items etc. wherein the product is made up of thousands of parts, variants & has significant impact contribution from other life cycle phases apart from manufacturing

Output: LCA with New Approach

CO₂ Impact (%) for ICE



System Boundary: *Cradle-to-Grave*



Cradle-to-Grave

Cradle-to-Grave Nexon ICE Diesel & EV LCA is externally verified by TÜV Rheinland



Certificate

TÜV Rheinland (India) Pvt. Ltd
performed the Critical Review of Cradle to Grave Life Cycle Assessment (LCA) study of
Tata Motors Passenger Vehicles Limited
For the following passenger car

Tata Nexon XZA+ (Diesel)

Compliance with the requirements of the following international standards has been demonstrated, ensuring full adherence to their principles and guidelines:

- ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework
- ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines
- ISO 14071:2024 Environmental management — Life cycle assessment — Critical review processes and reviewer competencies

This assessment confirms adherence to these standards in **Conformity**.

Results:

- The LCA study was carried out according to ISO 14040:2006 and ISO 14044:2006. The methods used and the modelling of the products correspond to the state of art. They are suitable to fulfil the goals stated in the study. The report is comprehensive and provides a transparent description of the framework of the LCA study.
- The LCA study comprehensively addressed key aspects such as extensive maintenance, multiple End-of-Life scenarios, and a detailed sensitivity analysis. By evaluating different End-of-Life processes and assessing the impact of various assumptions, the study provided a more robust and insightful assessment. These elements not only improved the accuracy of the findings but also set the study apart from others in terms of its thoroughness and methodological rigor.
- The assumptions used in the LCA study, especially fuel consumption during the use phase which were calculated using the MIDC (Modified Indian Driving Cycle) were analysed and verified.
- The assessment samples of data and environmental information included in the LCA study are plausible.

Review process:

The assessment of the input data and environmental information as well as check of the LCA process was performed in the course of the critical review. The data review consisted of the following aspects:

- On-site audit of databases, monitoring and reporting methodologies.
- Check of the applied methods and the software (LCA for Experts) product model of the vehicle.
- Inspection of technical documents (e.g. Bill of Material of the vehicle, supplier information, emission reports, etc.).
- Check of LCA input data (e.g. weight calculation, material composition, tail pipe and stack emissions, etc.).

Critical Reviewer: Hritik Patil

Paul Parker
Global Technical Manager - Carbon
London, 25th February 2025

Responsibilities:

Sole liability for the content of the LCA rests with Tata Motors Passenger Vehicles Limited. TÜV Rheinland (India) Pvt. Ltd was commissioned to review the said LCA study for compliance with the methodological requirements and to assess the correctness and credibility of the information included therein.



Certificate

TÜV Rheinland (India) Pvt. Ltd
performed the Critical Review of Cradle to Grave Life Cycle Assessment (LCA) study of
Tata Passenger Electric Mobility Ltd. (TPEM)
For the following passenger car

Tata Nexon EV

Compliance with the requirements of the following international standards has been demonstrated, ensuring full adherence to their principles and guidelines:

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- The LCA study thoroughly addressed critical aspects such as maintenance, multiple End-of-Life scenarios, and a detailed sensitivity analysis. It examined how changes in battery pack size, vehicle range, and the greening of the electricity grid affected environmental impacts. Larger batteries increased range but also production emissions, while cleaner electricity significantly lowered use-phase emissions. These analyses enhanced the robustness and credibility of the results, setting the study apart through its depth and methodological rigor.
- The assumptions used in the LCA study, especially regarding electricity consumption during the use phase—which was calculated based on the range certified by ARAI under the MIDC (Modified Indian Driving Cycle) were carefully analyzed and verified. In calculating electricity consumption, the study also accounted for real-world influencing factors such as charging efficiency losses, battery state of charge (SOC) variations, and auxiliary energy demands. By incorporating these parameters, the study ensured a more realistic estimation of energy use during operation, thereby enhancing the accuracy and credibility of the use-phase emissions.
- The assessment samples of data and environmental information included in the LCA study are plausible.

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- Check of LCA input data (e.g. weight calculation, material composition, use phase energy consumption etc.).

Critical Reviewer: Hritik Patil

Haminder Oberoi
Assistant Vice President — A.01 India
Gurgaon, 9th July 2025

Responsibilities:

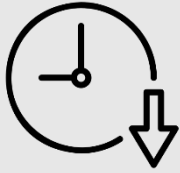

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Cradle-to-Gate

Cradle-to-Gate internal LCA completed for 11 ICE & EV models
(Tiago, Tigor, Altroz, Punch, Curvv, Harrier MCE, Safari MCE, Tiago EV, Tigor EV, Punch EV, Curvv EV)

Project Cost & Tangible Benefits

Project	Cost
Development of methodology & generalised parametric models for entire life cycle phases	~ 7 Lacs

Tangible Benefits		Savings (UOM)	Savings (in INR)	Payback (In years)
Man hours saving		Rs. (Lacs)	~ 41 Lacs	Immediate
In-house competency building for LCA		Rs. (Lacs)	~ 75 Lacs	Immediate

Intangible Benefits

Application of consistent methodology across all the models for evaluating impacts & complete baselining for SBTi

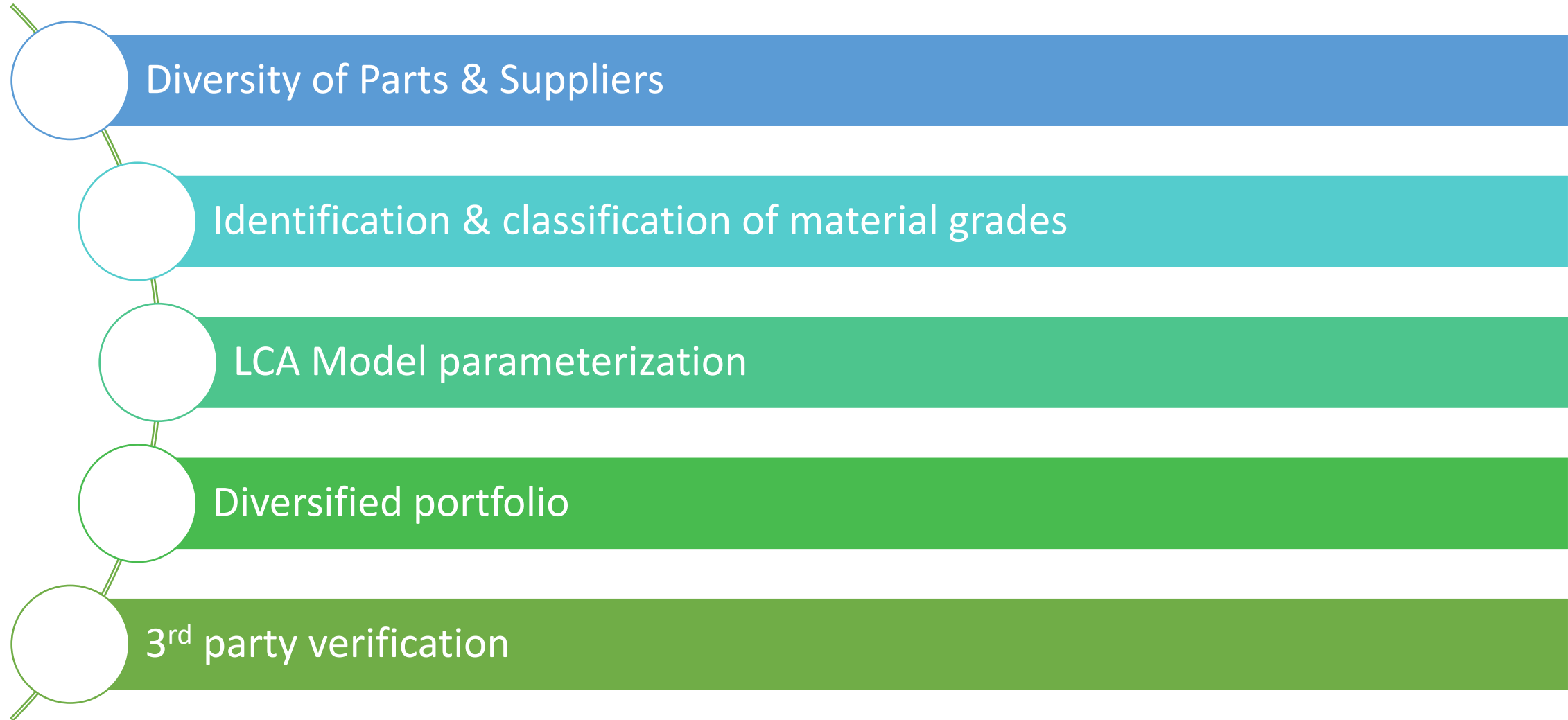
Increased precision & reliability in the results

Fast & quick analysis of Material, Process & phase level hotspot analysis which can provide inputs to create year on year CO₂ reduction roadmap and prioritise CO₂ reduction initiative

Faster evaluation of scenarios – change in material, weight reduction, efficiency improvement etc.

It is easy to maintain data confidentiality

Challenges faced during Implementation





Thank you....