FEV

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# Opportunities & Challenges of Hybrid Powertrain as Future of Indian Mobility

Prepared for:

**ECT 2025**

ECT-2025
16th International Conference

# AGENDA

**BACKGROUND AND INTRODUCTION**

OPPORTUNITIES AND CHALLENGES

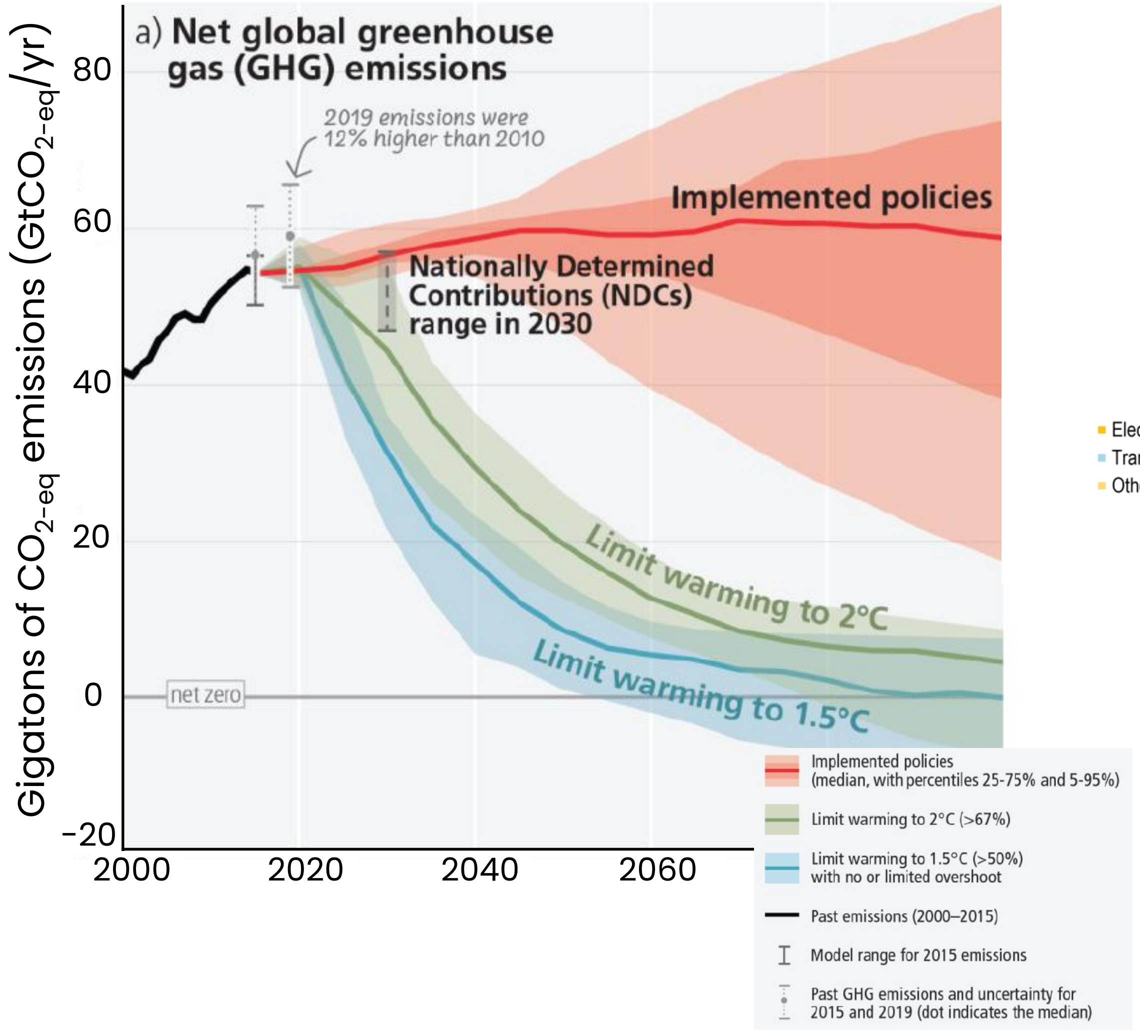
HYBRID TOPOLOGIES

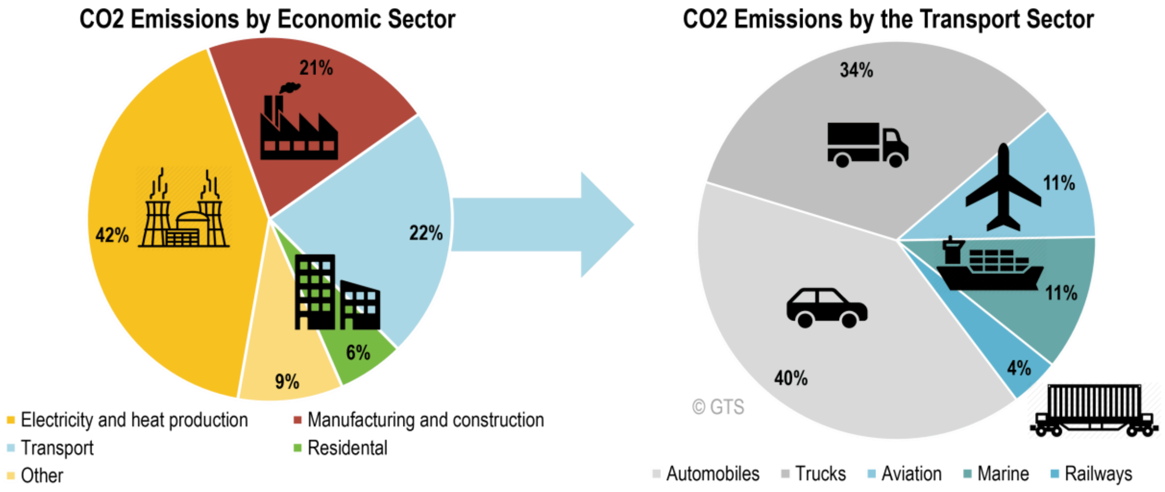
HYBRID MODEL CASE STUDY

SUMMARY

# According to the IPCC reports, limiting warming to 1.5°C and 2°C involves rapid and immediate greenhouse gas emission reductions

WITH IMPLEMENTED POLICIES, PROJECTED EMISSIONS LEAD TO WARMING OF **3.2°C**, RANGING FROM +2.2 TO +3.5°C




- Zero-CO2 powertrain solutions:
  - –Pure battery electric powertrain
  - –Hydrogen (H2) operated powertrains
    - – H2-ICE
    - – Fuel cell

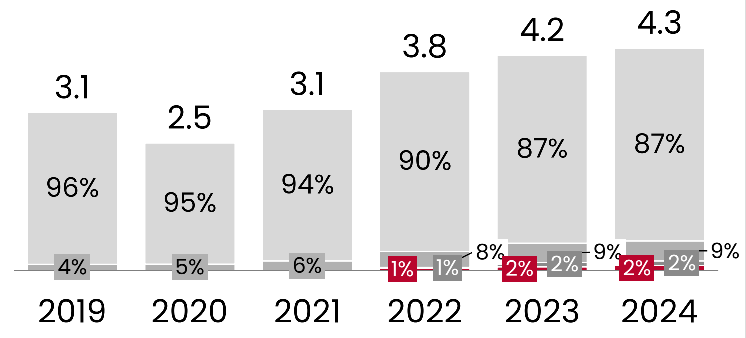
Source : Synthesis report of the Intergovernmental Panel on Climate Change's sixth assessment report

# In India, we expect a steep uptake of electric vehicle sales in the 2030s; Still governmental targets are expected to be missed

**PASSENGER CAR** – POWERTRAIN MARKET FORECAST

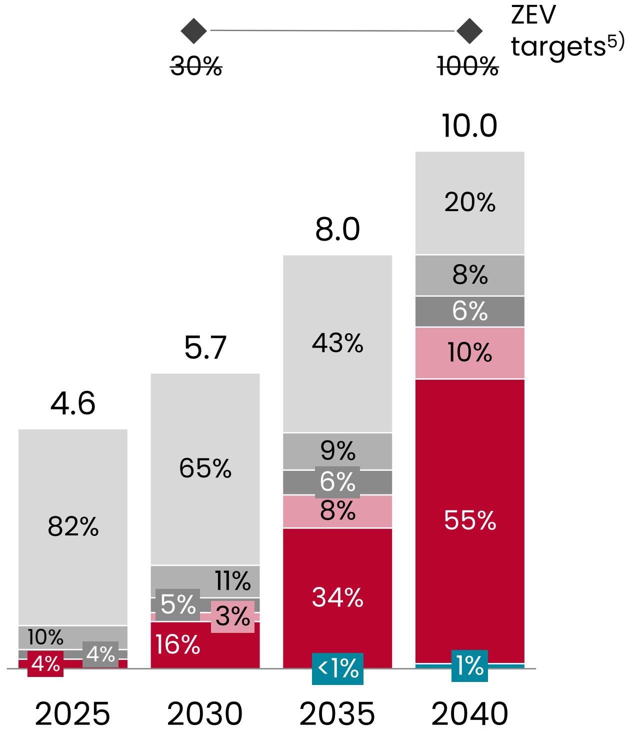
## Historic & Status quo

Sales in million units



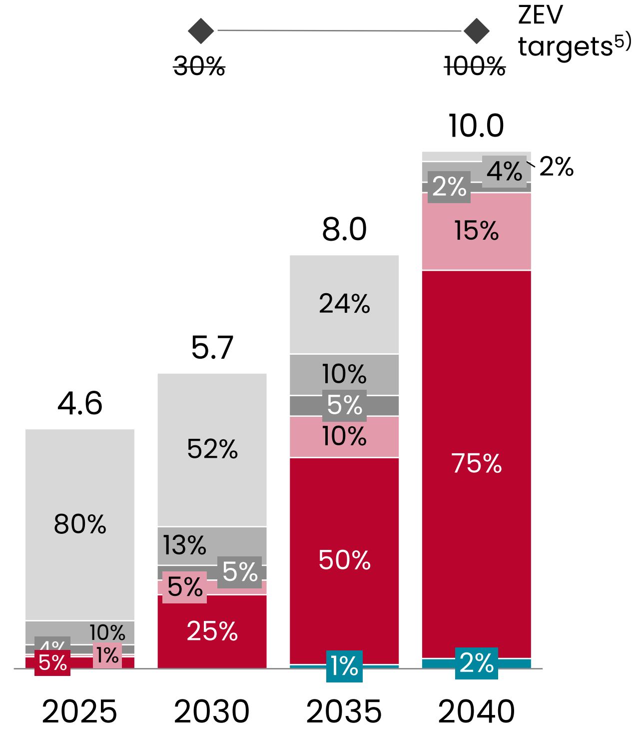

## Moderate transformation

Sales in million units




## Accelerated transformation

Sales in million units

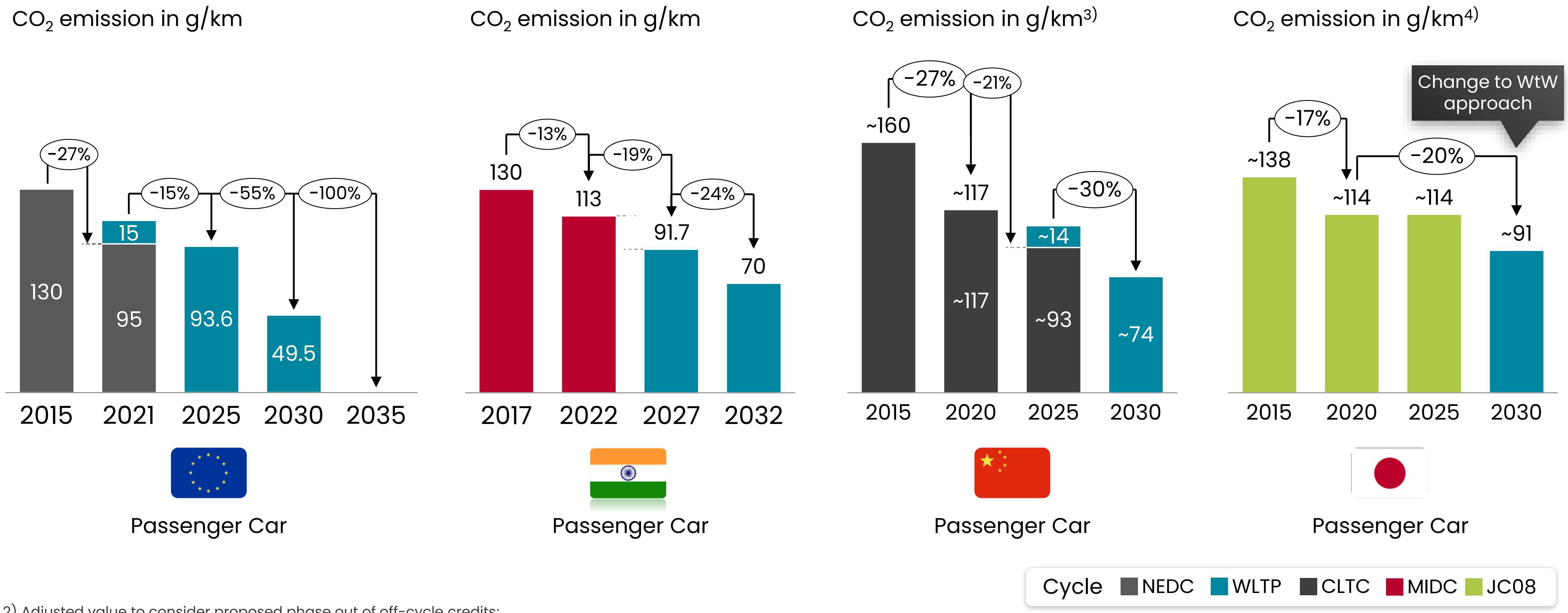



ICE only & Stop/Start 1) | Mild Hybrid 2) | Full Hybrid 3) | Plug-in Hybrid4) | Battery Electric | Fuel Cell

1) Stop/Start and 12 V energy management; 2) 12 V and 48 V mild hybrids; 3) Includes 48 V hybrids with full hybrid functionalities; 4) Includes range-extender electric vehicles;
5) Official governmental ZEV targets (not mandatory by law), expected to be missed or target to be adjusted
Source: FEV

# Fuel economy / $CO_2$ emission targets are continuously tightened in all major markets in the upcoming years

FUEL ECONOMY / $CO_2$ EMISSION REGULATION FOR AUTOMAKERS' VEHICLE FLEETS

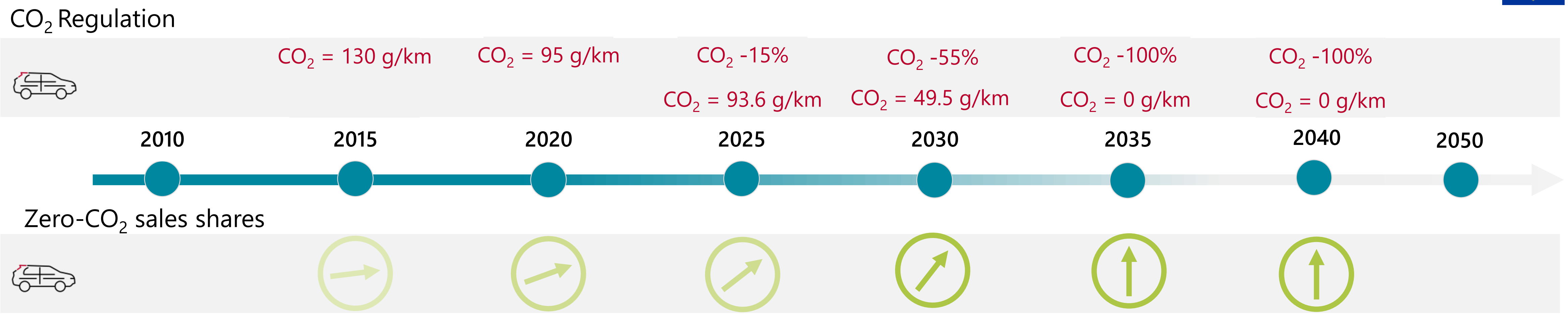



2) Adjusted value to consider proposed phase out of off-cycle credits;
3) Based on Roadmap 2.0 CAFC targets and conversion factor of 2.320 $gCO_2/l$
4) Calculated for gasoline cars based on CAFC targets and conversion factor of 2.320 $gCO_2/l$
Source: FEV

# Passenger cars must be $CO_2$ neutral in 2035, strong reduction already in 2030

$CO_2$ REGULATION BOUNDARIES AND RESULTING ZERO-$CO_2$ POWERTRAIN SHARE ESTIMATES

» ILLUSTRATIVE




## $CO_2$ EMISSIONS/FUEL ECONOMY

- Not regulated within EU7, but within a different standard[1)]
- The **fleet-average $CO_2$ emissions** targets are
  - **95 g/km** (reference cycle: **NEDC**) for cars **by 2020**
  - **93.6 g/km** (reference cycle: **WLTC**) for cars **by 2025**
  - **49.5 g/km** (reference cycle: **WLTC**) for cars **by 2030**
  - **0 g/km** for cars and vans **by 2035**
- Test procedure: NEDC until 2020, WLTP since 2021

Political discussion to average $CO_2$ emissions over 3 years

Discussion to allow ICE with $CO_2$ emissions in case they can only fueled with e-fuels / renewable fuels

Note: Regulation (EU) 2019/631 and Regulation (EU) 2023/851
Sources: EU7 Draft from 10.11.2022 (European Commission), Regulation (EU) 2019/631, Regulation (EU) 2023/851, https://climate.ec.europa.eu/eu-action/transport/road-transport-reducing-co2-emissions-vehicles/co2-emission-performance-standards-cars-and-vans_en
Source: FEV

# India announced net zero emissions target by 2070 at COP26

CARBON PEAKING & NEUTRALITY

**Carbon neutrality** by **2070**

**2021**

Prime Minister Narendra Modi announced bold climate commitments at COP26, Glasgow under the '**Panchamrit**' framework emphasizing climate justice, sustainable living and global cooperation

**2025***

- 36% emissions intensity reduction achieved by 2020
- ~50% installed capacity is from non-fossil sources.
  - Actual utilization is 28%
- 2.5 billion tons of $CO_2$ eq. carbon sink created (2023)

**2030**

- **500 GW of non-fossil energy**
- **Emissions intensity reduction by 45% from 2005 levels**
- **50% of installed capacity from non-fossil sources**
- Create 2.5 to 3 billion tons CO2 eq. of carbon sink

**2070**

- **Net ZERO**

India has not declared a year by which its total greenhouse gas emissions will peak.

**Carbon peaking**

$CO_2$ emissions **reach a maximum** in a certain year and then go into a downward phase

**Carbon neutrality**

Over a period, $CO_2$ generated by the activities of specific organizations or society is absorbed and offset by natural and man-made means, such as afforestation and oceanic absorption, so as to achieve "**zero $CO_2$ emissions**"

Carbon peaking Carbon neutrality

Source: FEV
* Press Release:Press Information Bureau

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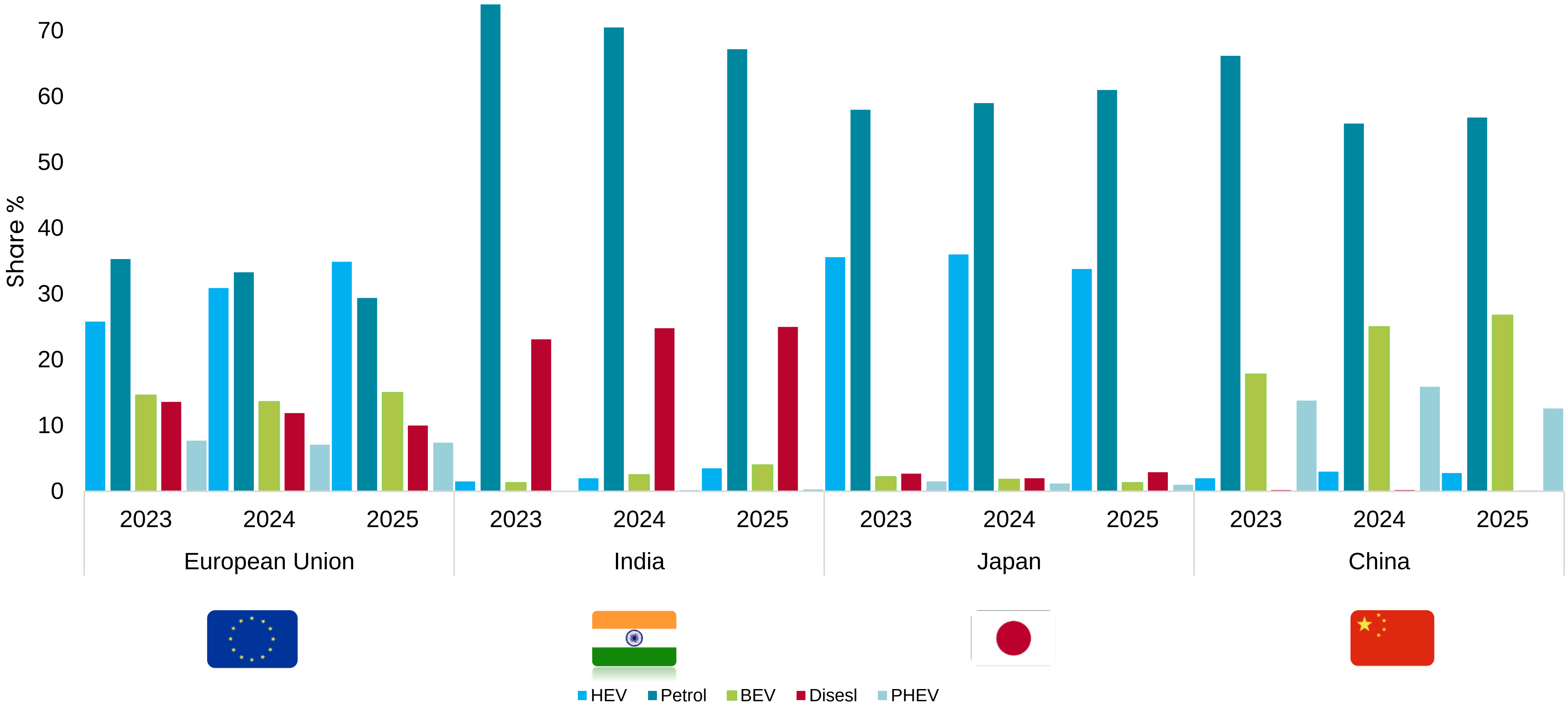
# Market adoption of Passenger vehicle by power source




New car registrations: +0.8% in 2024; battery-electric 13.6% market share - ACEA - European Automobile Manufacturers' Association EVreporter – January 2023 Sales FADA – January 2025 Vehicle Retail Data JAMA – Motor Industry of Japan 2024 Electrive – NEV Sales in 2024 Gasgoo Auto News – Jan 2025 Registrations

# Opportunity for HEVs: EV Adaptation Challenges in India

## Structural and Market barriers

- High upfront costs
  - India is cost sensitive market and entry level (budget segment) EV's are 20 to 40% still expensive compared to ICE vehicles for same category.
- Supply chain constraints
  - Battery material are rare earth minerals and largely imported which increases cost.
- Fragmented policy
  - State level policy all over states in India causes confusion and uneven adoption.
- Limited charging infrastructure

## Why China has more EV penetration

- Massive Industrial Capacity
  - Giga factory growth: China leads in lithium-ion battery production with firms like CATL and BYD dominating supply chains globally.
- Centralised policy and Investment
  - Over 230 billion USD invested n EV subsidies and infrastructure.
- Infrastructure expansion
  - World's largest EV infrastructure with millions of public charging points and fast chargers available.
  - Companies like Neo and Aulton are pioneers in battery swapping station, reducing downtime and range anxiety.
- Consumer Accessibility
  - EVs are available across all price segments, including affordable city cars
  - Urban policies favours EVs with perks like free license plate, priority parking and toll exemption.

China spent $230 billion to build its electric car industry, CSIS says

# HEVs as bridge to EVs in India

- Infrastructure readiness
  - No charging dependency
- OEM readiness
  - Low supply chain dependency: HEV requires relatively smaller sized battery so less imports of raw material
  - Toyota, Honda and Maruti Suzuki already offer strong HEVs in India.
- Policy leverage potential
  - HEVs offer quick emission gains over ICE vehicles by reducing NOx and $CO_2$ emissions significantly
- Ethanol
  - India can produce 1810* crore litres fuel per year which can be used in HEVs to further mitigate emissions


Maruti Invicto


Toyota Hyryder


Honda City eHEV

*Ethanol Production in India Surges to Record Levels Under Modi Government: Aiming for 20% Blending by 2025-26, ETAuto

# Measuring Fleet Fuel Consumption

SUPER CREDITS AND CO2 REDUCING TECHNOLOGIES

| S.No. | Vehicle Type | Volume derogation factor for super credit ($v_i$) |
|---|---|---|
| 1 | Strong Hybrid Electric Vehicles | 2.0 |
| 2 | Plug-in Hybrid Electric Vehicles / Range Extender Hybrid Electric Vehicles | 2.5 |
| 3 | Pure Electric Vehicles | 3.0 |

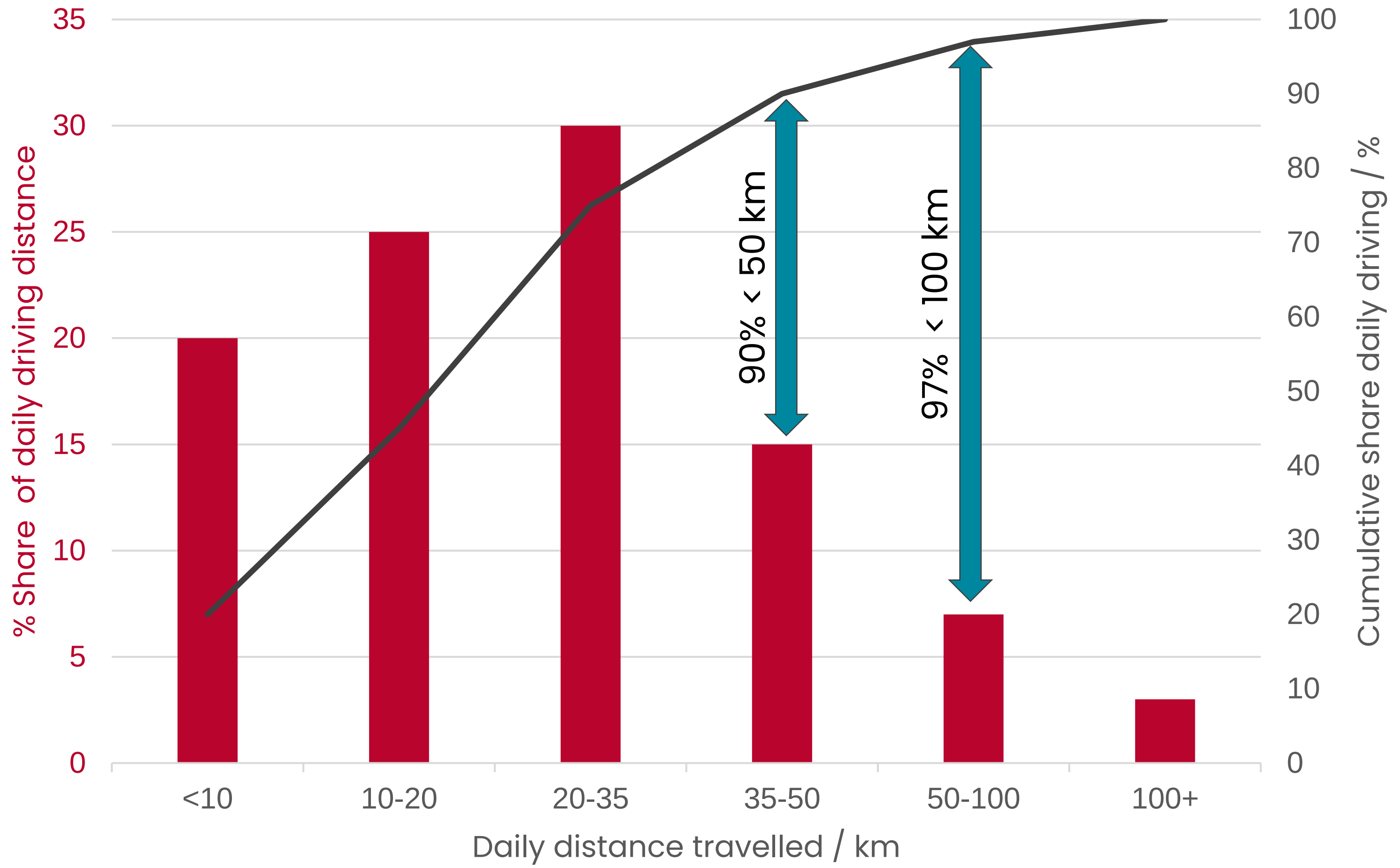
| $CO_2$ Reducing Technologies | $CO_2$ reducing technology derogation factoron $CO_2$ emission ($c_i$) |
|---|---|
| Regenerative braking | 0.98 |
| Start-Stop System | 0.98 |
| Tyre pressure monitoring system | 0.98 |
| 6 or more Speed Transmission | 0.98 |

- A hybrid vehicle in fleet can be counted as equivalent to 2 or 2.5 depending on technology
- All $CO_2$ reduction technologies listed in table can be exploited by HEVs to reduce effective fleet $CO_2$

CO2 Regulations ARAI

# Daily Driving Range for Indian Commuters

90% COMMUTERS TRAVEL <50 KM




- India daily driving data representation shows maximum short distance drives in low speed pattern
- 90% of passenger cars cover below 50 km per day
  - Perfect scenario for hybrid vehicles
- Only 3% of passenger cars are driving more than 100 km

Indian commuters travel 35 km/day, says survey - Times of India

# Current market trend shows substantial efficiency increase of new engine generations, trade-off with specific power depending on technology

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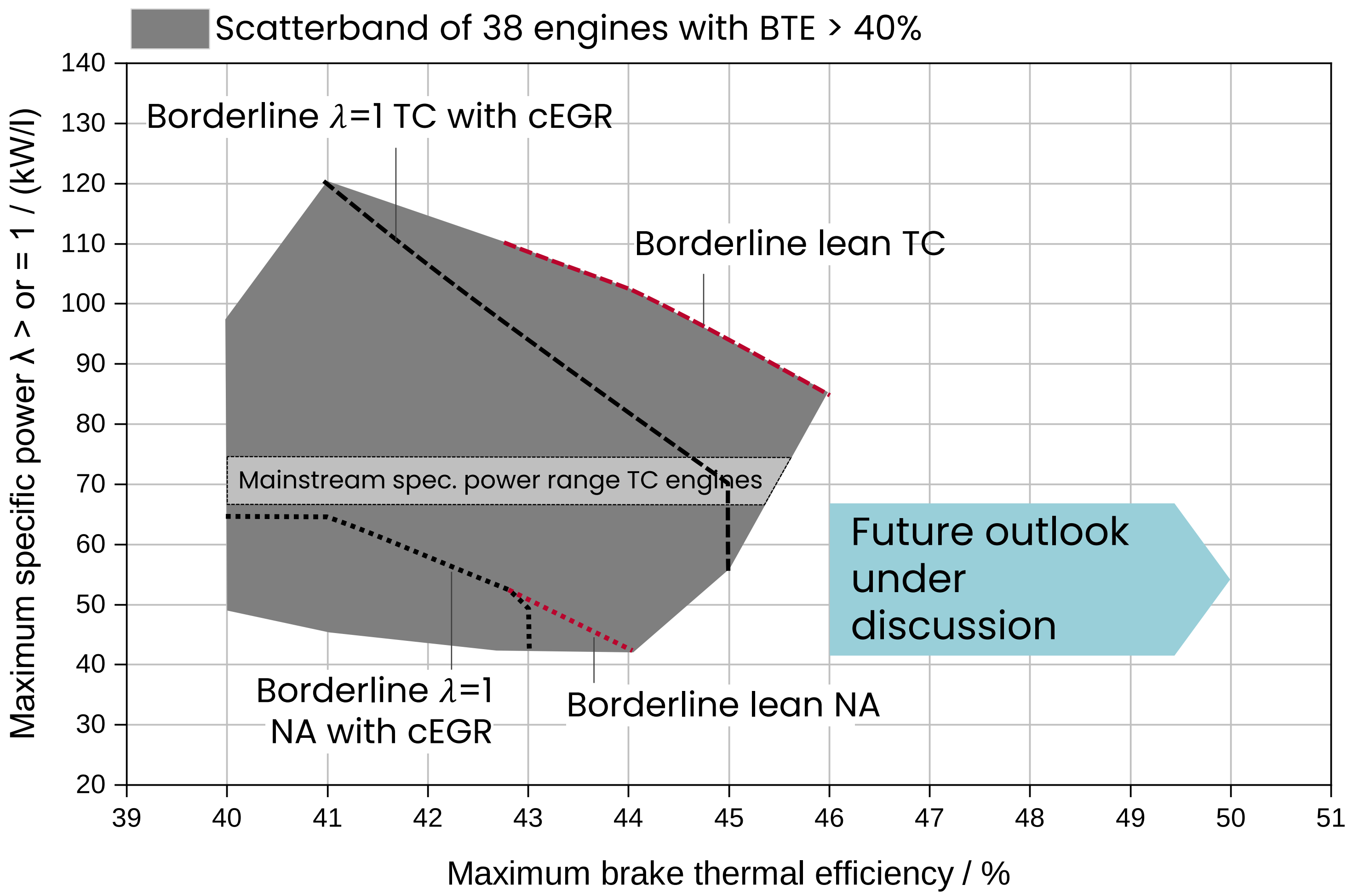
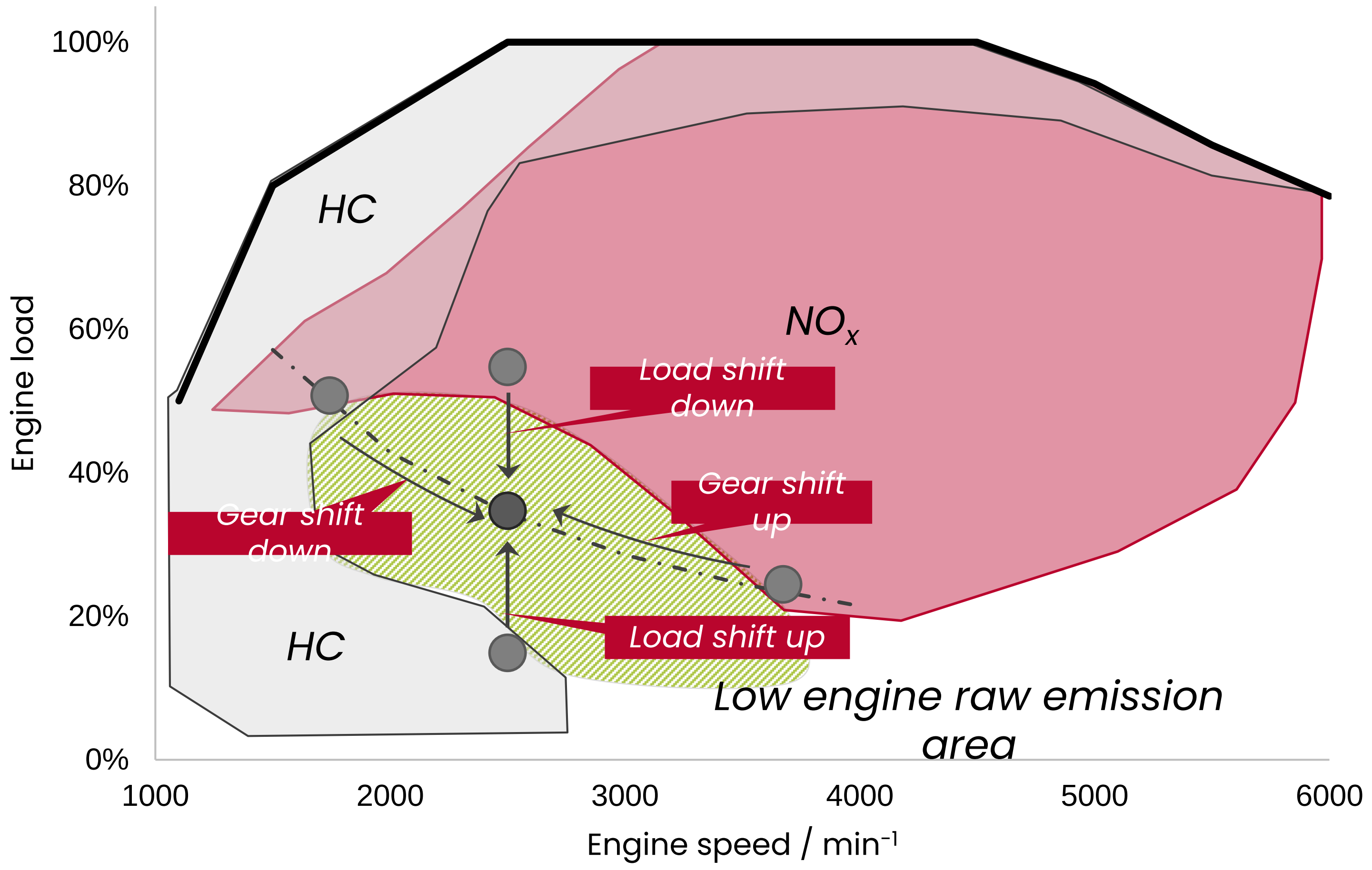
» STATUS 10/2021




- Data includes series-production engines as well as engines under development
- Series-production benchmark status (only λ=1 with cEGR):
  - NA: BTE = 41%
  - TC: BTE = 42.5%
- Future outlook beyond 46% BTE mostly considering additional exhaust heat recovery systems

# During catalyst heating, areas prone to raw emissions can be avoided by shifting gears or changing engine load using the hybrid system

ONLY A SMALL AREA IS SUITABLE DURING CATALYST HEATING




Source: FEV

## Avoiding high raw emission areas

A large part of the engine operation area shows high raw emissions

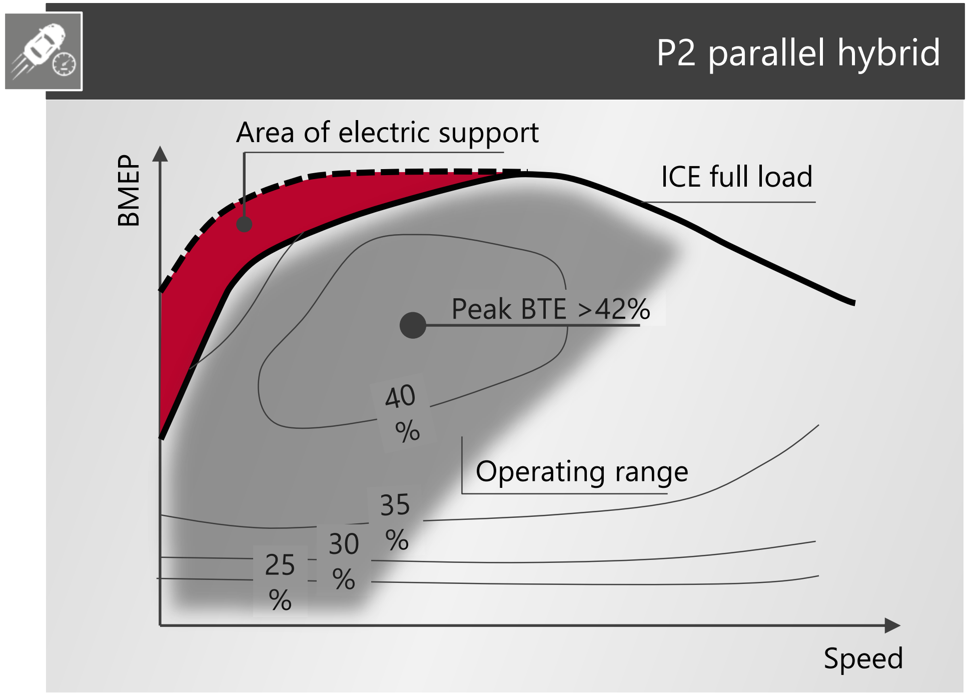
- HC
- $NO_x$

These areas should be avoided during the catalyst heating phase when the conversion rate is still low

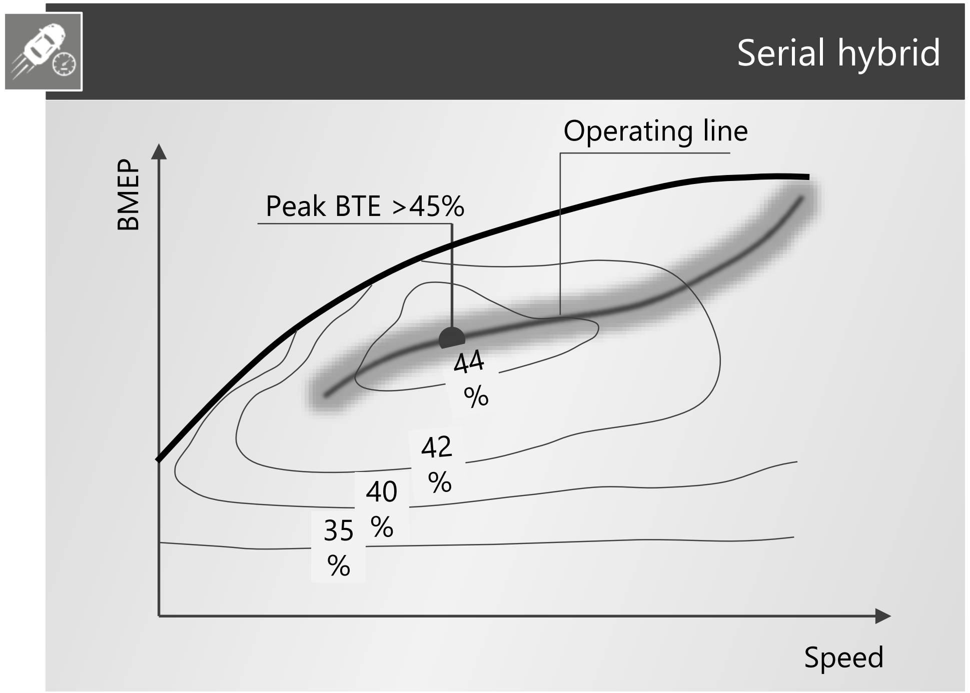
The following measures can be taken to avoid using these areas

- Shifting gears up or down
- Increase engine load
- Decrease engine load

# Specific requirements depend on hybrid powertrain topology
# Case example: TC-GDI DHE for P2 parallel or serial hybrid




- High efficiency (BTE>42%) in sweetspot operating point
- Boosting support through electric machine reduces low-end torque requirements
- Transient requirements less important than conventional engine, but still relevant due to direct mechanical drive of ICE




- Ultra-high efficiency (BTE>45%) in sweetspot operating point (Requires positive pumping work and non knock-limited combustion)
- No low-end torque required
- Quasi-steady operation

TC-GDI DHE: Turbo Charged Gasoline Direct Injection Dedicated Hybrid Engine

# Challenges: Tax Structure for Passenger Cars

MUCH HIGHER TAXATION FOR HYBRIDS COMPARED TO ELECTRIC VEHICLES; ALSO, AT COMPONENT LEVEL

| Vehicle Type | GST Rate | Cess | Effective Rate |
|---|---|---|---|
| **EVs** | **5%** | ... | **5%** |
| **Hybrids** | 28% | 15% | **43%** |
| ICE > 1.5L, Length > 4m GC > 170 mm | 28% | 22% | 50% |
| ICE > 1.5L, Length > 4m | 28% | 20% | 48% |
| ICE < 1.5L, Length > 4m | 28% | 15% | 43% |
| ICE Diesel < 1.5L, Length < 4m | 18% | 3% | 21% |
| ICE CNG/Petrol/LPG < 1.5L, Length < 4m | 18% | 1% | 19% |

- Buyer and manufacturer being disincentivized to go for hybrids
- GST on EV battery packs sold with EVs reduced to 5%
  - Charging stations and related equipment taxed at 5%
- Hybrid vehicles treated similar to ICE engines and hence components attract higher taxes
  - GST on standalone batteries used in hybrid vehicles: 18%
- Rajasthan govt rescinded 25% exemption on road tax for hybrids
  - Although Uttar Pradesh govt has declared zero road tax for hybrids

GST on Hybrid Cars: Rates, Market Impact and Tax Differences

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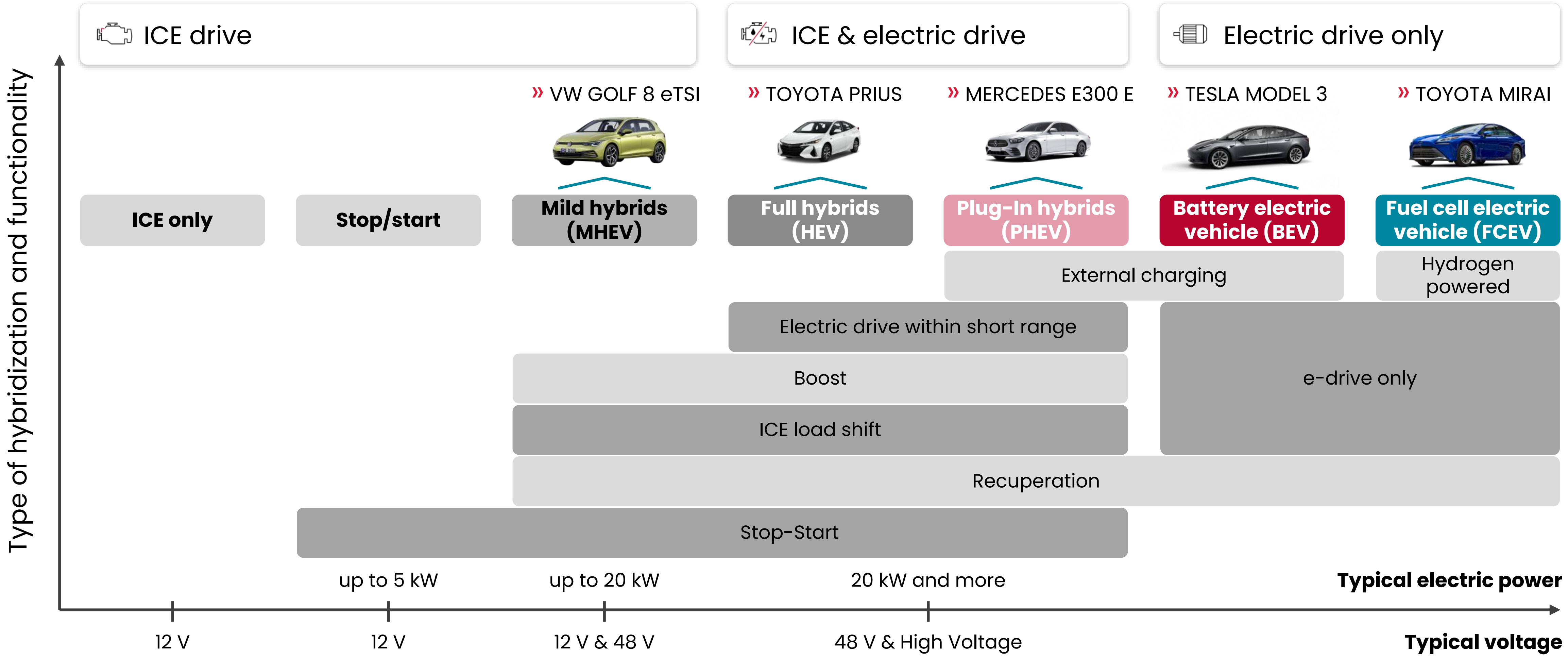
# FEV defines the hybridization level according to the vehicle's functionality

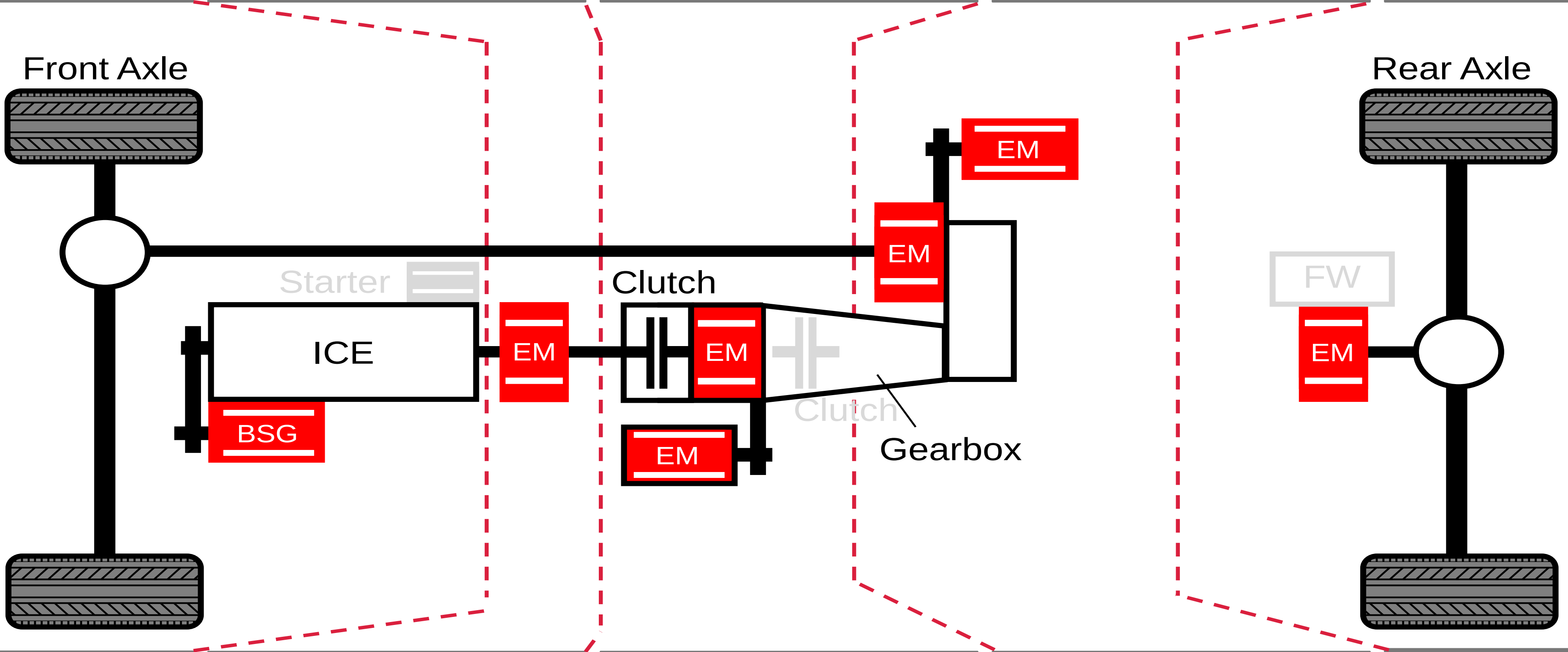
POWERTRAIN LANDSCAPE




Source: FEV

# Hybrid topologies

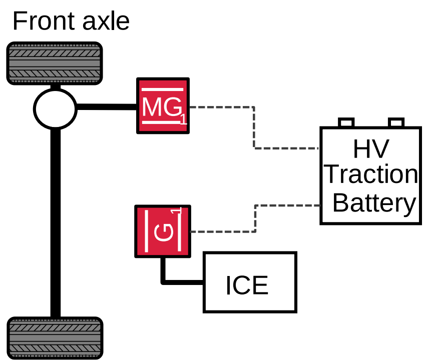
| P0 | P1 | P2 | P3 | P4 |
|---|---|---|---|---|
| Belt-Starter-Generator Electric Power up to 15kW | Integrated-Starter-Generator between ICE and clutch up to 20kW | Integrated-Starter-Generator between gearbox and clutch | Integrated-Starter-Generator at Gearbox Output | Electric Motor at Rear Axle with an optional Flywheel |



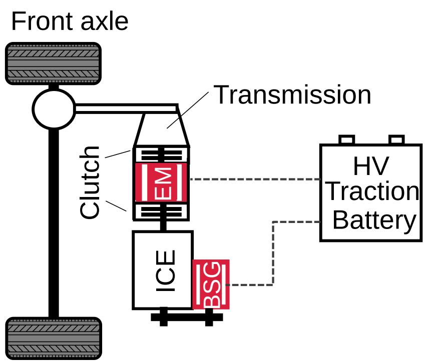
# Investigation of various hybrid powertrain architectures: Component sizing to fulfill vehicle targets. Changing boundary conditions will change which topology comes out with best $CO_2$

## OVERVIEW OF HYBRID POWERTRAIN ARCHITECTURES

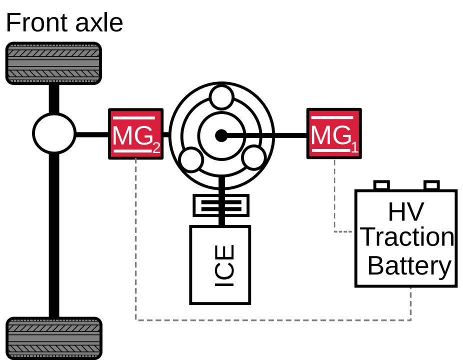
### Serial Hybrid



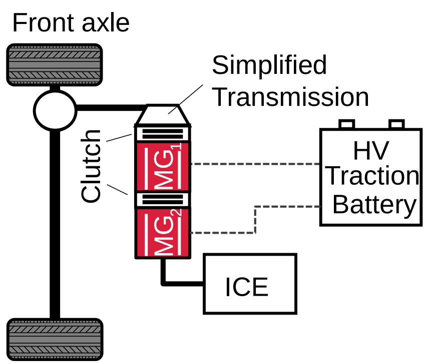

### Parallel Hybrid

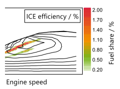


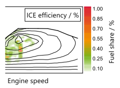

### Powersplit

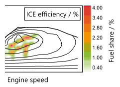


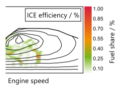

### Combined Hybrid



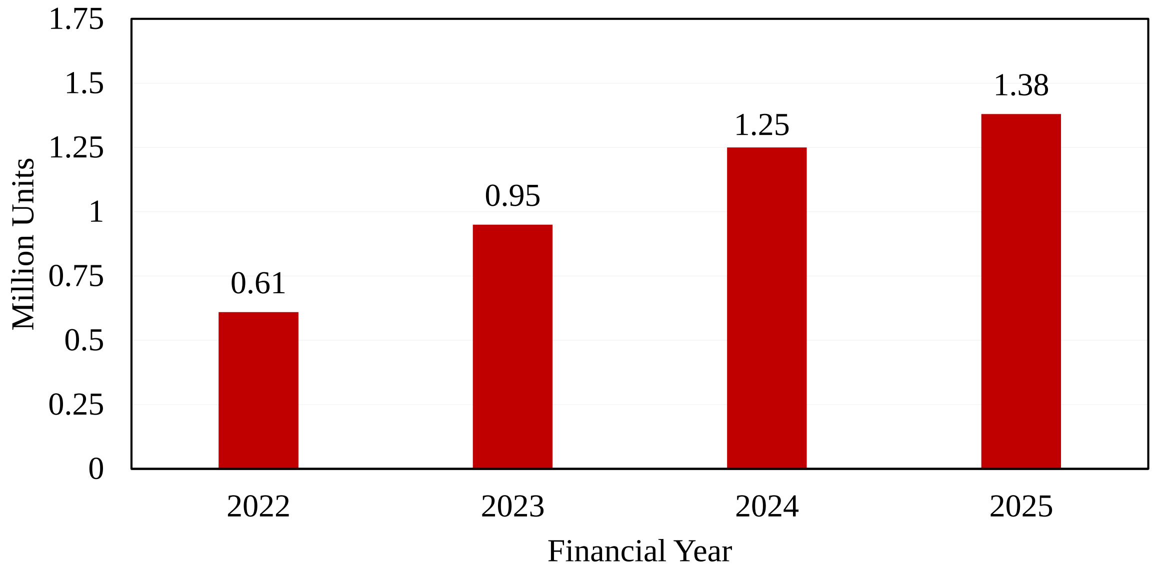



# AGENDA

# Case study: Vehicle Specifications

COMPACT SUV

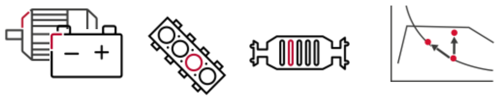



- India's Fastest growing passenger vehicle segment
- Compact sub 4 m SUVs perfect balance between affordability, features & aspirational design for Indian consumer
- Driven by tax benefits, urban mobility needs and consumer preference shift from hatchbacks to compact SUV.

| **Vehicle Segment** | **Passenger Vehicle** |
|---|---|
| Fuel | Gasoline |
| Curb Weight (kg) | 1255 kg |
| Maximum Speed | 160 km/h |
| Emission Compliance | BSVI - Phase II |
| Peak Power | 88 kW |
| Peak Torque | 170 Nm |
| Coefficient of drag | 0.35 |
| Frontal Area | 2.5 $m^2$ |
| Rolling resistance | 6.05 kg/t |
| Number of gears | 6 |

# Drivetrain Optimization

### Parametric description of powertrain components & operation strategy



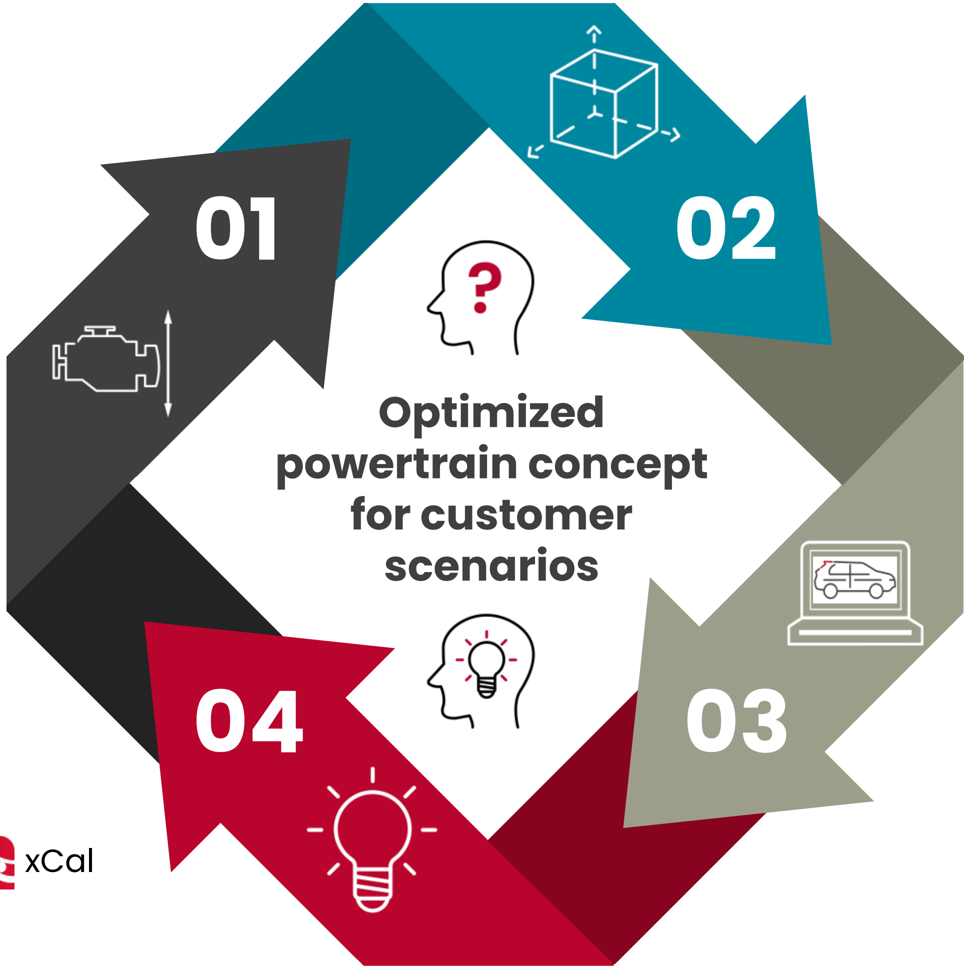
Variation parameters

- Powertrain component sizing
- Operation strategy

### Mathematical modeling and numerical optimization

- Impact of all variable parameters on $CO_2$, pollutant emissions and fuel economy
- Consideration of constraints, eg. Acceleration performance and running GP optimization using XCal

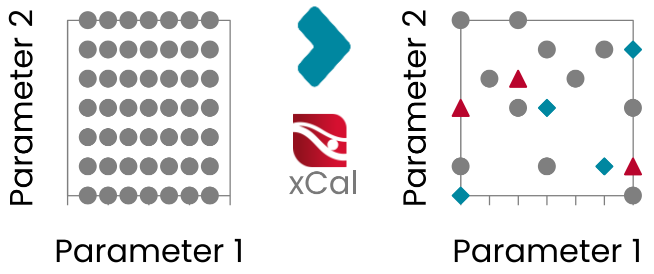
xCal

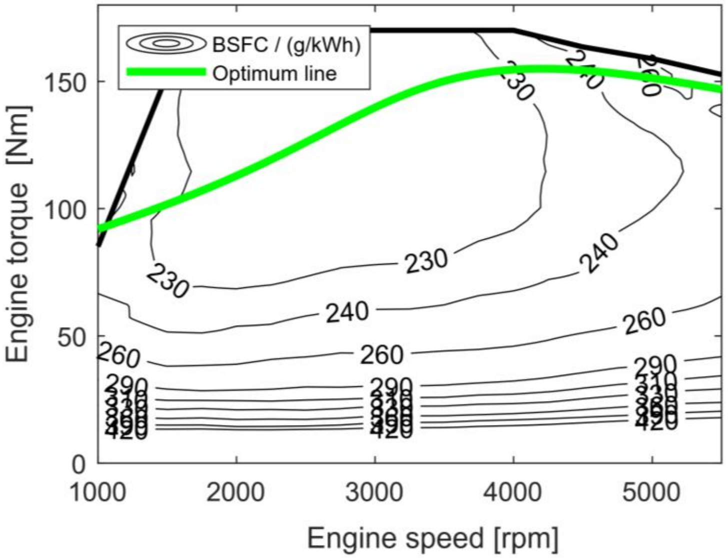



### Creation of DoE test plan

- Variation of all parameters within defined constraints

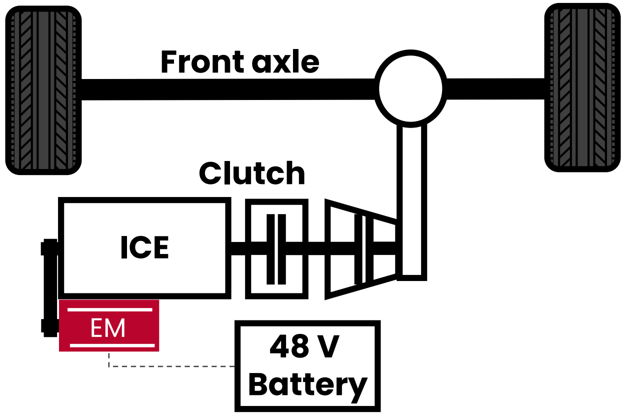
Model point
Validation point
Repetition point



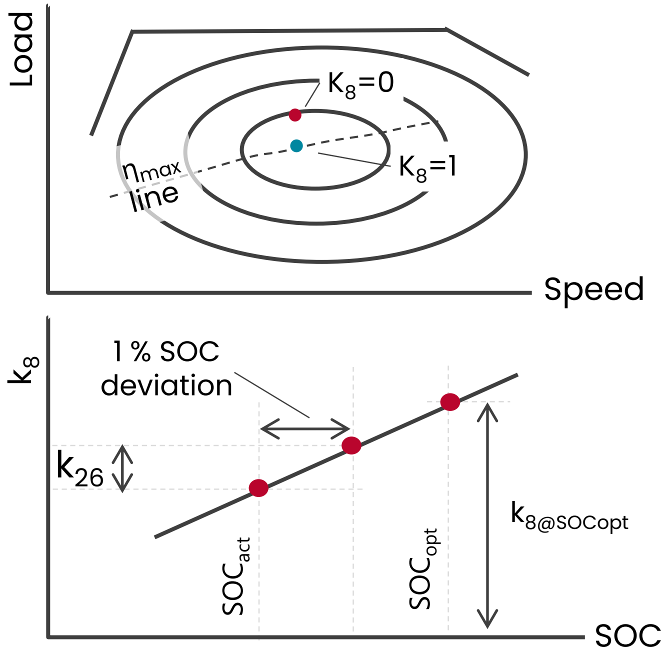
# Example of Hybrid Operation Strategy

48V P0 MILD HYBRID




**Topology characteristics**

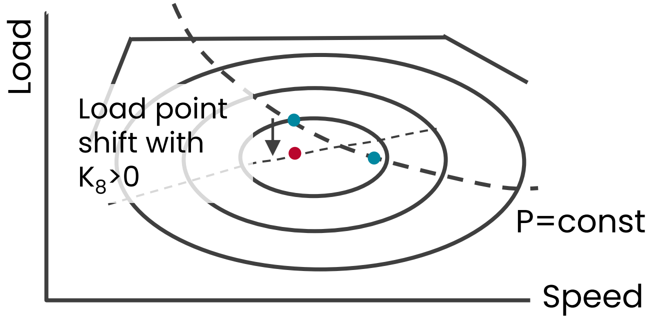
- Pros
  - Cost-efficient enabler of hybrid functions
  - Only limited ICE control and E/E modifications
- Cons
  - Reduced recuperation potential (ICE and belt drag torque)
  - Modifications of crankshaft, bearings, belt and cooling system




$$k_8 = k_{8@SOCopt} - (SOC_{opt} - SOC_{act}) \cdot k_{26}$$

- $k_8$ = 0: no load point shift
- $k_8$ = 1: load point shift to max. efficiency line

**Adaptation of shifting strategy**




- In case the vehicle can recuperate more energy than can be used by load point shifting to maximum efficiency line, then the gear shifting strategy can be adapted
- Due to earlier upshifting, the operation point is shifted to lower engine speeds / higher load
- With a load point shifting parameter $k_8$ > 0, the operation point is shifted towards maximum efficiency line

# Topologies simulated and investigated in this study

## 48V P0 Mild hybrid

- Main Functionalities
  - Regenerative braking
  - Applying Partial boost energy
- Motor Power: 10 kW

## 12V P0, 48V P2

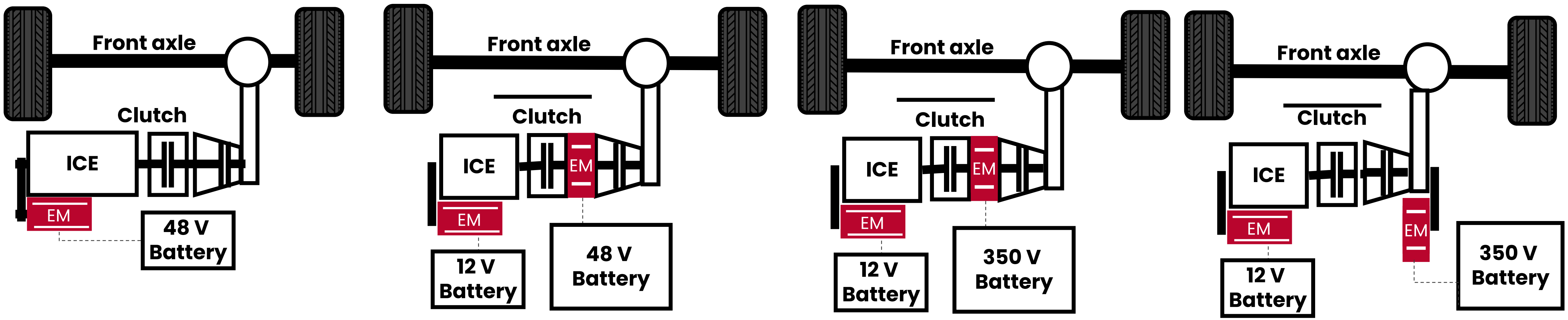
- Main Functionalities
  - Pure electric driving
  - Regenerative braking
  - Applying boost energy
- Motor Power: 21 kW

## 12V P0, 350V P2

- Main Functionalities
  - Pure electric driving
  - Regenerative braking
  - Applying boost energy
- Motor Power: 35 kW

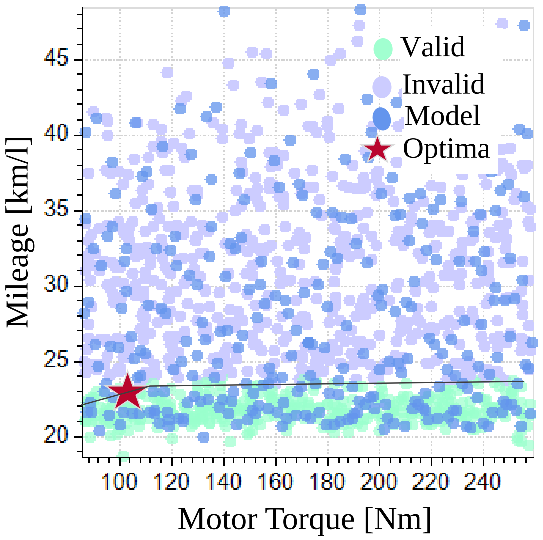
## 12V P0, 350V P4

- Main Functionalities
  - Pure electric driving
  - Regenerative braking
  - Applying boost energy
  - 4 WD available
- Motor Power: 30 kW

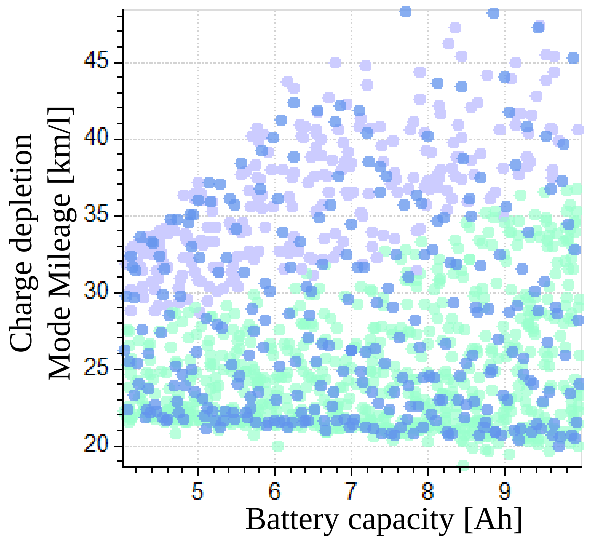


# DOE trade off plots P0P2 HV, the valid points indicates a solution which fulfills all boundary conditions

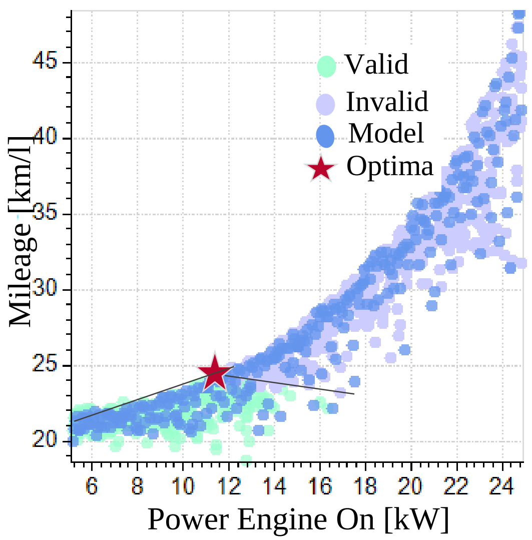
- Range of motor torque
  - Minimum 80Nm / 27 kW
  - Maximum 240 Nm / 80kW
- Optimum – 108Nm / 35 kW



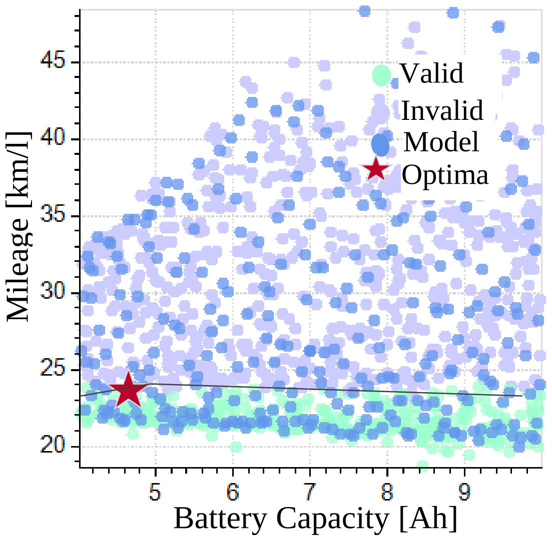

- Range of Battery capacity charge depletion
  - Minimum 4 Ah
  - Maximum 10 Ah




- Range of Engine on power request
  - Minimum 6 kW
  - Maximum 24
- Optimum – 11.5 kW



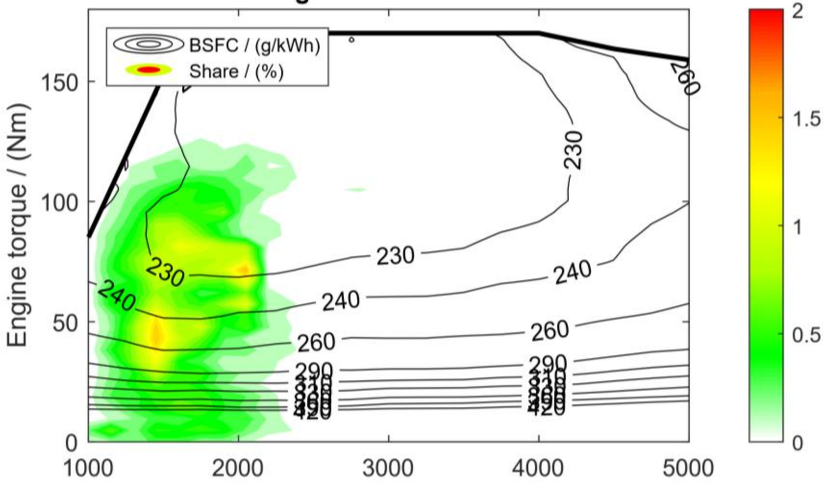

- Range of battery capacity charge sustaining [ Ah]
  - Minimum 4 Ah
  - Maximum 10 Ah
- Optimum – 4.5Ah



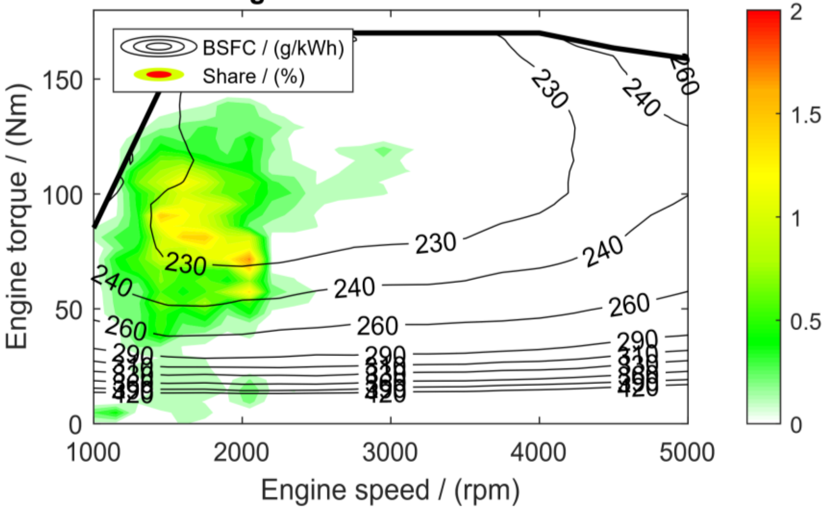
# Engine share plot comparison

CYCLE WLTC 3B

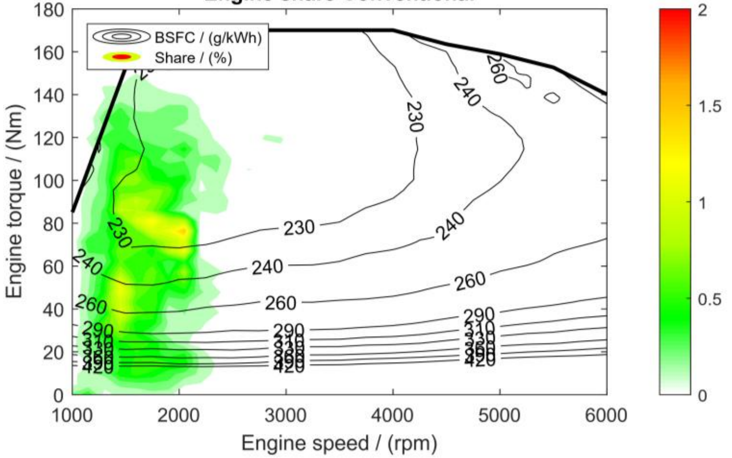
Engine fuel share P0



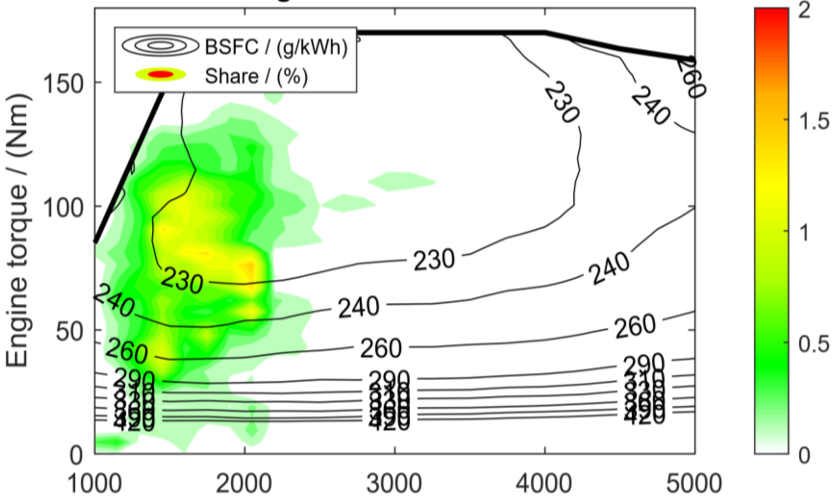

Engine fuel share P0P2 HV



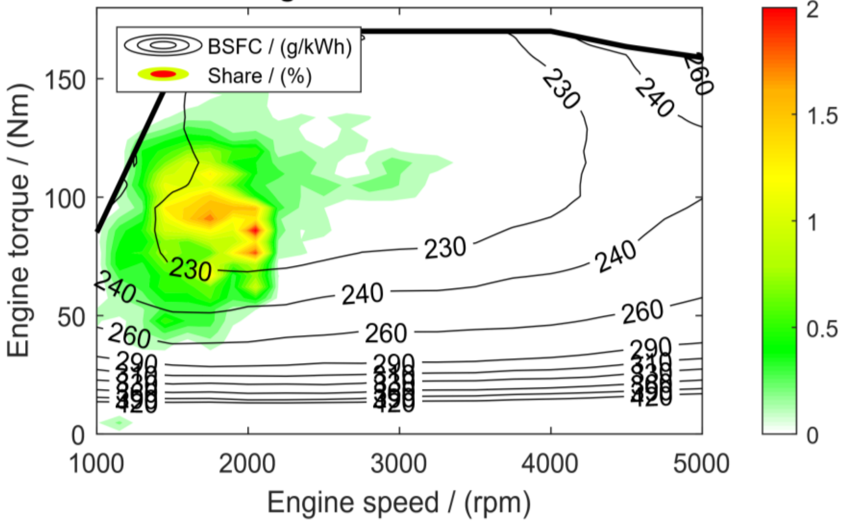

Engine share Conventional




Engine fuel share P0P2



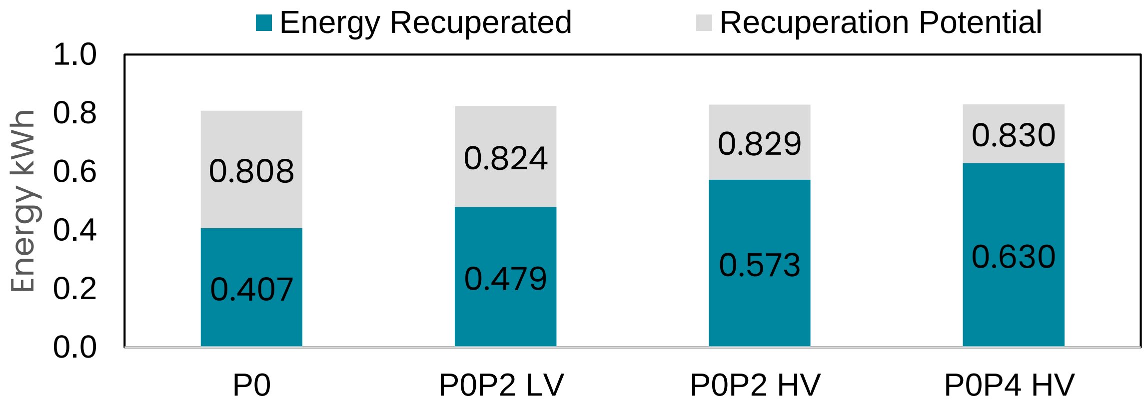

Engine fuel share P0P4



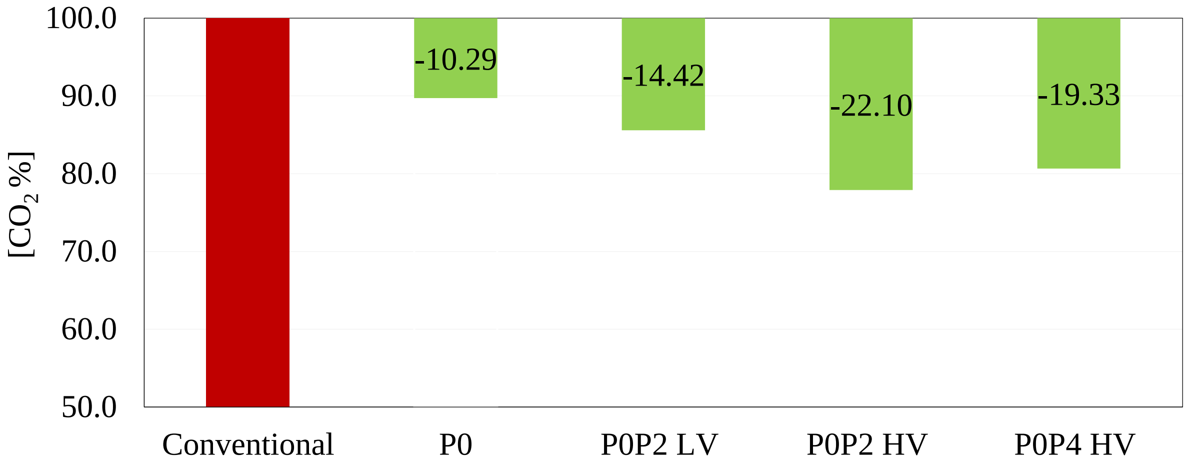
# Fuel Economy Improvement and Regeneration Potential

## COMPARATIVE ANALYSIS FOR $CO_2$ REDUCTION WITH VARIOUS HYBRID TOPOLOGIES OVER WLTC CLASS 3B TEST CYCLE

- P0P2 HV system recovers 69% of total potential available
- P0 has a low level of regeneration potential being the last component in reverse order of transmission. Around ~50.4% of potential energy available during deceleration phase is recuperated by a P0.
- P0P4 HV: 75% energy is recuperated
- P0P2 48V hybrid config, approximately 58.2% recuperation




- P0P2 HV shows ~28% fuel consumption improvement
- P0P4 HV offers ~24% fuel improvement over conventional. Even with better recuperation and better operation of engine than P0P2, P0P4 losses the advantage in energy deployment because of efficiency in propulsion.



# AGENDA

BACKGROUND AND INTRODUCTION

OPPORTUNITIES AND CHALLENGES

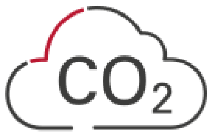
HYBRID TOPOLOGIES

HYBRID MODEL CASE STUDY

**SUMMARY**

SUMMARY

# Hybrid Vehicles for India




- Drastic steps needed to reduce fleet CO2 emissions to meet upcoming CAFÉ' norms.
- Most incentives including PLIs and tax slabs pushing towards mass adoption of EVs, yet overall share of EVs remains primarily due to issues like customer range anxiety, lack of charging infrastructure in remote regions etc.
- Strong case to use hybrids as a step to eventual complete fleet electrification
  - Urgent need to reform tax structure
  - Treat hybrids different from ICE vehicles
  - Identify certain vehicle classes to encourage hybridization – M1, N1 etc.
- Enough levers in legislation to exploit for fleet reduction with hybridization
- Preliminary investigations show P0P2 HV as optimal solution for compact SUV segment:
- From regulation perspective the $CO_2$ reduction potential achieved by various topologies indicates a clear pathway for OEMs to meet upcoming norms