POLITECNICO
MILANO 1863

Comparison of AWD vehicle powertrains

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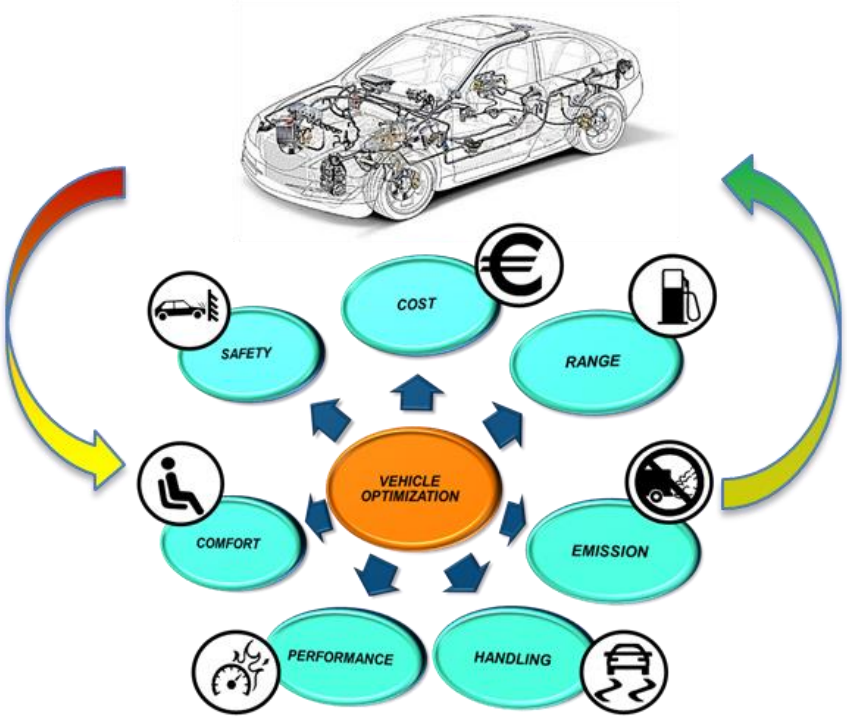
Field of interest

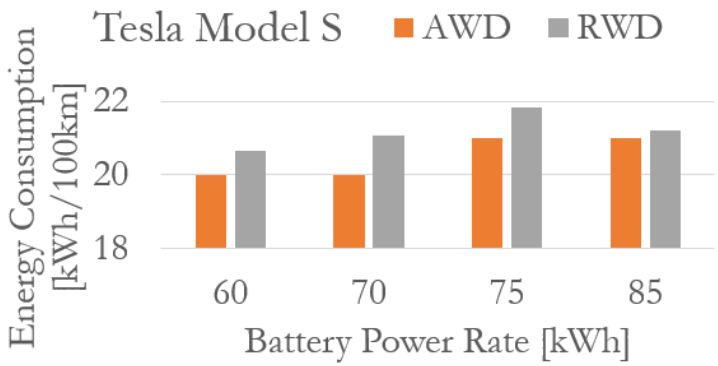
- Vehicle and powertrain subsystems
- Powertrain architectures
- Modelling and simulation methods
- Multi-objective optimization

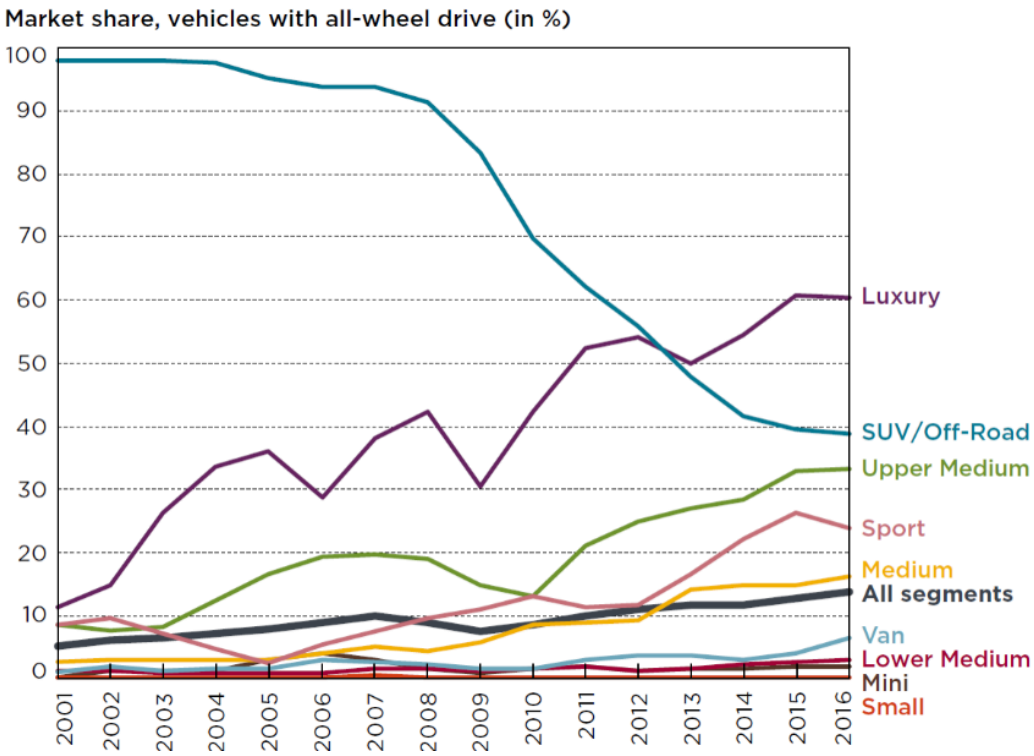


AWD powertrains

EU average market share 5% in 2001 → 15% in 2016

- AWD
  - driving performances
- electrified powertrains
  - energy consumption





Methodological approach

- Modelling
- Optimization
- Results
- Conclusions

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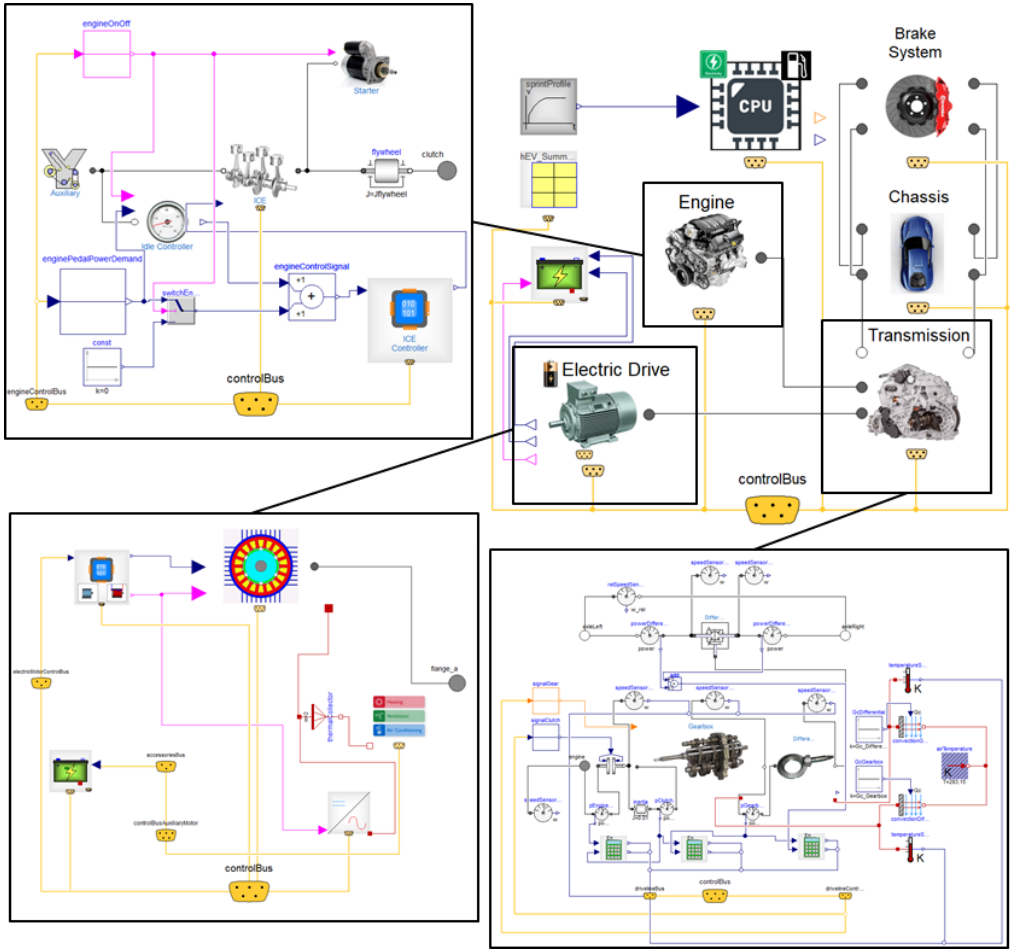
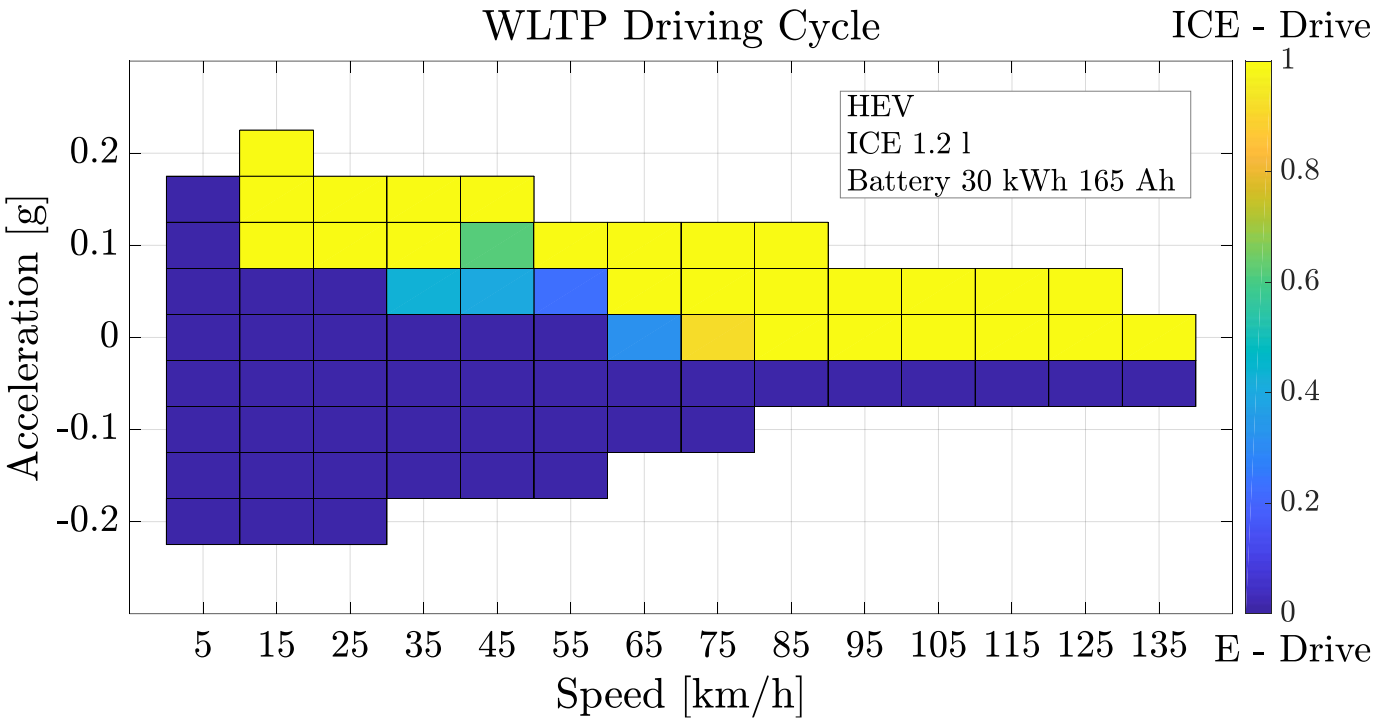
Modelling

- Vehicle: lumped parameters + lookup tables
- Internal Combustion Engine: 1D CFD
- Electric Motor: Electromagnetic FEM



Energy management strategy

- Gear shifting
- Power management
  - Axle power distribution
  - Hybrid operating modes



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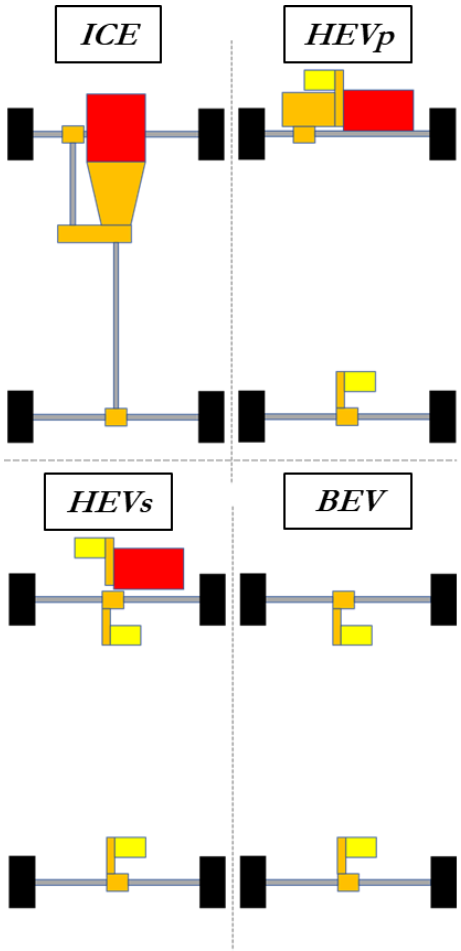
Optimisation

Vehicle Level	• Specific vehicle • **AWD Class D**
Subsystem Level	• Individual powertrain analysis
Components Level	• Design variables



Design Variables

- Focus on powertrain subsystems
- Reduced set of subsystems main design variables

Battery	*Series cells*	30,…,160(120*)
	Parallel cells	10,…,70(50*)
	Scaling factor	0,…,1
ICE	*Bore/Stroke*	0.8,…,1.2
	CR	9,…,13
	Bore [mm]	65,…,100
	Cylinders	3,4,6,8 (3,4**)
EM(GEN)	*Type*	PMSM,AIM
	EM Power distribution (rear/front)	0.1,…,0.9
	Current ratio (GEN/Battery)	0.1,…,2
	GEN speed [rpm]	10000,…,20000
	EMF speed [rpm]	10000,…,20000
	EMR speed [rpm]	10000,…,20000
Gearbox^{ICE}	*Gears add*	0,1,2
	Max gear ratio	3,…,5
	Min gear ratio	0.4,…,0.9
	type	MT,DCT,AT
	Progression factor	0,…,1
Gearbox^{EM}	*Max gear ratio*	2,…,4
	Front gears	1,2
	Rear gears	1,2
Differential	*Scaled gear ratio*	0.5,…,1.5

Objectives

- ❑ Consumption
- ❑ Range
- ❑ Emission
- ❑ Cost
- ❑ Dynamics (Vehicle)
- ❑ Overtaking
- ❑ Consumer

Normalisation values [min-max]

Consumer	Average consumer satisfaction based on: objectives fulfillment of common vehicle performances, off-road driving capabilities, cornering stability and optional components installation $\text{Consumer} = \frac{1}{7}\Big(\text{Consumption}\left[6-10\,\frac{€}{100\text{km}}\right] + \text{Range}[400-500\text{ km}] + \text{Emission}[100-150\,\%]$ $+ \text{top speed}\left[250-300\,\frac{\text{km}}{\text{h}}\right] + 0-100\,\frac{\text{km}}{\text{h}}\,\text{acceleration}[3-5\text{ s}] + \text{Dynamics}$ $+ \text{Cost}\,[10-50\text{ k€}]\Big) + \text{optional components} \times 5\%$ $+ \text{off-road}[30-40\,\%] \times 5\%$ $+ \sqrt{\text{wheel steer angle}[\pm 10-0\,°] \times \text{roll stability}[0.1-0.5]} \times 5\%$

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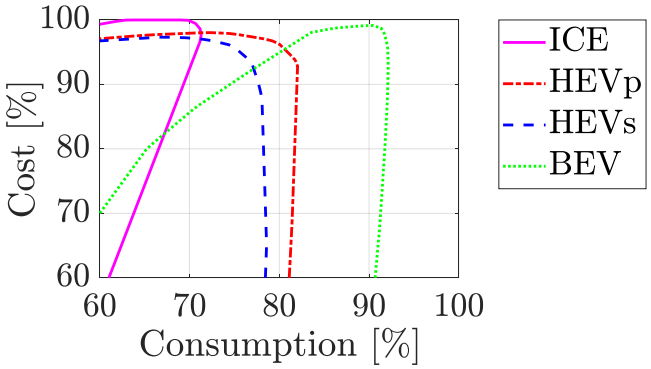
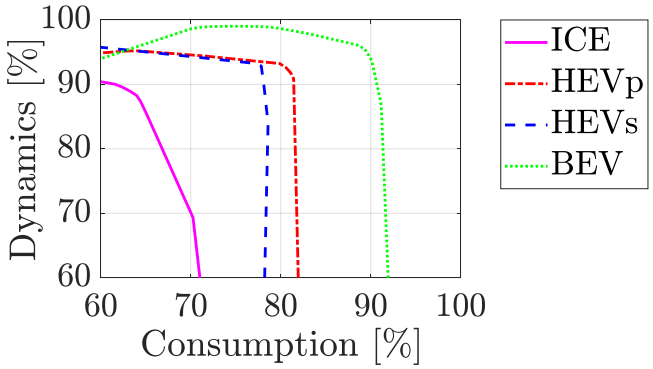
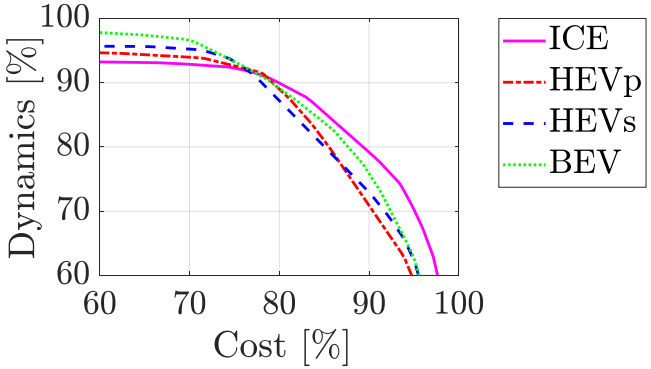
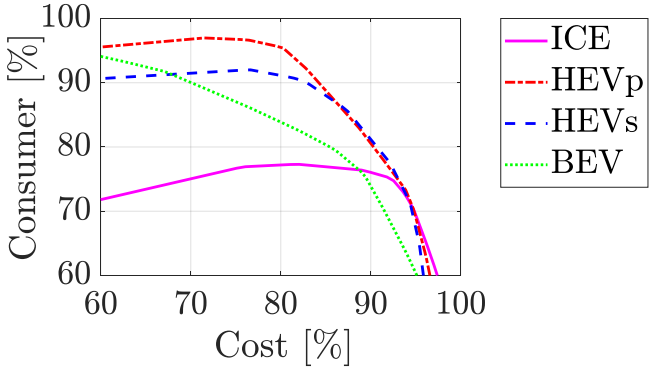
Solution space frontiers

Powertrain	*Objective*
ICE	*Cost*
HEVp	*Consumer, Trade-Off ICE-EV*
HEVs	*Trade-Off ICE-EV*
BEV	*Consumption , Dynamics*





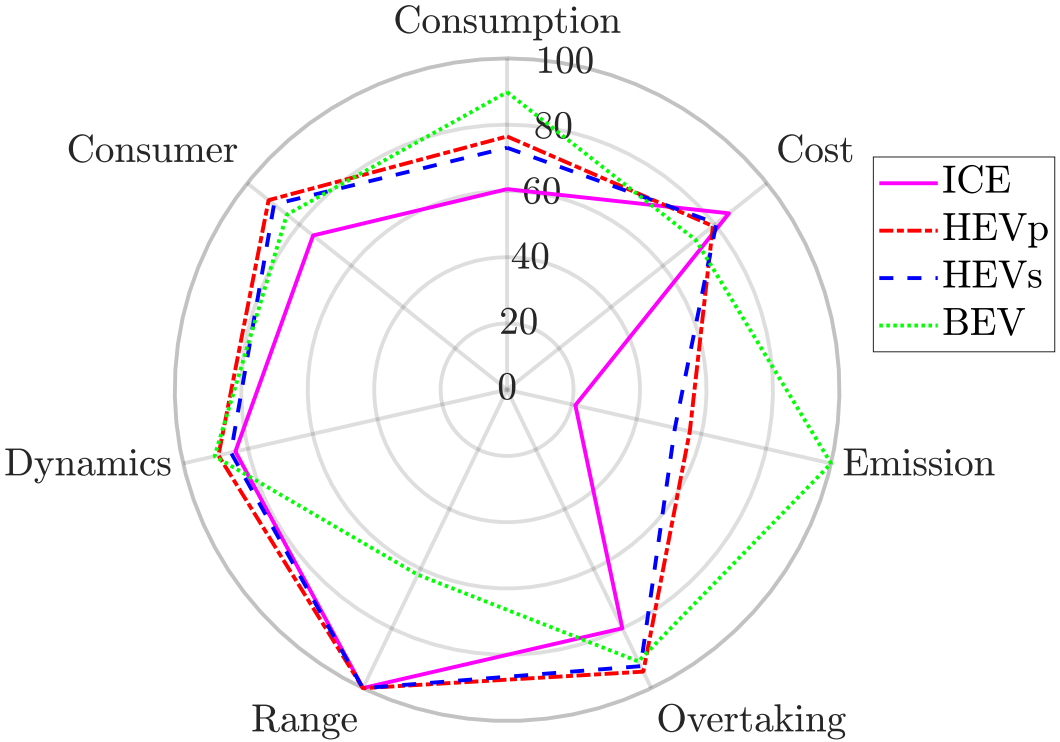




Optimal design

Optimal design identified considering:

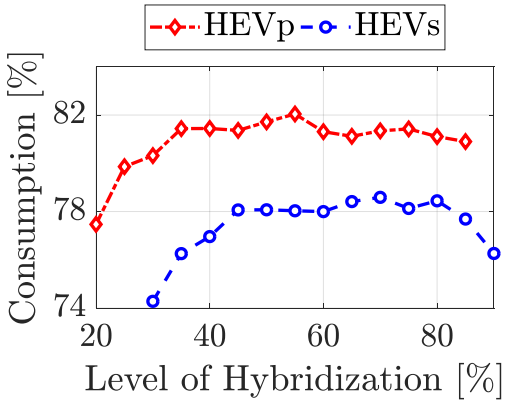
- ❑ Correlation coefficients
- ❑ Values range
- ❑ Distance from Utopia point (ideal optimal result)

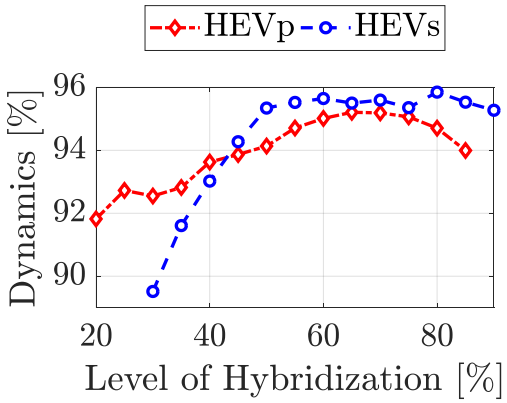


Design variables analysis

$$Level\ of\ Hybridization = \frac{P_{Battery}}{P_{Battery} + P_{ICE}}$$

- HEVp more efficient energy flow in the powertrain
- Dynamics improvement with the level of hybridization related to electric power increase (favourable low-end torque of electric motors)

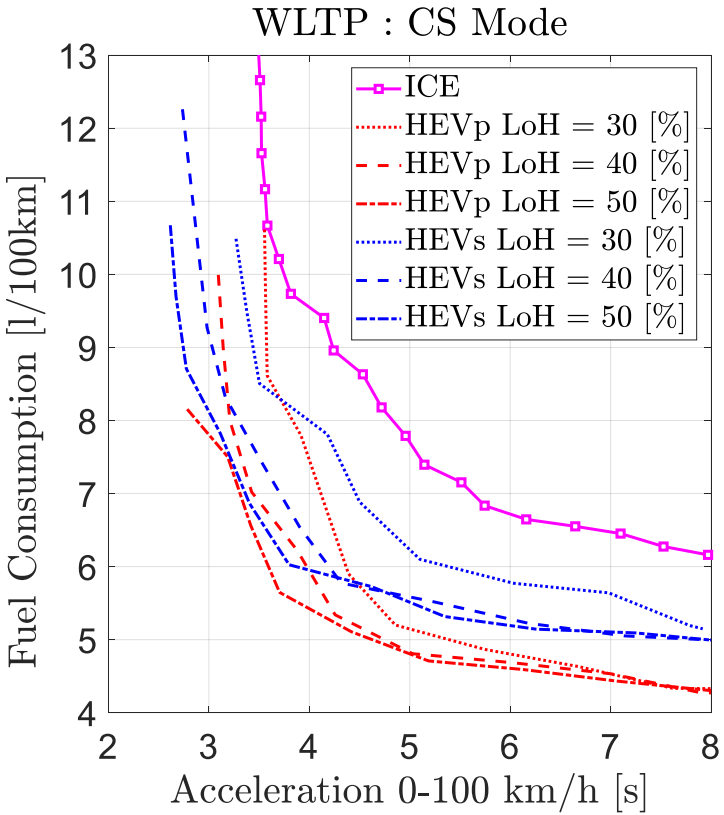




Design variables analysis

Level of Hybridization (LoH)

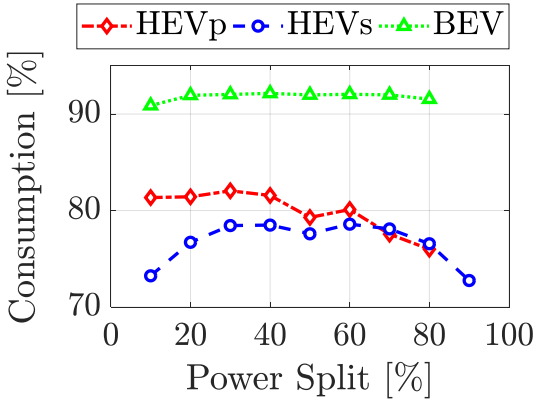
- Charge Sustaining Mode in WLTP driving cycle (CS Mode)
- Remarkable fuel consumption savings for LoH up to 40%
- LoH > 40% allows to further improve maximum achievable acceleration

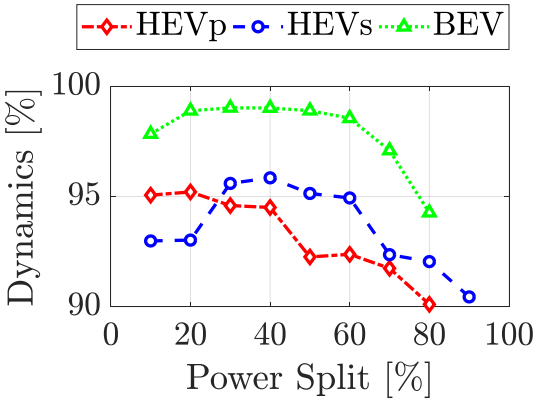


Design variables analysis

$$Power\ Split = \frac{P_{EM,front}}{P_{EM,rear} + P_{EM,front}}$$

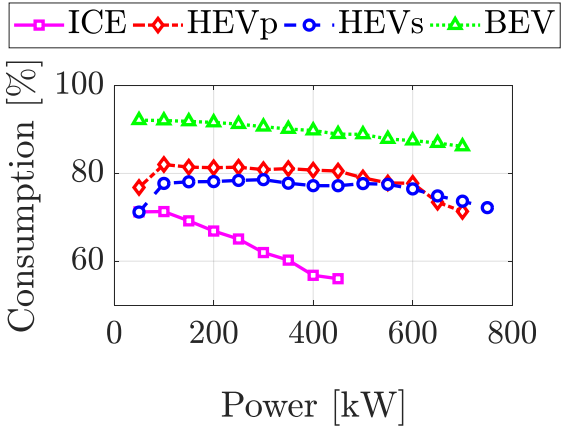
- Consumption optimal solution lies in the range 30-40%
- Dynamics optimal solution depends on powertrain layout, 30-40% for BEV and HEVs, 10-20% for HEVp (combustion engine on front axle)

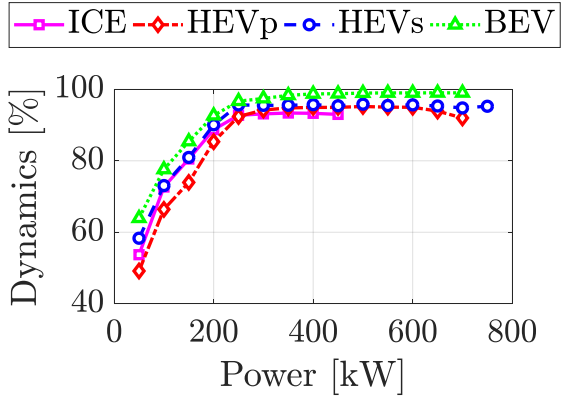




Design variables analysis

- Power increase worsens consumption, the effect is less sensitive in HEV by optimally selecting the level of hybridization
- Dynamics reaches a plateu value showing that further power increase doesn't provide relevant improvements in vehicle dynamics





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Conclusions

- Modelling
  - ❑ detailed definition of the powertrain subsystems
  - ❑ optimal energy management strategy
- Optimization
  - ❑ problem definition
  - ❑ design variables, objectives
- Results
  - ❑ comparison of several powertrain architectures
  - ❑ identification of optimal design solutions
  - ❑ analysis of the main design variables

Thank you for the attention