

# Powertrain Calibration Optimisation

Optimisation

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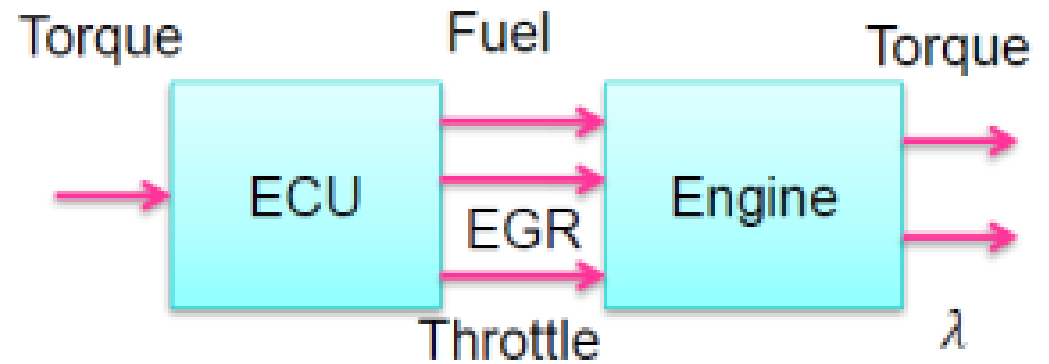
# Aim

- ❑ Overview of the calibration objectives
  - ❑ What is optimisation
    - ❑ Objective function
    - ❑ Algorithm – finding the minimum
    - ❑ Constraints
  - ❑ Pareto curve and the NOx tradeoff
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## Calibration Goal: Model Inversion

Access the desired reference via

- ❑ Inversion of the static non-linear model
- ❑ Inversion of the dynamic model
- ❑ Or control



Obtain the desired torque

## Multicriterial Optimisation

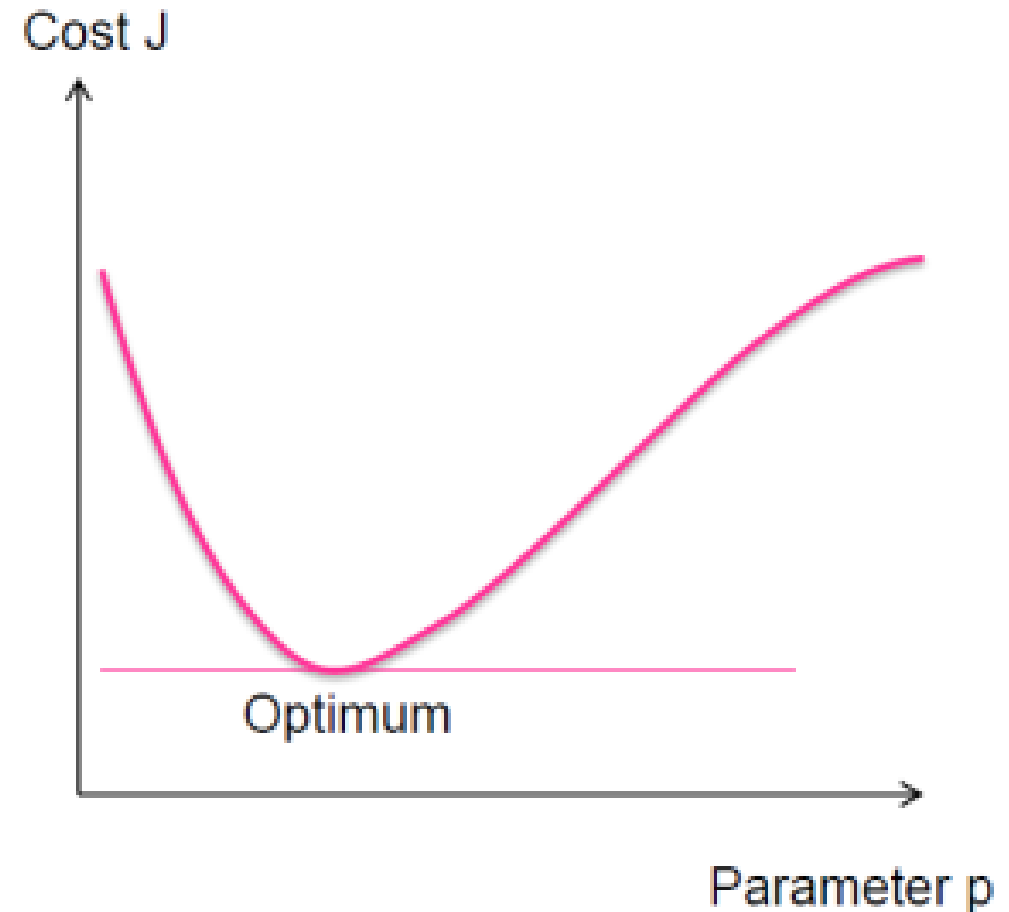
- Model all the relevant factor – responses
  - Fuel consumption
  - Emissions
  - Driveability

Create a weighted cost function:

$$\begin{aligned} J &= \alpha J_{fuel} \\ &+ \beta J_{emissions} \\ &+ \dots \end{aligned}$$

## Optimisation

- Use an algorithm to find the best compromise - the lowest total cost.
- Lots of dimensions to consider
- How to find this?



## Limits

### □ Physical limits

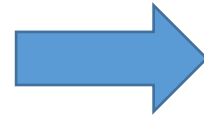
- Cylinder pressure
- Fuel flow
- Valve range
- VGT range

### □ Legal limits

- Emissions
  - Power
  - Noise
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## Limits

- Limits are difficult. Hard limits;
  - Active limit: equality constraint
  - Inactive limit: not relevant
- Soft limits
  - Cost penalty



Handling differs by algorithm and tool.

## Optimisation with weighted Objectives

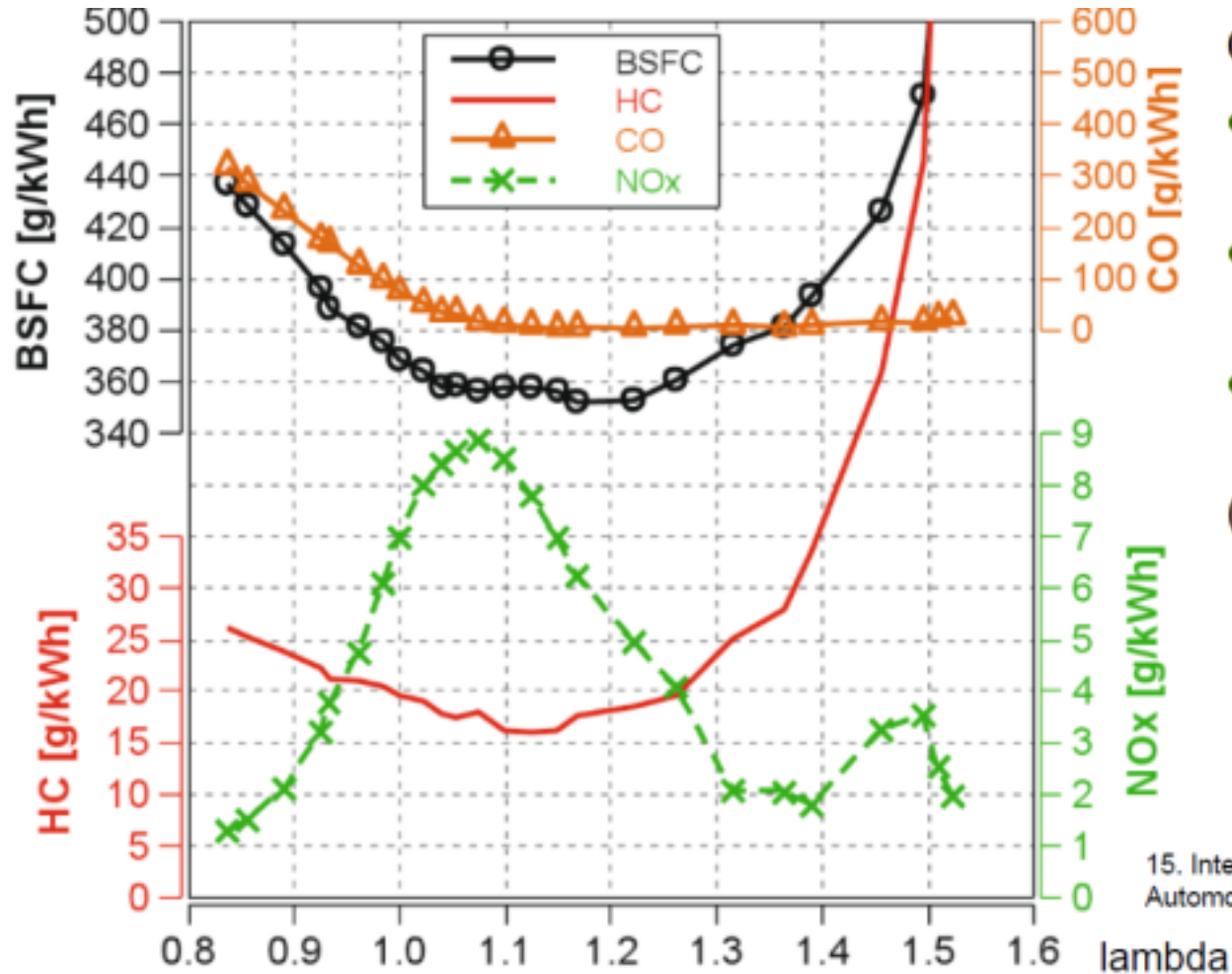
- Optimisation is the process of finding the best combination of controls to meet a specified task.
- In an optimisation process a cost function is formulated and minimised.
- The Cost function contains quantities to be minimised.
- The **weighting** is essential

$$\min_{p \in P} J(p) \text{ with } J = \sum_i \alpha_i f_i(p)$$

- $f_1$  may be a measure of fuel consumption
- $f_2$  may be a measure of NOx emissions etc
- $p$  is the decision variable (a vector)



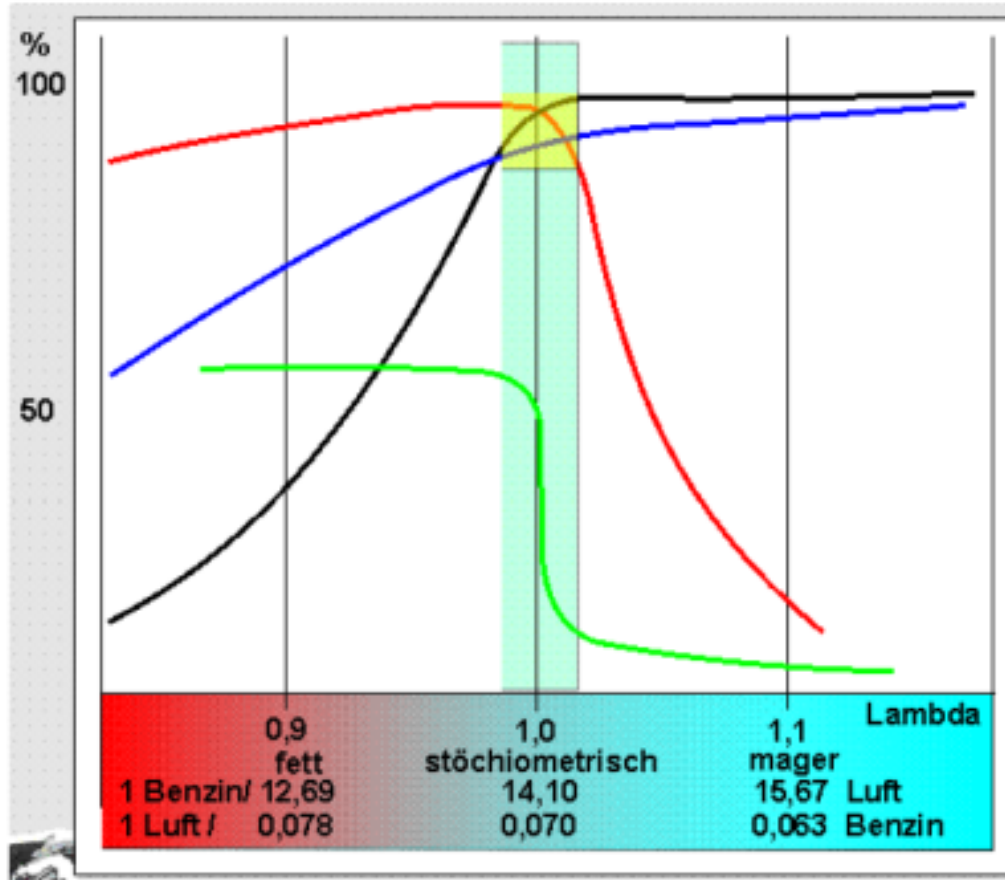
# Engine Model



Observations:

- BSFC is convex, min at 1.2
- CO is convex, min at 1.1
- NOx is bimodal, max at 1.1 (but mind the TWC)

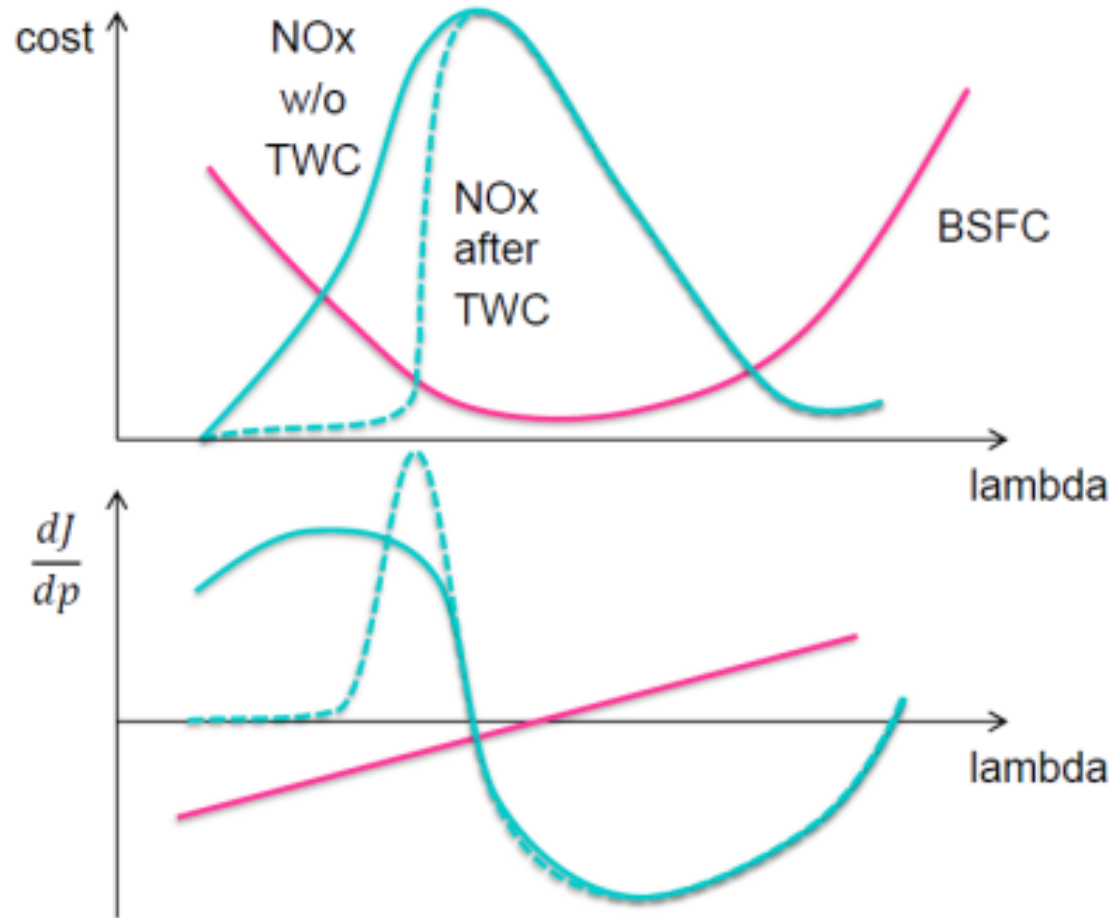
# Catalyst Performance



## Observations:

- HC conversion from 1.0
- NOx conversion up to 1.0
- Very narrow operating window

## Finding the Optimum



Critical point:

$$\frac{dJ}{dp} = 0$$

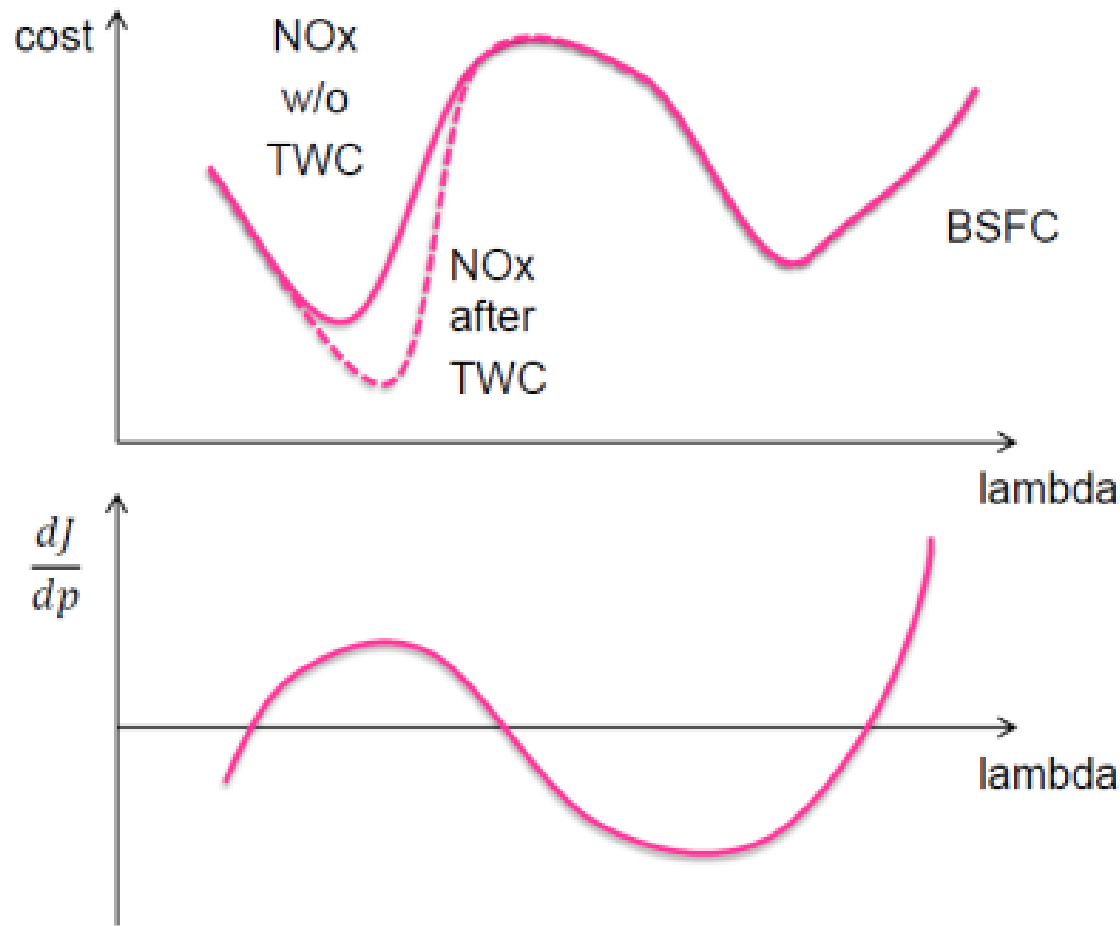
Or

$$\alpha_1 \frac{dJ_1}{dp} + \alpha_2 \frac{dJ_2}{dp} = 0$$

BSFC is:

- Convex
- One optimum
- Easy to solve

## Finding the Optimum



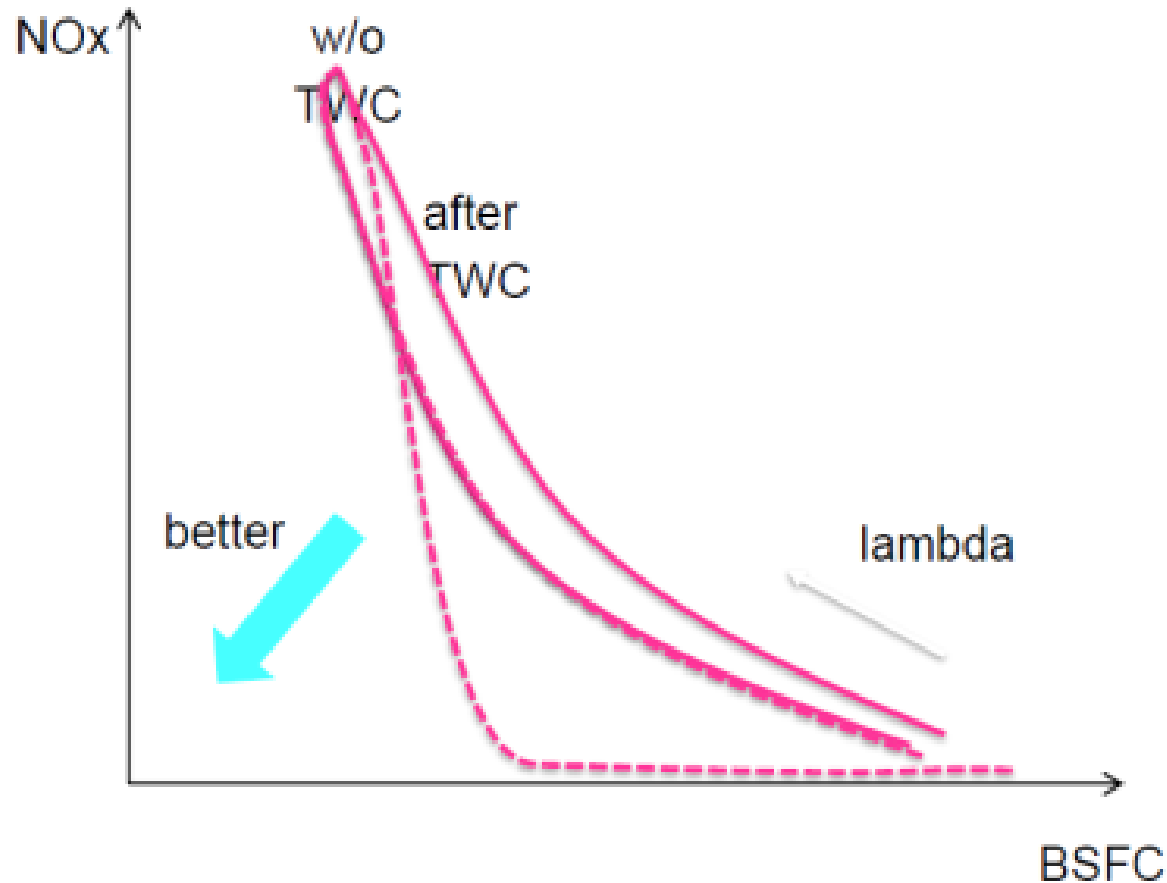
Total cost is:

- Bimodal
- Not convex
- Has a maximum

Derivative shows

- Sign reversal
- Three roots

# Pareto Curve



Shows the trade-off

Slope corresponding to the ratio of weights defines the optimum

Disadvantage:

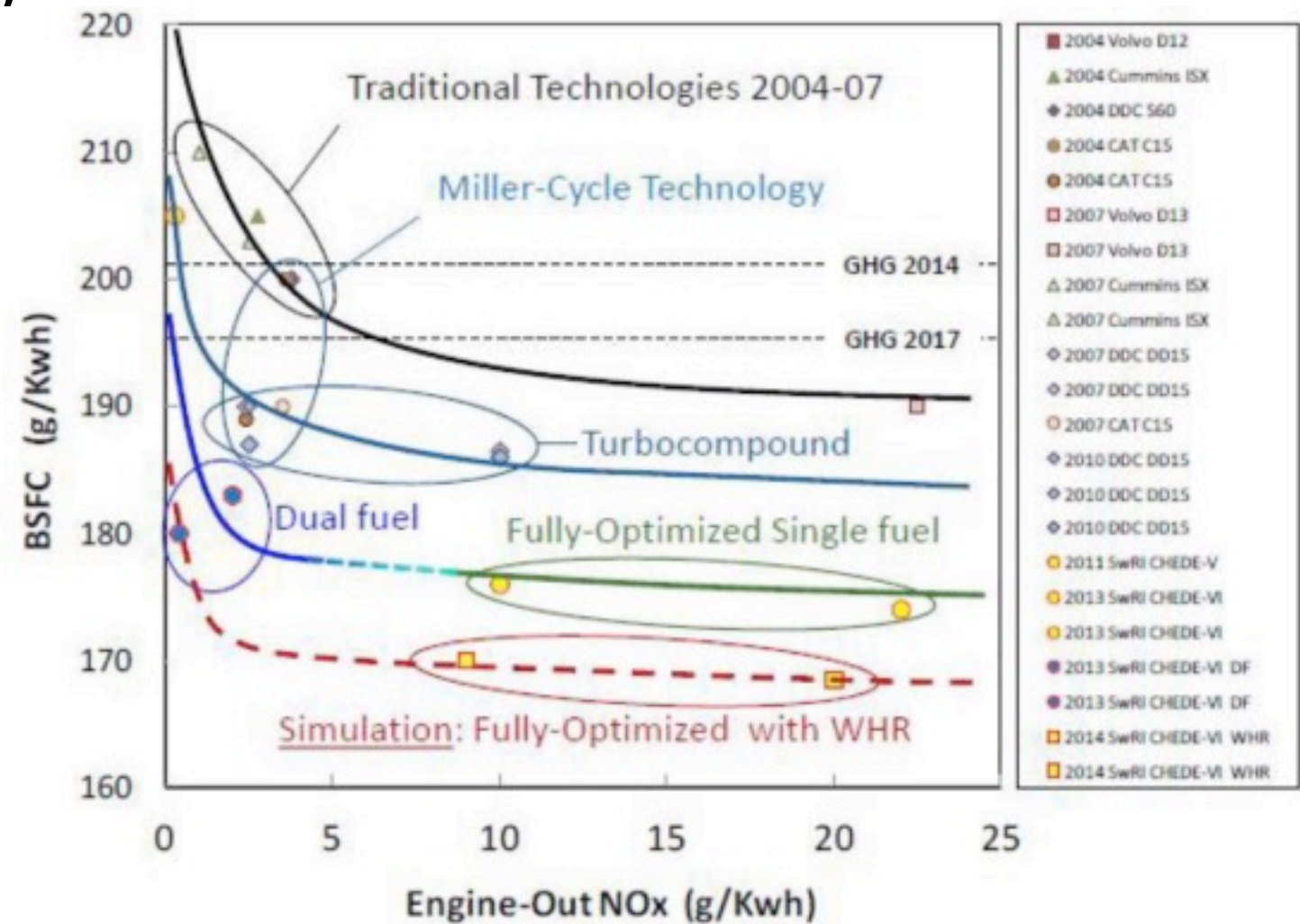
lambda is not visible

Conclusion:

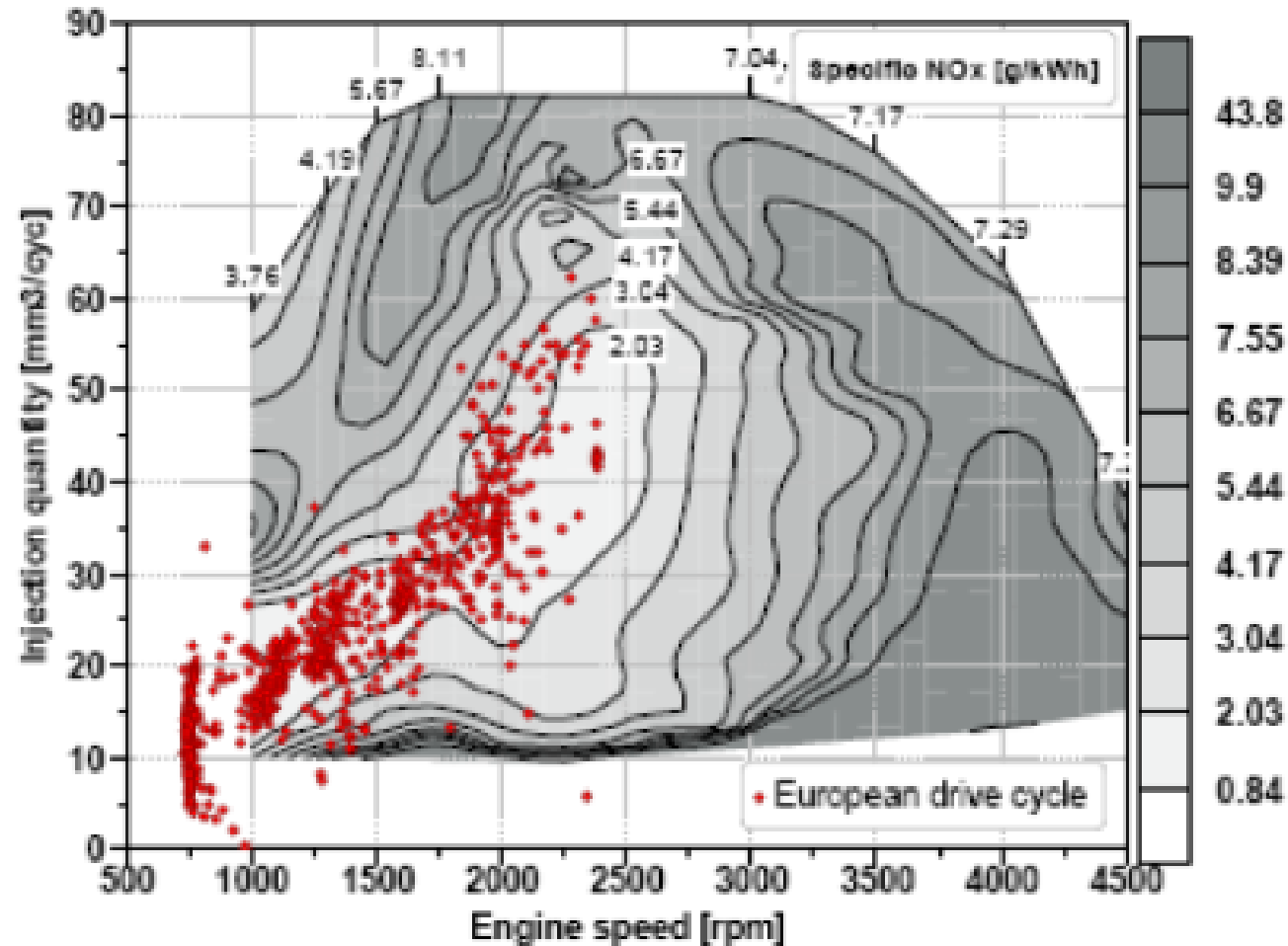
With TWC,  $\lambda = 0.99$ .

W/o TWC:  $\lambda \approx 1.2$

# NOx Tradeoff (CI)



## Typical Calibration Results: NOx



Emissions are

- good on the NEDC
- bad elsewhere

Note the scale!

## Conclusion

- Calibration is the structured selection of parameters
  - Optimising a cost function vs finding a compromise
  - For all environmental conditions / speed / load
  - Software support is essential and available
  - Parameters have to be considered together.
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