REAL WORLD NOX EMISSIONS OF NON-ROAD EQUIPMENT

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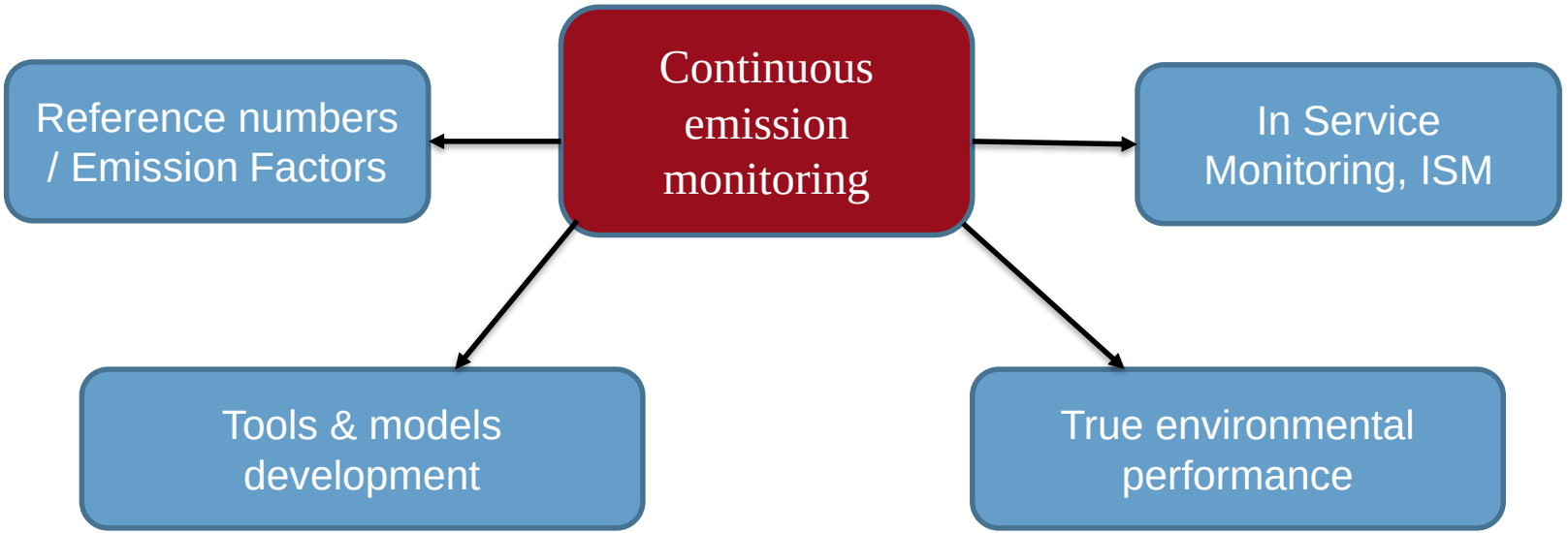
CONTENTS

- Introduction
- SEMS measurement system
- NOx monitoring on 4 NRMM machines
- Conclusions

Work presented is supported by Connekt and RIVM

INTRODUCTION

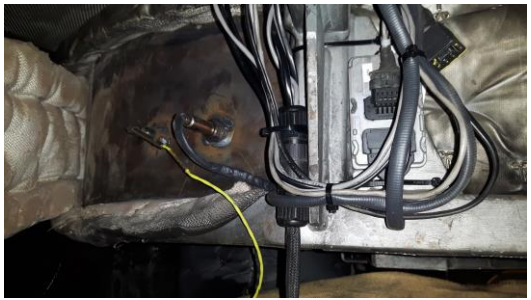


SEMS MEASUREMENT SYSTEM

Cars/Trucks

Ships

Rail-locomotive



NRMM

SEMS MEASUREMENT SYSTEM

EQUIPMENT FOR CONTINUOUS MONITORING

Standard components

3x CAN bus interfaces
- OBDII or WWH-OBD
- J1939
- Additional CAN

Main unit
12V / 24V
power supply

GPRS Modem
Remote data
reading

Post-processing
Calculated values like:
- Mass flow of NO_x, NH_3, CO_2, fuel in [g/s]

GPS
5Hz
speed, altitude and
position

SD-card memory
Up to 160.000 hours

NO_x / O_2/ Lambda automotive sensor
[ppm] and [v%]

K-type thermo couples
2 pieces standard

Optional

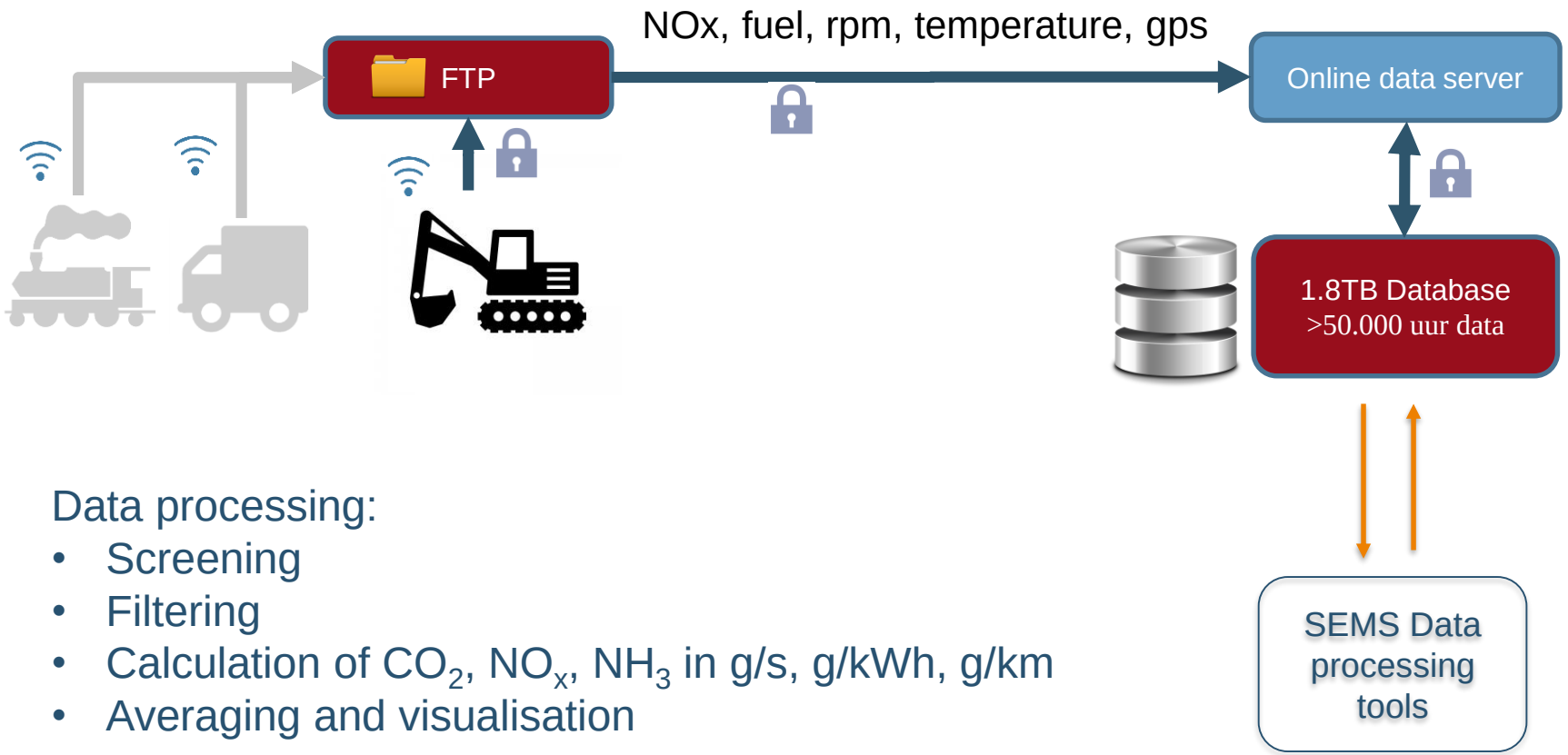
NH3 automotive sensor
[ppm]

Future option

PM/PN automotive
sensor(s)

Robust, compact monitoring tool for determination of real world emissions

Economic alternative for PEMS ISC, ISM



Data processing:

- Screening
- Filtering
- Calculation of CO_2, NO_x, NH_3 in g/s, g/kWh, g/km
- Averaging and visualisation

SEMS MEASUREMENT SYSTEM

COOPERATION HORIBA - TNO

HORIBA
Explore the future

- Worldwide leading manufacturer of emission measurement technology
- 8.500 employees in 27 countries in Asia, Europe and America
- “ONE STEP AHEAD” with the spirit of “JOY AND FUN”

TNO innovation for life

- An independent Dutch research organization, more than 30 years experience in measurement of emissions of vehicles
- More than 3.500 employees worldwide
- “INNOVATION FOR LIFE”

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OVERVIEW NRMM TEST PROGRAM

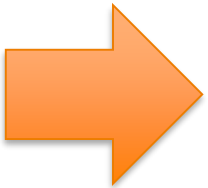



Machine	1	2	3	4
Type	Excavator 1	Shovel	Excavator 2	Tractor
Emission Control	EGR, SCR, DPF	EGR - DPF	EGR - DPF	SCR - DPF
Power [kW]	152	129	159	114
Stage class	IV	III B	III B	IV
NOx limit [g/kWh]	0.4	3.3	2.0	0.4
PM limit [g/kWh]	0.025	0.025	0.025	0.025

OVERVIEW TEST PROGRAM

PARAMETERS

- NOx + O_2 concentration (EC-sensor)
- From engine CAN:
  - Fuel consumption
  - Engine speed
  - Exhaust T + P



Mass emissions based on carbon balance and fuel flow

Fuel flow → CO_2 mass flow

NOx/O_2 → NOx/CO_2

> NOx mass flow

If fuel consumption is not available:

Mass emissions are calculated via exhaust flow, which is based on:

- Engine speed, manifold air density and O_2 concentration
- And, via engine speed, torque and O_2 concentration

RESULTS




Machine	1	2	3	4
Type	Excavator 1	Shovel	Excavator 2	Tractor
Duration [hrs]	131	344	291	44
Idle time	35%	57%	18%	25%
Average CO_2 [kg/h]	42	18	53	30

→ Idle time share ranges from 18% to 57%

→ Average CO_2 emissions ranges from 18 to 53 kg/h

RESULTS

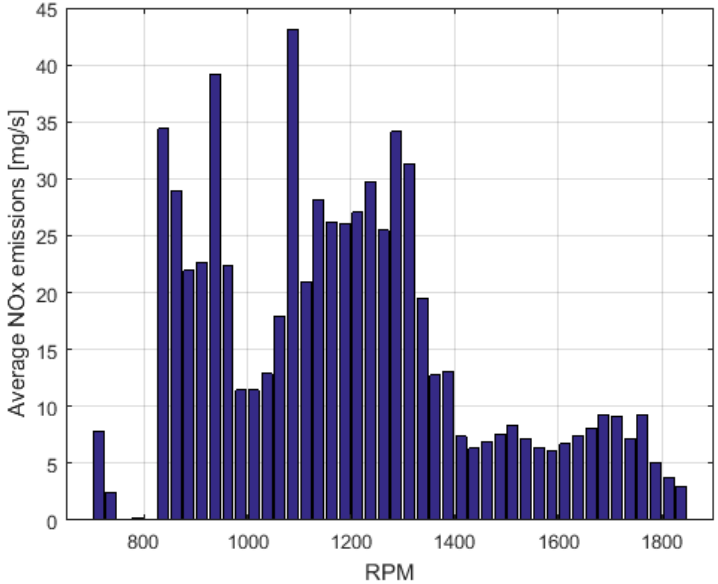
Idle operation Excavator 1:

- 75% of idle time is from periods > 4 minutes
- 50% of idle time is from periods > 12 minutes

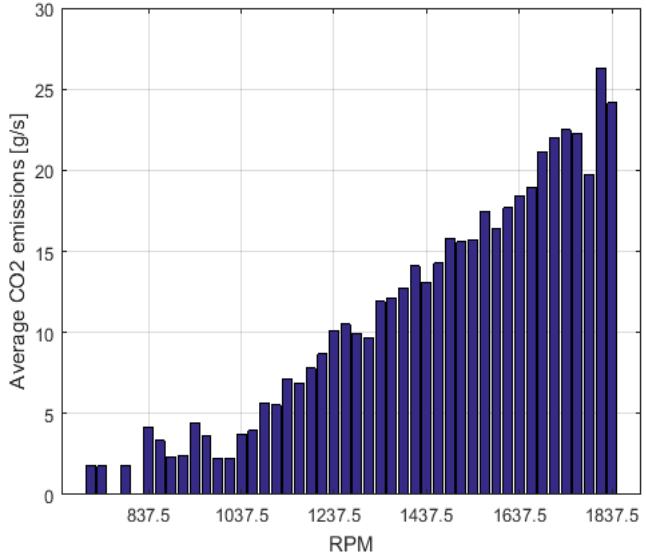
RESULTS

PARAMETERS AS FUNCTION OF ENGINE SPEED – EXCAVATOR 1

NOx in mg/s



CO_2 in g/s

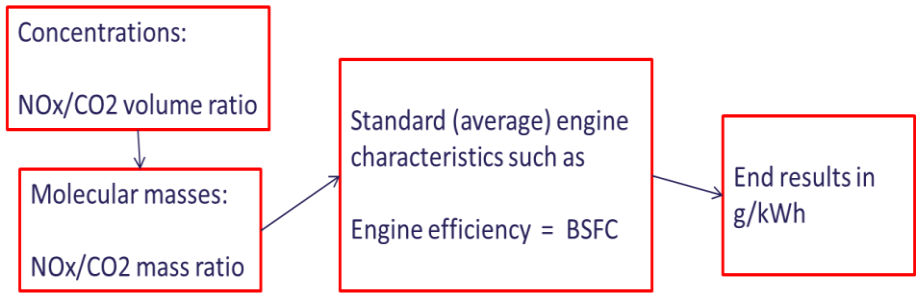


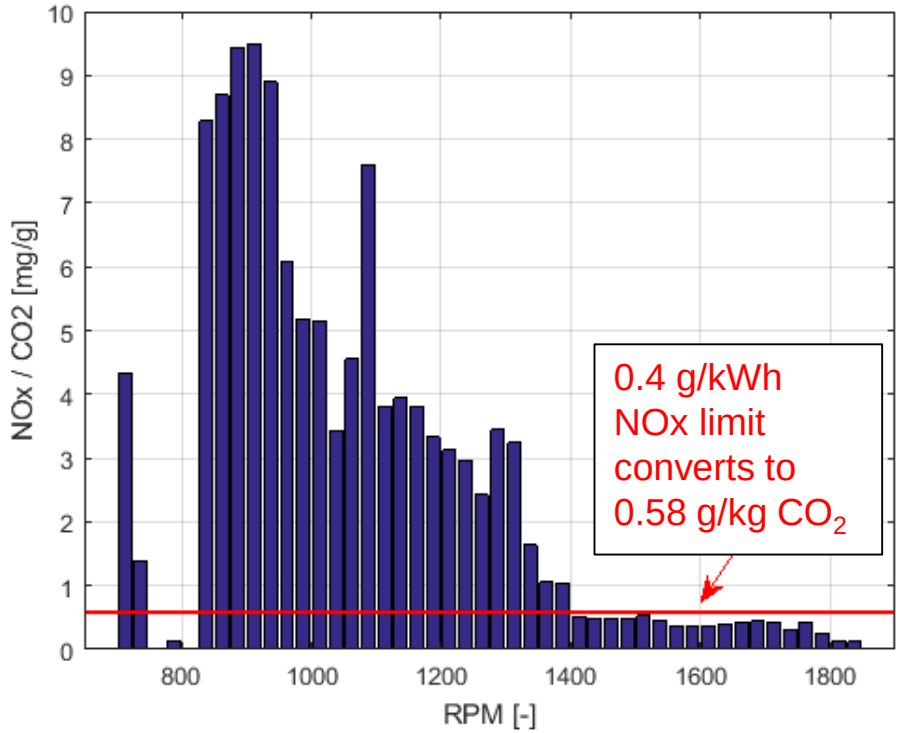
NOx mass flow is higher at low speed than at high speed

RESULTS

PARAMETERS AS FUNCTION OF ENGINE SPEED EXCAVATOR 1

- NOx/CO_2 ratio has a simple relation with NOx in g/kWh. Only engine efficiency is in between. Advantages:
  - Less susceptible to errors
  - No amplification of values at low power

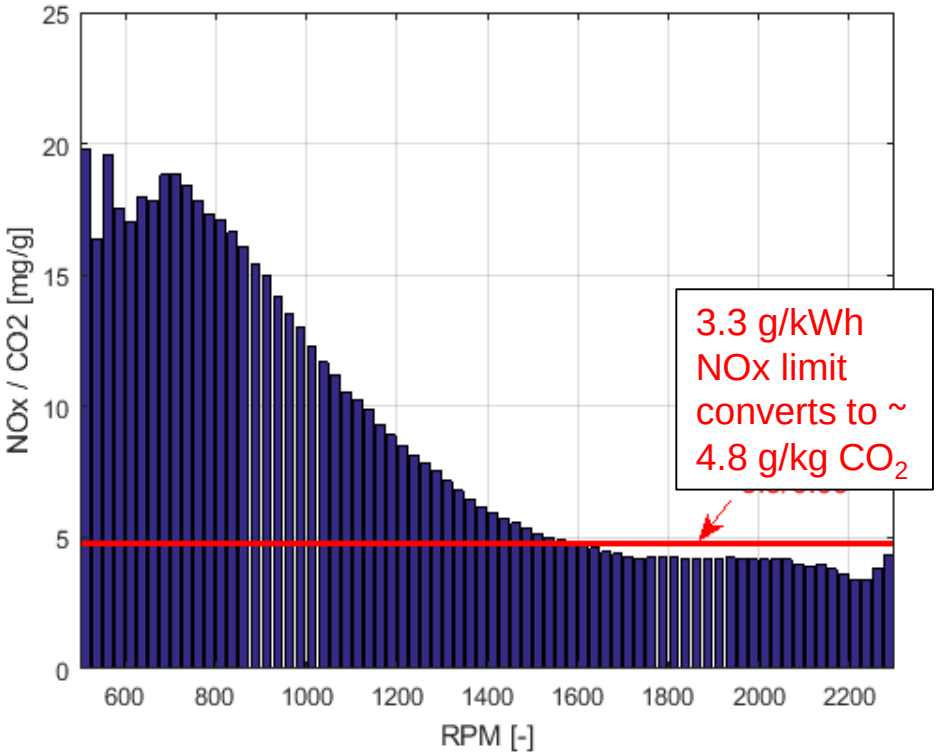




RESULTS

PARAMETERS AS FUNCTION OF ENGINE SPEED SHOVEL

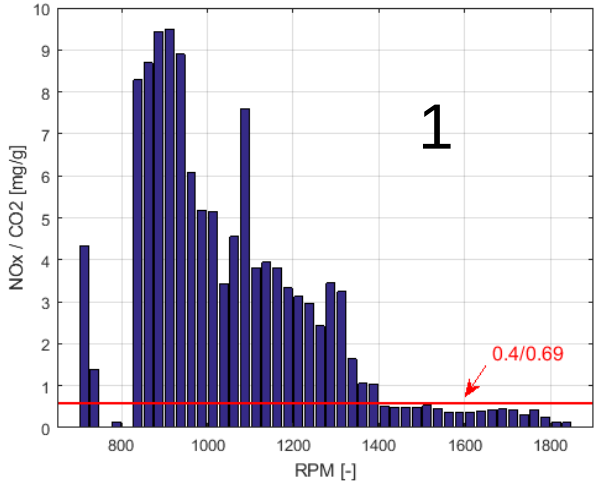
Similar characteristic for NOx/CO_2 ratio for the shovel

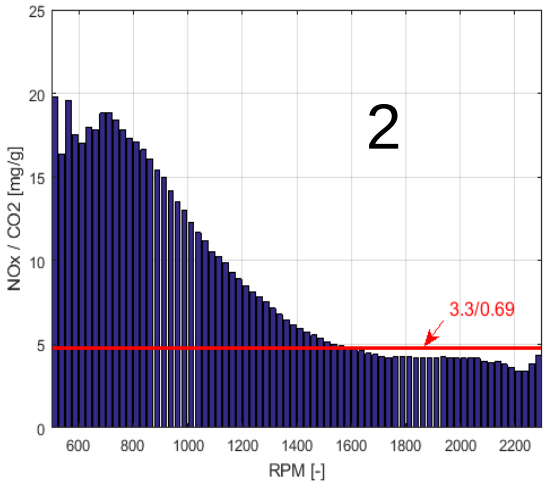


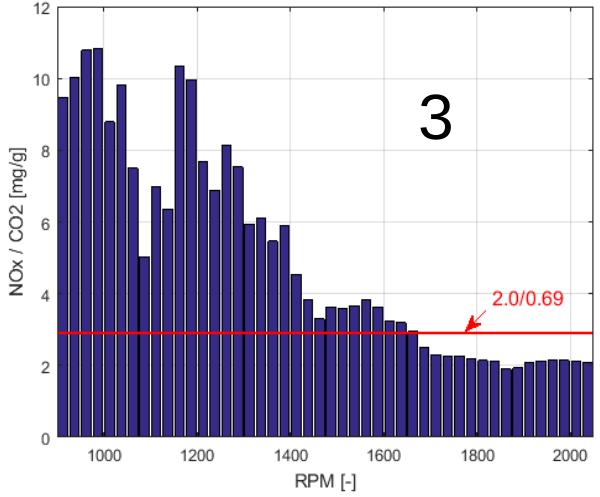
RESULTS

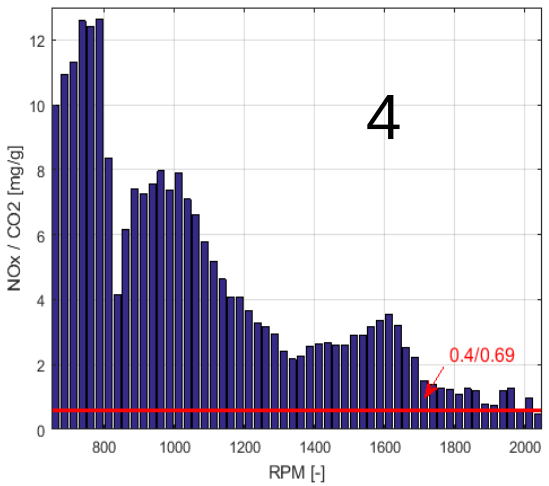
Similar characteristic for all 4 machines

NOx/CO_2 ratio at low speed up to 20 times higher than at high speed





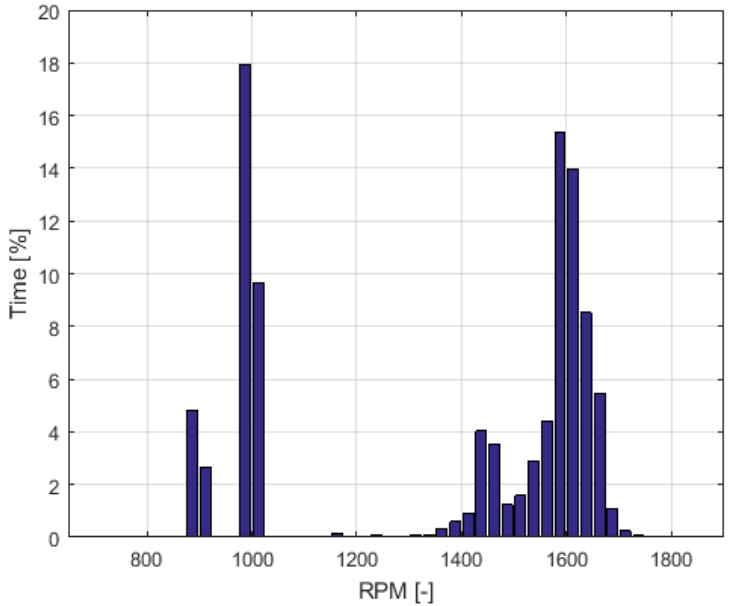




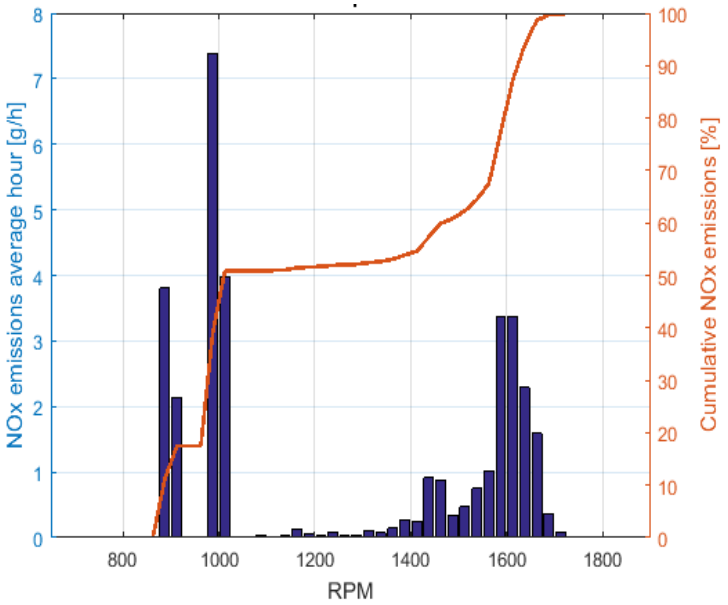
RESULTS

EXCAVATOR 1

time spend



contribution to average NOx



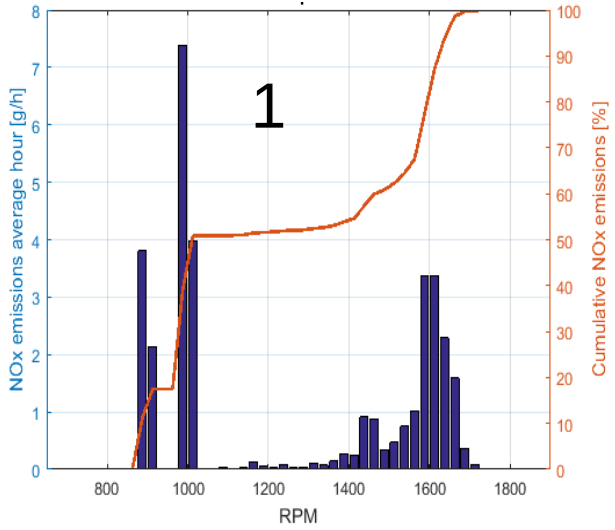
50% of the NOx emission during idle for this machine

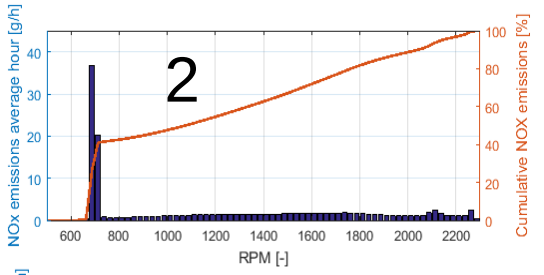
Idle time ranges from 18% to 57% (4 machines)

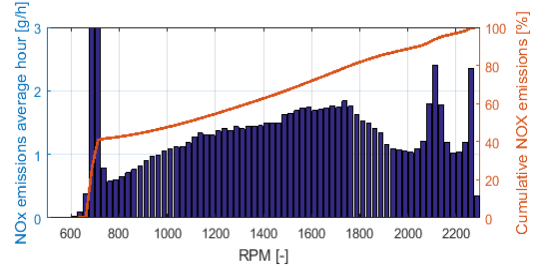
RESULTS

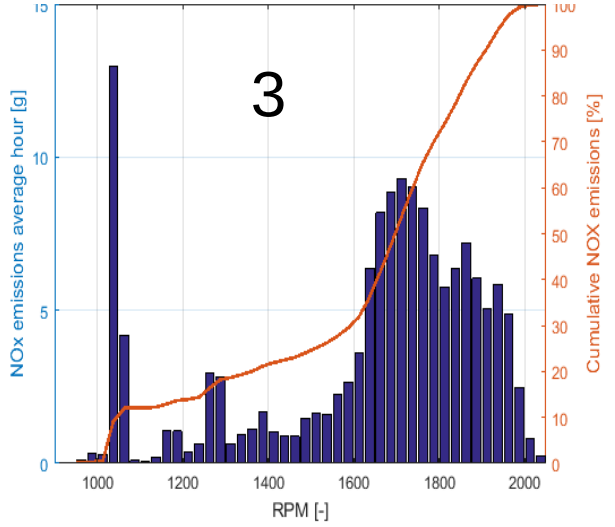
4 machines: contribution of idle NOx

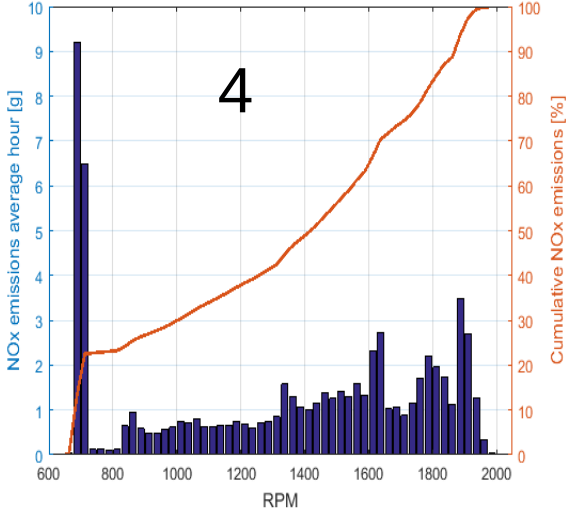
This ranges from 12% to 50%





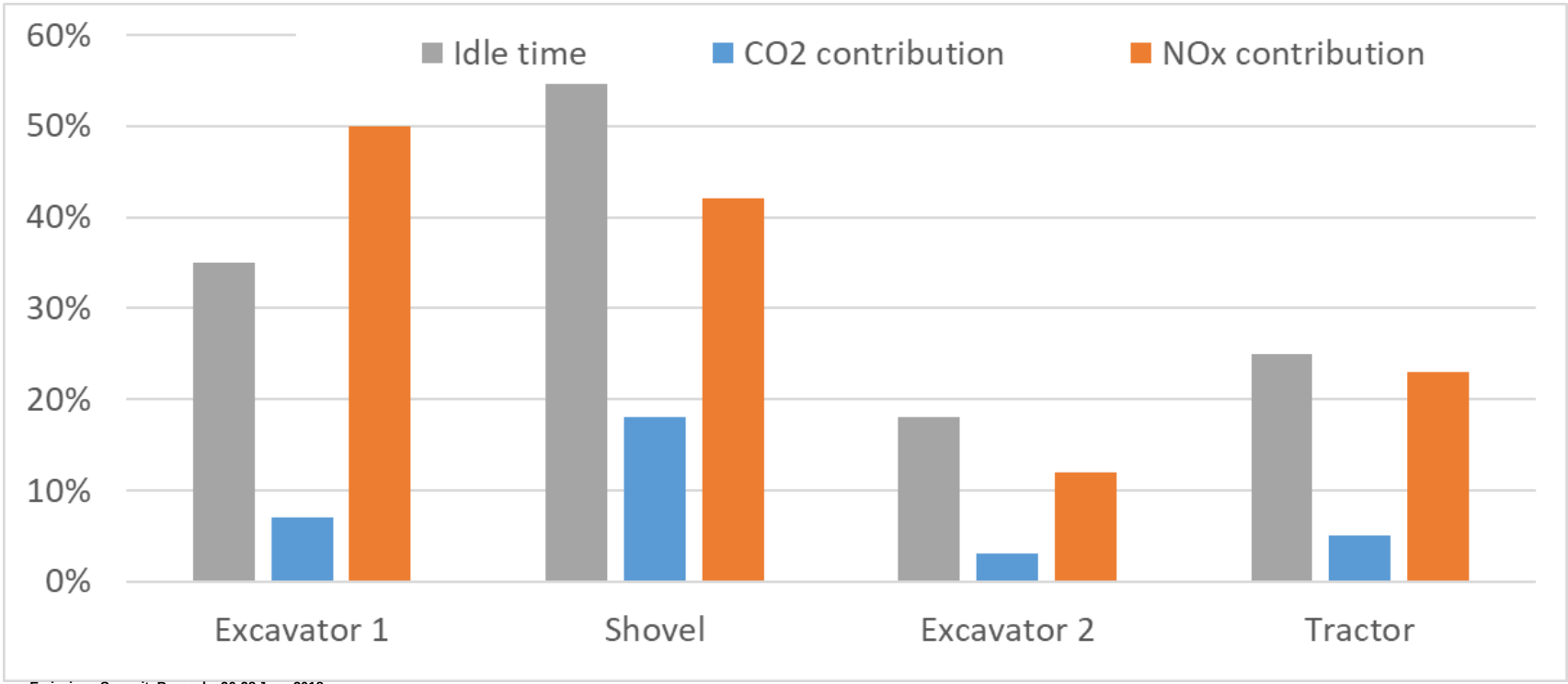






RESULTS

NO_X AND CO_2 CONTRIBUTION FROM IDLE



RESULTS

COMPARISON REAL WORLD NOX WITH TYPE APPROVAL LIMIT VALUE

Machine	1	2	3	4
Type	Excavator 1	Shovel	Excavator 2	Tractor
Stage class engine	IV	III B	III B	IV
Idle time	35%	57%	18%	25%
Real world NO_x [g/kWh]	0.5	4.9	2.8	1.8
NO_x-limit (lab) [g/kWh]	0.4	3.3	2.0	0.4
Real world NO_x above limit value	25%	48%	40%	350%
RW NO_x excl. idle, above limit val.	-38%	-14%	23%	247%

Real world NOx: 25% to 350% above the type approval limit value

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CONCLUSIONS

- Machines idle a lot: 18% to 57% of the time (4 monitored machines).
  This contributes to about 12% to 50% of the NOx emissions.

- Real world NOx: 25% to 350% higher than the type approval limit value:
  - for 3 out of 4 machines this was lower than 50%
  - high exceedance (350%) was seen with a Stage IV machine

- It is recommended to include idle and low load operation in a better way in future type approval test procedures (test cycle, ISM, ISC), otherwise real world NOx emissions do not keep track with type approval limit values

THANK YOU FOR YOUR ATTENTION

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