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Real-life emission of automatically stoked biomass boilers

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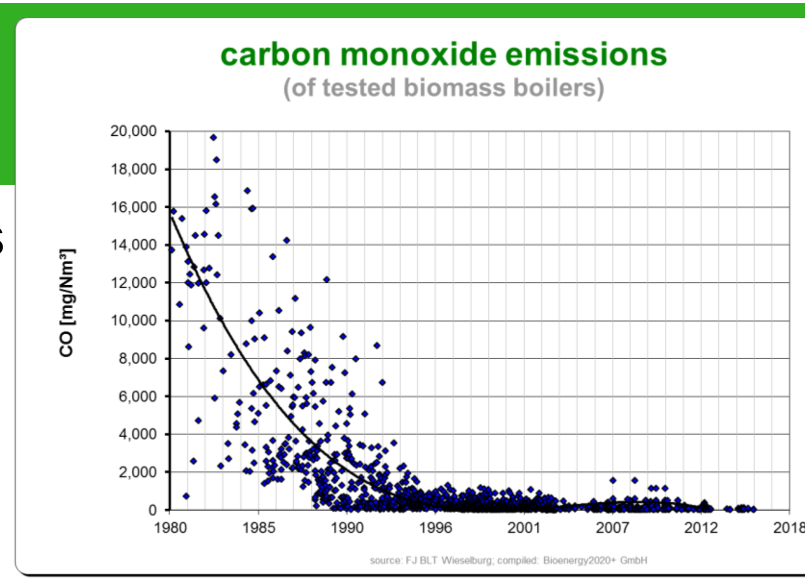
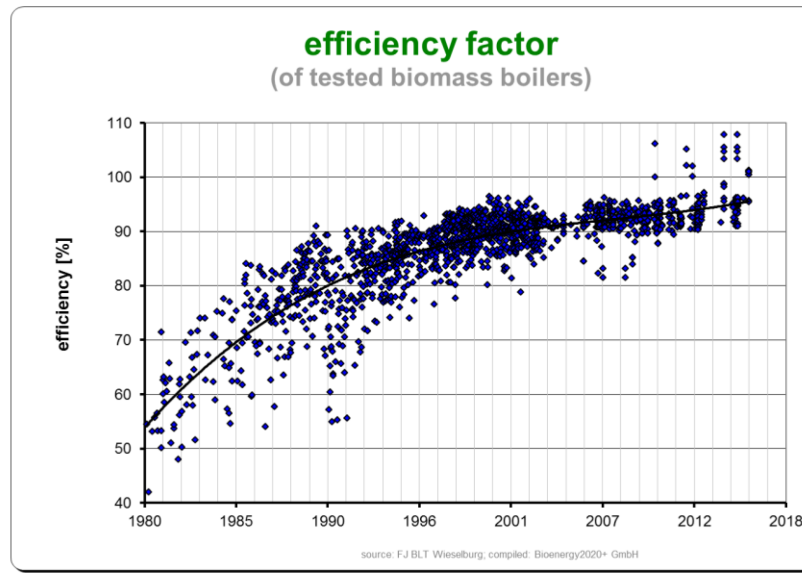
Introduction: General

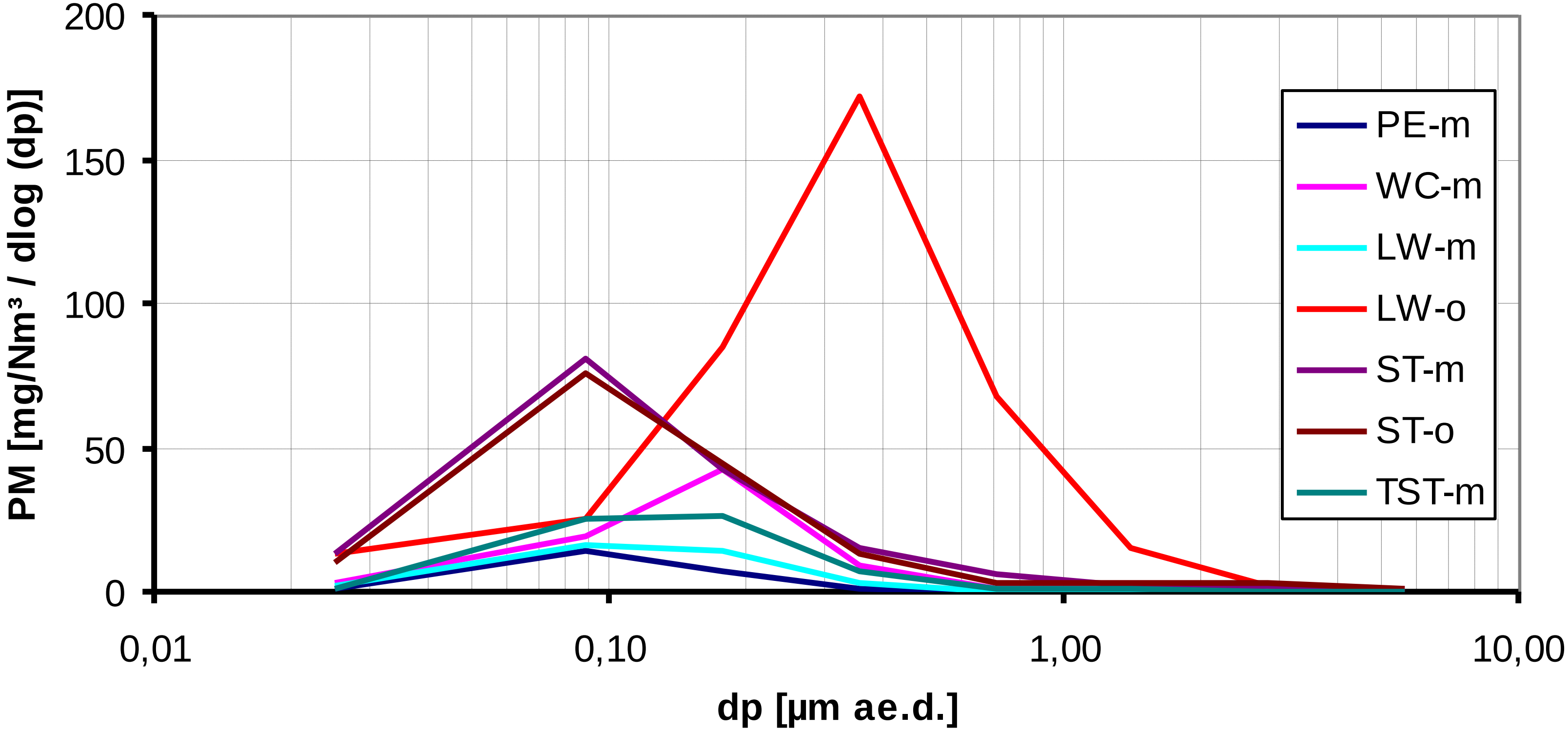
- Biomass combustion technology has improved tremendously:
- FJ-BLT Wieselburg type testing averages 2015/16 (n=26):
  - Efficiency = **96%**
  - Carbon monoxide = **5mg/m³**
  - Organic gaseous carbon < **1mg/m³**
  - **Total suspended particles = 7mg/m³**
- EN303-5 testing constant load conditions
- Limited information about field performance
- Beside particulates (PM10/2.5) Benzo[a]pyrene (PAH) is critical





(all emission results given at STP,13%O2)

Introduction: Particle size distribution of small-scale biomass combustion systems



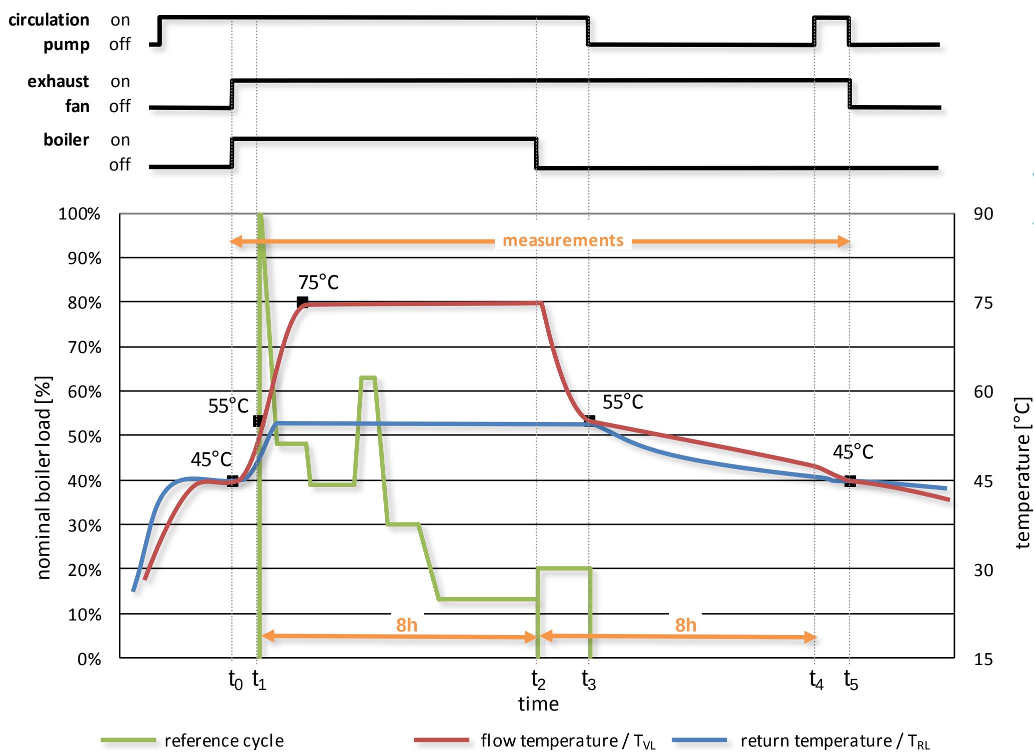
Explanations: average particle size distribution of the BLPI measurements performed over the test runs; data related to dry flue gas at STP and 13 vol. % O2; PE-m … modern pellet boiler; WC-m … modern wood chip boiler; LW-m … modern logwood boiler; LW-o … old logwood boiler; ST-m … modern stove; ST-o … old stove; TST-m … modern tiled stove

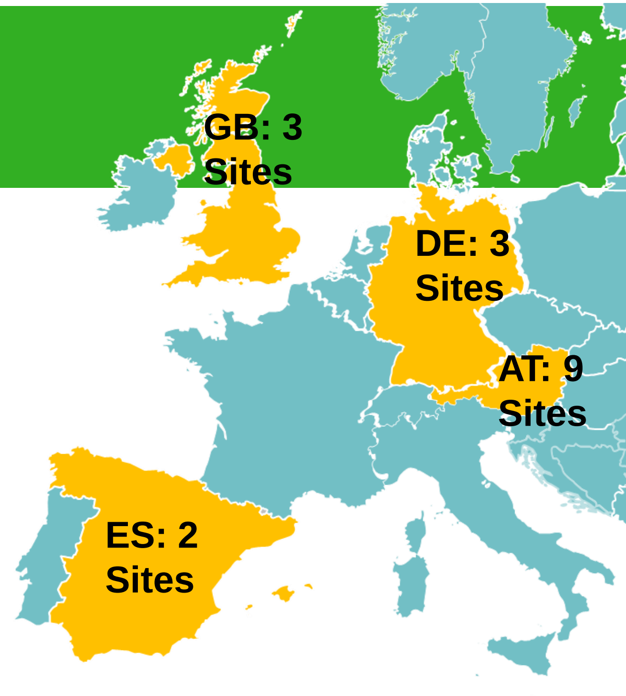
Objectives

- Evaluate emissions (and efficiency) of biomass boilers under **laboratory conditions simulating real-life operation**
- Investigate the operation performance of modern biomass boilers in **real installations in the field**
- Special focus particular **Benzo[a]pyrene**
  - Emissions of modern biomass boilers
  - Critical operation phases
  - Technology influence
  - Reduction measures

Methodologies Study 1

- Laboratory: Full Load, Part Load and **Load Cycle Test** (8-hour Modulation)





- Field Measurements (n=73):
  - 18 Sites, 3 Building Types (new, refurbished, old)
  - Continuous Efficiency Monitoring over up to 3 years
  - Full Load Test in Field
  - Real Life Operation: 24h Emission testing

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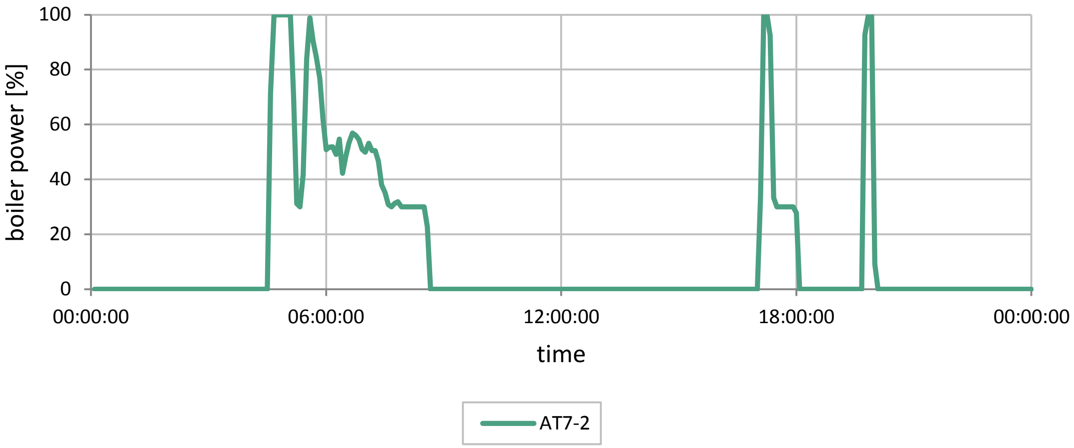
Results Study 1: Field measurements

- What's the real boiler operation behavior?
- Boiler operation behavior depends on
  - boiler type
  - weather
  - building
  - user habits



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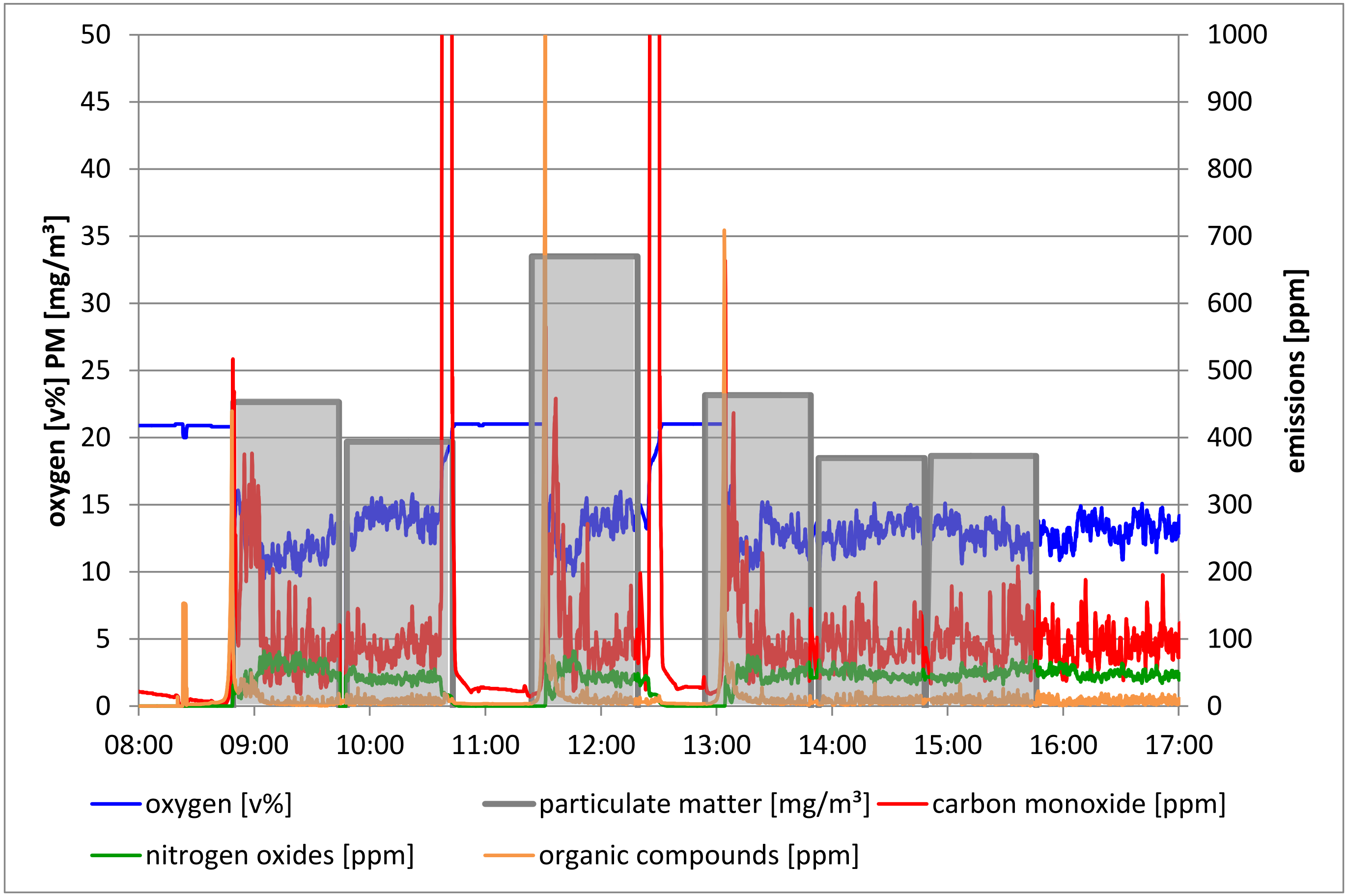
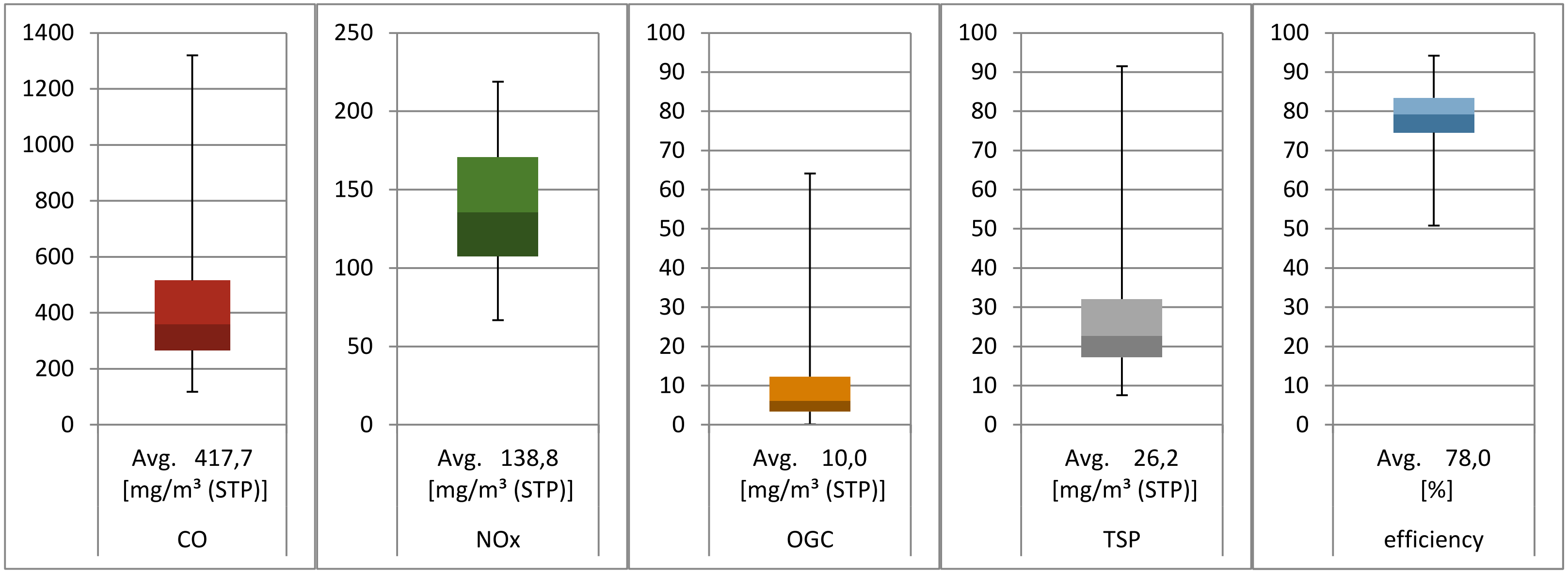
Example from 24h field emission measurement

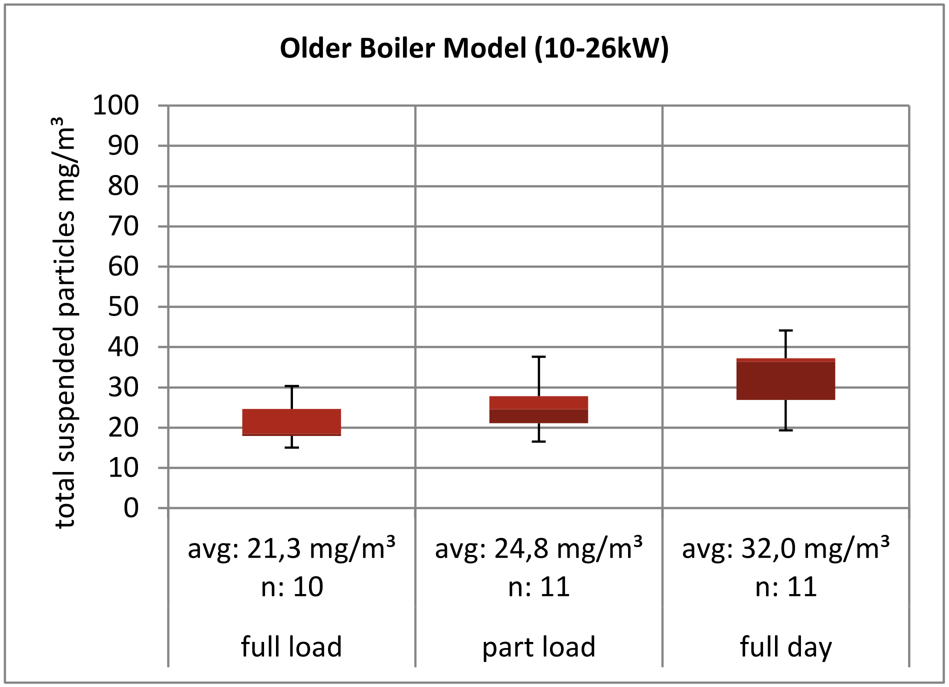


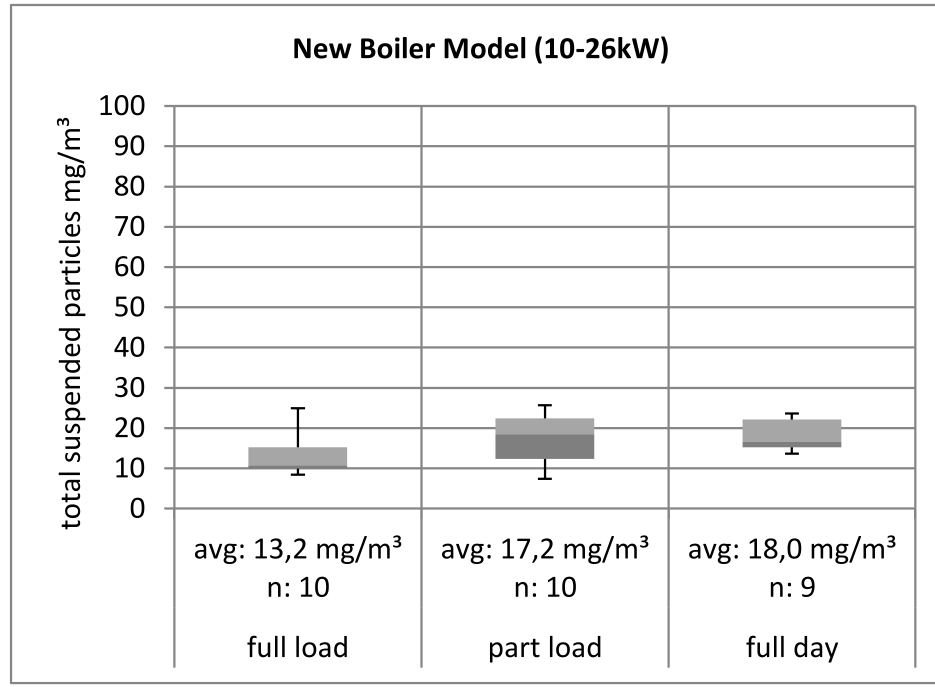
Overview: Field Performance of Pellet Boilers

- Emission factors of pellet boiler in modulating operation.
  - All top feed burner
  - Wide modulation range



Field performance: Pellet Boilers 10-26kW





- Improvement of boiler technology is evident
- Narrow distributions → very stable performance even in full day measurements

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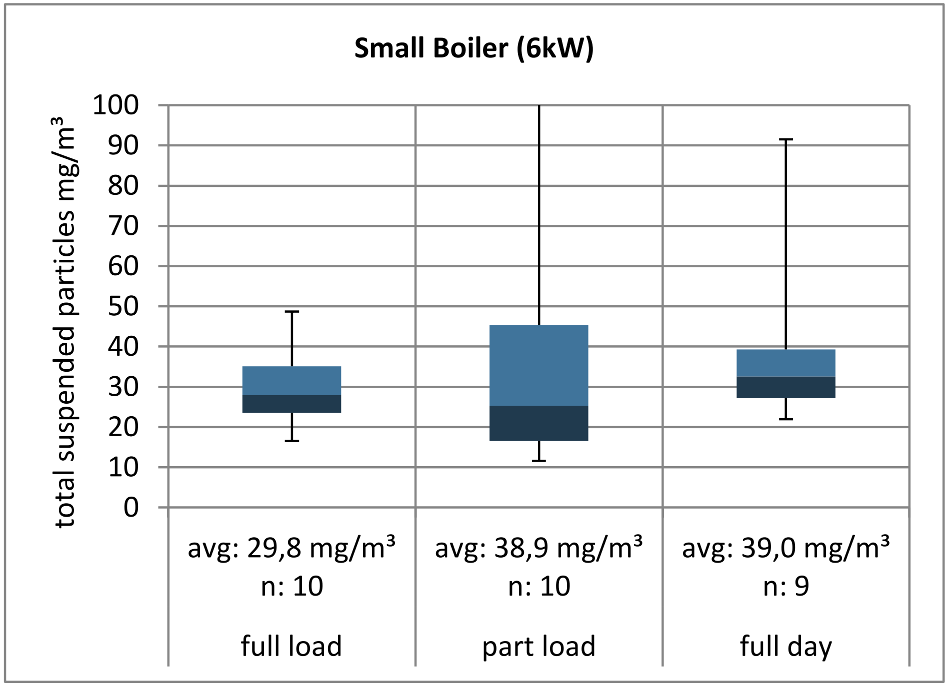
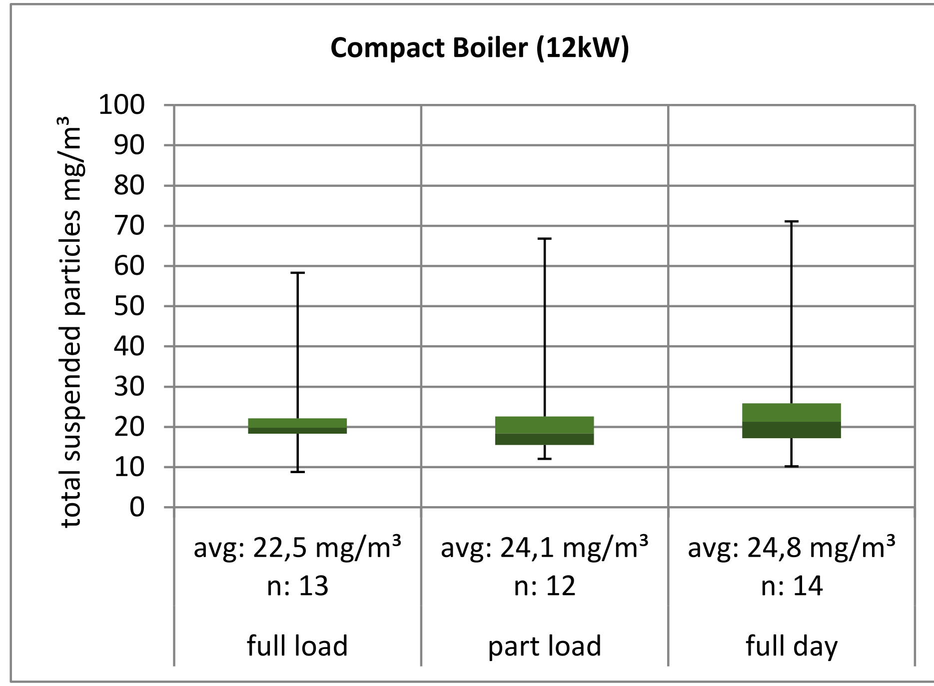
Field performance: Pellet Boilers 6-12kW





- Mean/Median emissions quite satisfying, but
- higher variability of emissions compared to bigger boilers
- Part load operation (30%) difficult for small boiler (6kW)

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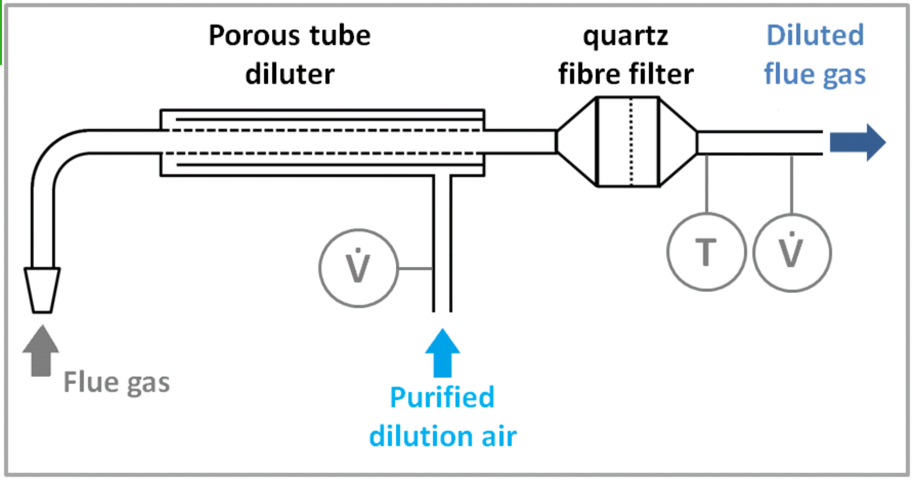
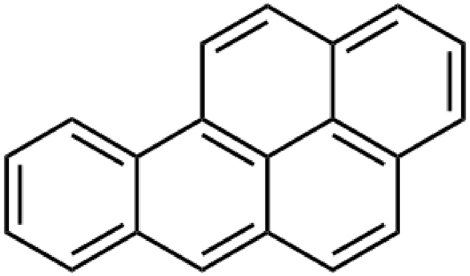
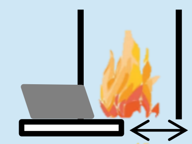
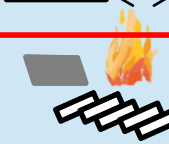
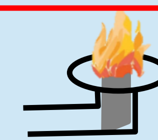
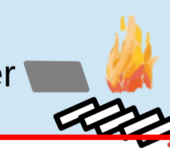
Methodology Study 2: Dilution Sampling for TSP and BaP



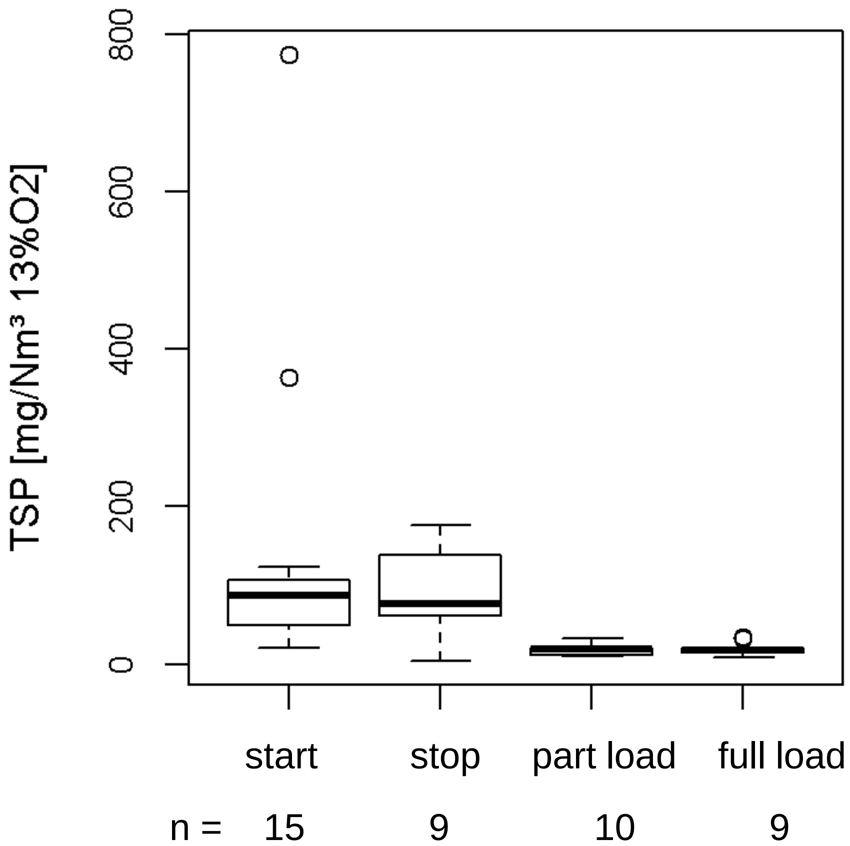
- Sampling:
  - Start/Stop/Nominal-/Part-Load
  - Dilution method (ISO 11338-1)
  - Dilution ratio: 1:10
  - Filter T <40°C
  - Isokinetic sampling at steady state operation
- Storage/Transport: sealed filter or solution; T < 0°C
- Analysis:
  - Adapted to DIN EN 15549:2008 and VDI 3874
  - Diluted in cyclohexane and dichlormethane
  - Analysis with GC-MS (Quadrupole – mass spectrometer)

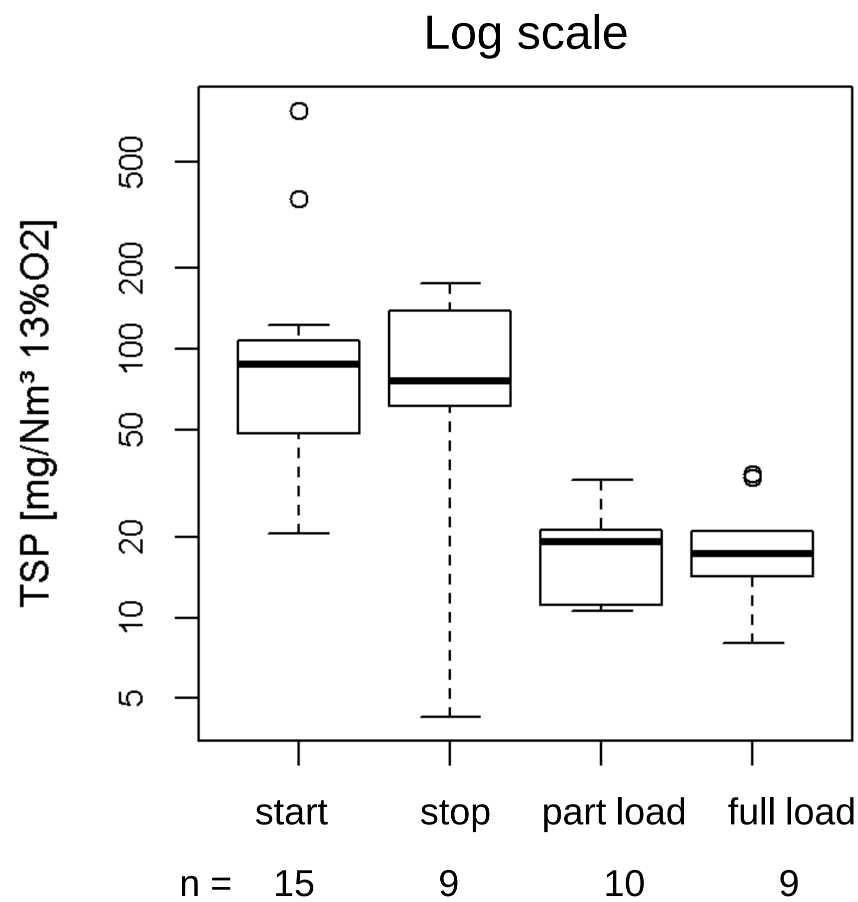


Study 2: TSP/BaP – Tested Technologies

	Power [kW]	Fuel	Principle of combustion	
A	15		topfed burner	
B	15			
C	70	Spruce pellets A1 quality EN14961-2	horizontally fed burner	
D	500			
E	12		underfed burner	
F	15			
G	500	Wood chips W20	horizontally fed burner	

Particle Emissions: Combustion Phases





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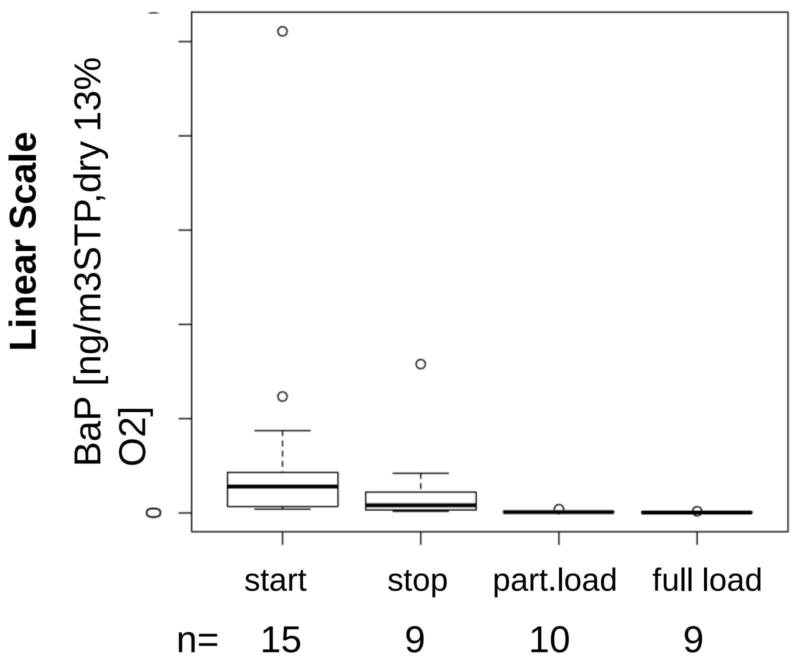
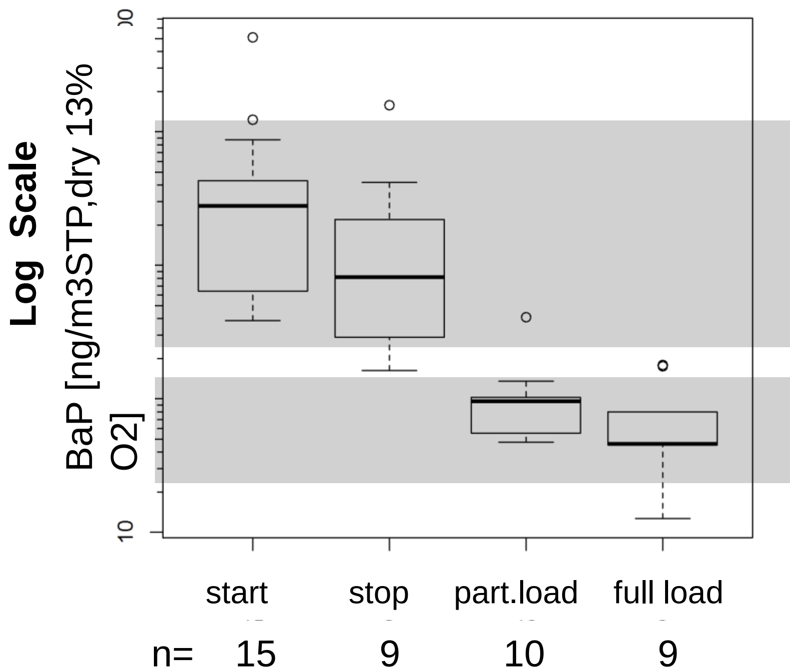
BaP Emissions – Operation Phases





The emissions during start and stop are 1 to 2 orders of magnitude higher than during continuous operation

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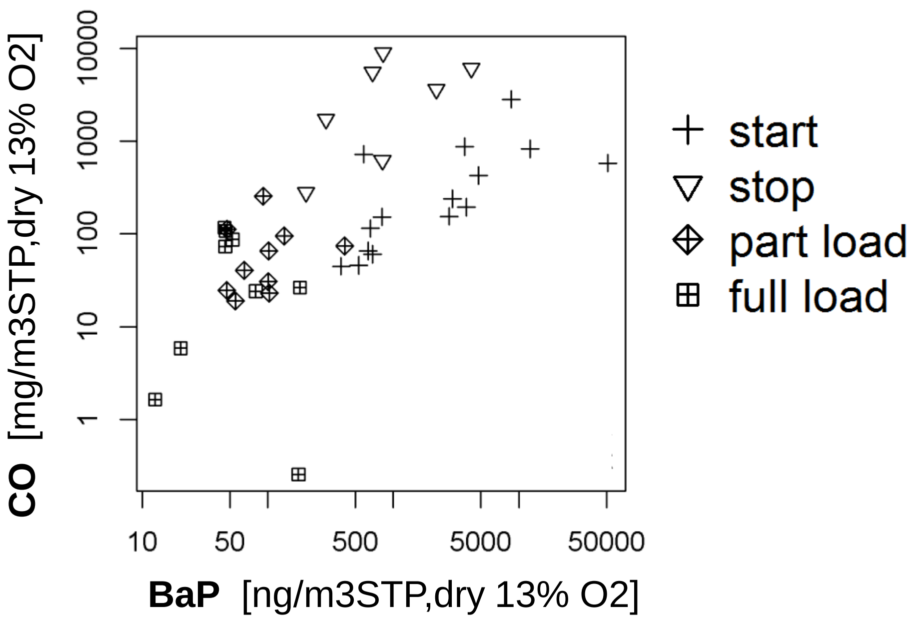
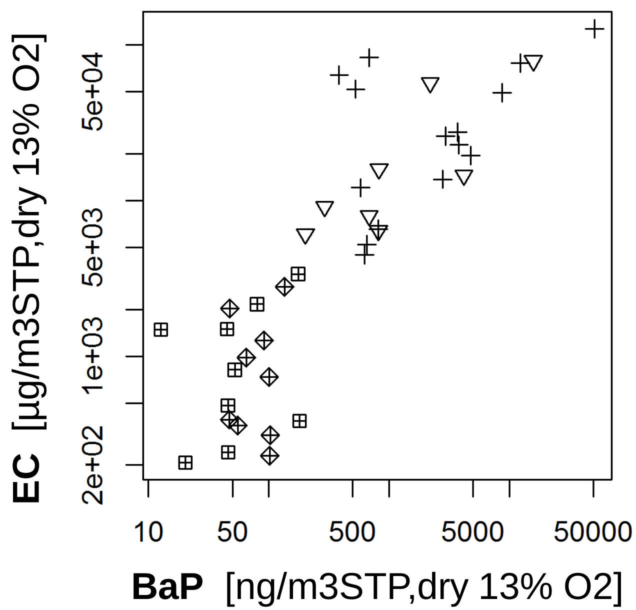
Correlation other parameters (Examples)

BaP - CO



BaP – EC (Elemental Carbon)



Only useful correlation with EC

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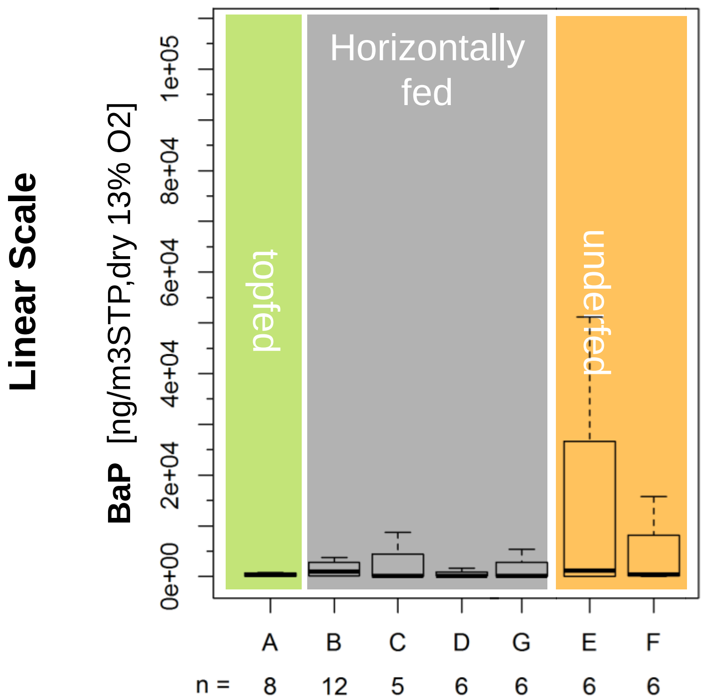
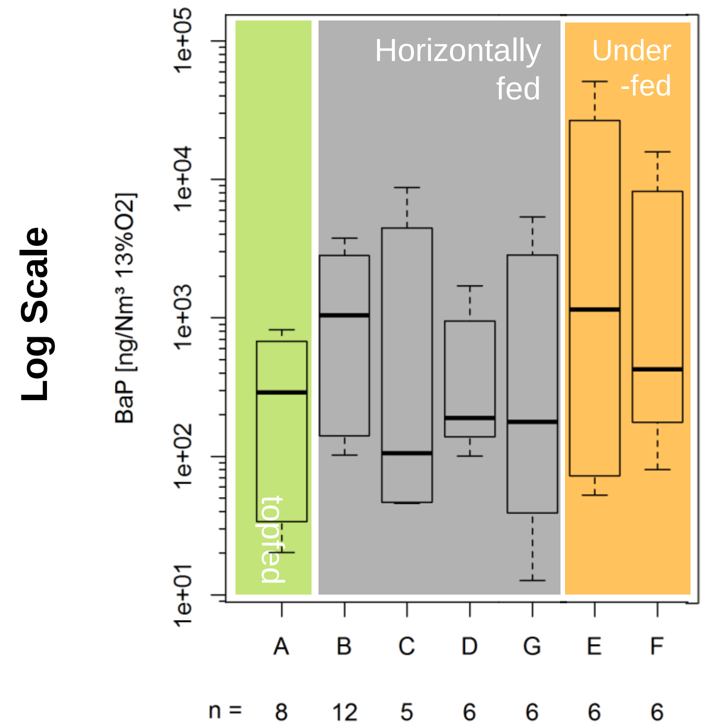
BaP Emissions - Technology Impact

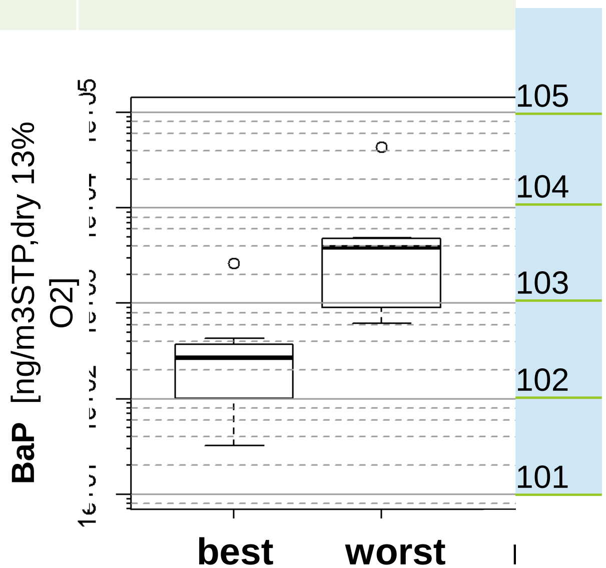




- Similar median values for different systems but...
- Lowest values observed for topfed systems
- Trend: higher risk of outliers with underfed systems

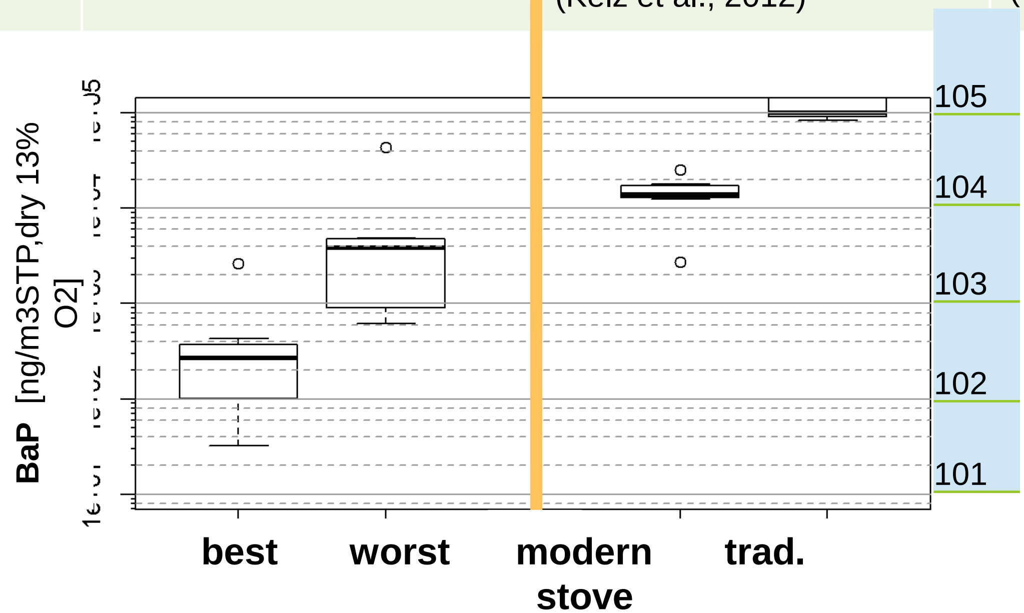
Comparison with Literature

Best Case operation	Worst Case operation
Automatic boilers	
1x Start and Stop, 8 h full load	Start-Stop-operation



Comparison with Literature

Best Case operation	Worst Case operation	modern	„traditional“
Automatic boilers		Logwood stoves	
1x Start and Stop, 8 h full load	Start-Stop-operation	Primary and secondary air supply (Ozgen et al., 2014) (Kelz et al., 2012)	(Kelz et al., 2012) (Orasche et al., 2012)



n= 7 7 6 4

Summary

- In general the tested biomass boilers peformed widely well under field conditions
- Higher variability of particle emission from smaller boilers
- Load cycle test is suitable to predict real-life performance
- Instationary phases of combustion (start / stop) are critical in terms of particle and BaP emissions
- Underfed combustion technology seems to have higher risk of incomplete combustion in these phases
- BaP emissions are lower for boilers compared to stoves but not neglibile when start/stop phases occur frequently

Conclusions

- Difference between lab and field performance of biomass boilers is evident, but widely is in an acceptable range (for the tested technologies)
- Real-life oriented test methods could trigger further development of already mature technology
- Further reduction of particle emissions is possible:
  - By appropriate design and control concept of the heating system to reduce start- / stop-phases
  - Optimisation of combustion conditions in start- and stop-phases

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SEVENTH FRAMEWORK PROGRAMME

and the Austrian COMET Research Programme.

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Thank you for your kind attention!

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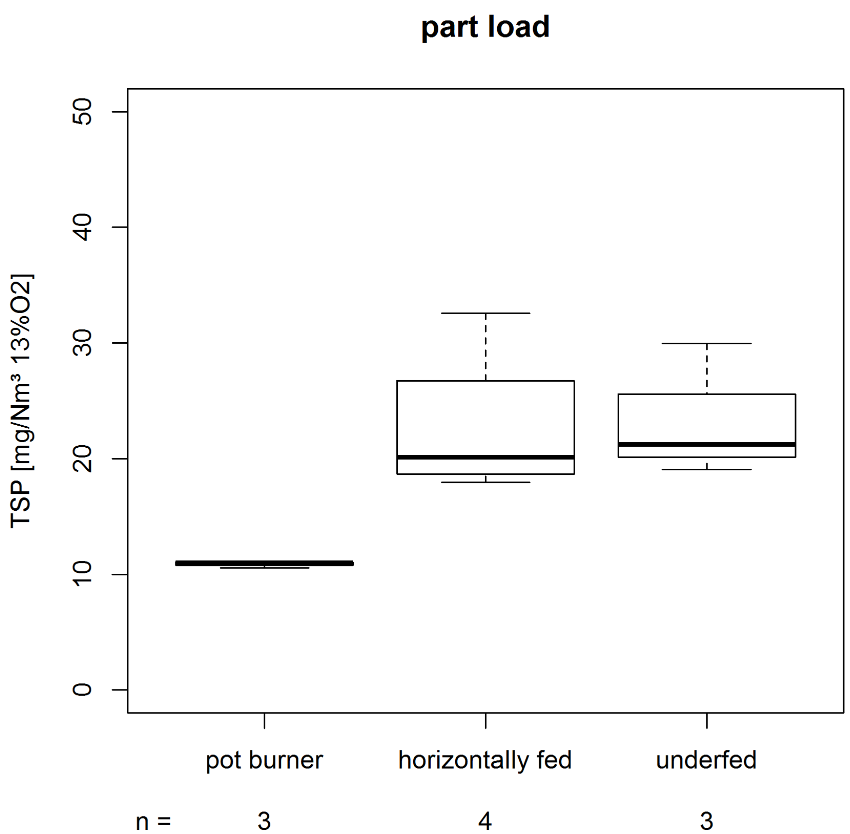
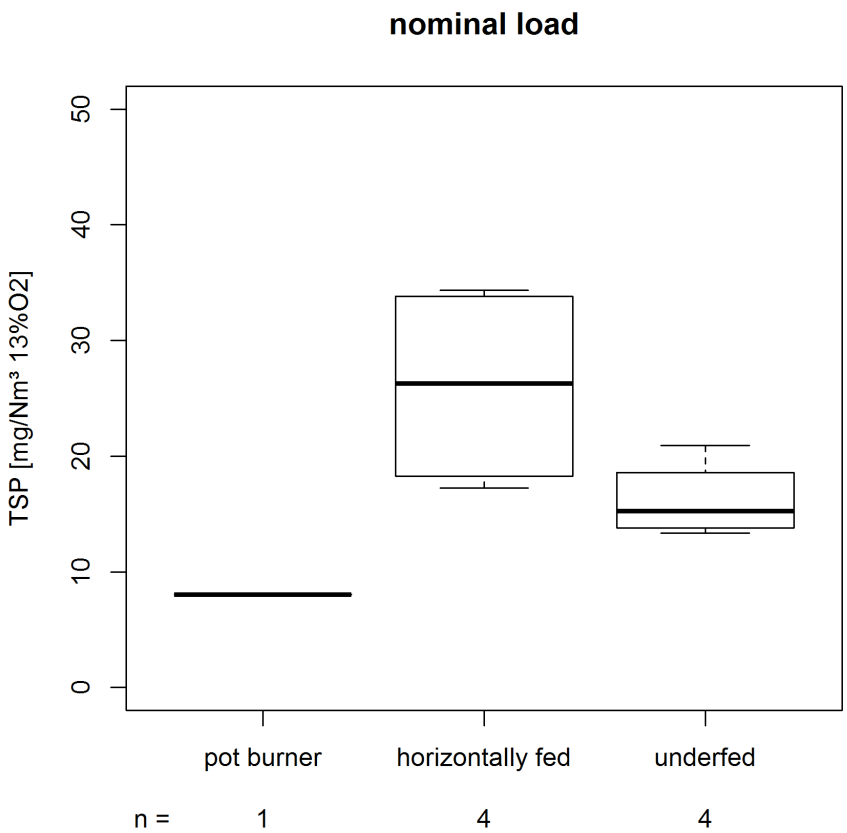
Supplemental Material

Comparison Load Cycle – Real Life Performance

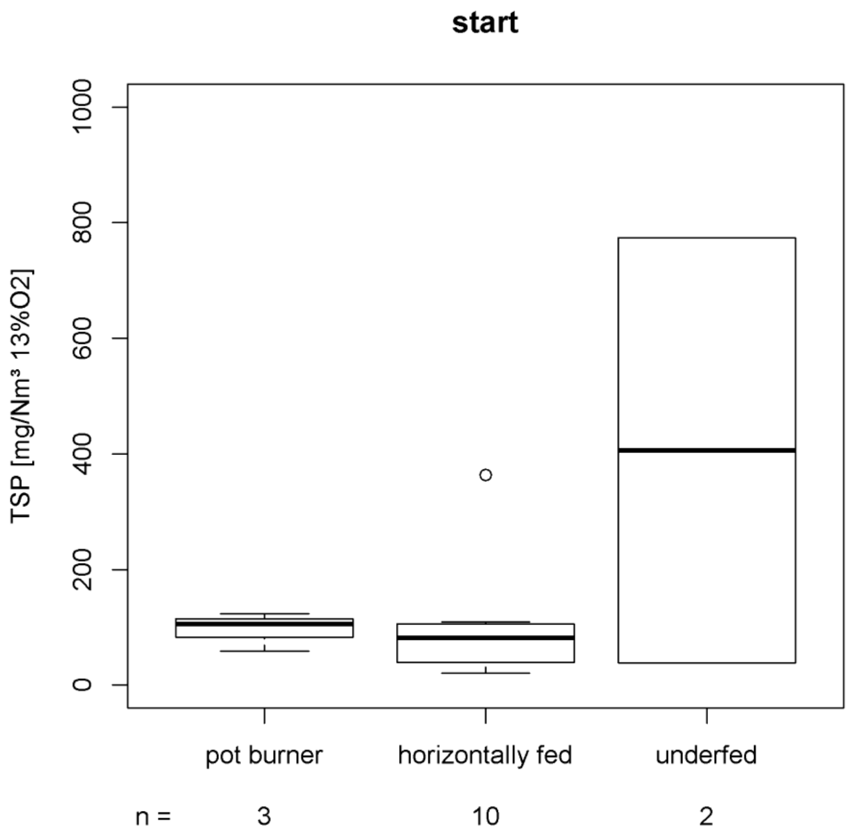
		Pellet Boiler 1		Pellet Boiler 2		Pellet Boiler 3	
Parameter	Unit	Load cycle	Real life	Load cycle	Real life	Load cycle	Real life
CO	[mg/m3STP]	272	343	434	358	415	447
NOx	[mg/m3STP]	110	135	158	151	128	120
OGC	[mg/m3STP]	9	7	24	7	3	5
Dust	[mg/m3STP]	37	25	30	32	27	18
Efficiency	%	78,2	75	75,2	83,6	81,1	83,2
Annual Efficiency	%	-	72,4	-	78,8	-	81,4

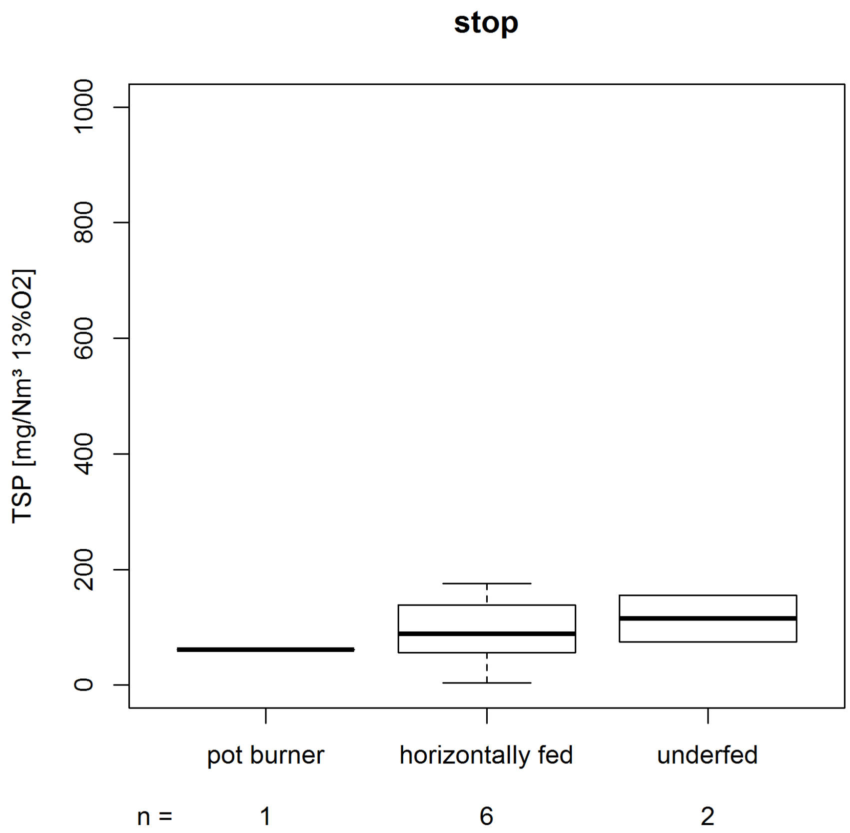
Technology Influence – Nominal/Part Load





Technology Influence – Start/Stop Phases





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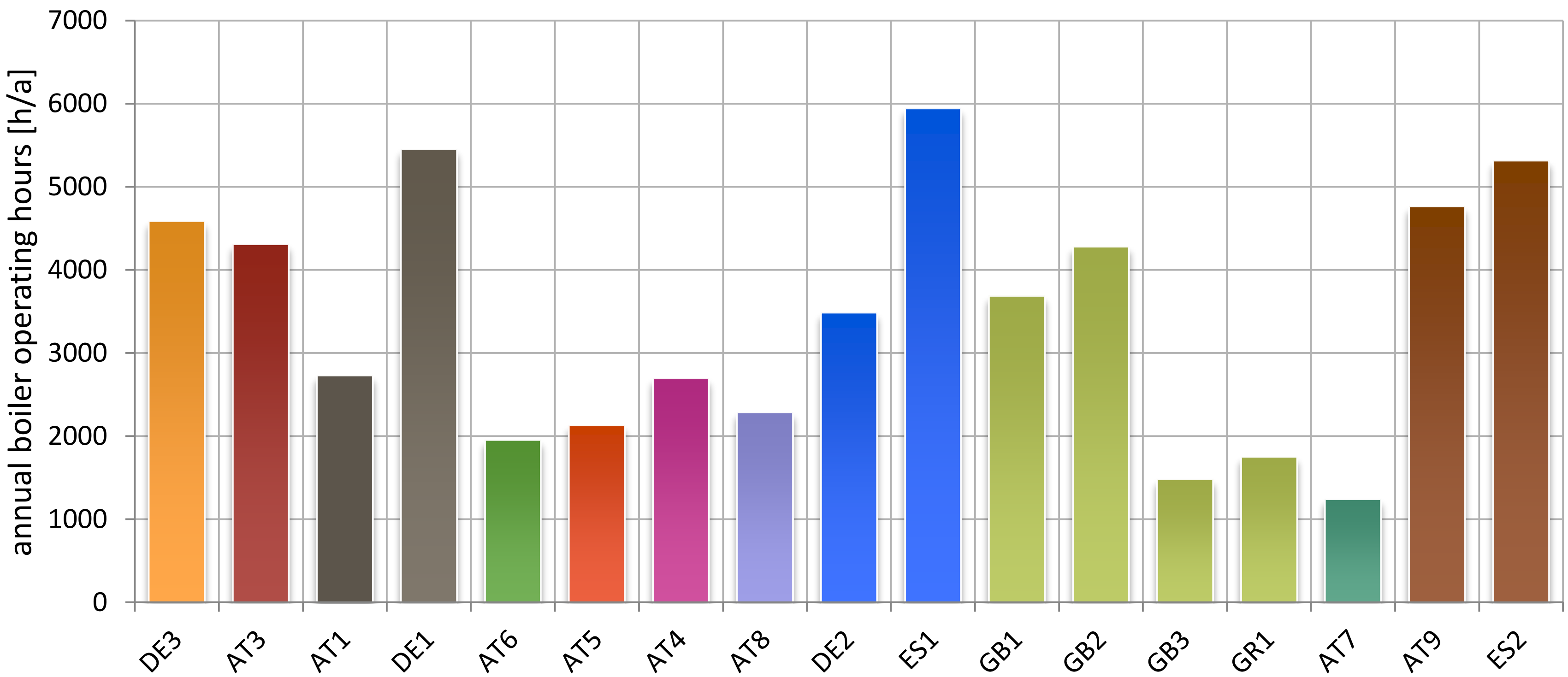
Boiler operation hours



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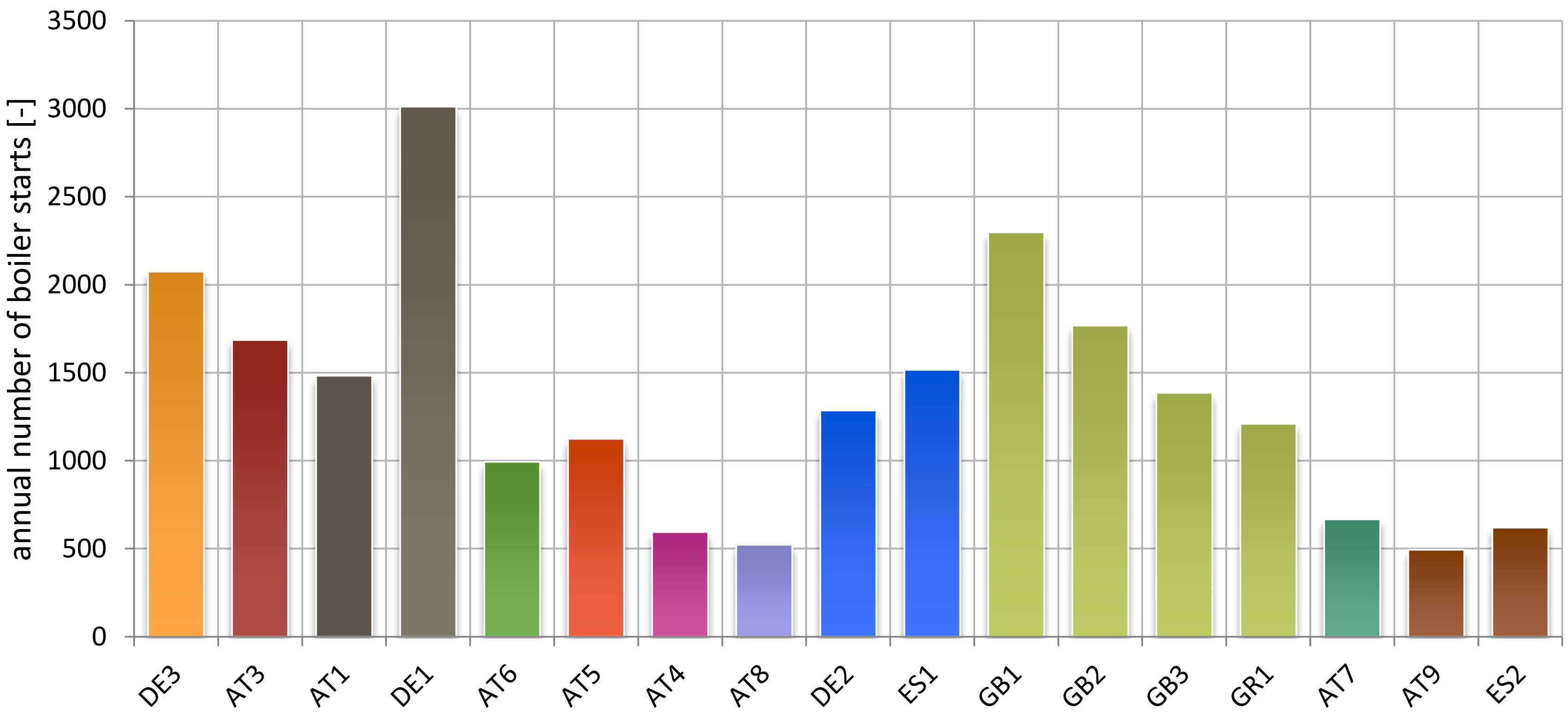
Boiler starts



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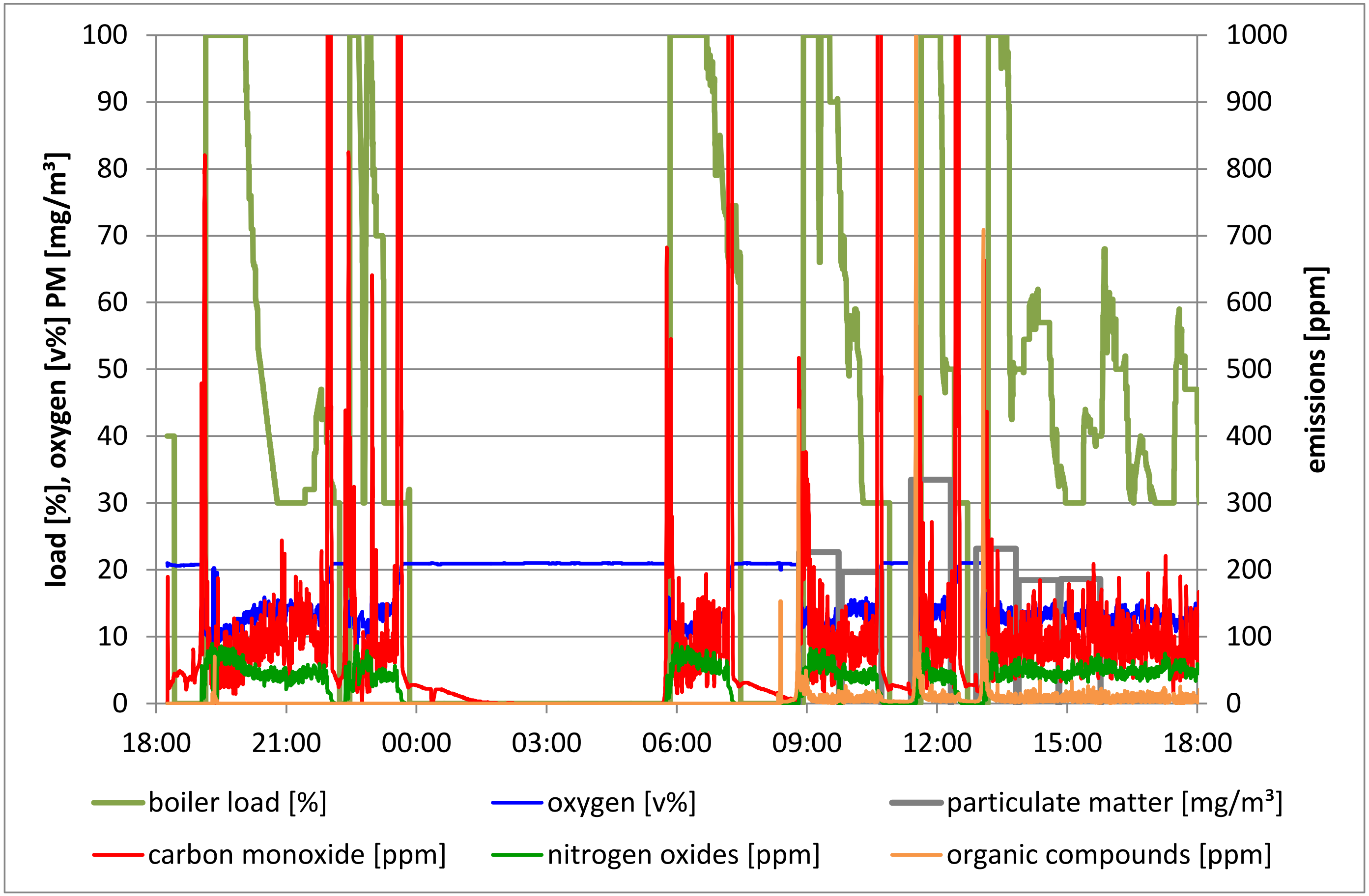
Example: 24h Field emission measurement



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Methodology BaP: Sampling periods

	From:	Until:
Start:	Start of the ignition system	CO- **&** Temp- criteria are fulfilled **→ (100ppm + ∅ COfull load) & (90% from ∅ Tfull load)**
Stop	Decreasing fuel load → indicated by increasing CO-conc	Air fan (air supply) stops.
Full load	At least 1 hr at steady conditions	
Partial load	At least 1 hr at steady conditions, 30 % of nominal load	

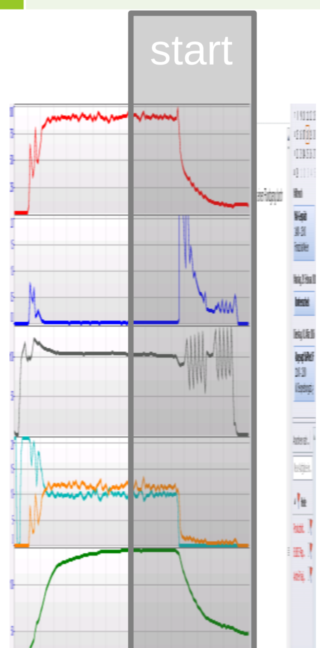
T (comb. Chamber) [°C]

CO [ppm]

Flow rate (flue gas) [m3/h]

O2 [%]
CO2 [%]

T flue gas [°C]



T (comb. Chamber) [°C]

CO [ppm]

Flow rate (prim. air) [m3/h]
Flow rate (sec. air) [m3/h]

CO2 [%]
T flue gas [°C]