Environmental optimisation of gas fired engines in Denmark

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Participants

The participants in this work are

- Rolls-Royce
- Wärtsilä
- GE Jenbacher
- PonPower (Caterpillar engines)
- National Environmental Research Institute, NERI
- Danish Gas Technology Centre, DGC.

Acknowledgement

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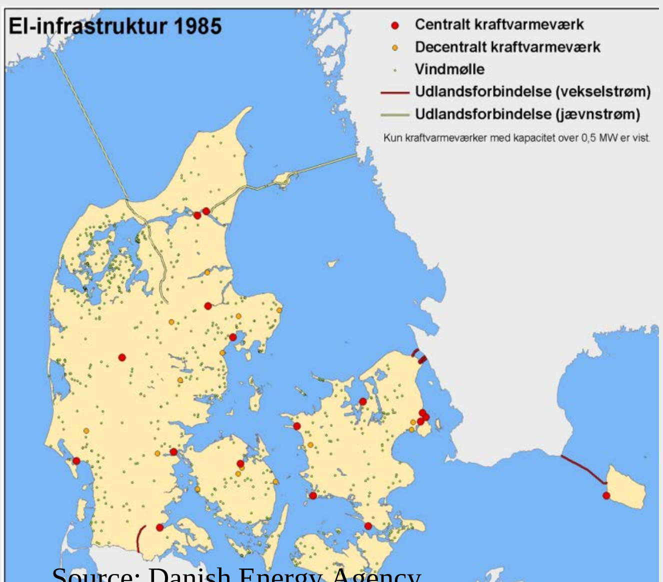
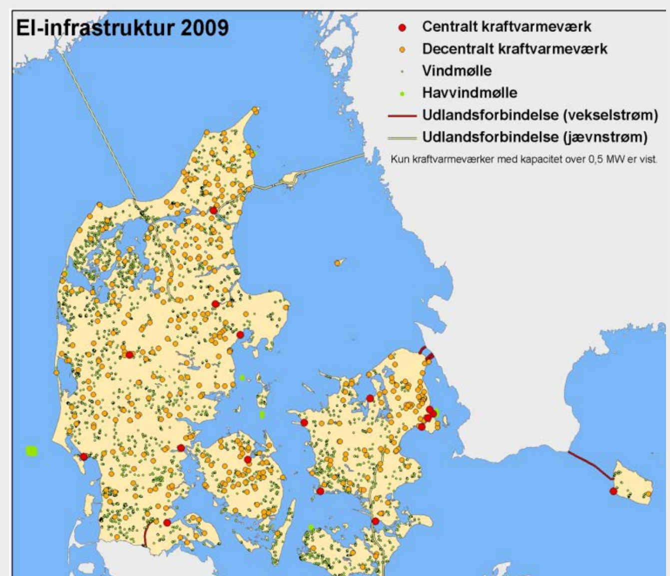
Background

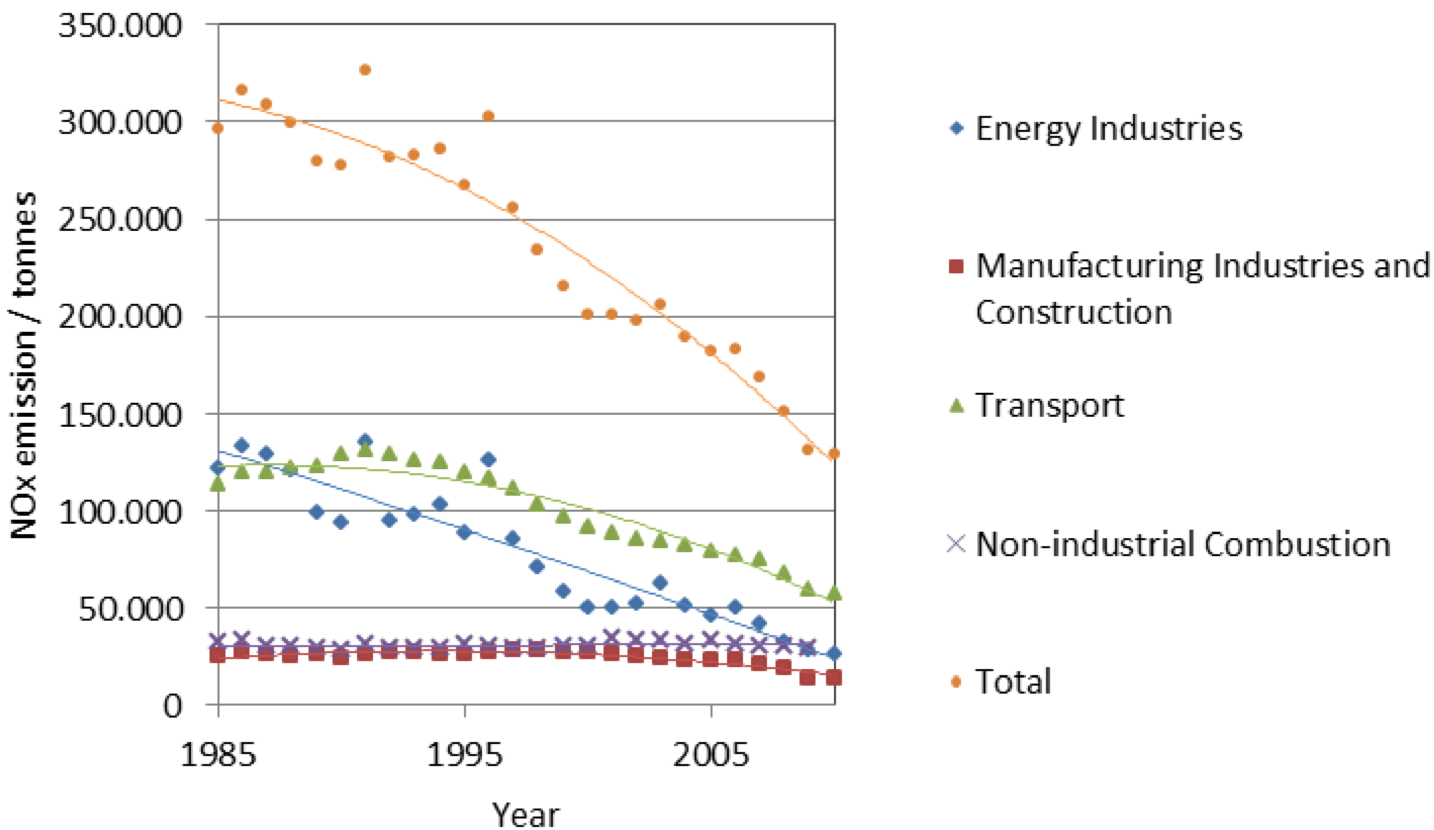
- ≈ 1.000 MW of electric power capacity is installed at natural gas fired engine based CHP plants
- Main purpose is to deliver heat
- The heat is produced by an engine or a boiler depending on electricity price.





Source: Danish Energy Agency

NO_x emissions in Denmark



Source: Based on DCE data

Background

- A projection says that Denmark will not be able to meet the 2020 target for NO_x
- One NO_x source is gas fired CHP engines
- Often engines are adjusted to meet emission regulation as well as to have high efficiency
- It is possible to reduce the NO_x by adjustment – however, it affects other emissions negatively

Purpose

The work will answer the questions

- What is the NO_x reduction potential by engine adjustment?
- What are the consequences on other emissions in terms of
  - Emitted amounts?
  - Related external costs?
- What are the socio-economic consequences?

Approach

How have we answered the questions?

- Measurement of efficiency and emissions at different settings
- Determination of external cost for different species
- Analysis of conducted measurements
- Economic analysis

Measurements

- selected engines

Unit	Make	Size
#1	Rolls Royce B35:40	4990 kW_e
#2	Rolls Royce KVGS-G4	2075 kW_e
#3	Wärtsilä V25SG	3140 kW_e
#4	Wärtsilä V34SG	6060 kW_e
#5	Jenbacher J320	1063 kW_e
#6	Jenbacher J620	3047 kW_e
#7	Caterpillar G3516	1047 kW_e
#8	Caterpillar G3616	3845 kW_e

Represents 85% of the natural gas consumption of all CHP engines in Denmark

Measurements
- selected engine settings

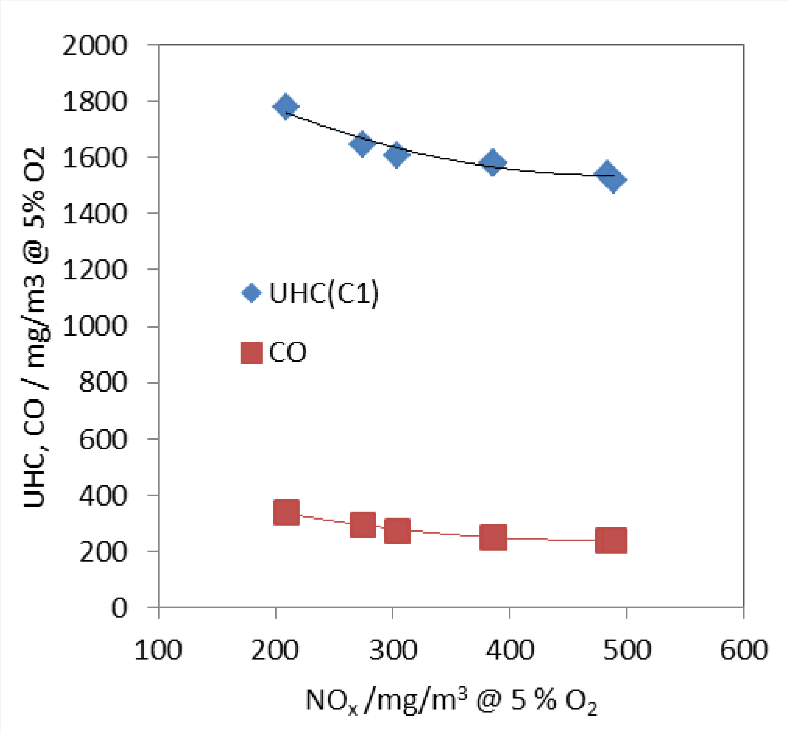
Unit mg/m³(n) @ 5% O_2	TI_1	TI_2	TI_3	TI_4
λ_1			M_5 $NO_x = 200$	
λ_2			M_6 $NO_x = 300$	
λ_3	M_1 $NO_x = 200$	M_2 $NO_x = 300$	$M_{3/7}$ $NO_x = 400$	M_4 $NO_x = 500$
λ_4			M_8 $NO_x = 500$	

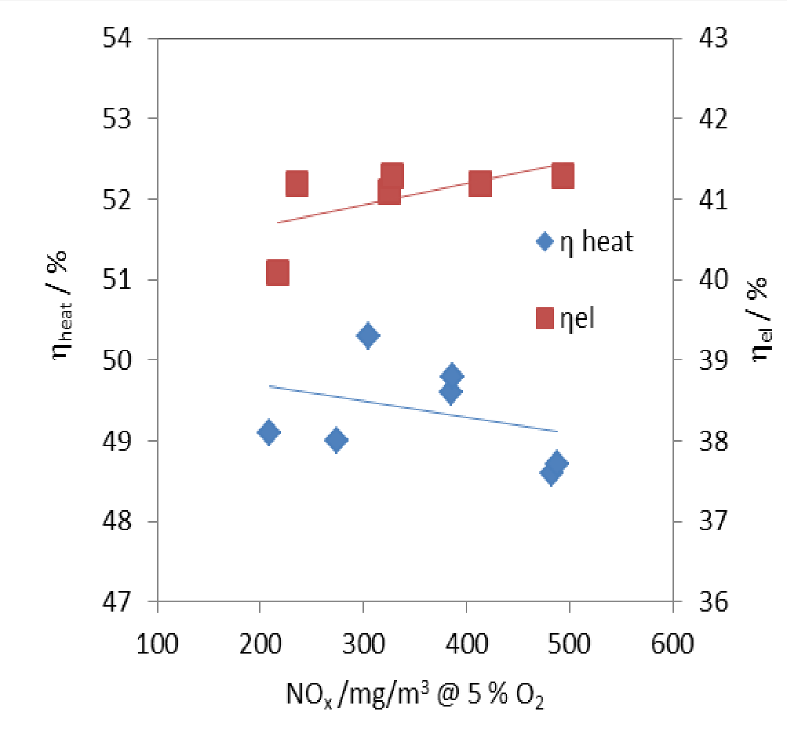
Measurements
- conducted measurements

- O_2, CO, CO_2, NO_x, NO_2, UHC
- Hydrocarbon composition – including formaldehyde
- Fuel consumption, heat and electricity production

Measurements

- results

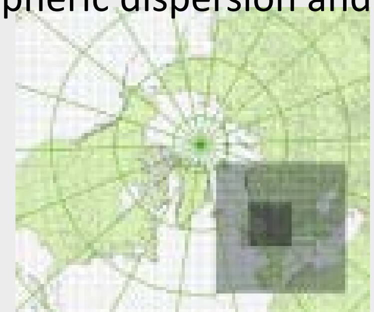




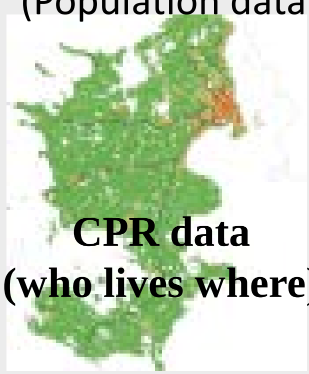
Health related external costs

Specific source
(Measured emissions)

Concentration distribution
(Atmospheric dispersion and chemistry)



Human exposure
(Population data)



Human impact
(Exposure response functions)

Resulting cost
(Economic valuation)

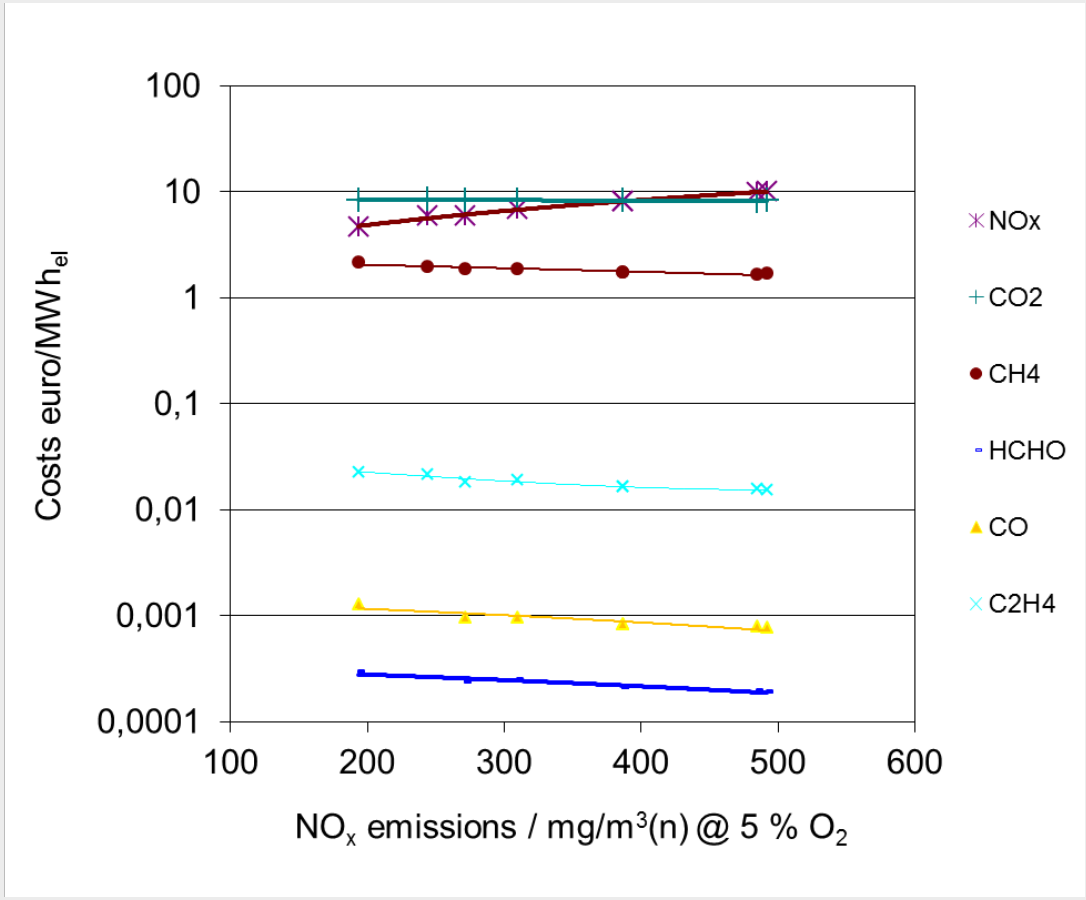
Health related external costs
- Results

NO_x €/kg ($NO_{2,eq}$)	CO €/kg	HCHO €/kg	C_2H_4 €/kg
7.6	$9.3\ 10^{-4}$	$1.3\ 10^{-3}$	0.29

CH_4, C_2H_6, C_3H_8:

No health effects at relevant concentrations

Health related external costs
- Relative importance, natural gas fired engines



Reduction potential

- Baseline: Emissions and gas consumption, 2010

	Natural gas consumption TJ	NO_x	UHC
		Emissions mg/m³(n) @ 5% O_2	
Jenbacher 600	2,203	327	1,164
Jenbacher 300	4,221	455	1,042
Rolls-Royce B	364	443	1,049
Rolls-Royce K	6,417	499	1,517
Wärtsilä 25 SG	1,369	420	1,182
Wärtsilä 34 SG	2,162	354	1,418
Caterpillar 3500	3,805	445	1,324
Caterpillar 3600	2,723	293	1,812

Reduction potential

- Results - gas engines

	NO_x		CH_4		CO		CO_2	
	Before	After	Before	After	Before	After	Before	After
	ton/year		ton/year		ton/year		million ton/year	
Jenbacher 600	227	175	834	993	144	197	122	123
Jenbacher 300	604	340	1,161	1,279	360	381	235	240
Rolls-Royce B	51	29	121	143	14	19	20	20
Rolls-Royce K	1,008	513	3,411	3,852	484	633	345	350
Wärtsilä 25 SG	181	109	608	719	126	164	74	75
Wärtsilä 34 SG	241	172	669	842	78	100	118	118
Caterpillar 3500	533	307	2,134	2,253	224	233	208	213
Caterpillar 3600	251	215	1,809	1,921	168	175	147	147
Sum	3,095	1,858	10,748	12,002	1,598	1,901	1,269	1,285
Increase		-40%		12%		19%		2%

Cost evaluation

- Examples

Engine

- Price of natural gas (taxes are fixed)
- Service and maintenance costs
- Electricity and heat efficiency of the engine

Boiler

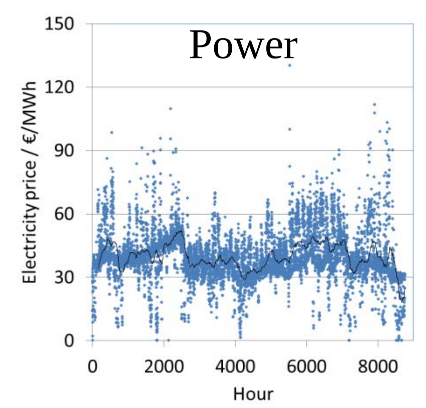
- Price of fuel
- Energy and CO_2 tax of fuel for the boiler if different from natural gas
- Boiler efficiency

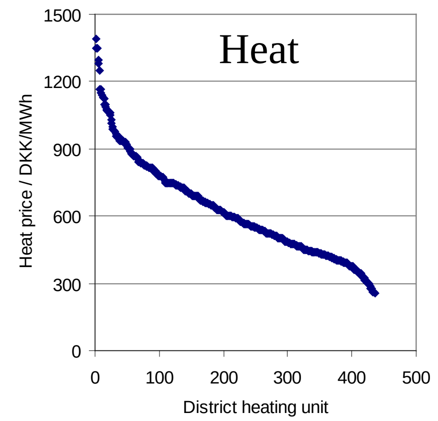
Cost evaluation

- production assumptions

$$\text{Total costs} = \sum Cost_{External} + \sum Cost_{production} + \sum Cost_{products}$$

- Power production is constant
  - →Higher gas consumption for the engines
  - →Higher heat production from the engines
- Total heat production is constant
  - →Reduced heat production using boilers





Cost evaluation

Influence on energy production and consumption

Electricity	TJ/year	0
Heat – engines	TJ/year	299
Natural gas - engines	TJ/year	359
Heat - boilers	TJ/year	-299
Natural gas - boilers	TJ/year	-285

Cost evaluation

Importance of externalities

	Unit	Before	After	Reduction
Natural gas	TJ/year	23,264	23,338	-74.5
NO_x	ton/year	3,095	1,846	1,248
CH_4	ton/year	10,748	12,002	-1,254
CO	ton/year	1,598	1,893	-295
CO_2	mill. ton/year	1,269	1,269	-0,4

Cost evaluation

Importance of externalities

M€/year	Before	After	Reduction
NO_x	23.5	14.0	9.5
CH_4	4.5	5.0	-0.5
CO	$1.5\ 10^{-3}$	$1.8\ 10^{-3}$	$-0.3\ 10^{-3}$
CO_2	21.1	21.2	-0.01
Total	49.2	40.2	9.0

Total welfare-economic consequence: Gain of 7.5 M€/year

Including effects on

- tax yield (-0.94 M€/year)
- natural gas consumption (-0.58 M€/year)
- maintenance costs (0.064 M€/year)

Conclusions

- For eight gas engine models it was possible to obtain NO_x emissions as low as 250 mg/m^3 @ 5% O_2 without after-treatment
- On average, the NO_x reduction potential for Danish natural gas fired CHP engines corresponds to a reduction of 40% relative to the present level. Consequences: hydrocarbon emissions will increase by 12% and the CO emission will increase by 19%.
- Harmfulness in terms of negative health effect as well as climate effect was assessed. Change in related costs due to adjustment:
  - NO_x: 9.5 M€/year (saved)
  - Sum of other emitted components: 0.5 M€/year (extra costs)
  - Other welfare-economic consequences: 1.5 M€/year (extra costs)

Thank you for your attention