

Environmental optimisation of gas fired engines in Denmark

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Torben Kvist

(tkv@dgc.dk)

Participants

The participants in this work are

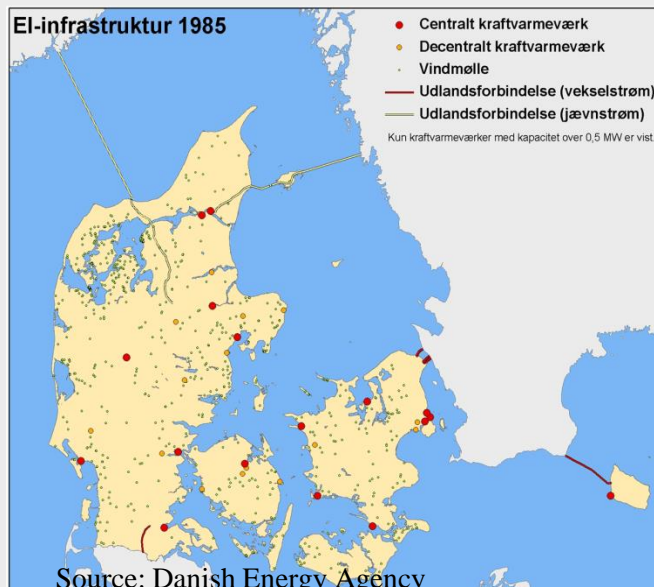
- Rolls-Royce
- Wärtsilä
- GE Jenbacher
- PonPower (Caterpillar engines)
- National Environmental Research Institute, NERI
- Danish Gas Technology Centre, DGC.

Acknowledgement

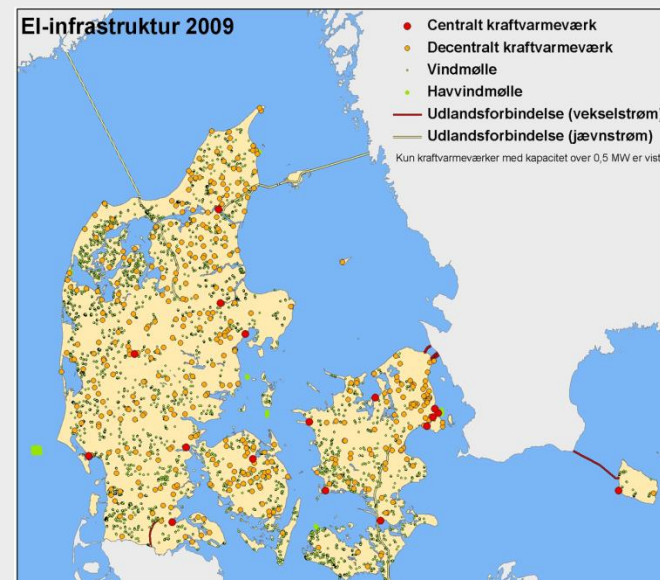
The work was financially supported by the ForskEL programme and Danish gas distribution companies.

Background

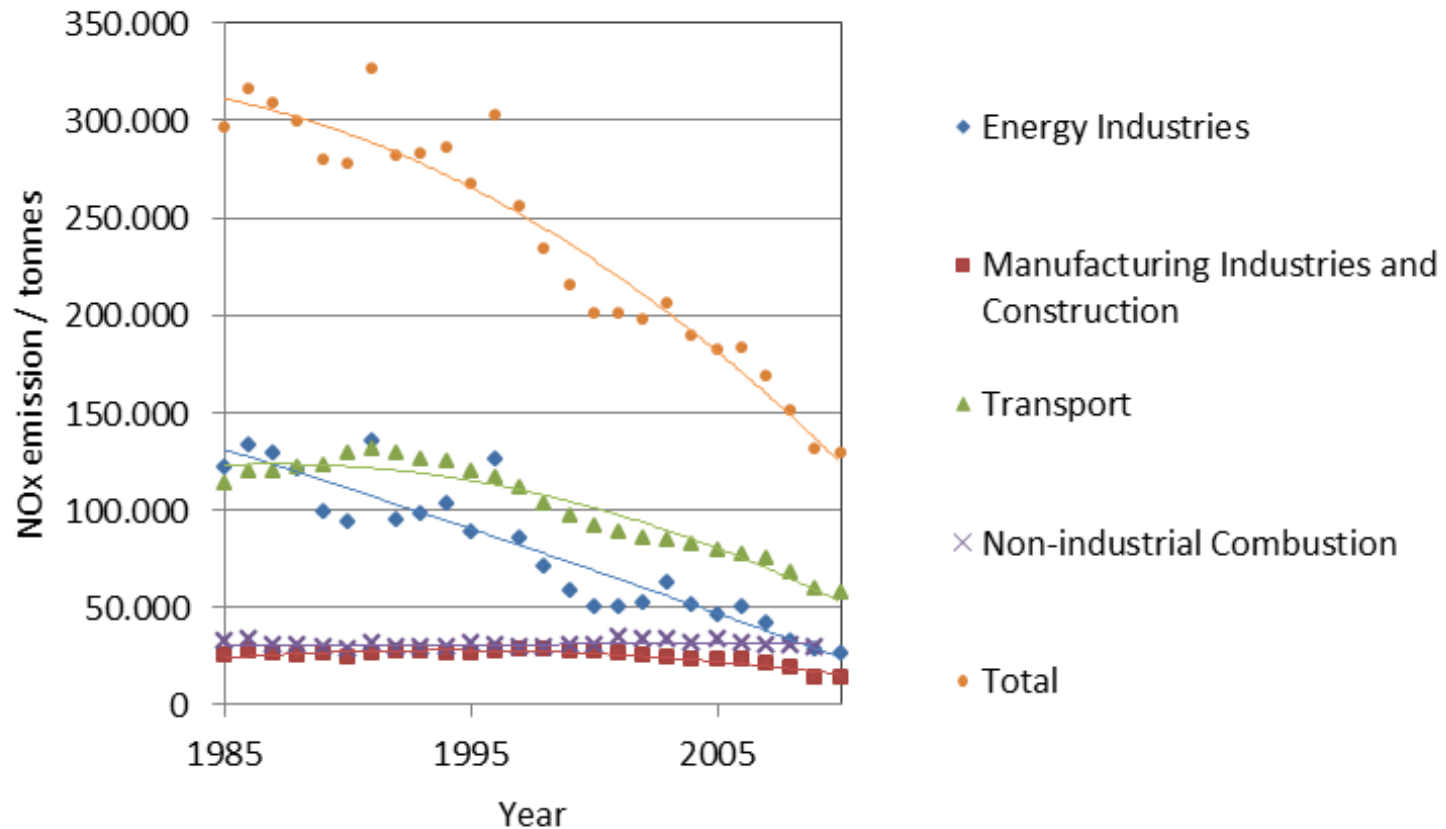
- ≈ 1.000 MW of electric power capacity is installed natural gas fired engine based CHP plants
- The plants supply an area with district heating
- The heat is produced by an engine or a boiler depending on electricity price.



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 overall 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/m ³ (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

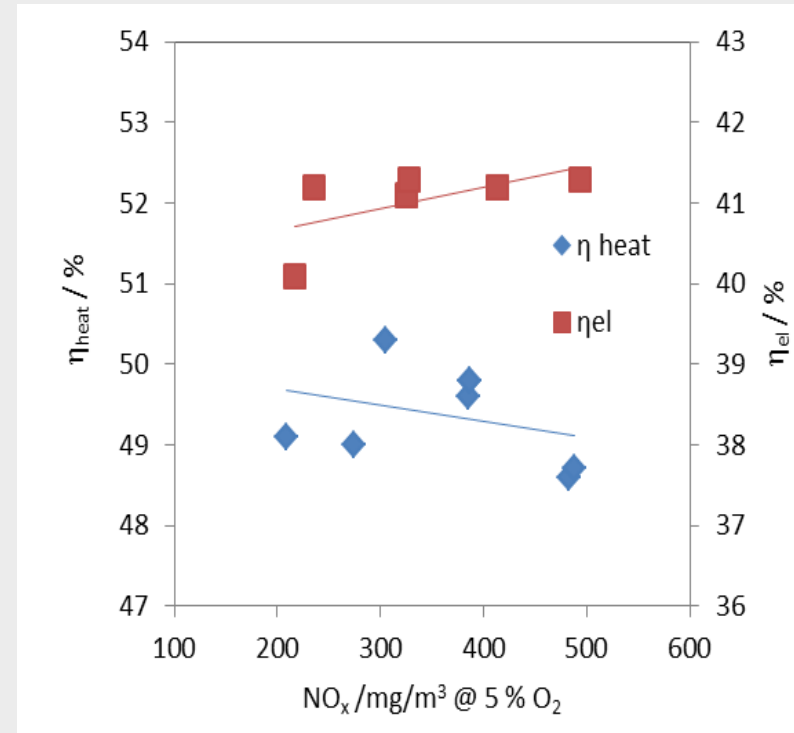
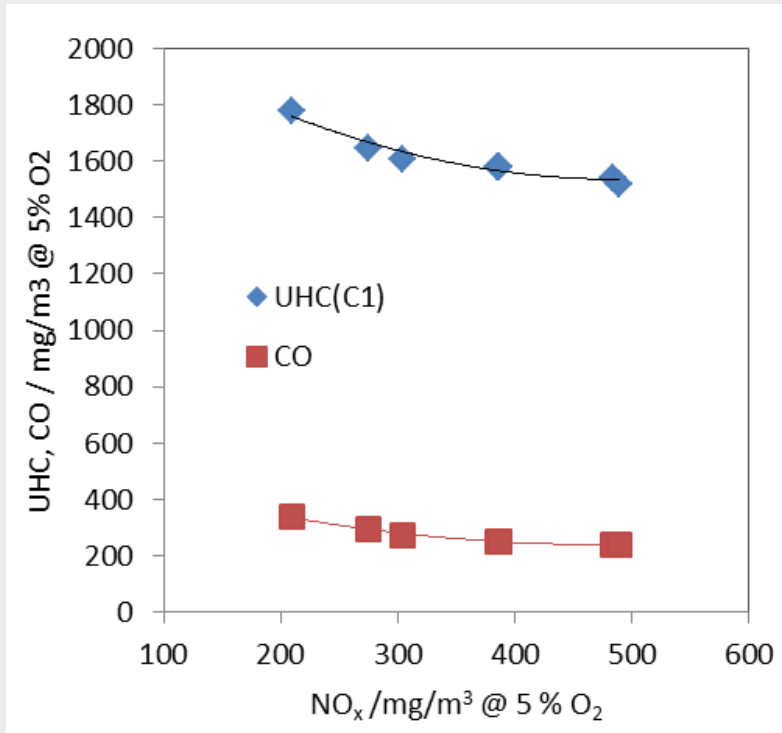
- conducted measurements

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

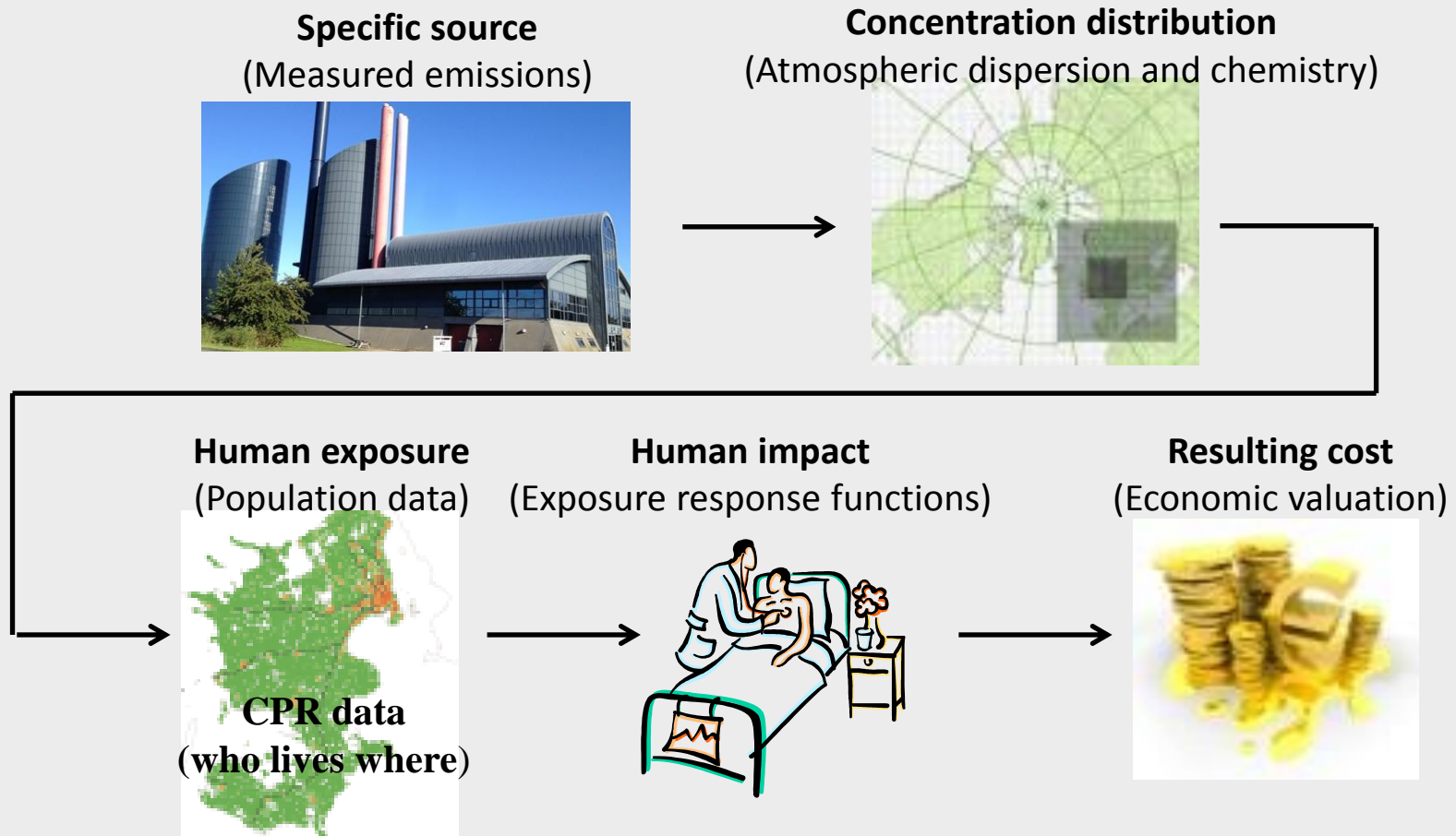


Measurements

- results



Health related external costs



Health related external costs

- Results

NO_x €/kg (NO _{2,eq})	CO €/kg	HCHO €/kg	C₂H₄ €/kg
7.6	9.3 10 ⁻⁴	1.3 10 ⁻³	0.29

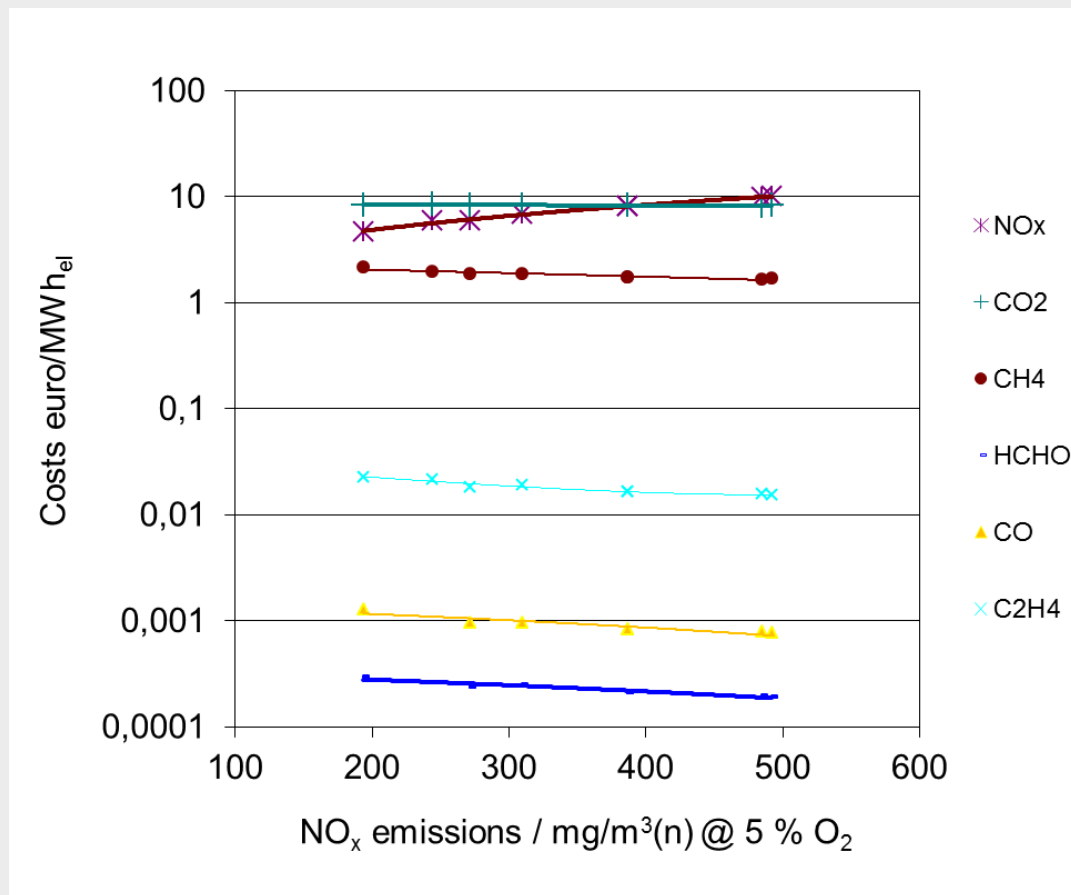
CH₄, C₂H₆, C₃H₈:

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	NO _x	UHC
	TJ	Emissions mg/m ³ (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

Reduction potential-including boiler operation

	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/m³ @ 5% O₂ 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)



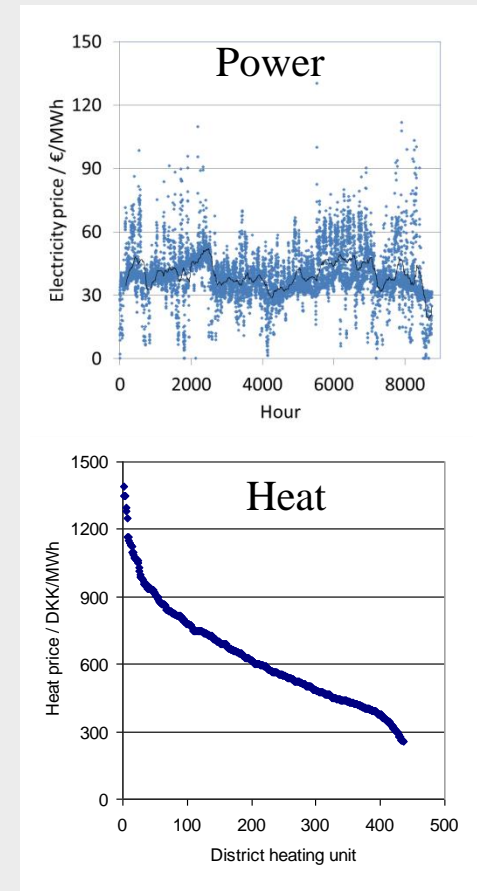
Thank you for your attention

Cost evaluation

- production assumptions

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

- 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

- 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 CO₂ tax of fuel for the boiler if different from natural gas
- Boiler efficiency

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

