KU LEUVEN

CHP, thermal storage & thermal networks, and the interaction with the electric and gas grids.

William D’haeseleer
KU Leuven Energy Institute
Belgium

Philosophical Question

Why do we see a societal tendency to move towards decentralized/distributed generation in electricity provision

and

a drive towards more centralized approaches for heat provision?

Is there some kind of ideological agenda behind it?

Boundary Conditions Thermal Networks

- The implementation of thermal networks is very much dependent on the situation and the context:
  - the meteorological circumstances,
  - whether-or-not there is already a heat network present,
  - the type of built environment,
  - the availability of energy at low marginal cost (such as e.g., geothermal heat, cheap “waste” heat from the process industry of electrical power plants, sometimes “superfluous” electrical energy generated from wind and/or PV solar),
  - the existence of a well-distributed natural gas grid, etc.

→ of uttermost importance to determine the boundary conditions before one can really start to deploy thermal grids and their operation.

KU LEUVEN

Boundary Conditions Thermal Networks

- Use of intelligent thermal networks is more than just ordinary "classical" district heating, but a correct estimation of it must be embedded in a full system integration approach, hence including the thermal sector, the electricity system (incorporating the grid) and the gas system (incorporating the grid).
- The "business case" often depends on the *cost of investment* of the thermal grid itself and the volume of *heat off take*.
  - The evaluation of the heat grid strongly differs whether the investment costs have already been spent or not in the past. It looks more interesting to start from already existing heat grids (because of the "sunk costs");
  - But existing grid may be a disadvantage because modern, more intelligent thermal grids offer more opportunities (such as heating and cooling);
  - Badly insulated houses vs zero energy buildings make a difference for the heat demand…

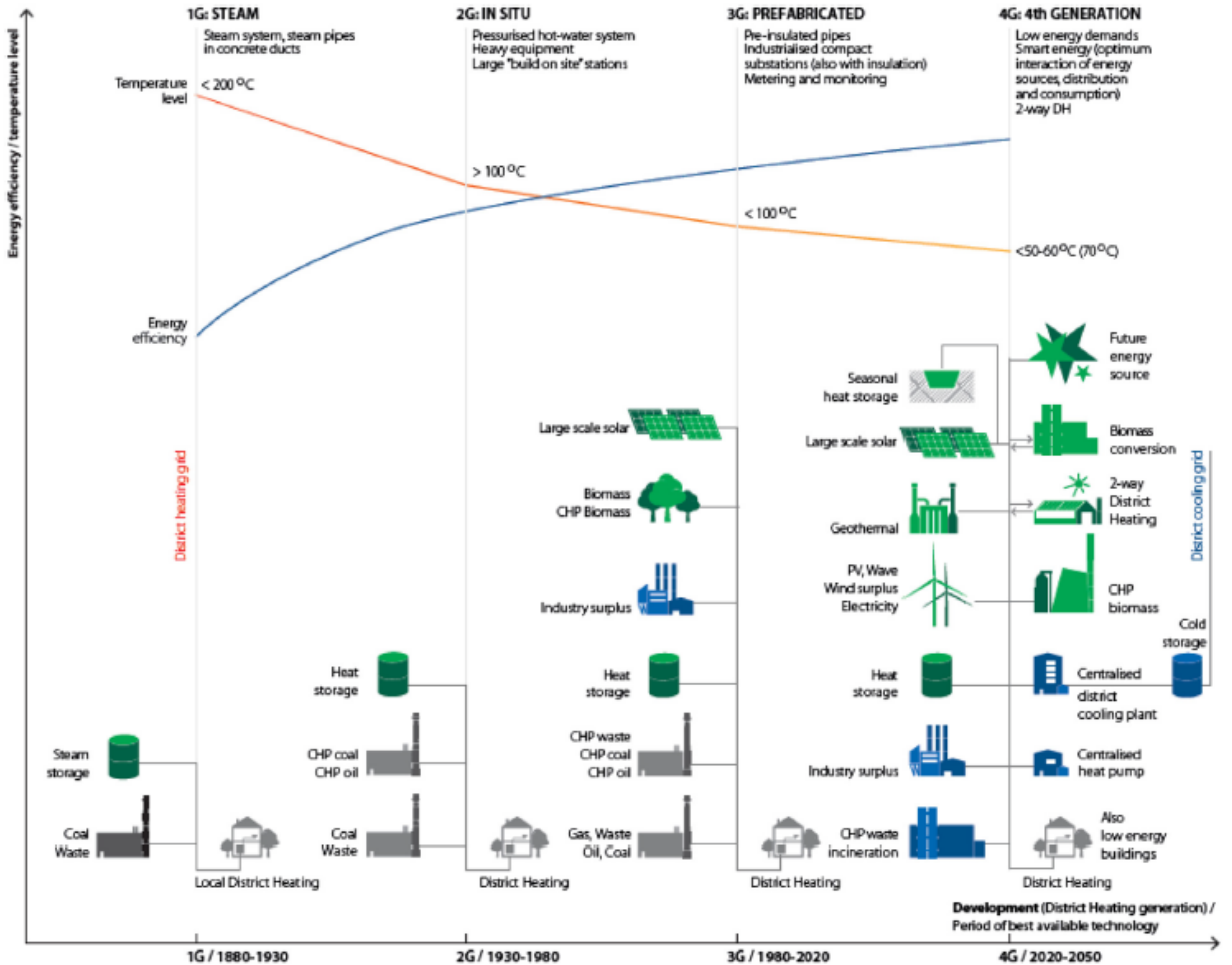
Boundary Conditions Thermal Networks

- An important aspect for the implementation of thermal networks is furthermore the <u>transition</u> of e.g. gas-fired individual heating to a more centralized philosophy.
- In this regard, also small micro CHP with local thermal storage, the future renewable methane (from "power-to-gas" conversion), must be considered as possible competing technologies.
- Also the temperature level of intelligent thermal networks must be integral part of this study for boundary conditions.

Boundary Conditions Thermal Networks

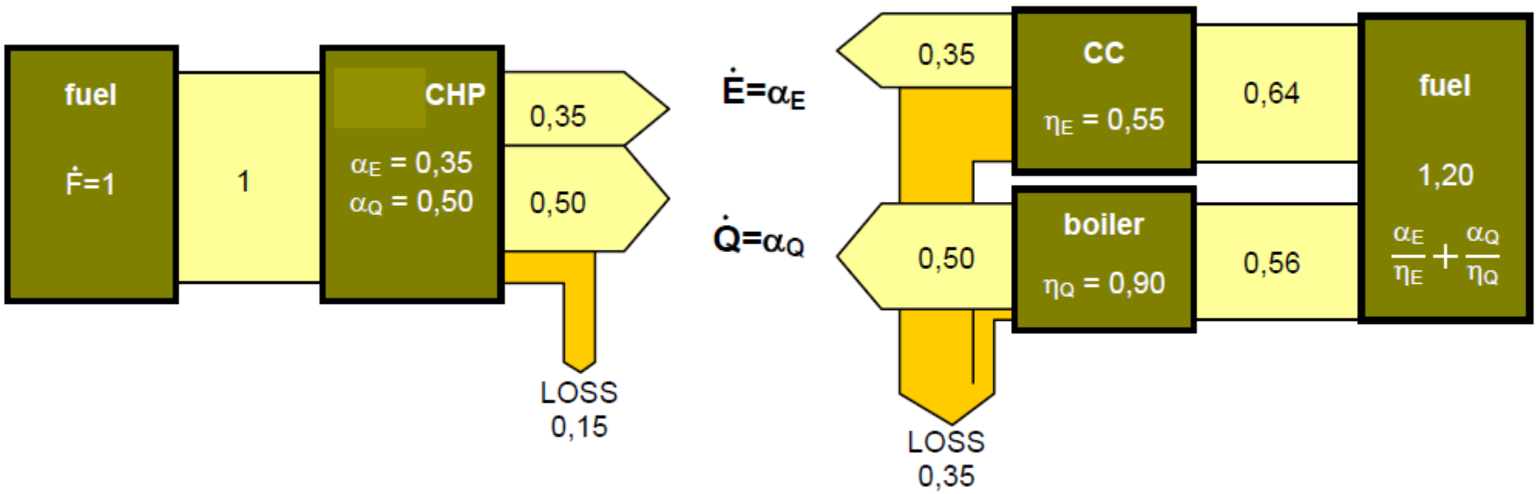
- The market and economic context will not be negligible:
  - Is there a liberalized market philosophy in existence with the authorities in a supervisory/regulatory role?
  - Or a fully regulated environment whereby the authorities basically do what they want?
  - Optimally, all technologies should be able to compete (condensing boilers, local CHP, gas grids, heat pumps – also for cooling, …)

Fourth Generation Networks



Ref: H. Lund et al, Energy, 2014

Static Evaluation Energy Savings CHP

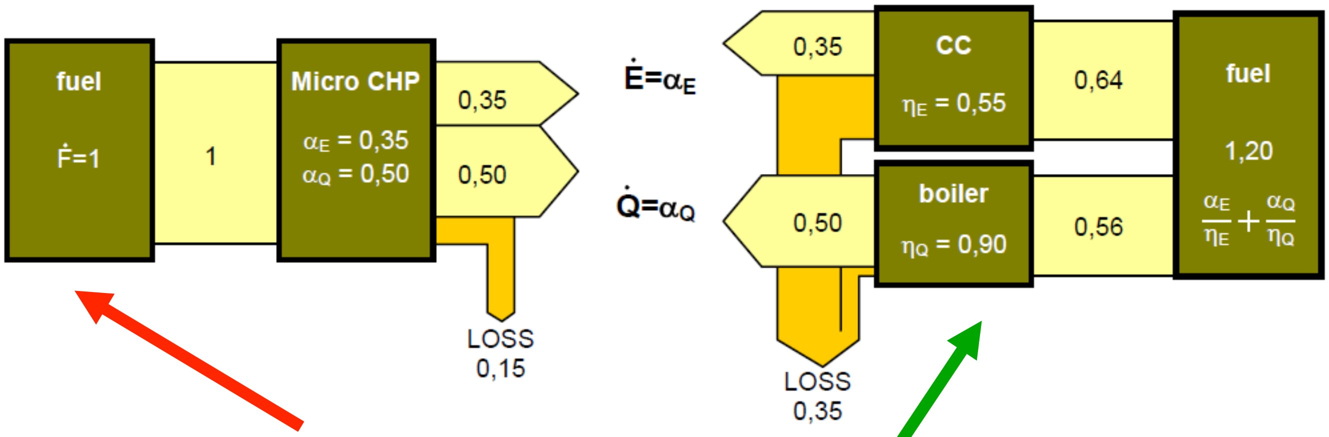


Electrical efficiency CHP $\alpha_E \equiv \frac{\dot{E}}{\dot{F}}$

Thermal efficiency CHP $\alpha_Q \equiv \frac{\dot{Q}}{\dot{F}}$

Evaluation criteria CHP

Primary Fuel Saving

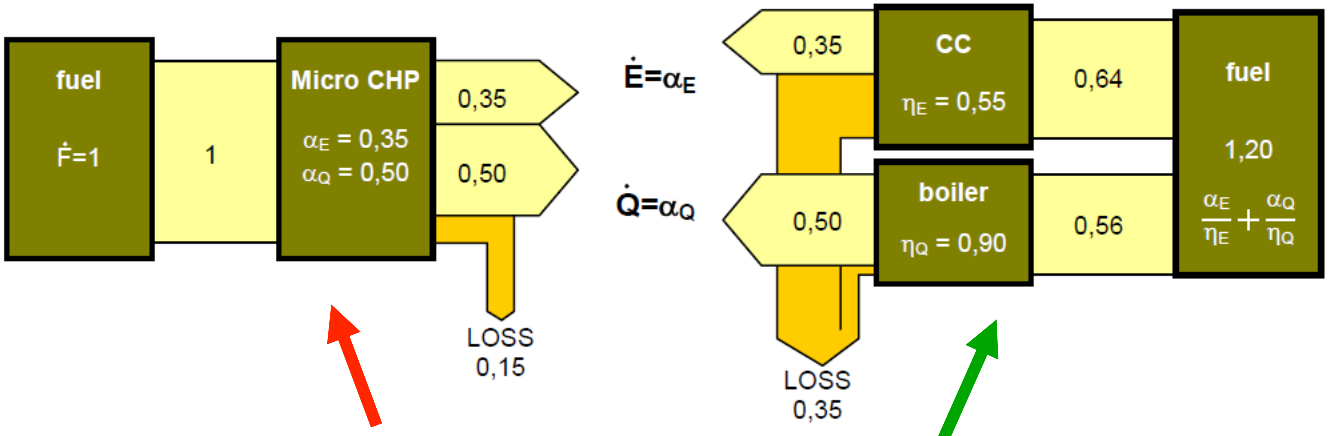


Primary fuel saving of CHP with respect to separate production

$$PFS = \frac{\alpha_E}{\eta_E} + \frac{\alpha_Q}{\eta_Q} - 1 \qquad (7)$$

Evaluation criteria CHP

Primary Fuel Saving



Primary fuel saving of CHP with respect to separate production

Important aspects :

- α_E and α_Q best nominal/rated efficiencies
- which η_E en η_Q for separate production?
- Utilization duration of the CHP – need for back-up el & heat
- No heat to be cooled away

Allocation of Advantage to E Side

Advantage savings to *electrical* side – often applied by service companies used to supply heat who now install CHP to produce and sell also electricity

Take from outset as basic hypothesis: $\alpha_Q^{\text{eff}} = \eta_Q$

$$\alpha_E^{\text{eff}} = \frac{\alpha_E}{1 - \frac{\alpha_Q}{\eta_Q}}$$

Example with gas engines as CHP:

$$\left.\begin{array}{l} \alpha_E = 35\% \\ \alpha_Q = 50\% \\ \eta_E = 55\% \\ \eta_Q = 90\% \end{array}\right\rangle \quad \alpha_Q^{eff} = 90\% \;\&\; \alpha_E^{eff} = 79\%$$

Allocation of Advantage to Q Side

Advantage savings to _thermal_ side – often applied by electric utilities used to supply electricity who now install CHP to produce and sell also heat

Take from outset as basic hypothesis: $\alpha_E^{\text{eff}} = \eta_E$

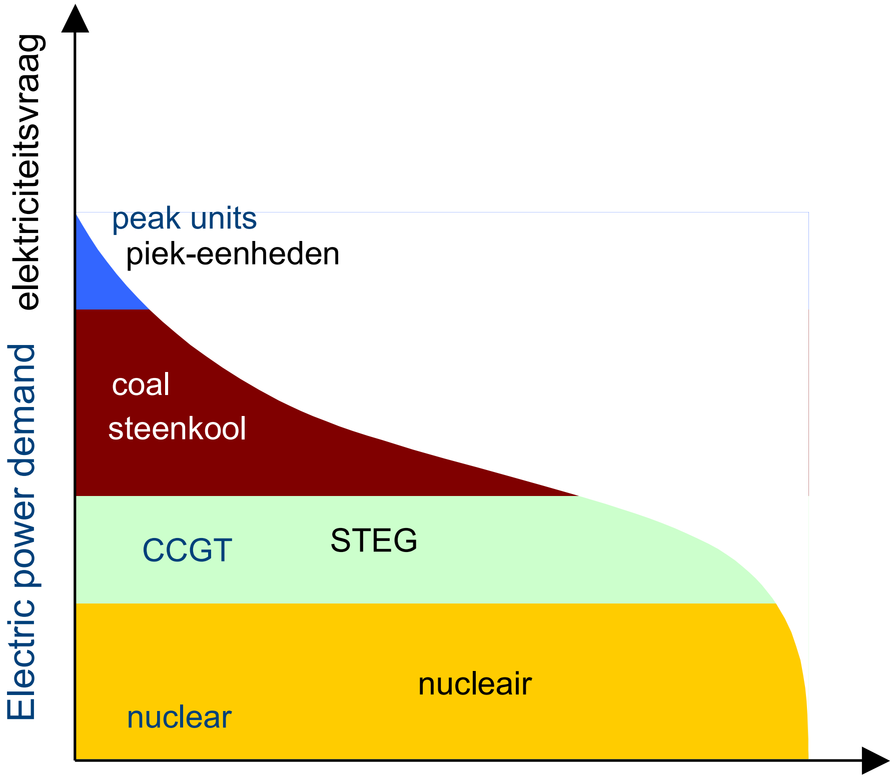
$$\alpha_Q^{\text{eff}} = \frac{\alpha_Q}{1 - \frac{\alpha_E}{\eta_E}}$$

Example with CCGTs as CHP:

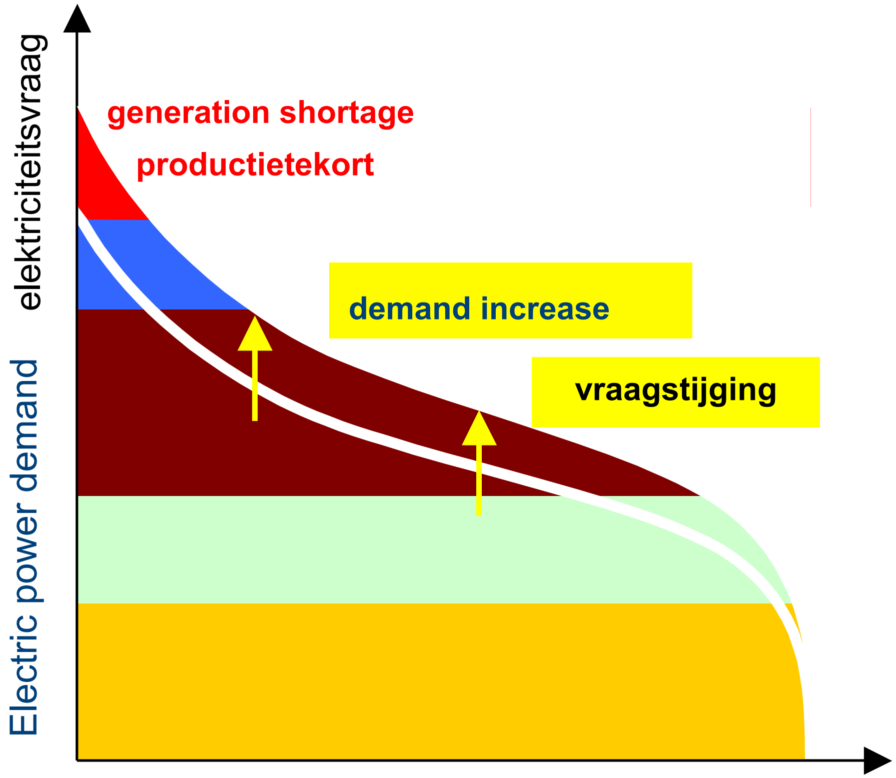
$$\left.\begin{aligned} \alpha_E &= 45\% \\ \alpha_Q &= 45\% \\ \eta_E &= 55\% \\ \eta_Q &= 90\% \end{aligned}\right\rangle \quad \alpha_Q^{eff} = 248\% \;\&\; \alpha_E^{eff} = 55\%$$

Evaluation criteria CHP – System Approach

- Influence CCGT investment at increasing ‘central’ elec demand (1) -

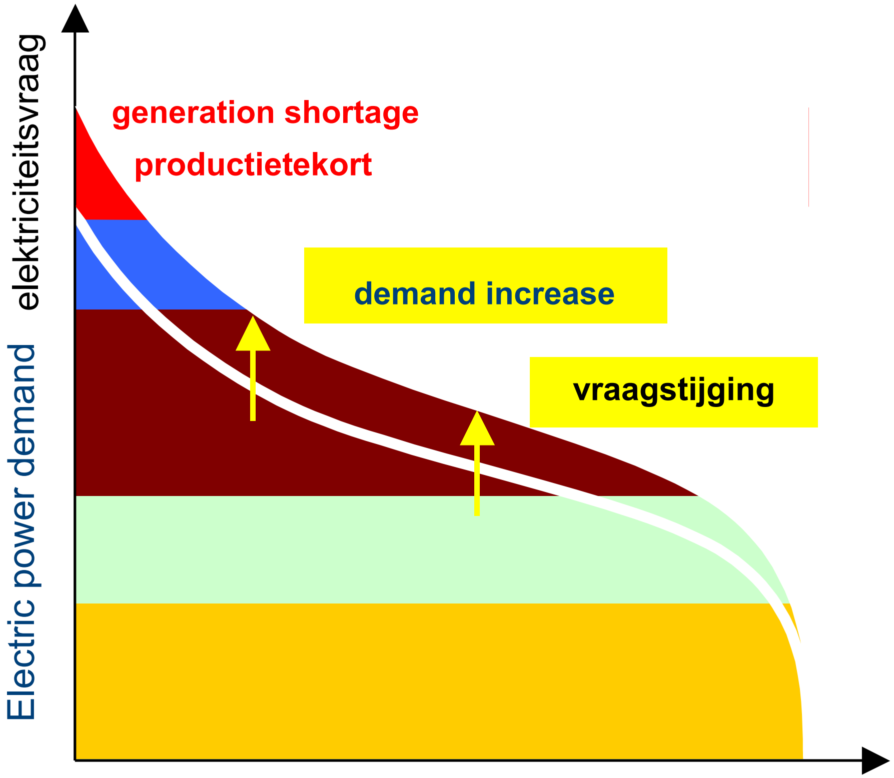


Increase of demand for electricity

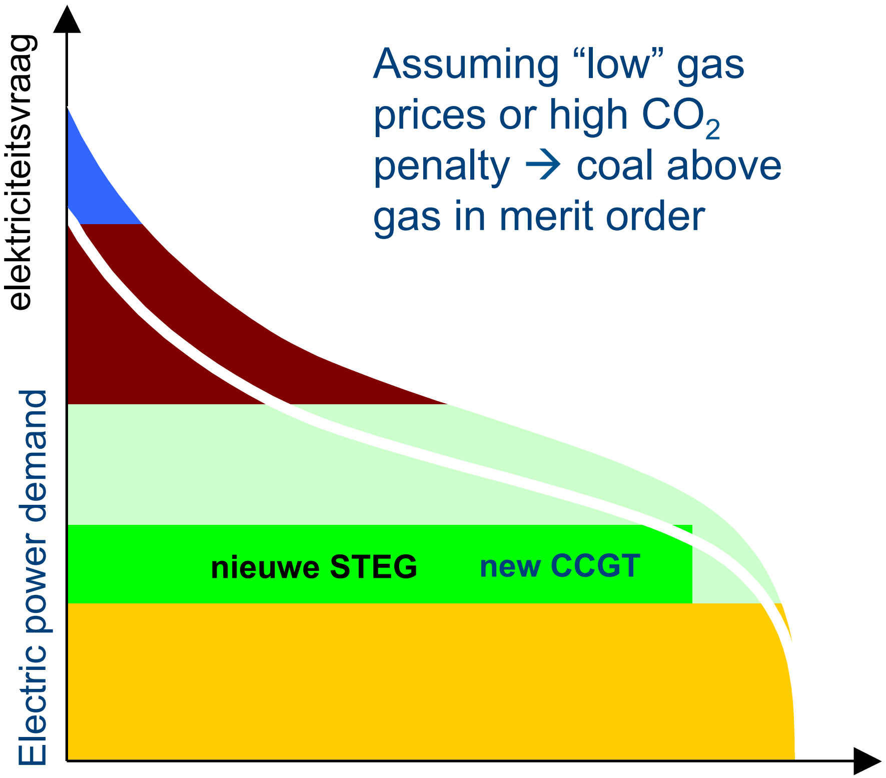


Evaluation criteria CHP – System Approach

- Influence CCGT investment at increasing ‘central’ elec demand (2) -



Need for extra generation capacity

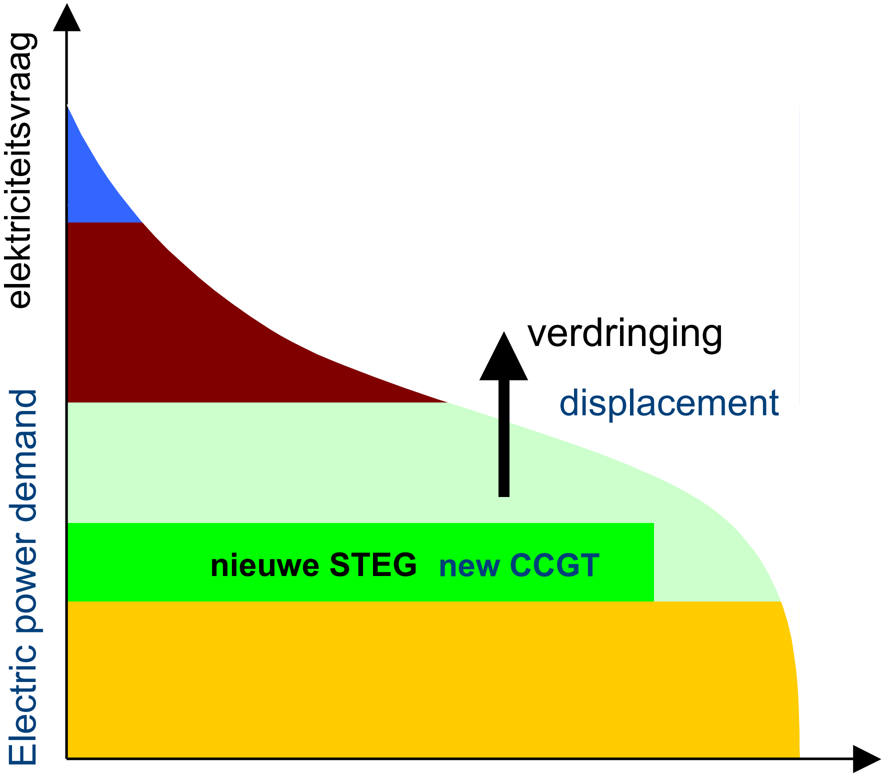


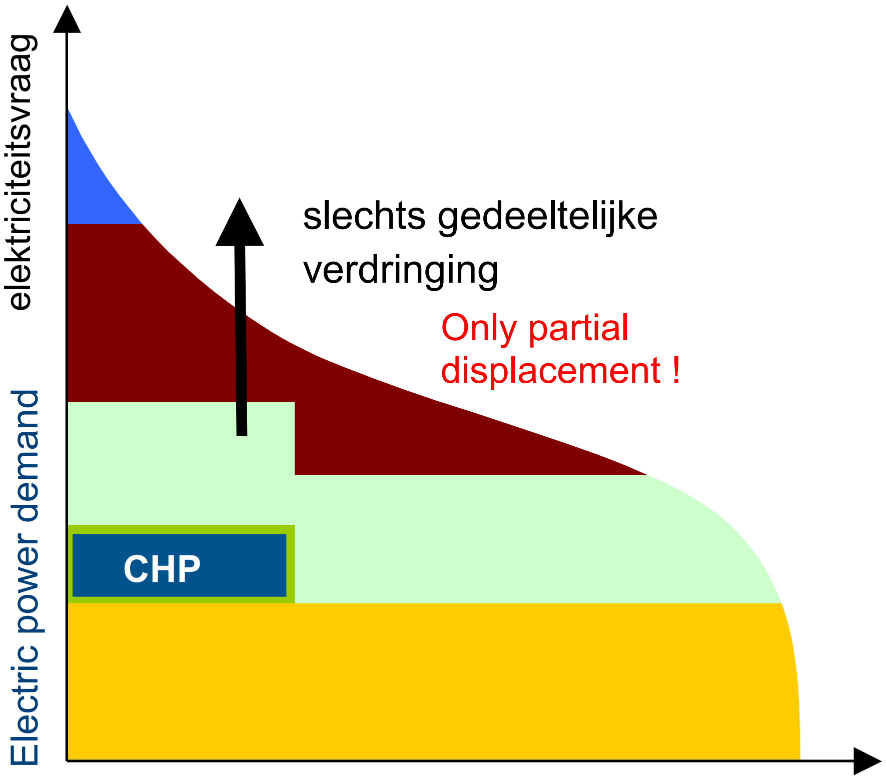
Assuming “low” gas prices or high CO_2 penalty → coal above gas in merit order

Evaluation criteria CHP – System Approach

- Dynamic aspects [1] -

CCGT versus CHP with limited operation time duration





Less coal-fired PP pushed out → less CO_2 avoided

KU LEUVEN

Evaluation criteria CHP – System Approach

- Dynamic aspects (2) - **INDUSTRY**

2000 → 2010

360 MW_e extra CHP with α_E=38%, α_Q=42%, QI=14%, U=7500h/a

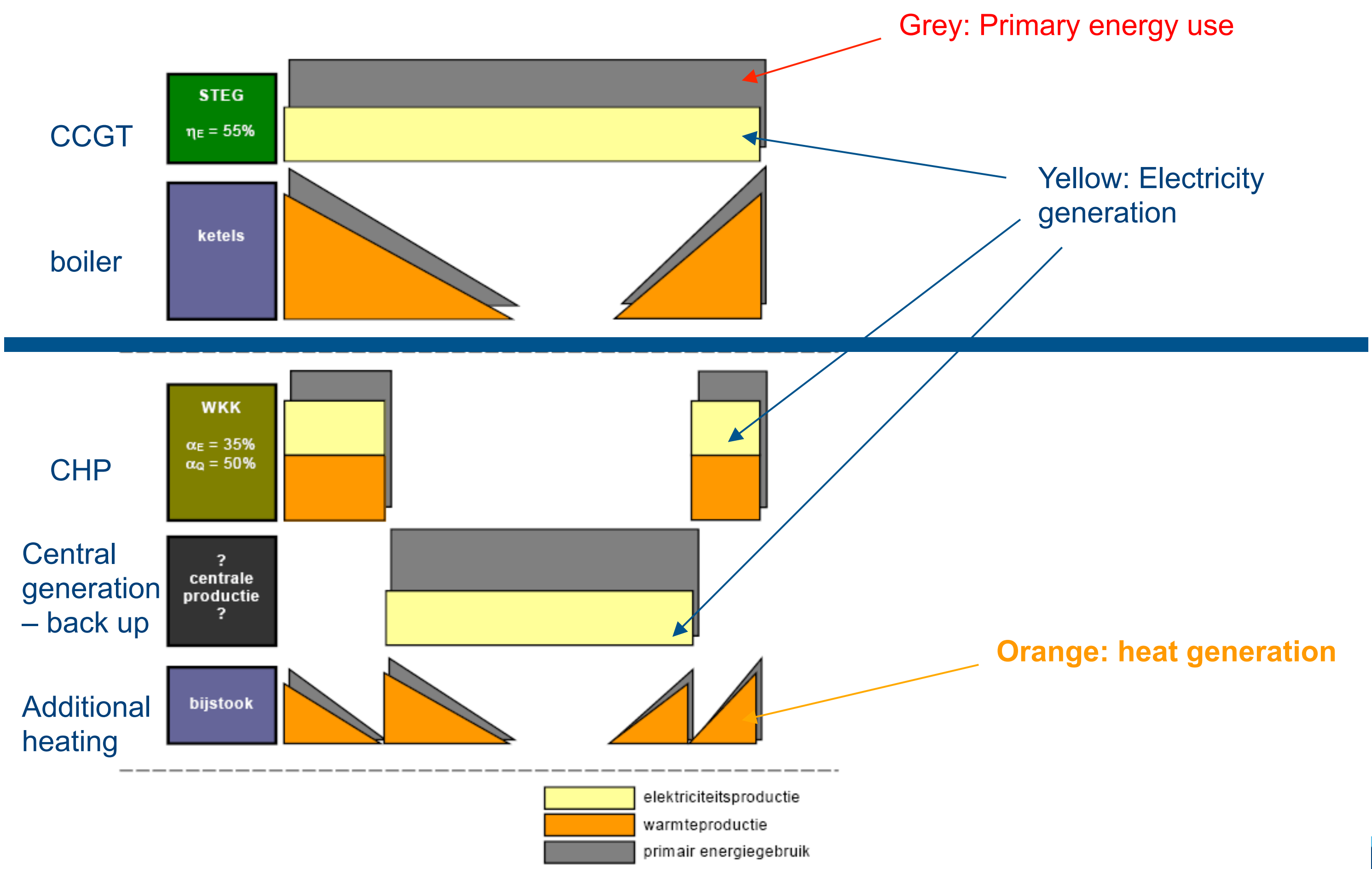
STATIC Primary Energy Saving = 4000TJ_i
CO_2-eq. reduction = 240 kton CO_2

SIMULATION Primary Energy Saving = 4000TJ_i
CO_2-eq. reduction = 250 kton CO_2

INDUSTRY		**w/o extra CHP**	**with 360 MW_e extra CHP**
thermal	CHP	0	2 990
[GWh_{th}]	boilers	2 990	0
electric	CHP	0	2 710
[GWh_e]	CCGTs	32 110	29 440
	Coal	2 600	2 550

Evaluation criteria CHP – System Approach
- Dynamic aspects (3) – SPACE HEATING

Simulations



Evaluation criteria CHP – System Approach

- Dynamic aspects[4], **service & commercial sector** -

2000 → 2010

360 MW_e extra CHP with α_E=35%, α_Q=50%, QI=16%, U=4000h/a

STATIC Primary Energy Saving = 2900TJ_i

CO_2-eq. reduction = 170 kton CO_2

SIMULATION Primary Energy Saving = 1800TJ_i

CO_2-eq. reduction = 30 kton CO_2

S & C Sector		**w/o extra CHP**	**with 360 MW_e extra CHP**
thermal	CHP	0	2 080
[GWh_{th}]	boilers	4 630	2 540
electric	CHP	0	1 480
[GWh_e]	CCGTs	32 110	30 450
	Coal	2 600	2 830

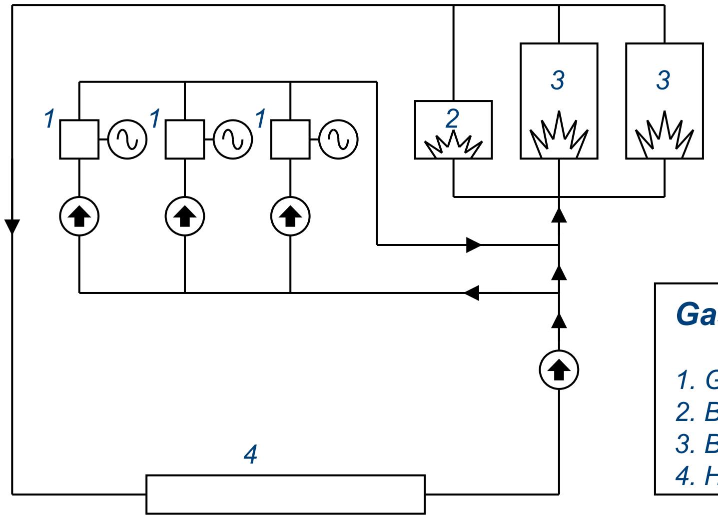
Typical Examples of District Heating

- *Campus Louvain la Neuve*

  grid length ~ 4 km

  heat losses ~ 10%

  Originally 4 boilers – then replaced by gas engines CHP



Gas Engines Based:

1. Gas engines 3 x 3,3 MWth
2. Boiler 5,8 MWth
3. Boilers 2 x 11,6 MWth
4. Heat Grid

- Average performance:
  - 9.4 MW_e; 9.9 MW_{th}
  - α_E=35%; α_Q=36%

Typical Examples of District Heating

Campus Louvain la Neuve

- Static Evaluation (as seen in LLN)
  - Reference efficiency, η_E = 55% (standard CCGT) and η_Q = 90%
  - Relative primary energy saving ~1.8% (incl grid losses)
- Dynamic Evaluation (generically for country – over 10 y)
  - Low gas prices
    - Primary energy “savings” vary from ~ - 5 PJ to 2 PJ
    - “Avoided” CO_2 emissions vary from ~ - 190 kton to 110 kton
  - High gas prices
    - Primary energy “savings” vary from ~ - 6 PJ to 1 PJ
    - “Avoided” CO_2 emissions vary from ~ - 260 kton to 80 kton

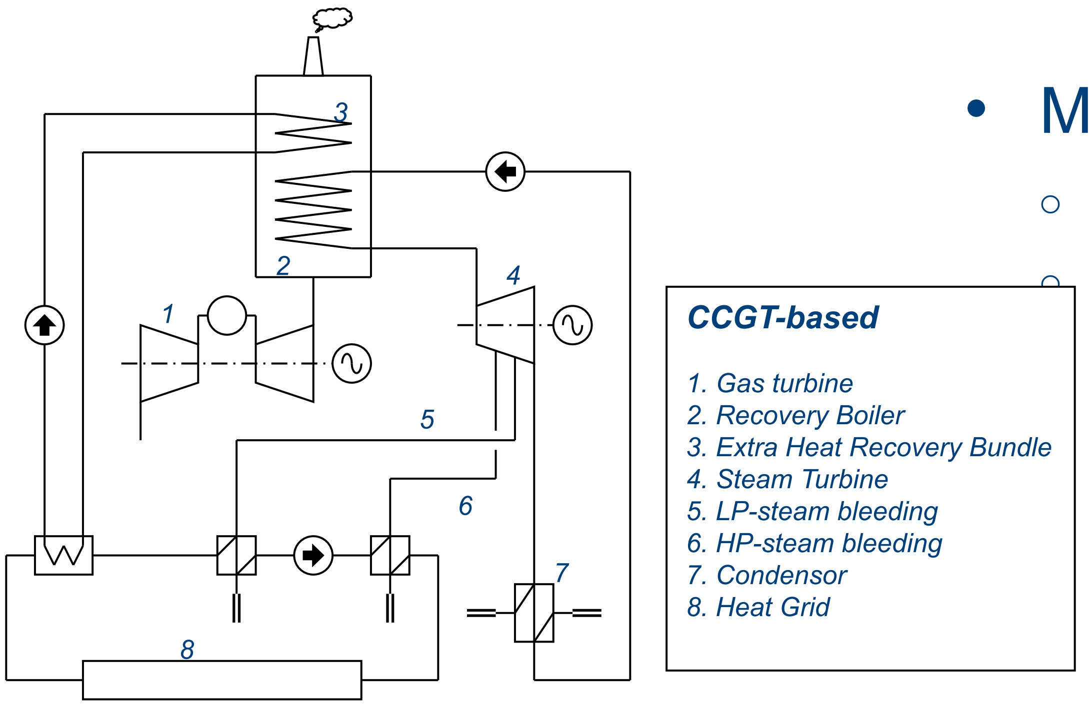
KU LEUVEN

Typical Examples of District Heating

- *Gent Belgium*

  grid length ~ 10 km

  heat losses ~ 10%



- Max elec gen mode:
  - 51.2 MW_e; 9.1 MW_{th}
  - α_E=50.7%; α_Q=8.8%

- Max heat gen mode:
  - 46.2 MW_e; 27.4 MW_{th}
  - α_E=45.2%; α_Q=26.8%

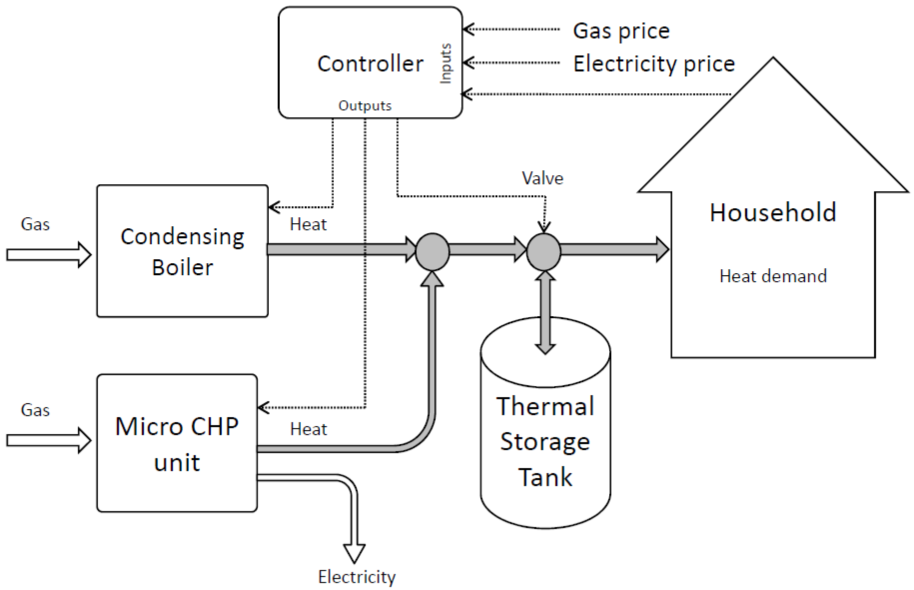
Typical Examples of District Heating

Gent Belgium

- Static Evaluation (as seen in Gent)
  - At time of investment decision Gent η_E = 48% and η_Q = 90%
  - Relative primary energy saving ~9.4%
- Dynamic Evaluation (generically for country – over 10 y)
  - Low gas prices
    - Primary energy “savings” vary from ~ 1 PJ to 5 PJ
    - “Avoided” CO_2 emissions vary from ~ - 40 kton to 330 kton
  - High gas prices
    - Primary energy “savings” vary from ~ 0.6 PJ to 3.2 PJ
    - “Avoided” CO_2 emissions vary from ~ 110 kton to 200 kton

KU LEUVEN

Impact CHP on Gas at Distribution Level



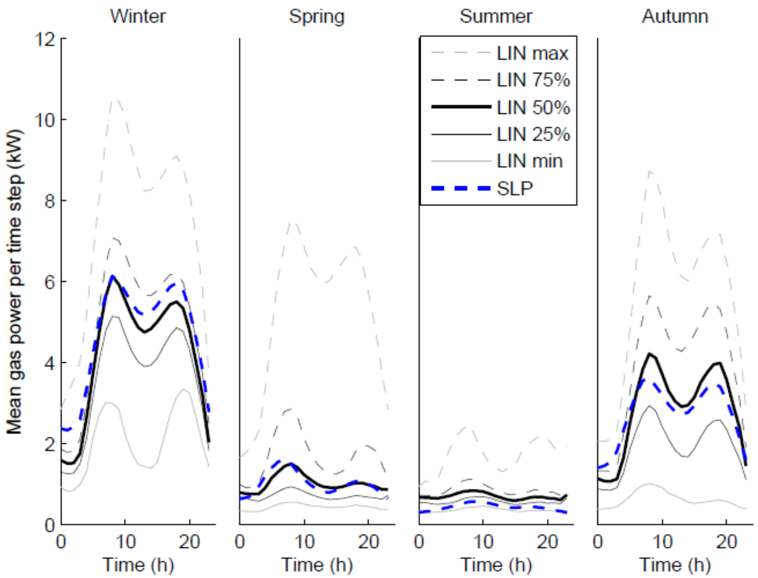
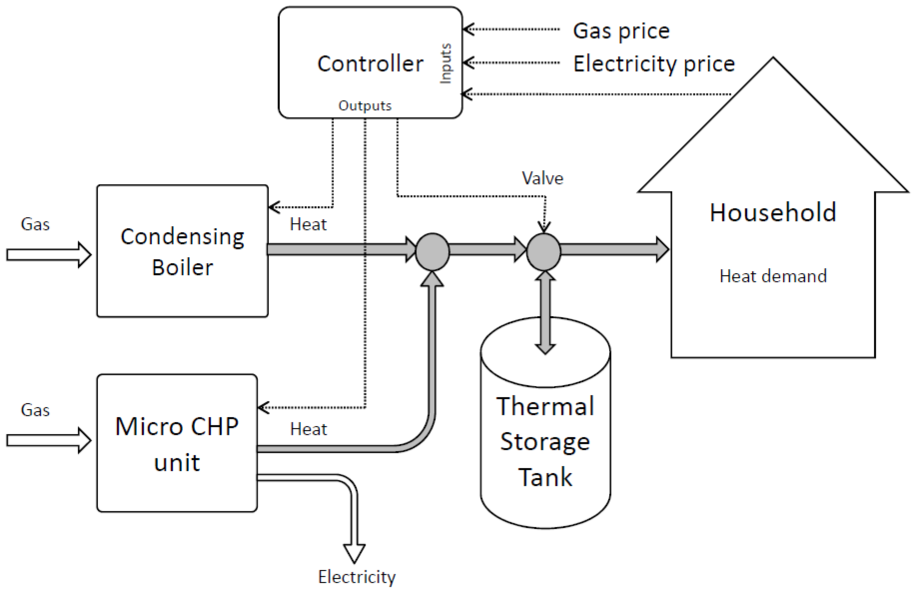


Figure 3.4: The distribution of the seasonally averaged gas demand profiles are given by 0, 25, 50, 75 and 100 % percentiles for the LINEAR profiles. The seasonally averaged SLP data are also shown. Although it cannot be seen on the seasonal averaged plots, the LINEAR profiles have a relatively rough behaviour.

KU LEUVEN

Impact CHP on Gas at Distribution Level



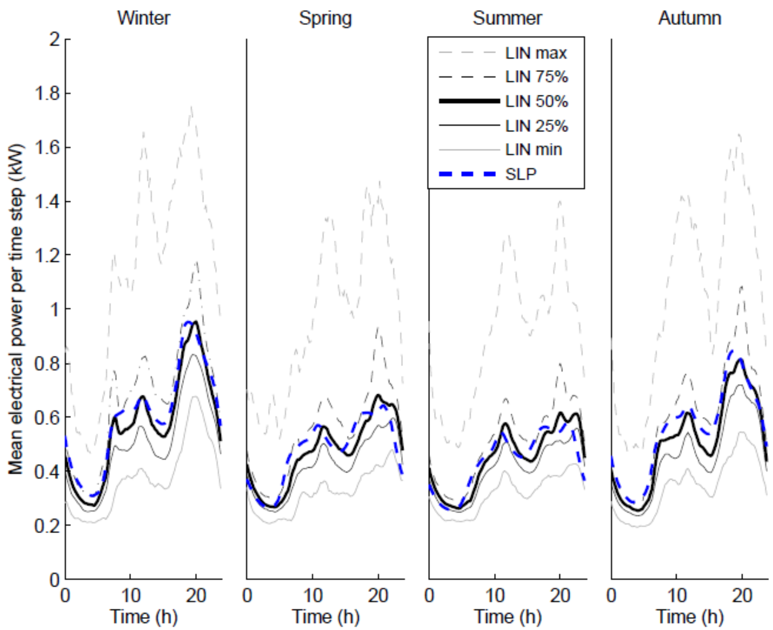


Figure 3.5: The distribution of the seasonally averaged electricity demand profiles are given by 0, 25, 50, 75 and 100 % percentiles for the LINEAR profiles. The seasonally averaged SLP data are also shown. The seasonal variance for the electricity profiles is very low, as opposed to the gas profiles.

Impact CHP on Gas at Distribution Level

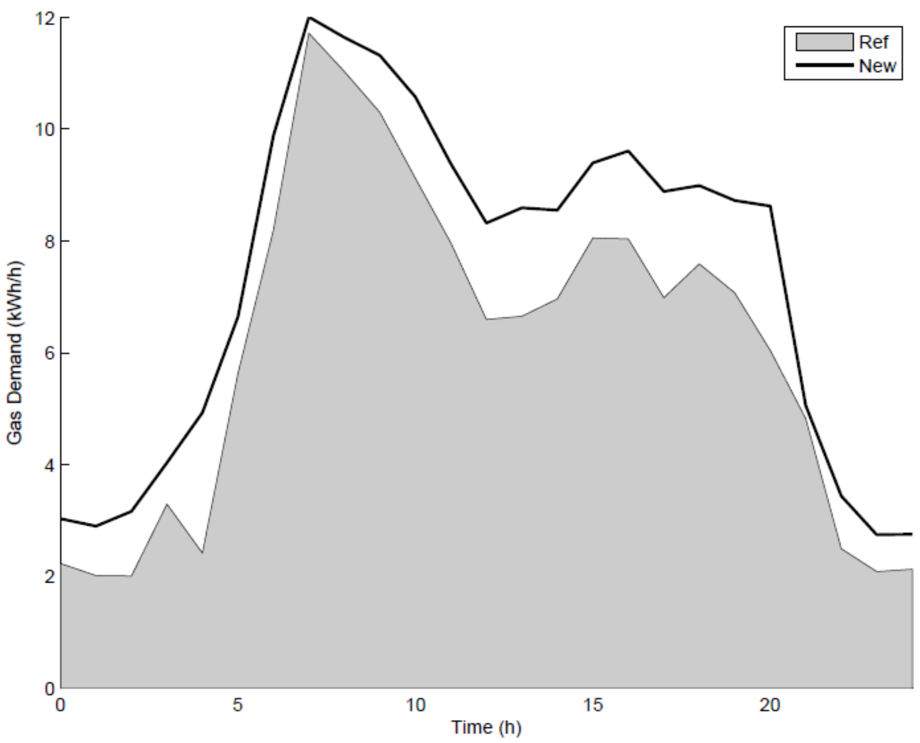


Figure 3.6: The effect of CHP on the aggregated gas demand of realistic profiles: the impact is 2.5 % in this case which is considerably lower than predicted with the SLP data (13.9 %). Ref = reference profile, New = with CHP. ($R_{HE} = 4:1$ and $RSC = 2$).

R_{HE} =
Heat/Electricity ratio

RSC =
Relative Storage Capacity

Ref: J. Vandewalle, 2014

Impact CHP on Gas at Distribution Level

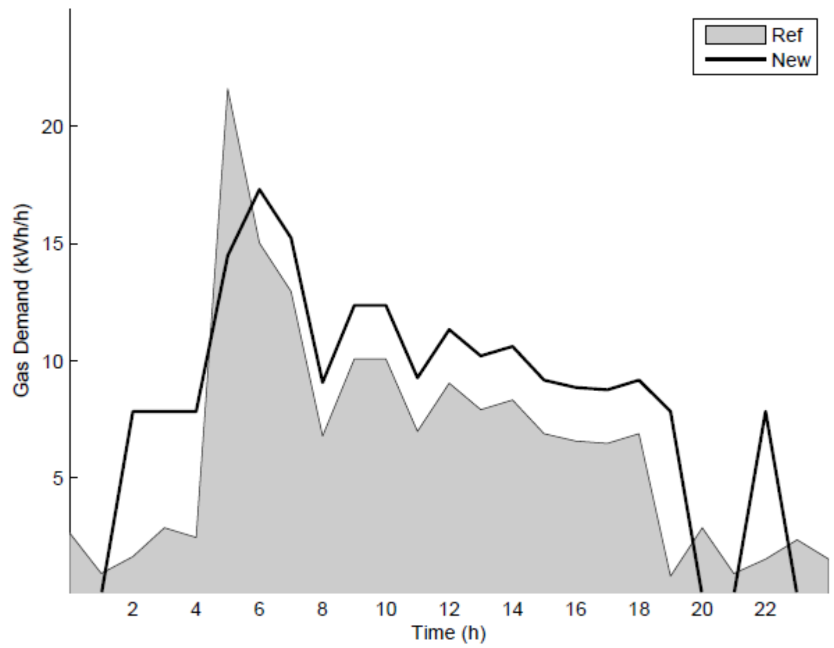


Figure 3.7: Example of a profile where adding CHP leads to smoothening of the gas demand. Just before the heat load peak, the CHP turns on to generate electricity revenues. The excess heat is stored in the storage tank, reducing the need for additional gas for the auxiliary boiler during the heat demand peak.

R_{HE} =
Heat/Electricity ratio

RSC =
Relative Storage Capacity

Ref: J. Vandewalle, 2014

Impact CHP on Gas at Distribution Level

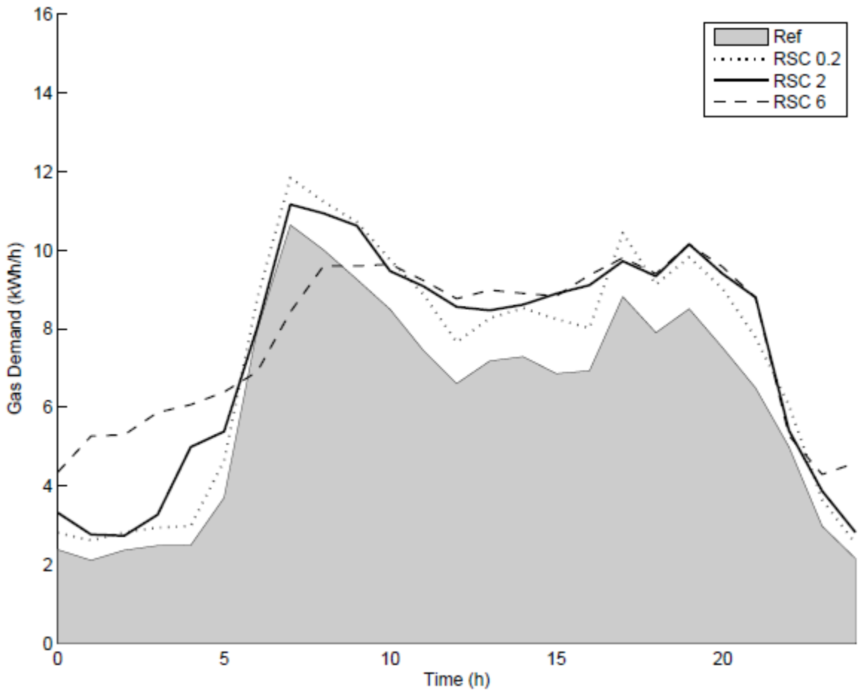


Figure 3.8: The impact on the gas demand of the capacity (RSC) of the storage tank that accompanies the CHP. Larger storage tanks lead to lower impacts on the gas demand peak. ($R_{HE} = 4:1$, aggregated result)

R_{HE} =
Heat/Electricity ratio

RSC =
Relative Storage Capacity

Ref: J. Vandewalle, 2014

Impact CHP on Gas at Distribution Level

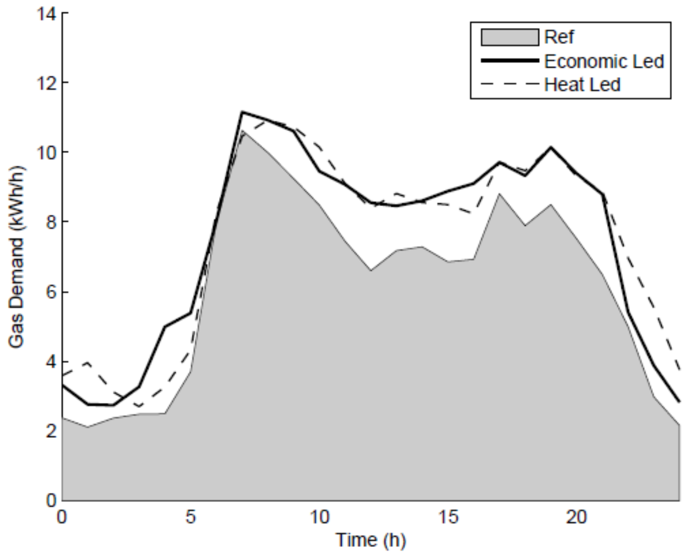


Figure 3.9: The resulting gas demand of heat led control (HL) is generally very similar to economic led (EC). A difference can be noted during the night where heat led leads to a higher gas demand during the first part of the night because the thermal storage tank can be filled. Economic led optimises the costs, and thus the thermal losses and postpones thermal storage to the period just before the heat demand peak. The impact on the gas demand peak is generally higher for heat led but not for this particular day depicted here. ($R_{HE} = 4:1$, $RSC = 2$ and aggregated result)

Heat Led (HL): CHP only on when Q_{CHP} is sent to customer or to storage tank

Economically Led (EC): most economic operation depending on elec and gas prices

R_{HE} =
Heat/Electricity ratio

RSC =
Relative Storage Capacity

Ref: J. Vandewalle, 2014

Conclusions

- Boundary conditions of thermal networks important
- Full system integration needed
  - Heating-purpose “sector”
  - Electricity system
  - Natural gas system
- Optimal solution where all technologies can freely compete, if all are penalized for external costs

KU LEUVEN

KU LEUVEN