TU Clausthal

The Carnot-Method

for the Allocation of Input Factors on Multiple Energetic Co-Products

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Agenda

- Combined Production's Cost Calculation
- Allocation for Energetic Co-Products
- Exergetic Allocaton – the Carnot Method
- Figure: Primary Energy Factor for the Heat
- Examples for Exergy Balances

Cost Calculation with Combined Production

- CHP unit as cost center determining product features of Heat & Power
  - Monetary in € (variable costs)
  - Energetic in kWh_{INPUT} per kWh_{OUTPUT} (primary energy factor)
  - Environmental in g_{CO2e}/kWh (emission factor)
- Problem: How to allocate incoming variable costs on both co-products: electrical energy and useful heat
- Relevance
  - Heating bills for residentual buildings
  - Calculation of variable production costs for large CHP plants
- Known methods such as
  - Substitution method
  - Equivalent parameter method
  - Disadvantages: external reference needed, variable at will
- BUT: Energetic co-products follow the rules of thermodynamics and can be transformed into each other

Allocation for Energetic Co-Products

- First Law: Conservation of Energy
- Energy goes In = Energy goes Out
  - $f_{fuel} \times Q_{fuel} = f_{el} \times P_{el} + f_{th} \times P_{th}$
  - Equation with two unknown variables as weighting factor

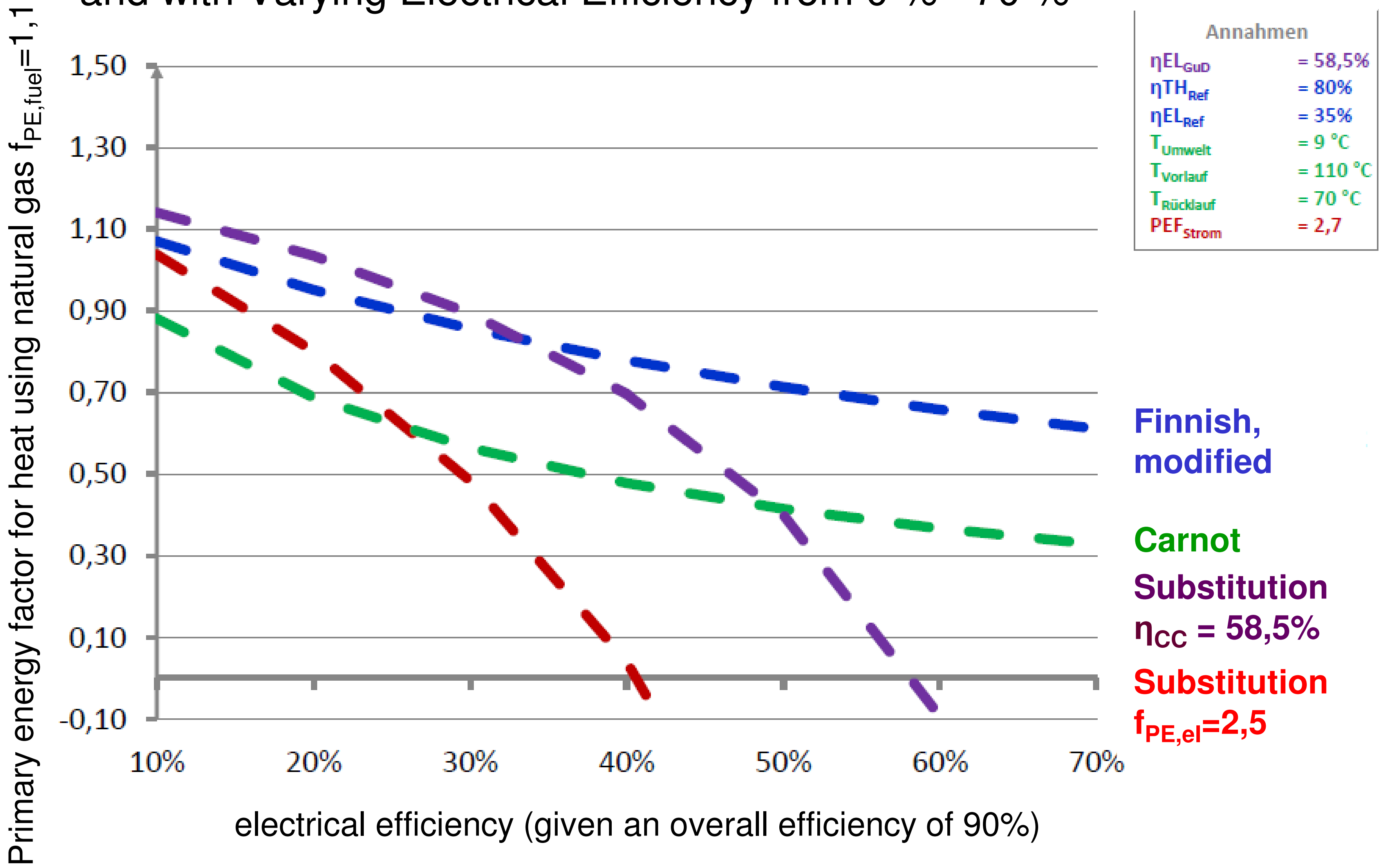
- Second equation is needed
  - Substitution method: external reference value for the by-product
  - Equivalent parameter: eg. energy content with $kWh_{th} = kWh_{el}$
  - **Or:**
- Second Law: Carnot's efficiency for transforming el ↔ th
  - $\eta_c \times P_{th}(T_s) = P_{el}$
  - $\eta_c = 1 - T_i/T_s$ depending of the ambient temperature T_i and the useful heat P_{th} at level T_s

Exergetic Allocation – The Carnot Method

- Allocation of fuel input according to exergy content of energy output
- Carnot factor for the assessment of useful heat: $\eta_c = 1 - T_i/T_s$ describes the exchange value of heat and electricity

- Primary energy factors for heat and electricity:
  - $f_{PE,th} = (\eta_{th} \times \eta_c) / (\eta_{th} \times \eta_c + \eta_{el}) \times f_{PE,fuel}$
  - $f_{PE,el} = \eta_{el} / (\eta_{th} \times \eta_c + \eta_{el}) \times f_{PE,fuel}$
- Allocation without the need of external reference system
  - only unit parameters are needed η_{el}, η_{th} and T of heat output
- Example for a fuel cell (η_{el} = 40%, η_{th} = 40%)
  - $f_{PE,el}$ = ~2,0 and $f_{PE,th}$= ~0,5
  - Efficiency of the virtual generator 50 %
  - Efficiency of the virtual boiler 200 %
- Exergetic efficiency as important quality feature for energy transformation

Primary Energy Factor for useful Heat at 90 % Overall Efficiency and with Varying Electrical Efficiency from 0 % - 70 %



Quelle: IFEU, Richtvert

Exergy – what is that exactly?

- Exergy: „valuable share of energy“
- Electrical and chemical energy: exergy content = 1
- Useful work which can be done by thermal energy $W = \eta_c \times Q$

- From energy to exergy savings?
- Exergy based labelling for CHP units?

- Examples for energy transformation (X: exergy unit, T_i=0°C)
  - Mini CHP unit (~20 kW): 100 X → 30 X + 60 * 0,25 X = 45 X
  - Boiler (90°C): 100 X → 100 * 0,25 X = 25 X
  - Large CC w/h CHP: 100 X → 60 X
  - Heat pump (50°C): 100 X → 400 * 0,15 X = 60 X
  - Power-to-Gas: 100 X → 60 X

Ask now or later:

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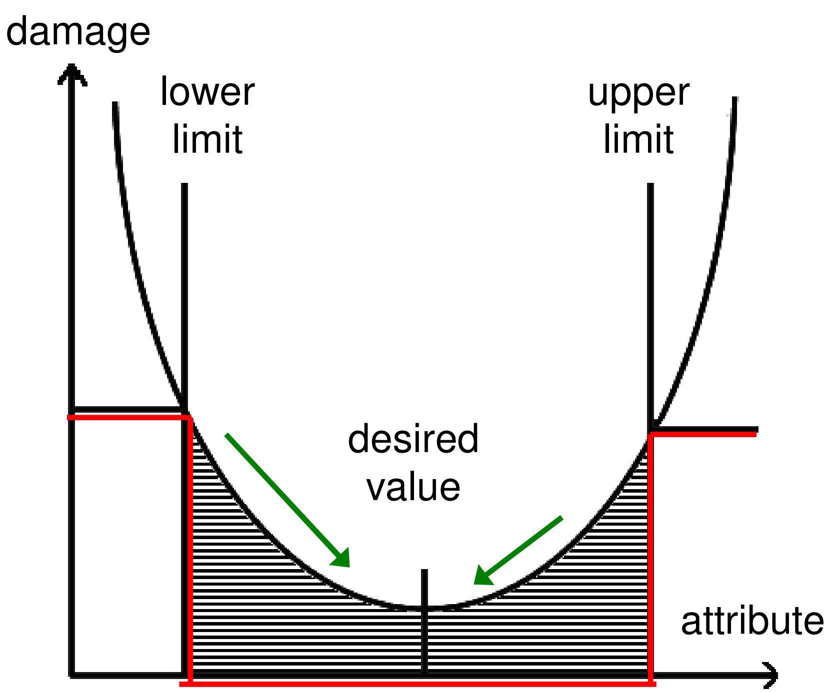

Genichi Taguchi's quality assessment function