Energy efficiency revisited

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what it means in an integrated energy system & the impacts on infrastructure investment

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Energy Efficiency Revisited

Preparatory reflections, based on current work

forthcoming paper by
William D’haeseleer, Erik Delarue & Guido Pepermans

Energy Saving

For an overall energy economy:

Energy ‘saving’ refers of <u>two components</u>:

energy consumption =

demand for ener services * energy intensity

Energy Saving

energy consumption =

demand for ener services * energy intensity

This is applicable to the so-called

'*supply sides*' & '*demand sides*'

In fact, useful end energy to provide those services runs through a chain of conversion / transformation technologies &

transport/distribution networks/fleets

each of them having 'losses'

Energy Saving

Energy saving refers of two components:

energy consumption =

demand for ener services * energy intensity

Energy Saving
Energy Services

- Demanded energy services related to

  comfort, discipline, different behavior,
  shift to different processes and activities

- Examples:

  comfort temperature (winter & summer),
  turn off lights when leaving,
  living & working area in dwellings & offices
  number of miles or km's driven
  shift industrial society to service oriented economy

Energy Savings Potential

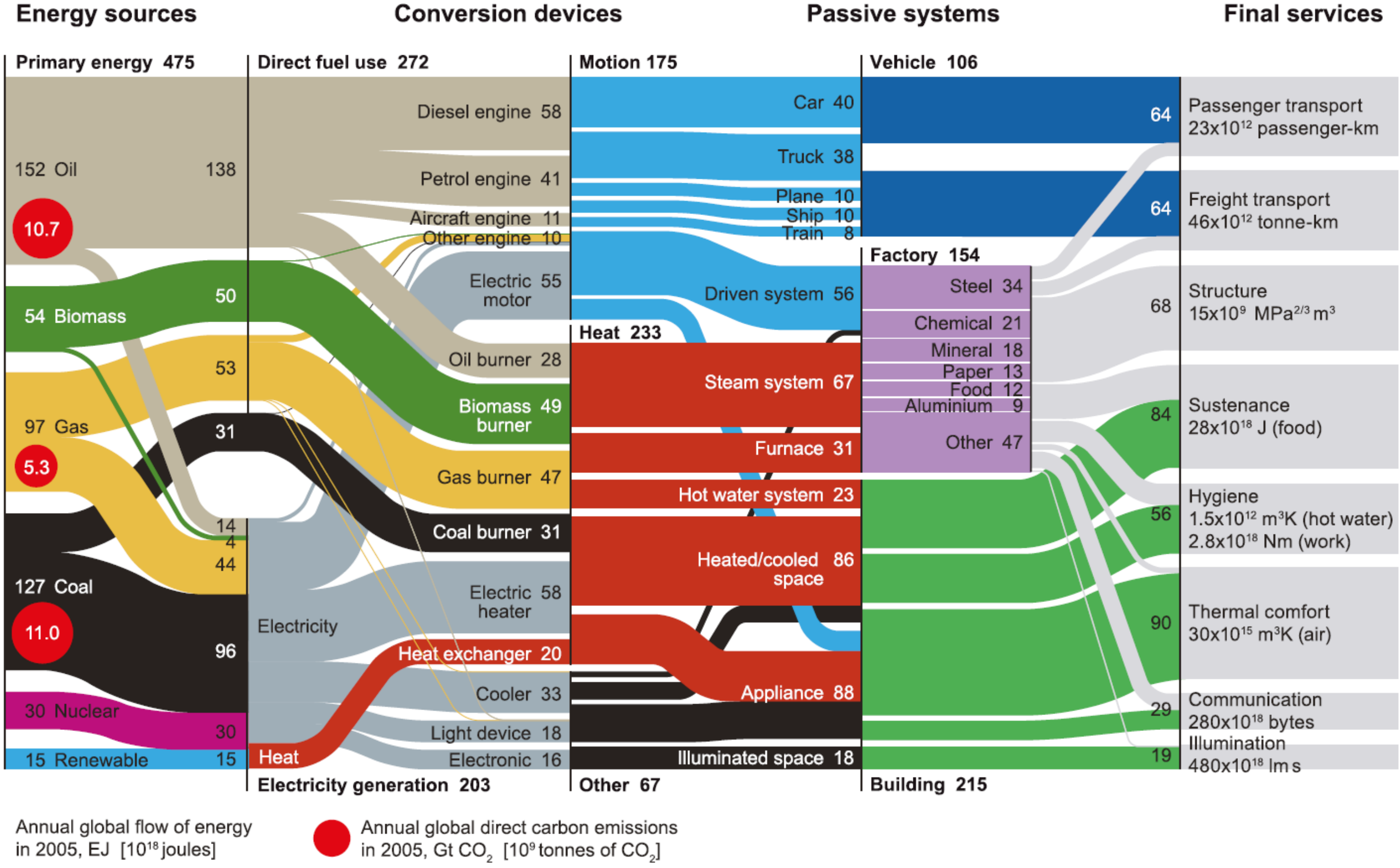


Fig. 2. From fuel to service: tracing the global flow of energy through society.

JM Cullen and JM Allwood, *Energy Policy* 38 (2010) 75−81

Energy Saving

Energy Intensity

Energy Intensity =

energy use

per unit activity or product or service

Energy Saving

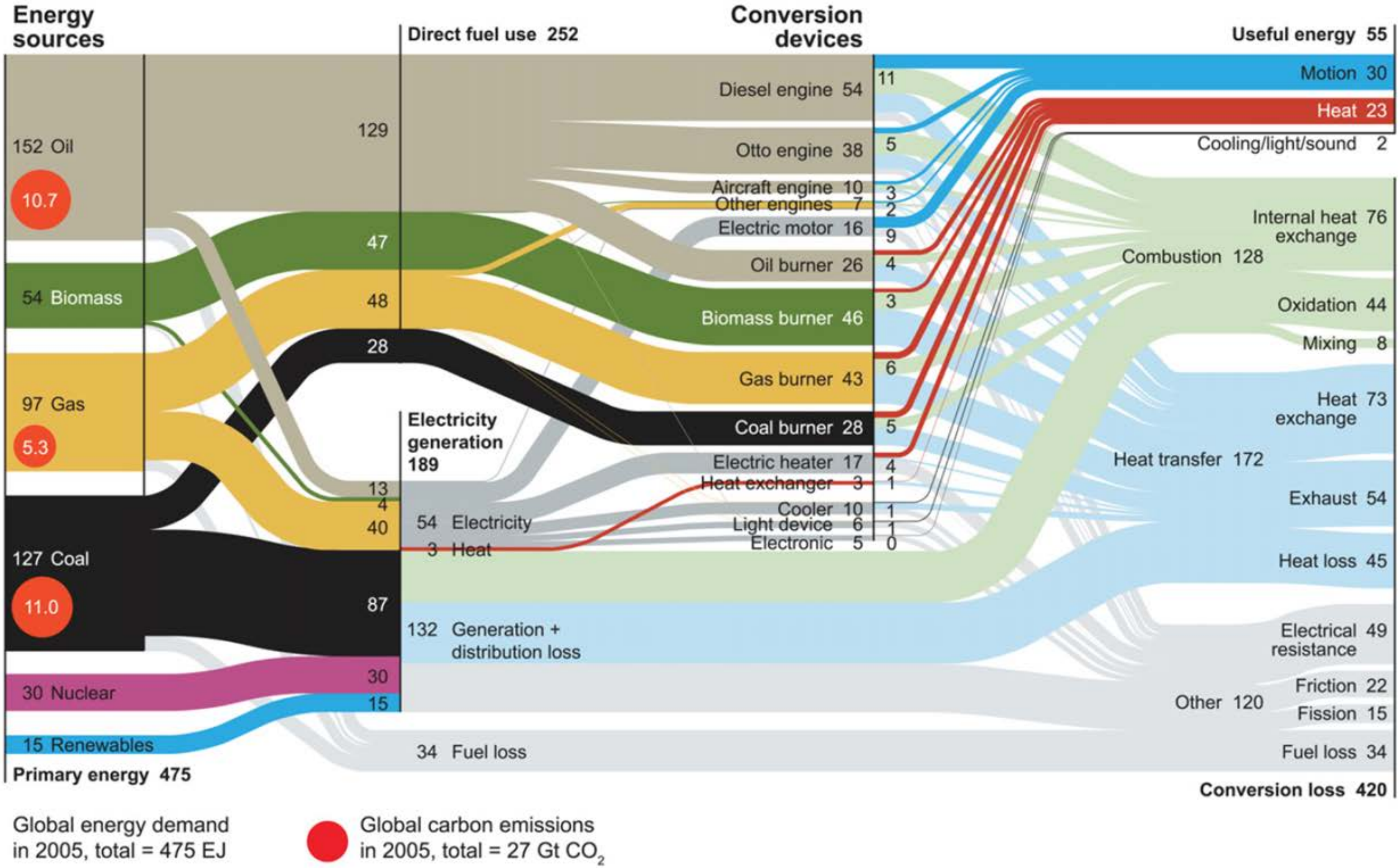
Energy Intensity

Energy Intensity

~ 1 / efficiency

Must get EI ↓ *or* ***efficiency ↑***

Energy Savings Potential



JM Cullen and JM Allwood, *Energy Policy* 38 (2010) 75−81

What *is* energy efficiency?

Efficiency of technologies
is classically defined by the

Laws of Thermodynamics

Energy Saving

Energy Intensity / Efficiency

- Determined by ‘good engineering’

  → energy-conversion technology

  (appliances, equipment, facilities, better control, …)

simple first law efficiency = η

$$\frac{\text{useful energy-‘transfer’ output (Q or W)}}{\text{energy input of appliance}}$$

η ≅ 90 - 95 % for modern boilers

Energy Saving

Energy Intensity / Efficiency

- But need actually the

second law efficiency = ε

$$\frac{\text{useful exergy-'transfer' output (Q or W) by appliance}}{\text{max possible output of 'any' appliance with same input}}$$

if, boiler: $\eta = 90\ \%$ but $\varepsilon = 9\ \%$

→ look for the most efficient appliance !

→ for heating, heat pumps are much more efficient!

Note: in USA, synonym for “exergy” = “Availability”

Energy efficiency - revisited

- Thermodynamic ‘operational’ efficiency makes sense if *fuel* input has substantial value:
  - fuel can be used for other purposes (e.g. petrochemical)
  - fuel is a scarce good, and hence ‘expensive’

- In a world with zero-cost fuel (i.e., sunshine, wind), higher operational efficiency is translated into higher ***return on investment (ROI)***
- Similarly for nuclear power: efficiency basically translates into **ROI** – Uranium that is not used will decay in earth crust
- **ROI** of capital intensive technologies also determined by *capacity/load factor*

Energy efficiency – revisited - *examples*

‘Energy efficiency paradox’

- When superfluous electricity generation (overcapacity PV, when very sunny); too much for own consumption
- Market not willing to buy superflous electric energy
- Leads to *negative electricity prices*...

  → Produced electricity *will* be used (even wasted...)

  → Local storage may help (but storage has ‘losses’)

  → Installing airco when not really needed
- Is already the case in regions with ‘net metering’

Energy efficiency – revisited - *examples*

‘Curtailment of superfluous electric power’

- Curtailment is indeed ‘throwing away energy’
- But perhaps this is no longer *useful* energy

- Cutting *power* for short periods (when too large peaks) amounts to small amount of *energy* wasted
- This is related to *optimal sizing of transmission* (distribution) infrastructure for ‘diverting’ superfluous power to other regions
  - Not meaningfull to be willing to ‘overdesign’ lines
  - Must find appropriate optimum from system perspective

Energy efficiency – revisited - *examples*

‘Electrically heating of water’

- Was considered a ‘sin’ from thermodynamic point of view
- But with zero marginal-cost generation, in case of superfluous electrical power,

  → it does make sense to use the electric energy to avoid burning primary fuels (with cost and polluting)

Energy efficiency – revisited - *examples*

‘Power to Gas in a system environment’

- **P2G (elec to synthetic methane & back to elec):**

  electric energy → electrolyzer (gives H_2 + O_2)
  → Sabatier reactor ($4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$)
  → back to electricity (and/or heat) via OCGT, CCGT, CHP
  → chain efficiency ~ from 25% (OCGT) to 50% (CHP)

- **$P2H_2$ (elec to hydrogen & back to elec):**

  electric energy → electrolyzer (gives H_2 + O_2)
  → back to electricity (and/or heat) via Fuel cells (FC) – PEM or SOFC
  → chain efficiency ~ from 30% (elec only and small) ... 70% (CHP)

***Lousy* efficiencies if valuable electrity as input; but interesting if cheap electric energy is available in the market!**

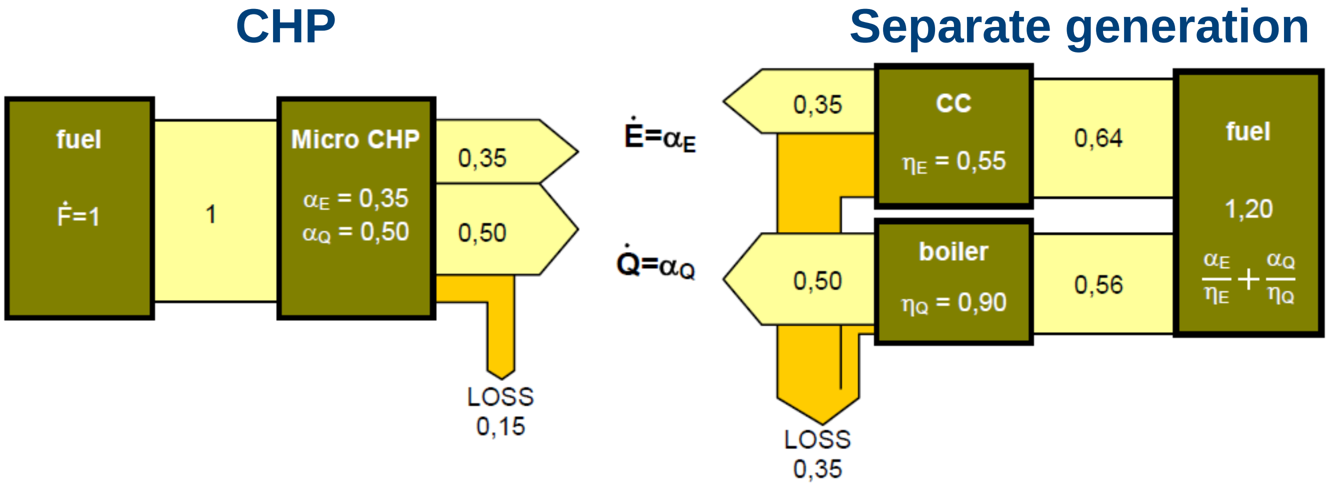
Energy efficiency – revisited - *examples*

‘CHP in a system environment’

- Mostly, Combined Heat and Power (CHP) is evaluated from a static point of view

Energy efficiency – revisited - *examples*

'CHP in a system environment'



Absolute Primary Fuel Saving:

$$PFS = \frac{\alpha_E}{\eta_E} + \frac{\alpha_Q}{\eta_Q} - 1$$

Energy efficiency – revisited - *examples*

‘CHP in a system environment’ (but pre massive RES injection)

From short to long term (η_E)

The more CHP is being invested in,
investment in new generation units (CCGTs) is being delayed

On long term (η_E)

only ‘correct’ basis for comparison:

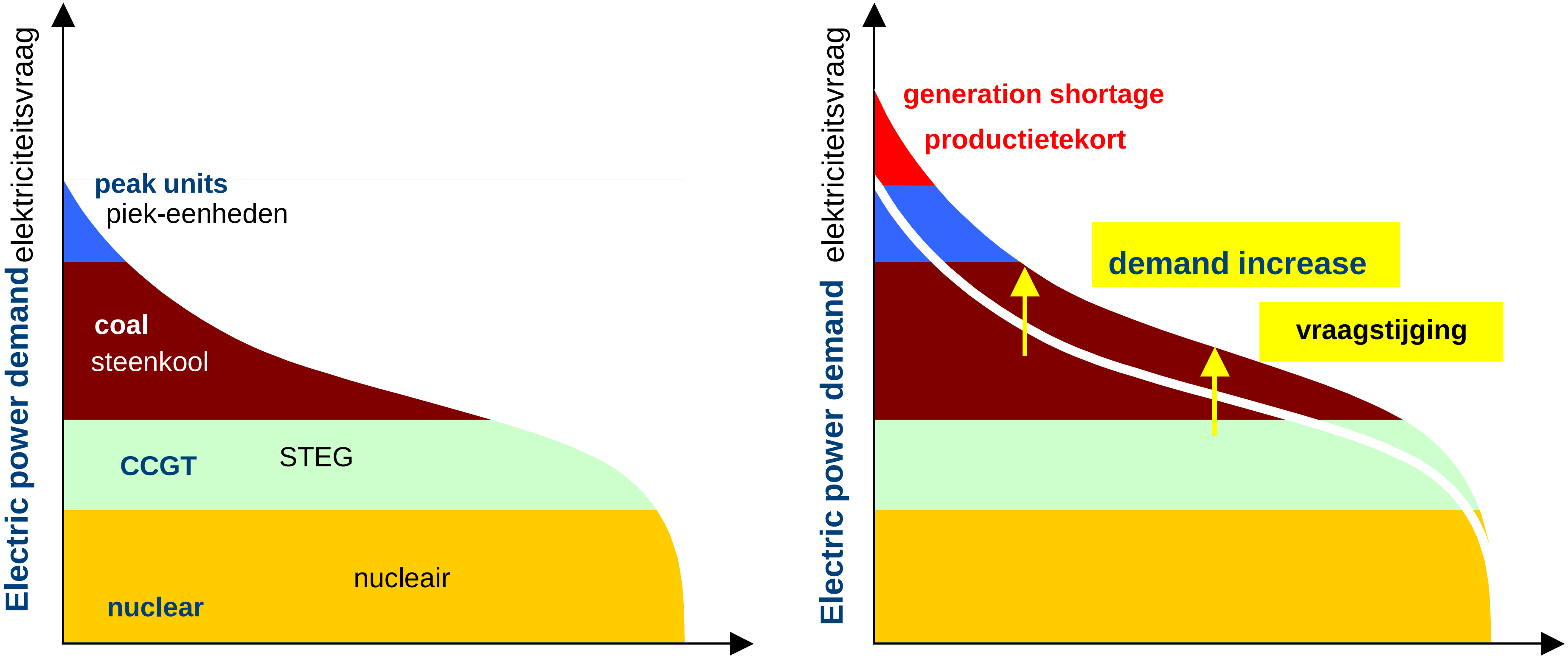
At moment of investment of CHPs,
what *would have been* the investment for the central generation system if one had not installed all those CHPs?

➔ BAT ➔ CCGT

Evaluation criteria CHP - revisited

- Influence CCGT investment at increasing ‘central’ demand -

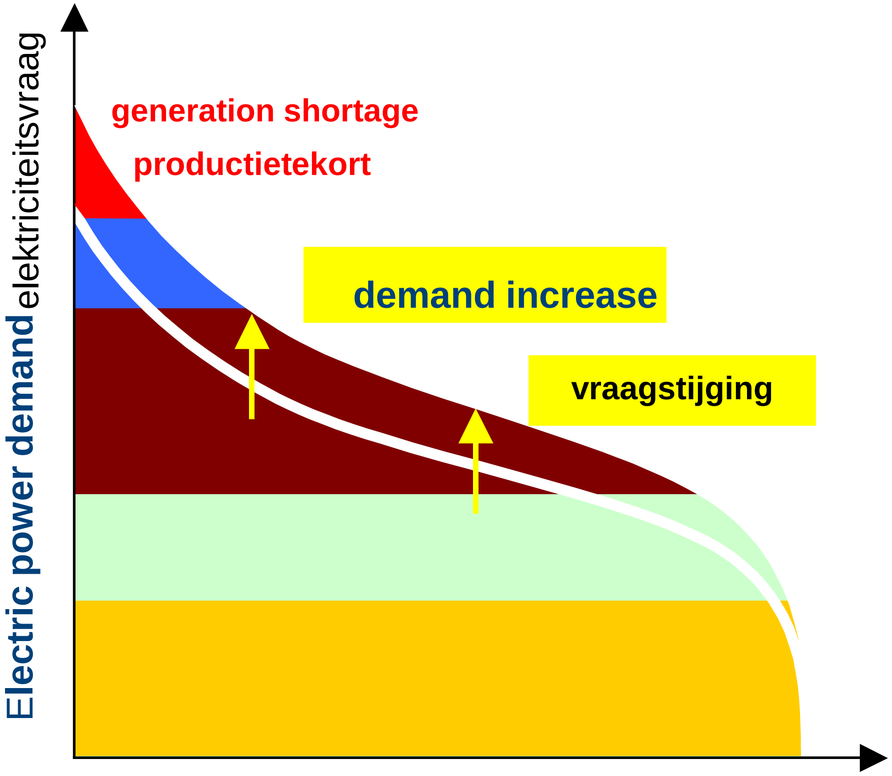
Simplified representation of load duration curve

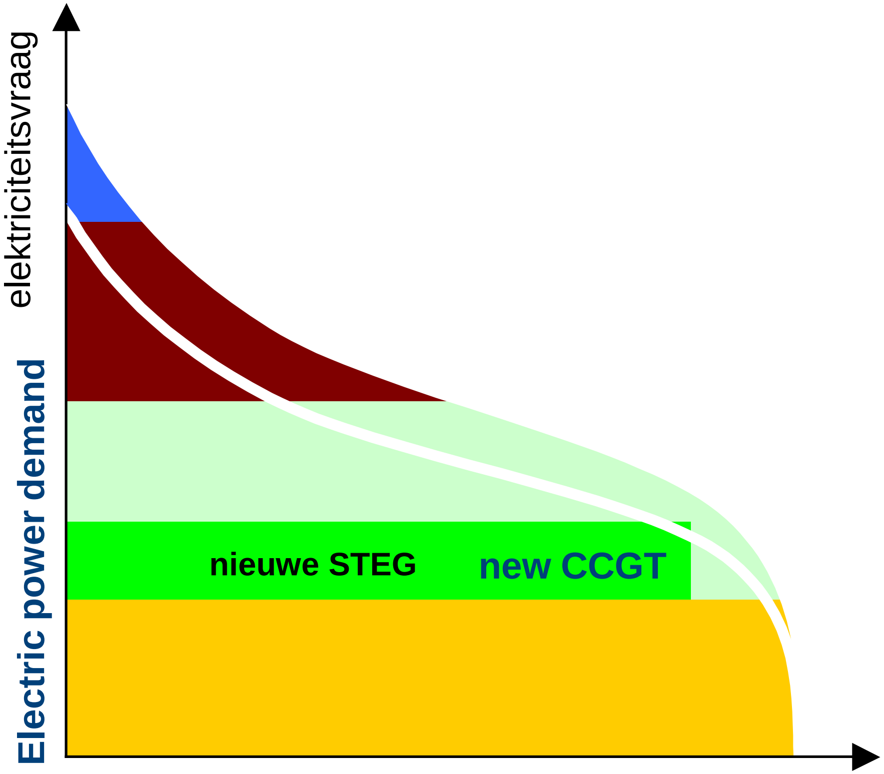


Increase of demand for electricity

Evaluation criteria CHP - revisited

- Influence CCGT investment at increasing 'central' demand -



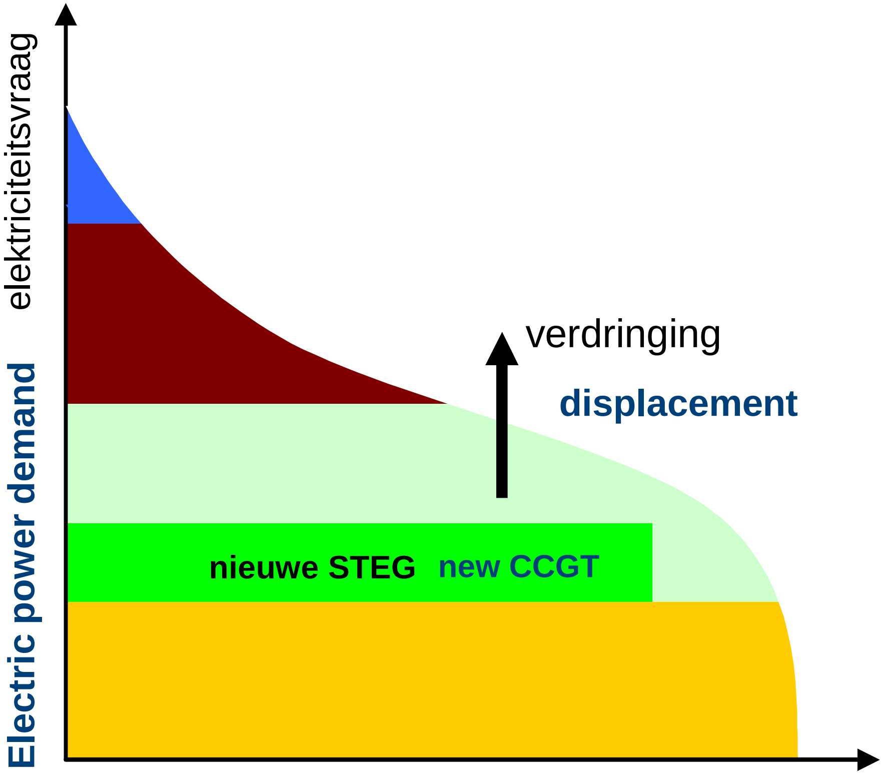


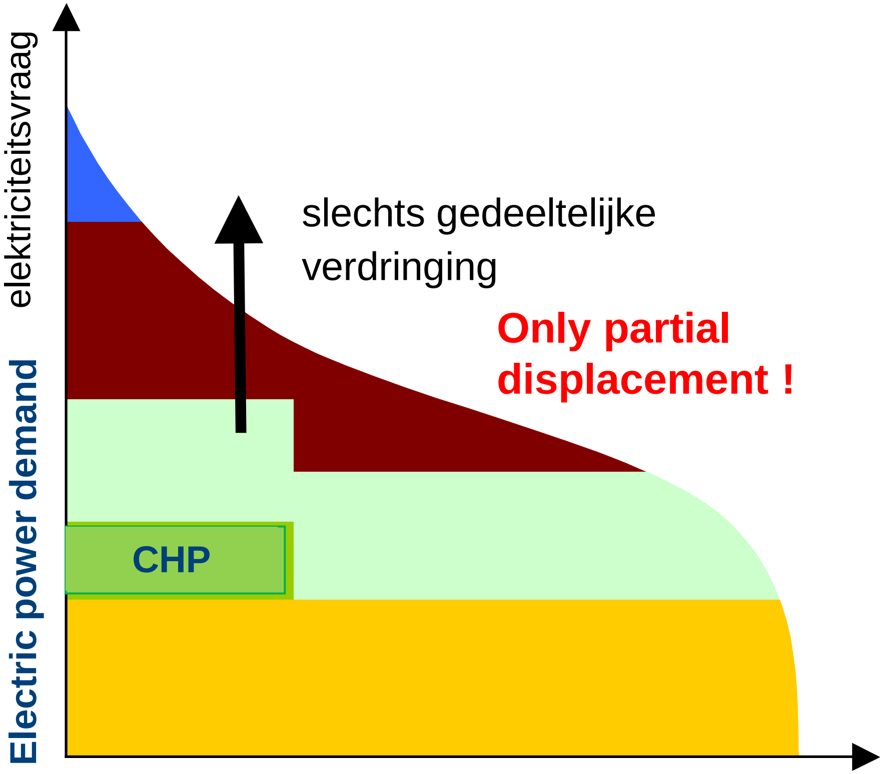
Need for extra generation capacity

Evaluation criteria CHP - revisited

- Dynamic system aspects -

CCGT versus CHP with limited operation time duration





Less coal-fired PP pushed out → less CO_2 avoided

Evaluation criteria CHP - revisited

- Dynamic system aspects - **simulation comm & service sector**

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

Simulation over a period 2000 → 2010

Energy efficiency - revisited

→ Must redefine / broaden efficiency to include ‘efficiency’ of investments in technologies

→ Must consider ‘***resource efficiency***’ (resources, labor, ...) of investment goods & ‘fuel’

- In ideal world, resource efficiency is correctly translated into **resource cost**
  - High efficiency → low cost → high ROI
  - Leads to metric ~ economic efficiency

Energy efficiency - revisited

→ Must redefine / broaden efficiency to include <u>system effects</u> (with interactions)

- Losses in some components or parts may be overcompensated by savings in other components/parts
- May need to ‘accept’ lower efficiency in parts for system stability, less CO_2 emissions or other objectives
- ‘**system efficiency**’ differs from $\sum$ components

Energy efficiency - revisited

→ Must perhaps distinguish between

overall system resource efficiency for planning

and

overall *operational system efficiency*

(accepting investments as ‘legacy’, i.e., comparable to sunk costs)

Operational efficiency:

Related to ramping of thermal generation, shutting down plants...

Energy efficiency - revisited Conclusions

1. Need to *improve existing technologies*
2. Use *2nd law efficiency* for *technologies*
3. Consider *resource efficiency* for *technologies*
4. In the end *system efficiency* is most important
   - ❖ Must concentrate on *efficient integration* of a multitude of technologies (conversion on supply side, transmission, ... storage, end-use conversion) – interaction with other carriers (perhaps using enablers like communication / data transmission handling)
     → *System integration optimization*
5. Distinguish btwn *efficiency for planning and pure operation*
6. All to be summarized in *economic efficiency*

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