Comparison of energy systems: On methods, parameters and system boundaries

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Climate Change

- A long-term issue
- A large reduction of greenhouse gas emissions is required

Other issues than climate change

- Other environmental issues
- Health issues
- Implementation issues
- Efficiency of natural resource utilisation

Basic assumptions for energy systems analysis

- The whole energy chain should be analyzed (from the primary energy resource to the final energy use)
- The same reference entity should be used in all systems compared
- In each step of the energy chain relevant parameters should be analyzed
- Preferably avoid allocation by systems expansion or subtraction

Assumed reference system when comparing biomass and fossil energy systems

- **The cheapest fossil energy system with the lowest greenhouse gas emission fulfilling the same energy service as the bioenergy system?**

Some other issues

- Investments have a long life-time
- What is the reference system between 2010 and 2050?
- Highly uncertain external costs
- Uncertain fuel prices and technology development

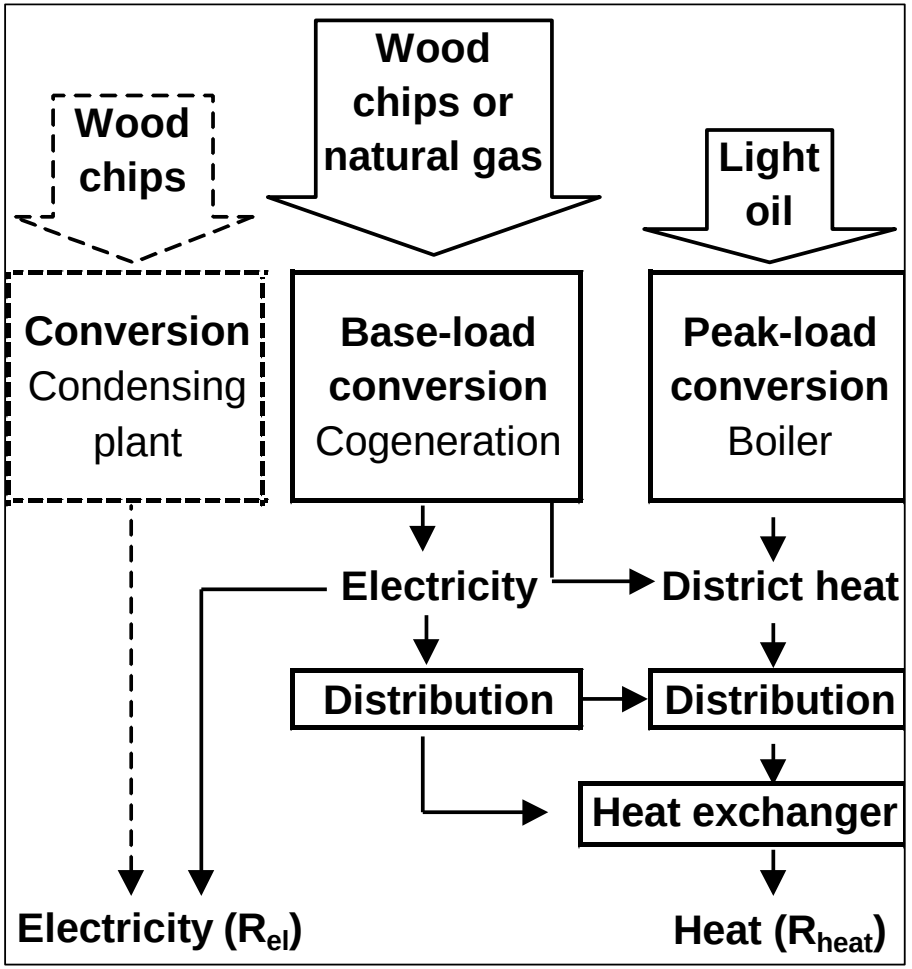
Cogeneration compared with stand-alone production

- Higher system efficiency
- Lower costs
- Lower environmental impact
- The benefits of cogeneration could be credited to the electricity or the heat production

A limited amount of heat sinks

- About 75% of the electricity production is in stand-alone power plants in EU (in Sweden ≈ 50%)
- Increased competition of the future use of heat sinks
  - » Cogeneration of electricity and heat
  - » Production of pellets
  - » Production of liquid fuels

A district heat system with cogeneration



Cogeneration compared with stand-alone production - Heat is the main product

- The reference entity is the sum of one unit heat produced by the system and the maximum amount of electricity that could be cogenerated from any of the systems being compared
- For systems that could not cogenerate the maximum amount of electricity, stand-alone power plants will cover the electricity deficit.
- This illustrates that cogenerated electricity replaces electricity produced in stand-alone power plants due to a lack of heat sinks.
- The benefits of cogeneration compared with separate production are credited to the heat production.

Which technology should be used for producing the by-product that is not cogenerated?

- The assumed most cost-efficient technology
- The cost-efficiency of energy systems depends on which costs are considered
- External costs, highly uncertain, could have an decisive impact on the cost of energy system ("Some uncertainties arise from a lack of knowledge, but a substantial share is related to fundamental methodological and ethical problems which have not yet been and may never be resolved")
- Low external costs imply fossil-based systems to be cost-efficient
- High external costs imply wood-based systems to be cost-efficient

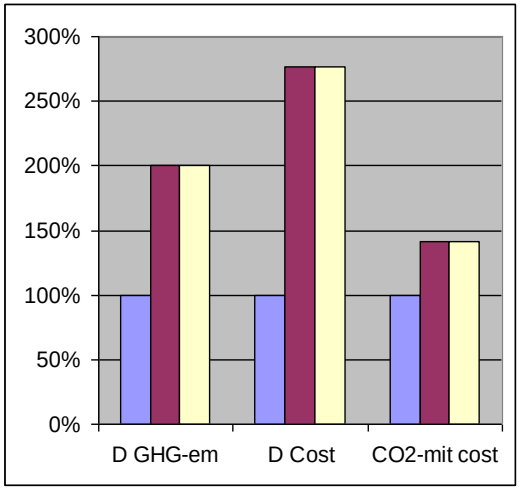
Varied results with diff. functional units and alloc. methods

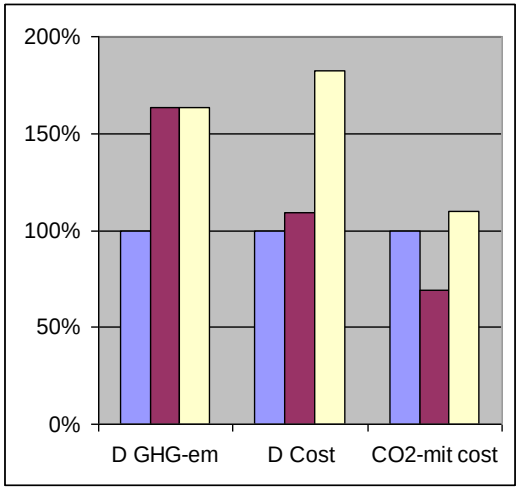
- f.u.: **Heat + Electr.**
- alloc: Multifunc.

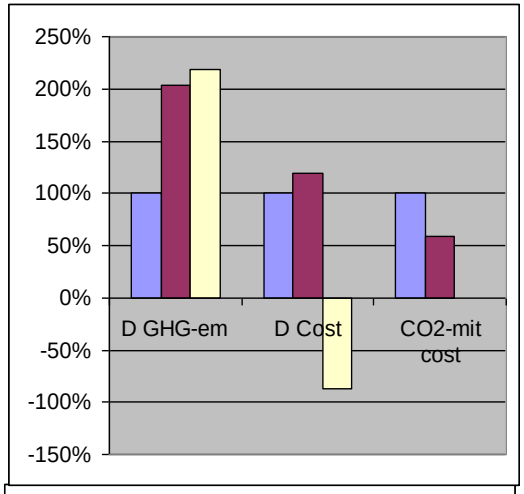
- f.u.: **Heat**
- alloc: Subtract.

- f.u.: **Heat**
- alloc: Subtract.

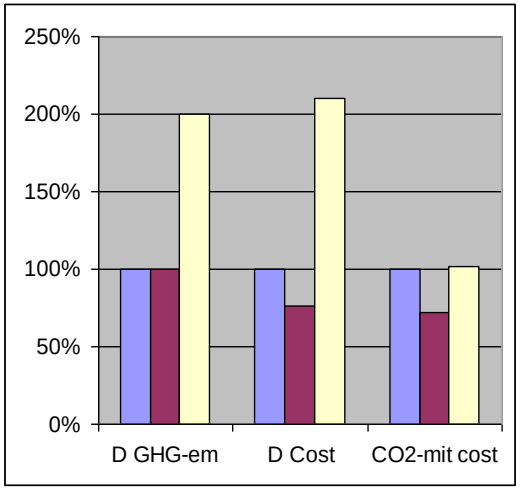
Corresponding technol. for producing the by-product

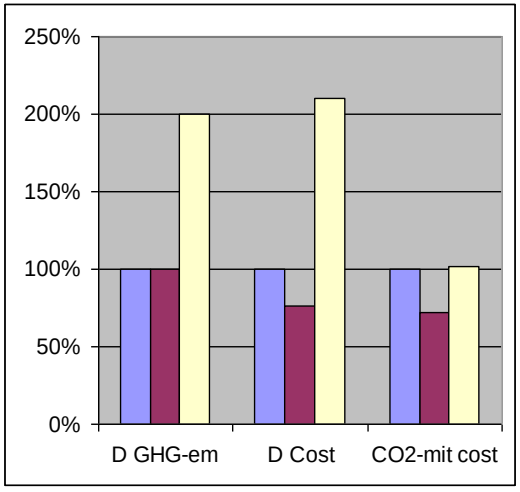


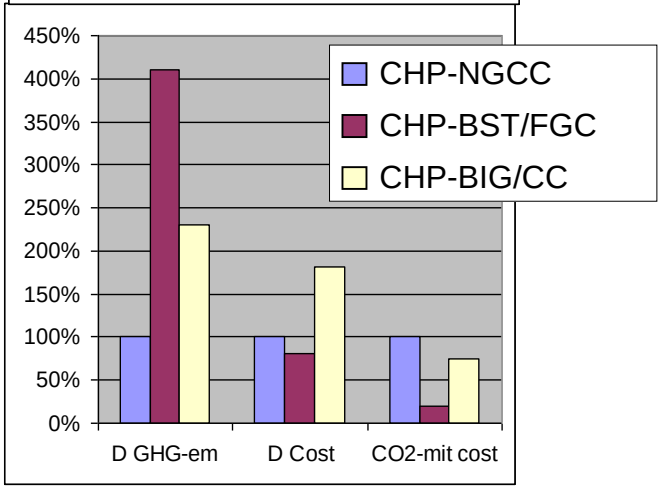




Most **cost-efficient** technol. for producing the by-product







Greenhouse gas mitigation can be expressed in terms of different parameters.

- The mitigation cost is an important parameter
- But, how to optimise the non-fossil system?
- The optimisation depends on the very uncertain external cost of which greenhouse gas emissions is strongly contributing
- Information about greenhouse gas mitigation would be more comprehensive if other parameters were also considered such as:
- **Primary energy use per unit of reduced greenhouse gas emissions.**
- **Renewable energy use per unit of reduced greenhouse gas emissions**

Greenhouse gas mitigation cost

- The greenhouse gas mitigation cost (m_{GHG}), i.e. the specific cost per reduced amount of greenhouse gas emission, can be used for comparing the benefits of replacing a system by a less emitting system

$$m_{GHG} = \frac{M_i - M_{ref}}{E_{ref} - E_i} = \frac{\Delta M}{\Delta E} \qquad \text{where } E_{ref} - E_i > 0$$

M is the direct cost and E is the CO_2 equivalents resulting from the production of the reference entity in a system. The indices *ref* and *i* represent the reference system and the system which is the object of comparison, respectively.

Specific primary energy use per amount of reduced GHG emission

- The energy effectiveness of greenhouse gas emission reduction can be measured by estimating the primary energy used by the system per reduced amount of greenhouse gas emission.

$$pe = \frac{PE_i - PE_{ref}}{E_{ref} - E_i} = \frac{\Delta PE}{\Delta E} \qquad \text{where } E_{ref} - E_i > 0$$

PE_i and PE_{ref} are the primary energy use of producing the reference entity in the compared system and the reference system, respectively

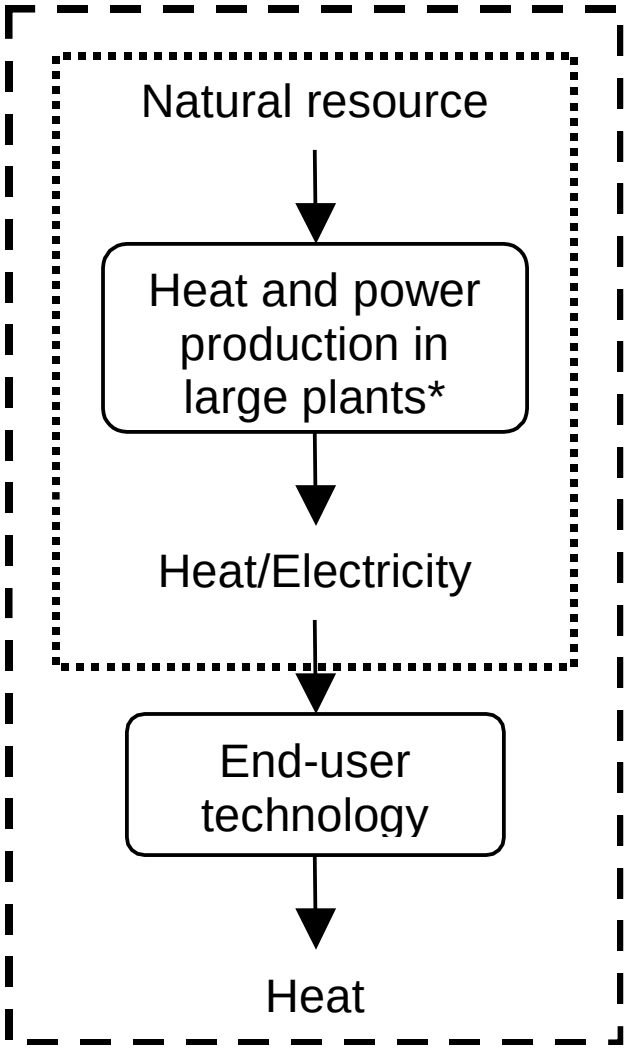
Specific wood-fuel use per amount of reduced GHG emission

- The parameter *w*, the specific wood-fuel use per reduced amount of greenhouse gas emission, is calculated for wood-fuel-based systems

$$w = \frac{W_i - W_{ref}}{E_{ref} - E_i} = \frac{\Delta W}{\Delta E} \qquad \text{where } E_{ref} - E_i > 0$$

W_i and W_{ref} are the wood-fuel use of producing the reference entity in the compared system and the reference system, respectively.

Analysed energy systems



The dotted line shows the boundaries of the large-scale system..The dashed line shows the boundaries of the total system for district heating and electric heating systems. In the local boiler systems, the large systems are used for producing the electricity input only.

*) Includes, refining, transport and distribution recovery of fuels.

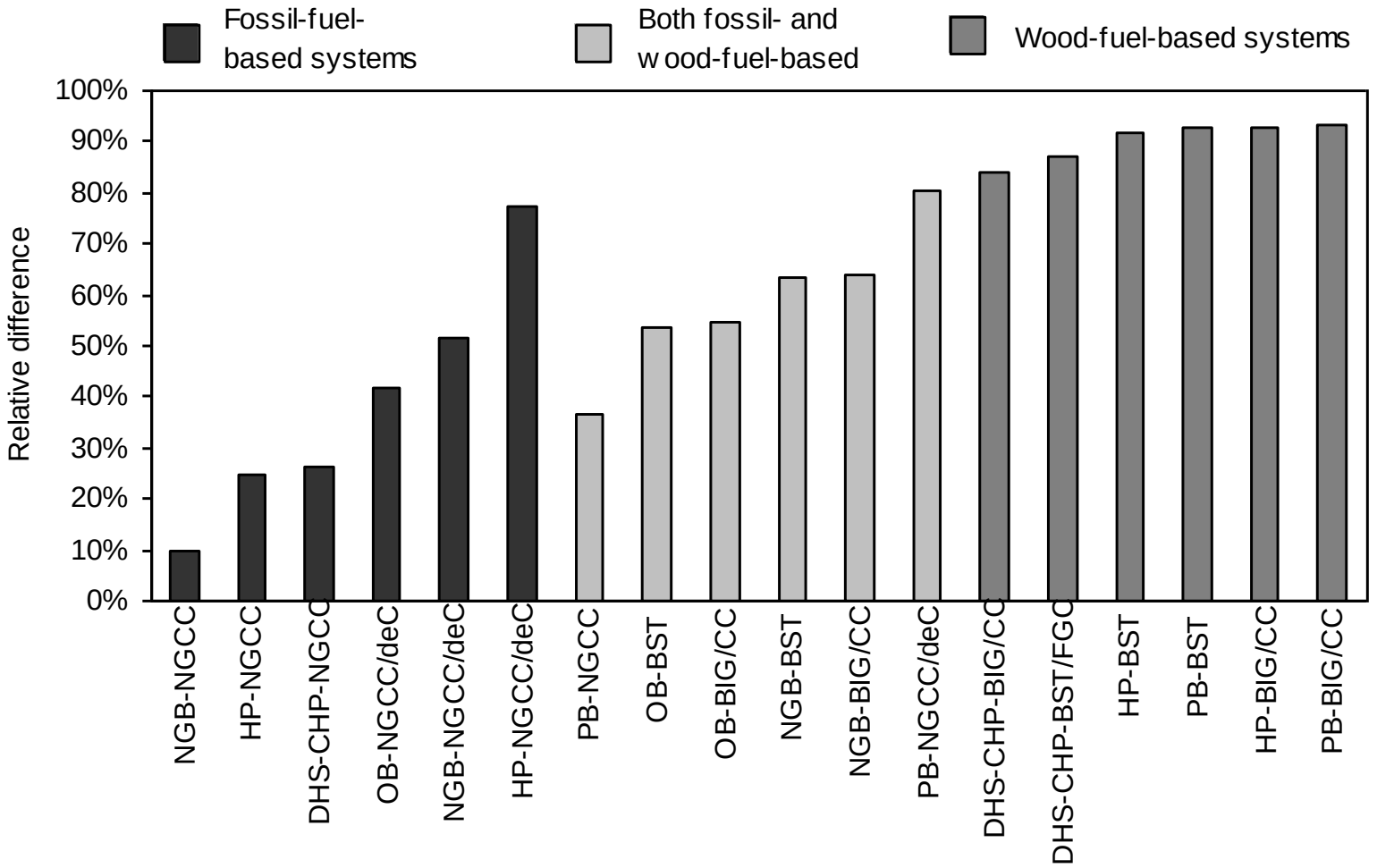
Conversion technologies in large supply systems

- *Hot water boilers used in district heating systems:*
  Wood-chips-fired (BHWB), Coal-fired (CHWB) or Light-oil-fired (LOWB)
- *Cogeneration plants used in district heating systems:*
  Biomass integrated gasification/combined cycle (CHP-BIG/CC)
  Steam turbine technology with flue gas condensation (CHP-BST/FGC)
  Coal-fired atmospheric circulating fluidised bed with steam turbine (CHP-CST)
  Natural-gas-based combined cycle technology (CHP-NGCC)
- *Stand-alone power production:*
  Biomass integrated gasification/combined cycle (BIG/CC)
  Steam turbine technology (BST)
  Coal-fuelled steam turbine (CST)
  Natural-gas-based combined cycle (NGCC).

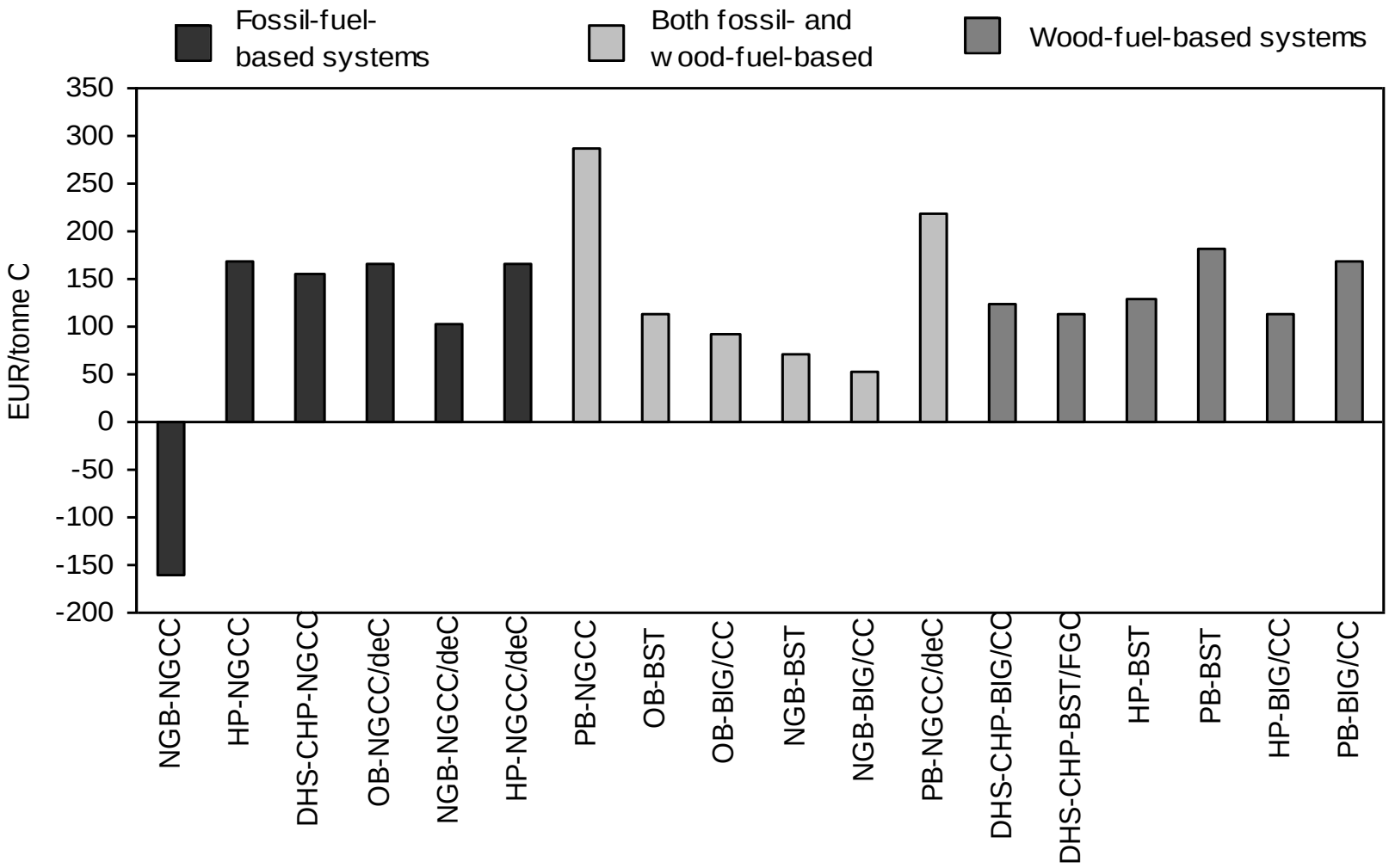
End-use technologies

- *Electric heating systems:*
  Electric boilers, heat pumps and resistance heaters. The base-load production of electricity (95%) was covered by stand-alone power plants BIG/CC, BST, CST, NGCC or NGCC/deC. The peak load was covered by by light-oil-fired gas turbines.
- *District heating systems:*
  Cogeneration technologies CHP-BIG/CC, CHP-BST/FGC, CHP-CST or CHP-NGCC for base-load production and light-oil-fired boilers for peak-load production.
- *Local boiler systems (at end-use):*
  Natural gas, light oil or wood pellets boilers

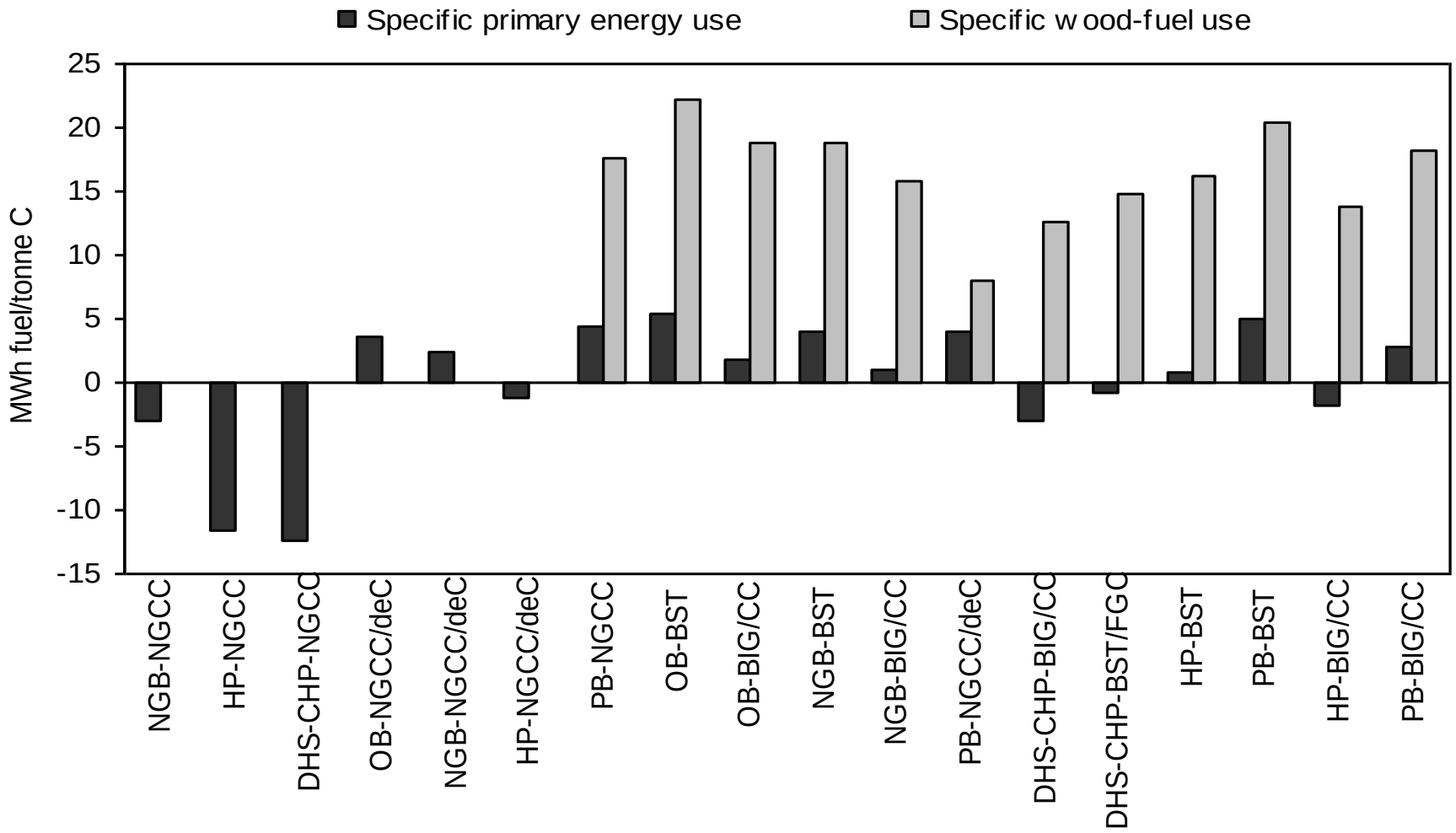
Relative emission difference when the reference entity is produced in the energy systems and the oil-boiler system using NGCC is the reference. The emission of the reference system was 220 kg C per reference entity



CO_2 mitigation cost when the reference entity is produced in the energy systems and the oil-boiler system using NGCC is the reference. The cost of the reference system was €100 per reference entity



The specific primary energy use and the specific wood-fuel use when the reference entity is produced in the energy systems and the oil-boiler system using NGCC is the reference. The primary energy use and the wood-fuel use of the reference system was 3.4 and 0 MWh_{fuel}, respectively.



Conclusions

- Analysis of greenhouse gas mitigation is complicated and depends strongly on the methods and assumptions employed
- The suitable systems to be compared varies with the spatial boundary conditions and time perspectives assumed.
- A range of possibilities may have to be analysed to identify a suitable strategy for replacing fossil-based systems with wood-based systems
- Identifying adequate strategies that could manage the large uncertainties at a reasonable cost appear to be more beneficial than to identify an optimum economic solution without considering external costs

A long term strategy to reduce greenhouse gas emission in the heating sector by using wood fuels

- Expand district heating systems
- Construct cogeneration systems with high electricity output for a given heat production
- Outside district-heating areas use heat pumps when a suitable heat sink is available and in other cases use pellet boilers (wood boilers)