     

What are the environmentally optimal uses of different biomass feedstocks - heating, electricity generation or transportation?

LCA DF 47

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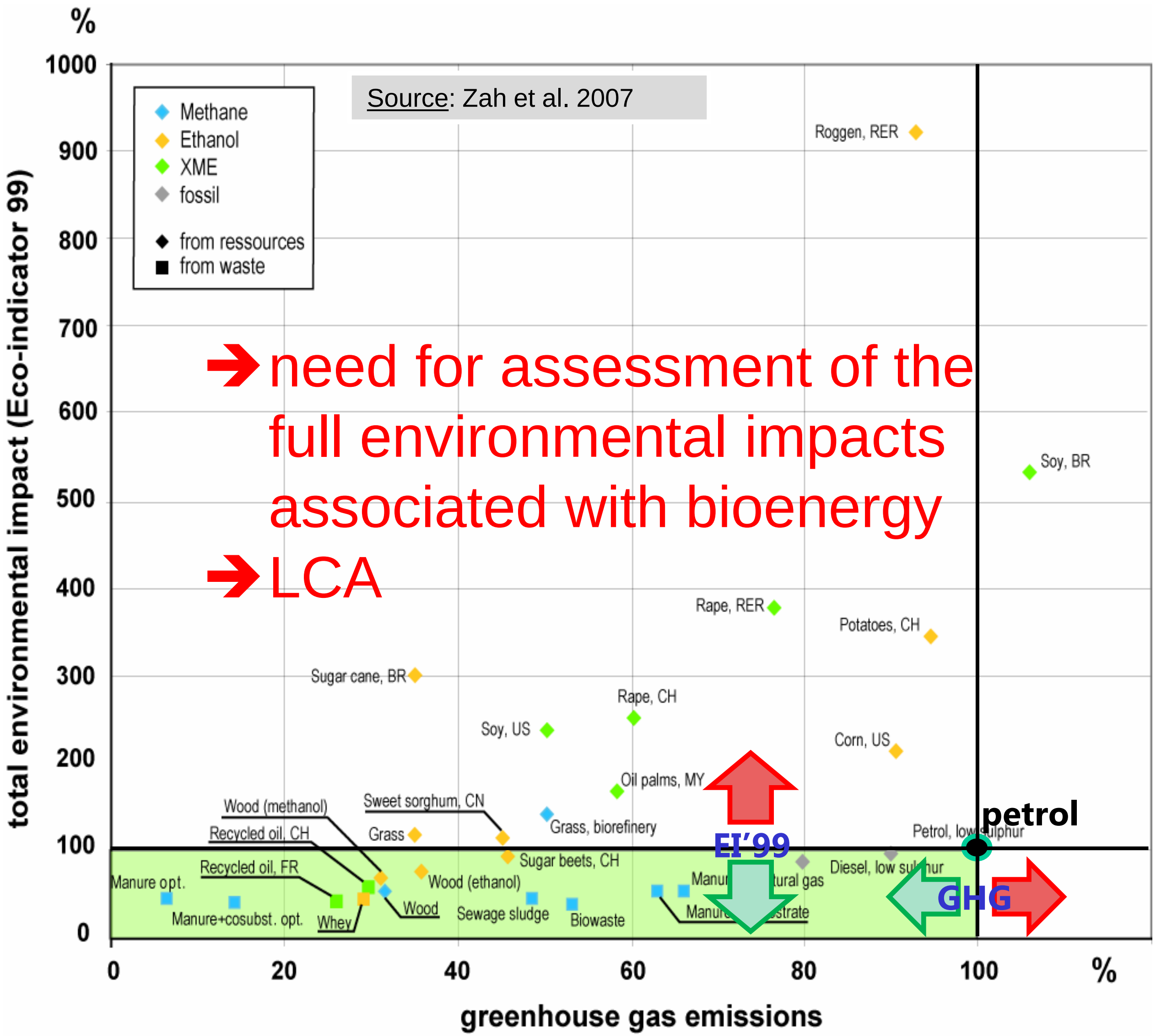
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

EMPA Materials Science & Technology

Bioenergy and the environment

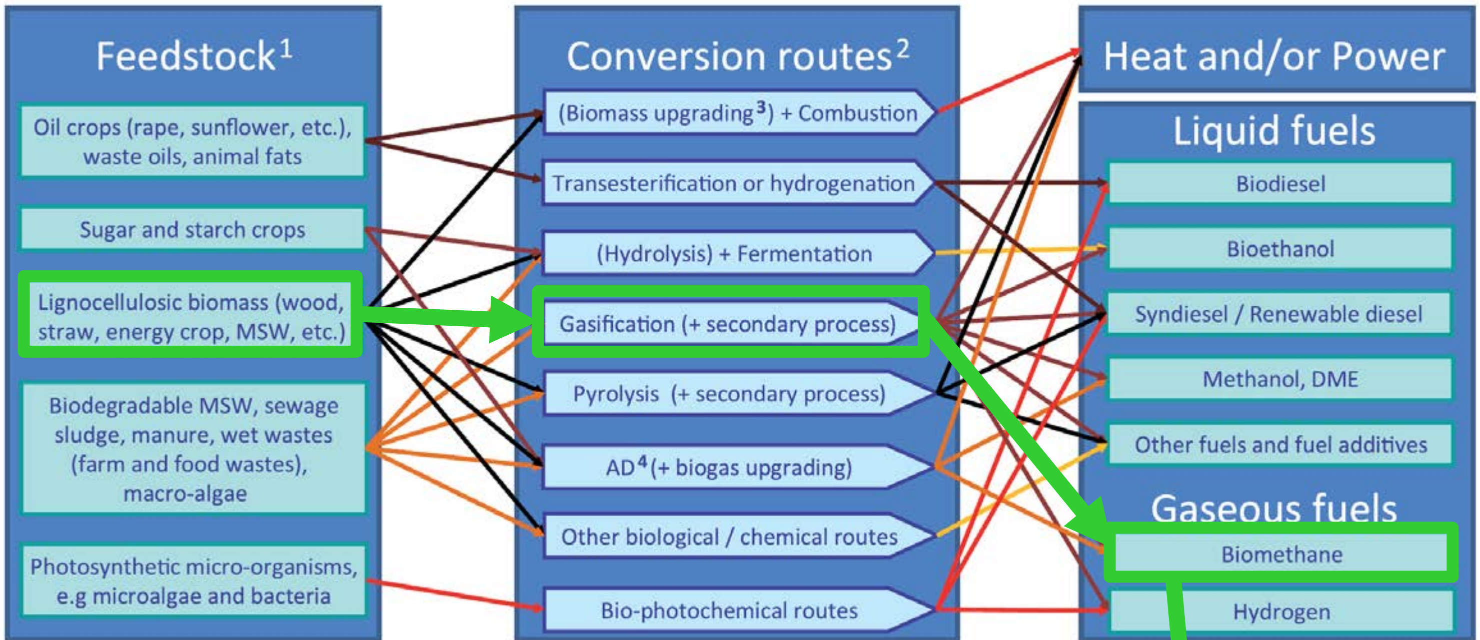


➔ need for assessment of the full environmental impacts associated with bioenergy

➔ LCA

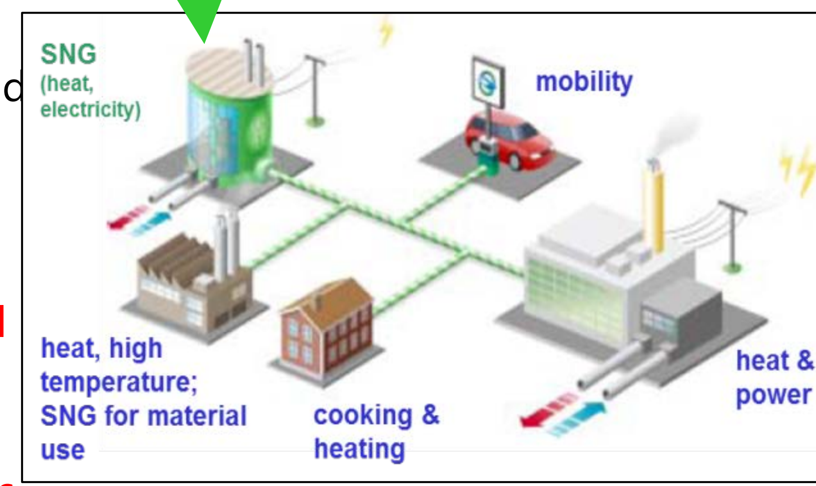
- Most biofuels show GHG benefits
- many show higher environmental impacts in other categories

Bioenergy conversion routes



Source: IEA 2009

- Bioenergy offers many opportunities: many feedstocks, conversion routes, and intermediate and final products
- challenge for environmental assessments (complexity)
- → **Need for LCI's** (**L**ife **C**ycle **I**nventories) of individual conversion routes
- → **Need for LCA-based decision support tools** to determine the optimal bioenergy conversion routes



Research questions / Outline

- What is the **availability of biomass** for energetic uses?

  → study for CH case

- What is the **environmental optimal use** of this biomass?

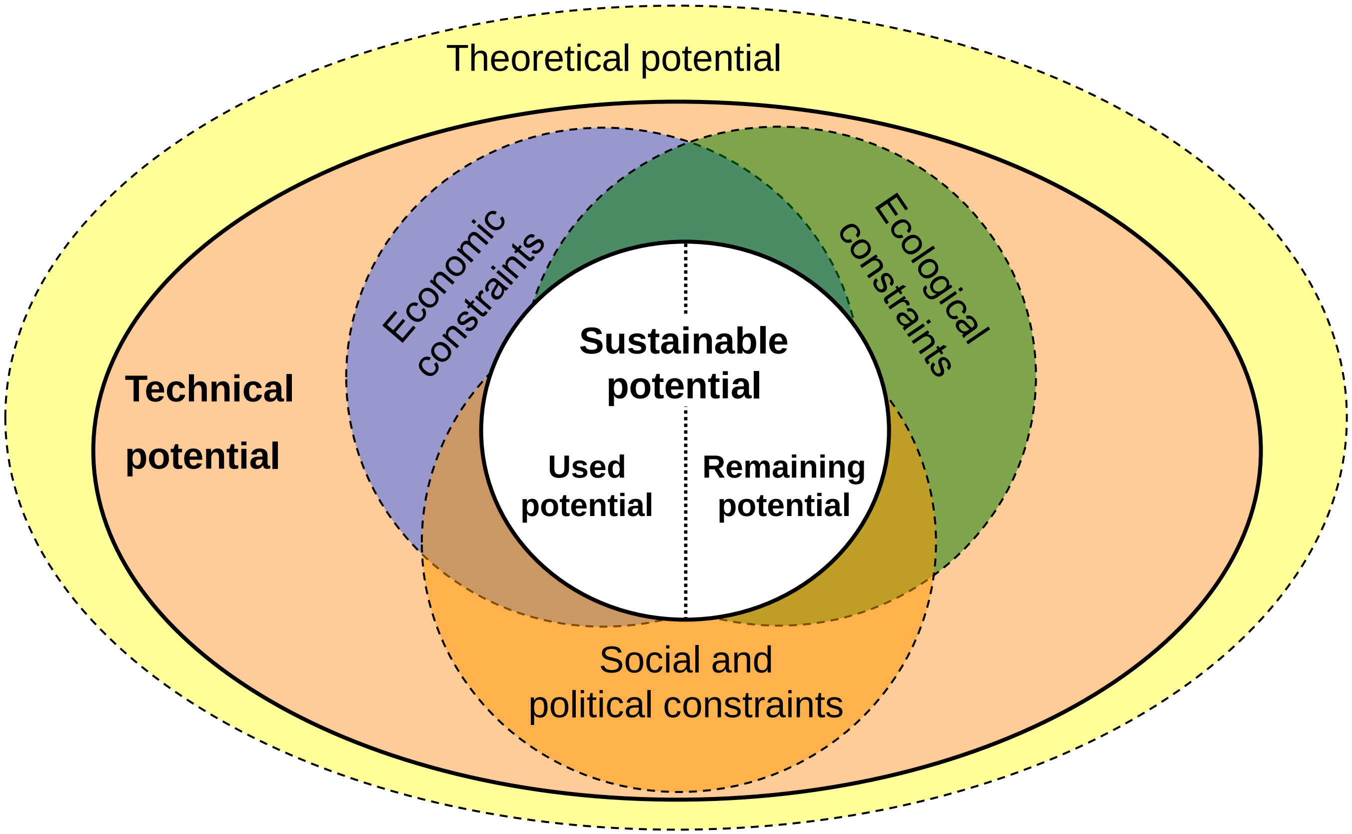
  → methodological approach

  → analyses for CH and EU-27

- Conclusions and recommendations

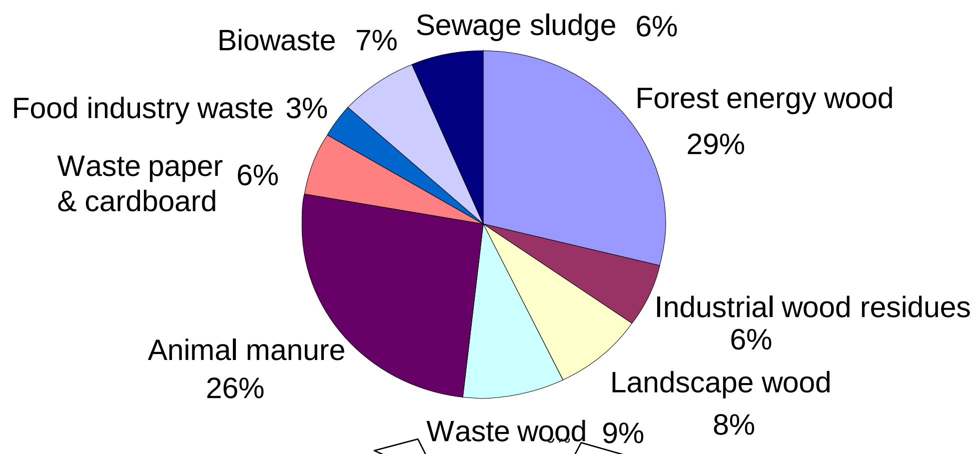
Biomass availability in Switzerland

Application of a sustainability constraints approach to quantify the sustainable biomass potential

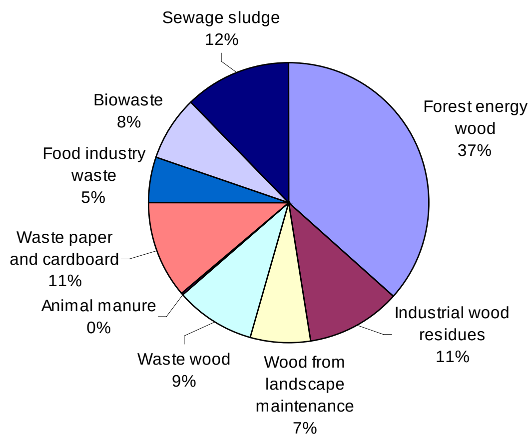


Sustainable, used and remaining potentials

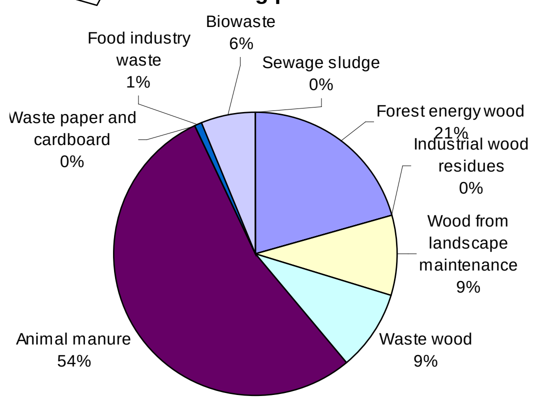
Total sustainable potential: 82 PJ
= 7% of CH primary energy demand



Used potential: 43 PJ



Remaining potential: 39 PJ



Optimal use of biomass for bioenergy production

Methodological approach

What kind of an assessment do we need to conduct to provide answers to the environmentally optimal use of bioenergy?

Optimization criteria ?

- Different environmental indicators:
  - GWP IPCC 100a
  - Ozone depletion
  - Human toxicity
  - Photochemical oxidant formation
  - Particulate matter formation
  - Terrestrial acidification
  - Freshwater eutrophication
  - Terrestrial ecotoxicity
  - Recipe single score
  - CED, non-renewable, fossil

Functional unit ? → resource-based

- Biomass input

System boundaries ? → systemic perspective

- All relevant biomass feedstocks, conversion routes, and uses (sectors)
- All relevant fossil energy substitutions

Constraints ?

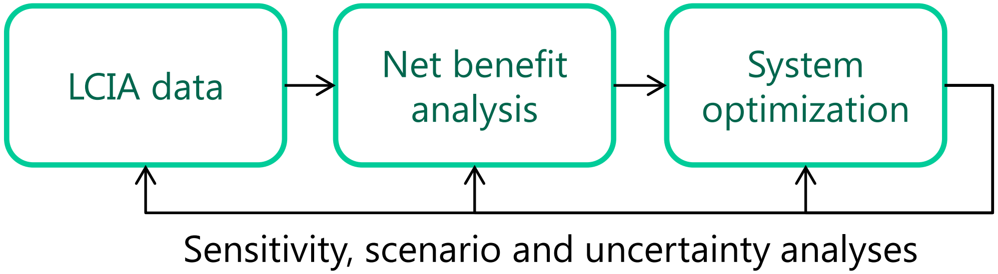
- Biomass availability
- Use of fossil energy technologies

Spatial and temporal dimension ?

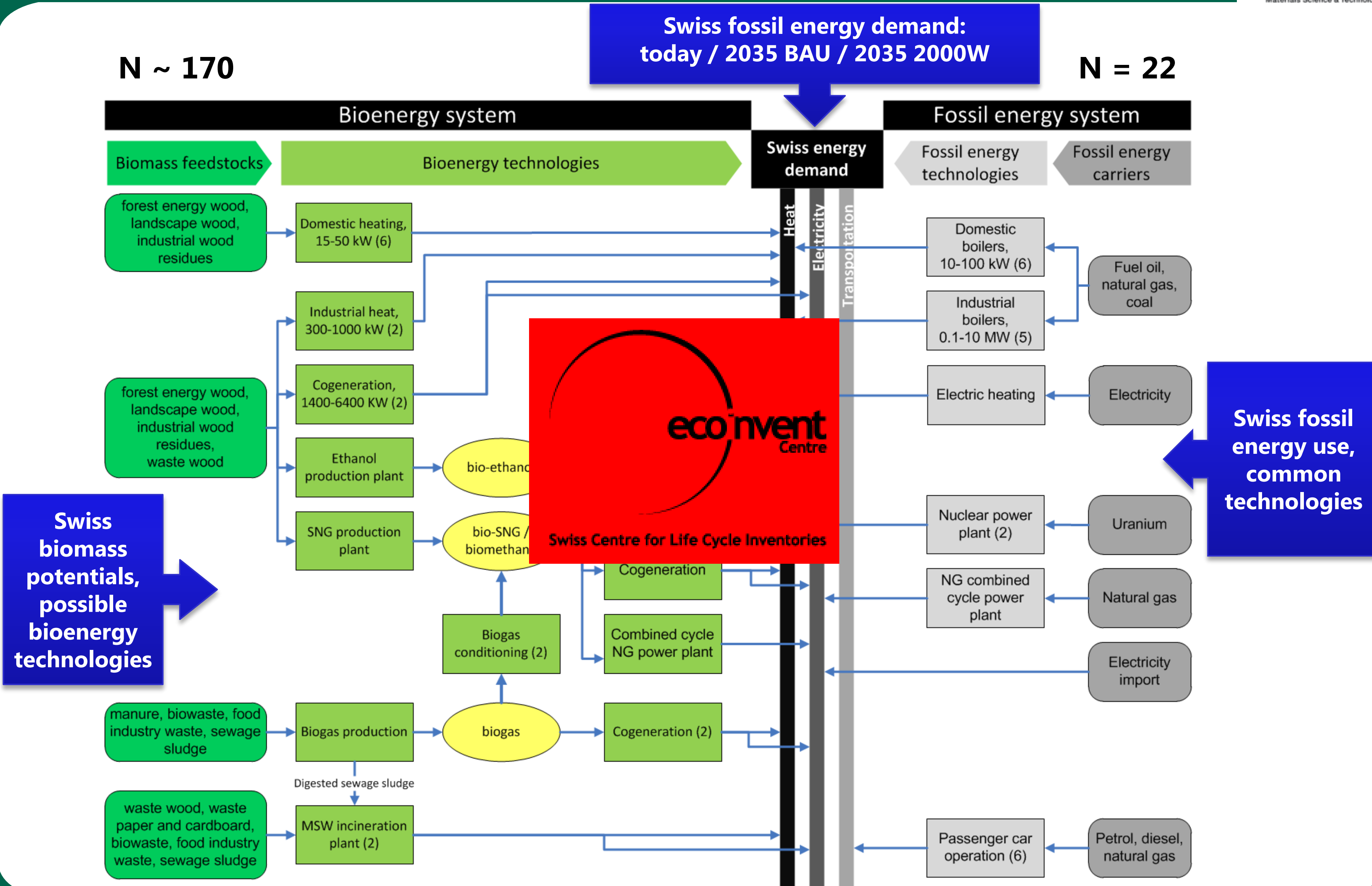
- CH / today and future (static)

Uncertainties ? e.g. LCI / LCIA / constraints

- Monte Carlo simulation for assumed uncertainties



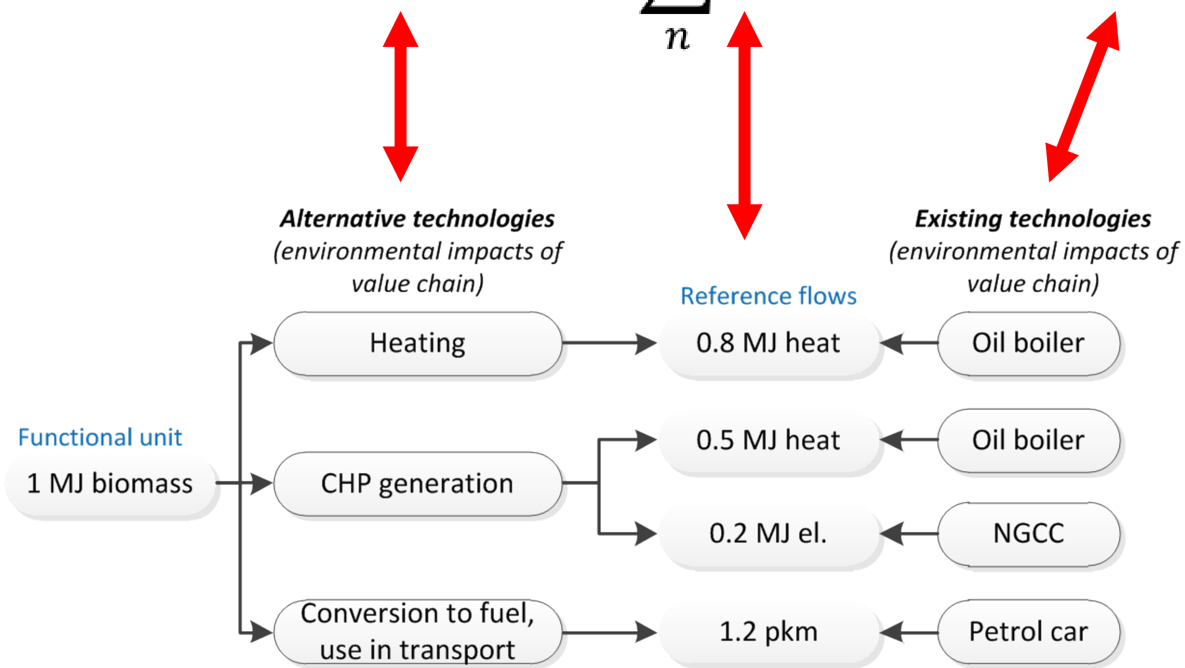
Bioenergy and fossil energy technologies (CH)



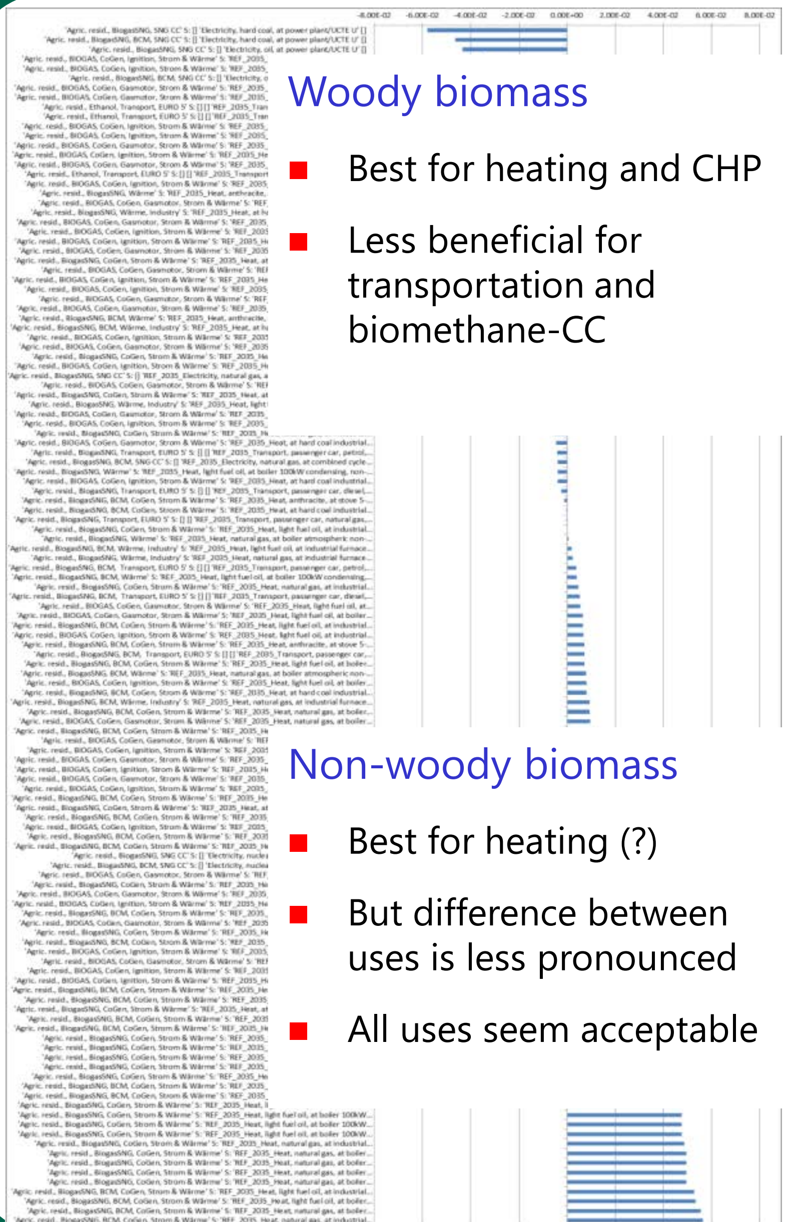
Net environmental benefit calculation

Net impact   bioenergy   non-renewable energy

$$EI^{i}_{net} = EI^{i}_{alternative} - \sum_{n} \eta_{alternative,n} EI^{o}_{existing,n}$$



Net benefit analysis results (CH)

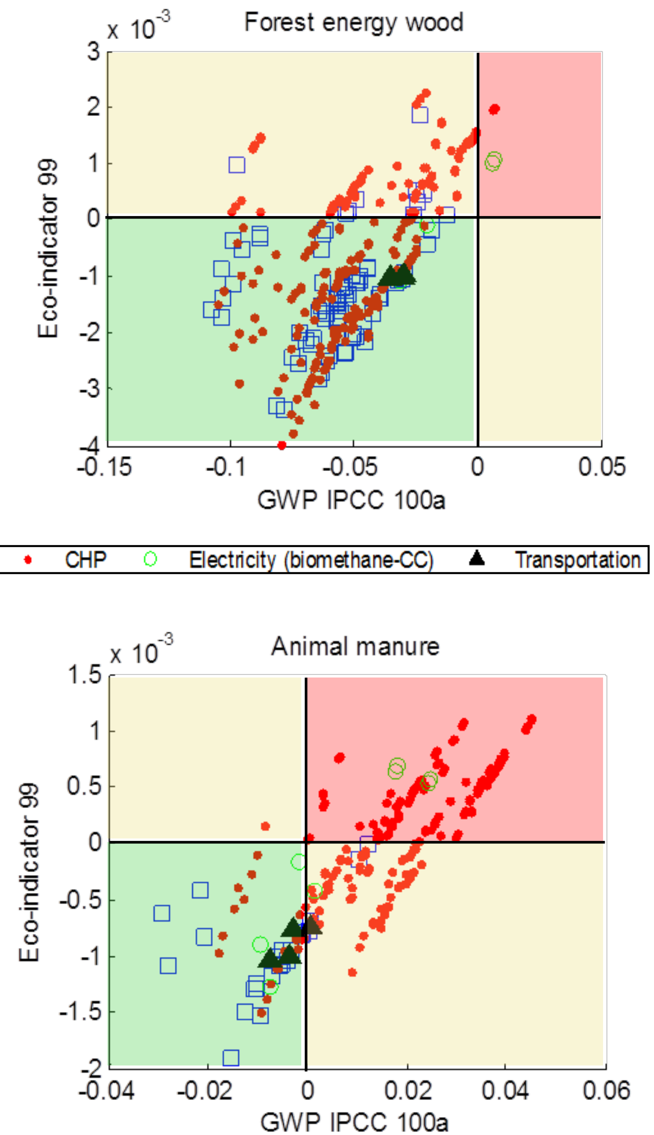


Woody biomass

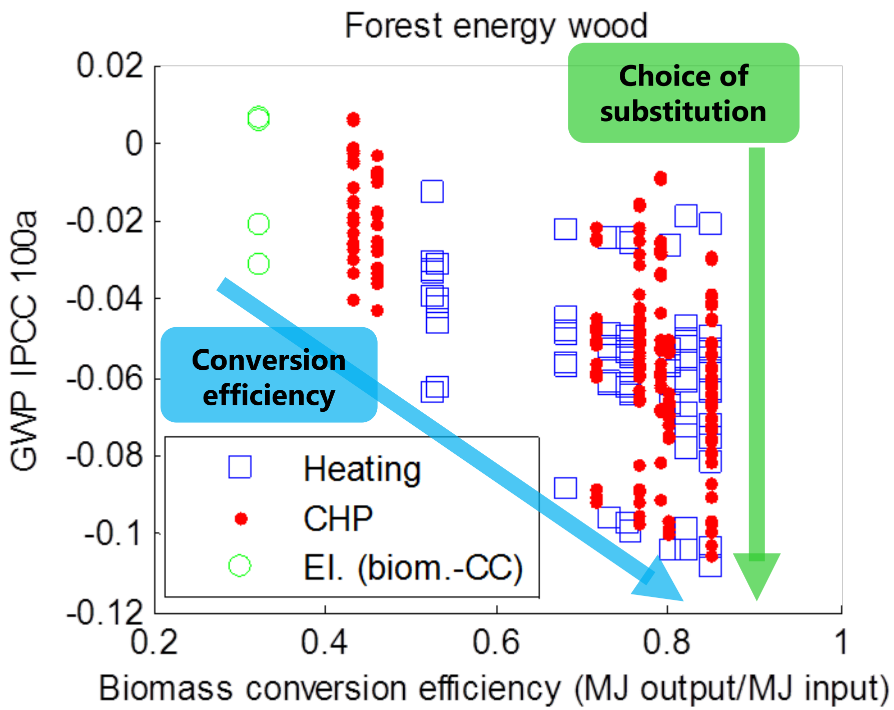
- Best for heating and CHP
- Less beneficial for transportation and biomethane-CC

Non-woody biomass

- Best for heating (?)
- But difference between uses is less pronounced
- All uses seem acceptable



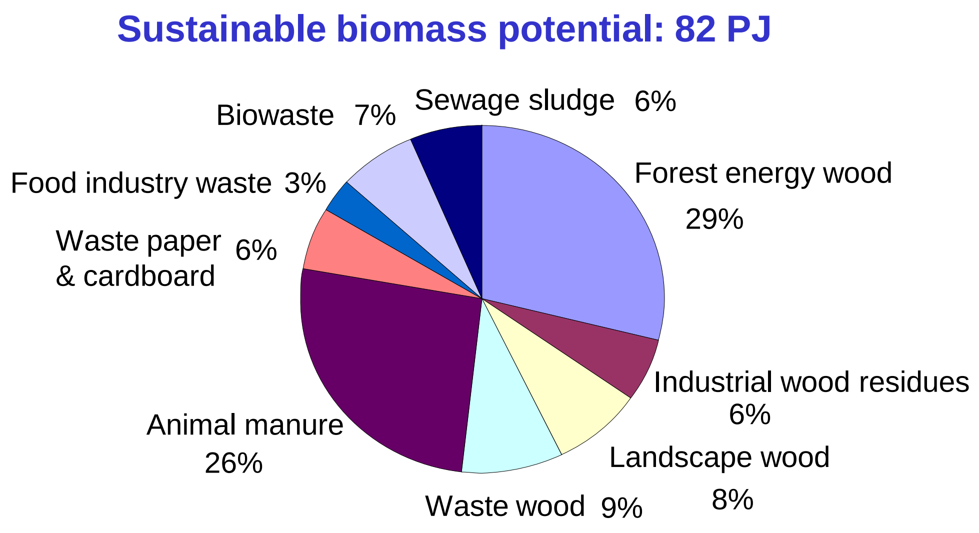
Correlation between GWP and efficiency

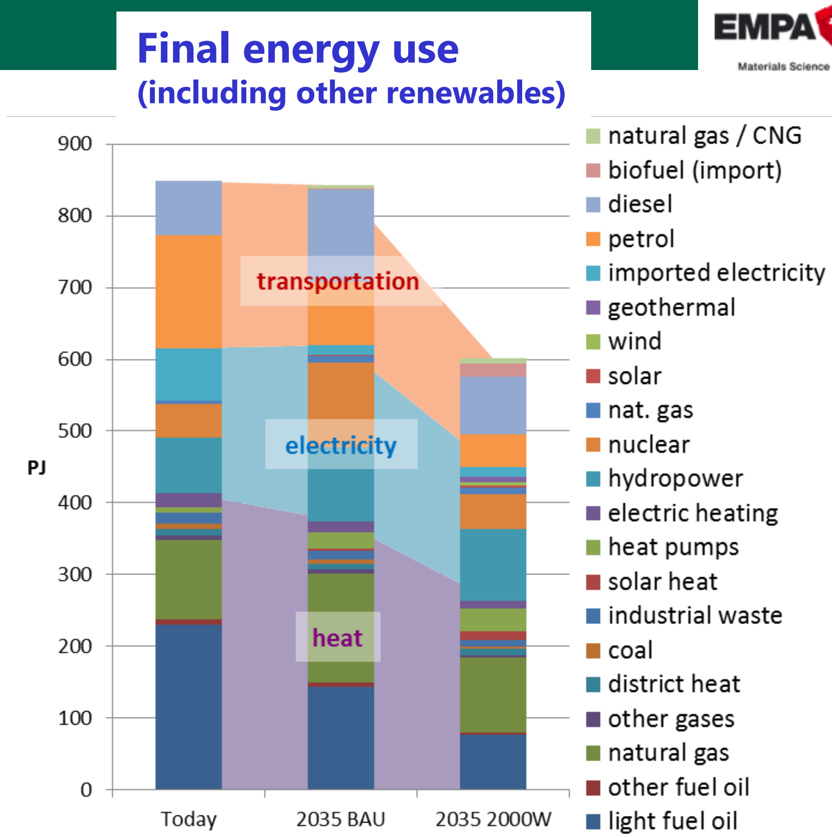


Key factors for environmental benefits:

- Biomass conversion efficiency
- Substitution choice

System optimization





Source: Swiss Energy Perspectives (BFE 2007)

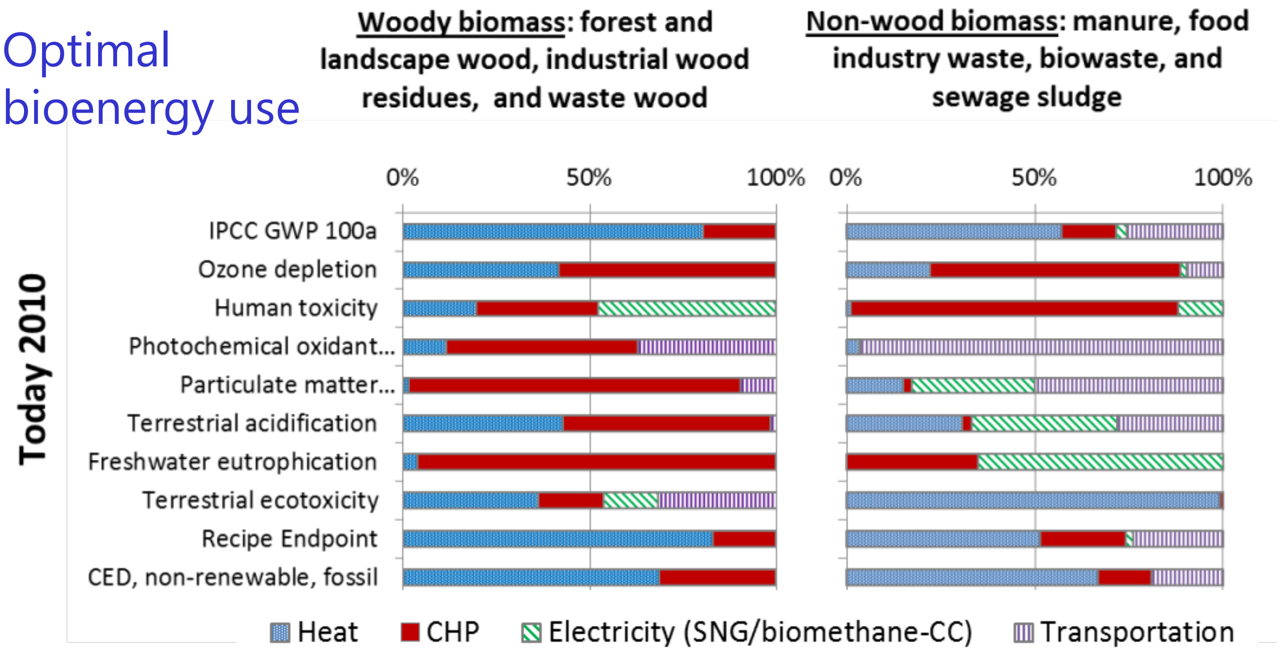
Optimization strategy:

- Calculate the net benefit for all possible combinations of bioenergy and non-renewable energy technologies
- Rank the combinations according to their net benefits for each optimization criterion
- Choose the best combinations until ***either*** no more biomass feedstock is available ***or*** no more of the fossil reference can be substituted

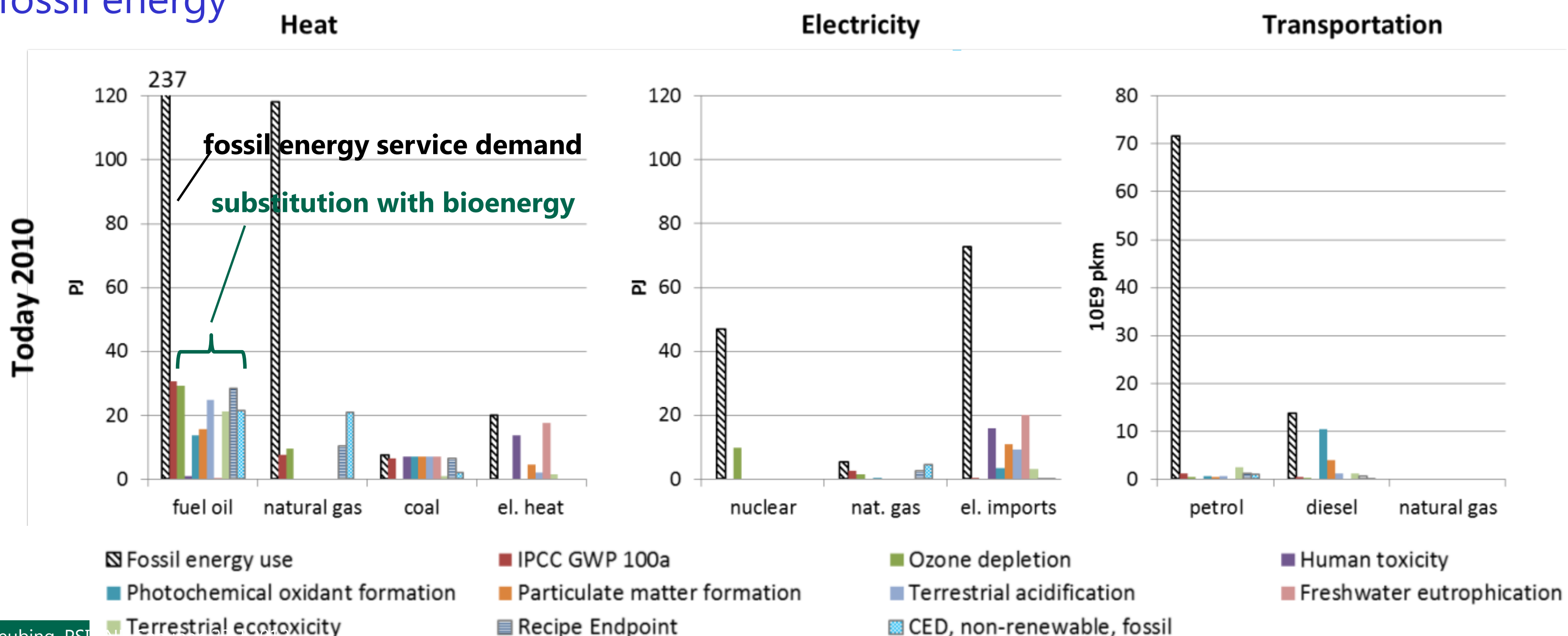
Results (CH) 2010

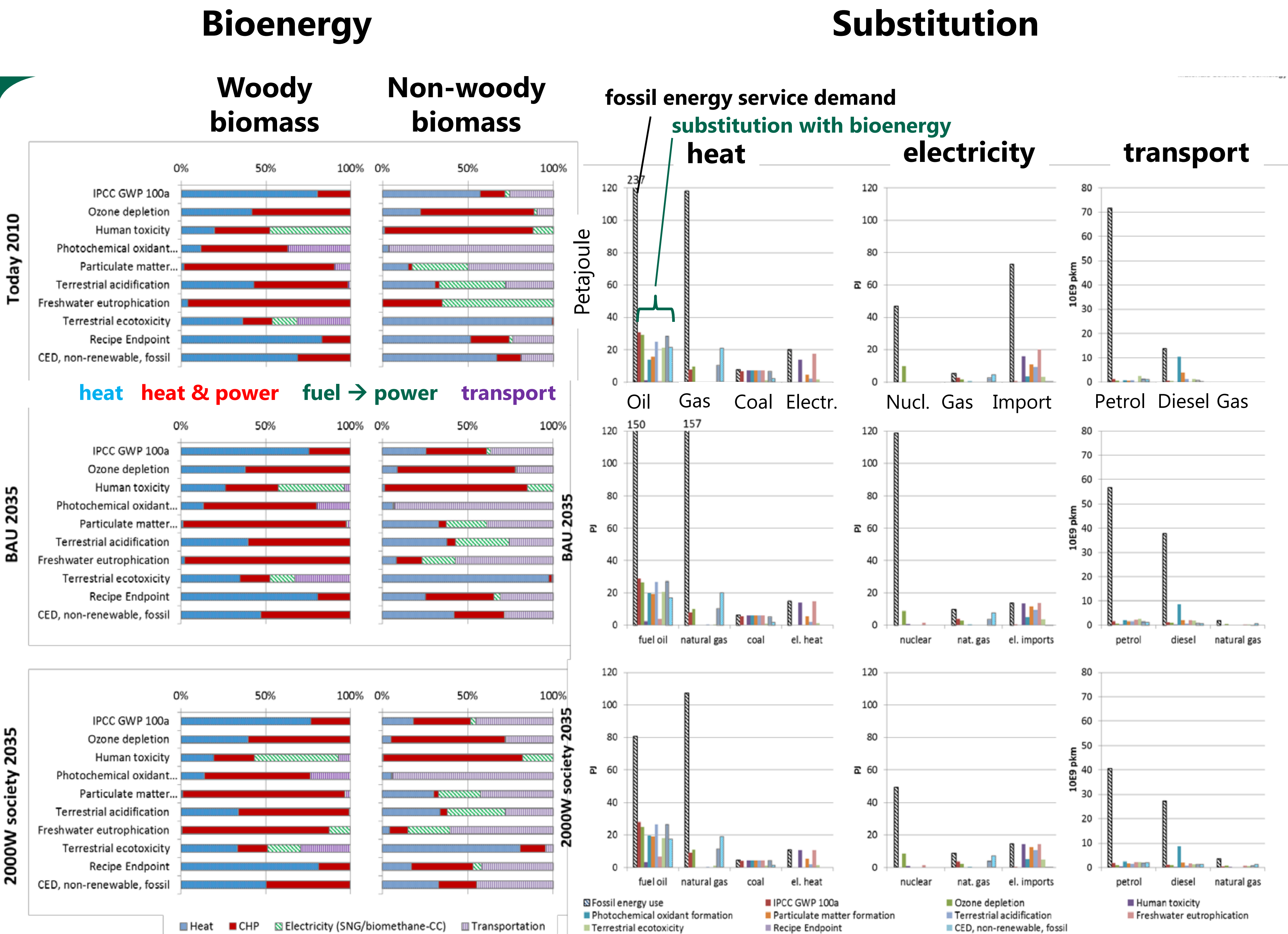
Monte Carlo analysis results for a standard deviation of 0.2 for LCIA results

Optimal bioenergy use



Optimal substitution of fossil energy




Bioenergy
Substitution
Woody biomass
Non-woody biomass
fossil energy service demand
substitution with bioenergy
heat
electricity
transport
Today 2010
BAU 2035
2000W society 2035
0%
50%
100%
IPCC GWP 100a
Ozone depletion
Human toxicity
Photochemical oxidant...
Particulate matter...
Terrestrial acidification
Freshwater eutrophication
Terrestrial ecotoxicity
Recipe Endpoint
CED, non-renewable, fossil
heat
heat & power
fuel → power
transport
Petajoule
PJ
10E9 pkm
237
150
157
Oil
Gas
Coal
Electr.
Nucl.
Gas
Import
Petrol
Diesel
Gas
fuel oil
natural gas
coal
el. heat
nuclear
nat. gas
el. imports
petrol
diesel
natural gas
Heat
CHP
Electricity (SNG/biomethane-CC)
Transportation
Fossil energy use
IPCC GWP 100a
Ozone depletion
Human toxicity
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Terrestrial acidification
Freshwater eutrophication
Terrestrial ecotoxicity
Recipe Endpoint
CED, non-renewable, fossil

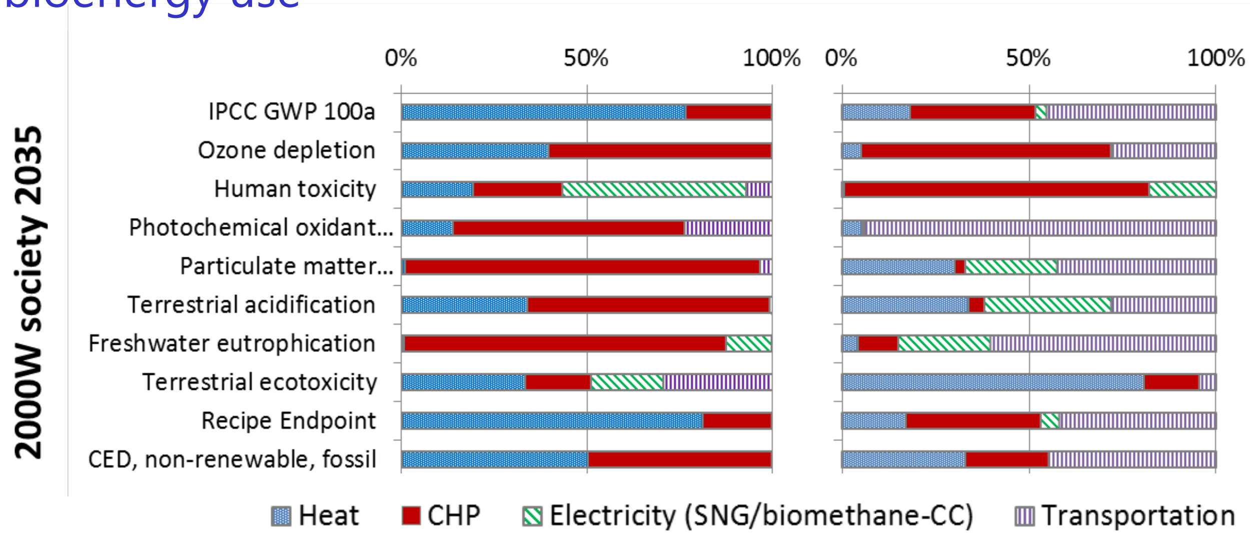
Results (CH) - 2035 way to "2000W society"

Monte Carlo analysis results for a standard deviation of 0.2 for LCIA results

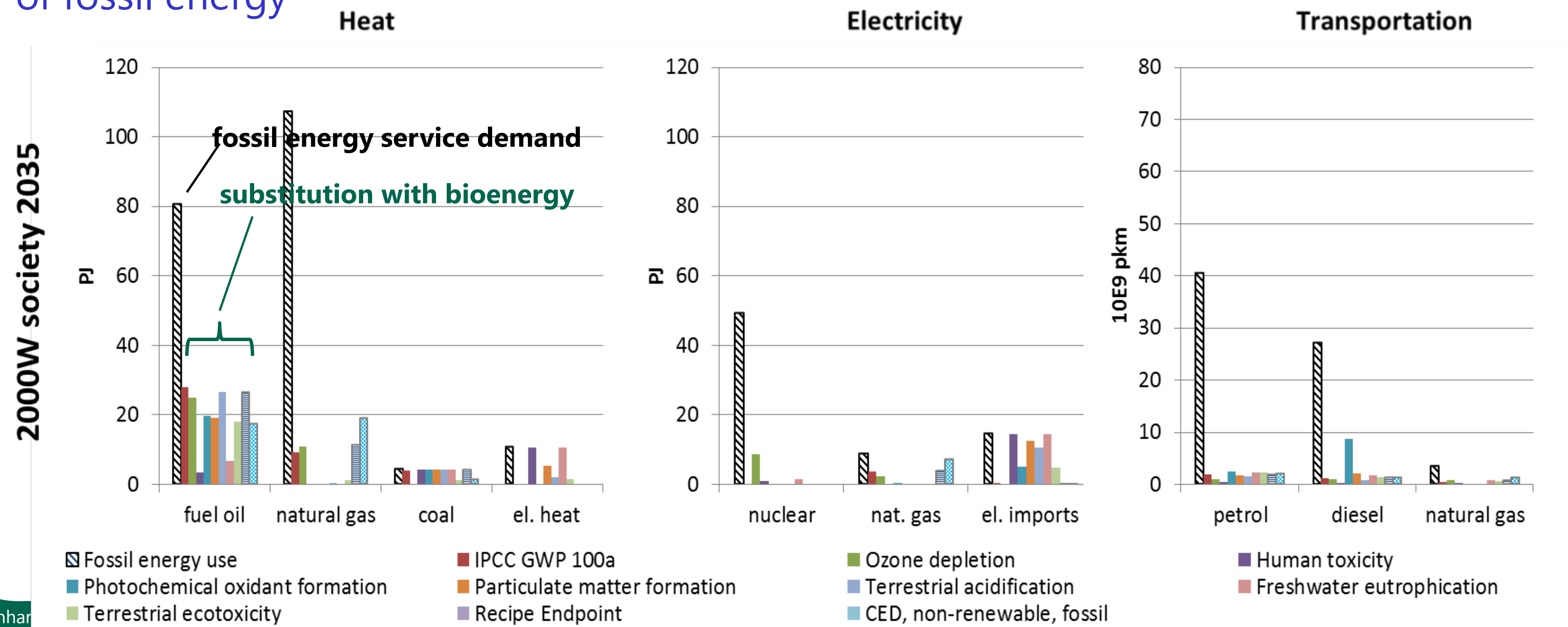
Optimal bioenergy use

Woody biomass: forest and landscape wood, industrial wood residues, and waste wood

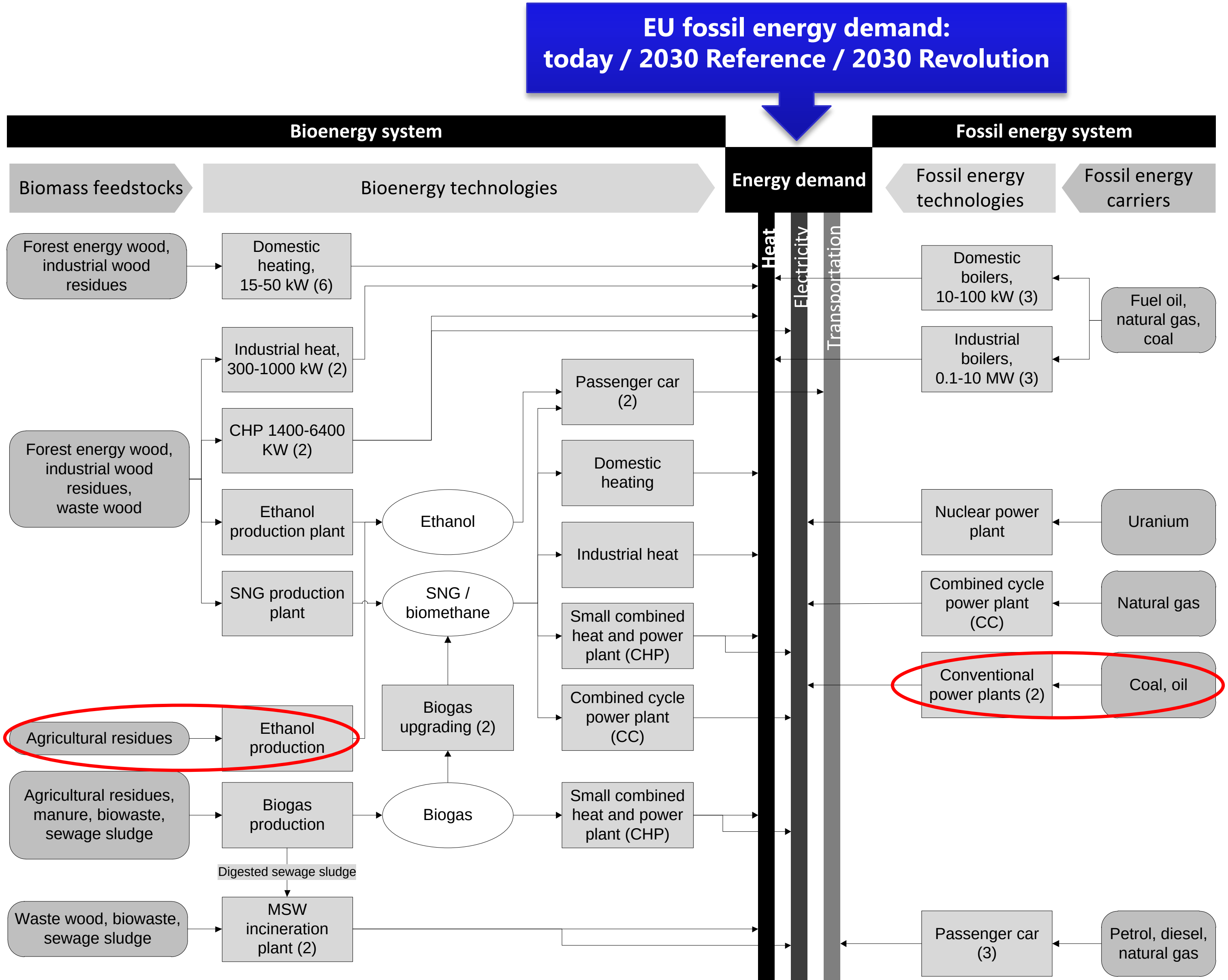
Non-wood biomass: manure, food industry waste, biowaste, and sewage sludge



Optimal substitution of fossil energy



Bioenergy and fossil energy technologies (EU)



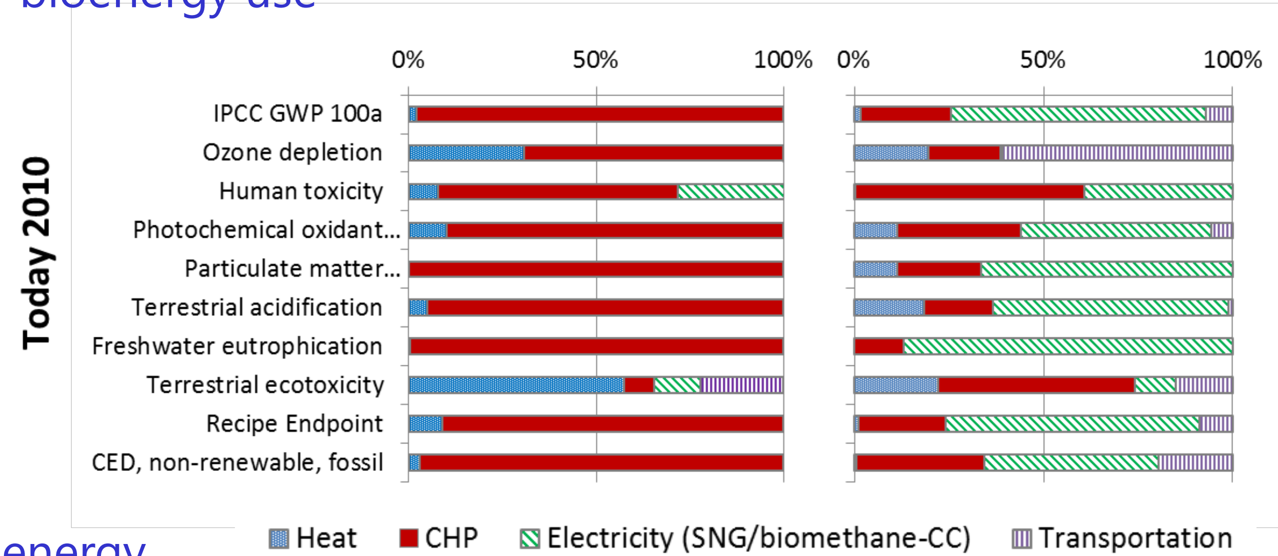
Results (EU) 2010

Monte Carlo analysis results for a standard deviation of 0.2 for LCIA results

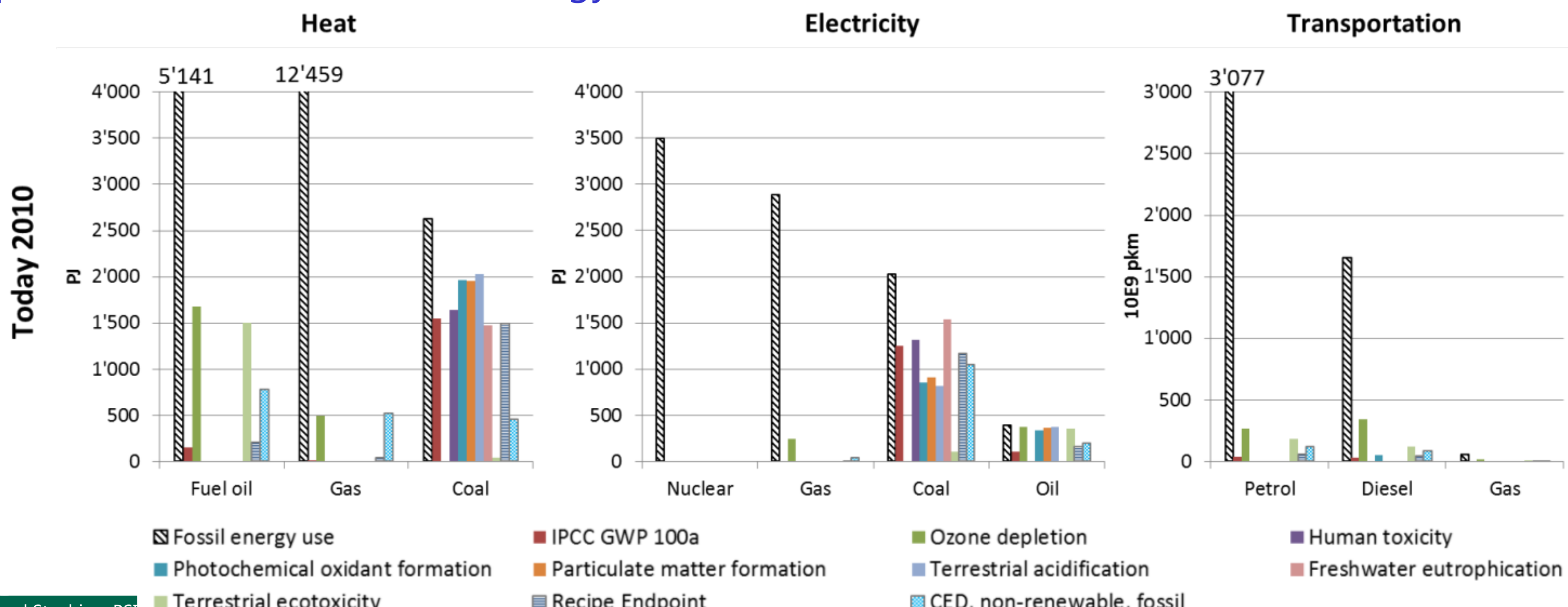
Optimal bioenergy use

Woody biomass: forest wood, industrial wood residues, and waste wood

Non-wood biomass: agricultural residues, manure, biowaste, and sewage sludge



Optimal substitution of fossil energy



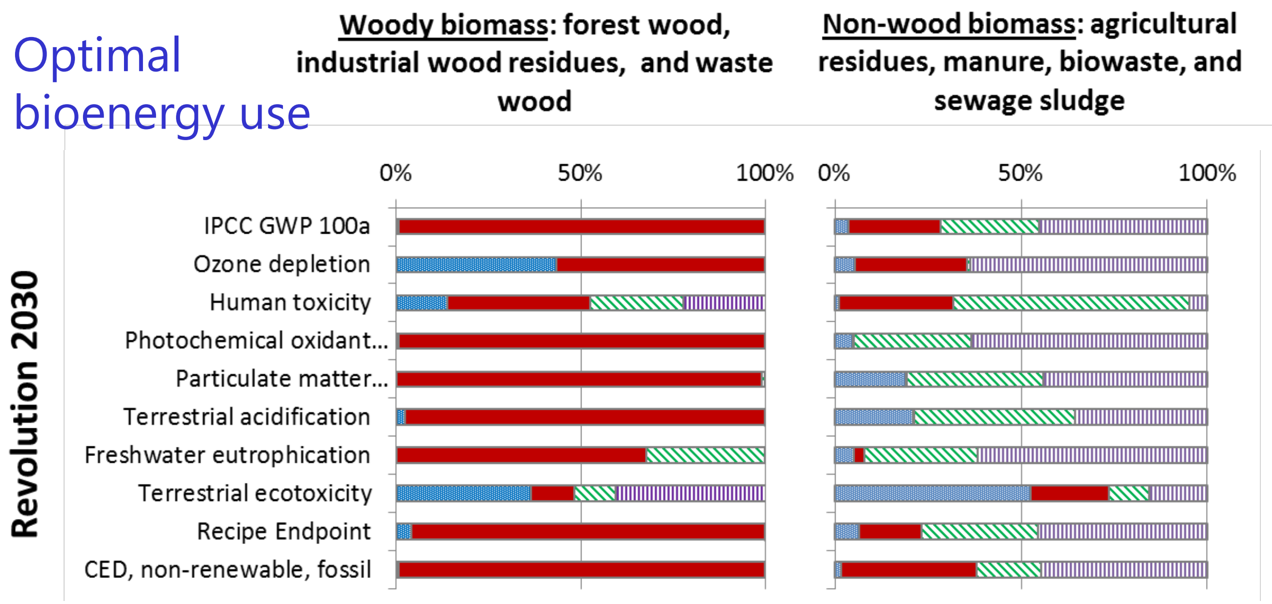
Results (EU)

fossil energy service demand
substitution with bioenergy
Woody biomass: forest wood, industrial wood residues, and waste wood
Non-wood biomass: agricultural residues, manure, biowaste, and sewage sludge
Today 2010
Reference 2030
Revolution 2030
heat
heat & power
fuel → power
transportation
IPCC GWP 100a
Ozone depletion
Human toxicity
Photochemical oxidant...
Particulate matter...
Terrestrial acidification
Freshwater eutrophication
Terrestrial ecotoxicity
Recipe Endpoint
CED, non-renewable, fossil
0%
50%
100%
Heat
Electricity
Transportation
PJ
10E9 pkm
5'141
12'459
3'077
4'480
13'419
12'754
4'544
Fuel oil
Gas
Coal
Nucl.
Nuclear
Oil
Petrol
Diesel
Heat
CHP
Electricity (SNG/biomethane-CC)
Transportation
Fossil energy use
IPCC GWP 100a
Ozone depletion
Human toxicity
Photochemical oxidant formation
Particulate matter formation
Terrestrial acidification
Freshwater eutrophication
Terrestrial ecotoxicity
Recipe Endpoint
CED, non-renewable, fossil

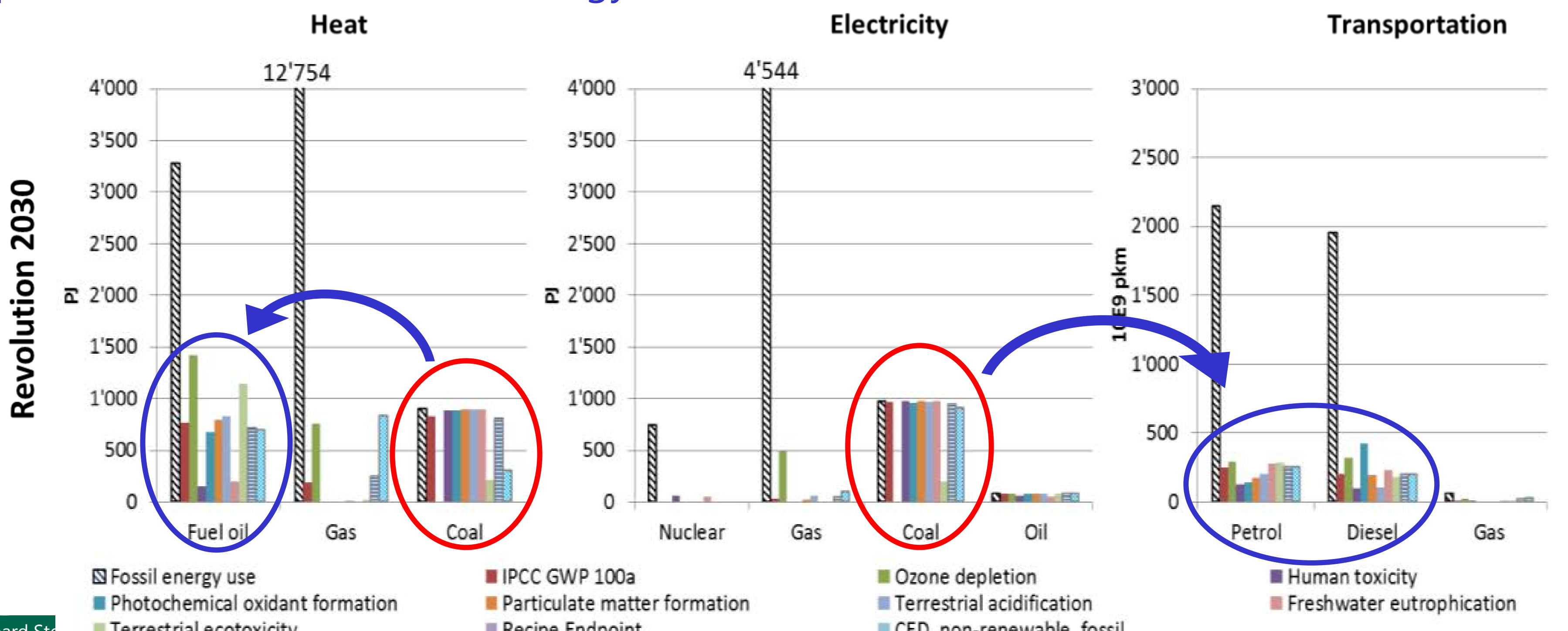
Results (EU) 2030 Revolution

Monte Carlo analysis results for a standard deviation of 0.2 for LCIA results

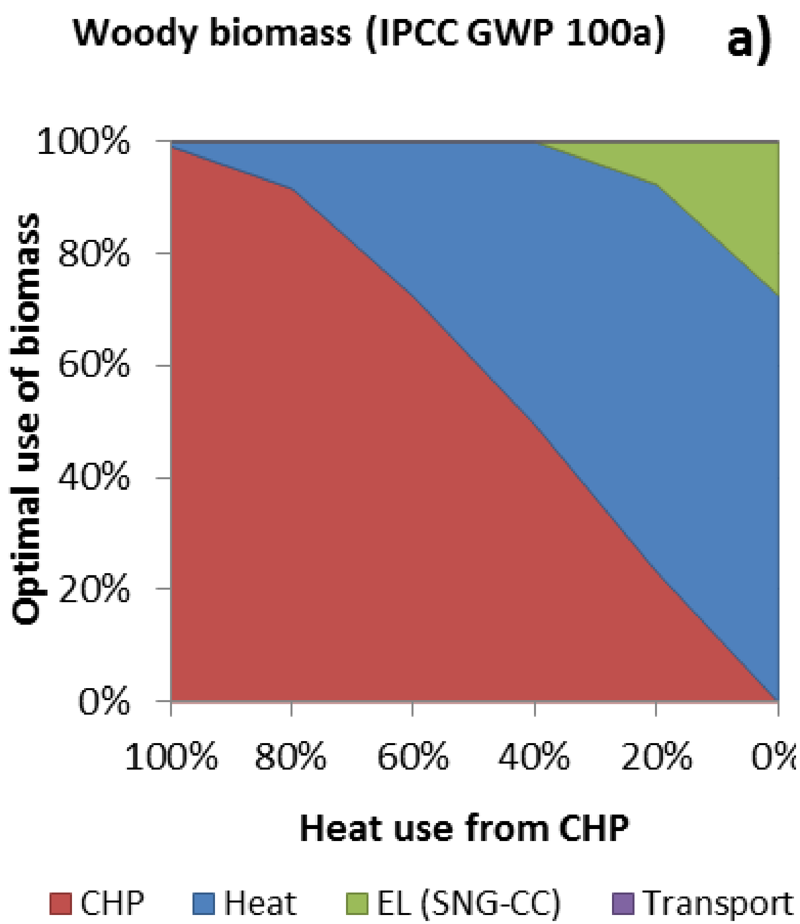
Optimal bioenergy use



Optimal substitution of fossil energy



Heat use from CHP (EU)



- Heat use from CHP is important to insure high efficiency
- If heat cannot be used, other biomass uses are preferable

Results comparison CH and EU (BAU 2035 / Reference 2030 scenarios)

Switzerland:

- CO_2 mitigation potential
  - 5 Mt ≈ 13% of CH's total emissions
- Fossil energy substitution potential (CO_2 optimization)
  - 13% of heat
  - 3% of electricity
  - 2% of transportation

EU:

- CO_2 mitigation potential
  - 600 Mt ≈ 15% of EU's total emissions
- Fossil energy substitution potential (CO_2 optimization)
  - 9% of heat
  - 13% of electricity
  - 1% of transportation

Conclusions – Recommendations – Outlook

Conclusions

- **Sustainable energetic biomass potential in Switzerland?**
  - ≈ 82 PJ or 7% of CH's primary energy demand, mainly from wood, manure, and waste biomass ➔ better assessments for specific feedstocks are needed!
- **How can the environmentally optimal use of bioenergy be determined?**
  - by adopting a *systemic perspective*, which is (amongst others) characterized by:
    - *resource-based functional unit*
    - *simultaneous / integrated assessments of existing and alternative technologies*
    - *system boundaries that encompass all relevant sectors*
- **What is the optimal use of bioenergy? CH-EU results (according to most indicators):**
  - woody biomass: *direct heating and CHP*
  - non-woody biomass: *all uses seem acceptable*; EU: bioelectricity, and biofuels in the future
  - under the conditions of (key factors for high environmental benefits):
    - *high biomass conversion efficiencies*
    - *substitution of fossil energy from coal, fuel oil, and other high impact energy carriers*
  - These *recommendations may change in the future* due to new technologies, changed supply and demand of energy services, etc.

Policy recommendations

- (Bio)energy policies should provide *integrated/simultaneous incentives to*
  - *make efficient resource use* (high biomass conversion efficiencies)
  - *replace the environmentally most critical technologies* (e.g. coal and oil-based heat and power generation)

- Does it make sense to produce advanced biofuels from lignocellulosic biomass (e.g. wood)?
  - *Currently environmentally sub-optimal* (for most indicators)
  - *In the future this may change* however, due to technology improvements and a different demand of heat, electricity, and transportation from non-renewable sources
  - Therefore, *research and development of these technologies should be encouraged*

Further research / NRP 66 project “wood resources”

- Data:
  - Need for additional / updated *life cycle inventories*
- Modeling:
  - *Temporal resolution:* e.g. seasonal and intra-day differences
  - *Spatial resolution:* regionalization, e.g. ranging from national level reassessments to site-specific analyses
  - *System boundaries:* e.g. extension to the material uses of biomass
  - *Impact assessment methodologies:* should be improved (e.g. biodiversity, toxicity effects)

- ETH-IfU-ESD new project in the NRP66 «wood resources»:

➔ **Goal: identify environmental strategies for a sustainable management of wood**

  - assess current and future wood use scenarios for material, chemical, and energetic applications including cascade use and substitution
  - establish life cycle inventories of new technologies
  - improve wood use related life cycle impact assessment (LCIA) methods

Thank you for your attention!

- Thanks to
  - Ph.D. thesis supervisors (Prof. Christian Ludwig, Dr. Patrick Wäger, Dr. Rainer Zah)
  - Funding: CCEM

- Related publications:

  - B. Steubing, R. Zah, C. Ludwig, ***Heat, electricity, or transportation? The optimal use of residual and waste biomass in Europe from an environmental perspective***, Environ. Sci. Technol., 46 (2012) 164-171.
  - B. Steubing, R. Zah, P. Waeger, C. Ludwig, ***Bioenergy in Switzerland: Assessing the domestic sustainable biomass potential***, Renewable and Sustainable Energy Reviews, 14 (2010) 2256–2265.
  - B. Steubing, R. Zah, C. Ludwig, ***Life cycle assessment of SNG from wood for heating, electricity, and transportation***, Biomass Bioenergy, 35 (2011) 2950-2960.
  - B. Steubing, I. Ballmer, M. Gassner, L. Gerber, L. Pampuri, S. Bischof, O. Thees, R. Zah**, *Identifying environmentally and economically optimal bioenergy plant sizes and locations: a spatial model of wood-based SNG value chains***, submitted.

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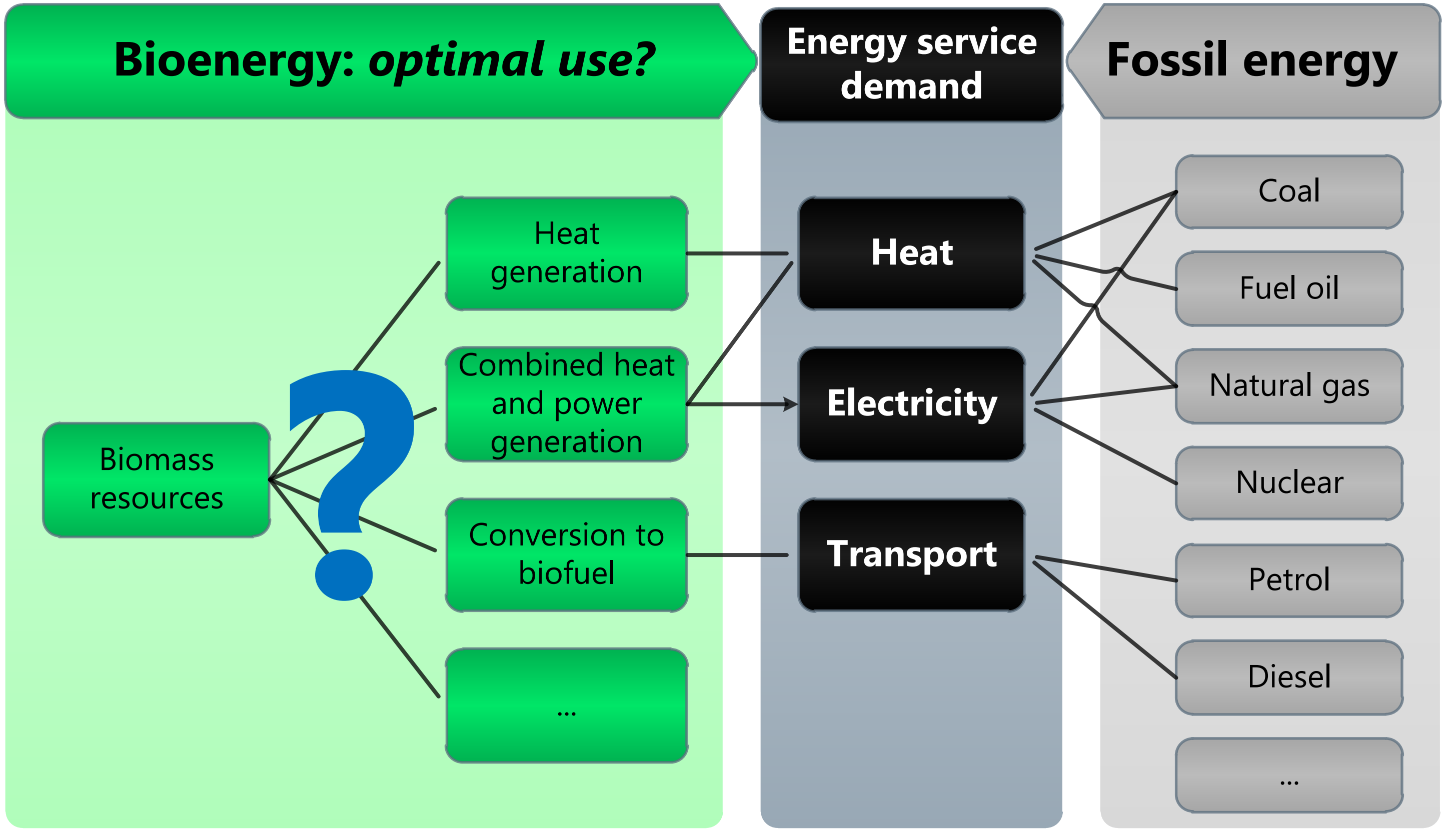
Outline



1. How much biomass is available for energetic utilization?
2. How can we make the environmentally optimal use of this biomass?

LCA-SO framework

Optimization criteria ?

- Different environmental indicators

Functional unit ? → resource-based

- Biomass input

System boundaries ? → systemic perspective

- All relevant biomass feedstocks, conversion routes, and uses (sectors)
- All relevant fossil energy substitutions

Constraints ?

- Biomass availability
- Use of fossil energy technologies
- Etc.

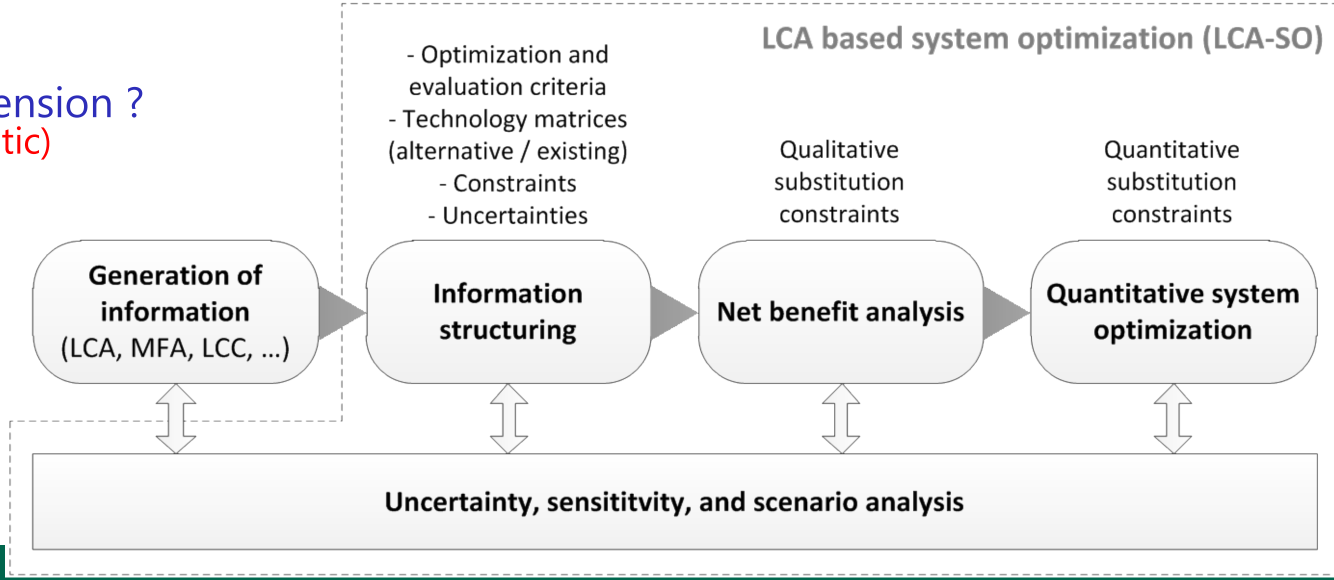
~~Spatial~~ and temporal dimension ? (quasi-static)

Uncertainties ?

- inventories
- impacts assessment
- constraints, etc.

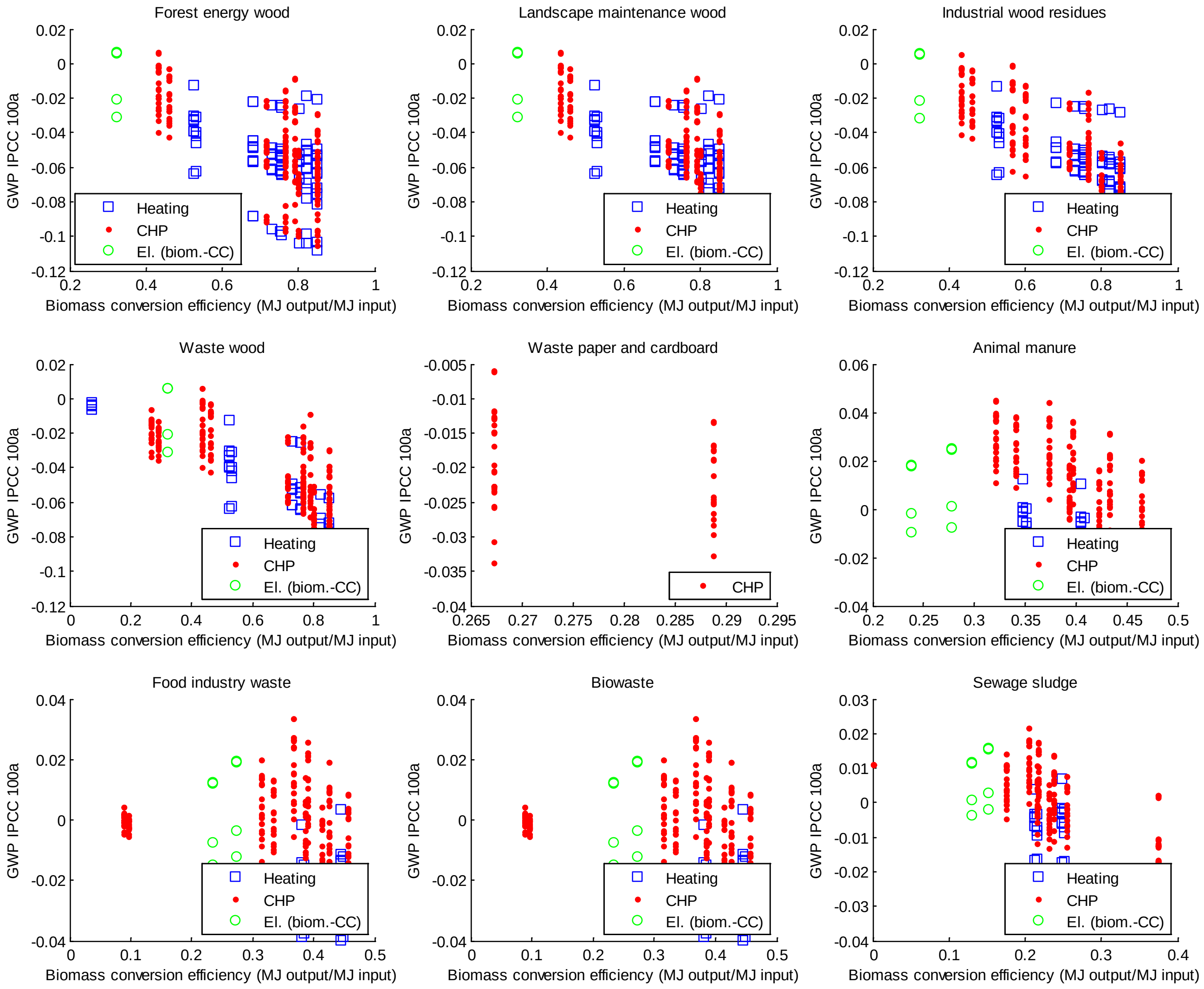
What kind of an assessment do we need to conduct to provide answers to the environmentally optimal use of bioenergy?

LCA-based **S**ystem **O**ptimization (**LCA-SO**) framework:



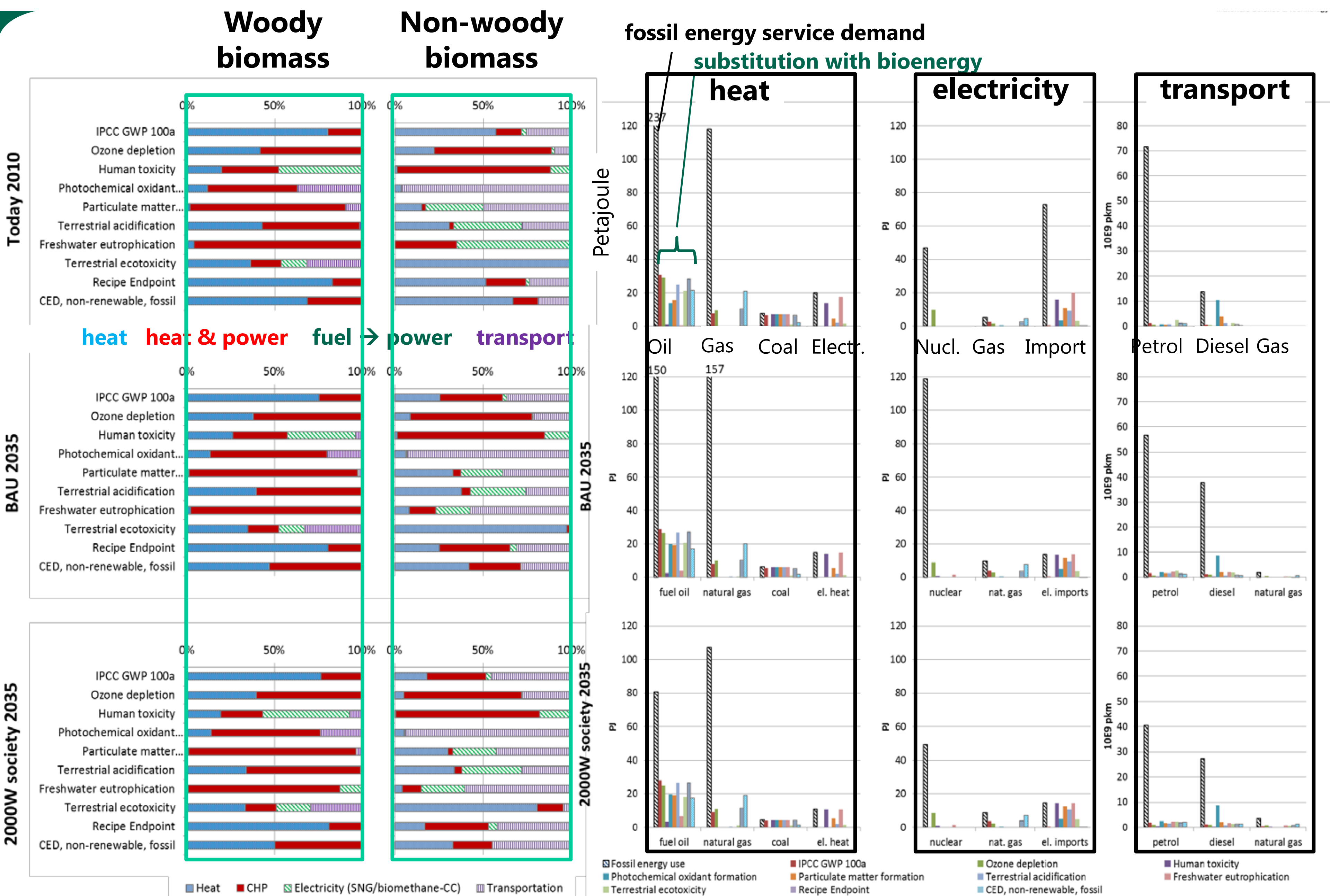
Results “Swiss case”

Biomass conversion efficiency and GWP

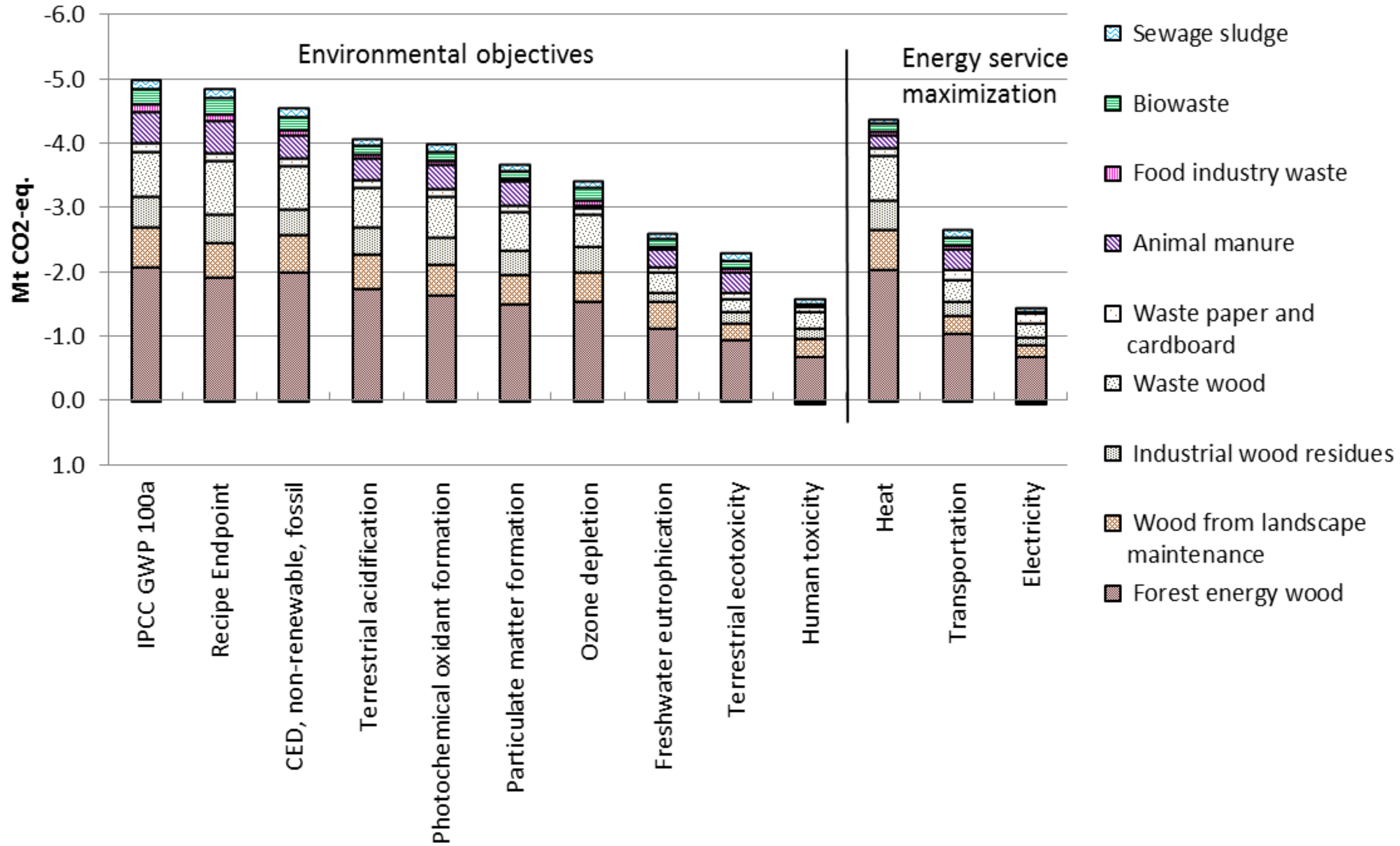


Bioenergy

Substitution



GHG mitigation potential, optimization objective, and feedstock contribution



- Trade-off between objectives
- max. GHG savings of 5 Mt → 13% of CH's total emissions

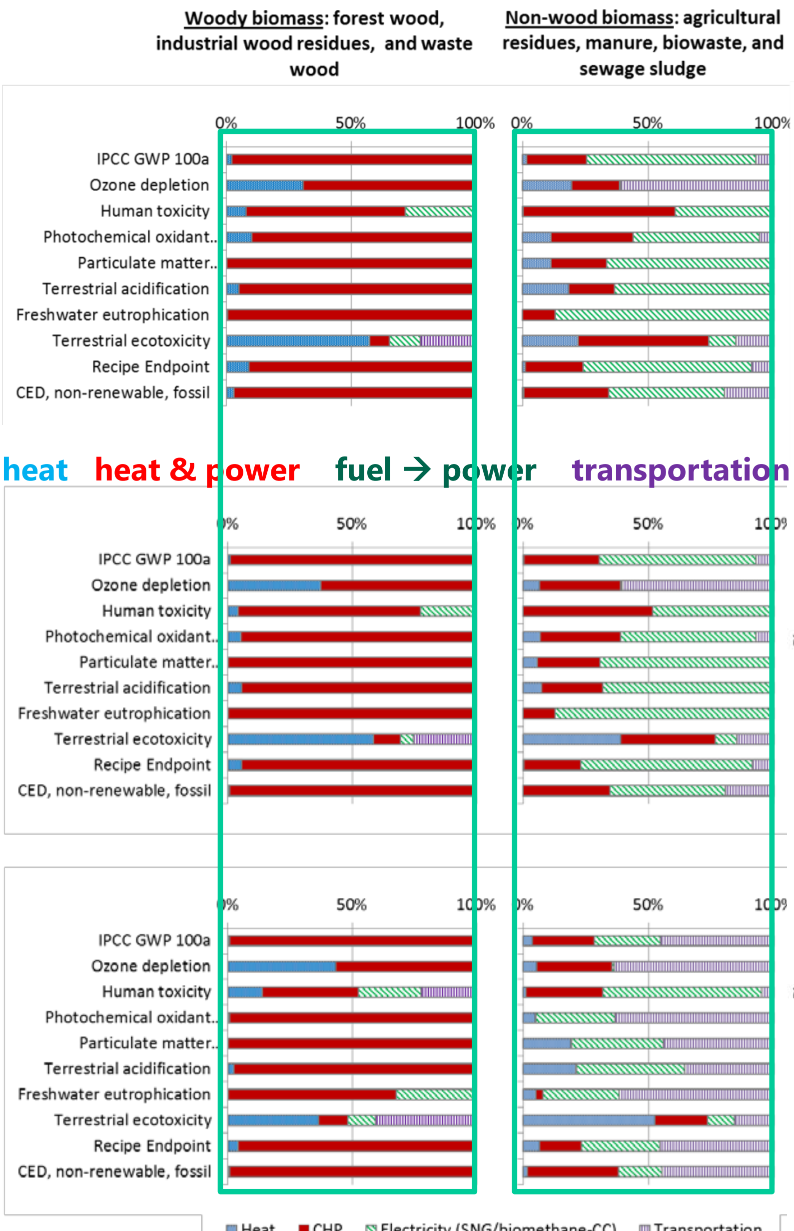
CH-case

Table 4-5: Optimal share of fossil energy services substituted according to optimization criteria

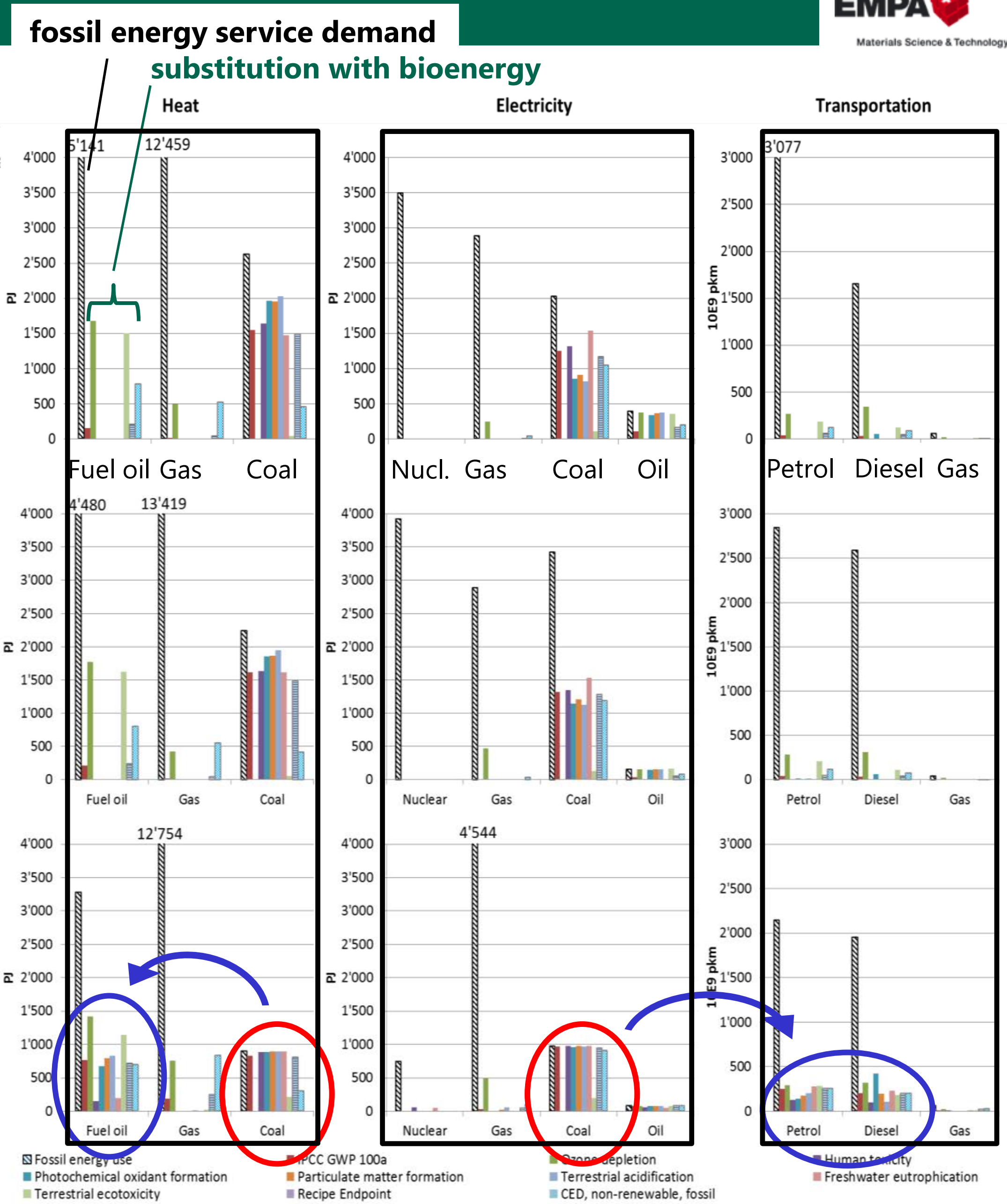
	Today (2010)			**BAU 2035**			**2000W society 2035**		
Optimization criterion	Heat	Electricity	Transp.	Heat	Electricity	Transp.	Heat	Electricity	Transp.
Heat	13%	0%	0%	16%	0%	0%	25%	0%	0%
Electricity	0%	18%	0%	0%	16%	0%	1%	22%	0%
Transportation	0%	0%	23%	0%	0%	25%	1%	0%	33%
IPCC GWP 100a	12%	2%	2%	13%	3%	3%	20%	4%	5%
Ozone depletion	10%	9%	1%	11%	8%	2%	18%	10%	4%
Human toxicity	6%	13%	0%	7%	10%	1%	9%	14%	1%
Photoch. oxidant formation	6%	3%	13%	8%	4%	11%	12%	5%	16%
Particulate matter formation	7%	9%	5%	9%	8%	4%	14%	12%	6%
Terrestrial acidification	9%	8%	2%	11%	6%	2%	16%	10%	3%
Freshwater eutrophication	7%	16%	0%	8%	11%	5%	11%	15%	7%
Terrestrial ecotoxicity	6%	3%	5%	7%	2%	5%	11%	5%	6%
Recipe Endpoint	12%	2%	2%	13%	3%	3%	20%	4%	5%
CED, non-renewable, fossil	12%	4%	2%	12%	6%	3%	18%	7%	6%

Results “EU-case”

Results (EU)

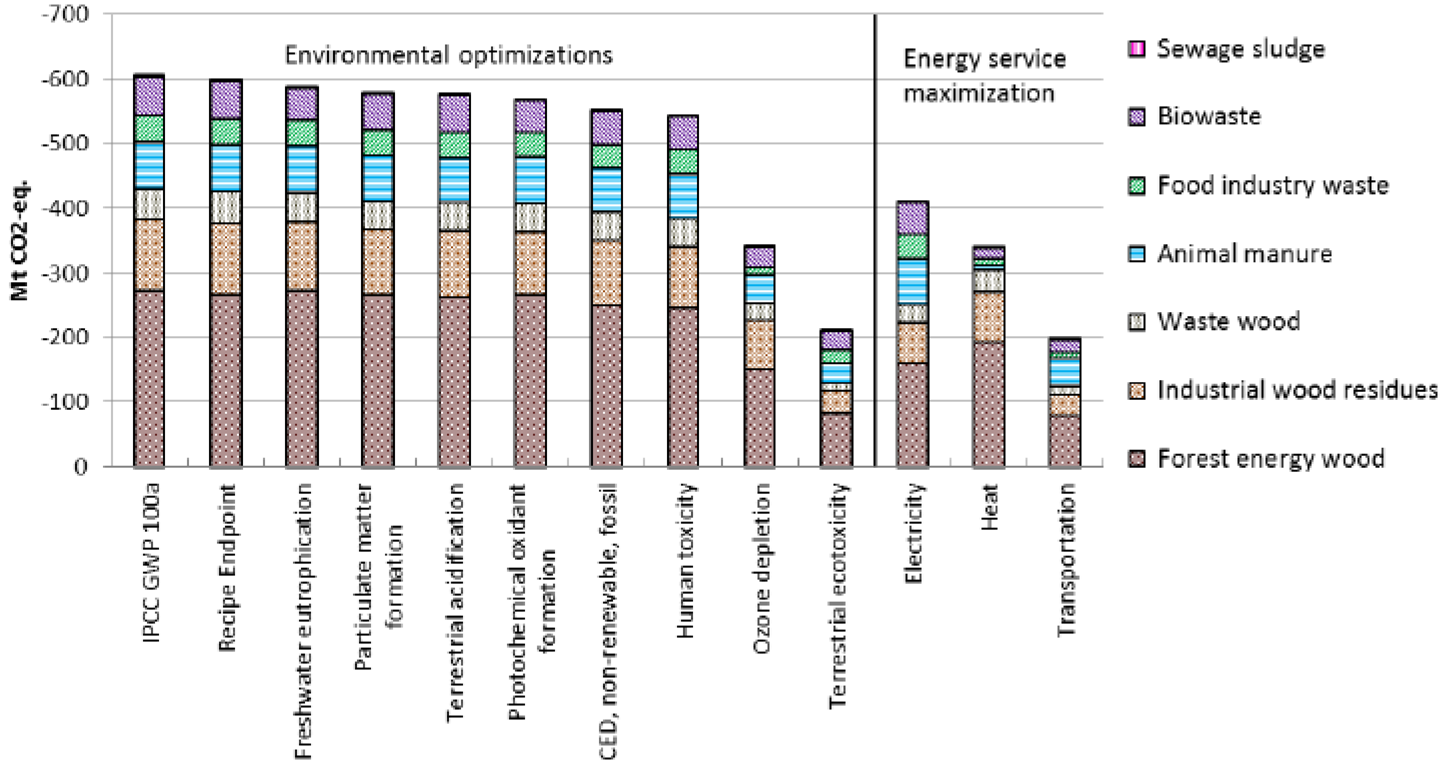


Woody biomass: forest wood, industrial wood residues, and waste wood
Non-wood biomass: agricultural residues, manure, biowaste, and sewage sludge
Today 2010
Reference 2030
Revolution 2030
0%
50%
100%
IPCC GWP 100a
Ozone depletion
Human toxicity
Photochemical oxidant..
Particulate matter..
Terrestrial acidification
Freshwater eutrophication
Terrestrial ecotoxicity
Recipe Endpoint
CED, non-renewable, fossil
heat
heat & power
fuel → power
transportation
Heat
CHP
Electricity (SNG/biomethane-CC)
Transportation



fossil energy service demand
substitution with bioenergy
Heat
Electricity
Transportation
5'141
12'459
3'077
Fuel oil
Gas
Coal
Nucl.
Oil
Petrol
Diesel
4'480
13'419
Nuclear
12'754
4'544
PJ
10E9 pkm
Fossil energy use
IPCC GWP 100a
Ozone depletion
Human toxicity
Photochemical oxidant formation
Particulate matter formation
Terrestrial acidification
Freshwater eutrophication
Terrestrial ecotoxicity
Recipe Endpoint
CED, non-renewable, fossil

GHG mitigation potential, optimization objective, and feedstock contribution



- Trade-off between objectives
- max. GHG savings of 600 Mt → 15% of EU's total emissions

EU-case

Table 5-3: Optimal share of fossil energy services substituted according to optimization criteria and scenario

Optimization criterion	Today 2010 Heat	Today 2010 Electricity	Today 2010 Transp.	Reference 2030 Heat	Reference 2030 Electricity	Reference 2030 Transp.	Revolution 2030 Heat	Revolution 2030 Electricity	Revolution 2030 Transp.
Heat	17%	0%	0%	17%	0%	0%	21%	0%	0%
Electricity	0%	19%	0%	0%	16%	0%	0%	26%	0%
Transportation	0%	0%	40%	0%	0%	34%	0%	0%	45%
IPCC GWP 100a	8%	16%	2%	9%	13%	1%	11%	17%	11%
Ozone depletion	11%	7%	13%	11%	6%	11%	13%	9%	15%
Human toxicity	8%	15%	0%	8%	13%	0%	6%	17%	6%
Photoch. oxidant formation	10%	14%	1%	9%	12%	1%	9%	16%	14%
Particulate matter formation	10%	15%	0%	9%	13%	0%	10%	17%	9%
Terrestrial acidification	10%	14%	0%	10%	12%	0%	10%	18%	8%
Freshwater eutrophication	7%	18%	0%	8%	15%	0%	6%	17%	13%
Terrestrial ecotoxicity	8%	5%	7%	8%	3%	6%	8%	4%	11%
Recipe Endpoint	9%	15%	2%	9%	13%	2%	10%	17%	11%
CED, non-renewable, fossil	9%	14%	5%	9%	13%	4%	11%	17%	11%

Uncertainty effects

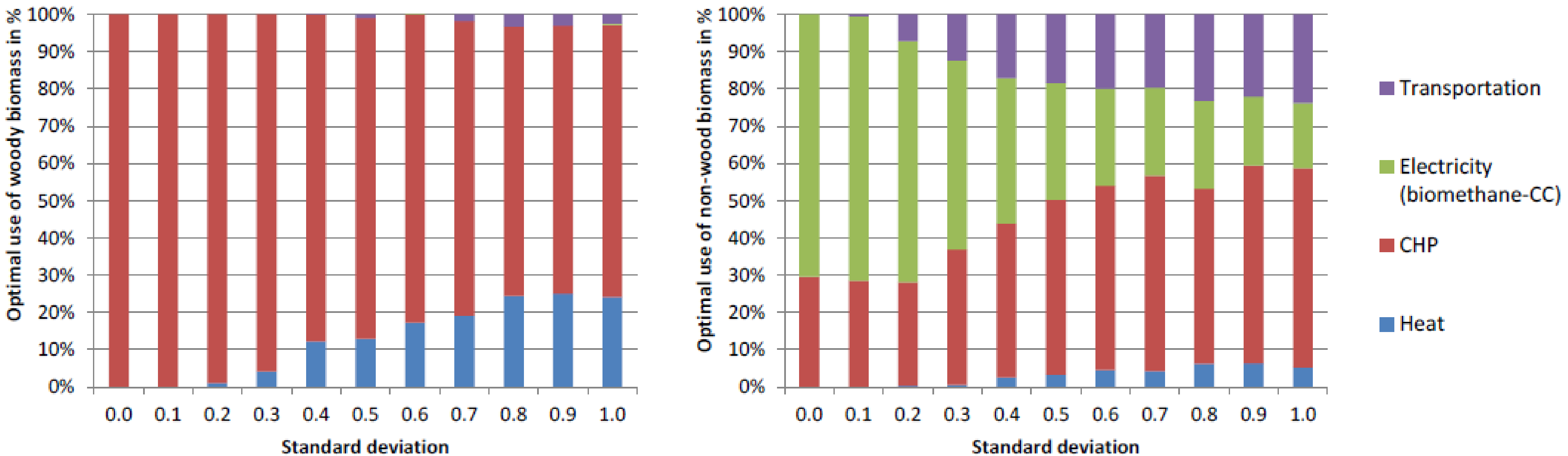


Fig. 5-5: Optimal use of woody (left) and non-woody (right) biomass for GWP IPCC 100a for heating, CHP, electricity generation, and transportation as a function of the assumed standard deviation