Techno-economic and ecological evaluation of a wood biorefinery

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Increasing use of biomass in fossil based industries

- Replacement of limited fossil raw materials
- Increasing prices for non-renewable raw materials
- Reduction of dependency on crude oil imports and securing of raw material supply
- Reduction of greenhouse gas emissions

⇒ Increase of competition for biomass and arable land through new biomass utilization concepts

⇒ Enhancement of research and development regarding new conversion technologies

Possible process steps and potential products of a wood biorefinery

Feedstock → **Precursors** → **Platform chemicals**

Feedstock		Precursors		Platform chemicals
Lignocellulosic Biomass	**Disintegration, Separation**	Cellulose Hemicellulose Lignin	**Enzymatic conversion** **Chemical conversion**	**Glucose** **Xylose** **Furfural** **Phenol-derivatives**
Wood chips Bark	Possible solvents: - Ethanol/Water - Ionic Liquids - H_2SO_4	Potential material utilisation, e.g. - Binding agents - Fillers - Polymer compounds - Pulp - Cellulose derivatives	e.g. chemical or enzymatic hydrolysis	Subsequent processing to various products, e.g. - Fuel additives - Polyethylene - PLA - Acrylic acid

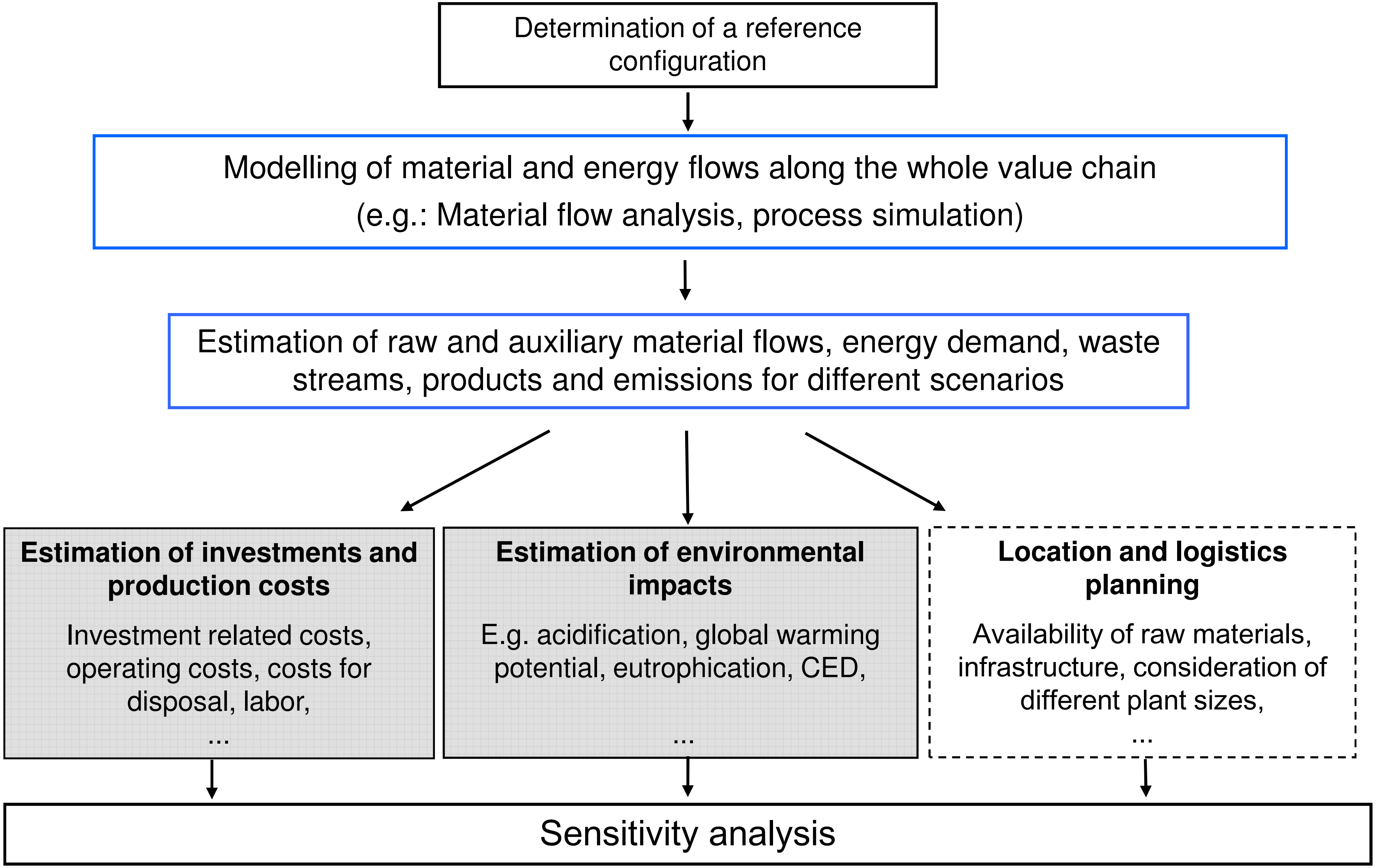
Objectives of the techno-economic and ecological evaluation

- Estimation of production costs and environmental effects of a process chain for the use of biomass at an early stage of process development

- Determination of economic and ecological key parameters and their influence on the sustainability of the process chain

- Identification of cost-effective and environmentally sound process configurations

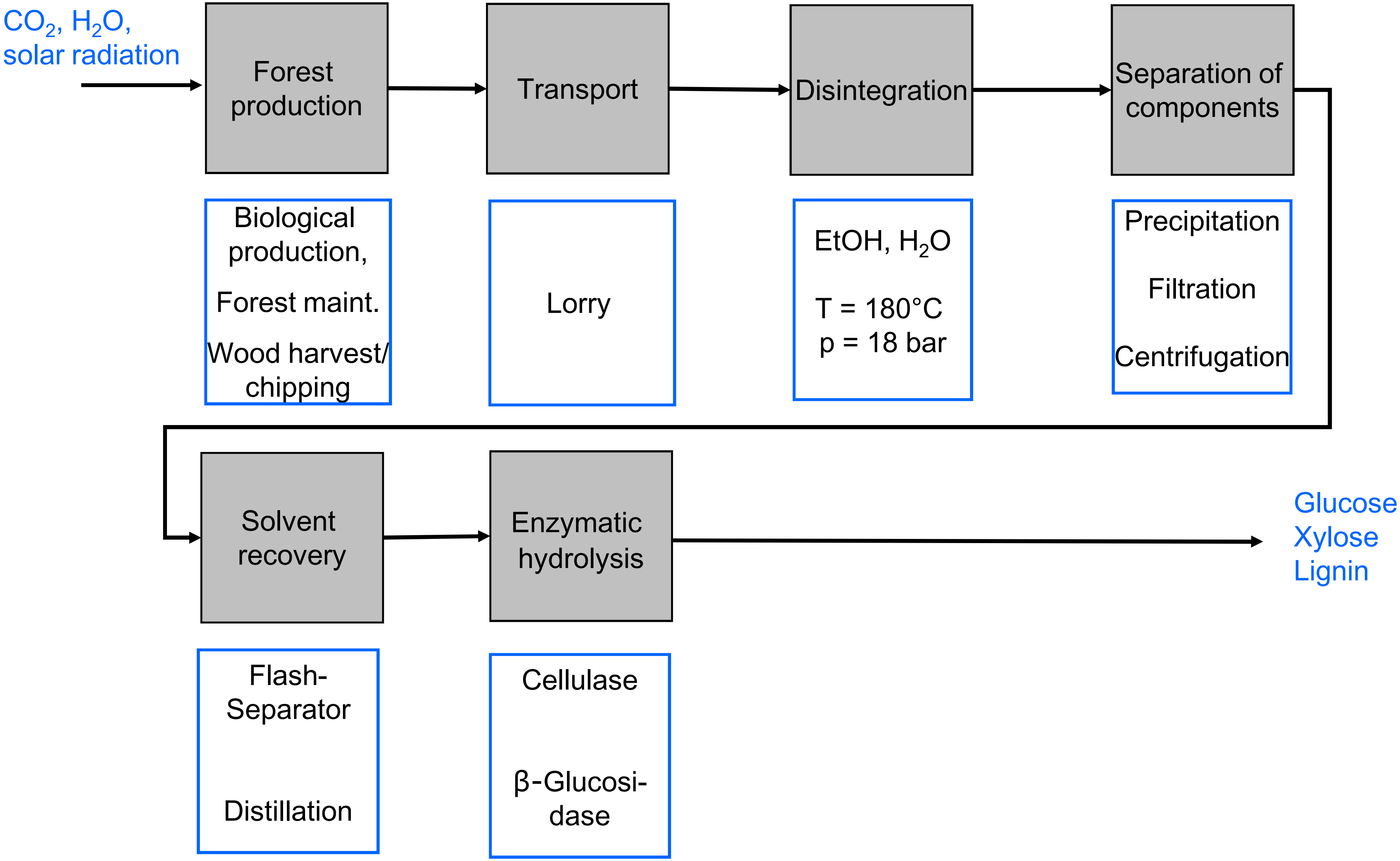
Methodology for the evaluation of process chains



Reference configuration of the modelled biorefinery

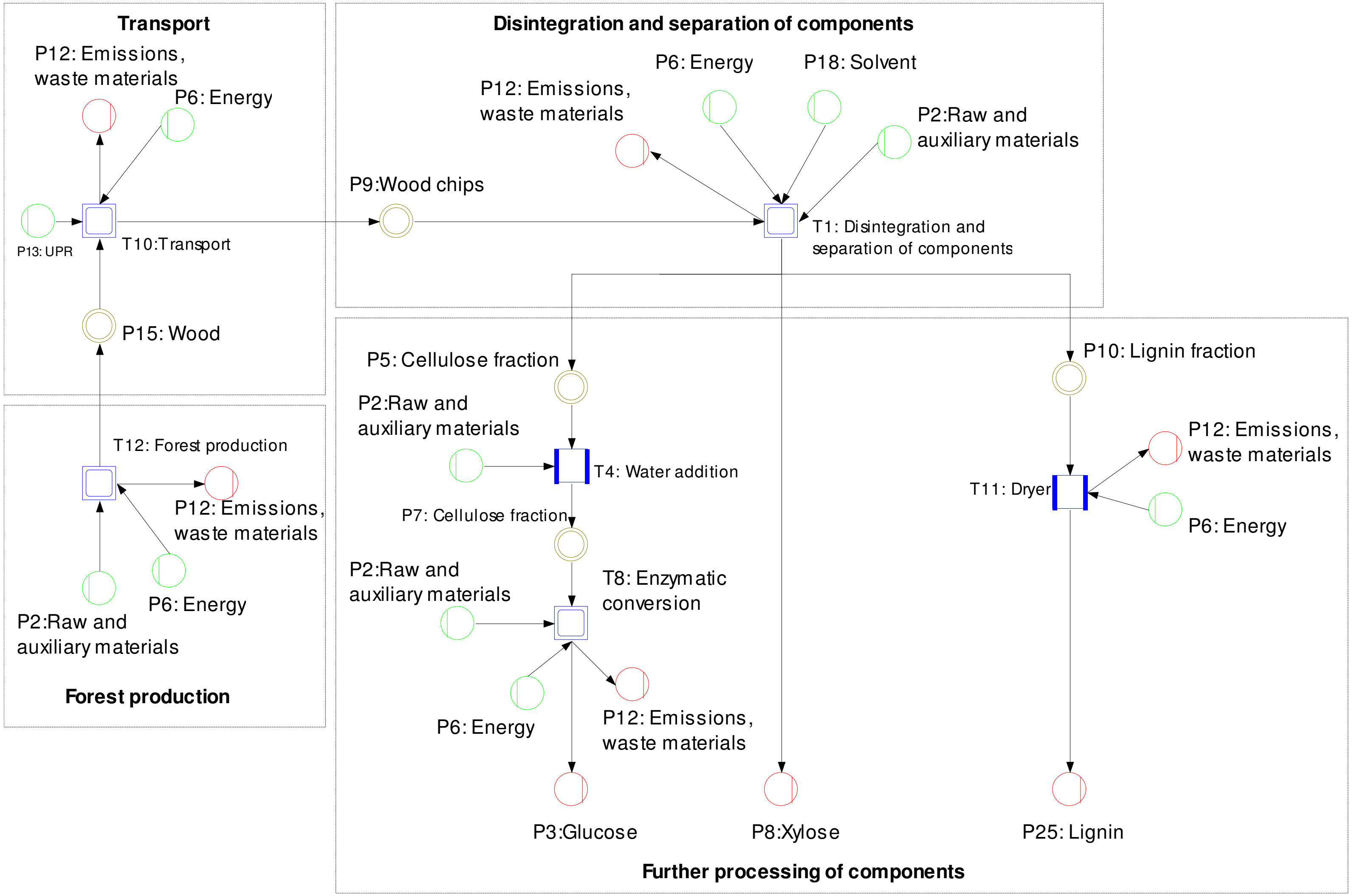
Plant capacity:	400.000 t dry wood/year
Load:	50 t dry wood/h (8000 h/year)
Feedstock properties :	Wood chips of residual wood (P100, 50% water content), 42 % cellulose, 29% hemicellulose, 24% lignin, 5% others
Organosolv pulping:	Ethanol/Water mixture (50/50) T = 180°C, p = 18bar Ratio wood : solvent = 1 : 6
Enzymatic conversion of cellulose:	Conversion rate to glucose: 82% Cellulase and beta-glucosidase enzymes
Hemicellulose fraction:	Solute hemicellulose fragments after organosolv pulping are subsumed to xylose
Final products:	Main product: Glucose (solution ~16 mass-%), Byproducts: Xylose (solution ~5 mass-%), lignin (dry)

Major process steps for the production of glucose from wood

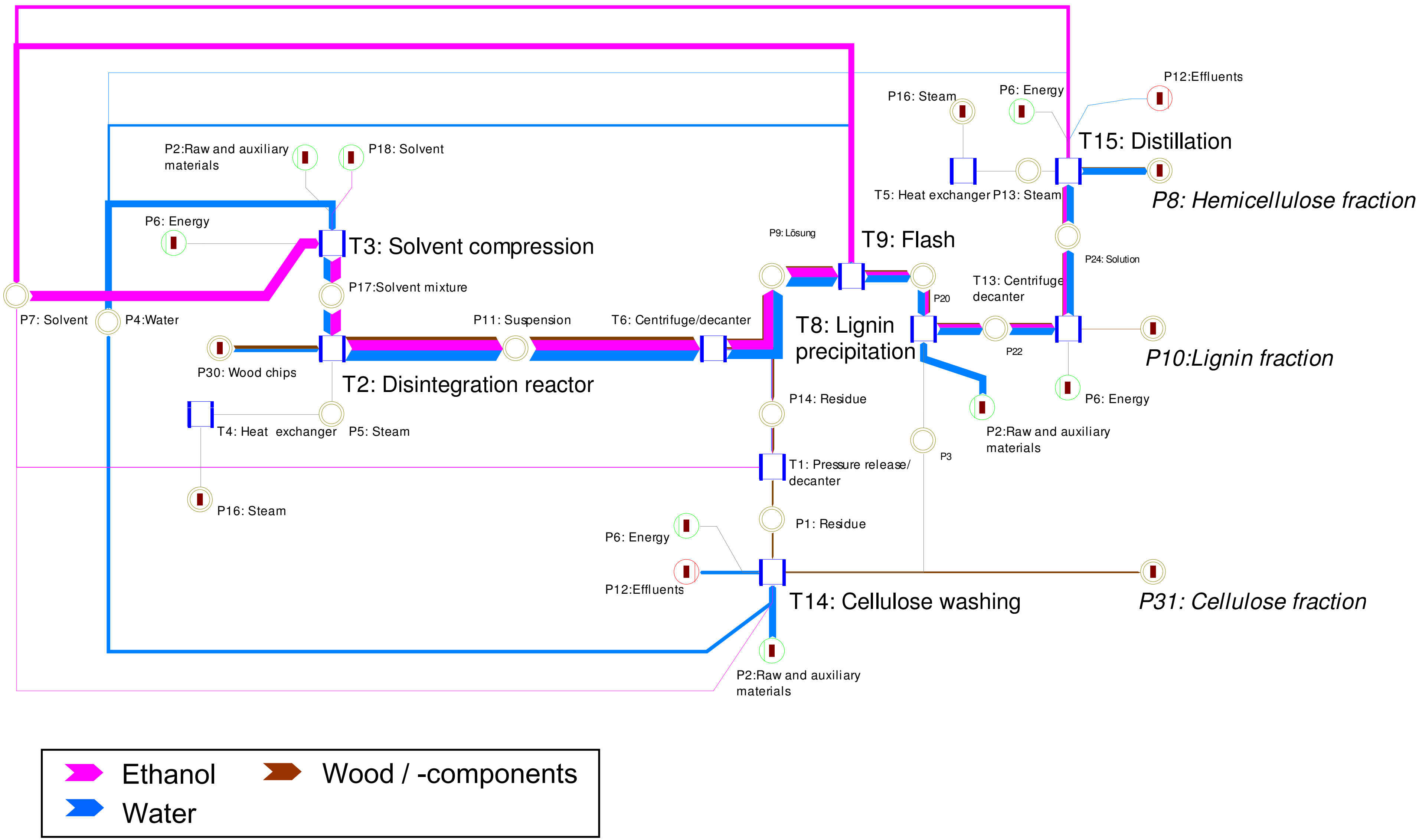


Modelling of material and energy flows along the whole value chain

- Umberto® material and energy flow network



Subnet „Disintegration and separation of components“ (Sankey Diagram)



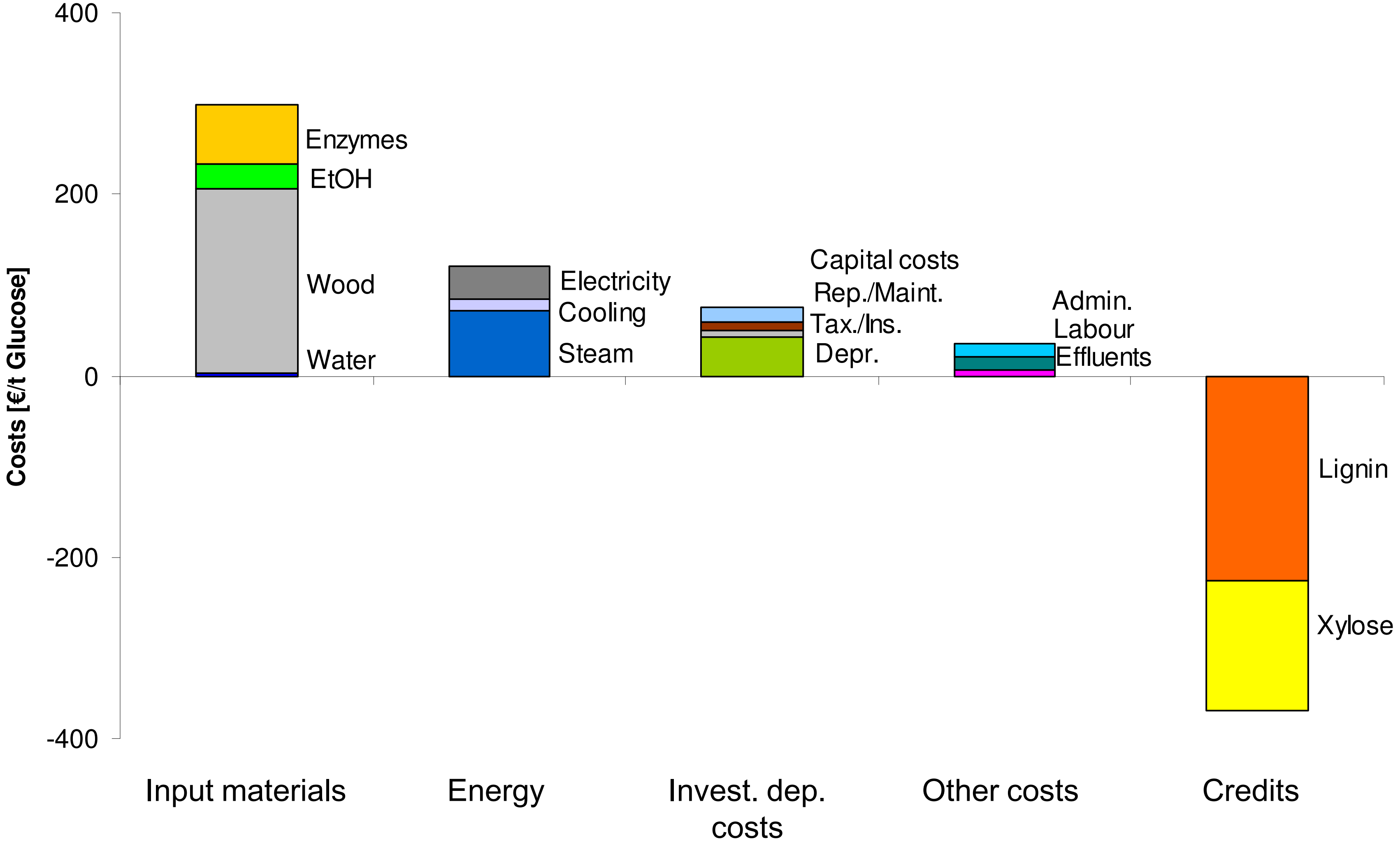
Methodology for economic analysis

- Estimation of investments:
  - +/- 30% accuracy
  - Site infrastructure completely available and useable (outside battery limits neglected)

- Determination of glucose production costs:
  - Variable costs and credits
    - Costs for raw and operating materials (wood chips, ethanol, water, enzymes)
    - Energy costs (electricity, steam, cooling)
    - Costs for sewage disposal
    - Credits for by-products (lignin as high grade product, xylose)
  - Investment related costs (depreciations, taxes and insurance, reparation and maintenance, costs of capital)
  - Labour costs

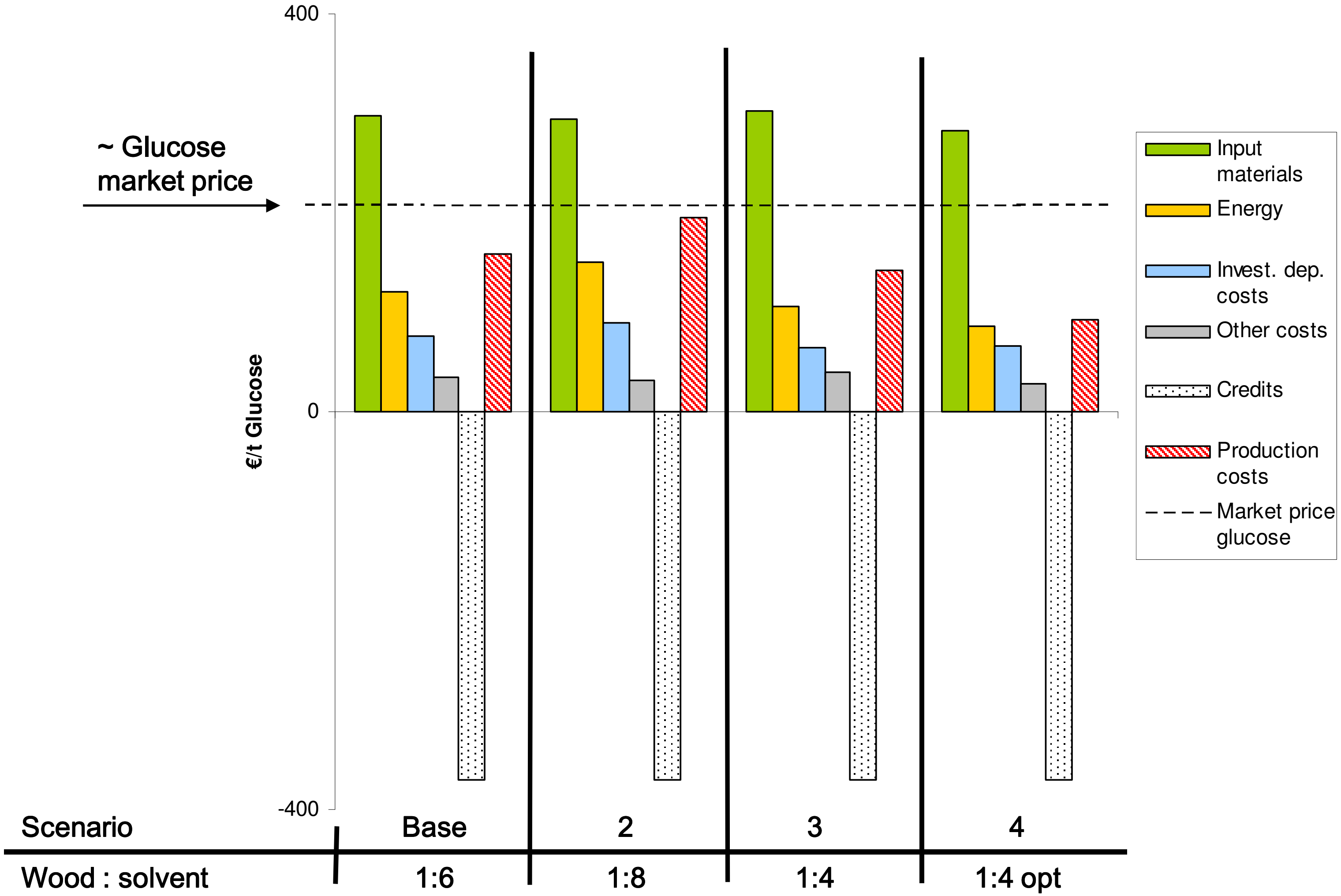
- Costs for sales, administration and research are not yet determined

Structure of costs and credits for the base scenario



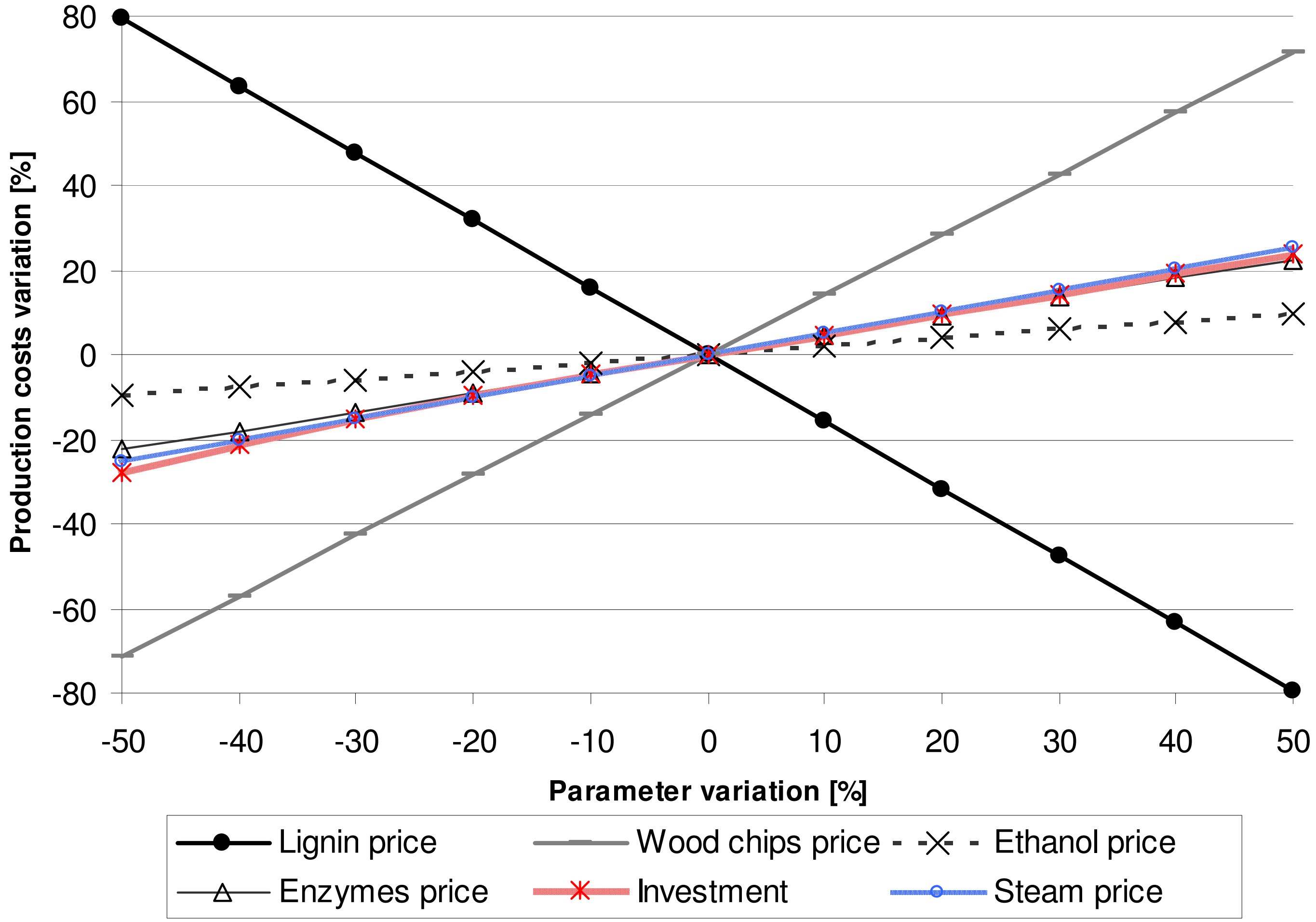
Estimation of glucose production costs for different scenarios

- Consideration of different wood : solvent ratios
- Requirement for economic efficiency: production costs << market price for glucose



Sensitivity analysis for the base scenario

- Prices for wood chips and lignin mainly influence glucose production costs

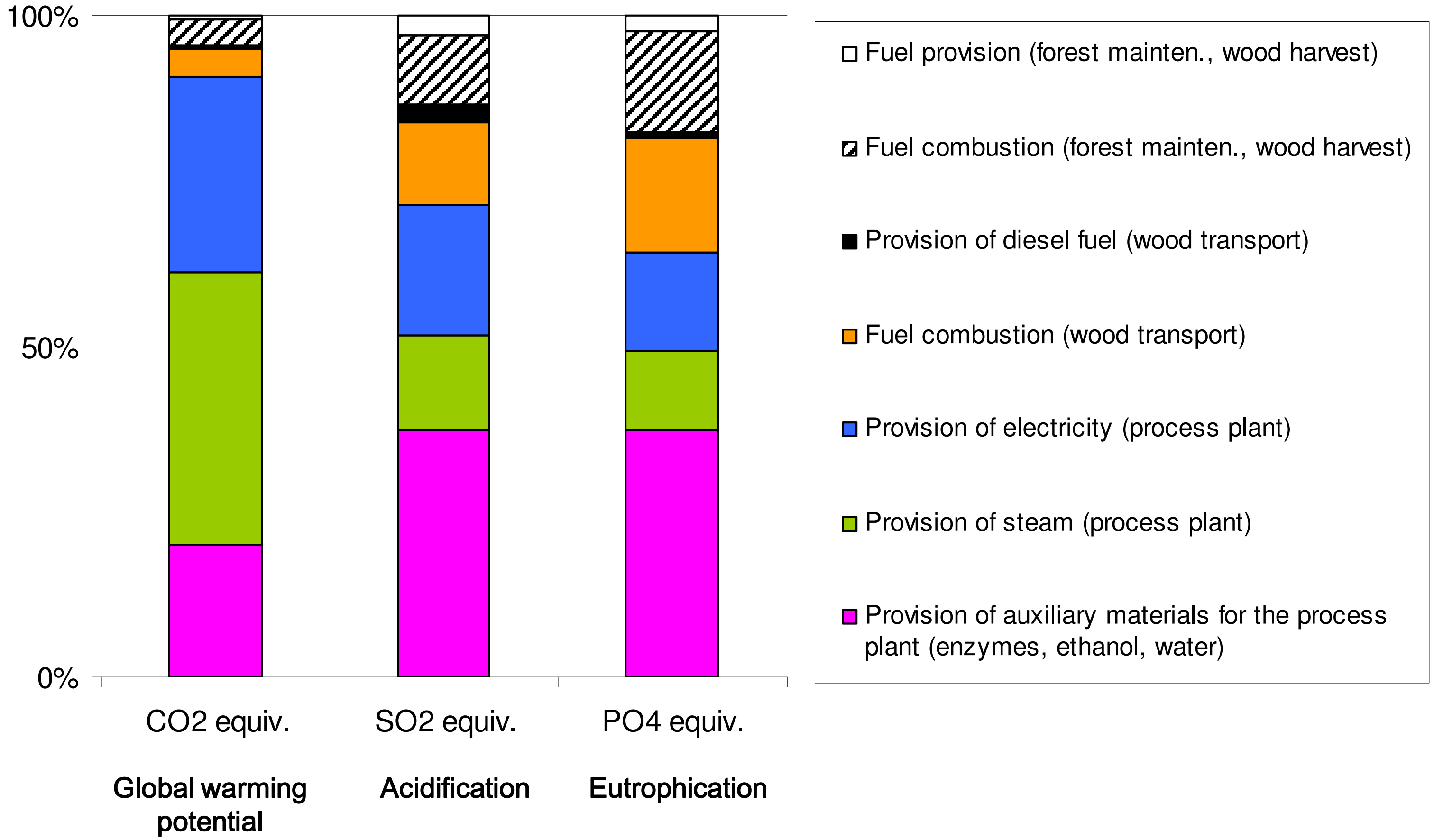


Methodology for ecological evaluation

- Methodology for life cycle assessment (LCA) according to the international standard DIN EN ISO 14040 and 14044
- Goal and scope definition and life cycle inventory analysis
  - „Cradle to gate analysis“ including forest production (wood maintenance, wood harvest/chipping), wood transport and the biorefinery processes
  - Integration of supply chains for the provision of energy and operating materials (ecoinvent v2.0 LCI database)
- Selection of impact categories, e.g. global warming potential, acidification, eutrophication
- Life cycle impact assessment (e.g. allocation of emissions to the corresponding impact categories and conversion to indicator values, e.g. CO_2 equivalents)

Ecological evaluation – Examples (1)

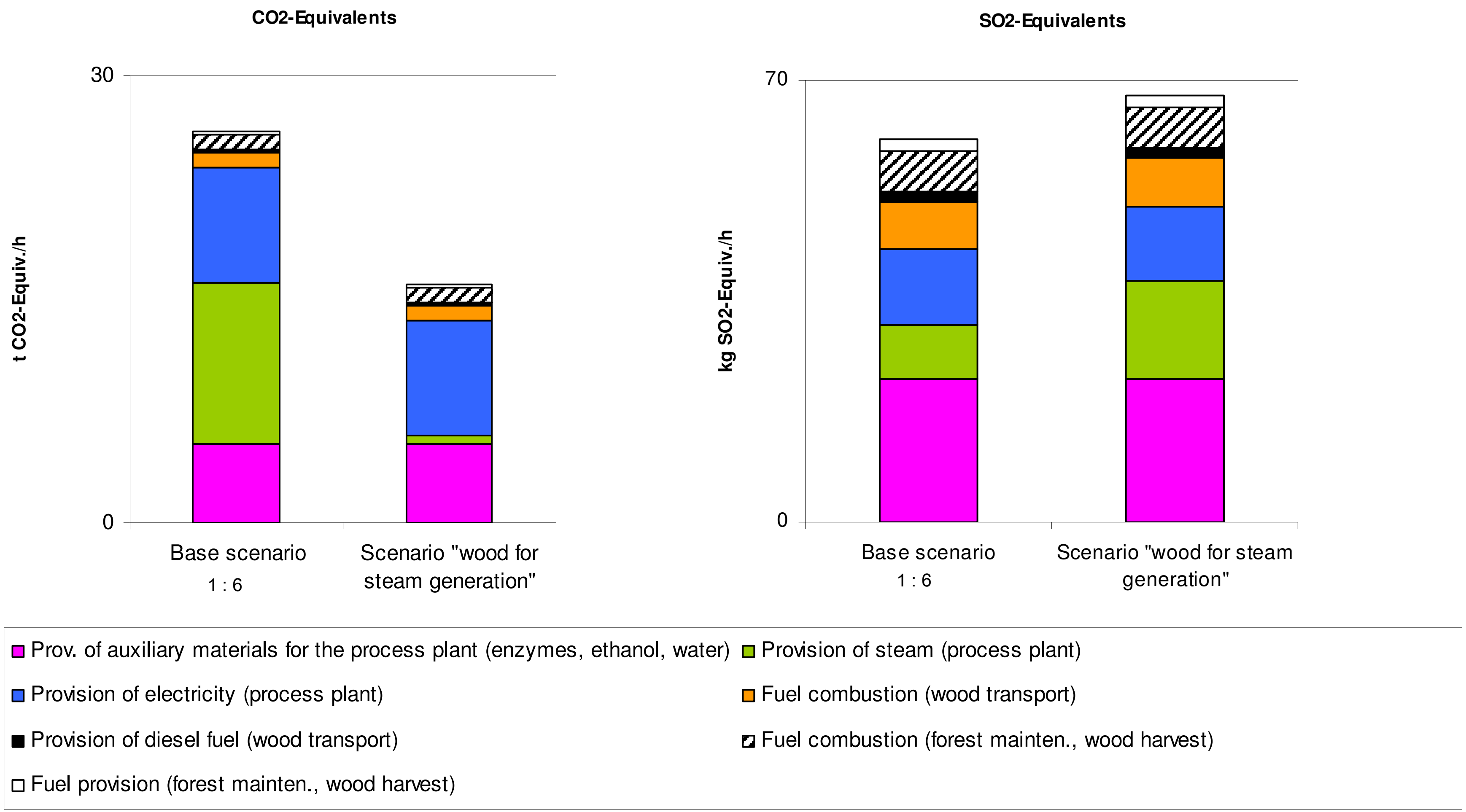
- Determination of proportions of particular process steps to the emission equivalents of selected impact categories (base scenario)



- Uncertainties for contributions caused by enzymes production especially for PO_4-Eq.

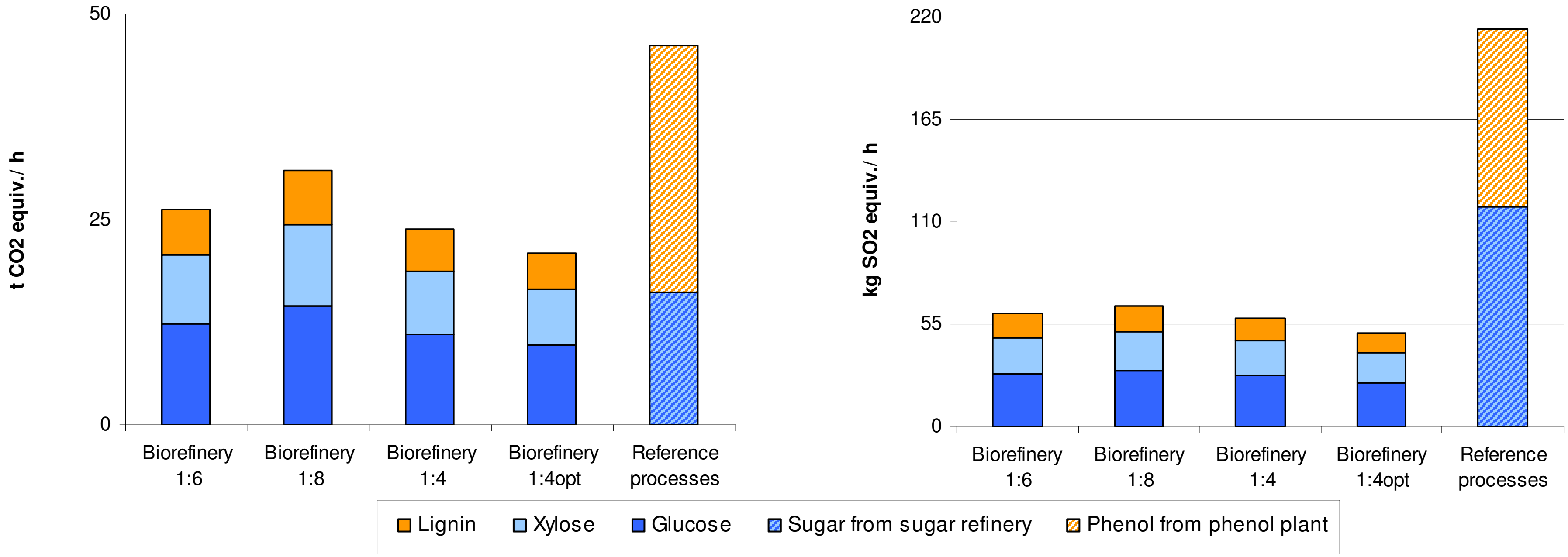
Ecological evaluation – Examples (2)

- Comparision of indicator values (CO_2- and SO_2- equivalents) for different scenarios
- Different scenarios result in different conclusions for several impact categories



Ecological evaluation – Examples (3)

- Comparison of CO_2- and SO_2- equivalents of the biorefinery with the production of potential reference products
- Assumptions:
  - Sugar from a sugar refinery as reference product for xylose and glucose
  - Phenol from a phenol plant as reference product for lignin
- Consideration of different wood : solvent ratios
- Biorefinery causes lower environmental effects compared to the reference processes[1]



[1] Values for reference processes derived from the ecoinvent v2.0 LCI database

Summary

- Development of new concepts for the non-energetic use of biomass, e.g. wood biorefineries producing platform chemicals
- Modelling of mass and energy flows of a wood biorefinery along the whole value chain for different scenarios
- Early-stage techno-economic and ecological evaluation for the identification of sustainable production processes
- Economic efficiency highly depends on prices for raw materials and the sales price for lignin
- Further improvement of process design is necessary to enhance economic efficiency
- Steam and electricity generation are crucial for the extent of GHG emissions
- Analysis of different impact categories may lead to different conclusions

Thank you for your attention!

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