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Wir schaffen Wissen – heute für morgen

Life Cycle Assessment of Options for Current and Future Electricity Supply

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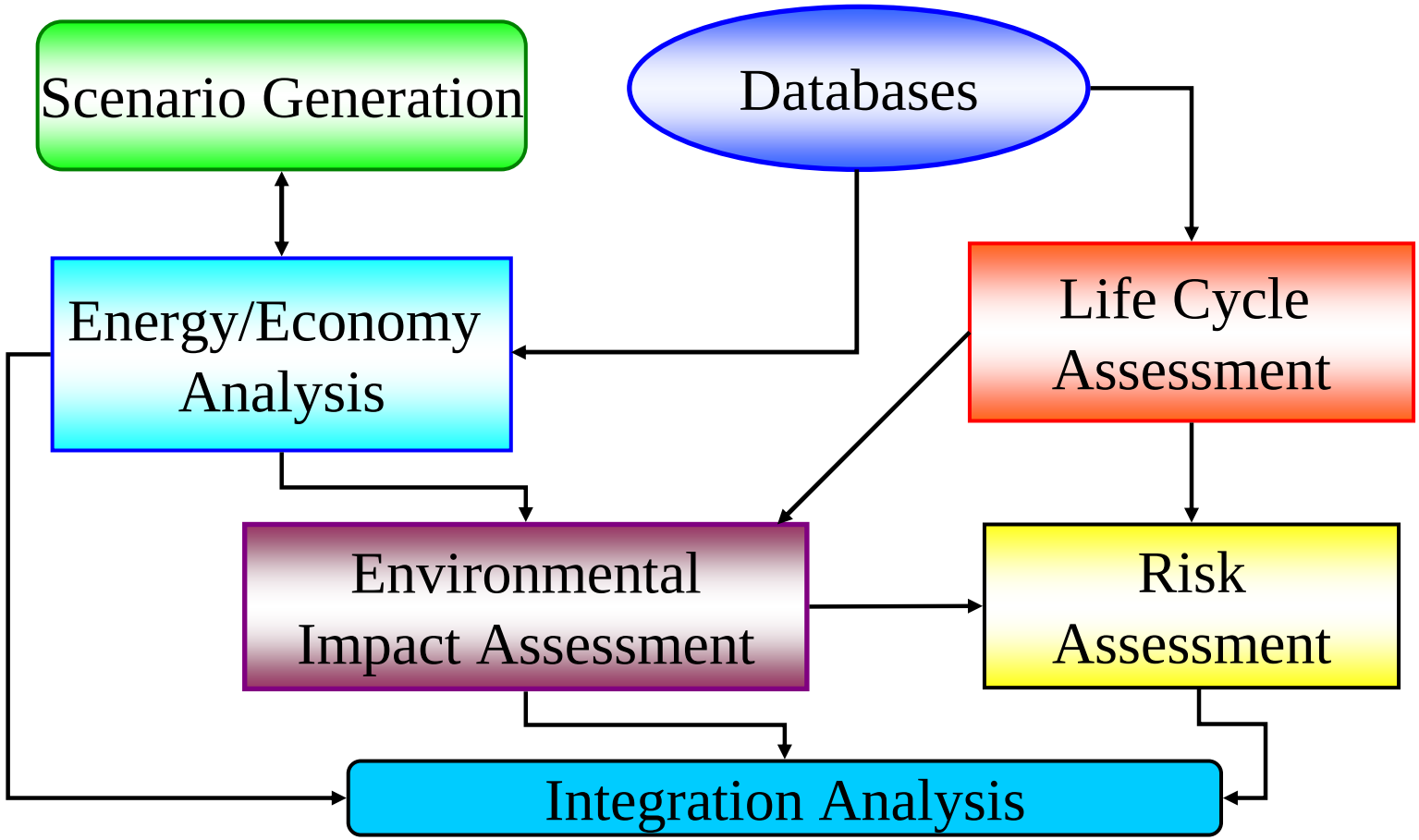
- Background LCA-database & selected LCA results
- Sustainability assessment for advanced technologies
- Conclusions

Simplified framework for Energy Systems Analysis at PSI



Motivation

Comparison of environmental burdens of different (energy) systems

Consideration of one single stage of energy systems may not be proper

Example: „Well to wheel“ comparison of two car types
a) Car with internal combustion engine, Fuel: Gasoline from oil refinery
b) Car with fuel cell engine,
Fuel: compressed Hydrogen (energy carrier) from natural gas reforming

Environmental burdens (or stressors) are various, which calls for:
aggregation into Categories, then Valuation using equivalent factors

Pros and Cons of energy systems are different:
Example: How to compare Electricity from Coal vs. Nuclear power plants?
→ **Necessity of Multicriteria Analysis**

Steps of Life Cycle Assessment (LCA)

Structure / Terminology of LCA has been defined by ISO (1996)

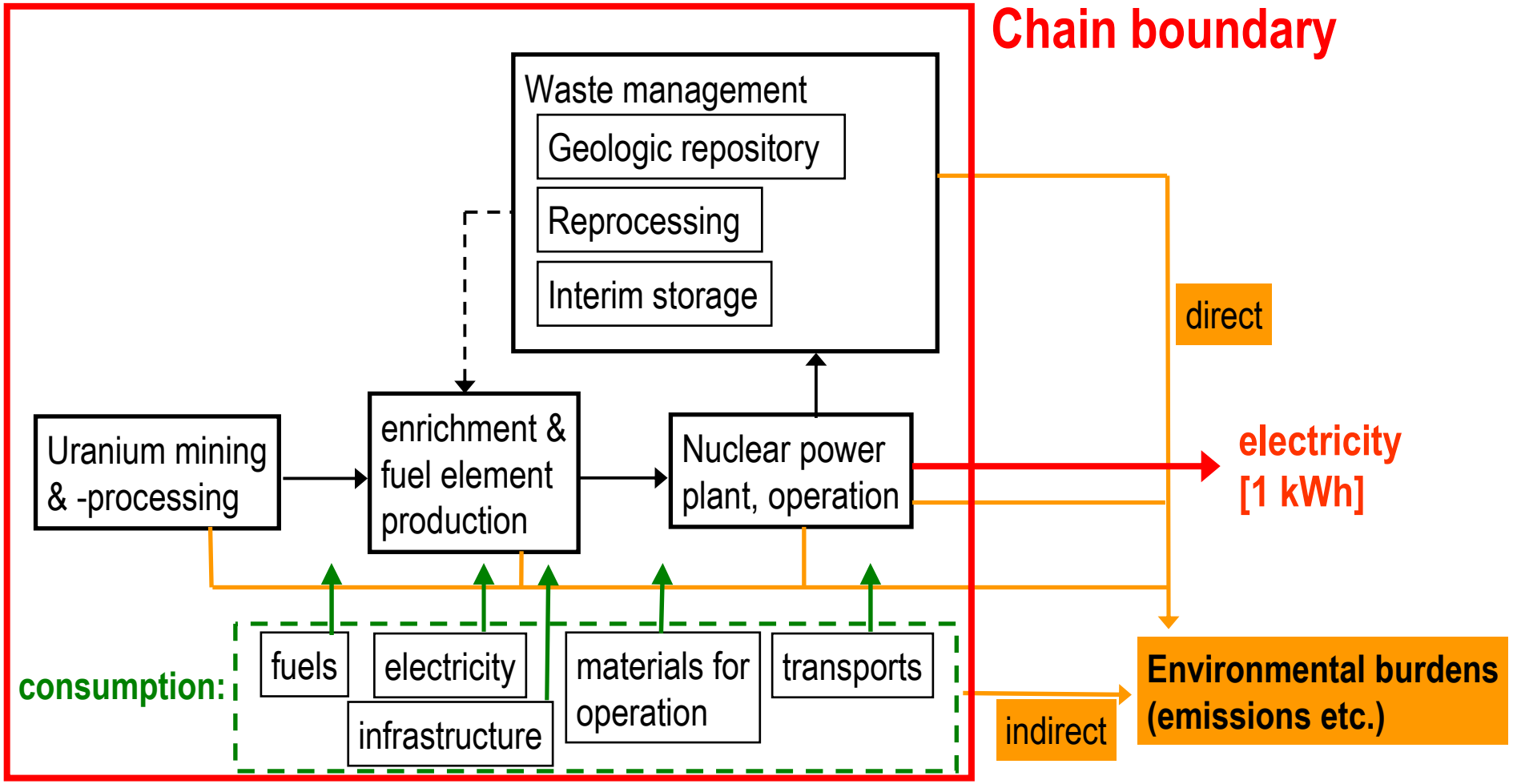
1. **Goal and Scope (system boundary definition)**

2. **Life Cycle Inventory (LCI)**
   Energy and Material Flow inventory into and out of the processes composing the system, within the defined system boundaries

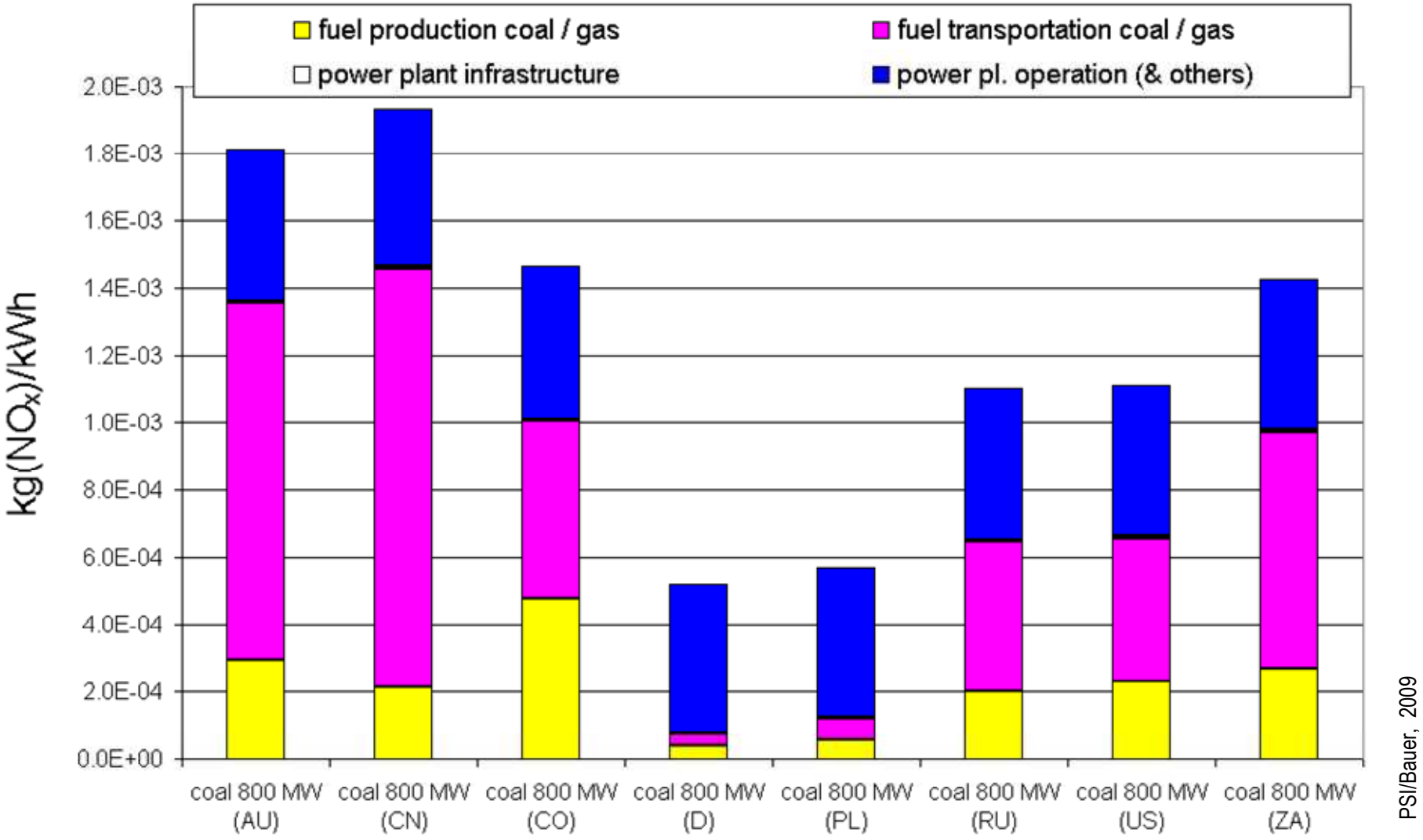
3. **Life Cycle Impact Assessment (LCIA)**
   - 3.1 Categories (environmental effects and protection targets)
   - 3.2 Classification (burdens/stressors → effects/damages)
   - 3.3 Characterization of effects (equivalent factors)
   - 3.4 Significance analysis (relevance to reference values)
   - 3.5 Evaluation (aggregation of potential environmental effects)
   - Weighting (using ethical / subjective elements)

4. **Interpretation: Sensitivity analysis, Error estimation, Conclusion**

Life Cycle Analysis - LCA (nuclear energy chain)



Hard coal chain: NO_x emissions



PSI/Bauer, 2009

Background LCA-database & selected LCA results

„Background data“: LCA Database ecoinvent

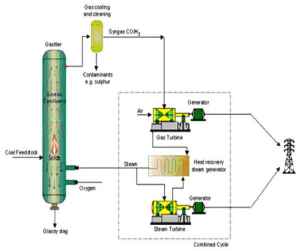
Swiss Centre For Life Cycle Inventories

- First version v1.0 developed in 2000-2003 on the basis of the 1992-1996 work *Ökoinventare von Energiesystemen* (ETHZ + PSI)
- Web-based; commercial; version v2.2 available on-line: *www.ecoinvent.ch (ecoinvent Centre,* supported by Institutes of the ETH Domain*)*
- ~4200 processes; besides energy (nearly 1700, PSI responsible), other sectors: construction materials, metals, chemicals, transport, agriculture → background DB.
- Swiss, European, and selected non-European country-specific average conditions and selected best power plant technologies (years 2000 and/or 2004/5).
- About 1000 individual „environmental flows“ accounted for:
  - pollutants to air, water & groundwater, soil;
  - energy and non-energy resource uses;
  - land use classes

Power generation: Technology portfolio

Nuclear

Coal

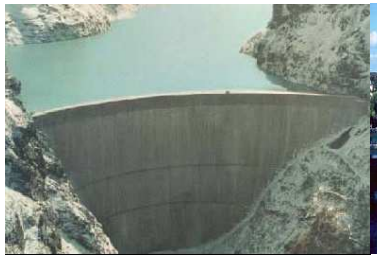


Natural gas

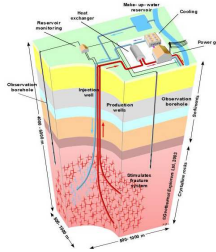
Fuel Cells

SNG

Hydro



Geothermal

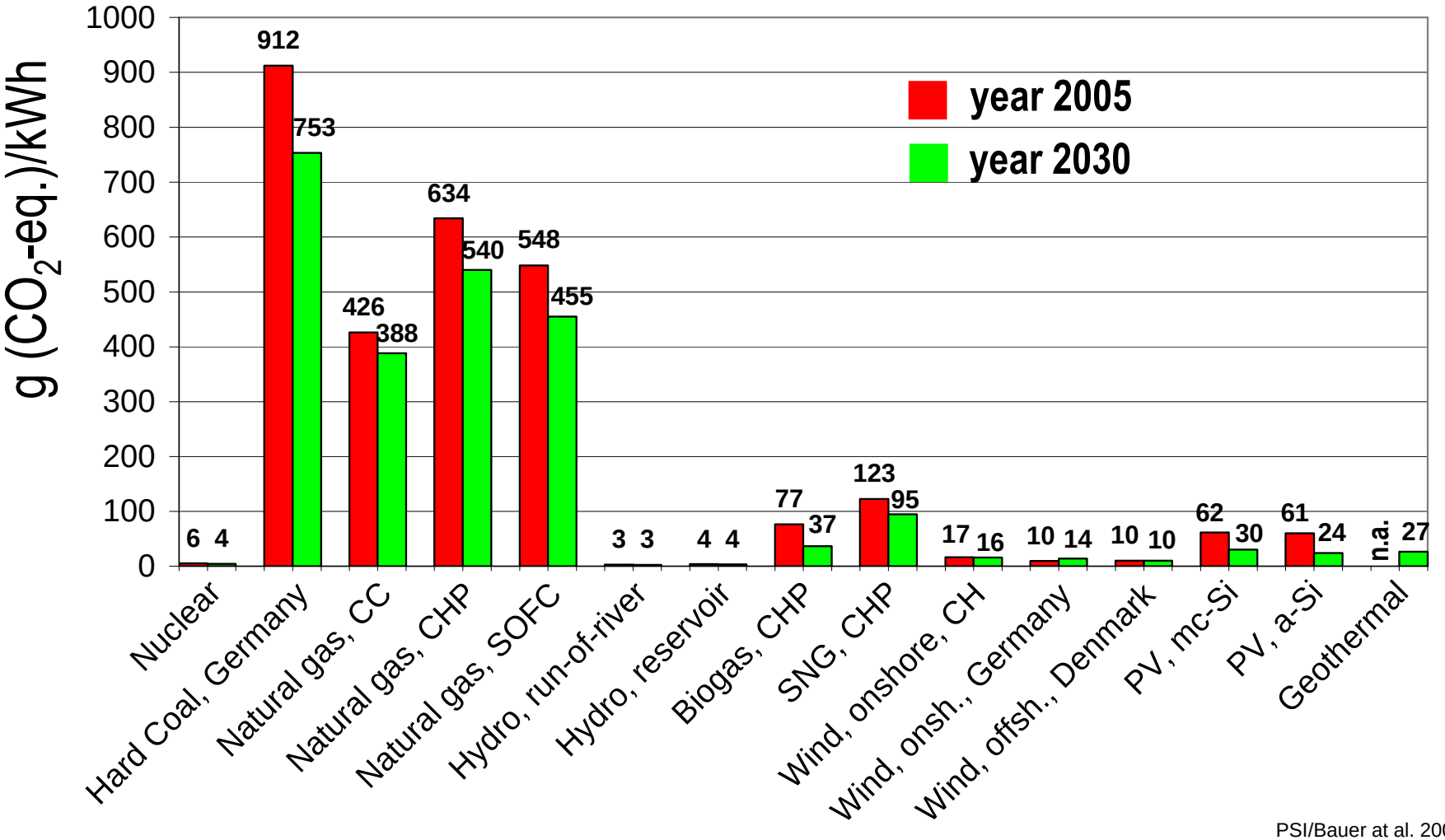


Wind

Biogas

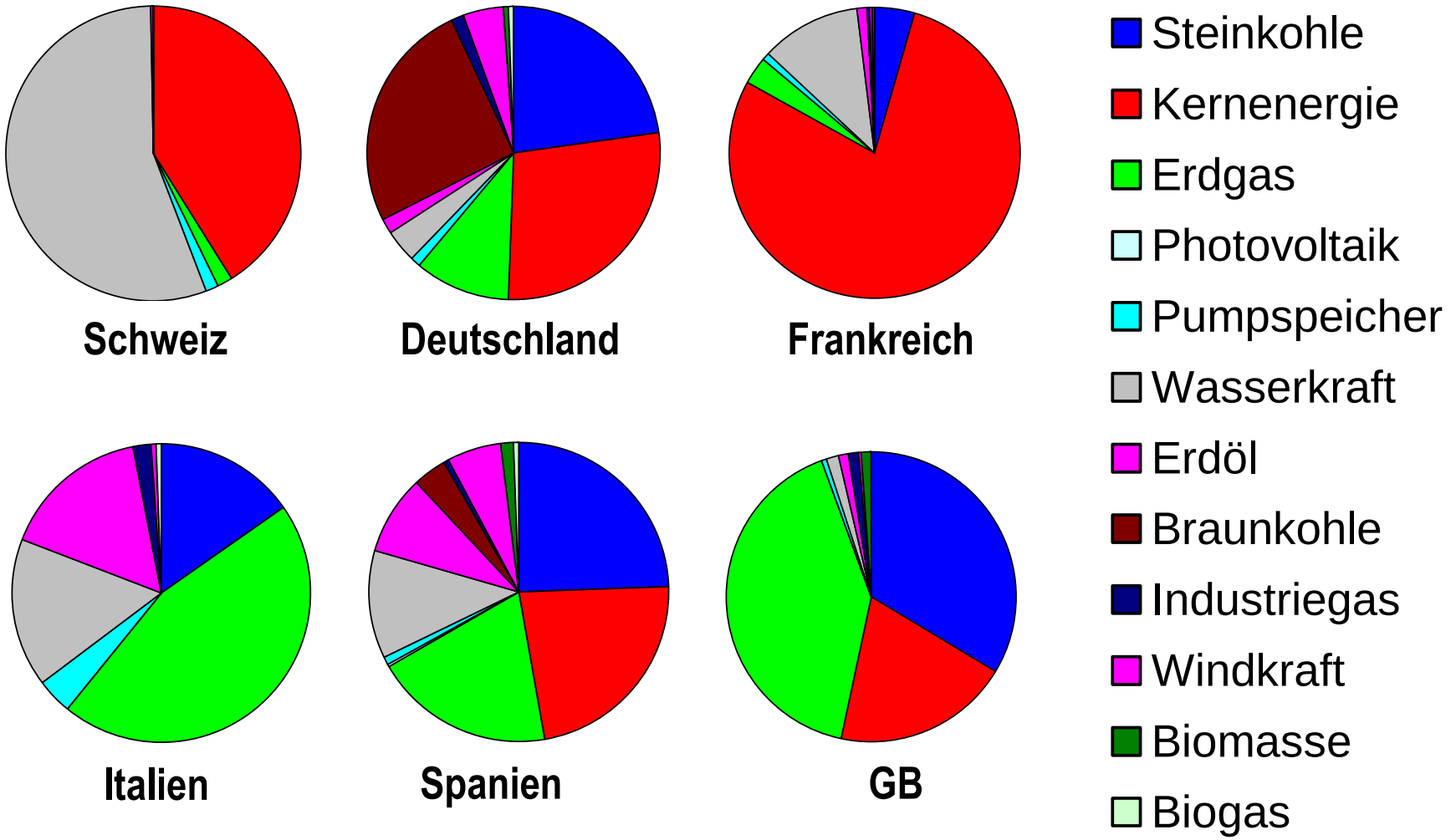
PV

LCA results: Greenhouse gas emissions



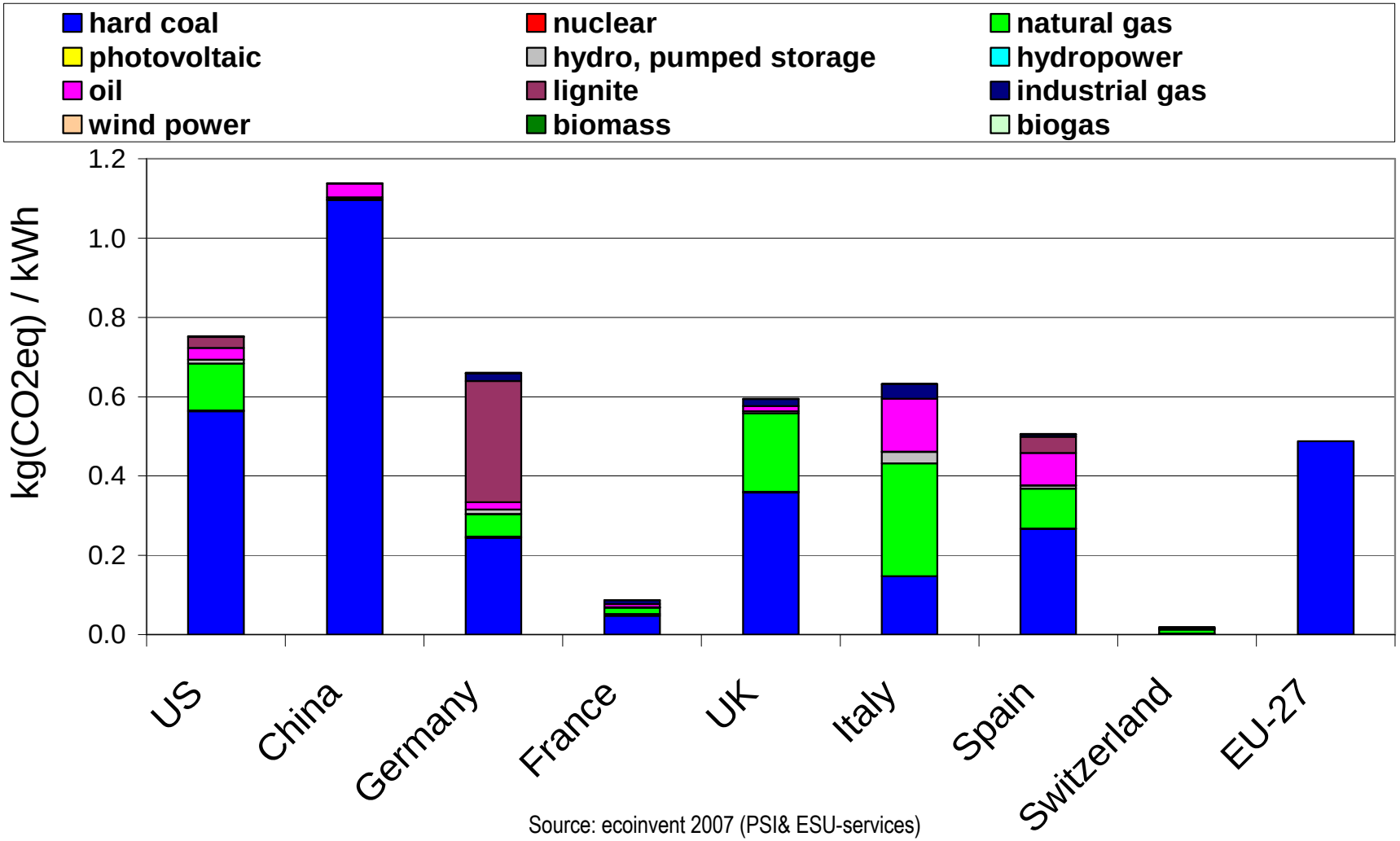
PSI/Bauer at al. 2008

EU Strommixe, Anteile Energieträger (Produktion 2004)



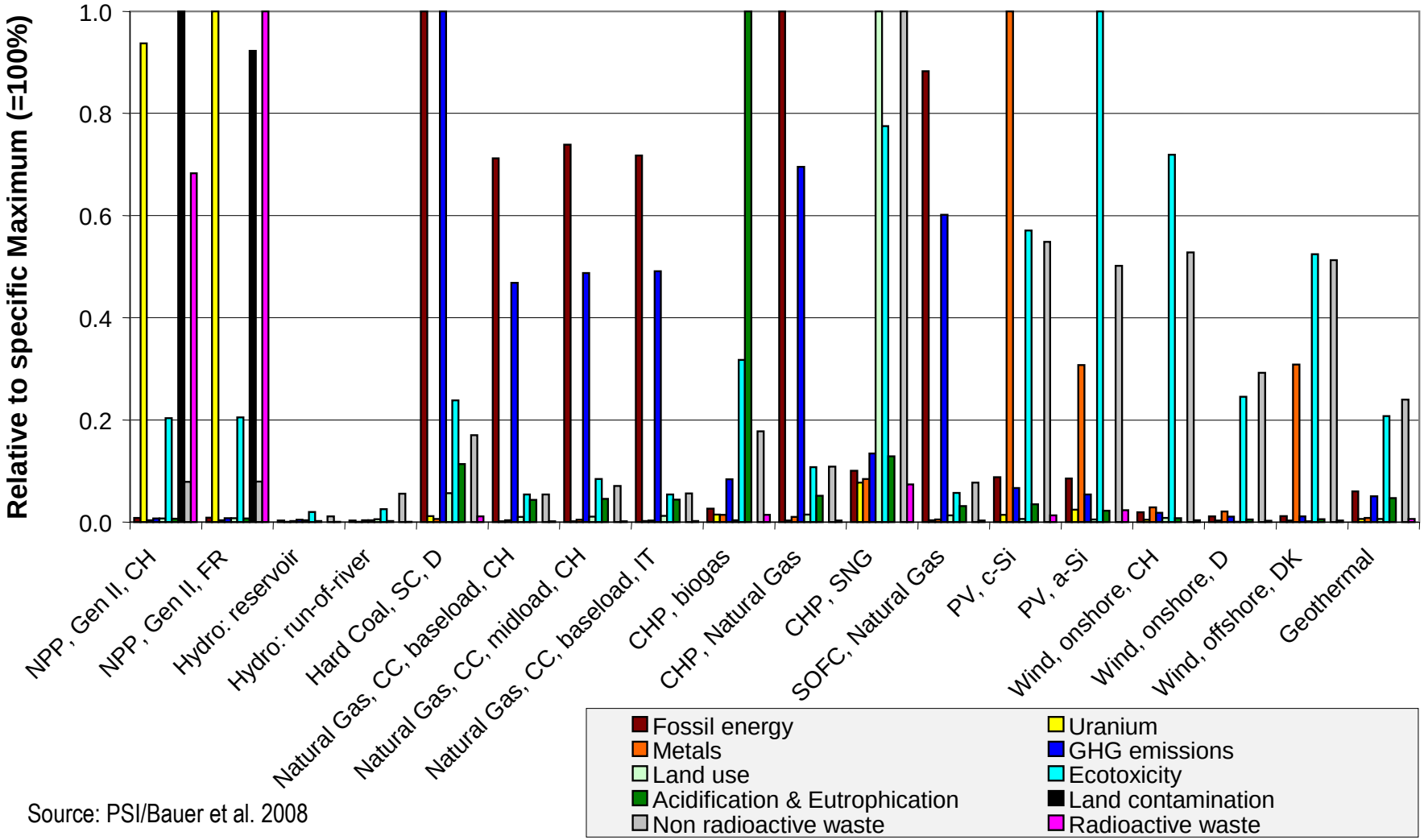
Quelle: ecoinvent, 2008

LCA-based GHG emissions, electricity production mixes



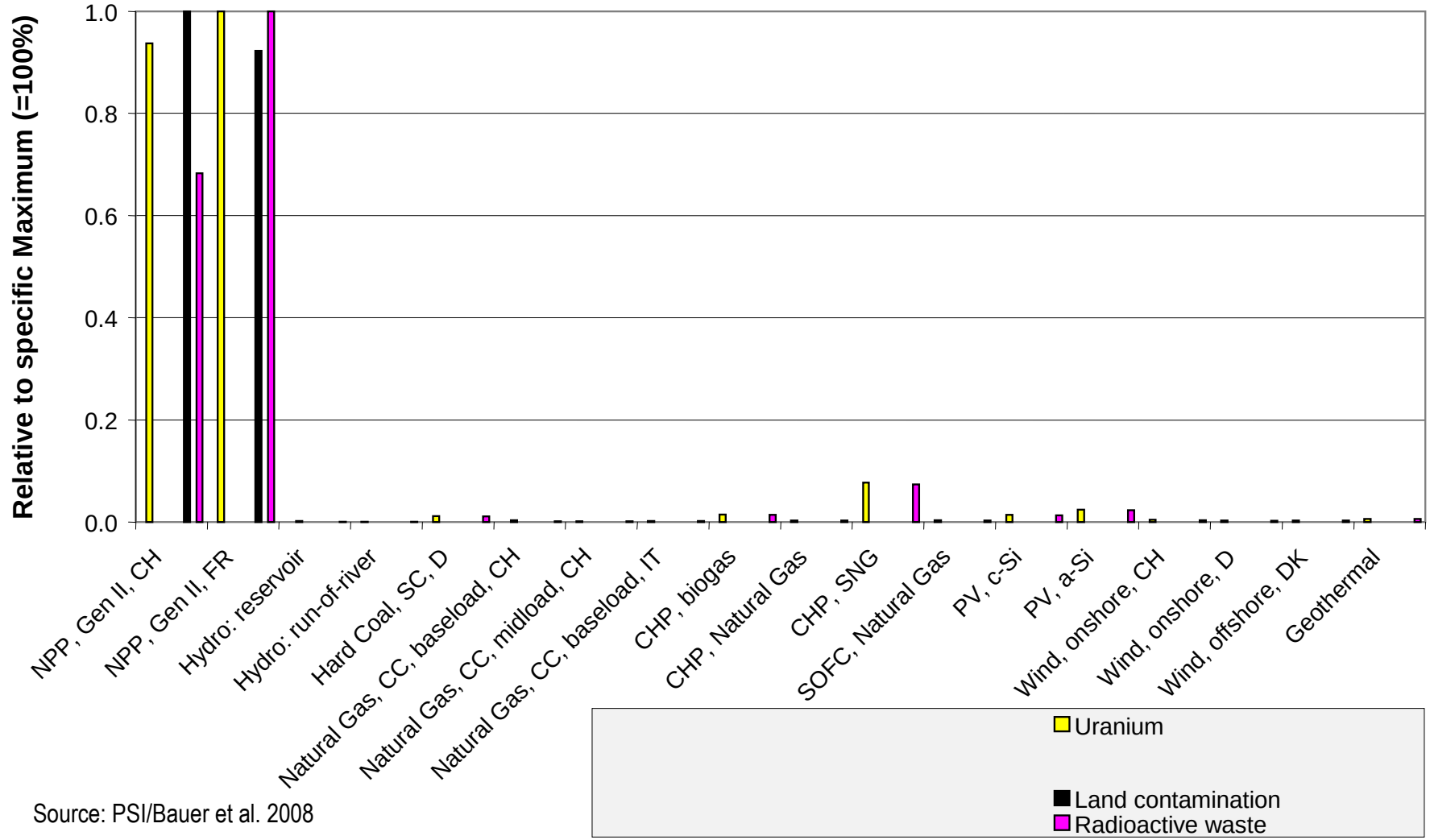
Source: ecoinvent 2007 (PSI& ESU-services)

Environmental Indicators, 2005



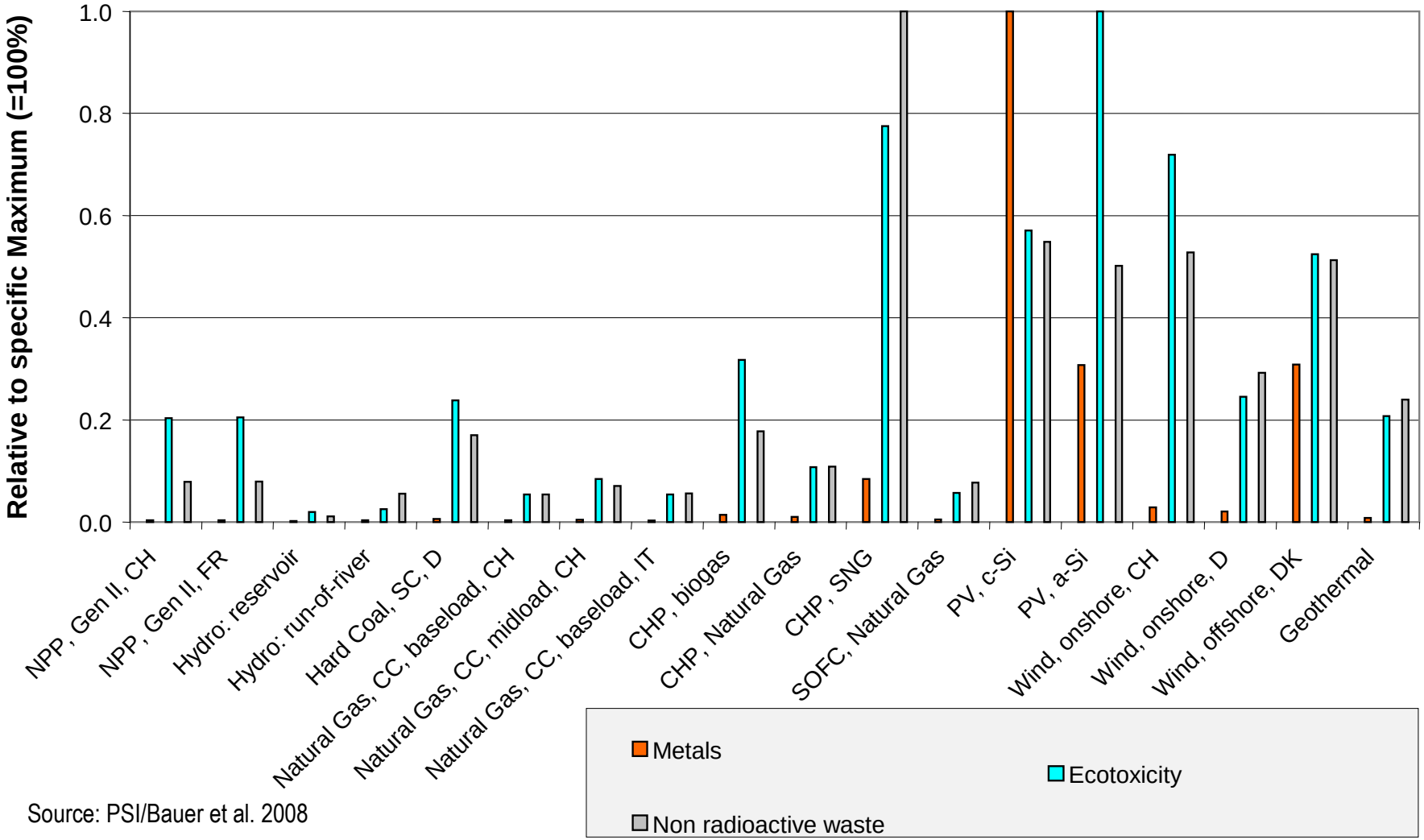
Source: PSI/Bauer et al. 2008

Environmental Indicators, 2005



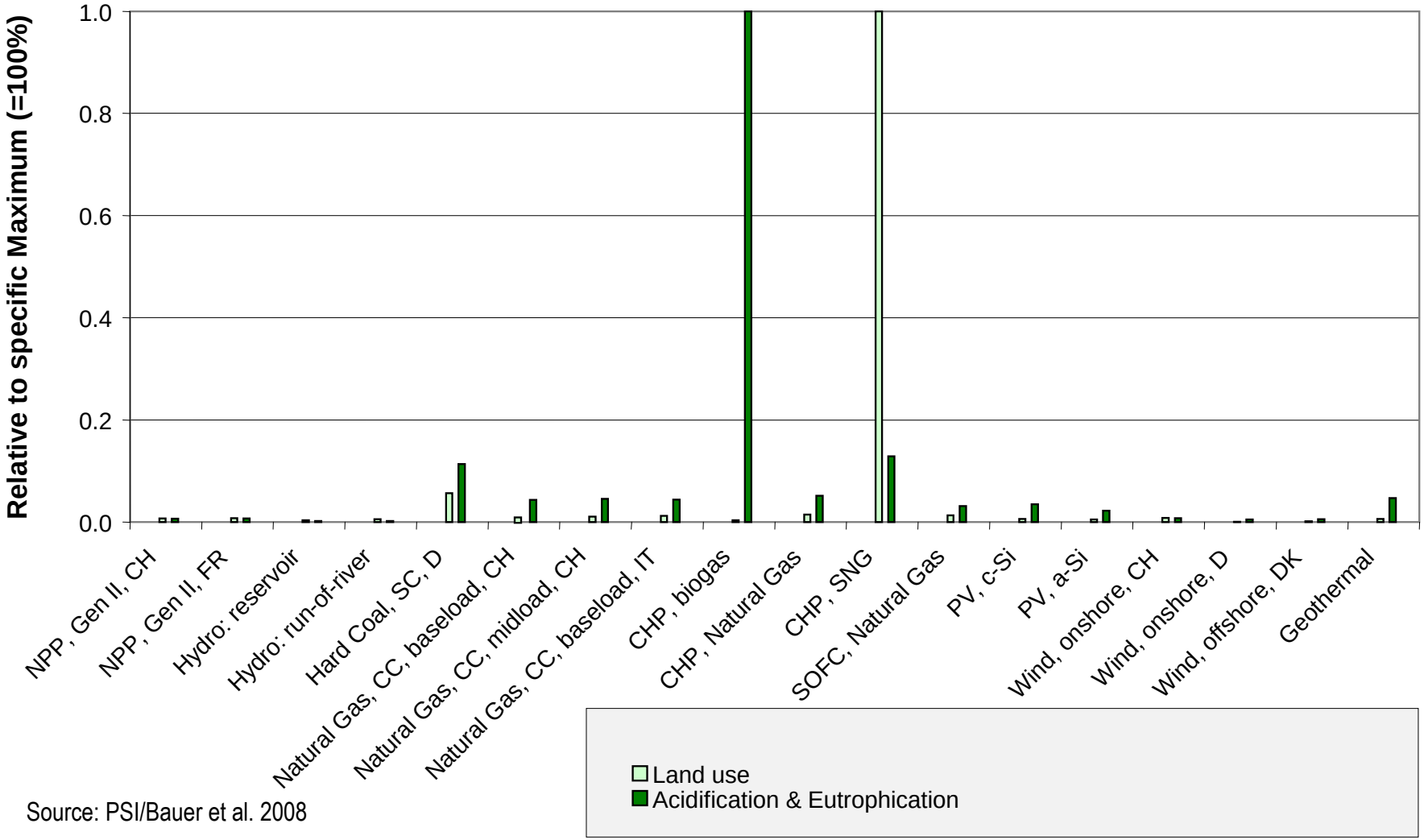
Source: PSI/Bauer et al. 2008

Environmental Indicators, 2005



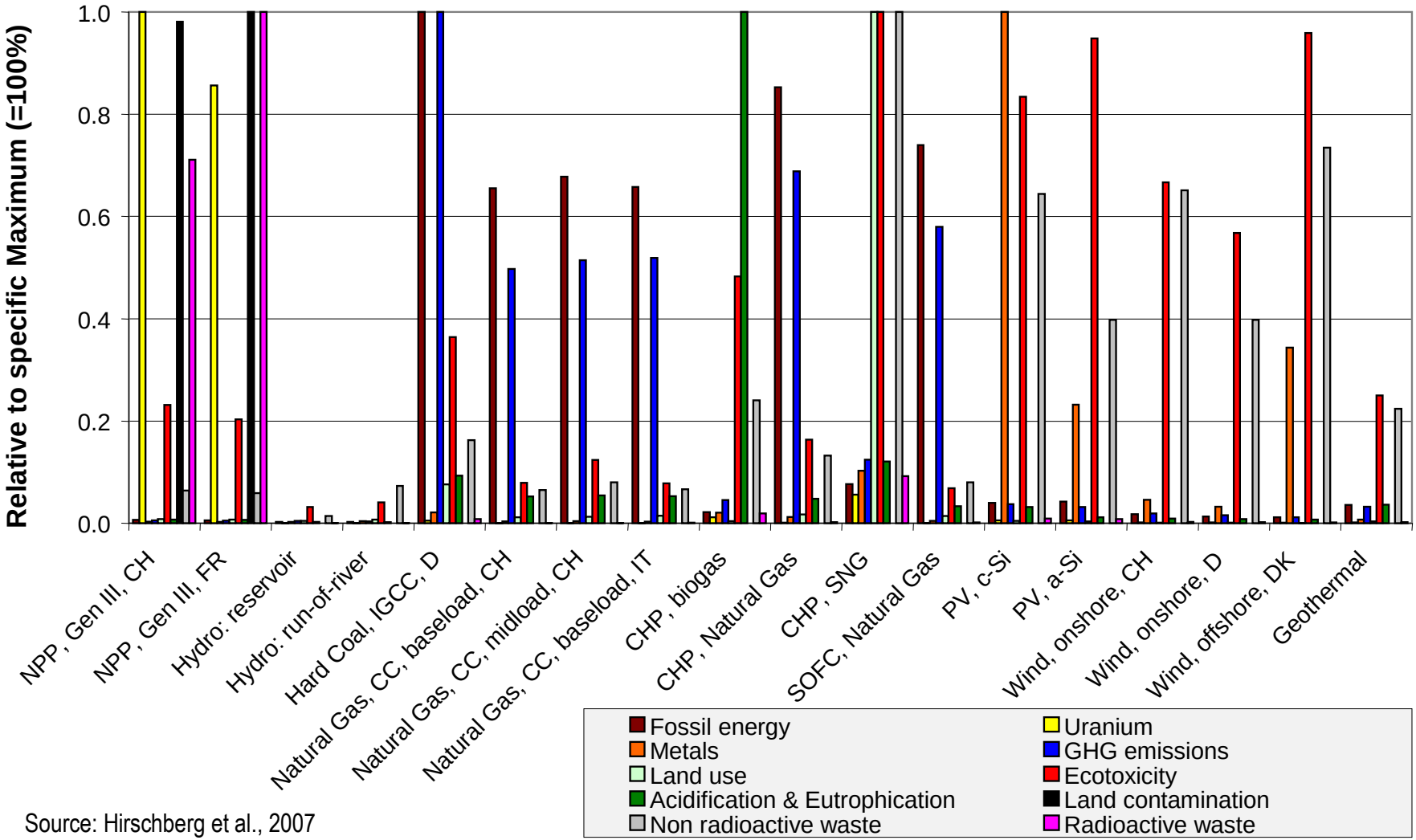
Source: PSI/Bauer et al. 2008

Environmental Indicators, 2005



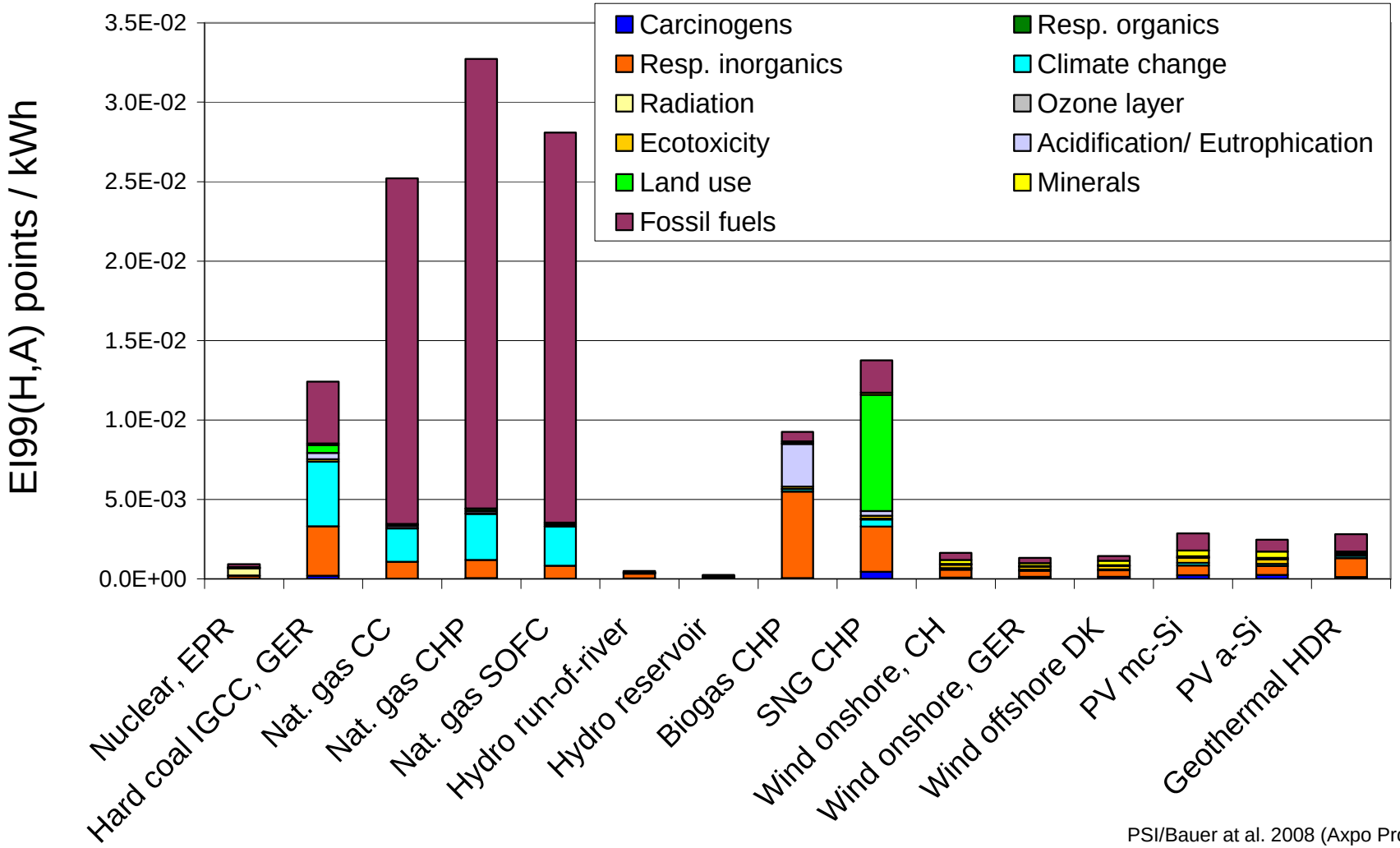
Source: PSI/Bauer et al. 2008

Environmental Indicators, 2030



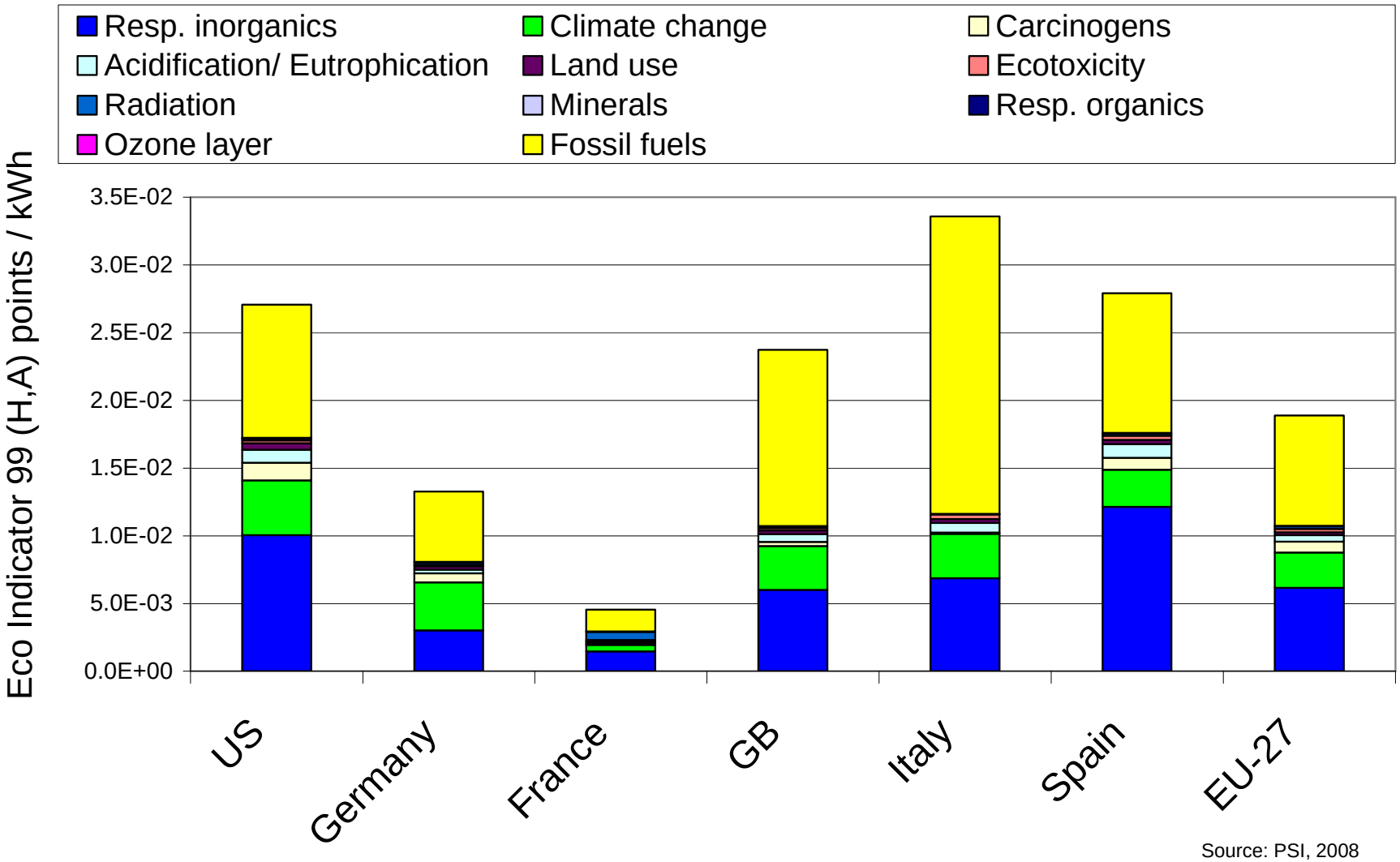
Source: Hirschberg et al., 2007

Swiss electricity systems (2030): Eco-indicator 99 (H,A)



PSI/Bauer at al. 2008 (Axpo Project)

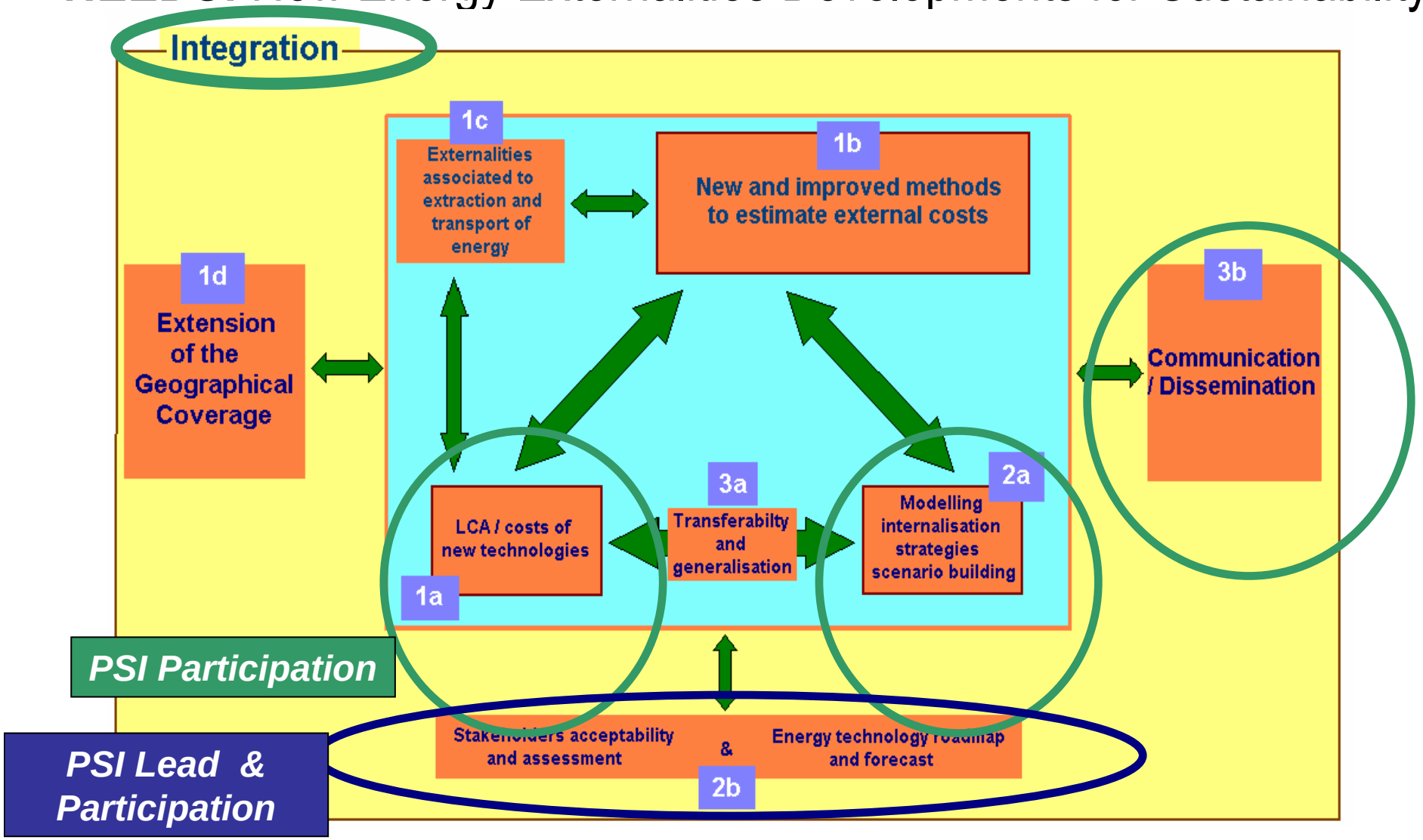
Eco-Indicator 99 (H,A): US vs. European electricity mixes



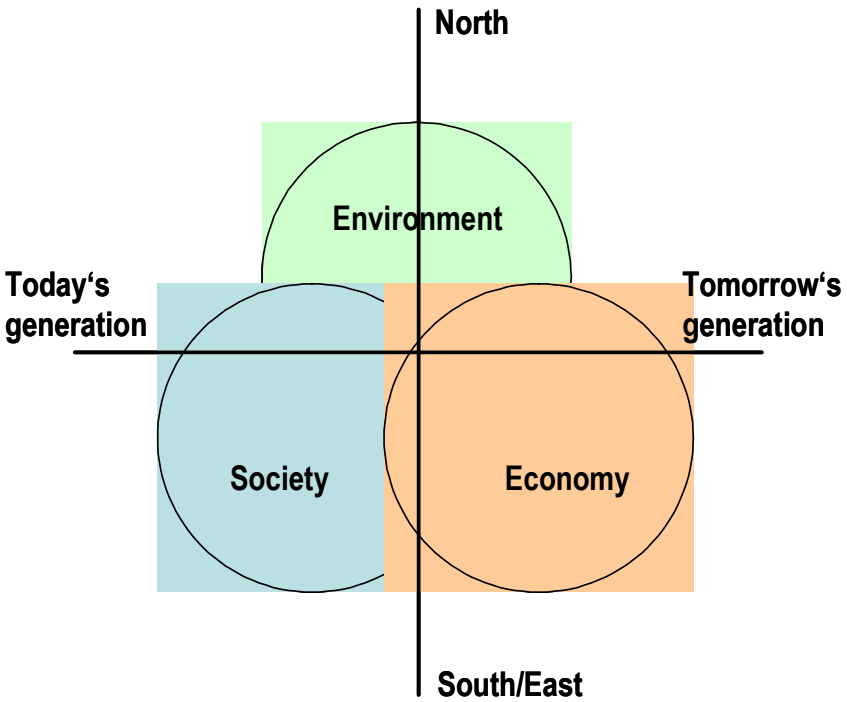
Source: PSI, 2008

Sustainability assessment for advanced technologies

NEEDS: New Energy Externalities Developments for Sustainability



Sustainability Criteria



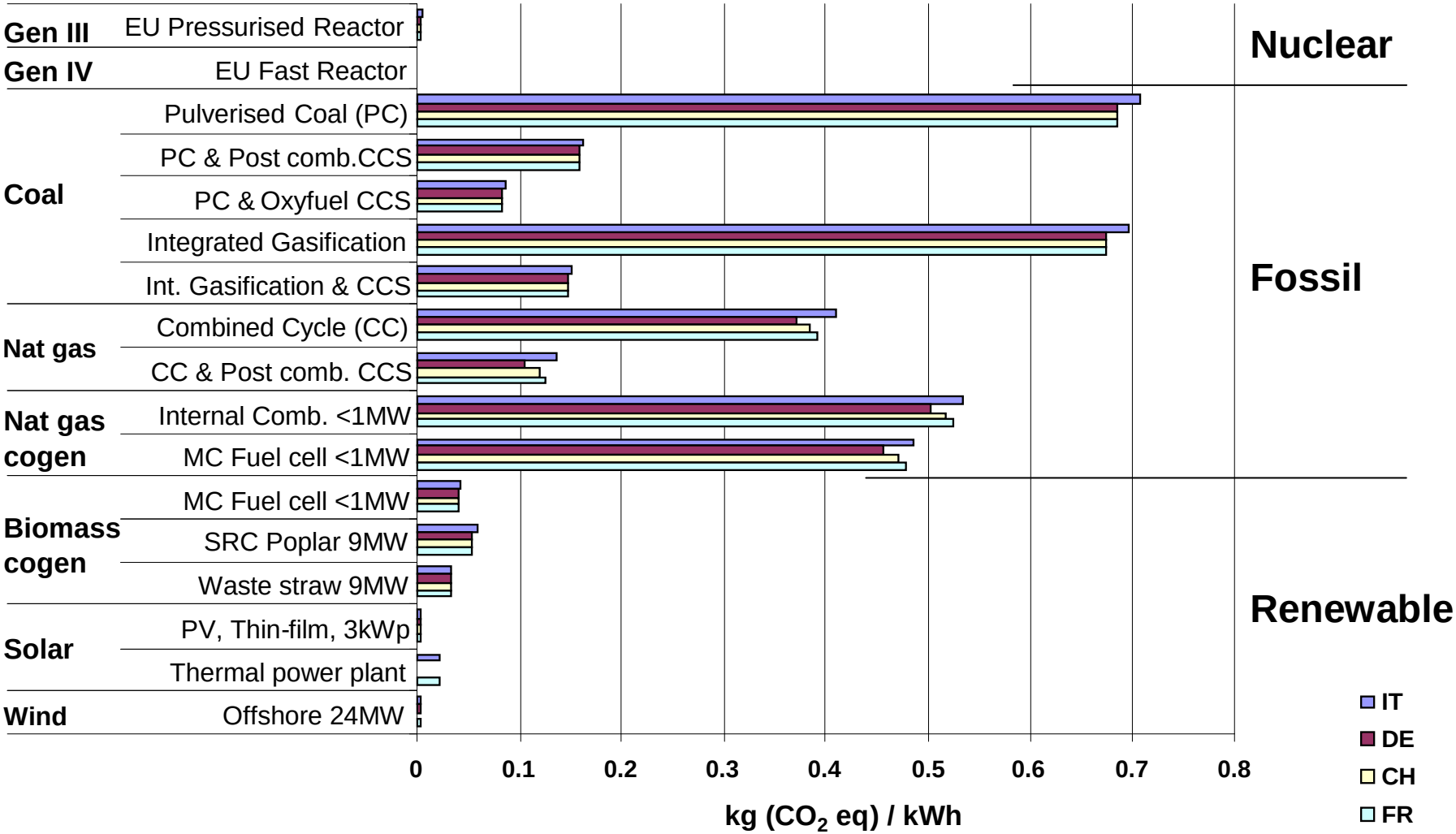
	Criterion
Environmental Dimension	**RESOURCES**
	Energy Resources
	Mineral Resources (Ores)
	CLIMATE CHANGE
	IMPACT ON ECOSYSTEMS
	Impacts from Normal Operation
	Impacts from Severe Accidents
	WASTES
	Special Chemical Wastes stored in Underground Depositories
	Medium and High Level Radioactive Wastes to be stored in Geological Repositories
Economic Dimension	**IMPACTS ON CUSTOMERS**
	Price of Electricity
	IMPACTS ON OVERALL ECONOMY
	Employment
	Autonomy of Electricity Generation
	IMPACTS ON UTILITY
	Financial Risks
	Operation
Social Dimension	**SECURITY/RELIABILITY OF ENERGY PROVISION**
	Political Threats to Continuity of Energy Service
	Flexibility and Adaptation
	POLITICAL STABILITY AND LEGITIMACY
	Potential of Conflicts induced by Energy Systems.
	Necessity of Participative Decision-making Processes
	SOCIAL AND INDIVIDUAL RISKS
	Expert-based Risk Estimates for Normal Operation
	Expert-based Risk Estimates for Accidents
	Perceived Risks
	Terrorist Threat
	QUALITY OF RESIDENTIAL ENVIRONMENT
	Effects on the Quality of Landscape
	Noise Exposure

Source: Hirschberg et al., 2007&2008

State-of-the-art methods for indicator estimation & aggregation

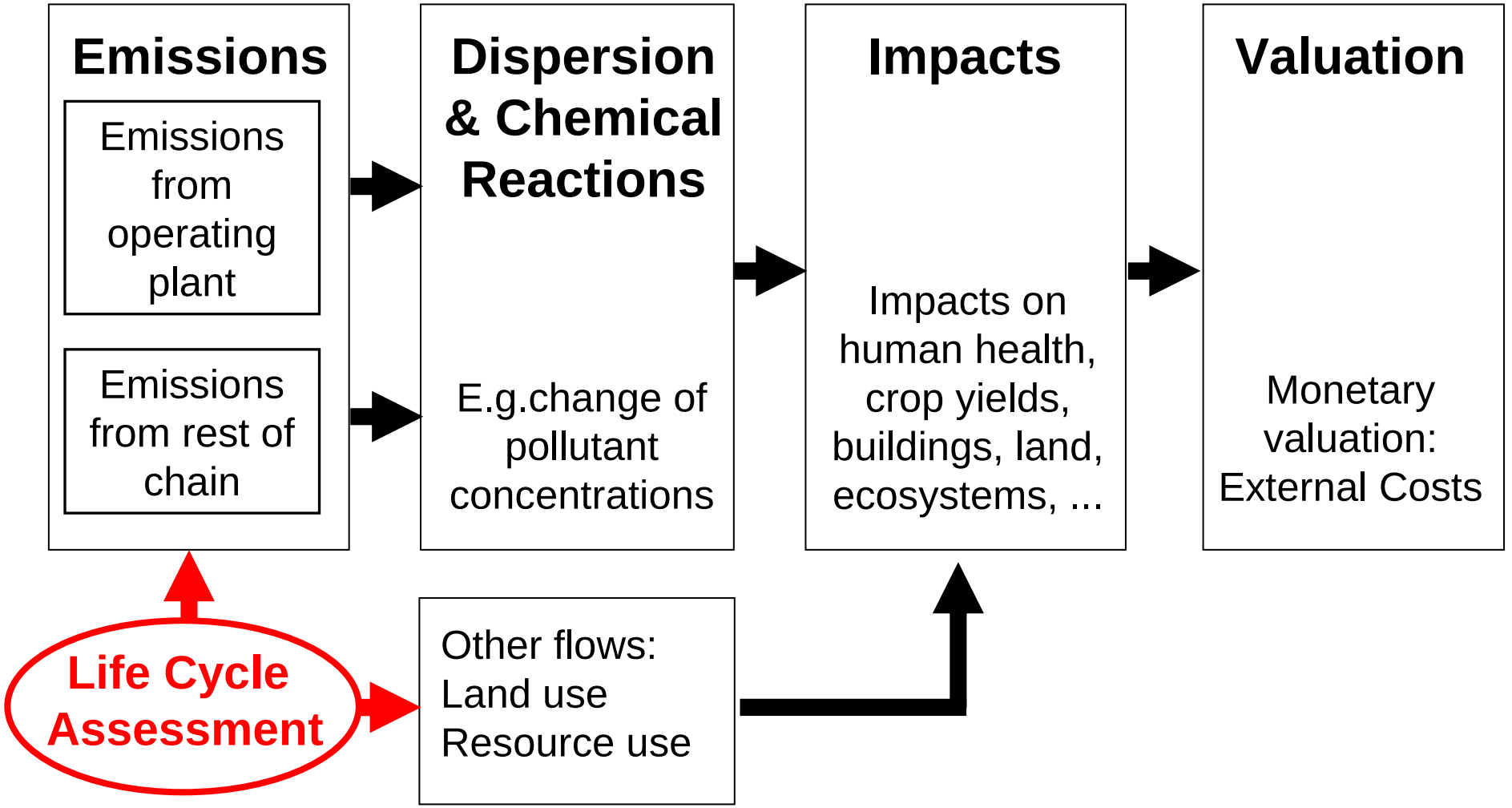
- **Environmental indicators:** Life Cycle Assessment and Impact Pathway Approach (regional or site-specific)
- **Risk indicators:** Historical experience (PSI database ENSAD) and Probabilistic Safety Assessment (PSA)
- **Economic indicators:** Learning curves and expert judgement
- **„Hard“ social indicators:** some of above, statistics
- **„Soft“ social indicators:** Expert judgement, expert and stakeholder interviews
- **Aggregation** by means of total (internal + external) costs
- **Aggregation** by means of Multi-criteria Decision Analysis (MCDA)

Environment: GHG Emissions (2050)

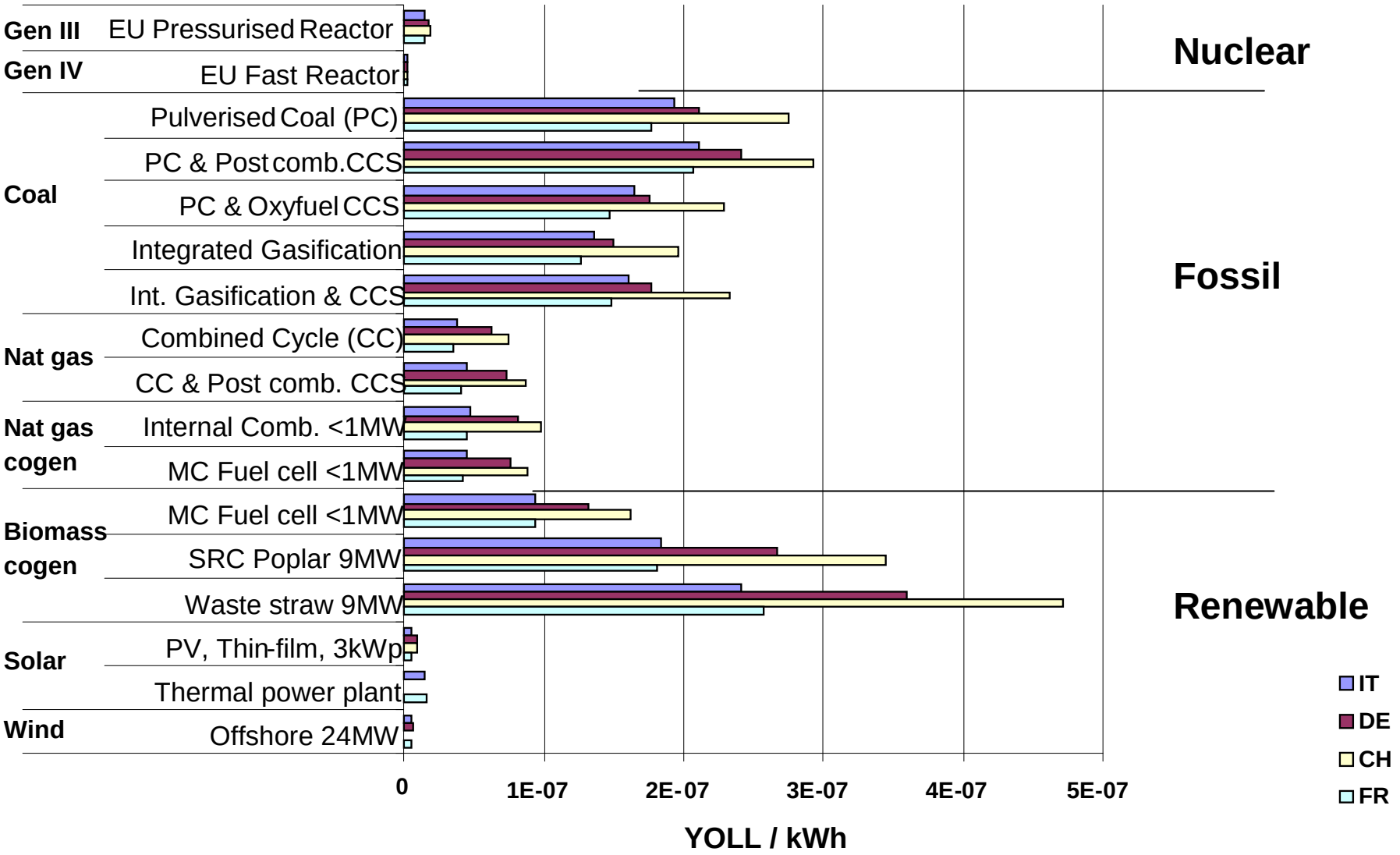


Source: Bauer et al., 2008

The impact pathway approach including LCA



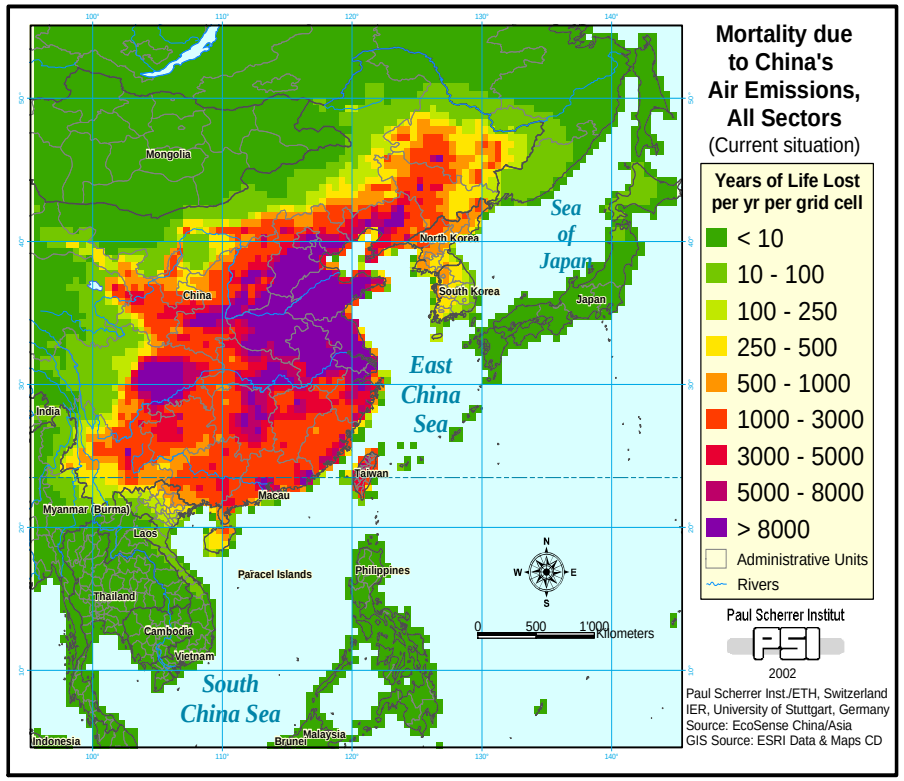
Social: Years of Life Lost - YOLL (2050)



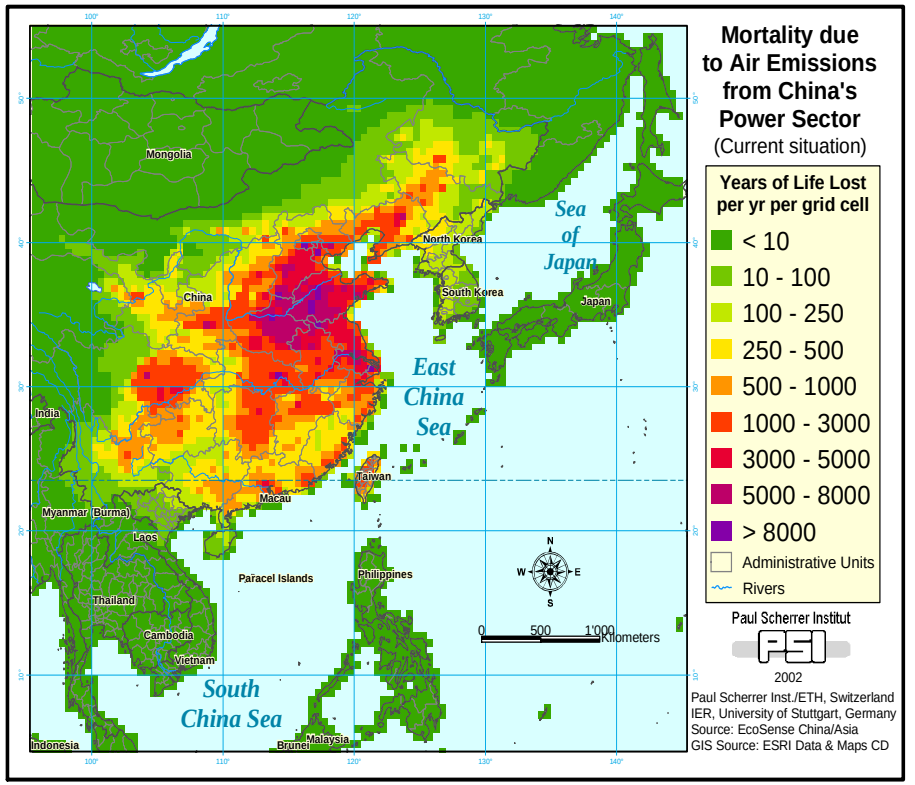
Source: Friedrich & Preiss, 2008

Mortality in China due to Air Pollution

Emissions from all Sectors

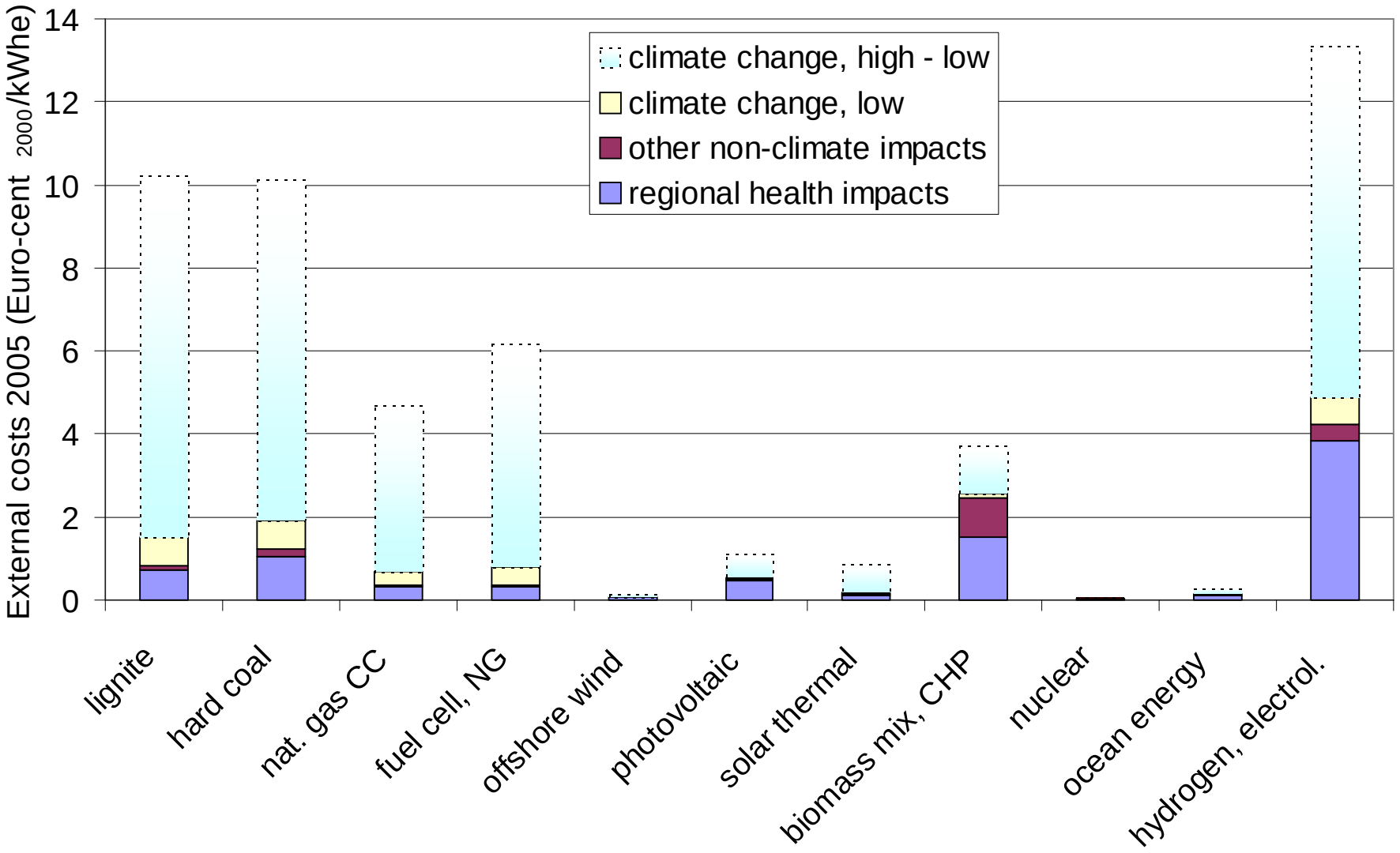


Emissions from Power Sector



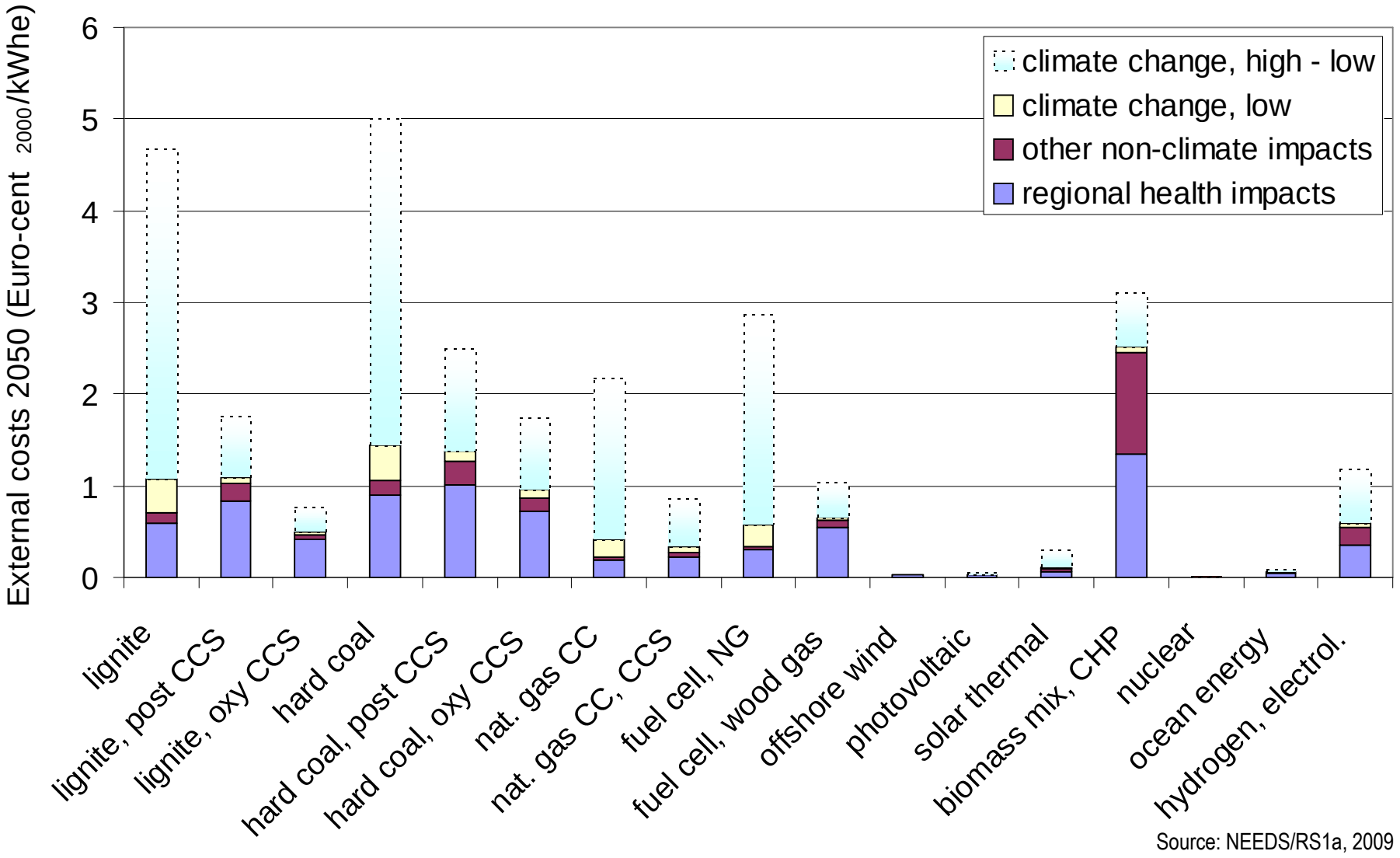
Source: Hirschberg et al., 2003

External Costs: Today, Western Europe (NEEDS Results)



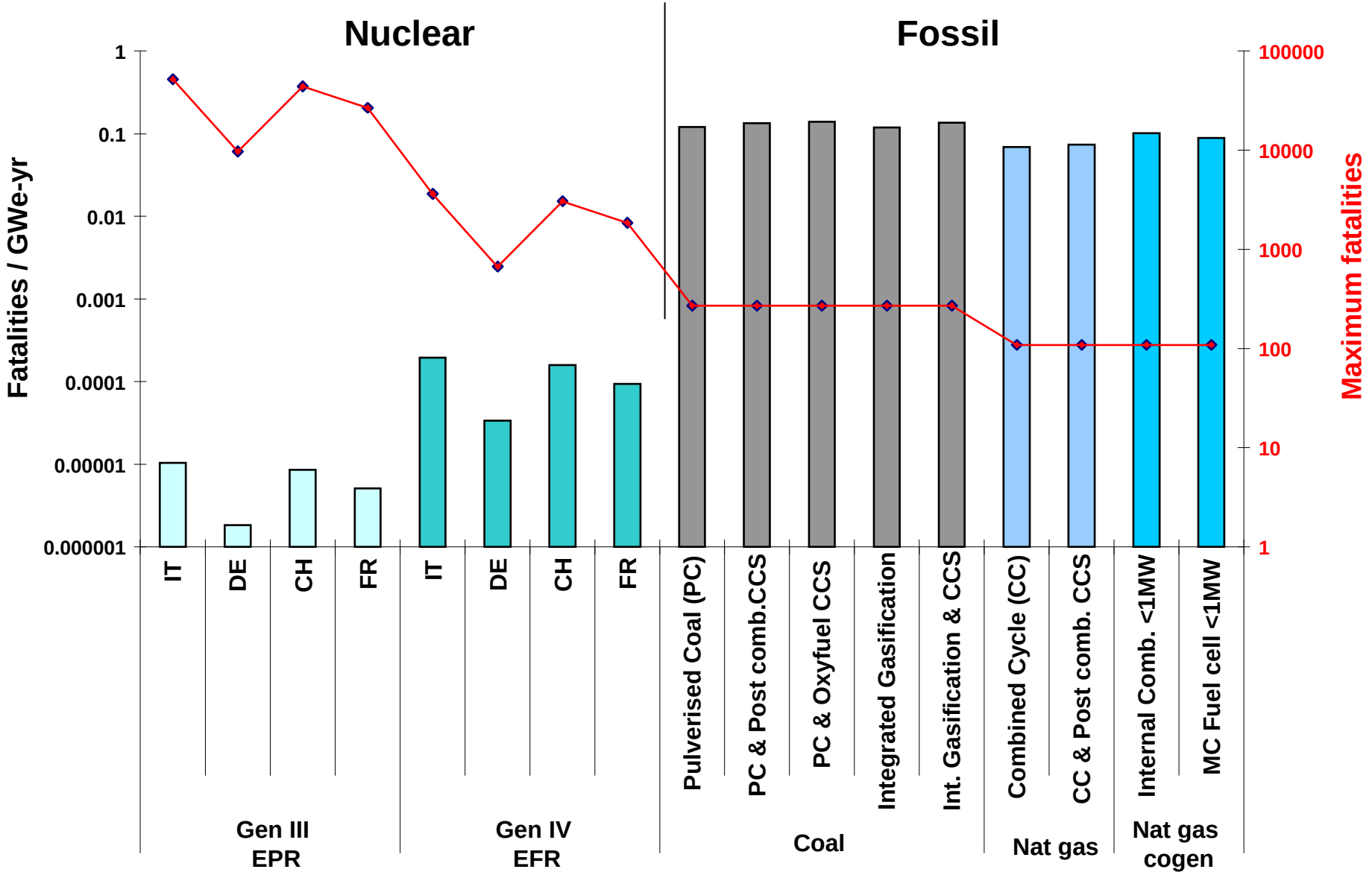
Source: NEEDS/RS1a, 2009

External Costs: Year 2050, Western Europe (NEEDS Results)



Source: NEEDS/RS1a, 2009

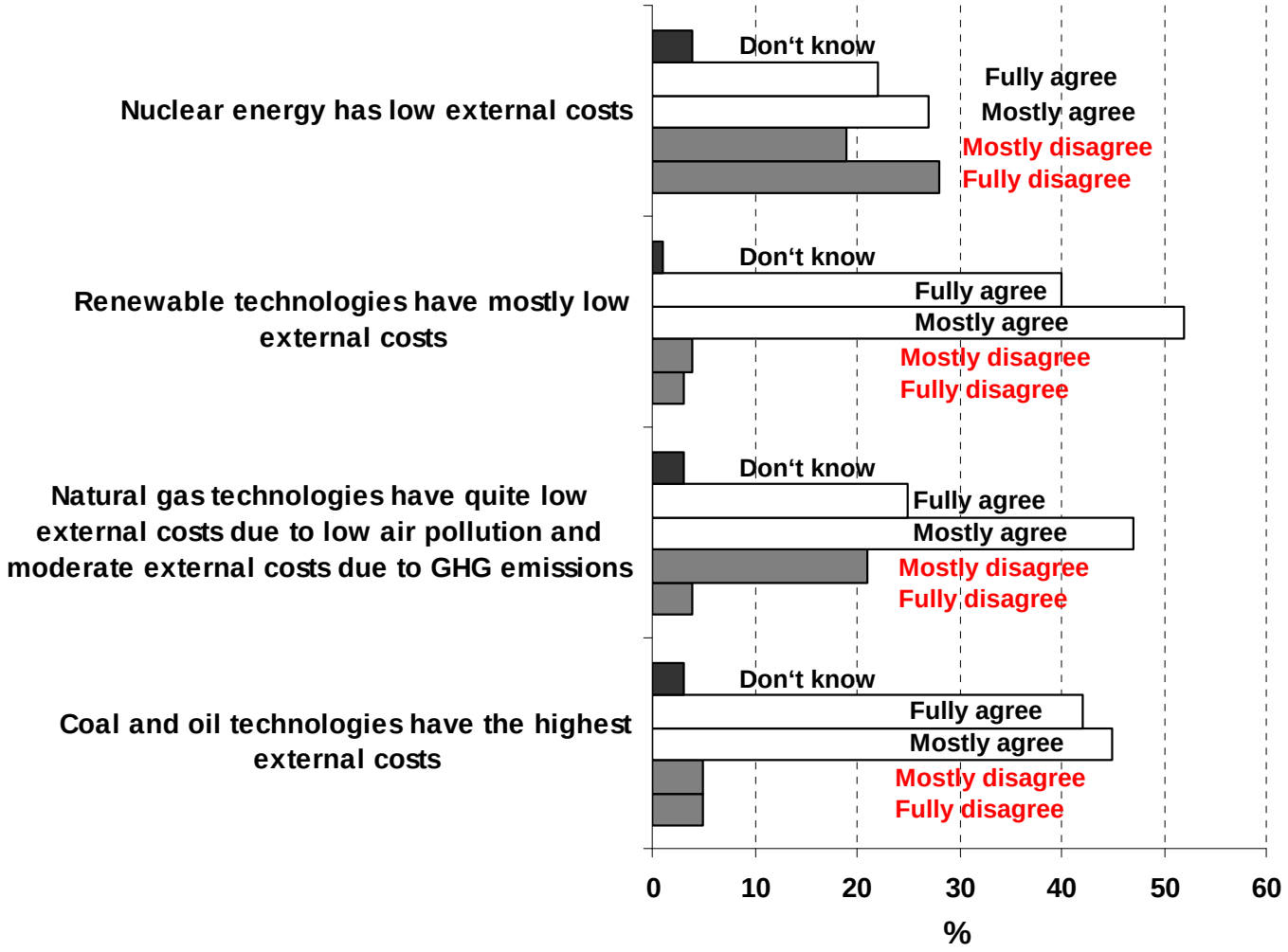
Social: Accident Fatality Rates and Max. Consequences



Source: Burgherr & Hirschberg, 2008

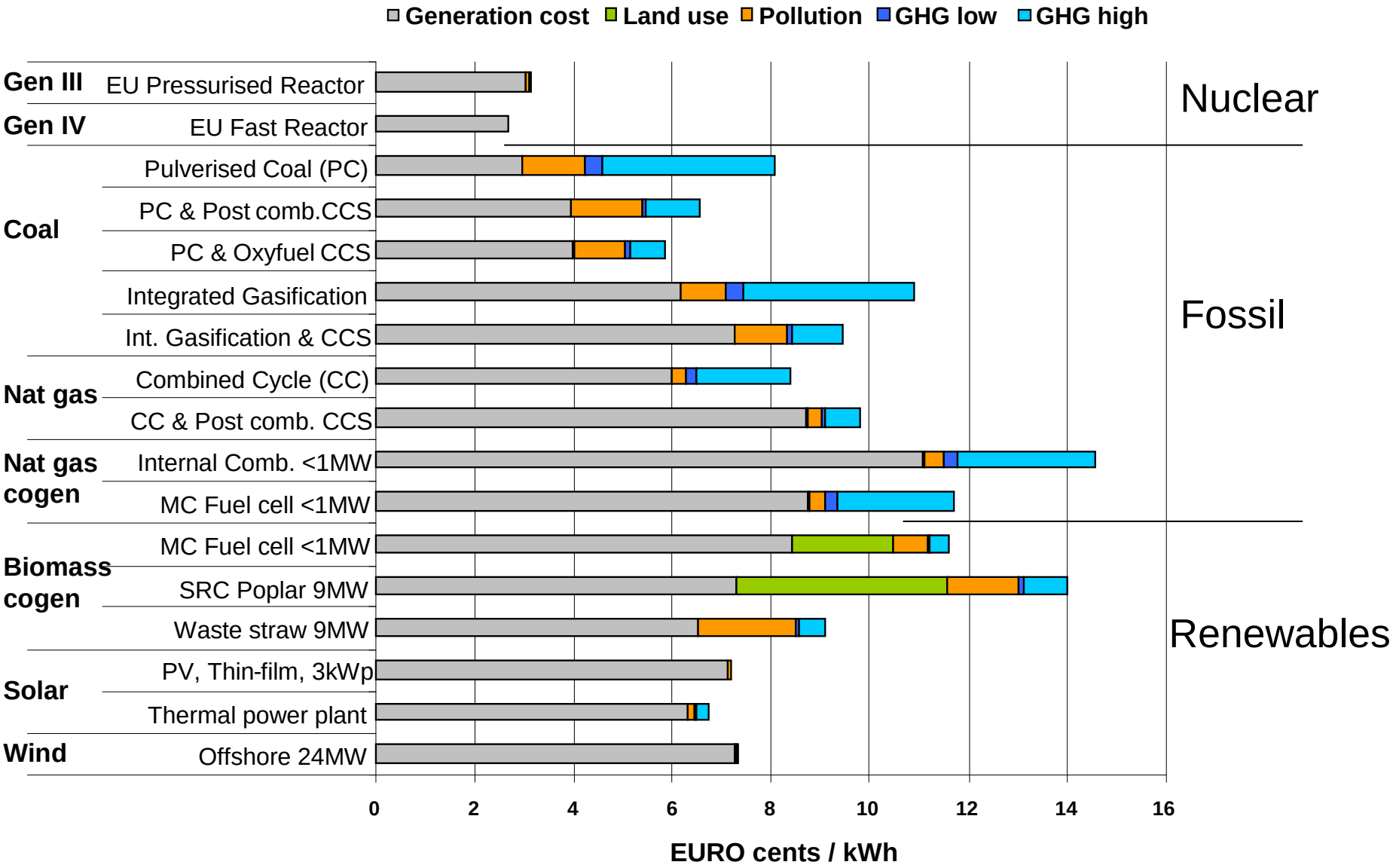
Survey I: Externality Concept, Results and

In spite of the limitations, there is general acceptance of the concept of externalities, of the internalisation of external costs and of most results, but…



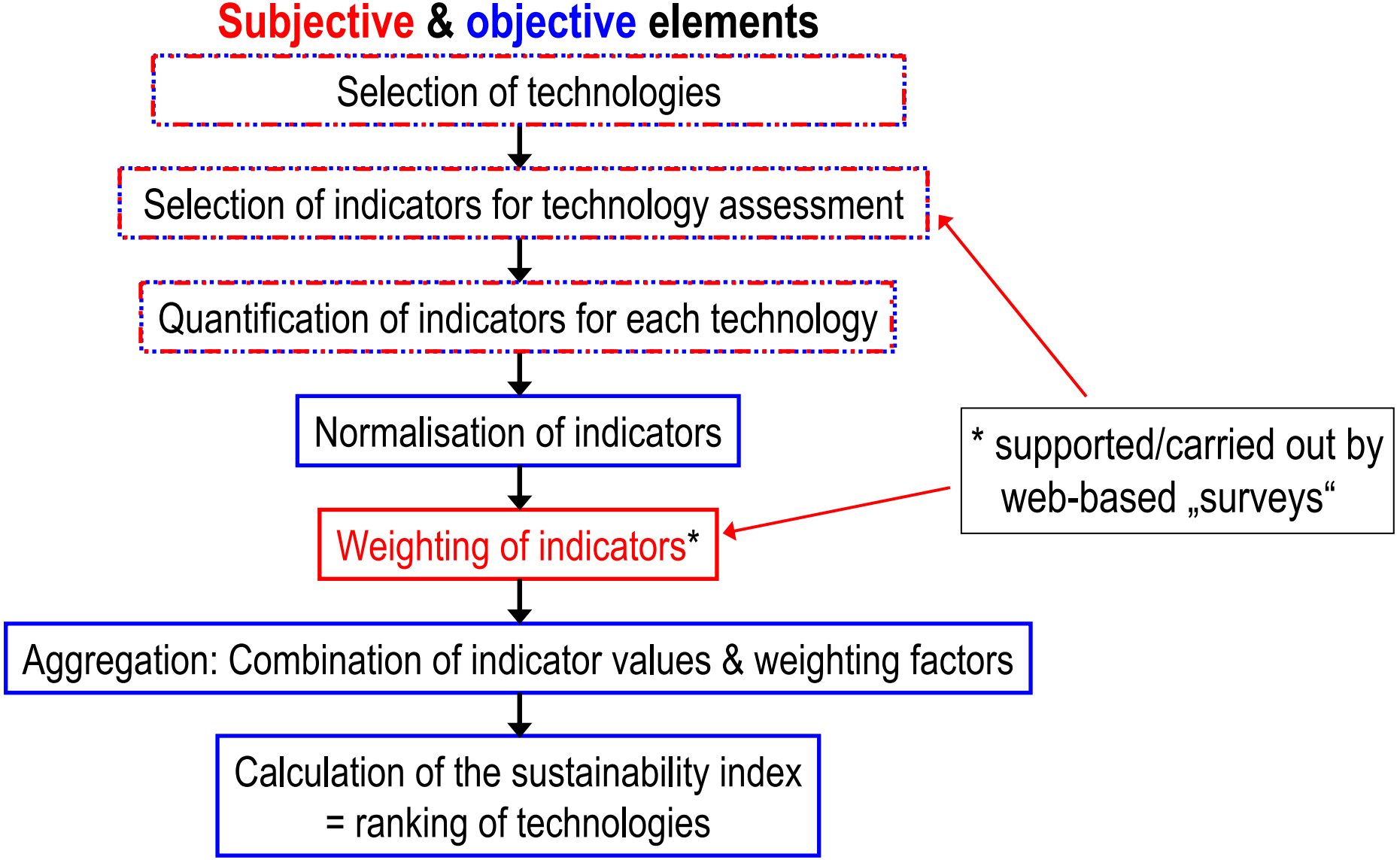
Source: Faberi et al., 2007

Total costs (2050)



Source: Schenler & Hirschberg, 2009

Multi-Criteria Decision Analysis (MCDA) process

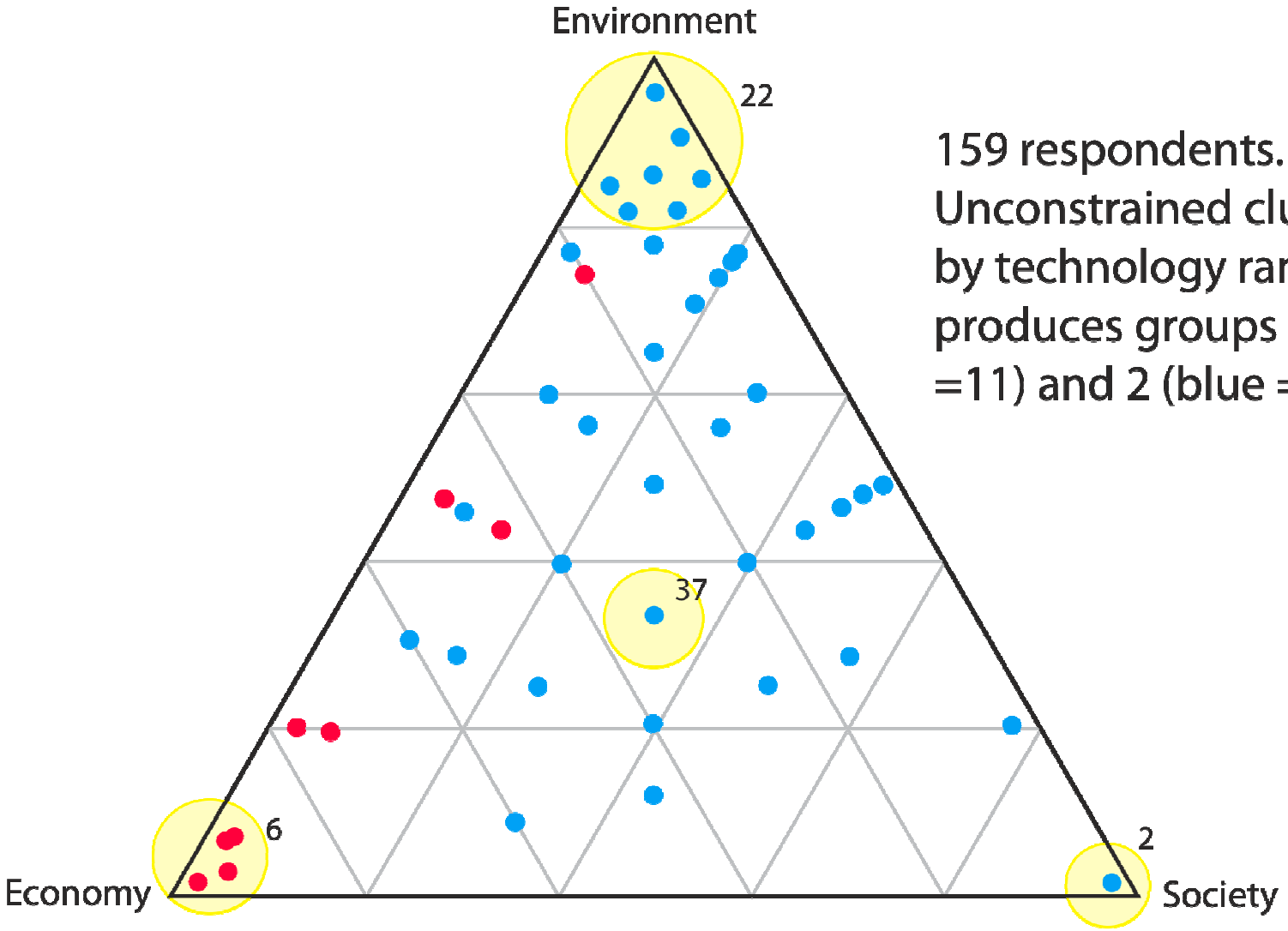


Main Stakeholder Categories

Each category is further divided into several sub-categories

Energy Supplier
Energy Consumer
Non-Governmental Organization (NGO)
Government Energy or Environmental Agency
Regulator / Government Authority
Association (e.g. trade or industry)
Politician
Researcher / Academic
Consultant
Other

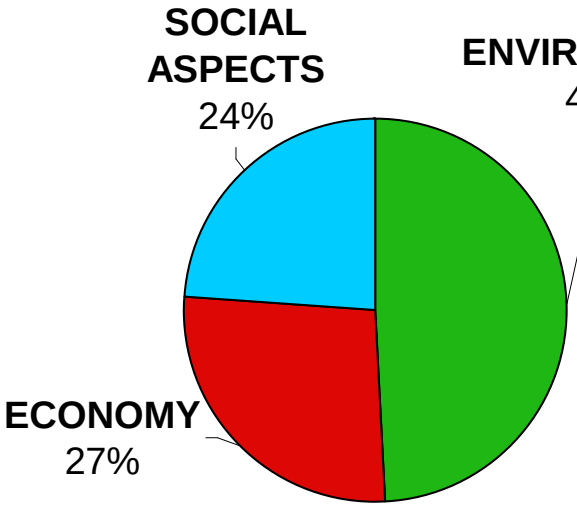
Distribution of top level indicator weights



159 respondents.
Unconstrained clustering by technology ranks produces groups 1 (red =11) and 2 (blue =148).

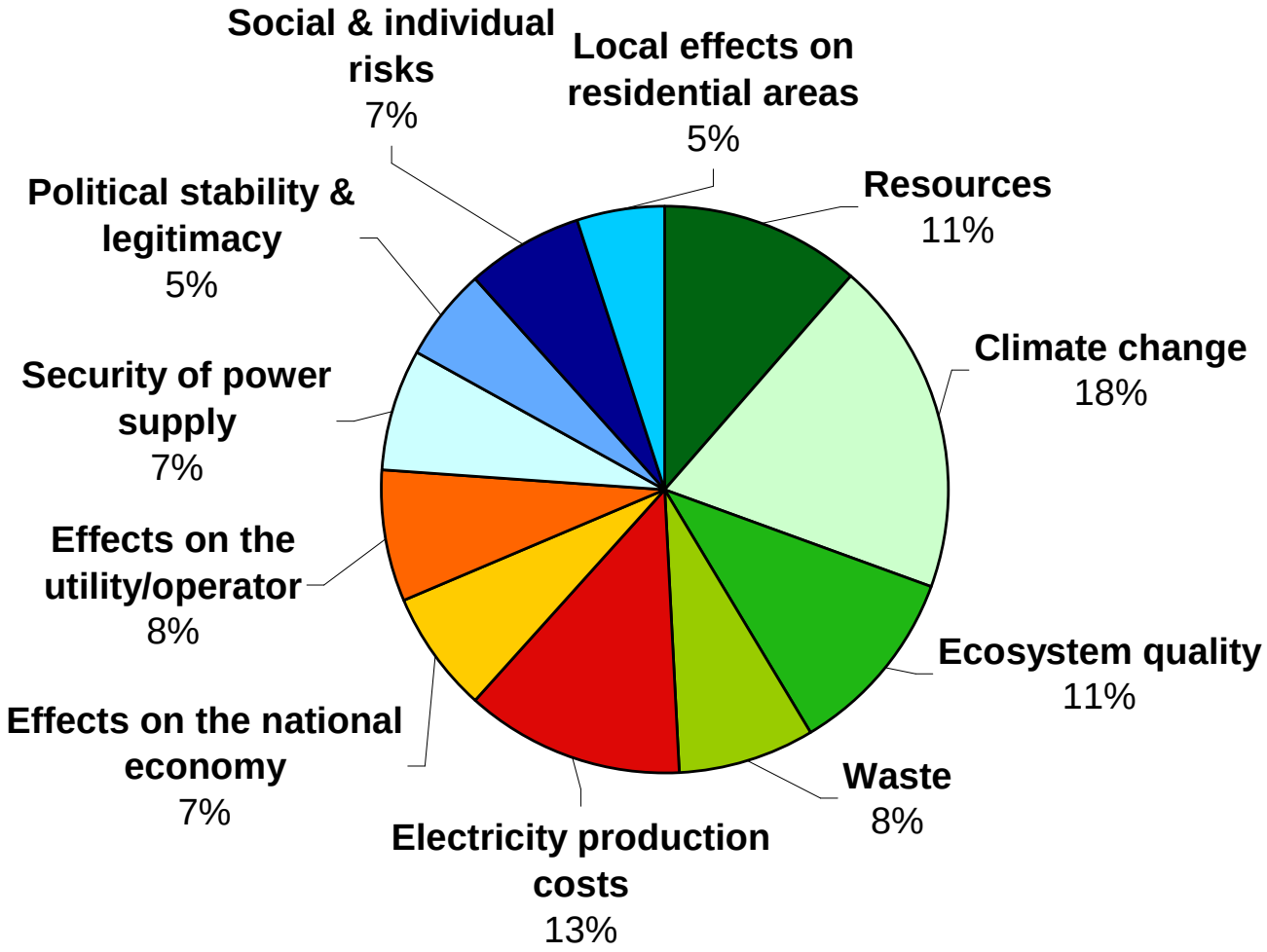
Source: PSI, Schenler & Hirschbergl., 2009

Average stakeholder weighting of MCDA indicators



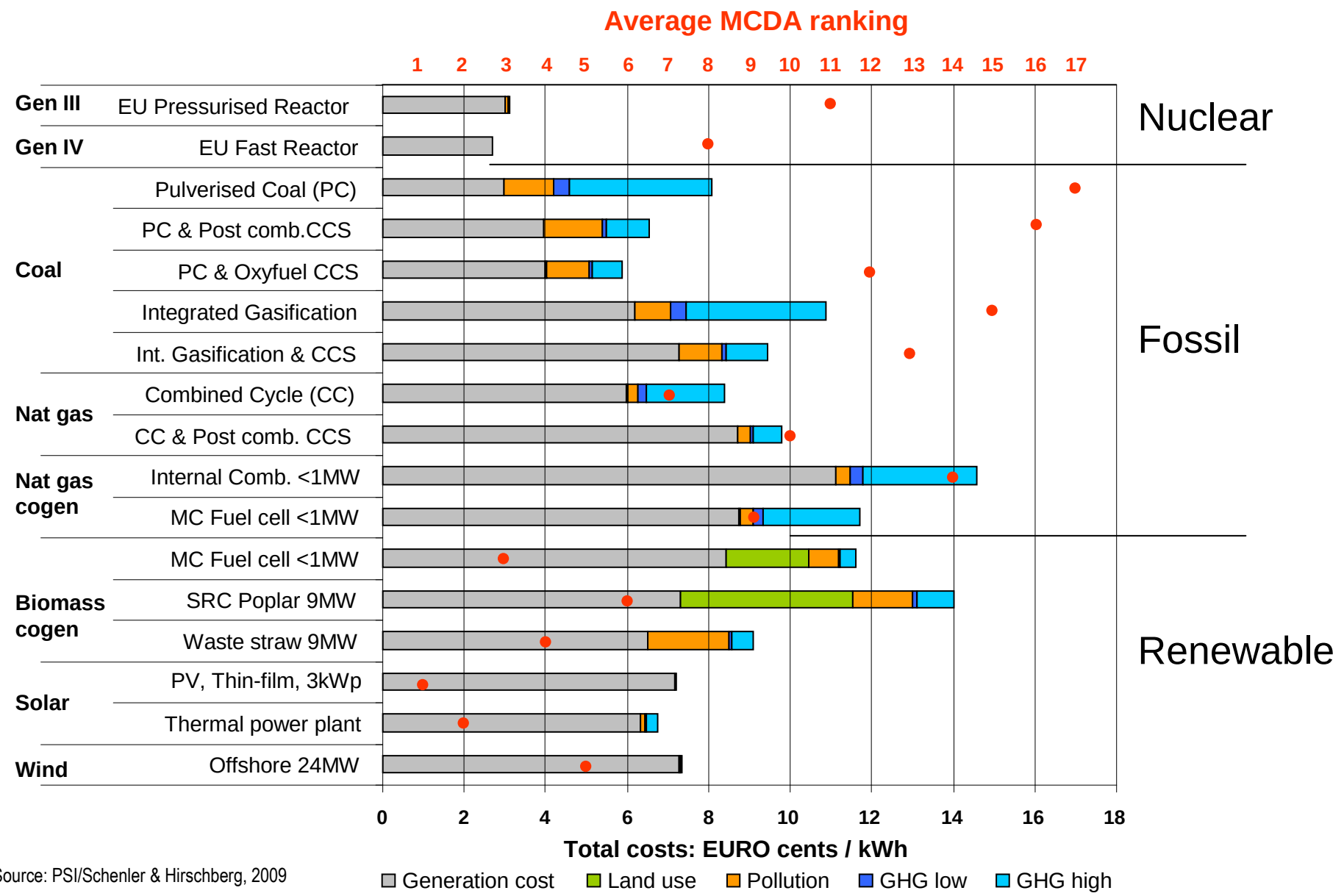
1st level

2nd level



Source: PSI, Schenler & Hirschberg, 2009

MCDA Ranking vs. Total Costs (2050)



Source: PSI/Schenler & Hirschberg, 2009

Conclusions

LCA with LCI as its basis is a fundamental tool for balanced and comprehensive systems comparison, and for a wide variety of environmental studies

Quantification of environmental, economic and social indicators builds on state-of-the-art methods. Comprehensive and transparent LCA is an indispensable part of the approach.

Total cost approach favours nuclear and disfavours biomass. Ranking of fossil technologies in comparison to (remarkably improved) solar and wind strongly depends on which value for GHG-damages is used.

MCDA-approach favours renewables, in particular solar technologies. Inclusion of a wide set of social criteria leads to lower ranking of nuclear.

Emphasis on environment penalizes fossil options; emphasis on economy penalizes renewable options; emphasis on social penalizes nuclear.

Thank you for your attention!

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