Life Cycle Analysis of Carbon Dioxide Emissions from Different Energy Sources

Stefan Hirschberg

Paul Scherrer Institut, Switzerland

stefan.hirschberg@psi.ch

Optimizing the mitigation of carbon dioxide emissions in Europe

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Content

- Introduction
- Why Life Cycle Assessment?
- LCA-framework
- Examples of comparative assessments of Greenhouse Gas emissions of electricity generation options
- Other environmental burdens and impacts
- Integrated perspective
- Conclusions

Comprehensive Assessment of Energy Systems at PSI

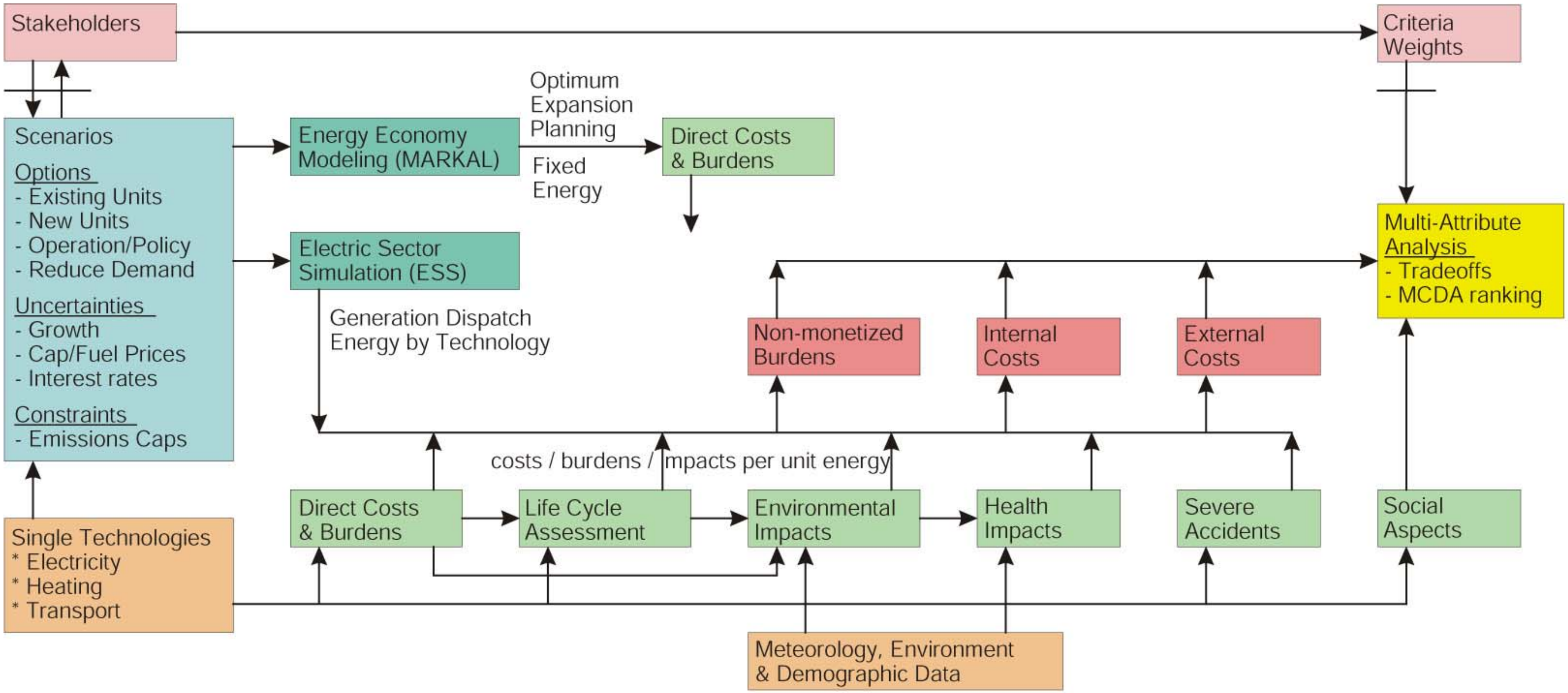
Goals

- **Inter-disciplinary** assessment of energy technologies and scenarios for Switzerland and other countries
- **Communication** of results to decision-makers and stakeholders (http://gabe.web.psi.ch/energie-spiegel/)
- Support of rational and **sustainable** decisions („ Honest Broker")

General Approach

- Development and implementation of „state-of-the-art" **methods and databases**
- Focus on **process-oriented** Life Cycle Assessment, Risk Assessment, Environmental Impact Assessment , External Costs, Energy-Economic Modeling, Electric Sector Simulation and Multi-criteria Decision Analysis

PSI Analysis Framework



Motivation for Life Cycle Assessment

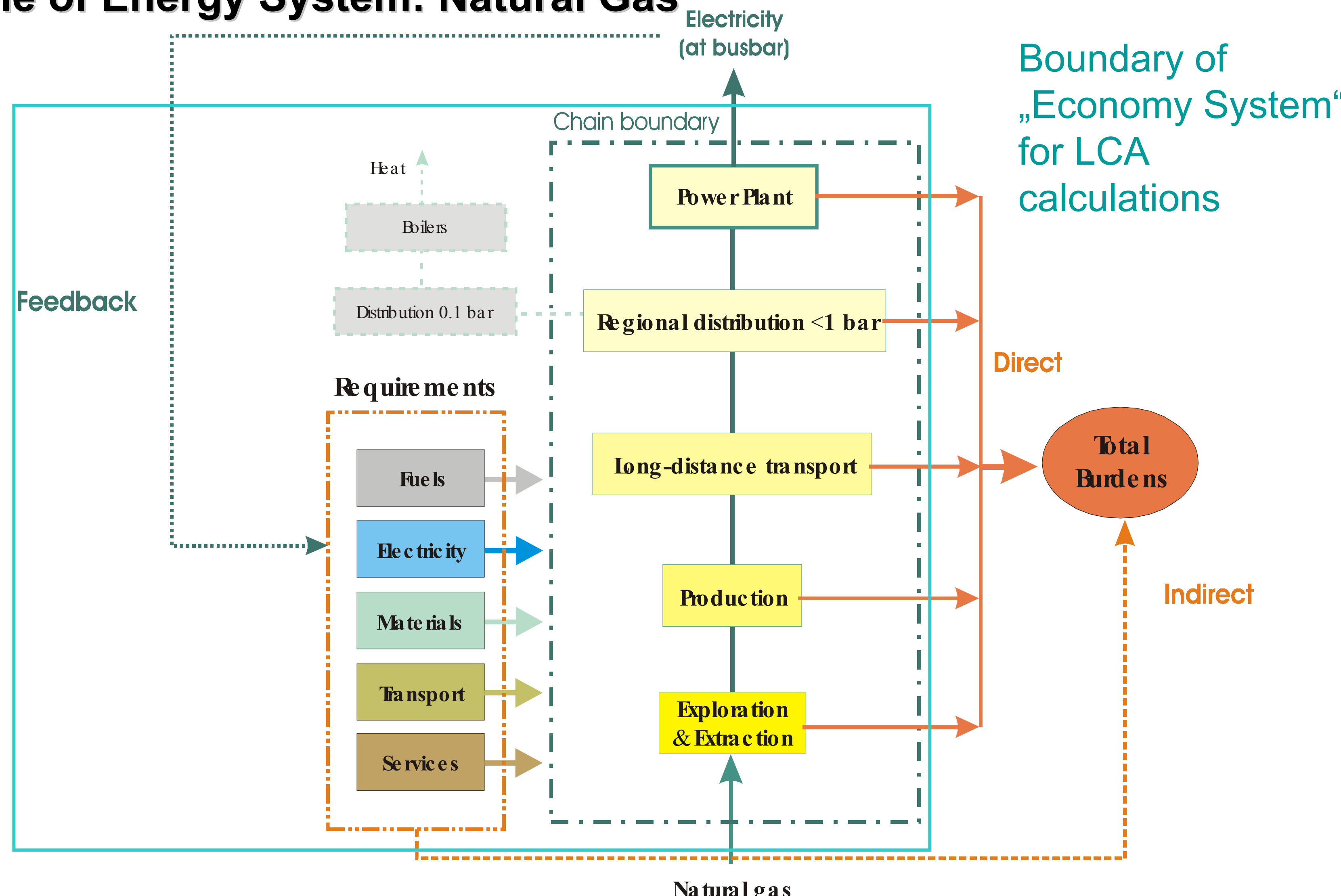
Comparison of environmental burdens of different (energy) systems

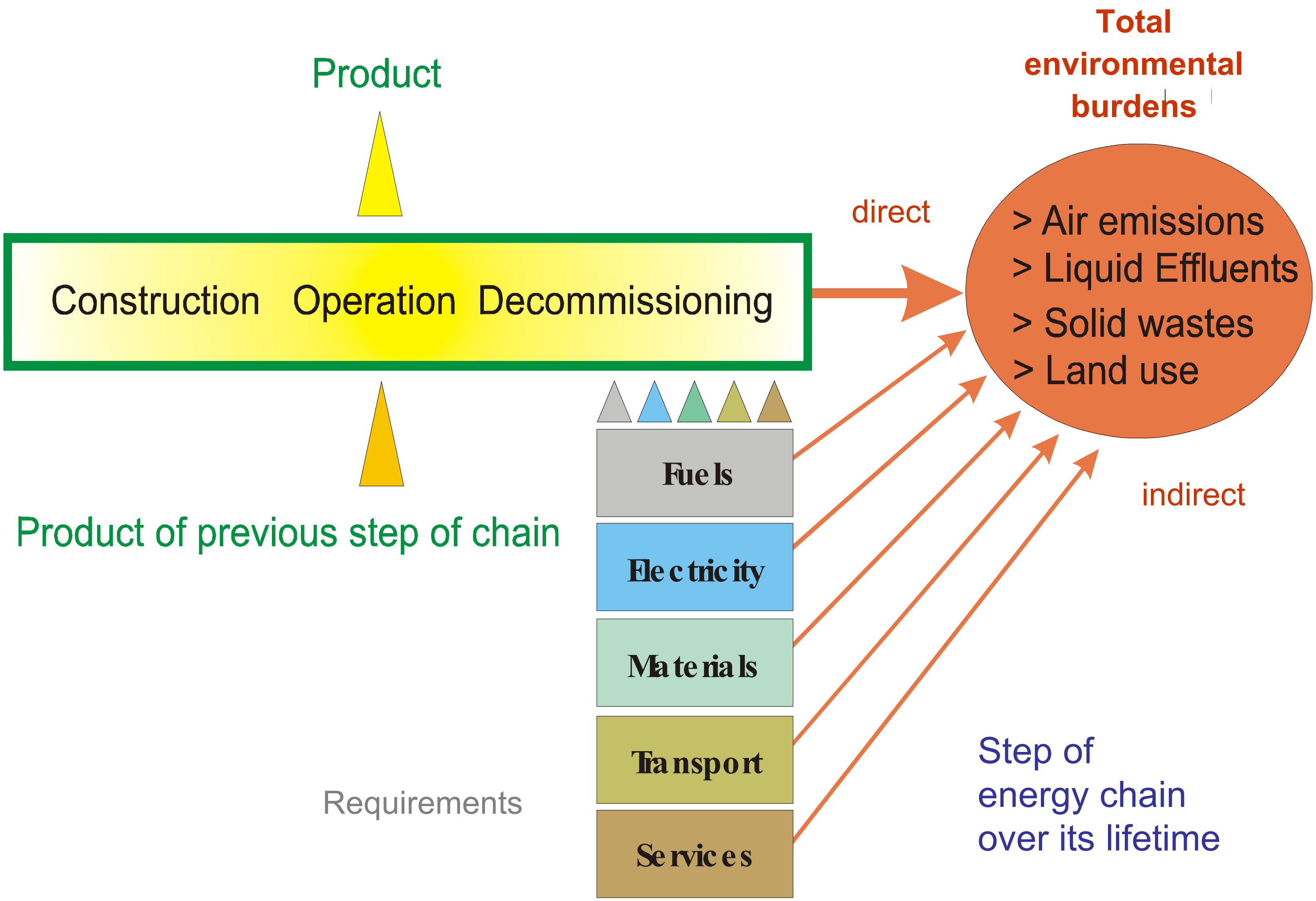
Consideration of one single stage of energy systems may not be proper

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

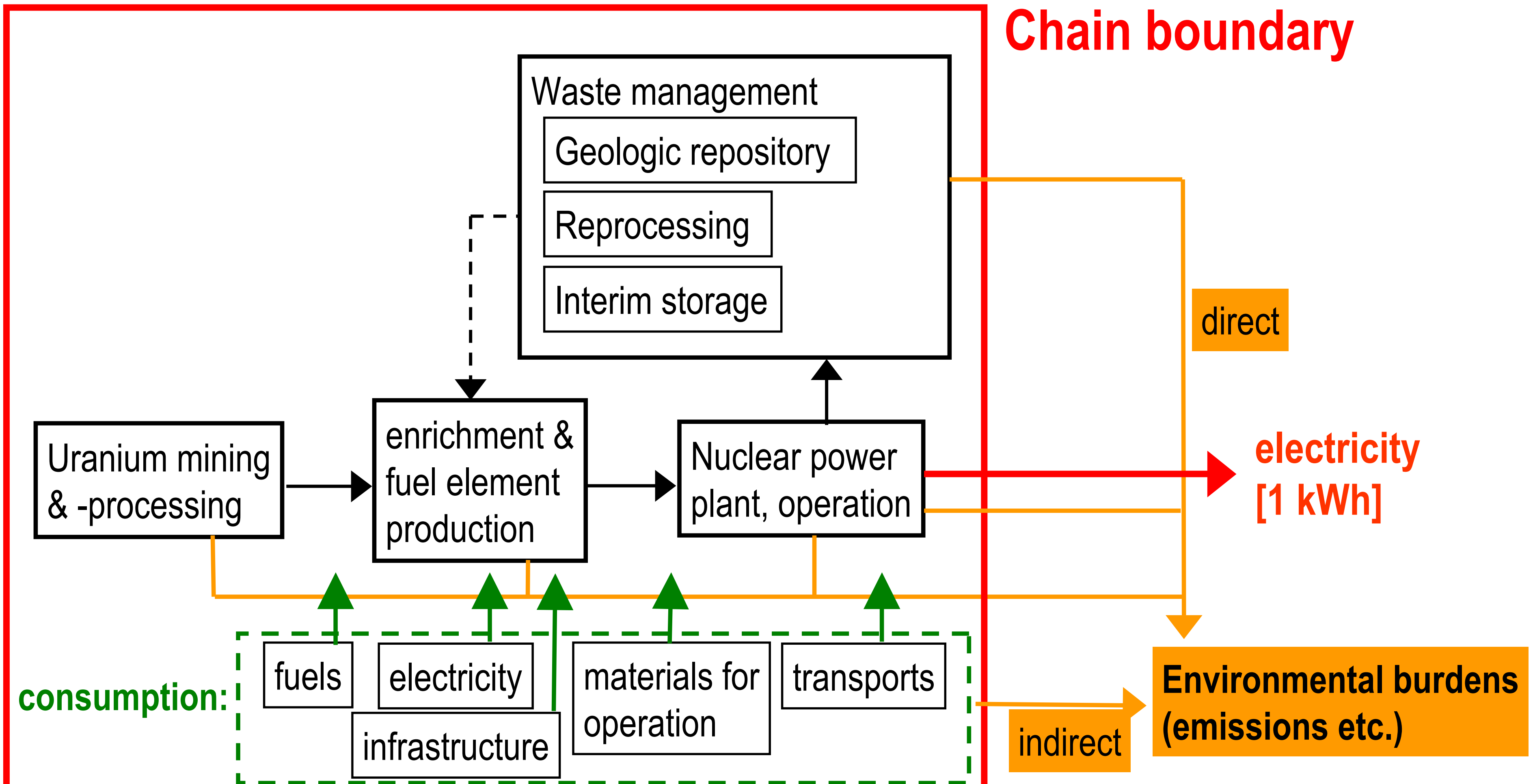
Environmental burdens (or stressors) are various, which calls for:
aggregation into Categories

Example of Energy System: Natural Gas

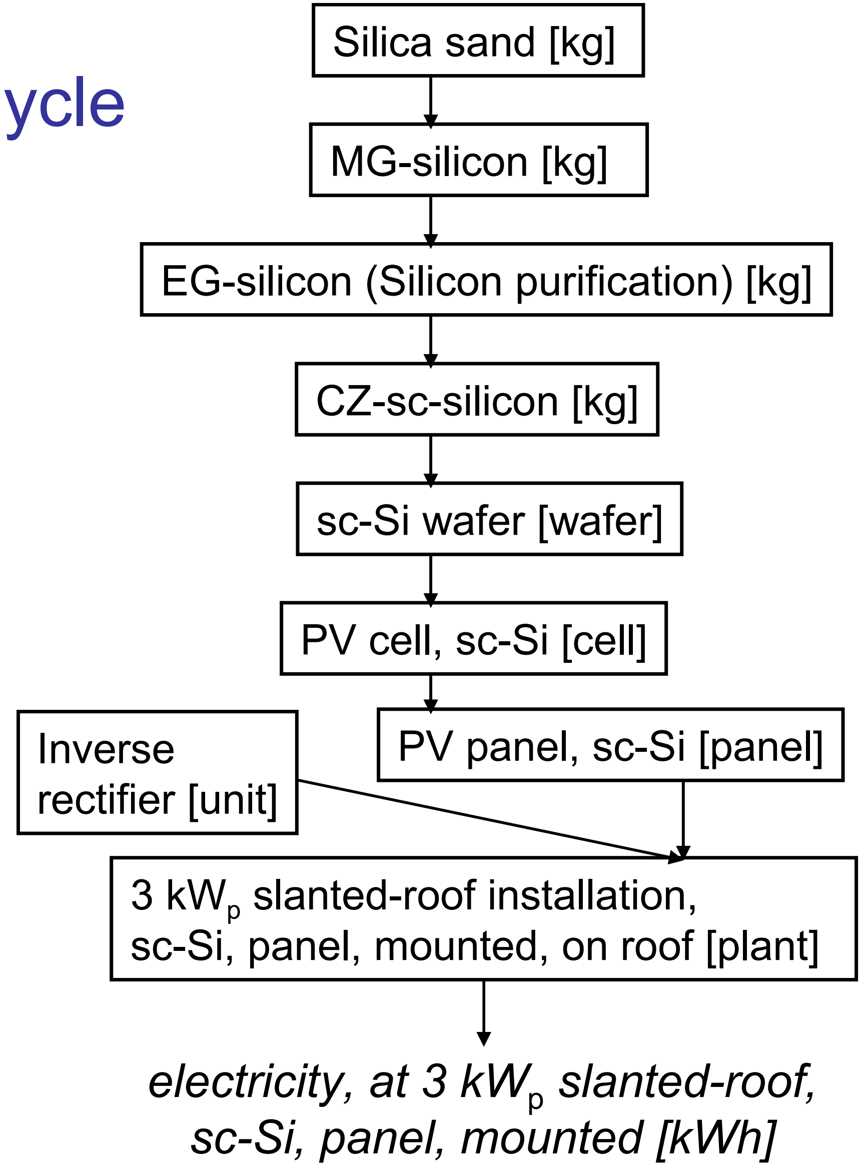



Total
environmental
burdens
Product
direct
> Air emissions
> Liquid Effluents
> Solid wastes
> Land use
Construction
Operation
Decommissioning
Fuels
Electricity
Materials
Transport
Services
indirect
Product of previous step of chain
Requirements
Step of
energy chain
over its lifetime

Life Cycle Analysis - LCA (nuclear energy chain)



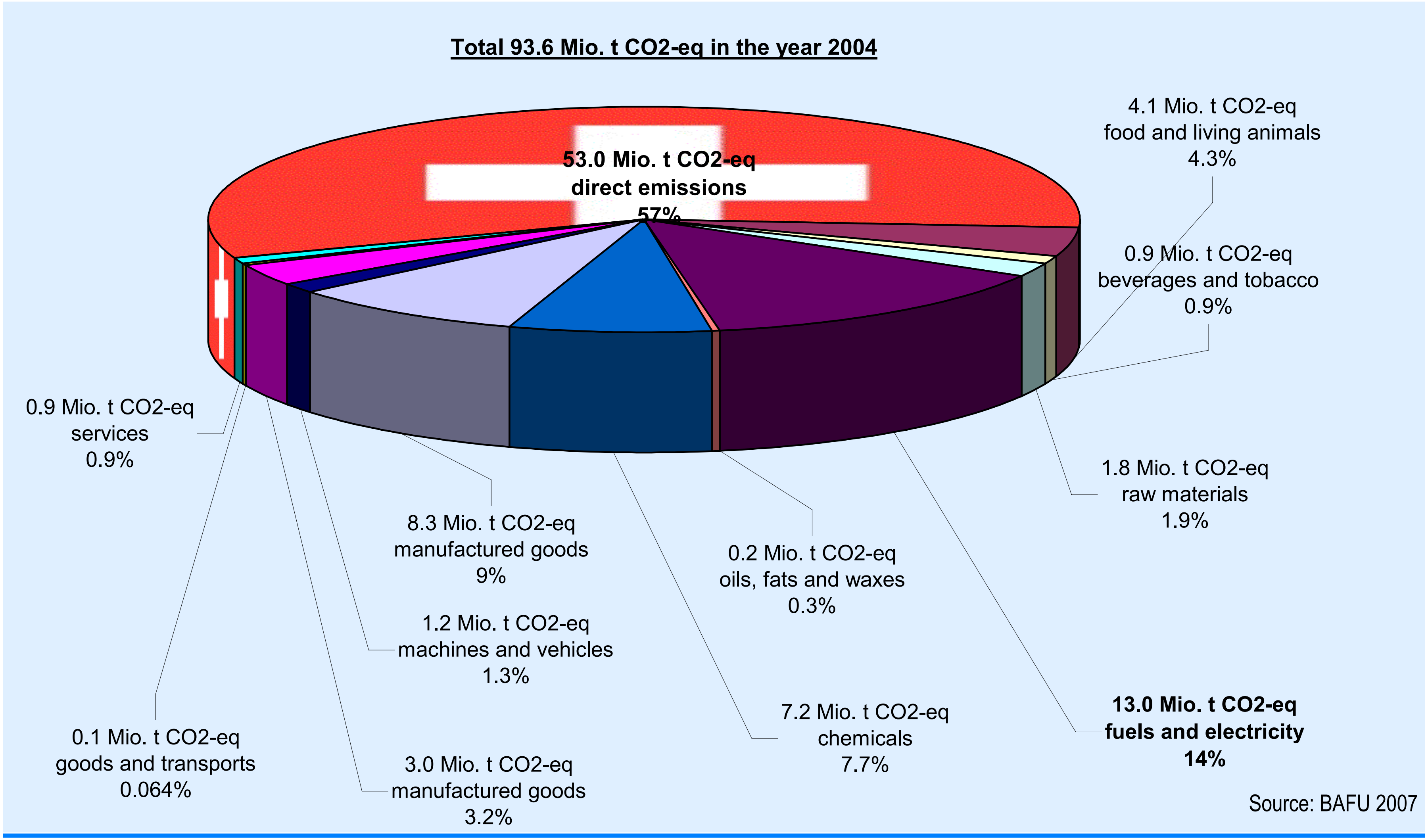
Solar PV Cycle



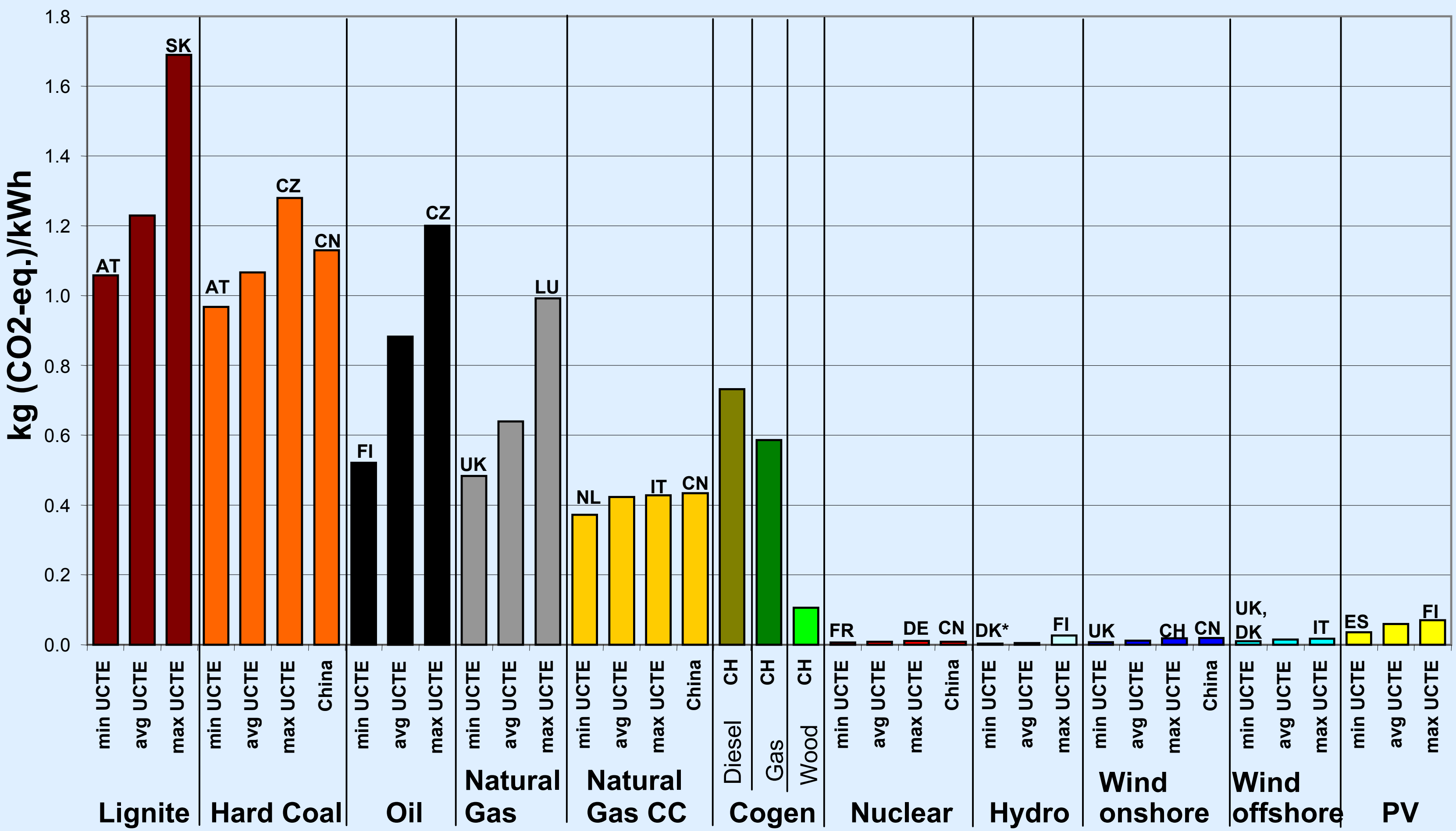
LCA Database *ecoinvent*

- Web-based; commercial; version v2.0 available on-line since 2007: 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
- About 1000 individual „environmental flows“ accounted for:
  - pollutants to air, water & groundwater, soil
  - energy and non-energy resource uses
  - land uses

Greenhouse gas emissions, Switzerland, direct & indirect (grey)

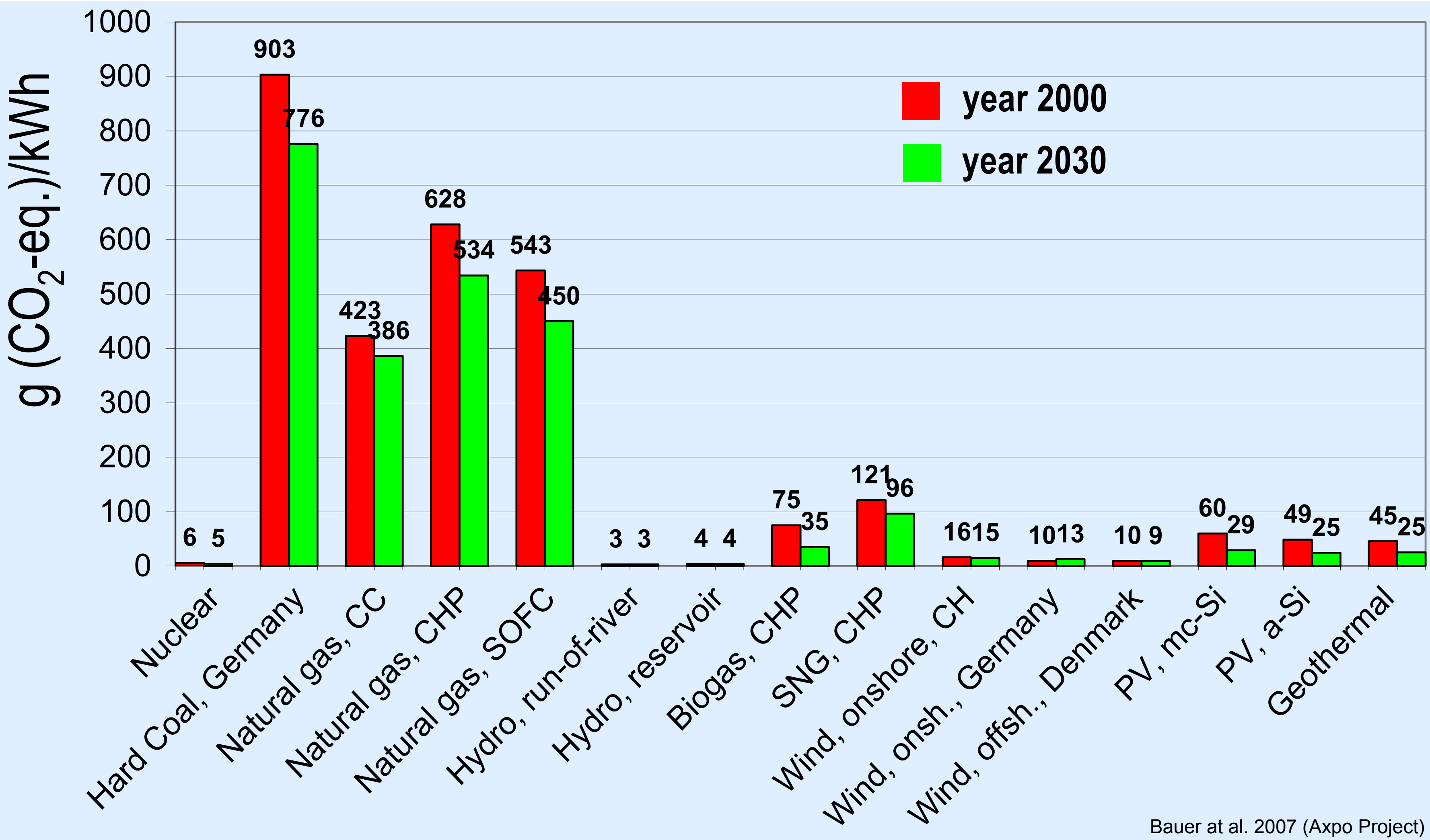


Greenhouse gas emissions of selected energy chains

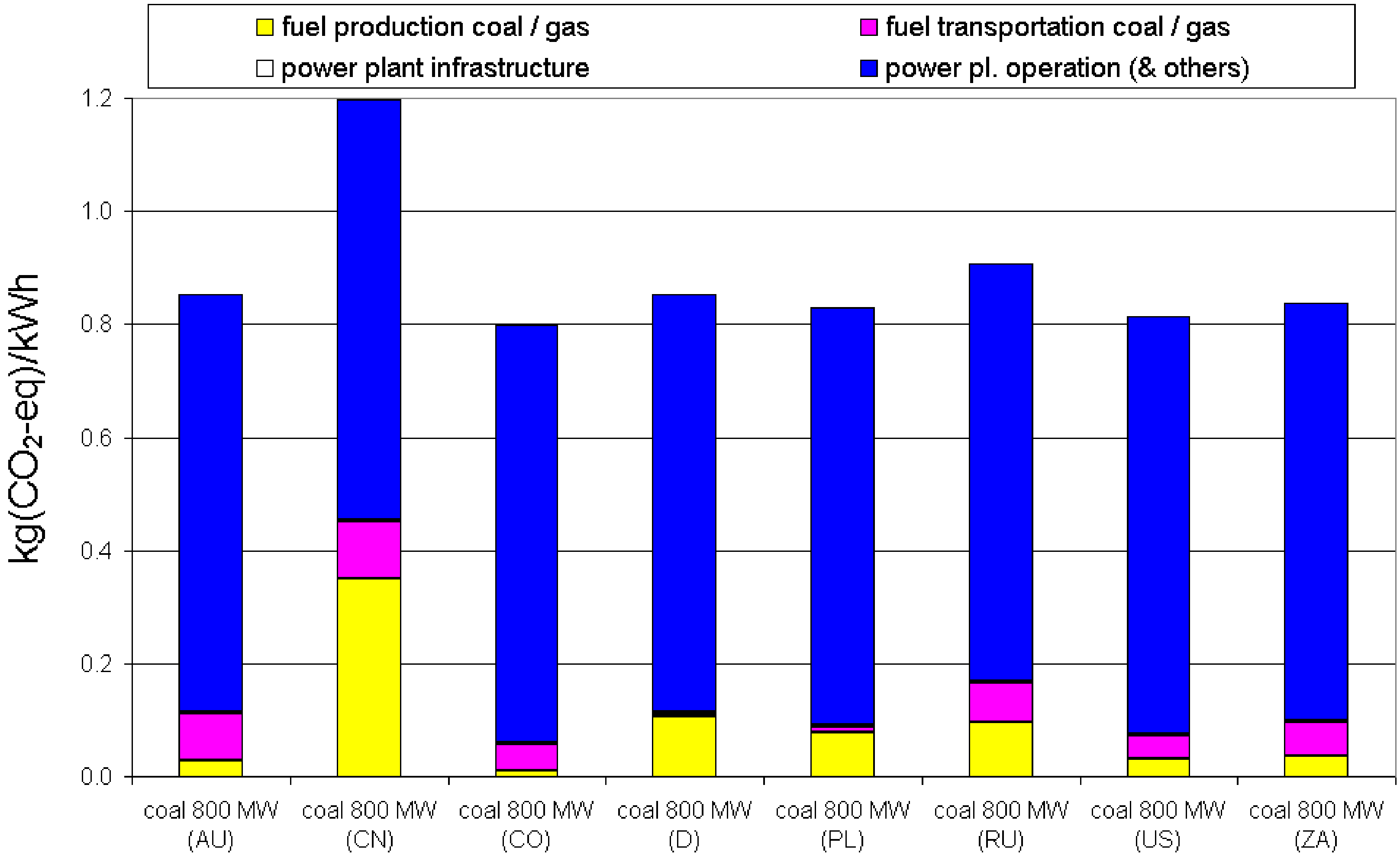


Source: after Dones et al. 2005

Swiss electricity systems: Greenhouse gases

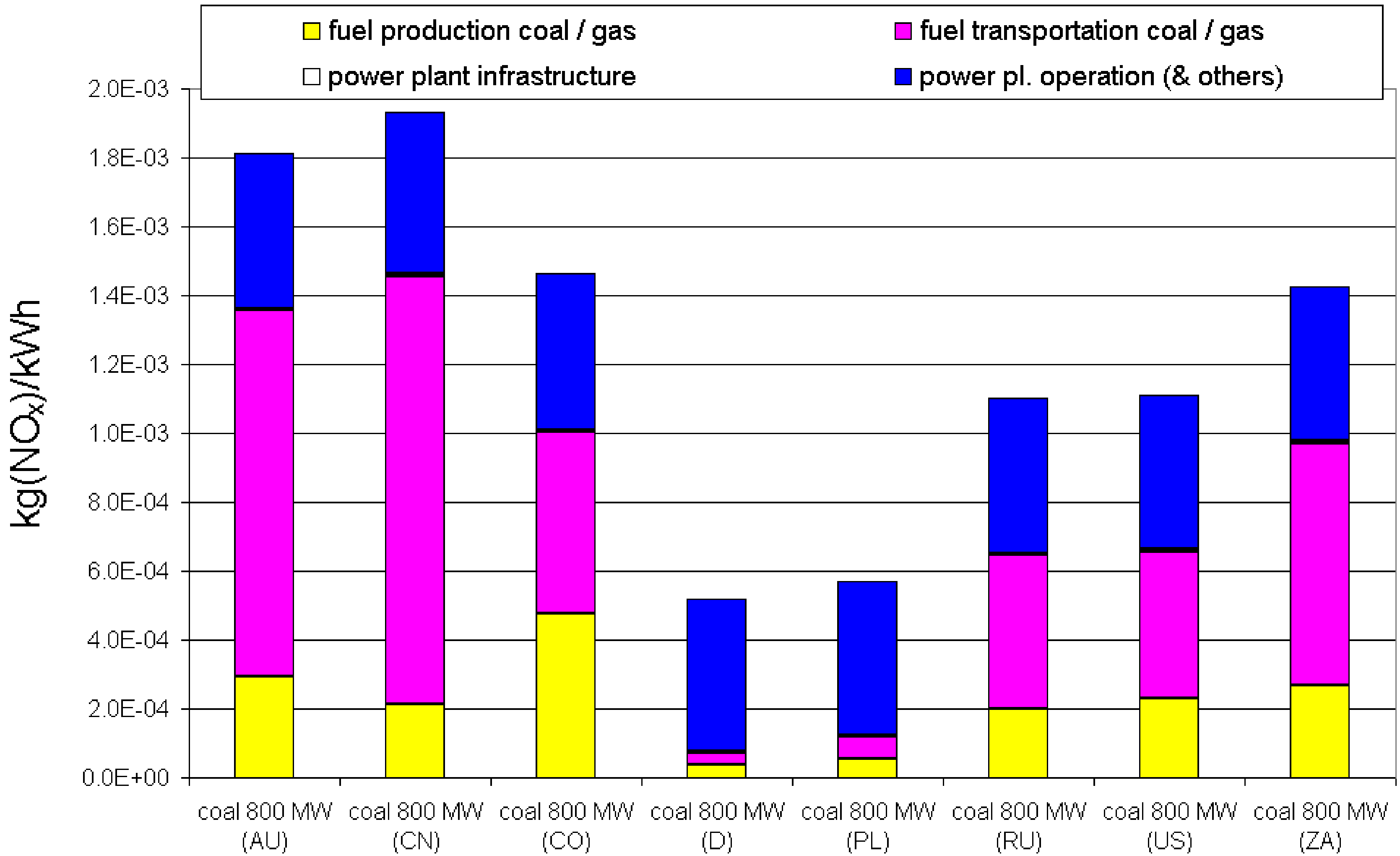


Hard coal chain: GHG emissions, power plant in Europe



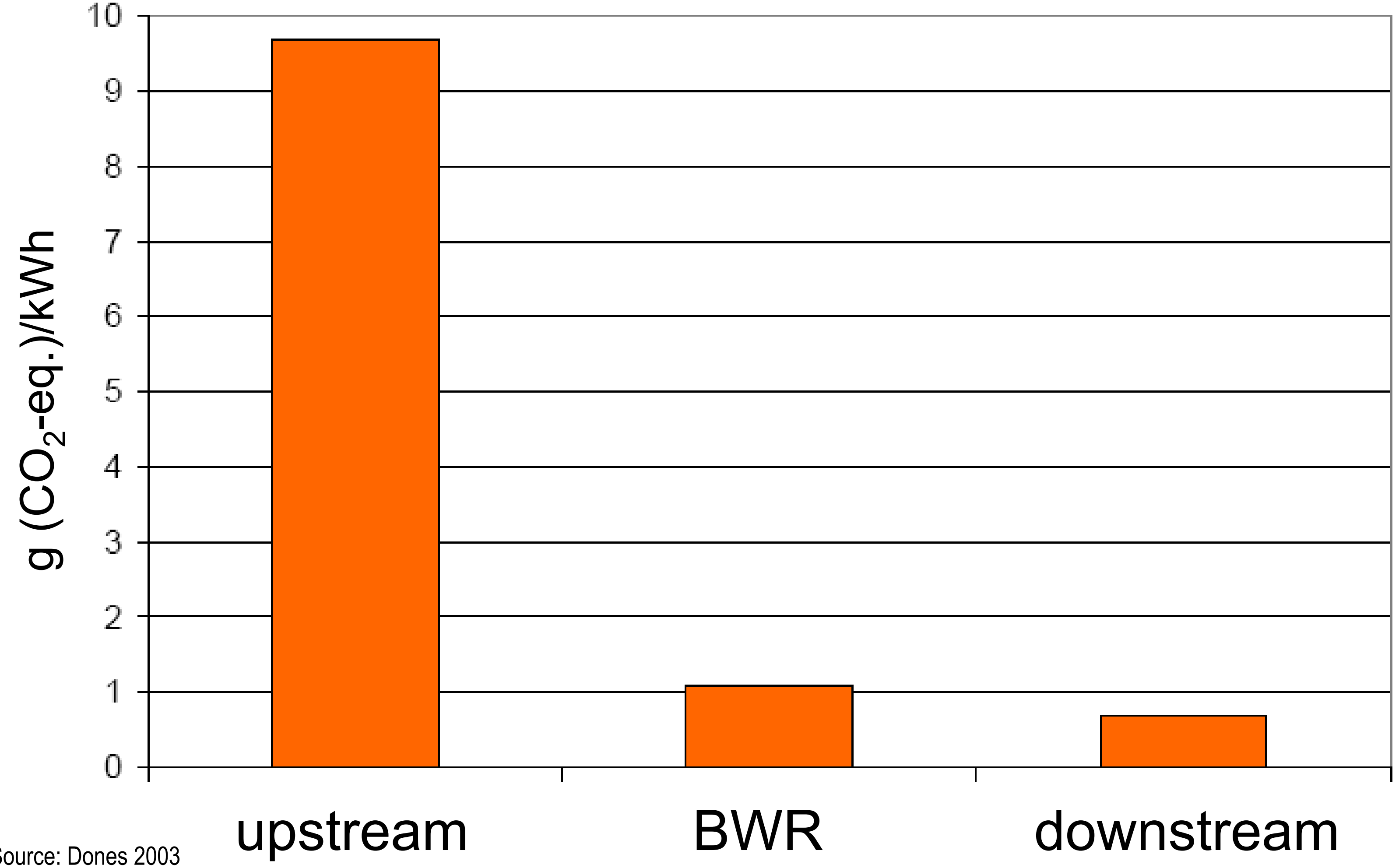
Source: Bauer, to be published 2008

Hard coal chain: NO_x emissions , power plant in Europe



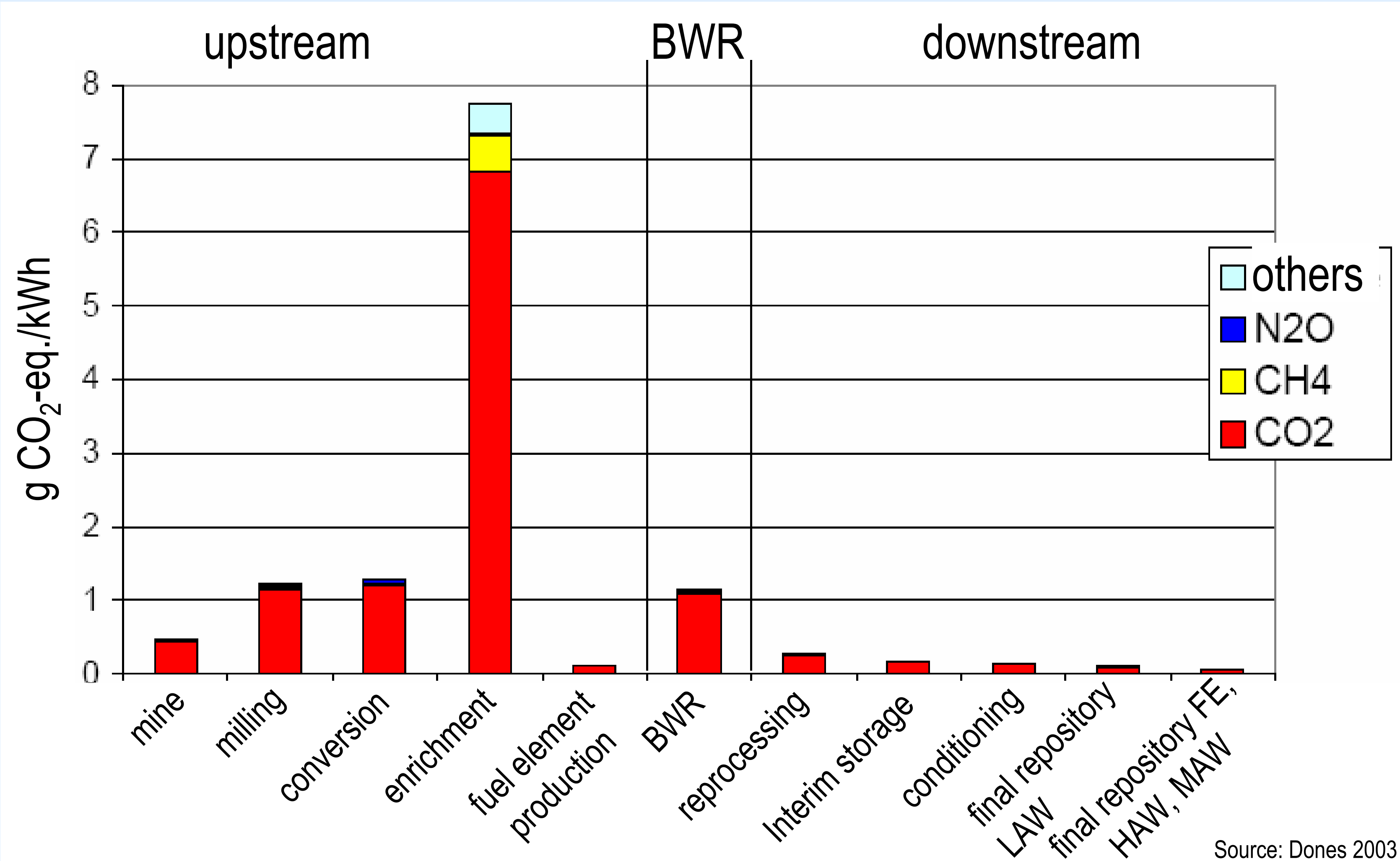
Source: Bauer, to be published 2008

Greenhouse Gas emissions, BWR in CH

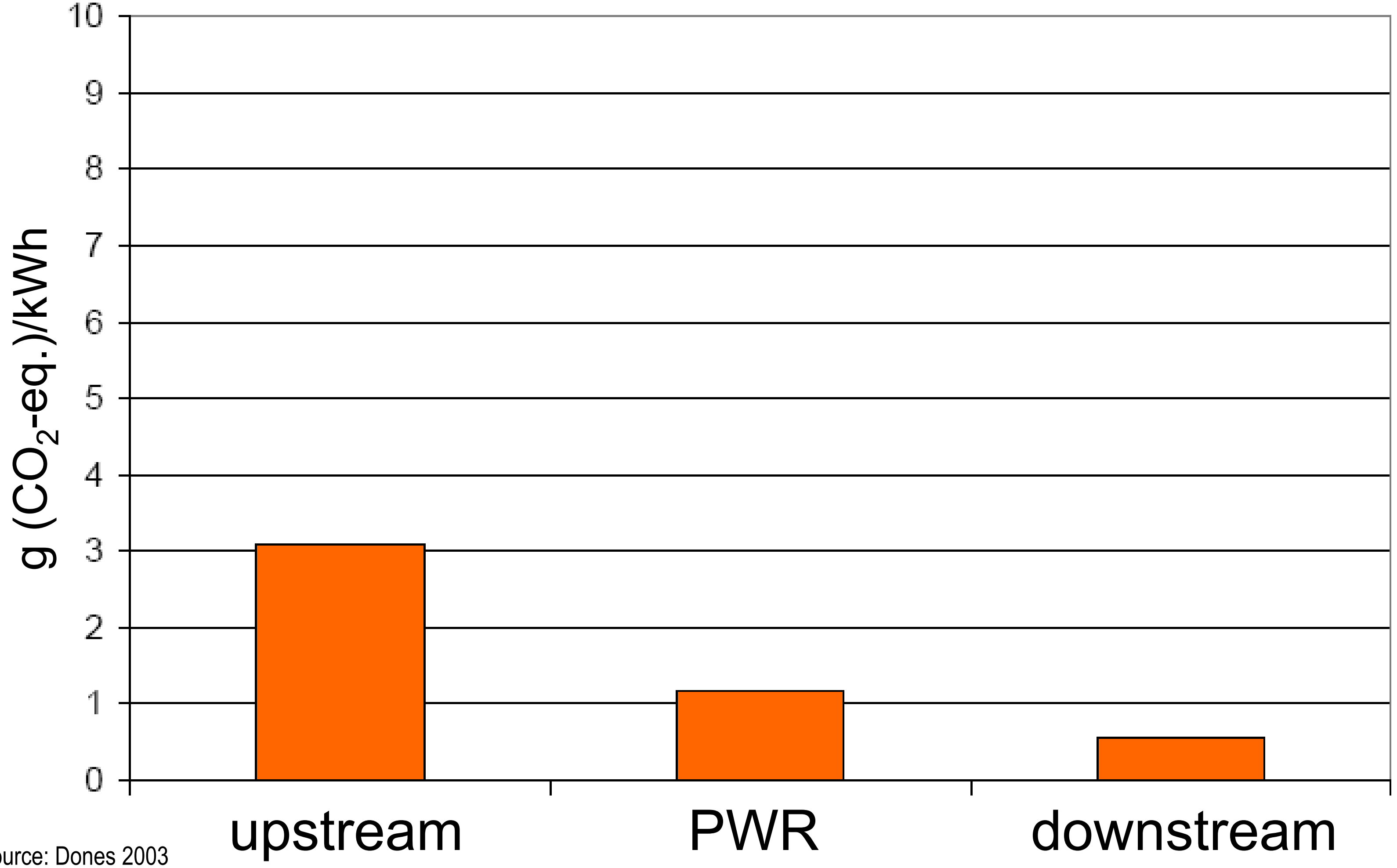


Source: Dones 2003

Greenhouse Gas emissions, average BWR in CH

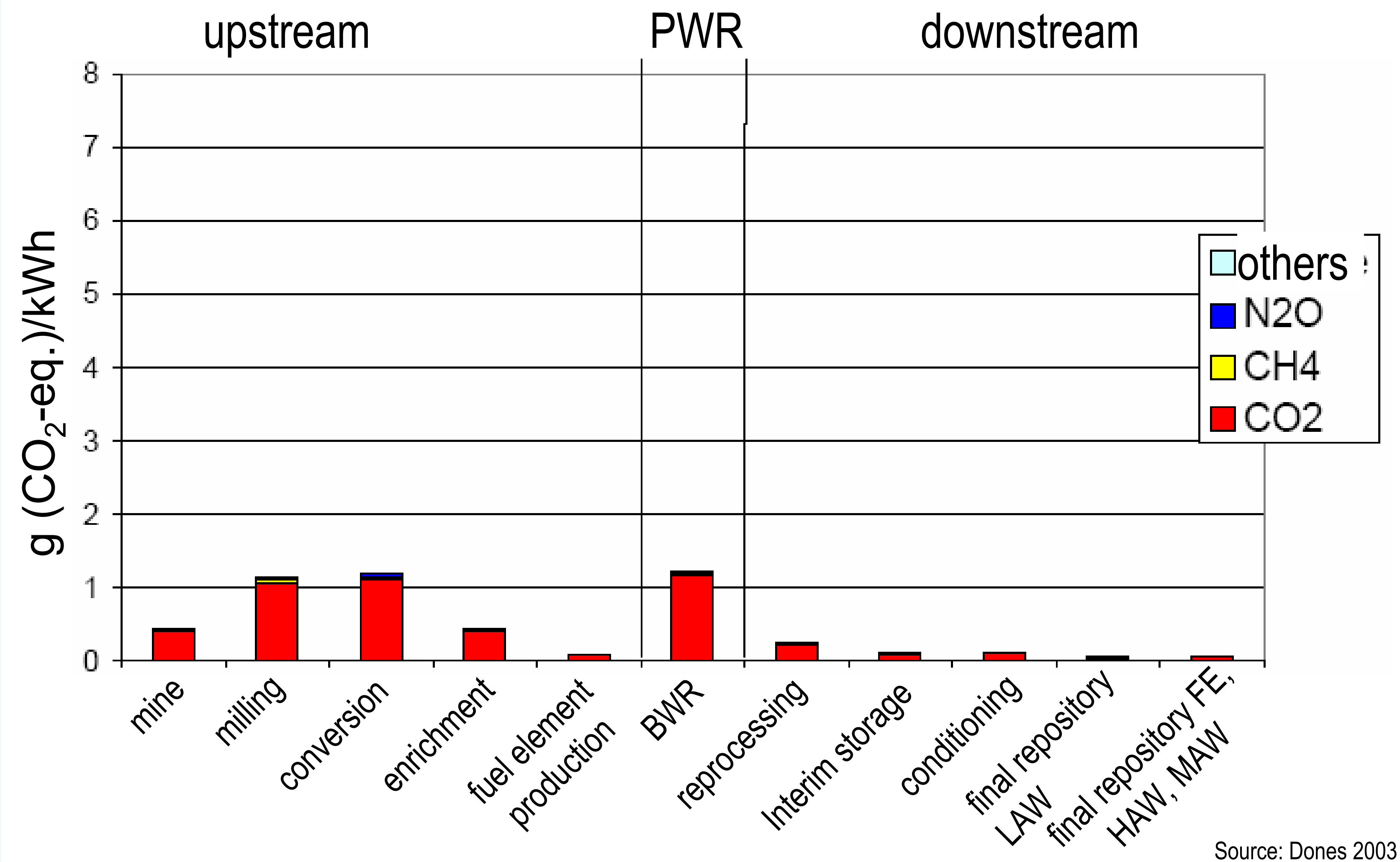


Greenhouse Gas emissions, PWR in CH



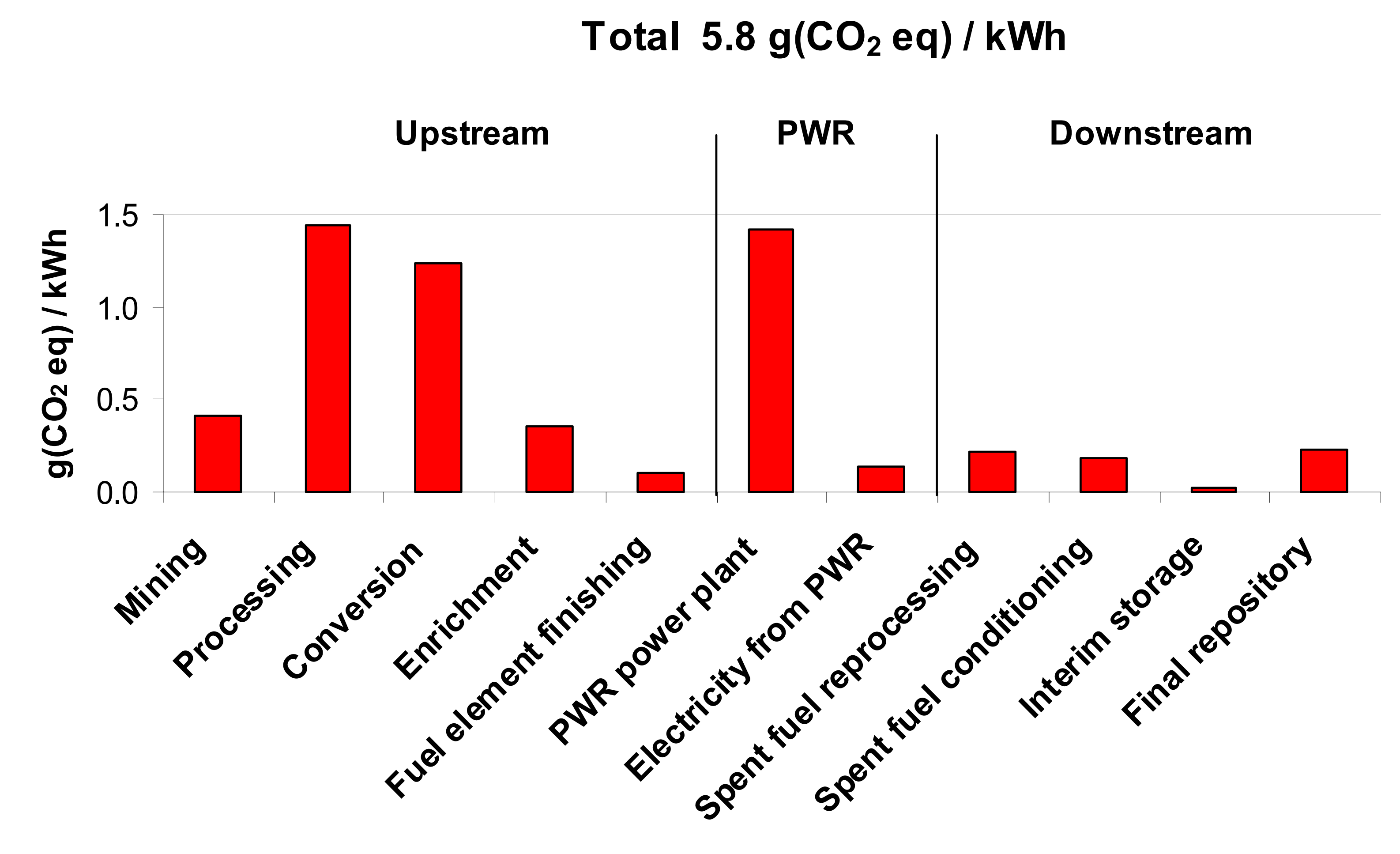
Source: Dones 2003

Greenhouse Gas emissions, average PWR in CH



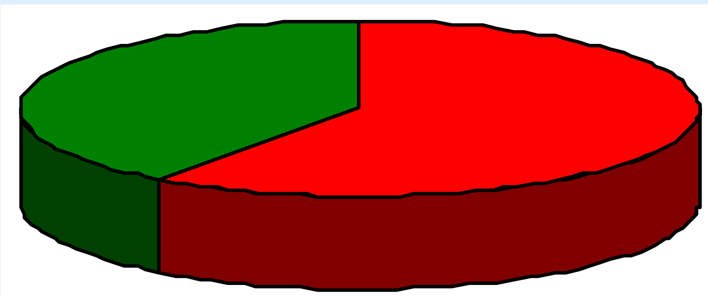
Source: Dones 2003

Greenhouse gas emissions: specific PWR in Switzerland

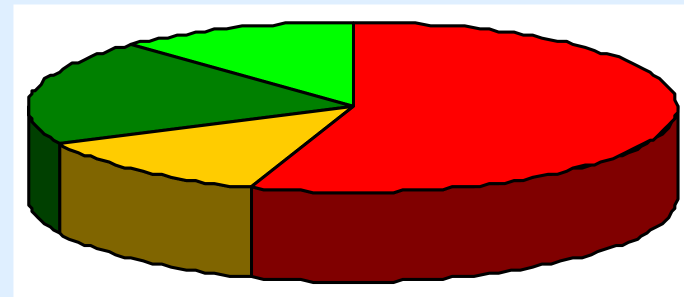


How and where is the fuel enrichment done?

PWR Switzerland

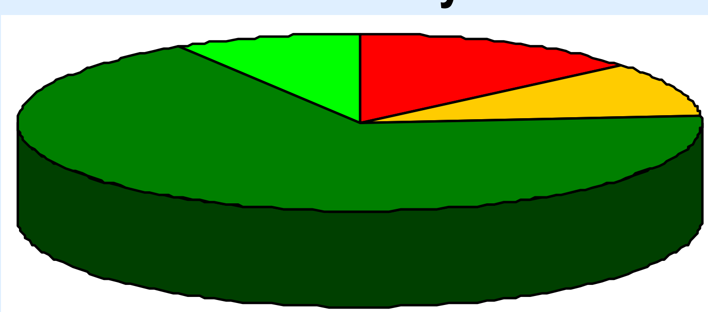


BWR Switzerland

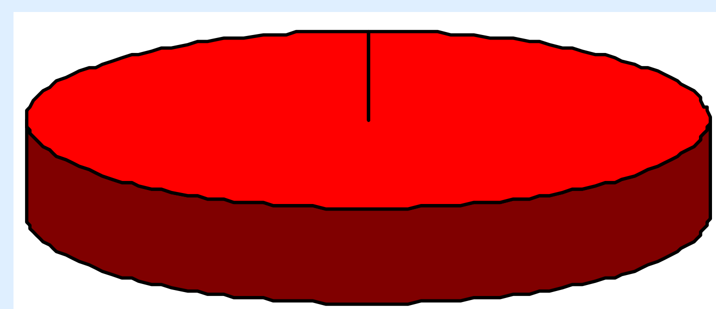


Diffusion EURODIF | Diffusion USEC | Centrifuge URENCO | Centrifuge TENEX

NPP Germany

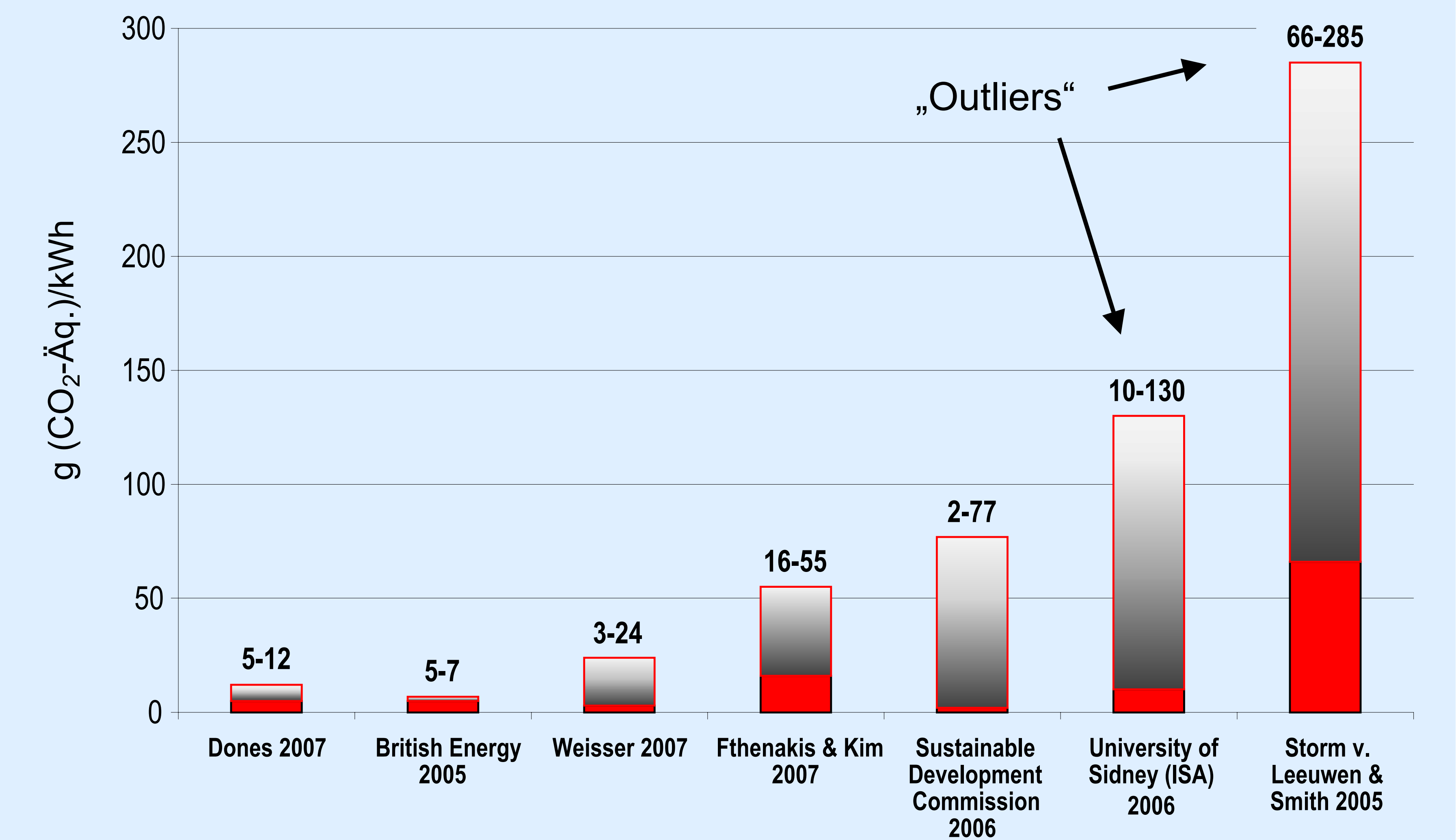


NPP France



Source: Dones 2003

Greenhouse Gases from the Nuclear Energy Chain



“Outliers”

ISA (2006)

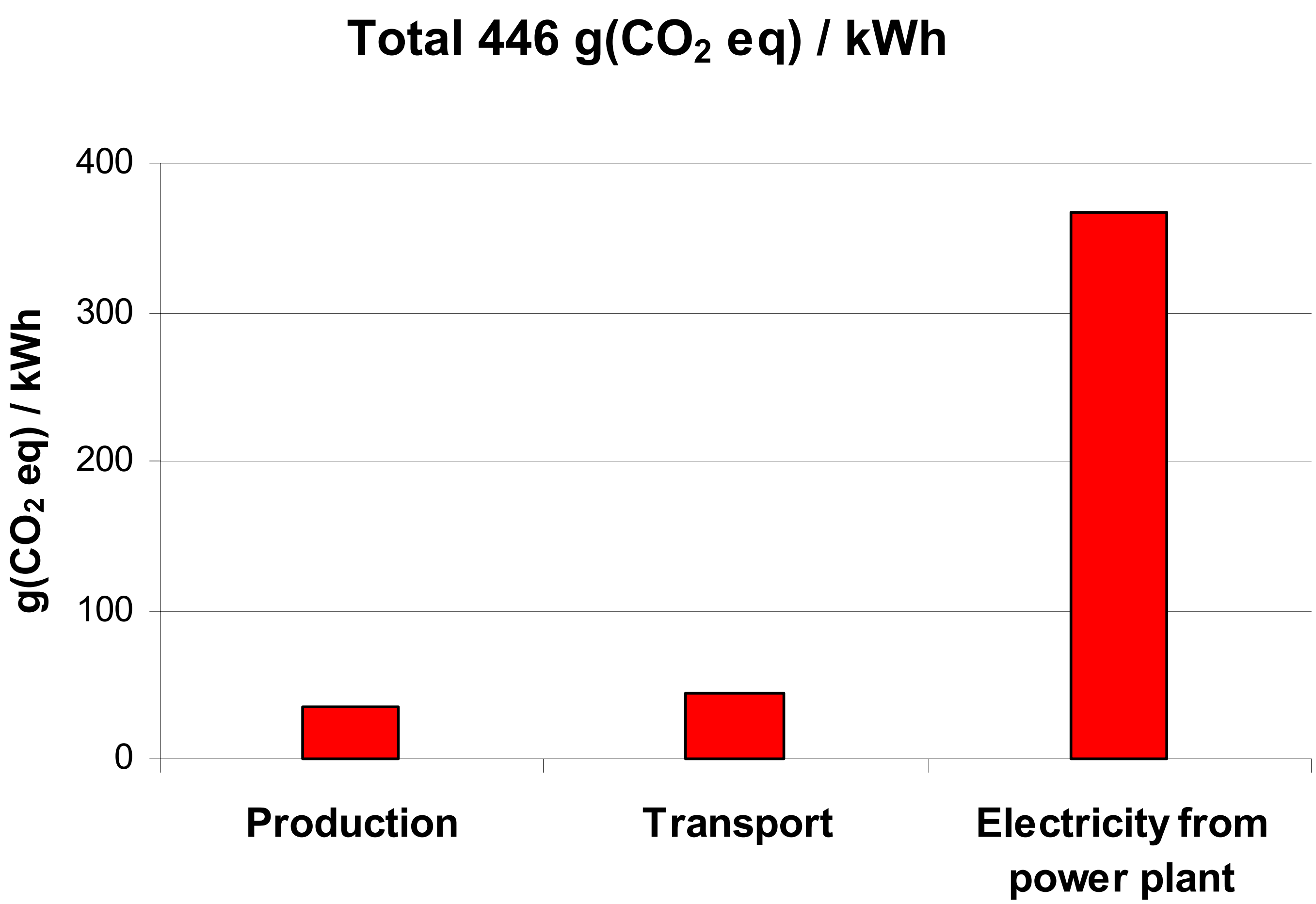
- Diffusion accounts for a high proportion of total enrichment
- Complete energy chain relies largely on hard coal as the primary fuel source
- Maximum value: Uses a very low uranium concentration in the mined uranium ore

Storm van Leeuwen & Smith (2005)

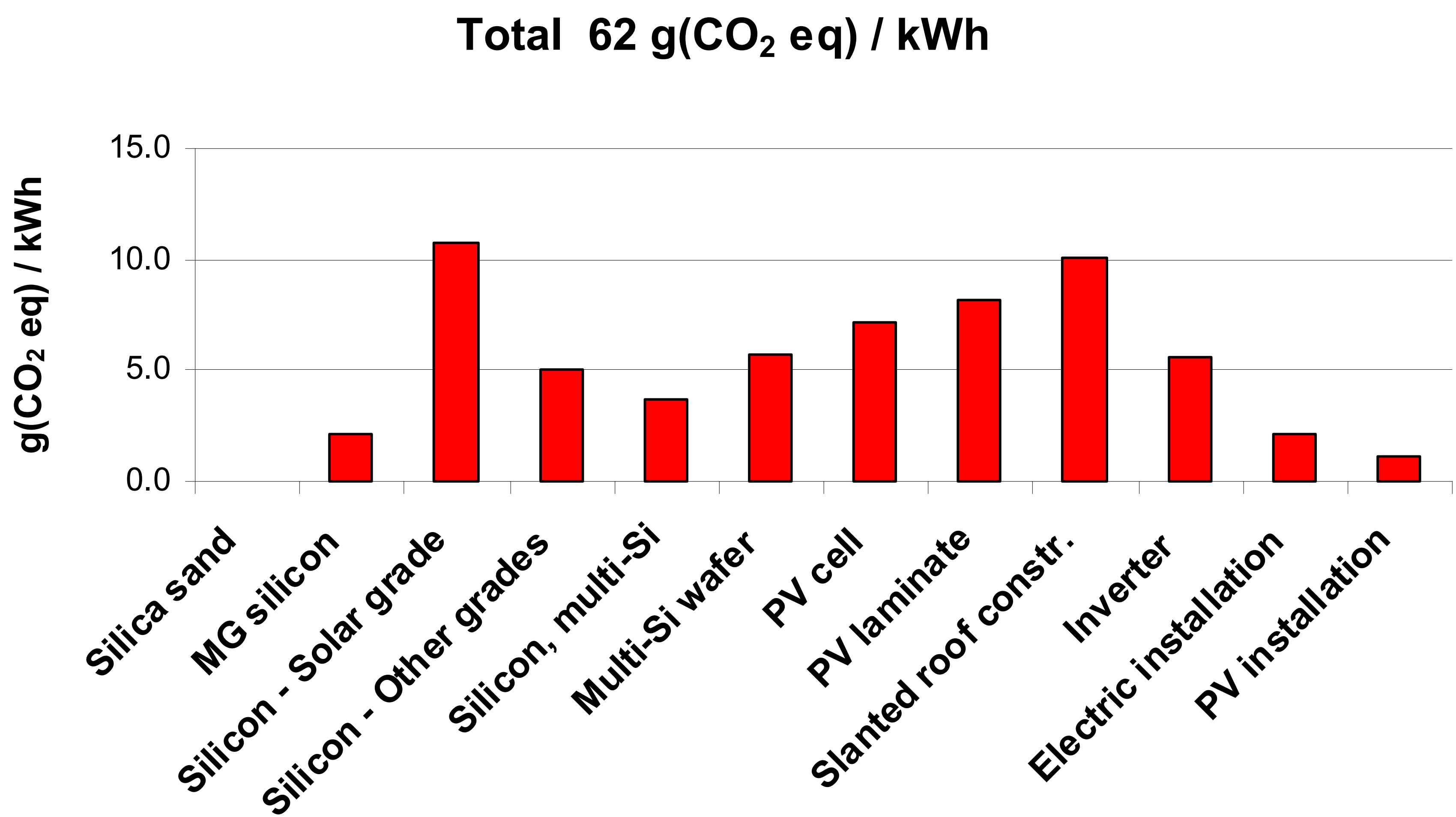
Much criticism from other experts and the criticism is supported by our own research:

- Methodology & assumptions are questionable and partly not transparent
- Used a lot of very old references
- Energy use in the nuclear cycle is systematically overestimated
  → exaggerated CO_2-emissions
- Current practice of uranium mining is not analysed correctly, especially for low concentrations in uranium ore – for Switzerland and W.Europe it is not relevant.
- Detailed research must be conducted of low concentration uranium ore mining, taking technological developments into consideration

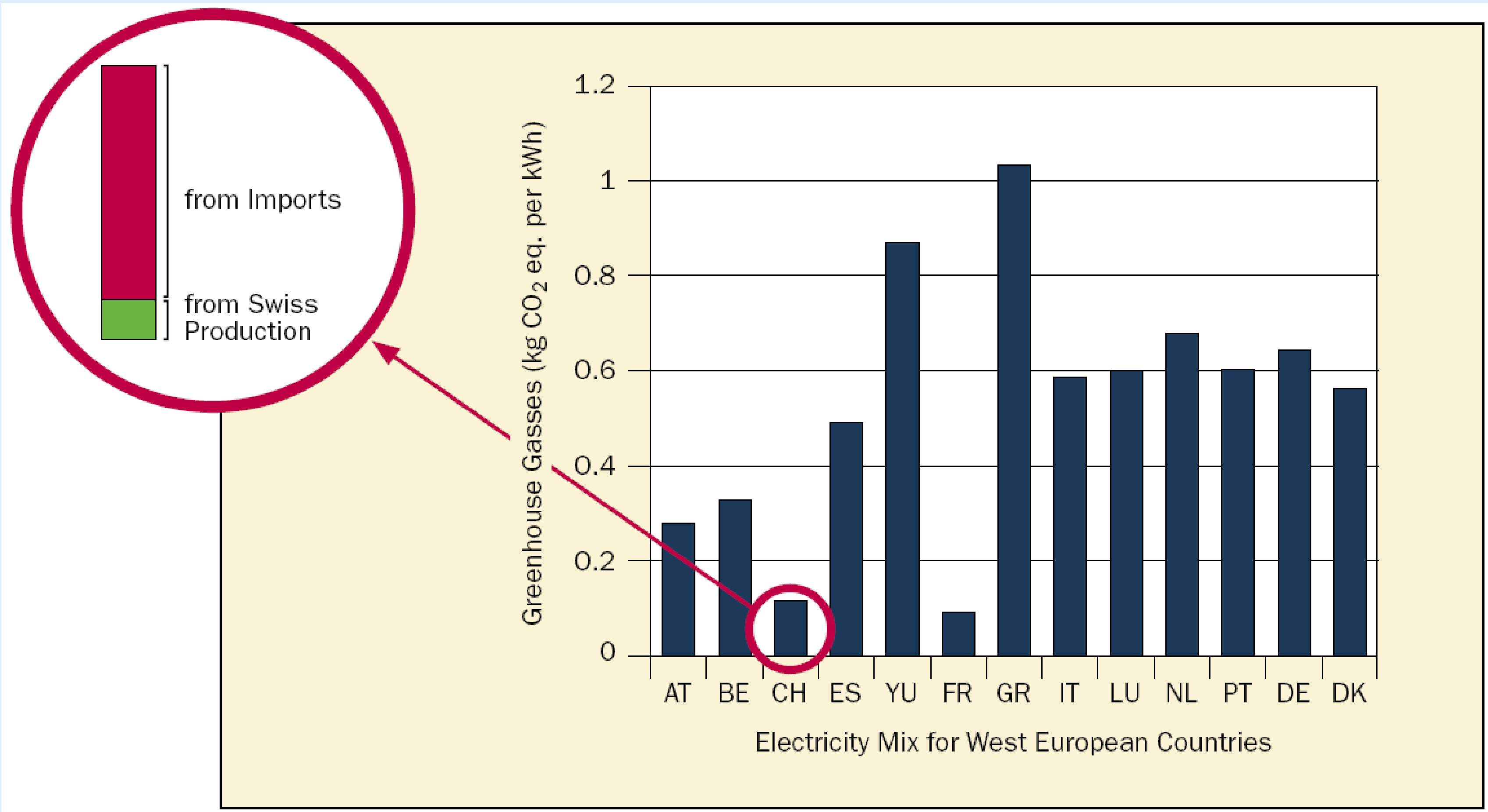
GHG-emissions: Natural Gas Combined Cycle in Italy



GHG-emissions: Photovoltaic multi-crystalline Silicon in Switzerland

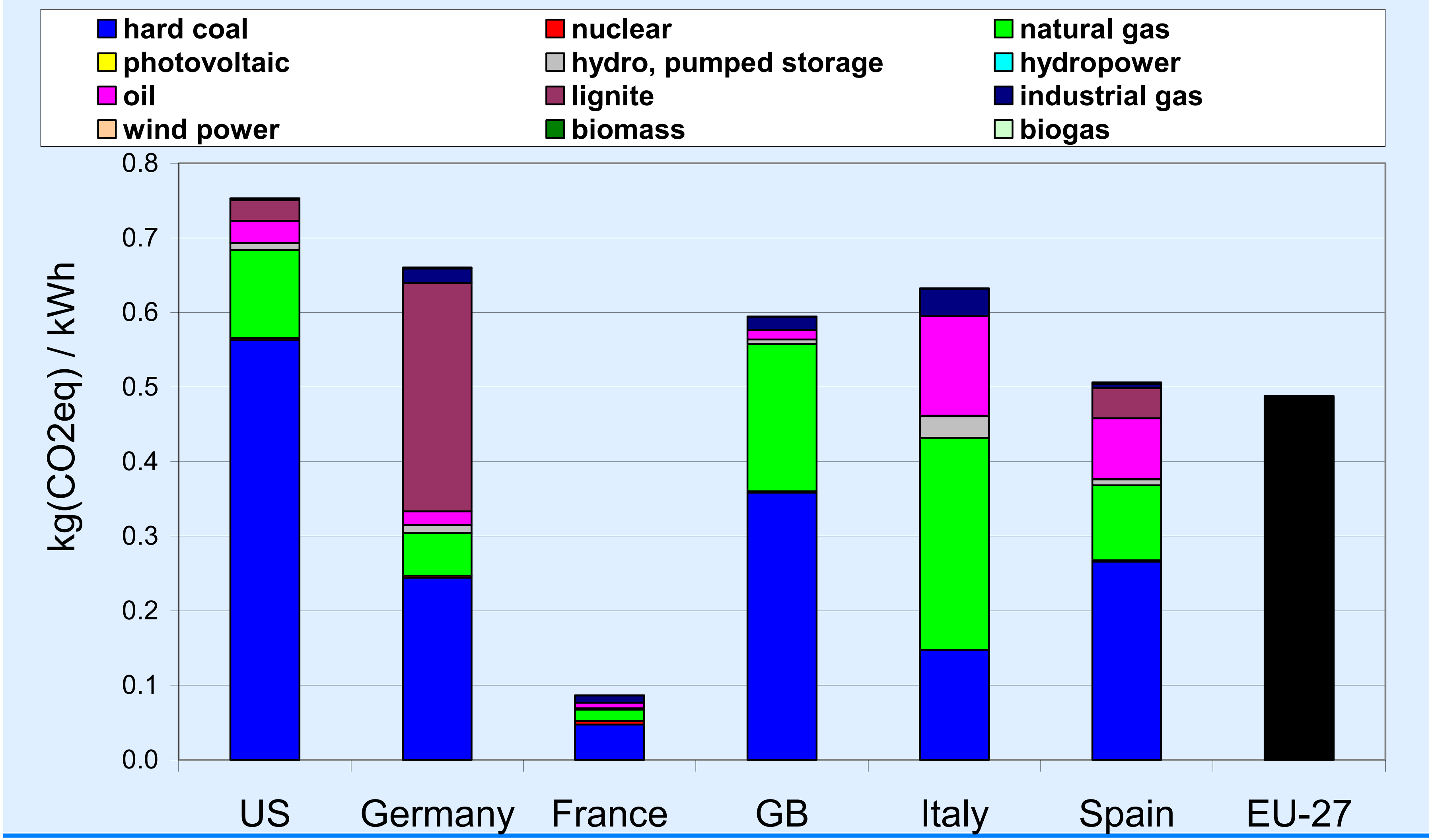


Greenhouse gas emissions, electricity mix

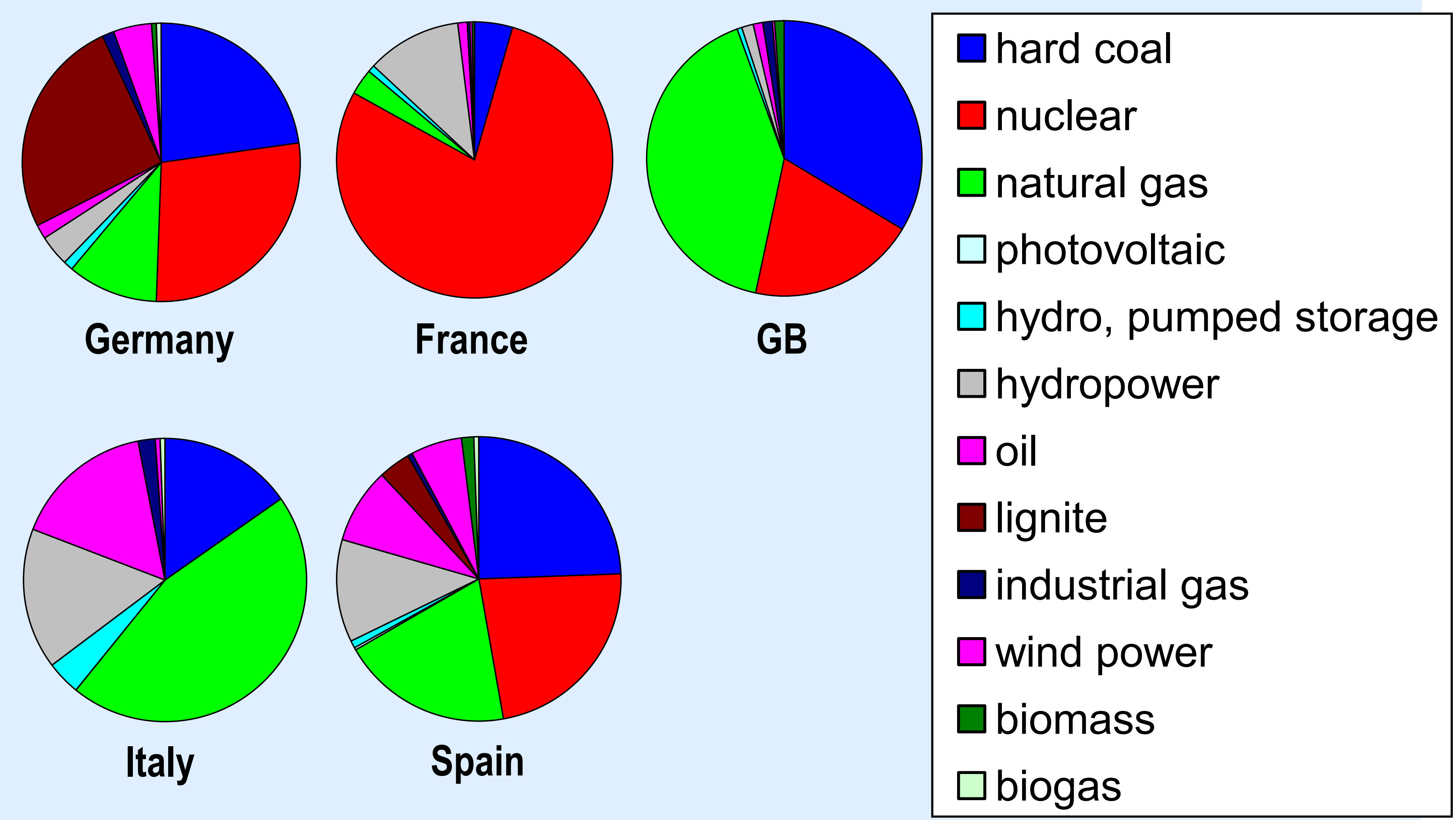


Source: ecoinvent,
Mirror on Energy No.11

GHG emissions, US & European electricity production mixes



Composition of European electricity mixes (2004)



Electricity Systems in UCTE (2000)
Life Cycle Impact Assessment LCIA (example)

The aim of LCIA is at simplifying the understanding of the results of the inventory phase (according to ISO 14040 and 14042), by using one single indicator.

Ecoindicator ’99 is a damage oriented LCIA method.

Impact potentials of environmental flows are estimated using factors;
The impacts are weighted and assigned to the damage categories:

- Human health
- Ecological quality
- Resources

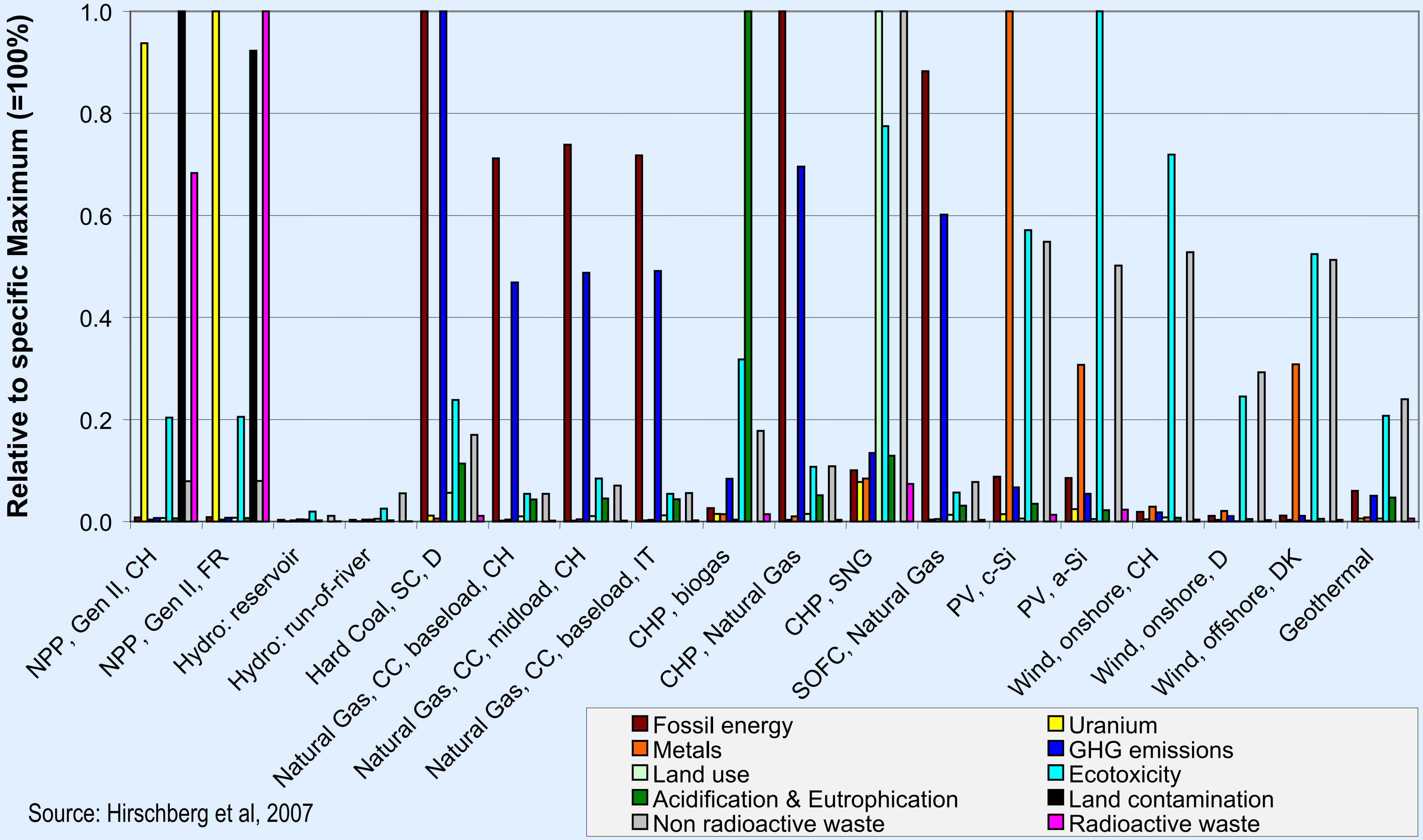
The weighting of the impact categories is made from 3 cultural perspectives:

Hierarchic: includes environmental damages that are proved.

Egalitarian: considers any effects, even with minimal scientific proof, and takes future generations into account.

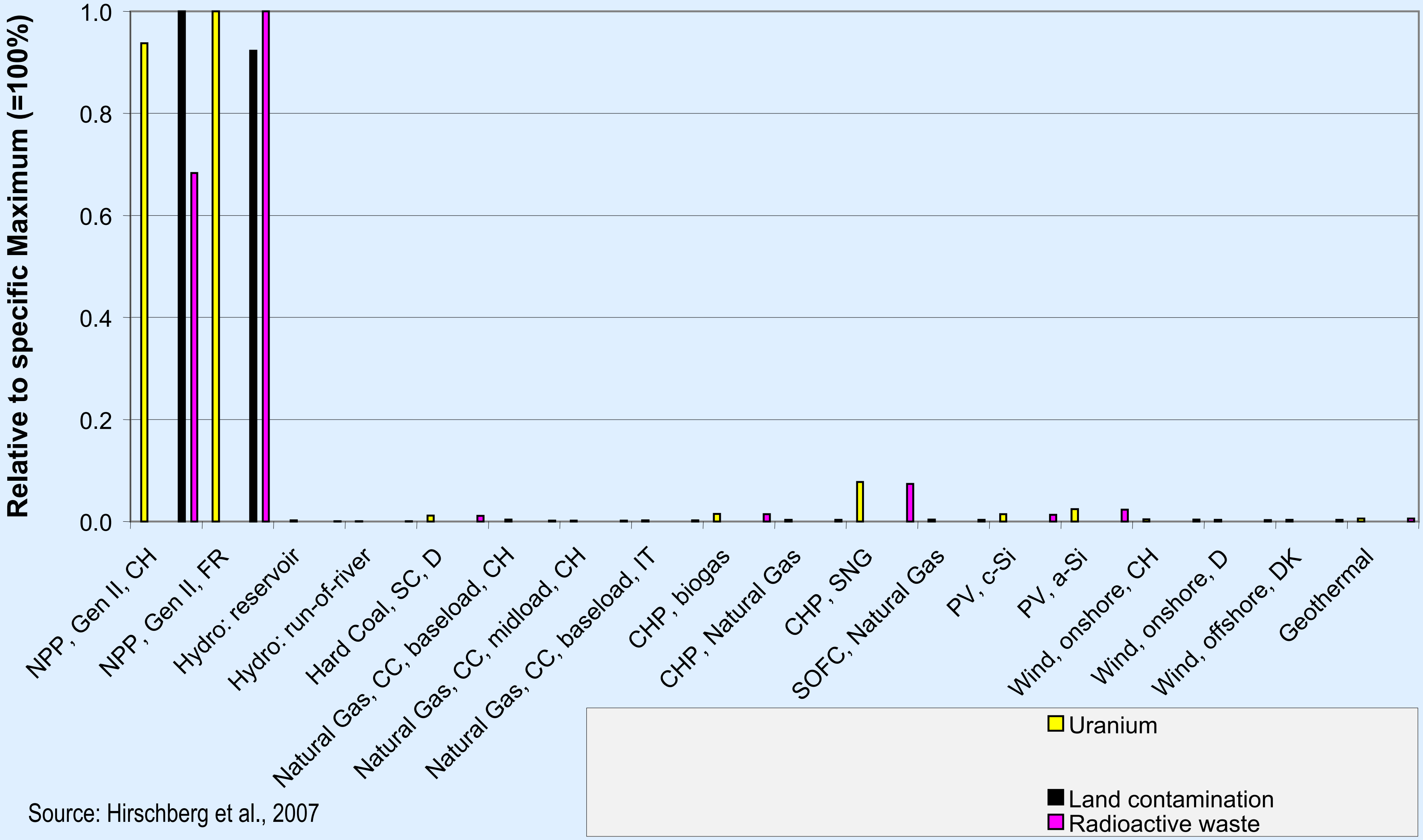
Individualist: focuses on the present, only for effects that are proven, and neglects long-term effects.

Environmental Indicators, 2000



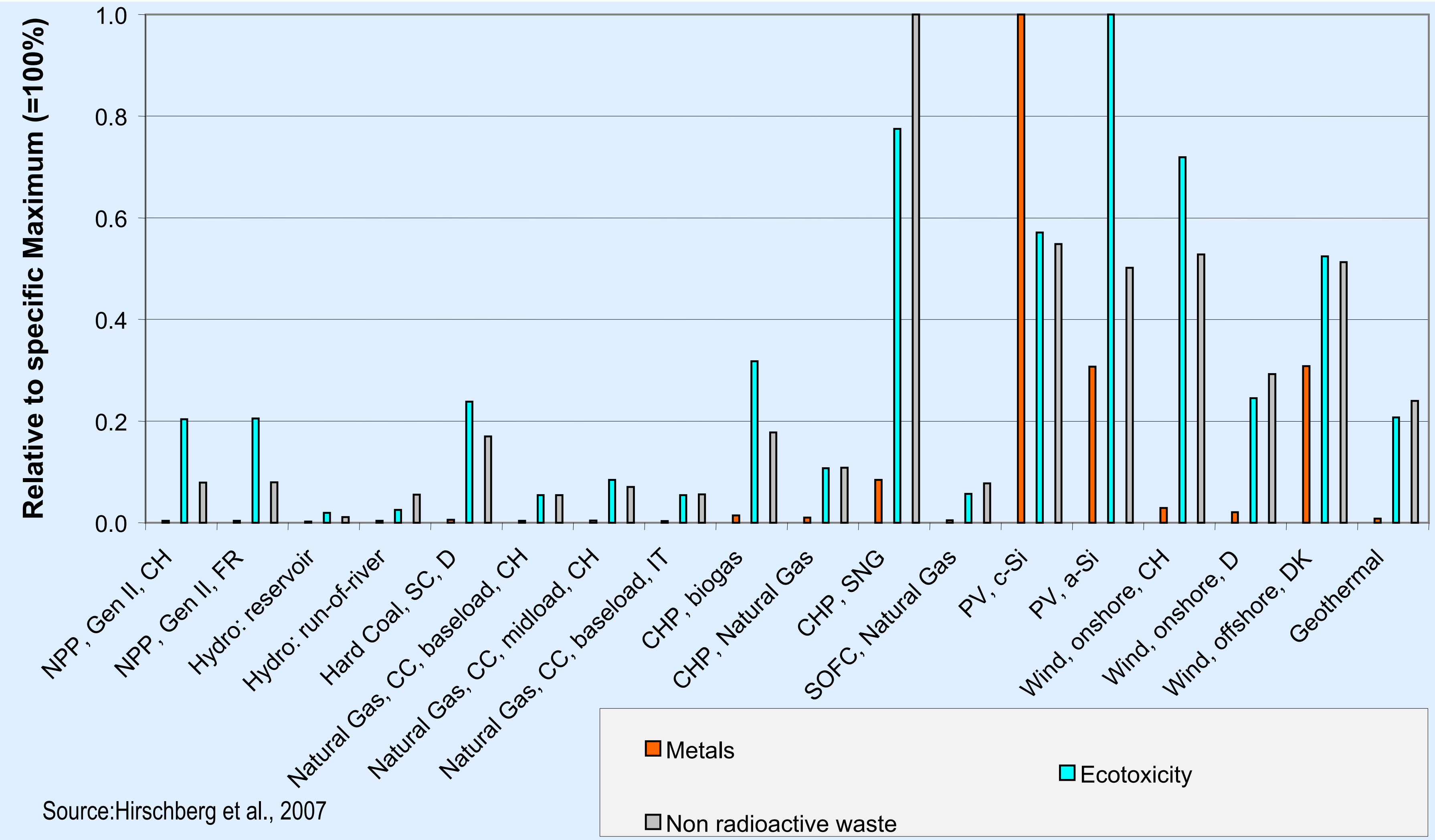
Source: Hirschberg et al, 2007

Environmental Indicators, 2000



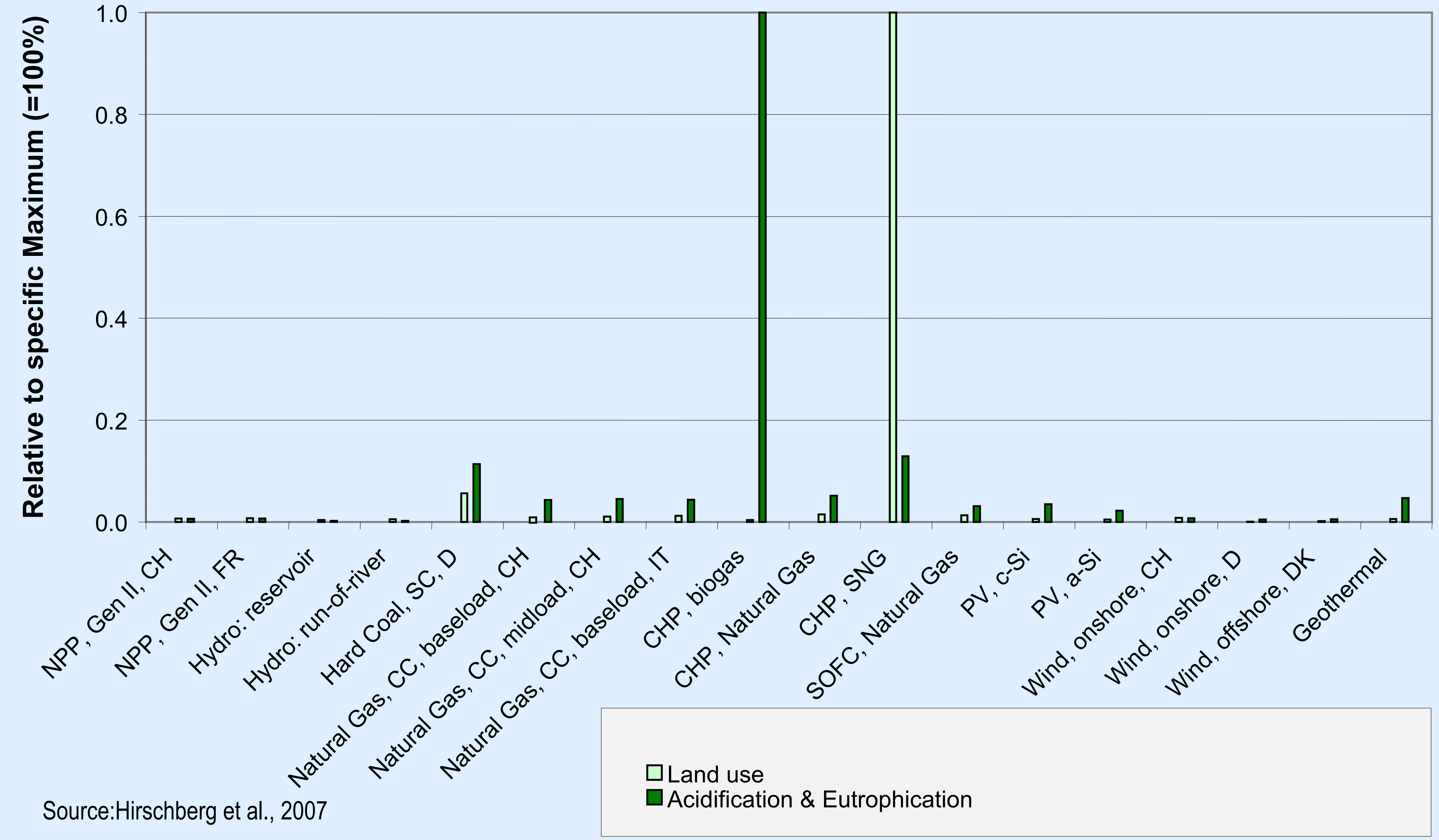
Source: Hirschberg et al., 2007

Environmental Indicators, 2000



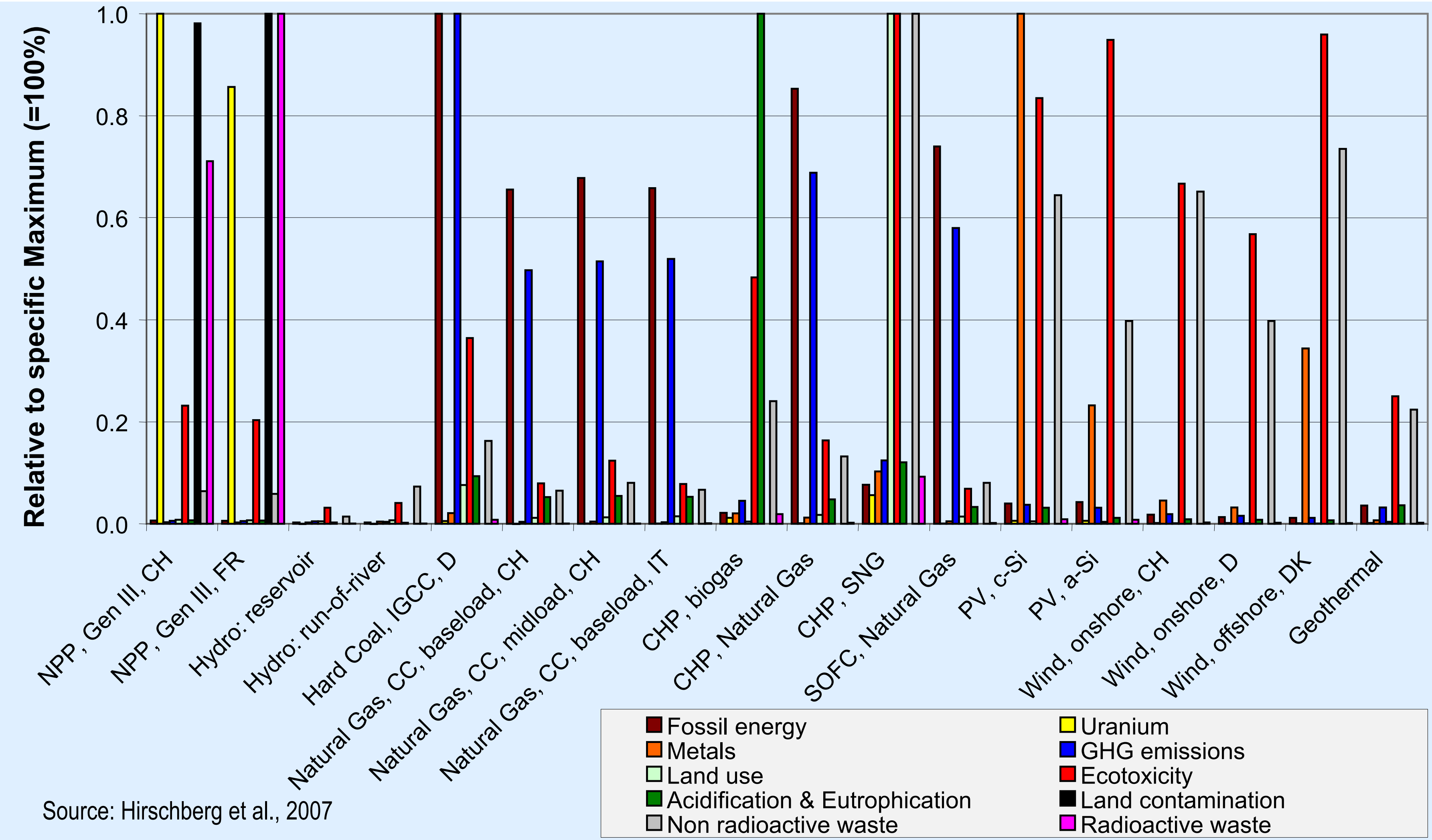
Source:Hirschberg et al., 2007

Environmental Indicators, 2000



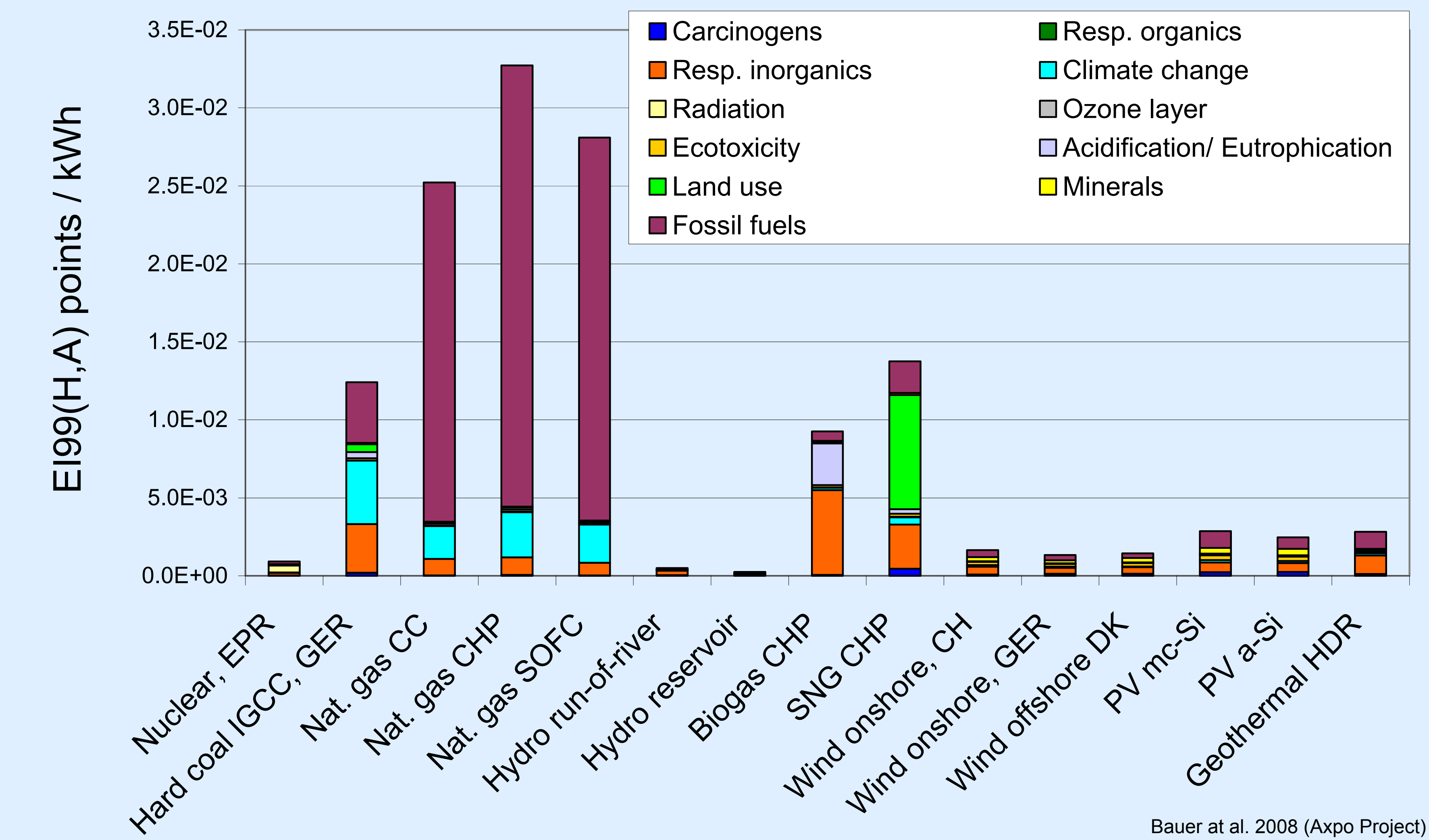
Source:Hirschberg et al., 2007

Environmental Indicators, 2030



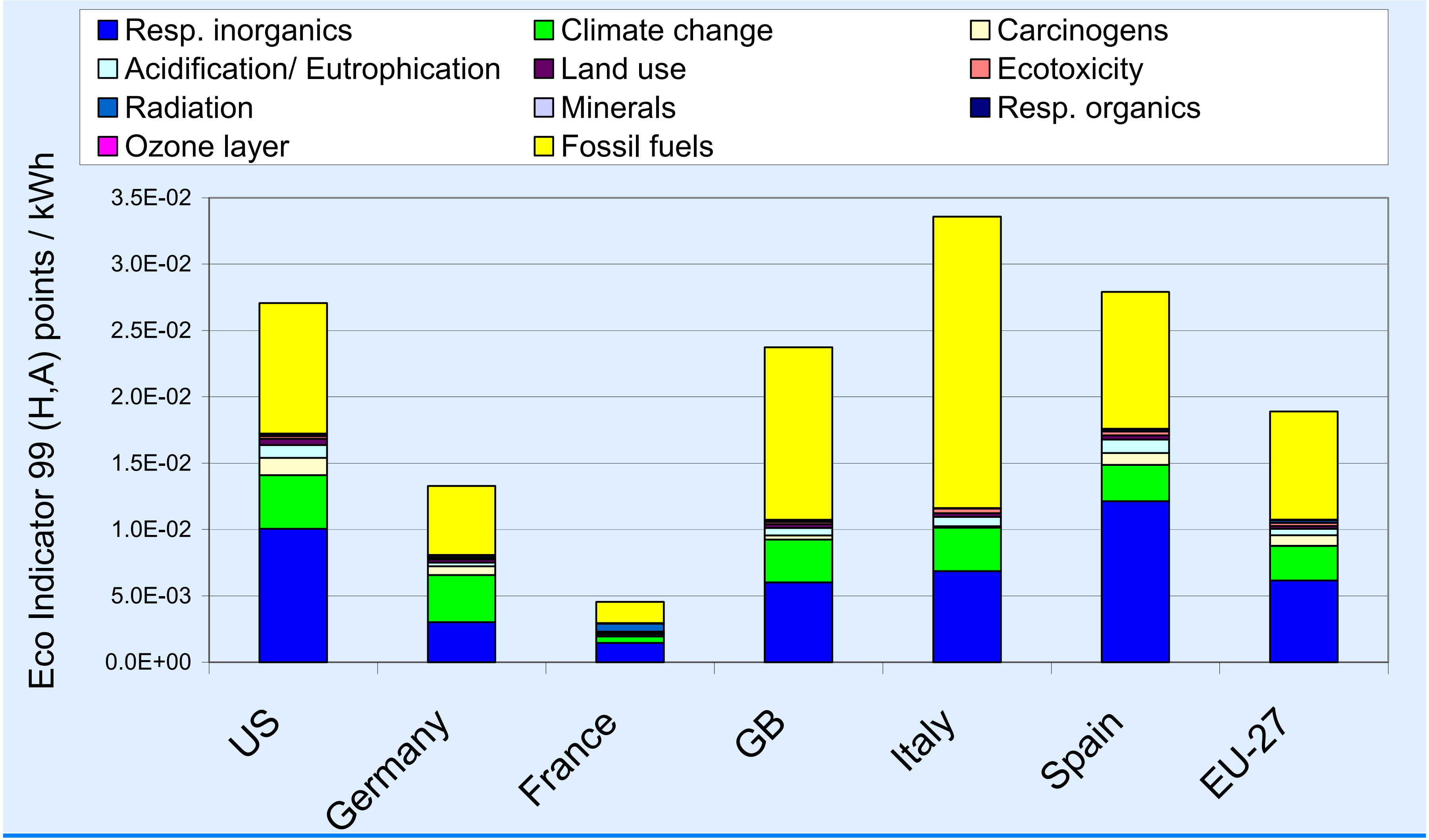
Source: Hirschberg et al., 2007

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

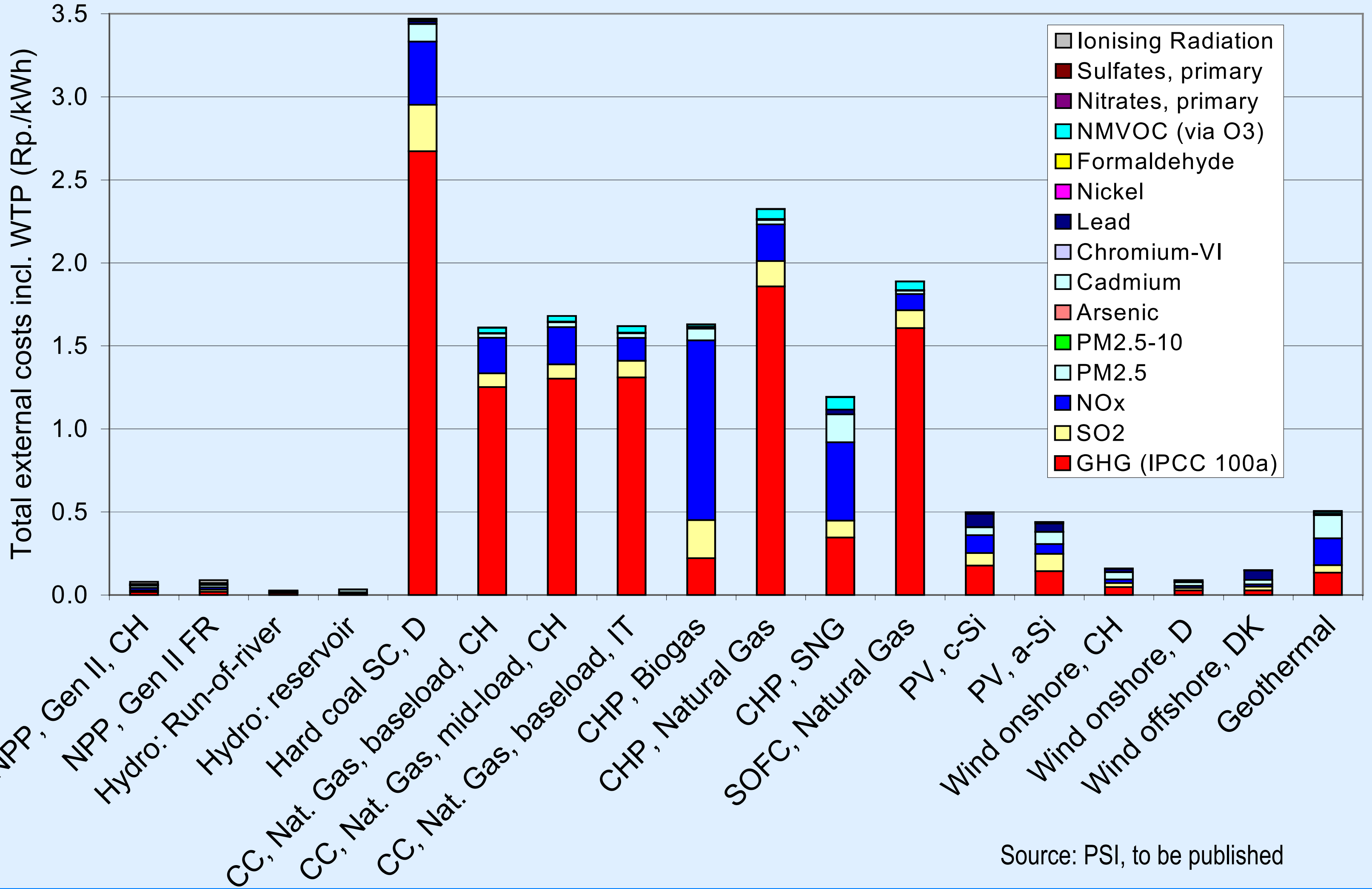


Bauer at al. 2008 (Axpo Project)

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

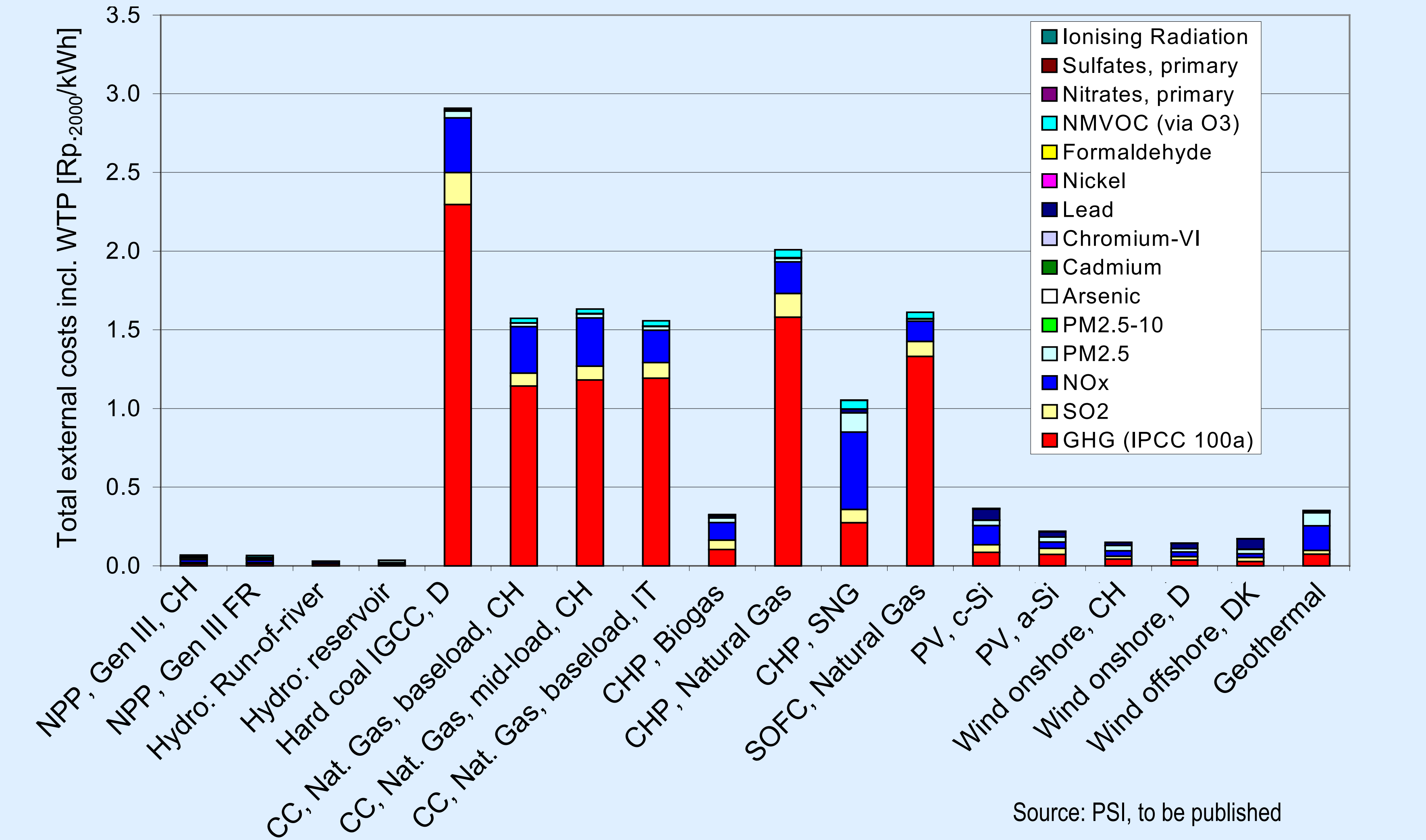


External costs, new power plants, 2000 (air pollution)



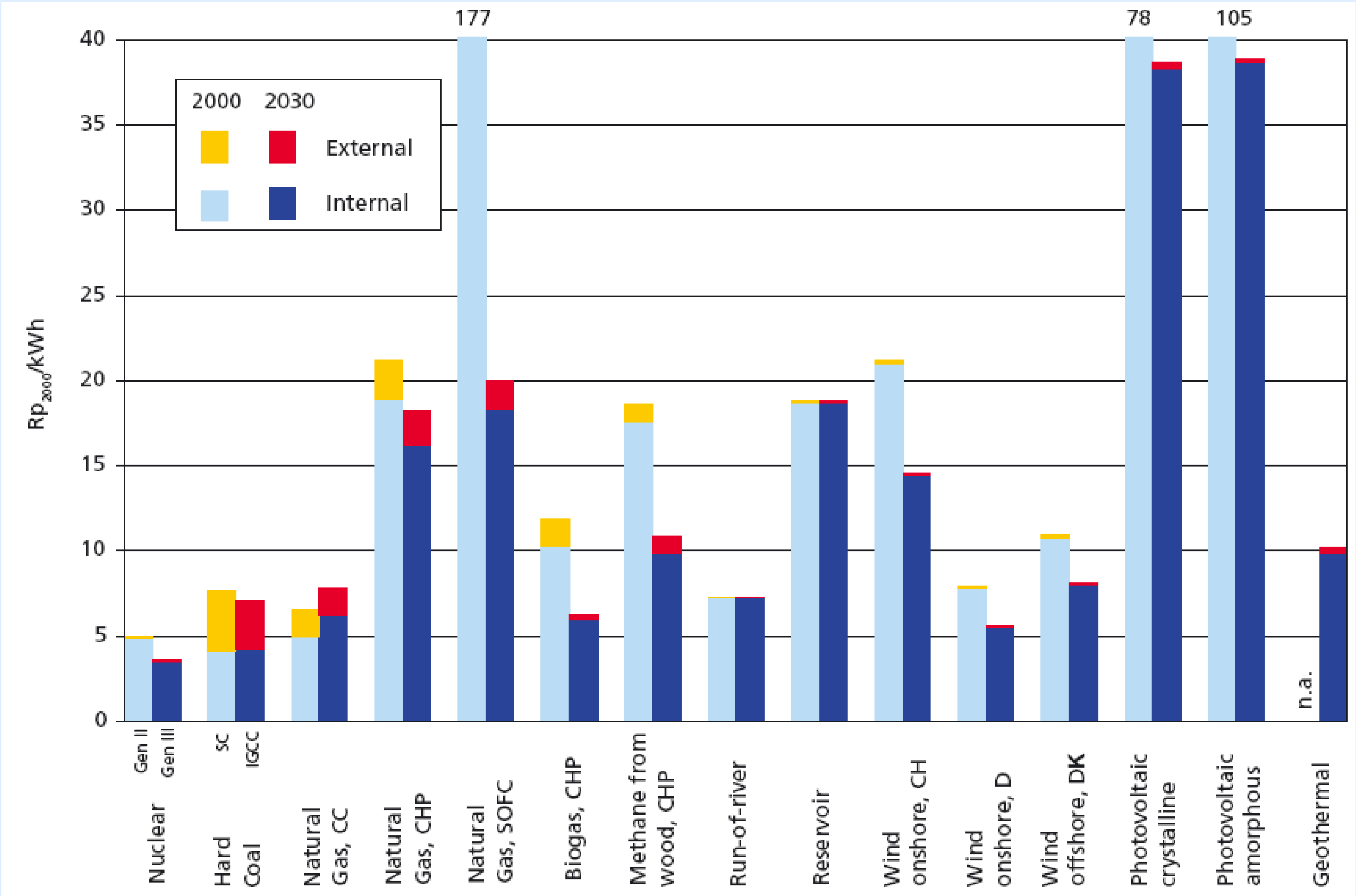
Source: PSI, to be published

External costs, 2030 (air pollution)



Source: PSI, to be published

Total costs of current and future electricity supply systems



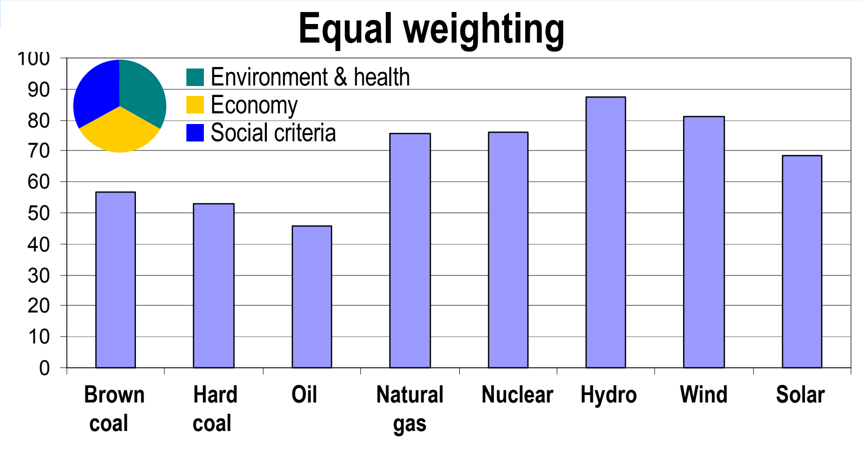
Source: Hirschberg et al., 2007

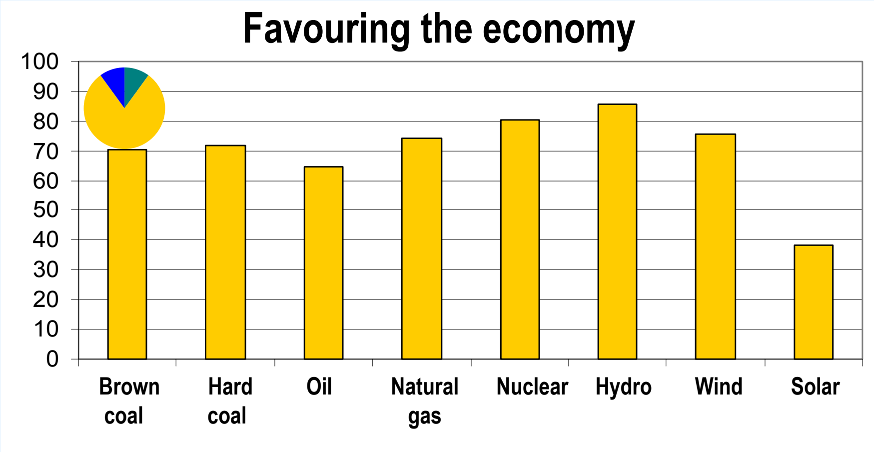
Overview of Criteria and Indicators for Comparative Sustainability Assessment of Energy Systems

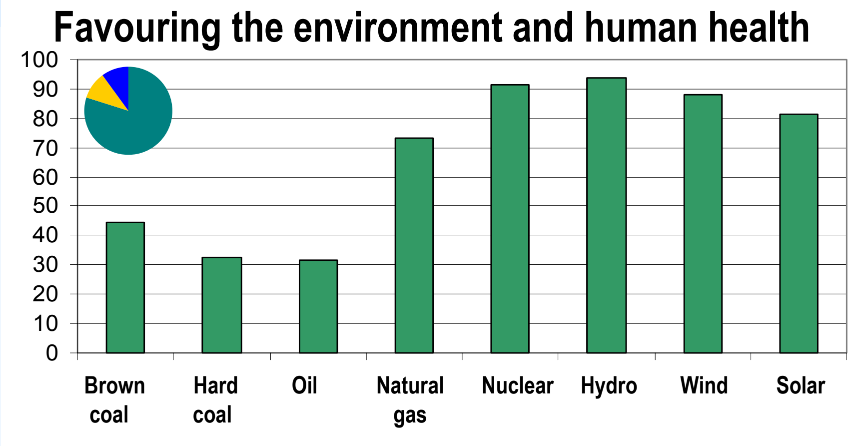
Sustainability Area	Impact Area
Economy	Financial Requirements
	Resources
Environment	Global Warming
	Regional Environmental Impact
	Non-Pollutant Effects
	Severe Accidents
	Total Waste
Social	Employment
	Proliferation
	Human Health Impacts (normal operation)
	Local Disturbances
	Critical Waste Confinement
	Risk Aversion

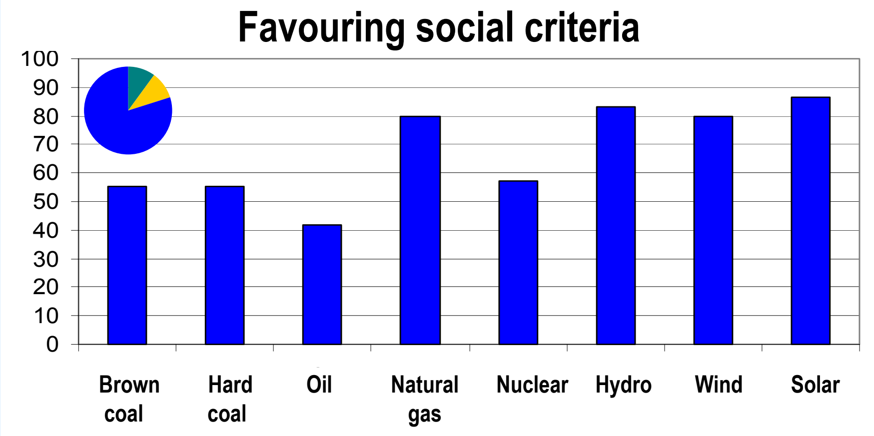
Source: Hirschberg et al., 2004

Multi-criteria Decision Analysis (MCDA), Current Systems, Germany









Source: Hirschberg et al., 2004, Current systems, Germany

Kaya Equation Implications

CO_2 Emissions = Carbon content of energy x Energy intensity of economy x Production per person x Population

Needs to be reduced by factor of 3 to reach the goal

Needs to be reduced by factor of 5 to reach the goal

Needs to be reduced by factor of 2 to reach the goal

Goal:
Reduction by 50% until 2050

Decrease by factor 2.5
(-1.8% per year in alternative scenario of IEA 2004)

Increase by factor 1.65
(1% growth per year)

Increase by factor 1.5
(IPCC 2000)

Necessitates very strong expansion of all “carbon-free” technologies

Kaya Equation Implications

CO_2 Emissions = Carbon content of energy x Energy intensity of economy x Production per person x Population

Needs to be reduced by factor of 3 to reach the goal

Needs to be reduced by factor of 6.5 to reach the goal

Needs to be reduced by factor of 4 to reach the goal

Goal: Reduction by 50% until 2050

Decrease by factor 1.6 (-1% per year)

Increase by factor 2.15 (1.6% growth per year)

Increase by factor 1.5 (IPCC 2000)

Necessitates very strong expansion of all “carbon-free” technologies

Concluding remarks

- LCA with LCI as its basis is a fundamental tool for balanced and comprehensive systems comparison, and for a wide variety of environmental studies.
- Detailed and transparent studies demonstrate that most renewables and nuclear have very low total GHG-emissions
- Both renewables & nuclear are needed to meet future demand & respond to the climate change challenge.
- None of the technological options can fulfill all criteria concerning sustainability and market requirements.
- Trade-offs between environmental, economic and social sustainability components are inevitable and are influenced by value judgements.