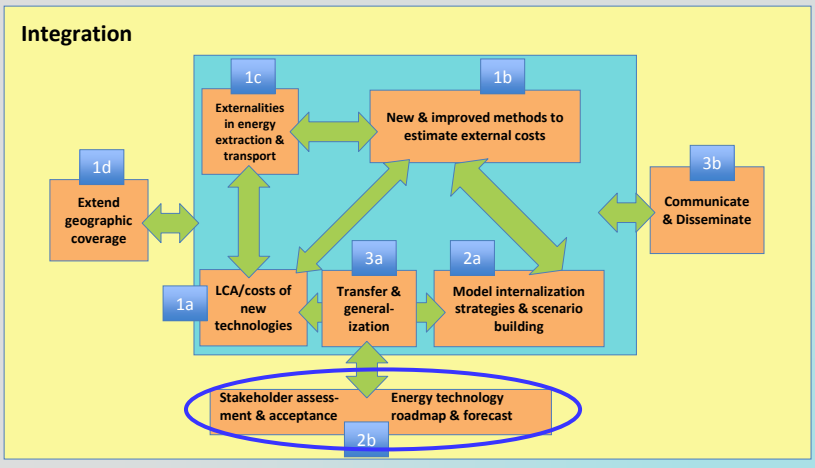
SIXTH FRAMEWORK PROGRAMME
[6.1]
[Sustainable Energy Systems]

Multi-Criteria Decision Analysis of Power Systems

Stefan Hirschberg
Paul Scherrer Institut

38th LCA Discussion Forum, Zurich, 19 June 2009

The NEEDS Integrated Project
(Where does RS2b fit in?)



NEEDS: New Energy Externalities Developments for Sustainability

Objectives and results

- General
  - To broaden the basis for decision support by examining the robustness of results under various **stakeholder perspectives**
  - To explore **stakeholder perspectives** on external costs
- Results
  - Stakeholder acceptance of external costs
  - Sustainability criteria and indicators for evaluation of energy technologies
  - Comparative sustainability of technologies by means of total (internal + external) and Multi-criteria Decision Analysis (MCDA)
  - Sensitivity to stakeholder preference patterns

Main Stakeholder Categories

Each category is further divided into several sub-categories (not shown)

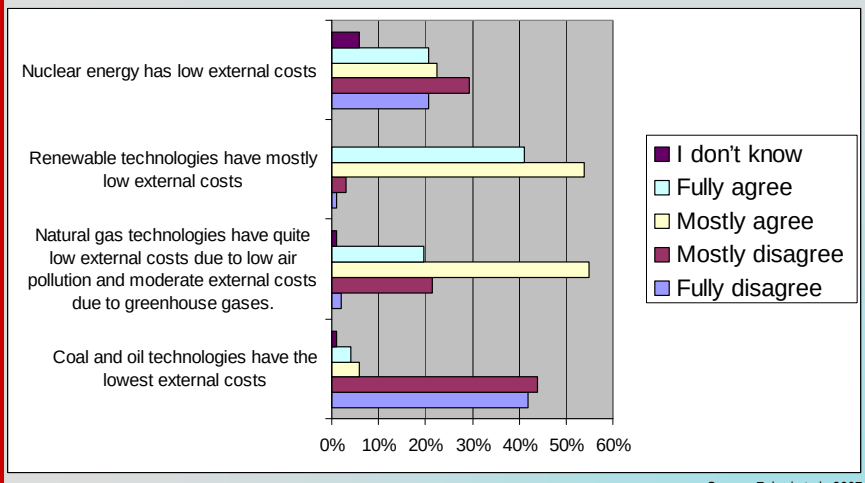
Energy Supplier
Energy Consumer
Non-Governmental Organization (NGO)
Government Energy or Environmental Agency
Regulator / Government Authority
Association (e.g. trade or industry)
Politician
Researcher / Academic
Consultant
Other

Approach to Aggregation (I): Total Costs

- Internal + External = Total Costs
- Money becomes *the* common denominator for all indicators.
- It is assumed that *all* indicators can be monetized.
- It is assumed that stakeholders can *agree* on the value of life, the environment, etc.
- Nevertheless, money is the most useful and widely accepted common numerator.
- Cost-benefit analysis based on (total) costs has great attractions for guiding public policy

Survey I: Externality Concept, Results and Uses

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...



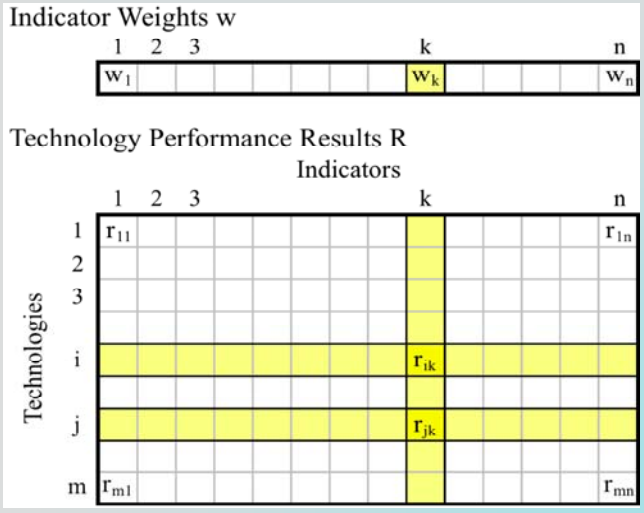
Source: Faberi et al., 2007

Examples of Difficult but Potentially Important Social Aspects

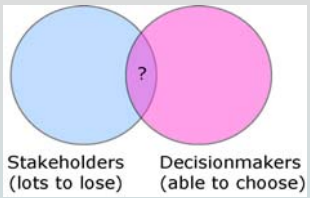
- Social justice
- Risk aversion and perception
- Resilience of the energy system
- Conflict potential

Theoretically, any externality can be monetized, but in practice methodologies and valuation are often controversial.

Approach to Aggregation (II): General MCDA Algorithm



The Multi-Criteria Decision Analysis (MCDA) problem



- Big, complex problems → multiple stakeholders, multiple criteria.
- Different interests → different preferences, no simple optima.
- Complexity & cognitive inadequacy can prevent even single decision makers from making consistent rankings.
- Purpose: aid to thinking and decision-making (but doesn't give **"the"** answer)

7 Steps Towards MCDA

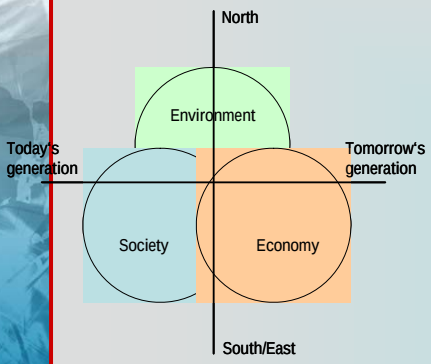
1. Select alternatives (with stakeholder input)
2. Establish criteria and indicators (with stakeholder input)
3. Quantify the technology- and country-specific indicators
4. Analyse the MCDA requirements
5. Select the most suitable MCDA method(s) and tool(s)
6. Test and adapt the selected method(s) and tool(s)
7. Elicit stakeholder preferences, provide feedback

Technology Range

NUCLEAR	• **Generation III** • **Generation IV**	• European Pressurised Reactor (EPR – GEN III) • European Fast Reactor (EFR- GEN IV)
FOSSIL	**Centralised** • Coal • Lignite • Natural Gas (NG).	• Conventional and gasification - with/without carbon capture (CCS) ▪ Post-combustion ▪ Oxyfuel
	Decentralised cogeneration • Natural Gas only (NG)	• Internal combustion engine (NG) • Molten carbonate and solid oxide fuel cells (NG)
BIOMASS	• **Decentralised cogeneration** - Fuel cells. - Gas turbine.	• Gasified waste wood to fuel cells. • Gasified cultivated wood and waste straw to gas turbine.
SOLAR	• **Photovoltaics** - Centralised and decentralised	• Cells - Crystalline silicon (ribbon) • Thin film (Cadmium Telluride)
	• **Centralised thermal power plant**	• Concentrating trough collectors
WIND	• **Offshore wind turbine**	• 24MW turbine in deep water

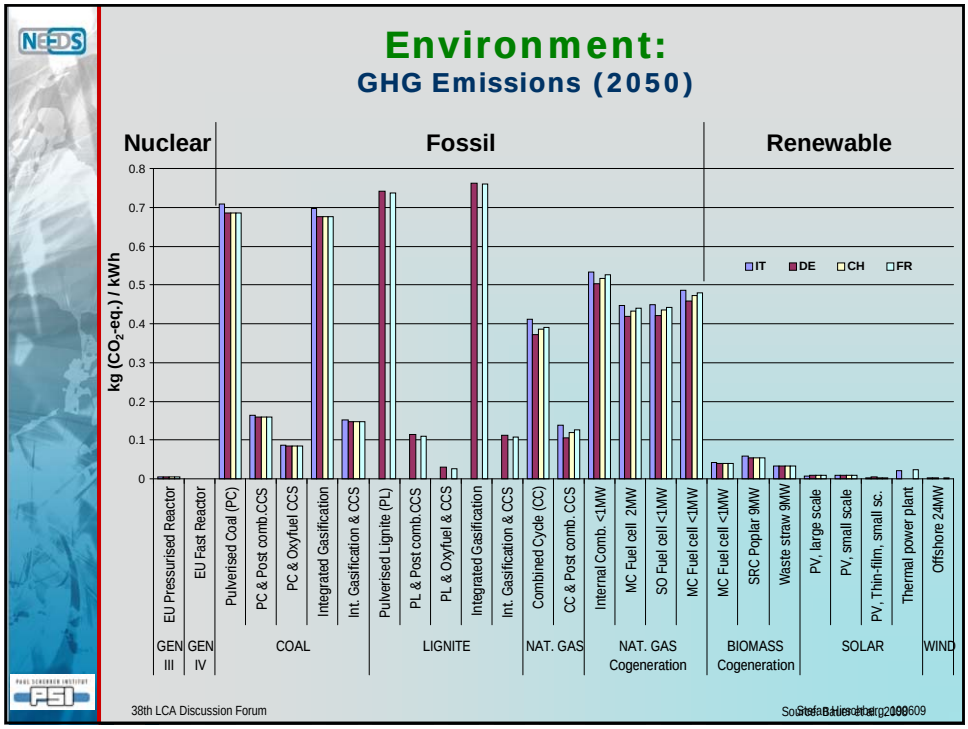
Total of 26 for FR, 25 for DE, 21 for IT and 19 for CH

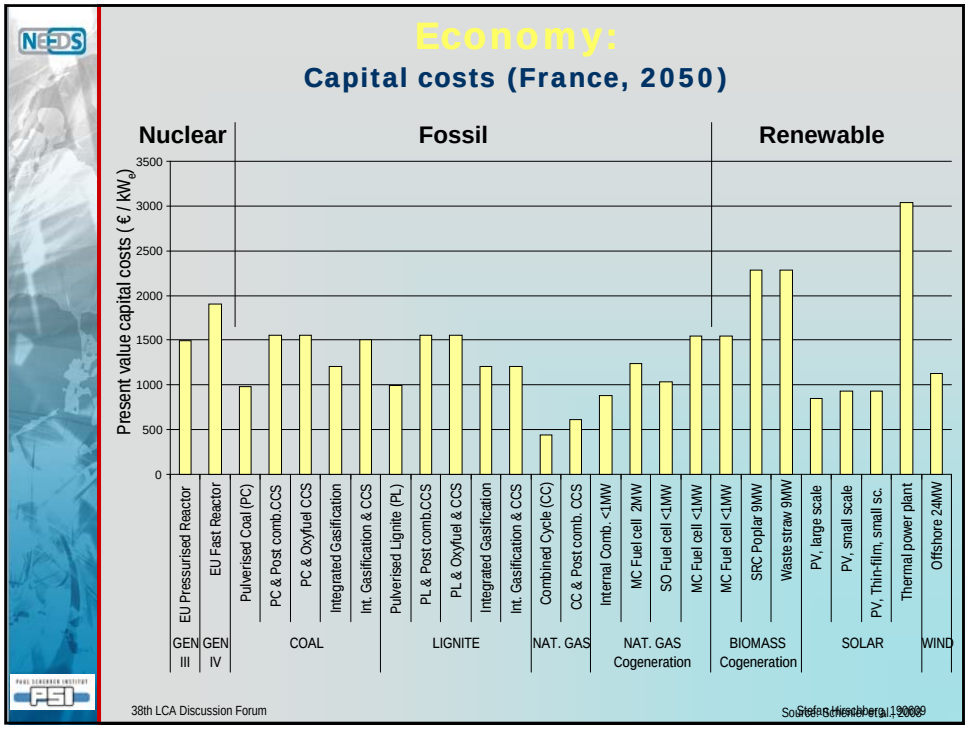
Sustainability

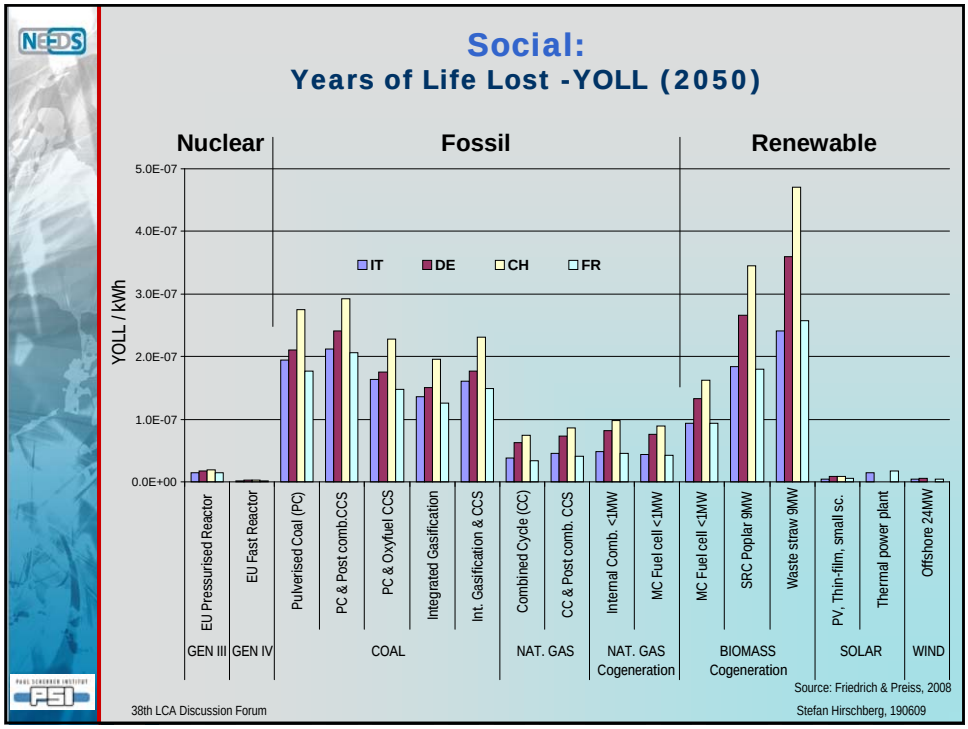


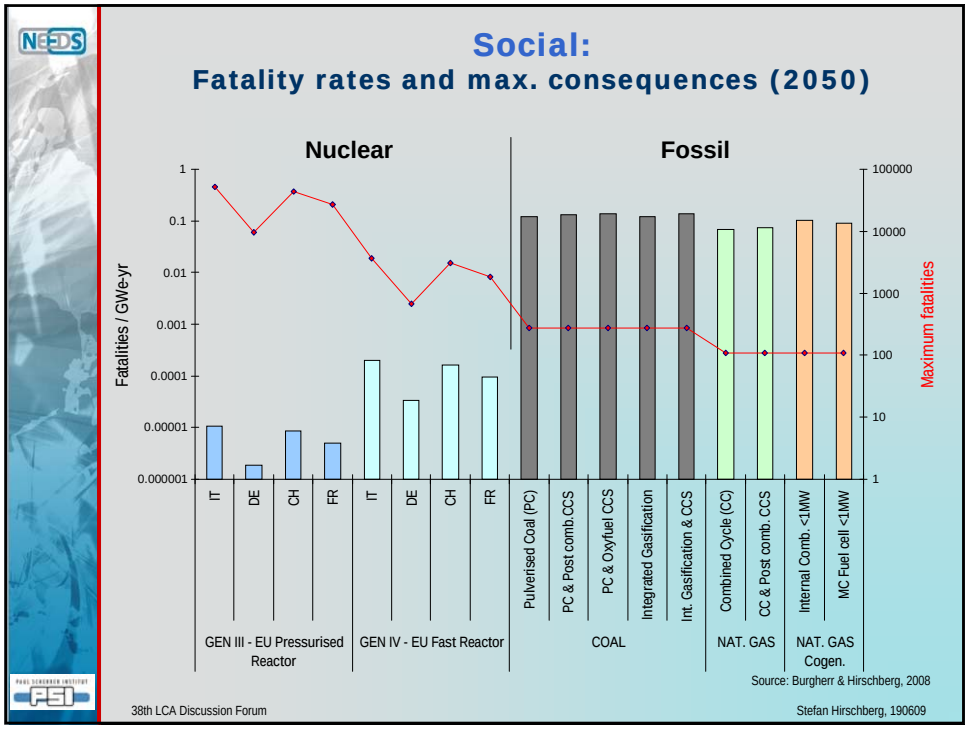
	Criterion
Environmental Dimension	**RESOURCES**
	Energy Resources
	Mineral Resources (Ores)
	CLIMATE CHANGE
	IMPACT ON ECOSYSTEMS
	Impacts from Normal Operation
	Impacts from Severe Accidents
	WASTES
	Special Chemical Wastes stored in Underground Depositories
	Medium and High Level Radioactive Wastes 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., 2008

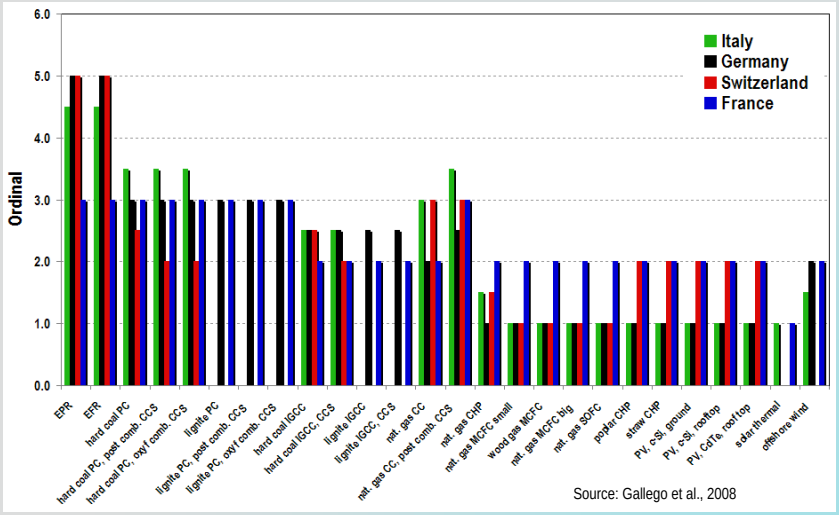

Environment:
GHG Emissions (2050)
Nuclear
Fossil
Renewable
kg (CO2-eq.) / kWh
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
IT
DE
CH
FR
EU Pressurised Reactor
EU Fast Reactor
Pulverised Coal (PC)
PC & Post comb.CCS
PC & Oxyfuel CCS
Integrated Gasification
Int. Gasification & CCS
Pulverised Lignite (PL)
PL & Post comb.CCS
PL & Oxyfuel & CCS
Integrated Gasification
Int. Gasification & CCS
Combined Cycle (CC)
CC & Post comb. CCS
Internal Comb. <1MW
MC Fuel cell 2MW
SO Fuel cell <1MW
MC Fuel cell <1MW
MC Fuel cell <1MW
SRC Poplar 9MW
Waste straw 9MW
PV, large scale
PV, small scale
PV, Thin-film, small sc.
Thermal power plant
Offshore 24MW
GEN III
GEN IV
COAL
LIGNITE
NAT. GAS
NAT. GAS Cogeneration
BIOMASS Cogeneration
SOLAR
WIND
38th LCA Discussion Forum


Economy:
Capital costs (France, 2050)
Nuclear
Fossil
Renewable
Present value capital costs (€ / kWe)
3500
3000
2500
2000
1500
1000
500
0
EU Pressurised Reactor
EU Fast Reactor
Pulverised Coal (PC)
PC & Post comb.CCS
PC & Oxyfuel CCS
Integrated Gasification
Int. Gasification & CCS
Pulverised Lignite (PL)
PL & Post comb.CCS
PL & Oxyfuel & CCS
Integrated Gasification
Int. Gasification & CCS
Combined Cycle (CC)
CC & Post comb. CCS
Internal Comb. <1MW
MC Fuel cell 2MW
SO Fuel cell <1MW
MC Fuel cell <1MW
MC Fuel cell <1MW
SRC Poplar 9MW
Waste straw 9MW
PV, large scale
PV, small scale
PV, Thin-film, small sc.
Thermal power plant
Offshore 24MW
GEN III
GEN IV
COAL
LIGNITE
NAT. GAS
NAT. GAS Cogeneration
BIOMASS Cogeneration
SOLAR
WIND
38th LCA Discussion Forum


Social:
Years of Life Lost -YOLL (2050)
Nuclear
Fossil
Renewable
YOLL / kWh
5.0E-07
4.0E-07
3.0E-07
2.0E-07
1.0E-07
0.0E+00
IT
DE
CH
FR
EU Pressurised Reactor
EU Fast Reactor
Pulverised Coal (PC)
PC & Post comb.CCS
PC & Oxyfuel CCS
Integrated Gasification
Int. Gasification & CCS
Combined Cycle (CC)
CC & Post comb. CCS
Internal Comb. <1MW
MC Fuel cell <1MW
MC Fuel cell <1MW
SRC Poplar 9MW
Waste straw 9MW
PV, Thin-film, small sc.
Thermal power plant
Offshore 24MW
GEN III
GEN IV
COAL
NAT. GAS
NAT. GAS Cogeneration
BIOMASS Cogeneration
SOLAR
WIND
Source: Friedrich & Preiss, 2008
38th LCA Discussion Forum
Stefan Hirschberg, 190609


Social:
Fatality rates and max. consequences (2050)
Nuclear
Fossil
Fatalities / GWe-yr
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
Maximum fatalities
100000
10000
1000
100
10
1
IT
DE
CH
FR
IT
DE
CH
FR
Pulverised Coal (PC)
PC & Post comb.CCS
PC & Oxyfuel CCS
Integrated Gasification
Int. Gasification & CCS
Combined Cycle (CC)
CC & Post comb. CCS
Internal Comb. <1MW
MC Fuel cell <1MW
GEN III - EU Pressurised Reactor
GEN IV - EU Fast Reactor
COAL
NAT. GAS
NAT. GAS Cogen.
Source: Burgherr & Hirschberg, 2008
38th LCA Discussion Forum
Stefan Hirschberg, 190609

Social:
Legitimacy, conflict potential

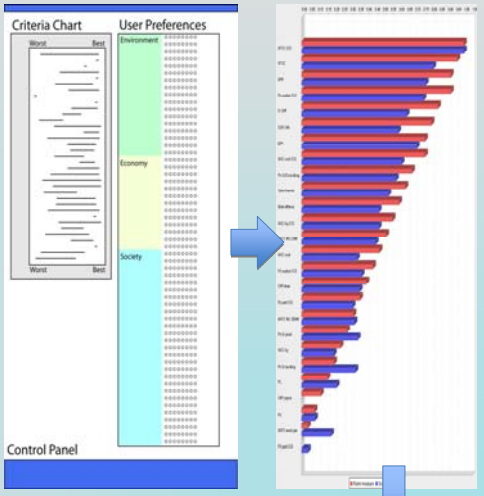


Source: Gallego et al., 2008

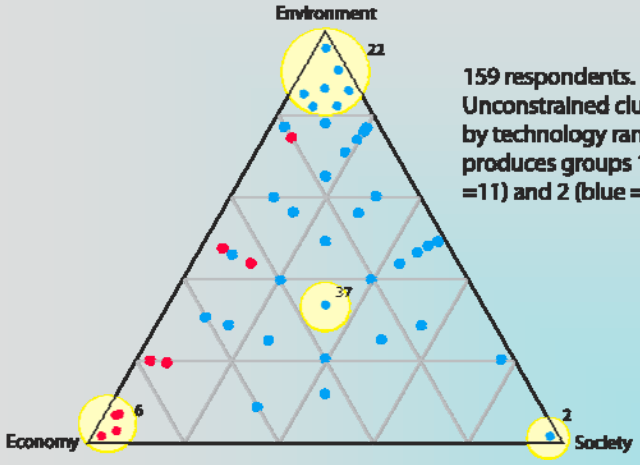
The Online MCDA Application

Key elements:

- Interactive, graphic interface
  1. Open website
  2. Enter preferences
  3. *Solve* to show ranking
  4. Examine trade-offs for 'best' technologies
  5. Repeat until satisfied
- Immediate feedback
- Iterative learning
- Automatic data collection

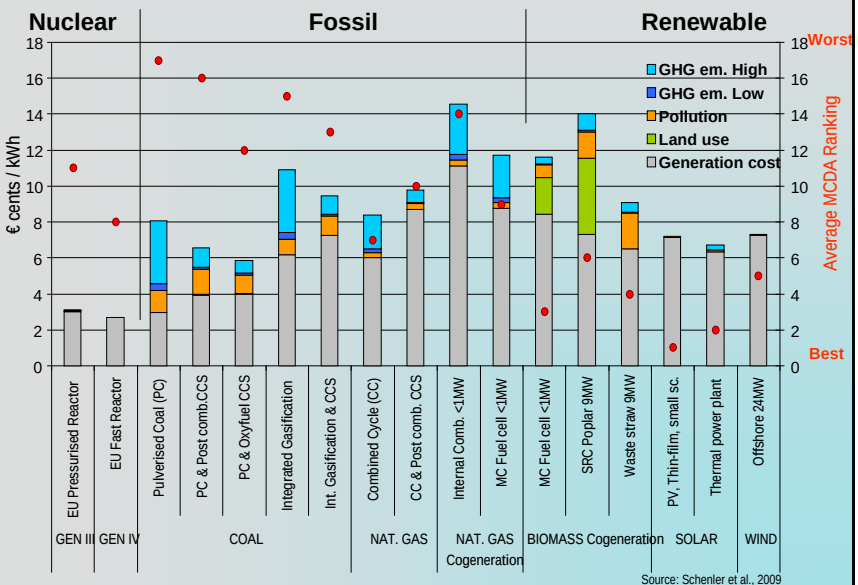


Distribution of NEEDS MCDA Survey Respondents by top level criteria weights



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

Total Costs with Average MCDA Ranking



Source: Schenler et al., 2009

Total costs = generation costs + externalities

Conclusions

- General acceptance of the concept of externalities, internalisation of external costs and most results in spite of limitations.
  - ☞ Results for nuclear remain controversial.
- A powerful framework for MCDA-based sustainability assessment developed, implemented and applied to four countries.
- Wide stakeholder acceptance of the proposed criteria and indicator set.
- Comprehensive indicator database established for four countries; also future technologies exhibit strengths and weaknesses.
- 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 with GEN IV fast breeder performing better than GEN III EPR.
- Coal technologies perform worst in MCDA while centralized gas options are along with nuclear in the midfield. CCS-performance is mixed.
- Emphasis on environment penalizes fossil options; emphasis on economy penalizes renewable options; emphasis on social penalizes nuclear.

Thank you for your attention

Stefan Hirschberg
stefan.hirschberg@psi.ch

Laboratory for Energy Systems Analysis (LEA)
http://lea.web.psi.ch/