The Scenarios as a Tool für Public Planning in Energy

Stefan Hirschberg

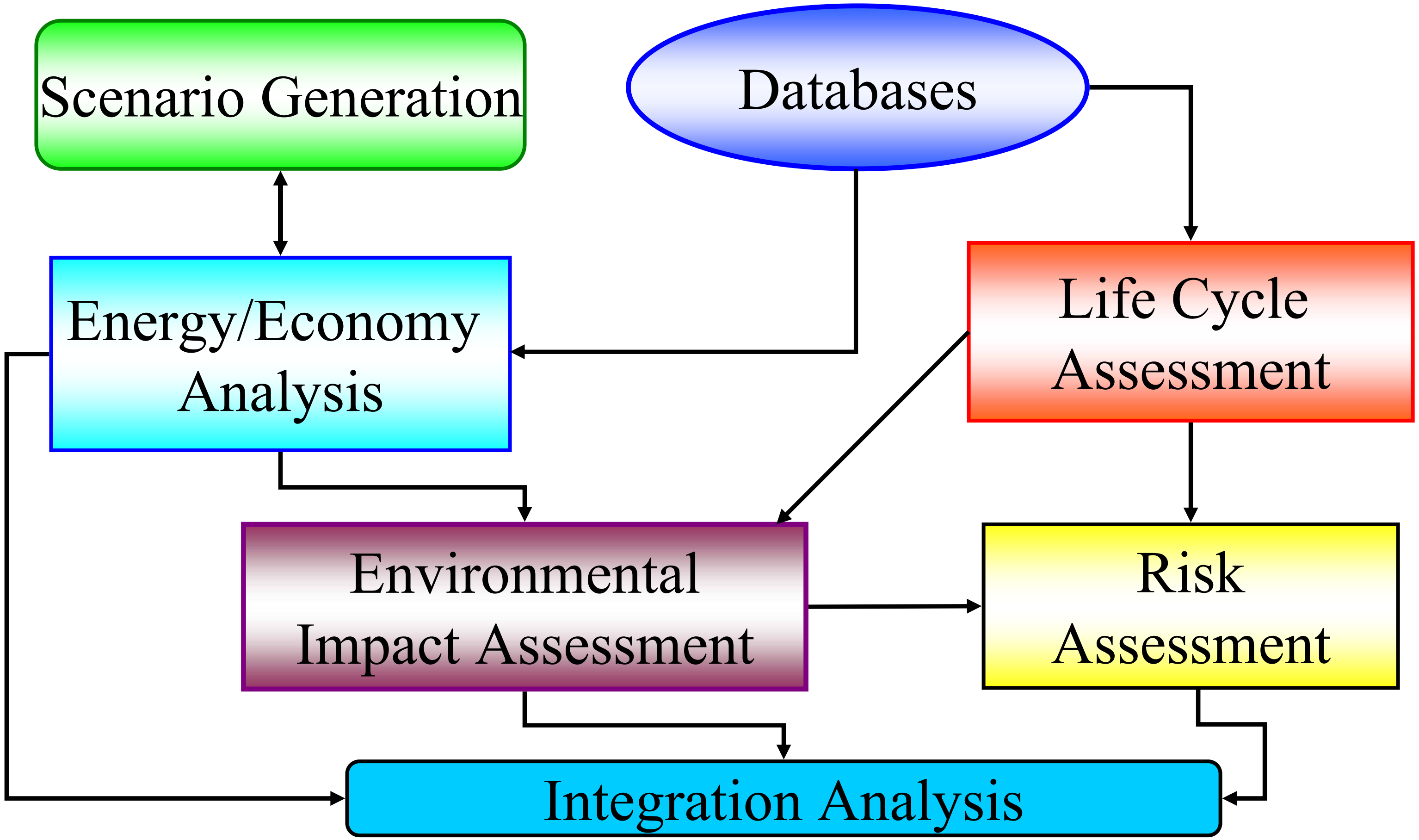
Laboratory for Energy Systems Analysis, Paul Scherrer Institut

WEC-Europe Regional Scenario Workshop
6-7 December 2011, Paris, France

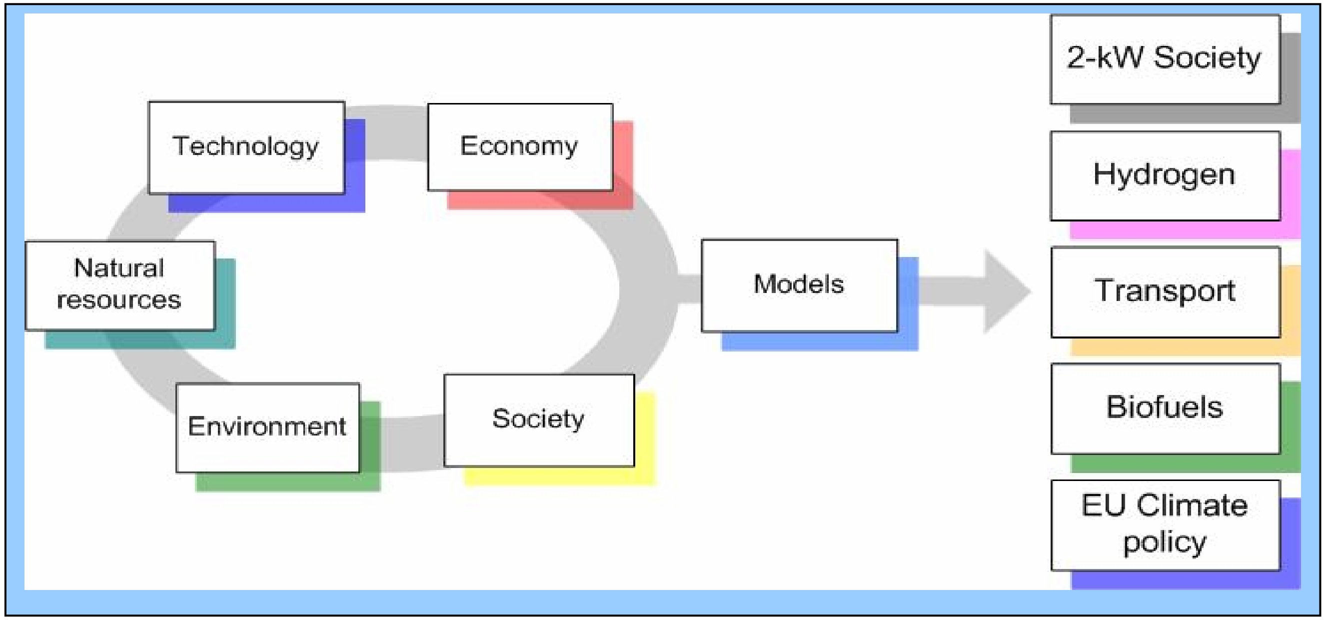
Outline

- Scenario modeling at PSI
- Review of recent major scenario analyses
  - Selected scenario input assumptions
  - Deployment of electricity generation technologies in scenarios
  - Key factors affecting the deployment
- Some emerging issues
- Implications for decision-making
- Recommendations

Simplified framework for Energy Systems Analysis at PSI



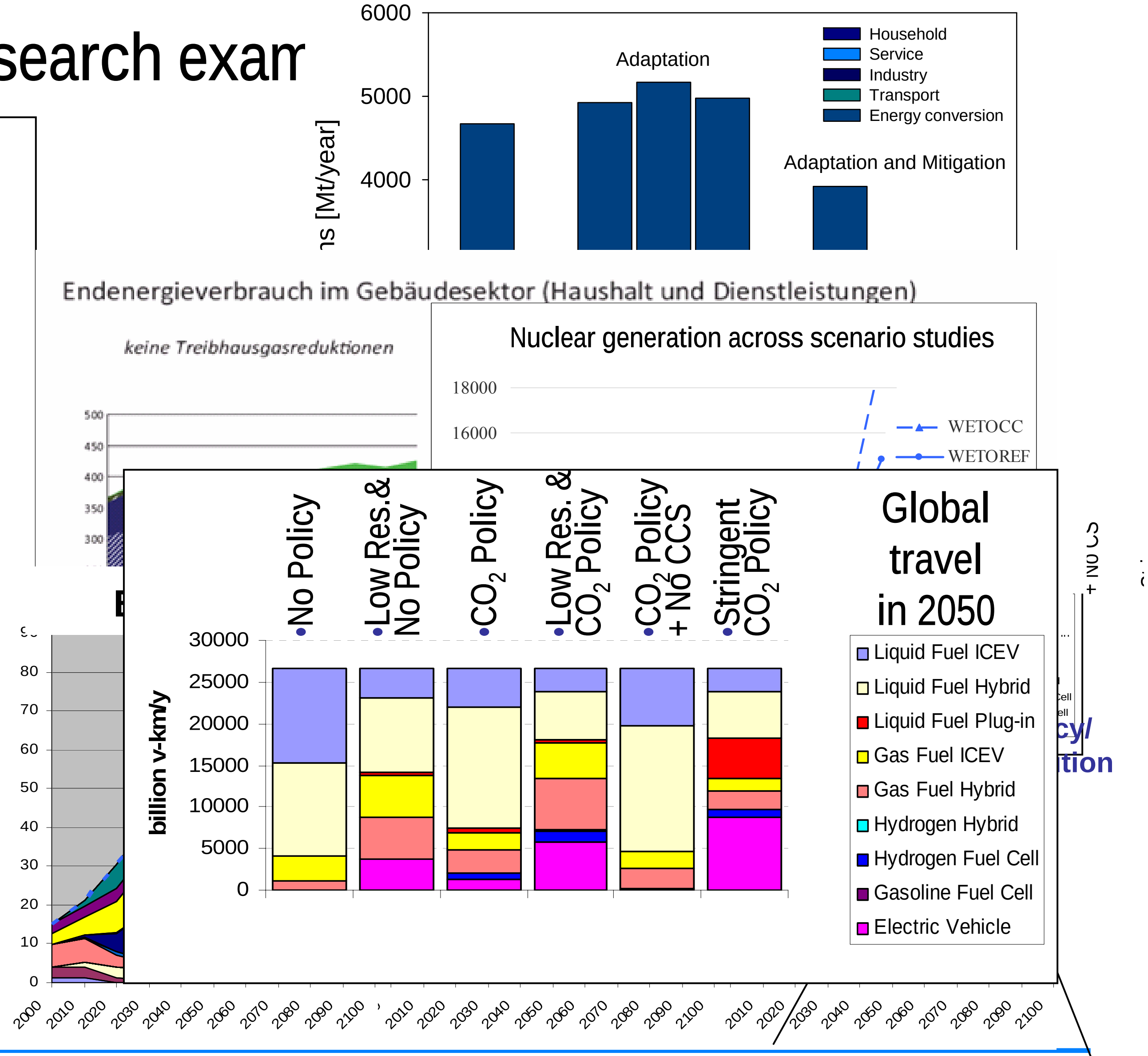
Methodology & Tools for Energy Economics



- **Detailed bottom-up energy-systems engineering models:**
  - Switzerland: Swiss MARKAL model; Swiss TIMES model; Swiss TIMES electricity model
  - Europe: European Hydrogen Model; European MARKAL model
  - Global: Global MARKAL model
- **Coupled economic-energy systems models:**
  - Global: MERGE-ETL (global); MARKAL-MACRO (regional); ECLIPSE (global, transport focus)

Specific (recent) research exam

- Technology options for a sustainable energy system in Switzerland; energy supply, conversion, and end-use efficiency
- Technology strategies for climate change adaptation and mitigation in the conversion sector for Europe
- Global technology options for very low stabilization pathways
- Global scenario analysis of the influence of uncertainties in the energy system on transport technology and fuel choice
- Review and technical analysis of leading energy scenario literatur

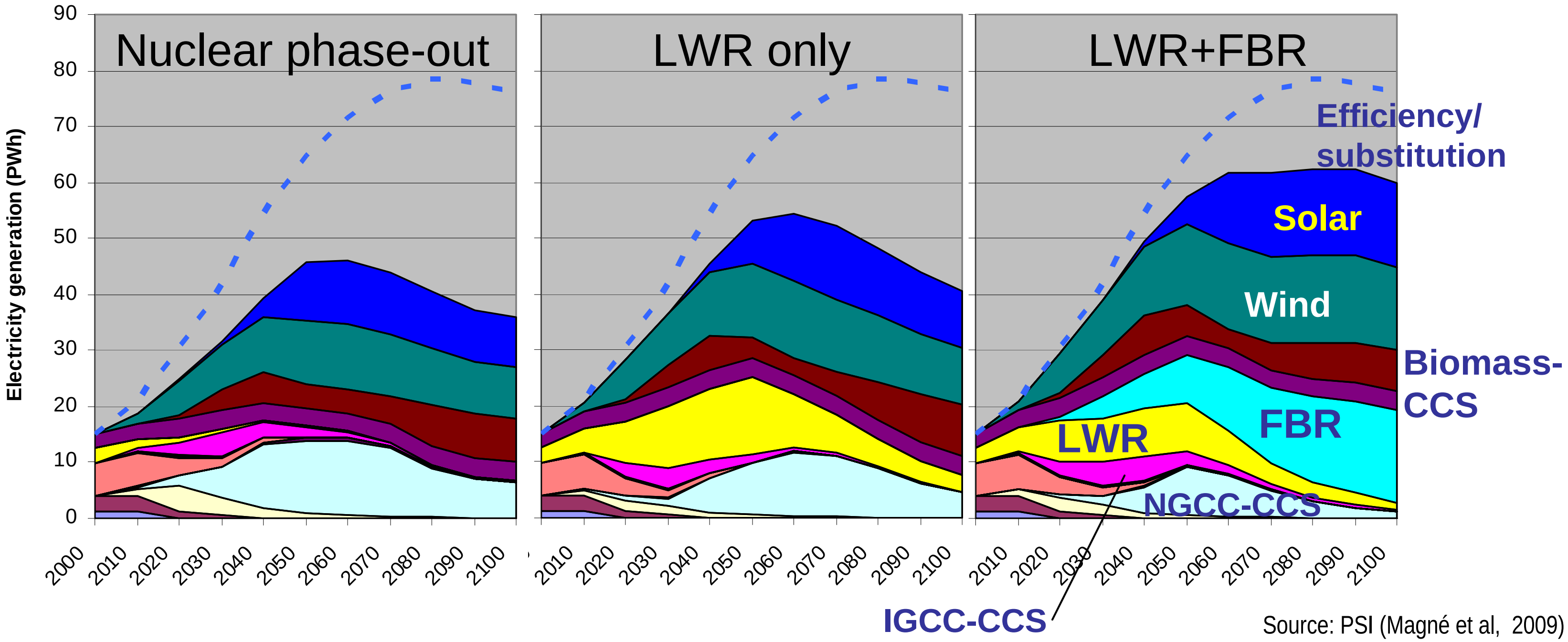


M2: Global mitigation and technology options

How can very low climate stabilization targets (e.g. 400 & 450 ppmv CO_2-equivalent) be achieved? What is the role of different technology options (incl. nuclear, carbon capture & storage, biomass, and renewables)?

- Stringent mitigation targets can be met under many technology scenarios, but major technological change is needed, highlighting important roles for R&D and learning-by-doing.
- Technology options such as biomass, carbon capture, nuclear, efficiency and renewables are important. Nuclear options avoid the need for more costly technologies (more efficiency, solar PV and CCS) (see figure).

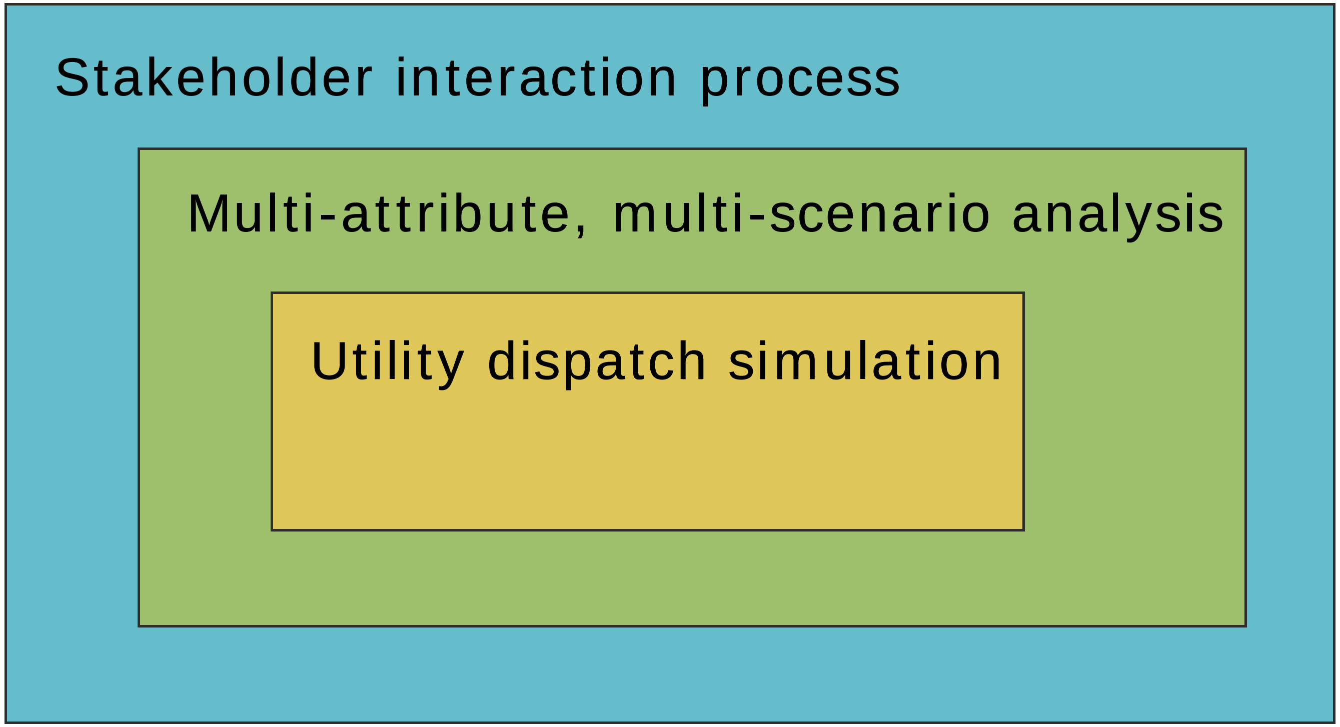
Electricity generation in low stabilization (400ppm), nuclear availability



Source: PSI (Magné et al, 2009)

Electric Sector Simulation - What is it?

A three layer approach...



PAUL SCHERRER INSTITUT

Objectives and Approach to Review of Major Scenarios

Key question:

- What factors explain the large **bandwidth** in the projections of leading energy scenarios?
- How are governance issues related to **climate change and energy security** accounted for?

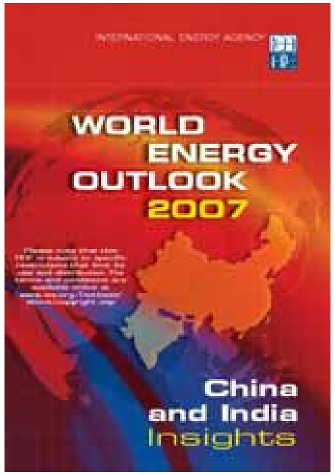
Scope:

- A systematic **review** of the energy scenario literature regarding the **deployment** of specific systems and technologies for **electricity generation**

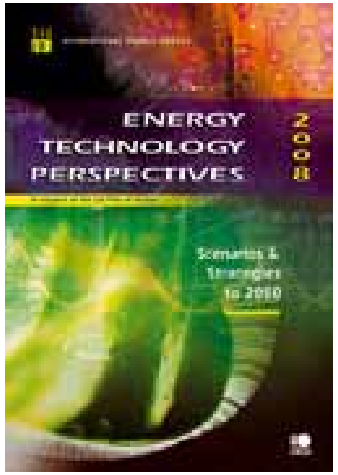
Approach:

- Identify and select relevant literature to cover a range of **leading energy scenarios**
- Evaluate and compile information to identify **key factors** affecting deployment of electricity generation technologies and the dynamics of technology uptake and diffusion
- **Compare** across different assessments to identify robust trends and conclusions

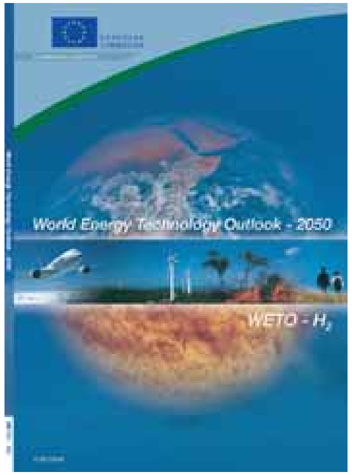
Studies assessed



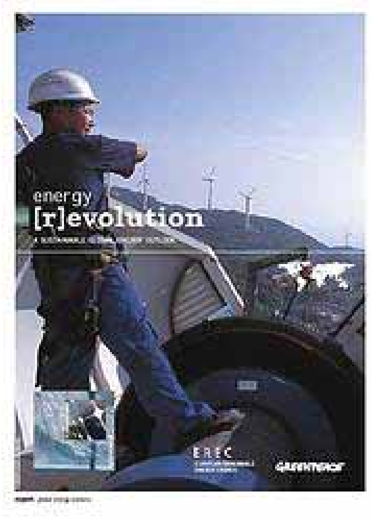
IEA 2007



IEA 2008



EC 2006



Greenpeace, EREC 2008

WEC 2006

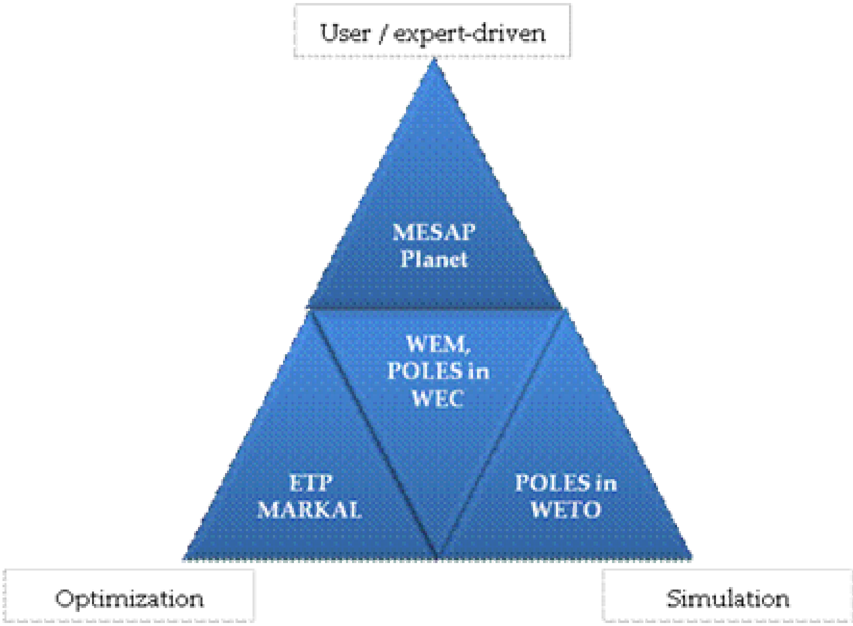
PAUL SCHERRER INSTITUT

Selected studies

	Model	Key uncertainties	Scenarios	Policy drivers
IEA: World Energy Outlook, 2007	World Energy Model	•Policies on energy security and environment •Economic growth in China and India	•Reference (REF) •Alt. Policy (ALT)	•Policies adopted by mid-2007 •All policies under consideration
IEA: Energy Technology Perspectives, 2008	ETP MARKAL	•CO_2 emissions	•Baseline (BASE) •ACT Map (ACT) •BLUE Map (BLUE)	•Extension of WEOREF •27 Gt CO_2/yr in 2050 •14 Gt CO_2/yr in 2050
EC: World Energy Technology Outlook, 2006	POLES	•CO_2 emissions •Deployment of hydrogen technologies	•Reference (REF) •C.Constraint (CC)	•Existing policies •25 Gt CO_2/yr in 2050
Greenpeace: Energy [r]evolution, 2008	•MESAP/PlaNet	•CO2 emissions	•Reference (REF) •[r]evolution (REVO)	•Extension of WEOREF •10 Gt CO_2/yr in 2050
WEC: Energy Policy Scenarios, 2007	•Delphi study •Quantified with POLES	•Government engagement (GE) •Internat. cooperation and integration (CI)	•Leopard (1LEO) •Elephant (2ELE) •Lion (3LIO) •Giraffe (4GIR)	•Low GE, low CI •High GE, low CI •High GE, high CI •Low GE, high CI

Source: Ruos, Turton & Hirschberg, 2009

Representation of technology deployment in selected studies



- To understand technology deployment, we focus on scenarios developed with technology-rich energy models.
- Different approaches are used across the studies:
  - In MESAP PlaNet (used for the GR-study), the user can directly select technology outcomes based on expert judgment
  - In contrast, ETP MARKAL is an optimization model that seeks to determine the least cost combination of technologies and fuels over the entire modeling time horizon
  - In WEC, WETO (both POLES model) and WEO (WEM) simulation-type models with optimization of the energy technology mix in each time period were used
  - In addition, in the WEO and WEC studies the models are coupled to expert judgment

Technologies investigated

Coal-fired	Gas-fired	Carbon capture and storage	Nuclear	Hydropower	Wind power	Solar
• thermal • IGCC • SC pulverized	• Steam cycle • Gas cycle • Combined cycle	• Coal retrofit • Coal IGCC • Coal pulverized • Gas CC	• Light-water reactors • Generation IV designs	• Large scale • Small scale	• Onshore • Offshore	• Photovoltaics • Thermal plants

These technologies **cover around 90% of the total installed capacity** within each scenario and therefore provide a sufficient basis to analyze technology deployment.

Excluded: (do not contribute significantly to total power generation until 2050 in any of the scenarios)

Ocean energy, geothermal energy, biomass or waste feedstocks, combined heat and power systems

Anticipated factors of deployment

General drivers

- Population growth, GDP growth, fossil fuel prices, CO2 prices, technical and economical potentials,…

Technology-specific drivers

- Powerplant data: plant lifetime, capacity factor, thermal efficiency, emissions per unit of activity, …
- Deployment data: learning rate, rate of deployment, all-in-cost to implement technology, …
- Economical data: investment cost, O&M cost, fuel cost, generation cost, discount rate, abatement cost, …

Other drivers:

- Environmental risks, energy efficiency, energy security issues, regulatory framework, public acceptance, policy instruments, education, subsidies, …

Scenario results:

- Installed power generation capacity
- Generated electricity
- Primary and final energy demand
- CO2 emissions

Scenario study inputs: Selected energy price assumptions

Fossil fuel and carbon prices in 2030	ETP			GR		WEC				WEO		WETO	
	ACT	BASE	BLUE	REF	REVO	1LEO	2ELE	3LIO	4GIR	APS	REF	CC	REF
Crude oil ($05/ bl)	60	60	60	120	120	76	68	65	74	60	60	59	64
Natural gas ($05/ boe)	43	43	43	110	110	55	48	48	55	43	43	56	57
Steam coal ($05/ boe)	13	13	13	53	53	19	18	19	20	13	13	?	16
CO_2 Annex-B ($05/ tCO2)	50	-	200	30	30	13	26	30	32	-	-	131	25
CO_2 non-Annex-B ($05/ tCO2	25	-	50	30	-	10	10	20	10	-	-	37	9

- Comparatively high prices for fossil fuels are assumed in the GR study (and to some extent in the WEC study)
- In the ETP and WETO emission scenarios, high CO_2 prices are implemented (either directly or via an emissions cap) to achieve emission targets and to support the deployment of zero- or low-emission technologies

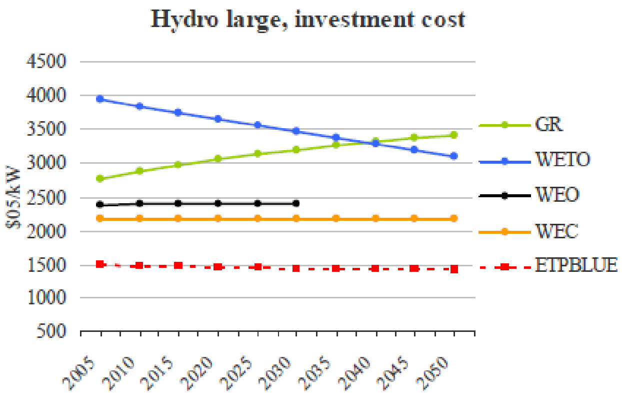
Source: Ruos, Turton & Hirschberg, 2009

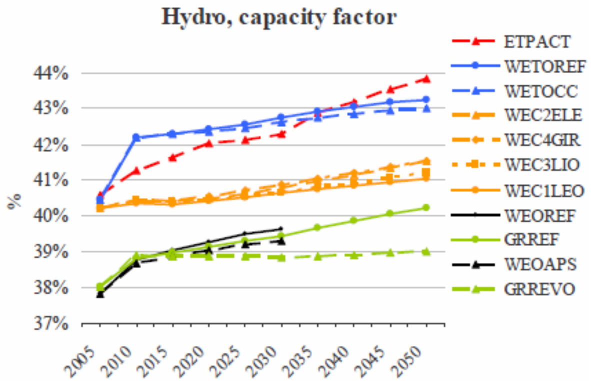
Scenario study inputs: Technology cost assumptions

- In most models, technologies compete on the basis of Levelized Cost of Electricity
- The most relevant components of LCOE were calculated (assuming unknown parameters to be identical)

		ETP	GR	WEC	WEO	WETO
Gas	Lev. ann. fuel cost	low	high	medium	low	medium
Coal	Lev. ann. fuel cost	medium	high	medium	low	medium
Nuclear	Lev. ann. investment cost	medium		medium	low	medium
Wind onshore	Lev. ann. investment cost	medium	medium	high	low	high
Wind offshore	Lev. ann. investment cost	medium	high	medium	low	medium
Solar PV	Lev. ann. investment cost	low	medium	high	medium	high
Solar thermal	Lev. ann. investment cost	medium	medium	high	low	high
Hydro	Lev. ann. investment cost	low	high	medium	medium	high

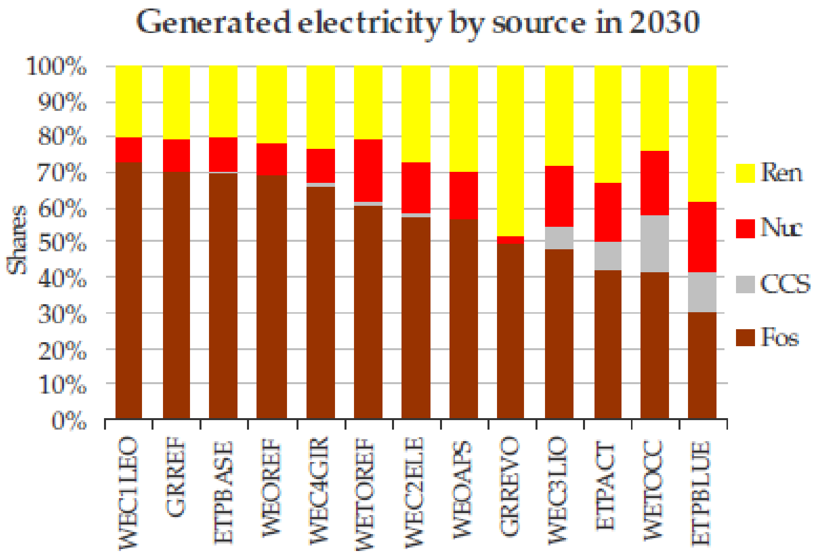
Example: Hydro in GR
comparatively high investment cost
and low capacity factors





Source: Ruos, Turton & Hirschberg, 2009

Scenario study outputs: Deployment of electricity generation technologies



- Fossil fuels remain the dominant source (market share > 50%) until 2030, except in ETPBLUE,GRREVO and ETPACT
- Carbon capture and storage plays an important role in WETOCC, ETPBLUE, ETPACT and WEC3LIO
- GRREVO is characterized by a 50% share of renewables in 2030; also ETPBLUE comes close to 40%
- Nuclear technologies produce almost 20% of electricity in ETPBLUE and the WETO scenarios

	Current	ETP			GR		WEC				WEO		WETO	
	(in 2005)	ACT	BASE	BLUE	REF	REVO	1LEO	2ELE	3LIO	4GIR	APS	REF	CC	REF
Coal-fired	50.7%	18.7%	44.0%	15.8%	39.4%	26.0%	41.1%	33.1%	30.3%	39.1%	34.3%	44.6%	33.6%	35.8%
Gas-fired	9.3%	29.1%	23.3%	22.8%	22.5%	21.8%	29.6%	22.8%	22.0%	24.6%	20.1%	21.9%	21.1%	21.6%
with CCS		*9.4%*	*0.7%*	*12.6%*			*0.0%*	*0.8%*	*6.6%*	*1.5%*			*16.1%*	*1.0%*
Nuclear	15.2%	16.3%	9.2%	19.9%	9.0%	2.3%	6.1%	14.4%	16.7%	9.6%	13.3%	9.3%	18.0%	17.4%
Hydro	16.0%	14.0%	12.7%	15.9%	13.7%	15.2%	11.6%	13.0%	12.5%	11.3%	17.3%	13.7%	12.1%	11.4%
Wind	0.6%	9.1%	2.7%	9.8%	3.6%	15.1%	4.4%	6.8%	7.7%	5.8%	5.8%	3.6%	6.6%	5.2%
Solar PV	0.01%	0.8%	0.4%	1.1%	0.3%	4.6%	0.1%	0.1%	0.2%	0.1%	0.8%	0.4%	0.2%	0.1%

Note: in this table, power generation from plants equipped with CCS is also counted in the categories „Coal-fired“ and „Gas-fired“

Source: Ruos, Turton & Hirschberg, 2009

PAUL SCHERRER INSTITUT

Key factors affecting the deployment

Technology deployment can only be understood from a holistic perspective:

- Definition of the storylines: business-as-usual vs. policy-driven scenarios
- Modeling approach (technology selection process): optimization vs. simulation vs. user-driven
- Availability of technologies: modeler’s choice (i.e. invention and innovation are not modeled)
- Input parameters and cost assumptions: quantification of storylines

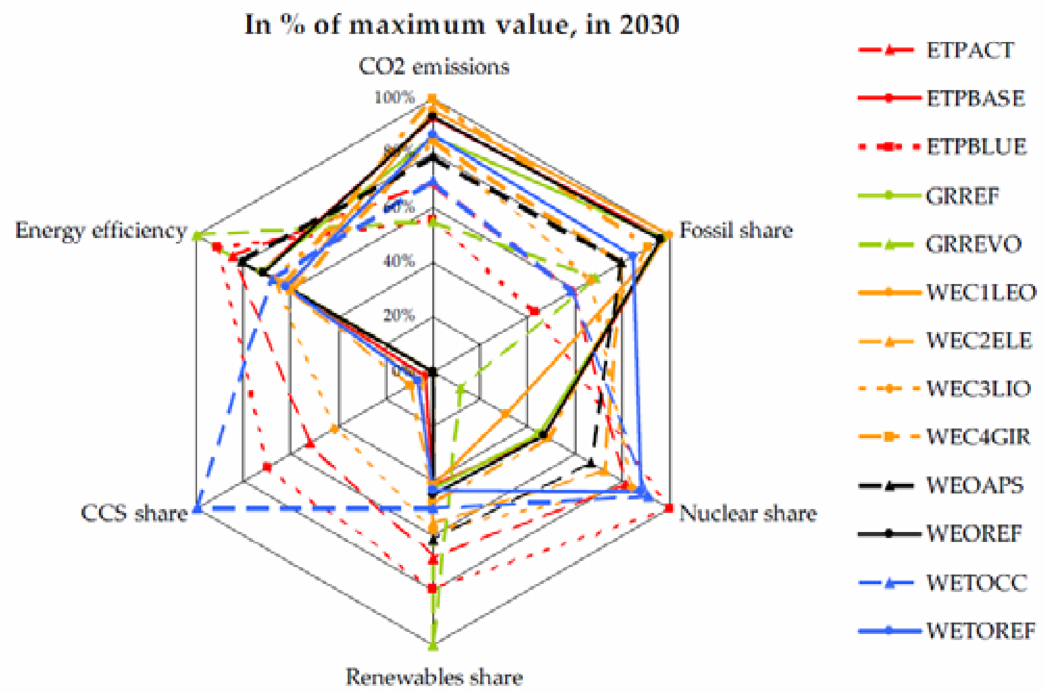
Coal-fired	Gas-fired	Carbon capture and storage	Nuclear	Hydropower	Wind power	Solar
• CO_2 prices • Availability of CCS	• CO_2 prices • Availability of CCS • Gas price	• (Availability of CCS) • Storage capacity	• Construction rate • Safety concerns	• Suitable sites	• Suitable sites	• Technology breakthroughs • (Investment cost)

- Interplay of technology options
- Scale of technology deployment: determined by economic growth, end-use efficiency, and electrification

Deployment of electricity generation technologies

Four indicators of aggregate electricity technology deployment and one each of energy efficiency and CO_2 emissions:

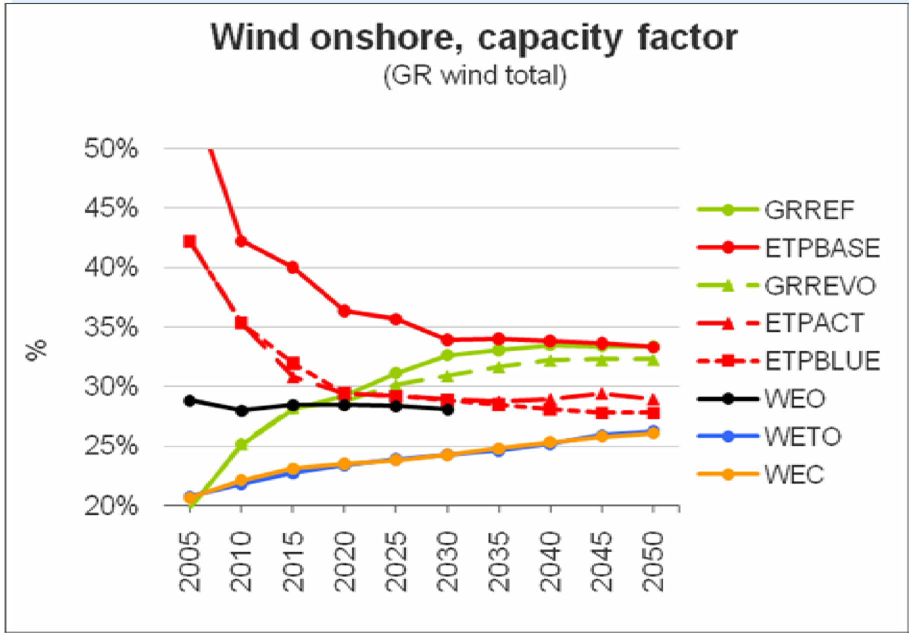
(presented as a relative indicator, as percentages of the highest value across the scenarios)

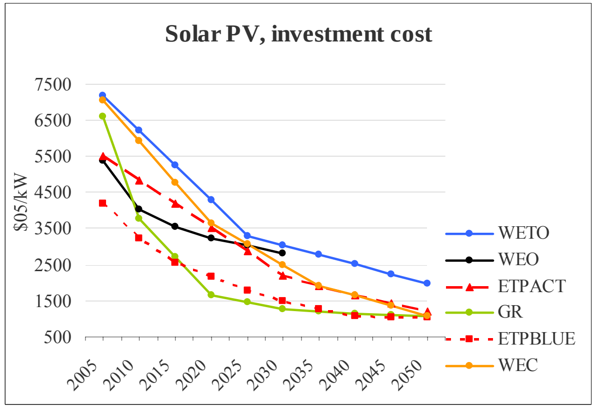


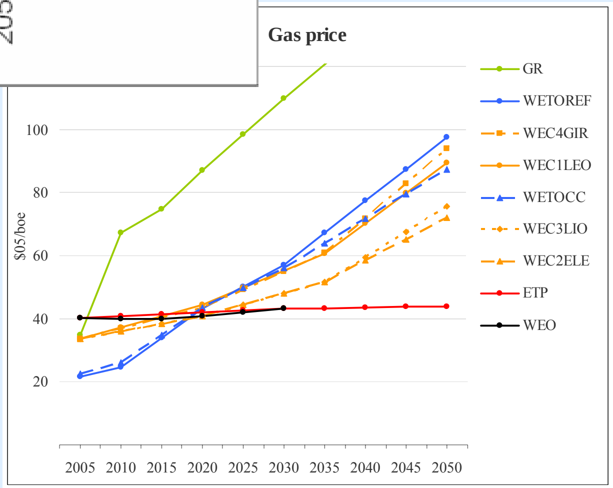
- Solid lines: business-as-usual scenarios with generally higher CO_2 emissions, based on high shares of fossil-fueled power generation and only modest energy efficiency improvements
- Dashed lines: policy-driven scenarios with lower CO_2 emissions, most of these scenarios exhibit a wide deployment of renewables, only some scenarios incorporate a large contribution of nuclear and the utilization CCS

Source: Ruos, Turton & Hirschberg, 2009

Technology assumptions

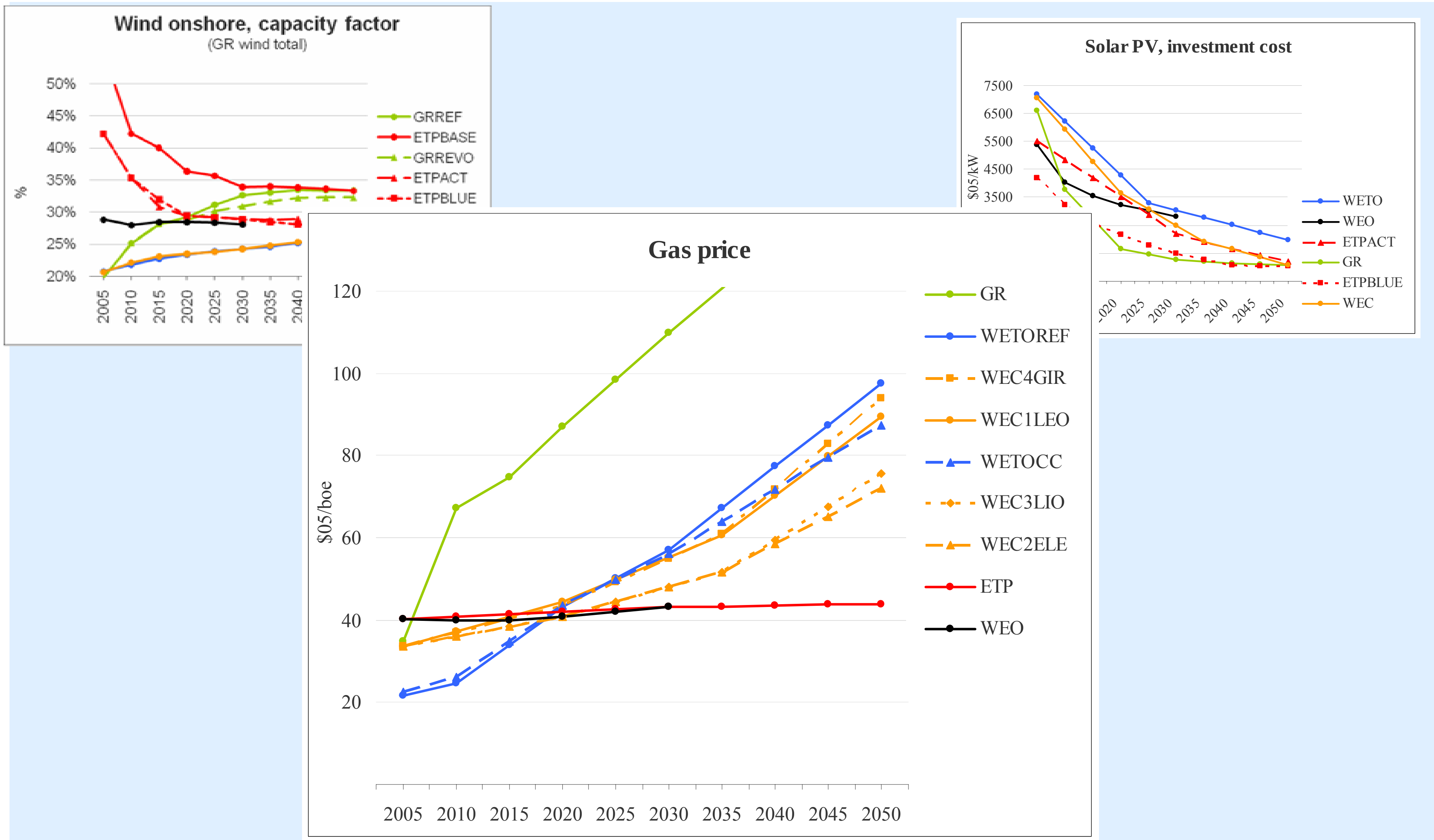






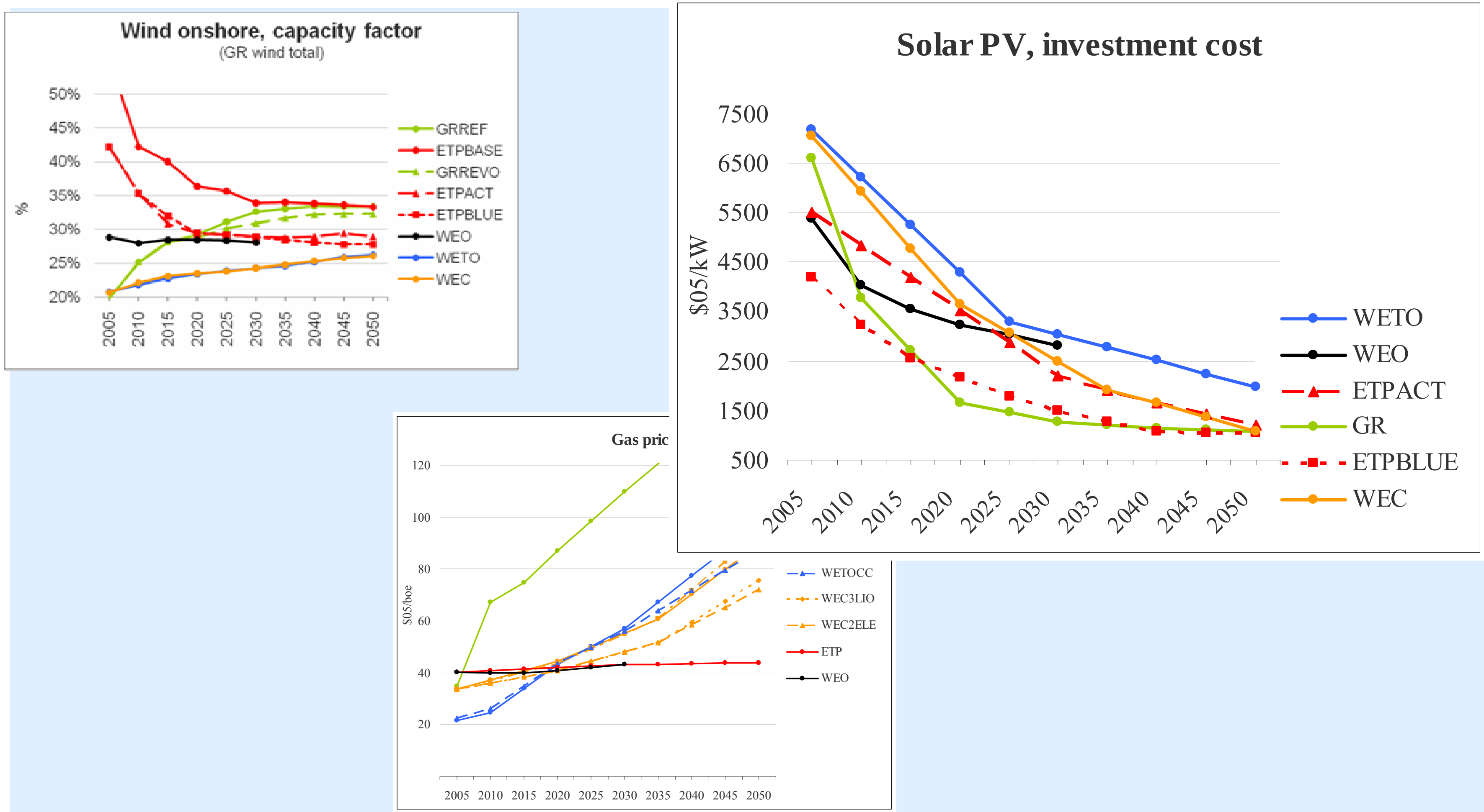
Source: Ruos, Turton & Hirschberg, 2009

Technology assumptions



Source: Ruos, Turton & Hirschberg, 2009

Technology assumptions



Source: Ruos, Turton & Hirschberg, 2009

PAUL SCHERRER INSTITUT

Summary of technology deployment and key factors

	Current	ETP			GR		WEC				WEO		WETO	
	(in 2005)	ACT	BASE	BLUE	REF	REVO	1LEO	2ELE	3LIO	4GIR	APS	REF	CC	REF
Coal-fired	50.7%	18.7%	44.0%	15.8%	39.4%	26.0%	41.1%	33.1%	30.3%	39.1%	34.3%	44.6%	33.6%	35.8%
Gas-fired	9.3%	29.1%	23.3%	22.8%	22.5%	21.8%	29.6%	22.8%	22.0%	24.6%	20.1%	21.9%	21.1%	21.6%
with CCS		*9.4%*	*0.7%*	*12.6%*			*0.0%*	*0.8%*	*6.6%*	*1.5%*			*16.1%*	*1.0%*
Nuclear	15.2%	16.3%	9.2%	19.9%	9.0%	2.3%	6.1%	14.4%	16.7%	9.6%	13.3%	9.3%	18.0%	17.4%
Hydro	16.0%	14.0%	12.7%	15.9%	13.7%	15.2%	11.6%	13.0%	12.5%	11.3%	17.3%	13.7%	12.1%	11.4%
Wind	0.6%	9.1%	2.7%	9.8%	3.6%	15.1%	4.4%	6.8%	7.7%	5.8%	5.8%	3.6%	6.6%	5.2%
Solar PV	0.01%	0.8%	0.4%	1.1%	0.3%	4.6%	0.1%	0.1%	0.2%	0.1%	0.8%	0.4%	0.2%	0.1%

	ETP			GR		WEC				WEO		WETO	
Selected key factors	ACT	BASE	BLUE	REF	REVO	1LEO	2ELE	3LIO	4GIR	APS	REF	CC	REF
Modeling approach for technology selection	Optimization			User/ expert-driven		Simulation, expert-driven				Simulation, expert-driven		Simulation	
Level of technology detail	++			0/ +		+/ ++				+		+/ ++	
Energy efficiency	+/ ++	+	++	+	++	0	0	+	0/ +	+/ ++	+	+	0/ +
Representation of energy security	0			0		++				+		0	
Stringency of CO_2 policy	+	0	++	0	++	0	0/ +	0/ +	0	0/ +	0	+	0
Acceptance and potential of nuclear power	+	+	+/ ++	+	0	0/ +	++	++	+	+	+	++	++
Potential sites for wind power	+			+/ ++		+/ ++				+		+/ ++	

Note: ++ high + moderate 0 low

Source: Ruos, Turton & Hirschberg, 2009

Management of energy-related risks in selected scenarios

Greenhouse gas emissions:

Each study explores a policy-driven scenario, with a wide range of policy measures to achieve emission targets:

- **CO_2 prices** to reduce the cost-competitiveness of emitting technologies: implemented through cap-and-trade policies or flexible Kyoto-mechanisms (Clean Development Mechanism, Joint Implementation)
- **Phasing out** of high-emission technologies: CO_2 prices, restrictions on the construction of new plants
- Support for **zero- or low-emission technologies**: RD&D projects, feed-in-tariffs or quota systems, subsidies
- Exploitation of **energy efficiency** options: policies to ensure efficient passenger and freight transport, to improve heat insulation, building design and energy-consuming appliances and equipment

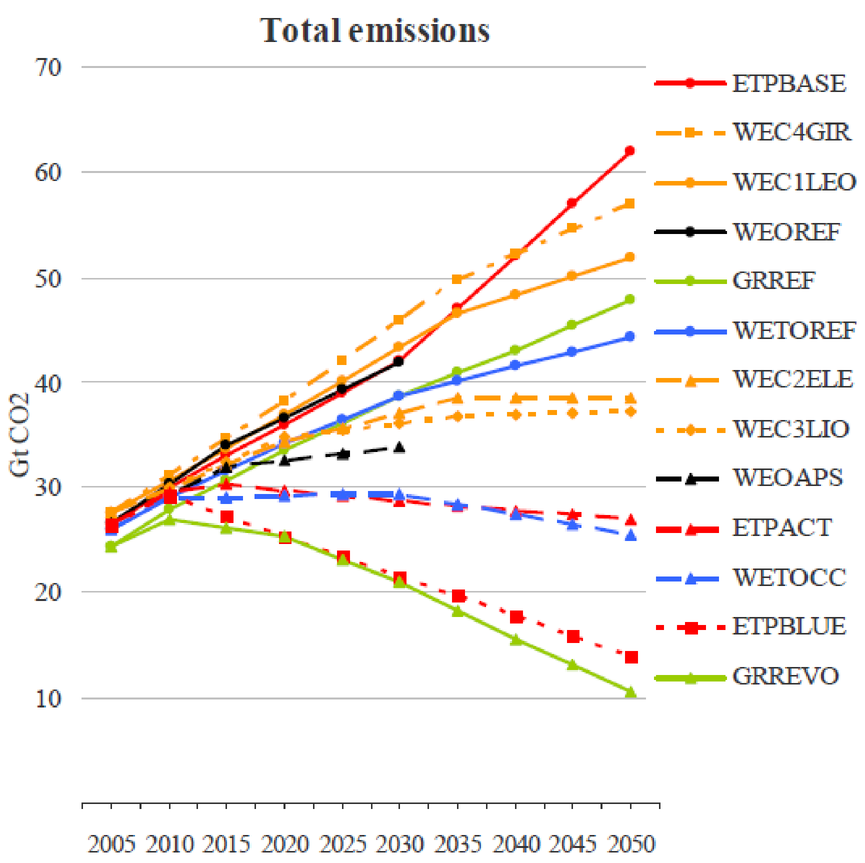
Energy security risks:

- In WEC: **storylines** are built according to the accessibility, availability and acceptability of energy services
- In WEO: **policy database** of current measures including those dealing with energy security, such as the *IEA emergency response mechanism*
- In GR, ETP and WETO: energy security is not considered in detail, but seen as a result of achievements with regards to climate change and energy efficiency

In general, scenario studies provide a rich set of insights about technology options for managing energy-related challenges posed by climate change, but do not treat energy security as extensively

Source: Ruos, Turton & Hirschberg, 2009

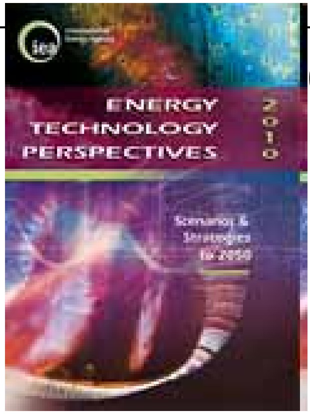
Climate change in energy technology scenarios

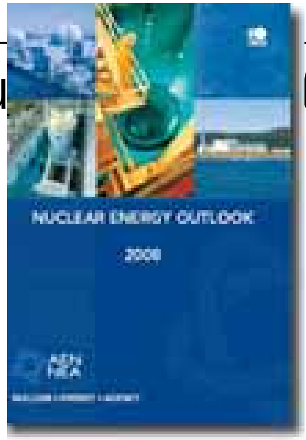


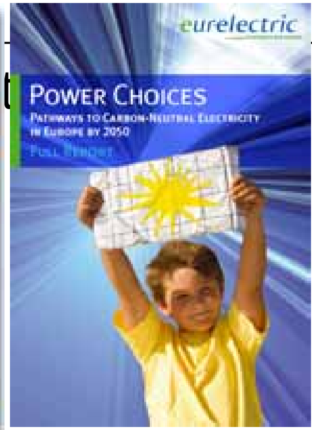
- A wide range of perspectives is covered on the future impact of the global energy system on greenhouse gas emissions, ranging from:
  - Business-as-usual scenarios with generally higher CO2 emissions; to
  - Scenarios with stringent targets such as ETPACT, WETOCC, ETPBLUE, and GRREVO; to
  - Intermediate scenarios with moderate emphasis on mitigation such as WEC2ELE, WEC3LIO and WEOAPS.

Source: Ruos, Turton & Hirschberg, 2009

Selected studies for review of nuclear scenarios

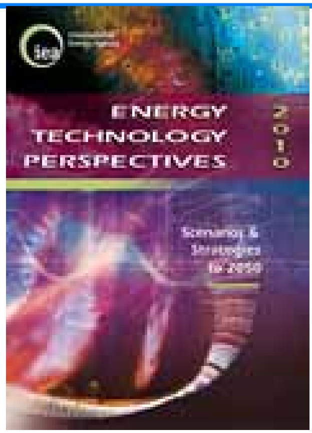


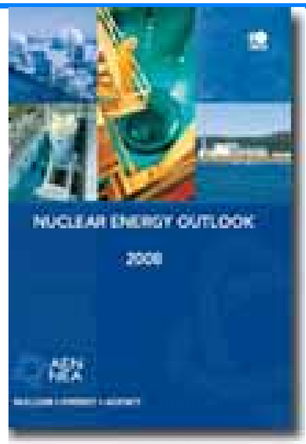


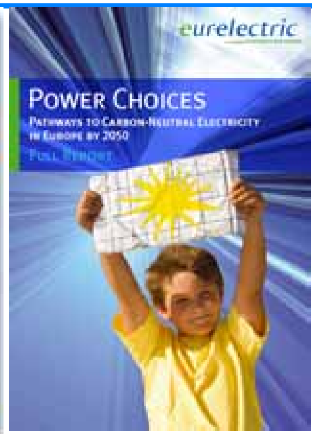


IEA	WEC	NEA	Eurelectric	European Commission
Energy Technology Perspectives 2010 (2010)	Energy Policy Scenarios to 2050 (2007)	Nuclear Energy Outlook 2008 (2008)	Power Choices (2010)	New Energy Externalities Development for Sustainability (2009)

Selected scenarios







Sponsor	IEA	WEC	NEA	Eurelectric	European Commission
Study	Energy Technology Perspectives 2010	Energy Policy Scenarios to 2050	NEO 2008	Power Choices	NEEDS
Selected scenarios	1. ETP Baseline 2. ETP BLUE Map 50% reduction in global emissions (-70% Europe)	1. WEC Leopard 2. WEC Lion Very high global concern on climate (lowest, +35%) (-26% Europe)	1. NEO Low 2. NEO High High concern on climate (emissions not quantified)	1. Eurelectric Baseline 2. Eurelectric PC 50% global reduction (-70% Europe)	1. NEEDS BAU 2. NEEDS 450 ppm Target consistent with +2 degree limit (-70% Europe)

- Role of nuclear in scenarios is determined by two sets of assumptions/driving forces:

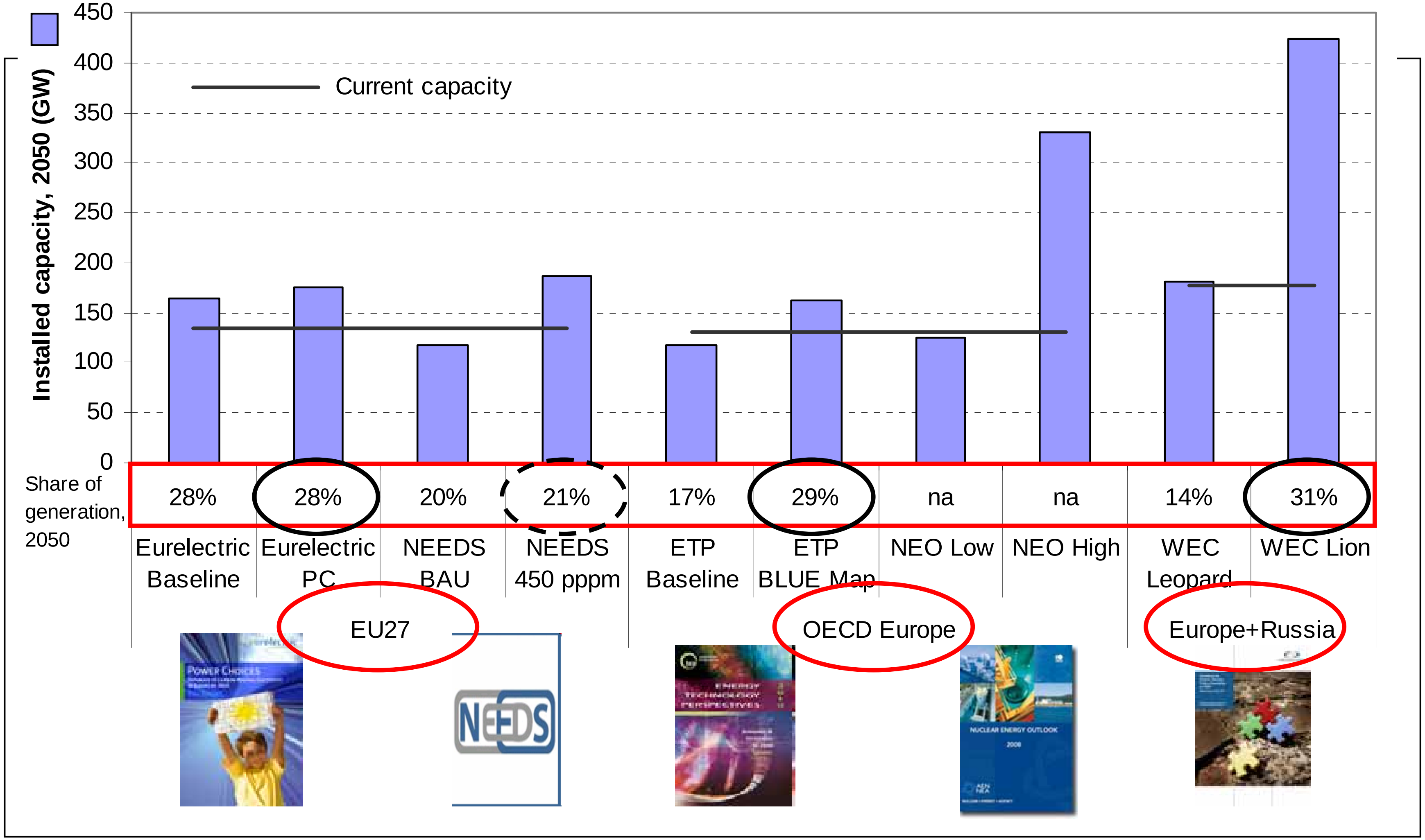
I. Size of the electricity market

- Economic growth
- Energy intensity/efficiency
  - sectoral
- Electrification
  - sectoral
  - Policy
  - Others…

II. Competitiveness of nuclear within market

- Generation cost (relative to other technologies)
- Non-cost barriers (moratoria, phase-outs, availability of new technologies, other barriers)
- Factors affecting role of alternatives (e.g. renewables, CCS availability)
- Policy
- Others…

Nuclear across the scenarios: summary



Conditions determining nuclear deployment

- Electricity market size:
- **Economic growth** and **energy efficiency** tend to correlate in the scenarios (with the exception of the NEEDS scenarios).
  - Thus, the divergence in energy demand across the scenarios is much smaller than the divergence in economic growth and efficiency, and together these assumptions are less important for determining the size of the market for nuclear.
- The extent of **electrification** is very important for the size of the market for nuclear; the success of electric mobility and large-scale electrification of industry and buildings seem to influence whether electrification levels are on the order of 30% or above 40%.

Conditions determining nuclear deployment

- **Nuclear competitiveness:**
- Nuclear generation is assumed to be **relatively cheap** in all scenarios, supporting the levels of deployment.
  - Realising these cheap costs is likely to be very important for achieving the projected levels of deployment.
- Political **limits on deployment** play a large role in constraining nuclear in all scenarios (with the possible exception of WEC Lion, which assumes strong government support).
  - Sensitivity analyses presented in the scenario reports suggest that these political constraints come into play before competition from CCS, renewables or CHP has a significant impact.
    - The role of renewables depends on renewable and climate policy assumptions (those scenarios with weak climate policy generally assume a continuation of current renewable support), while the success of CHP depends on whether gas-CHP-CCS options are assumed to be available (otherwise the contribution of CHP in stringent mitigation scenarios is limited by biomass availability).
- **Policy**: Climate policy also supports nuclear deployment. In the absence of strong climate policy, coal prices appear to influence the contribution of nuclear. Other policy assumptions (e.g. for energy security) are generally not described in detail across the studies.

Some emerging issues in scenario analysis

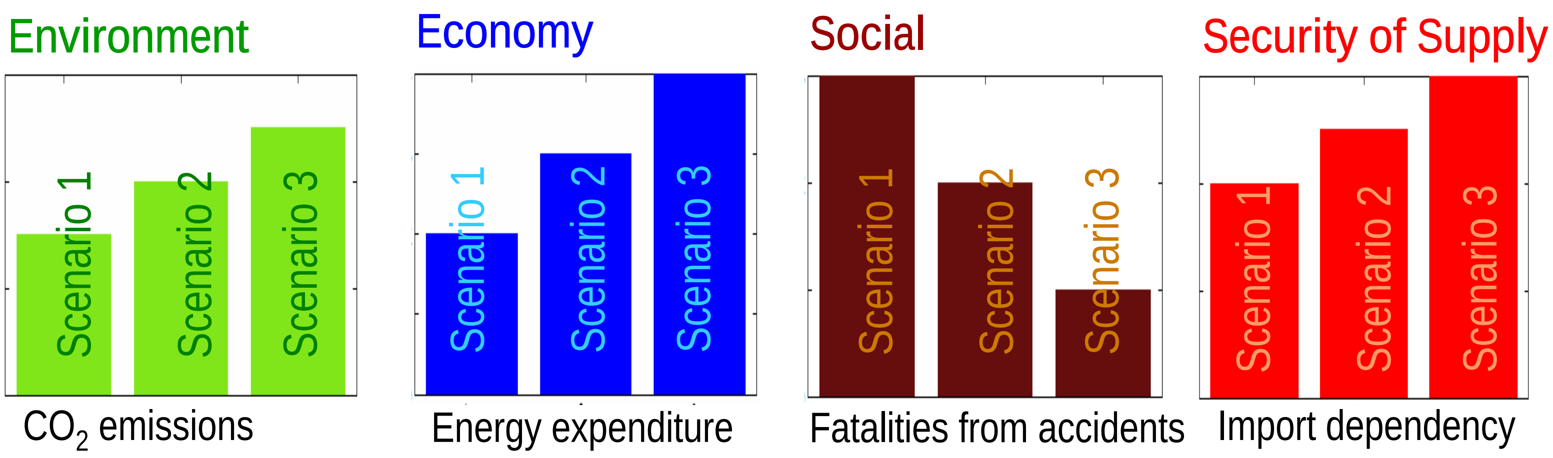
- Explicit treatment of security of supply
- Going beyond cost and climate implications
- Need to account for spatial dependencies and increase time resolution
- Need of transparency and validation

How does MCDA* work?

*MCDA = Multi-criteria Decision Analysis

Goal: Compare policy scenarios with different levels of CO_2 reduction

Scenarios differ in many aspects:



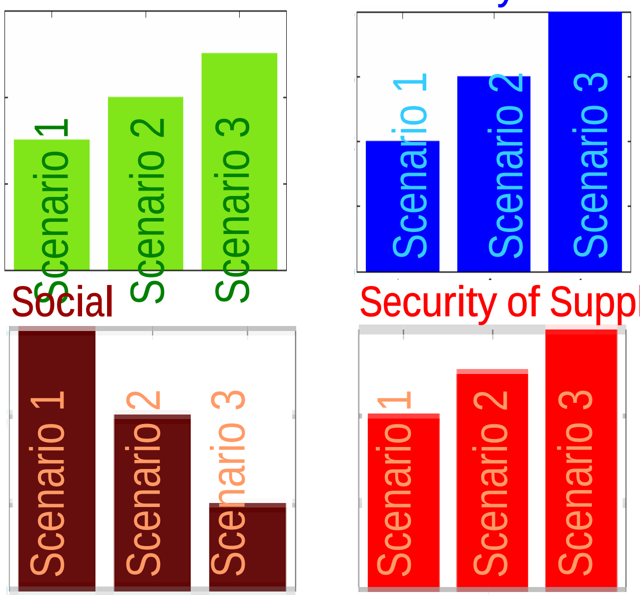
-> MCDA provides a tool to compare the scenarios on all aspects **simultaneously**

2 questions, separated in a two step process:

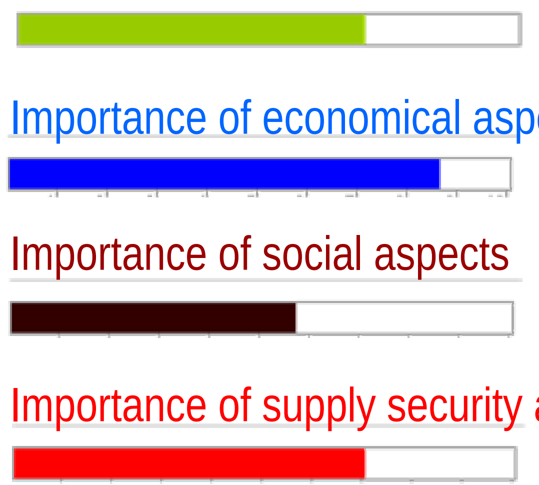
- How well does each scenario perform for each indicator: **objective calculation**
- How important is this aspect/indicator: **subjective preference**

MCDA

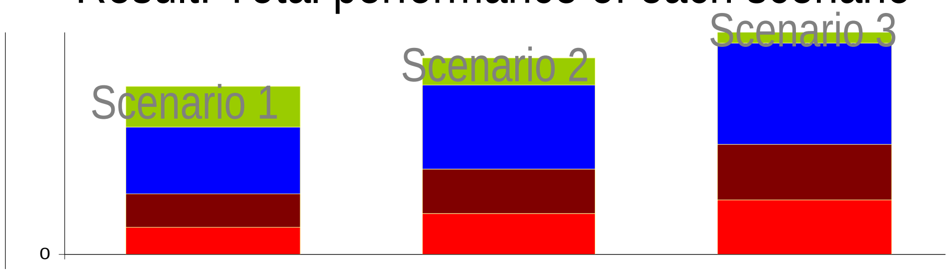
Step 1: **Objective** performance of the scenarios



Step 2: **Subjective** weighting of the importance



Result: Total performance of each scenario



	Criteria / Indicator	Description	Unit	Source
ENVIRONMENT	CO_2 Emissions World	Worldwide CO_2 emissions per capita	t CO_2 / capita	POLES
	CO_2 Emissions EU 27	EU 27 CO_2 emissions per capita	t CO_2 / capita	POLES
ECONOMY	Energy Expenditure World	Worldwide energy expenditure per Gross Domestic Product (GDP)	USD / GDP	POLES
	Energy Expenditure EU 27	EU 27 energy expenditure per Gross Domestic Product (GDP)	USD / GDP	POLES
SOCIAL	Severe Accidents	Risk from severe accidents		
	Average Number of Fatalities	Cumulated expected number of fatalities from severe (≥5 fatalities) accidents worldwide in fossil (coal, oil, gas), hydro and nuclear energy chains	Fatalities / year	PSI
	Consequences of Worst Accident	Maximum fatalities from severe (≥5 fatalities) accidents worldwide in fossil (coal, oil, gas), hydro and nuclear energy chains	Fatalities	PSI
	Oil Spills	Oil spill risk is assumed to scale linearly with the amounts of oil used, so the indicator scales with the amount of oil used globally	Mtons	PSI
	Terrorism Risk	Cumulated terrorism risk for EU 27, based on attack scenarios for a European Pressurized Reactor (EPR), hydropower dam, refinery and Liquefied Natural Gas (LNG) Terminal	Fatalities	PSI
SECURITY OF SUPPLY	Diversity EU 27 Consumption	Shannon-Wiener diversity index of EU 27 gross inland energy consumption (Mtoe) for the different energy carriers	Factor	POLES
	Share of energy imports EU 27	Ratio of Primary Production (Mtoe) / Gross Inland Consumption (Mtoe) in EU 27	Factor	POLES
	Diversity of Resources	*Shannon-Wiener diversity index of net exporters from 23 world regions in oil, gas and coal markets*		
	Diversity World Oil Market	Shannon-Wiener diversity index of net oil exporters (Mtoe) from 23 world regions in POLES	Factor	POLES
	Diversity World Gas Market	Shannon-Wiener diversity index of net gas exporters from 23 world regions in POLES	Factor	POLES
	Diversity World Coal Market	Shannon-Wiener diversity index of net coal exporters from 23 world regions in POLES	Factor	POLES

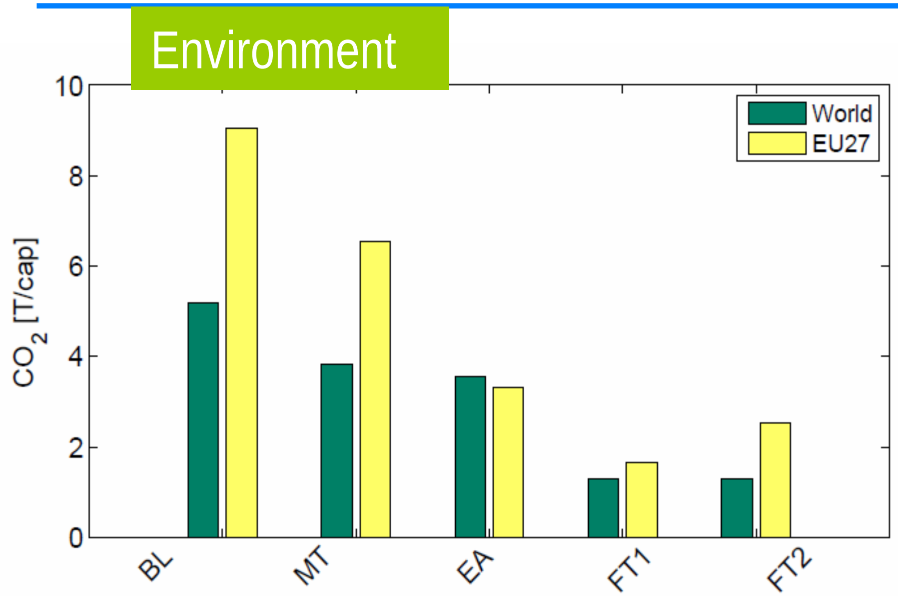
POLES Scenarios

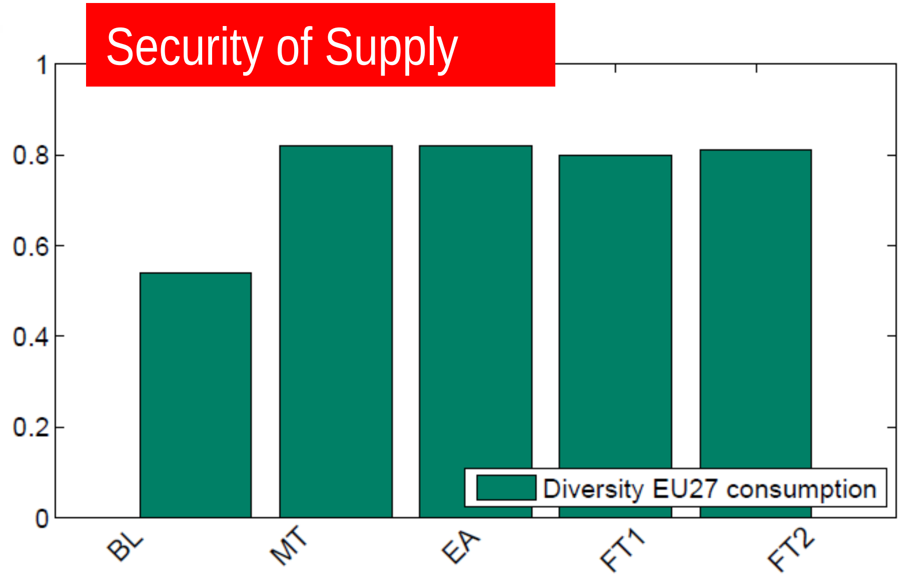
Main Scenarios	Baseline (BL): NO climate policy	Muddling through (MT): Copenhagen forever	Europe alone (EA): Climate policy with target of reducing GHG emissions by 60% in 2050 compared to 1990 levels only in Europe	Global regime - Full trade (FT 1& 2): a global climate regime with two sub scenarios
Nuclear accident Subsequent phase out of nuclear power	BL Nuc	MT Nuc	-	FT Nuc
Fossil fuel price Shock	BL Sh	MT Sh	EA Sh	-
No carbon capture & storage	-	MT CCS	EA CCS	FT CCS

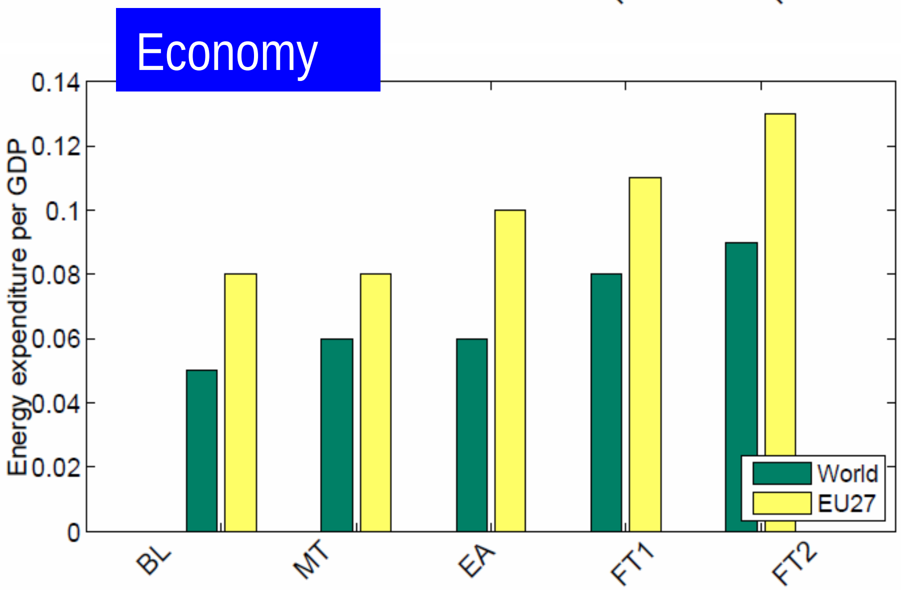
Source: LEPII/POLES

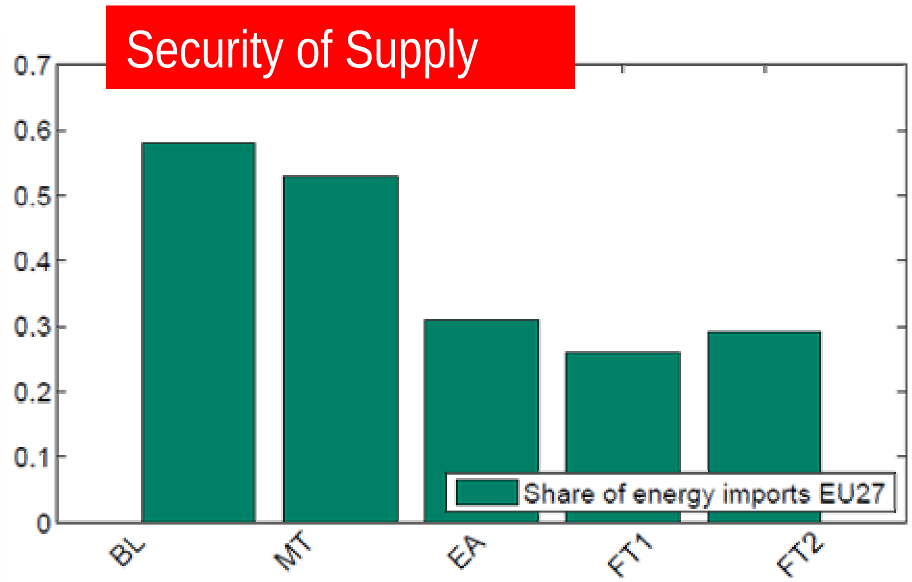
PAUL SCHERRER INSTITUT PSI

secure



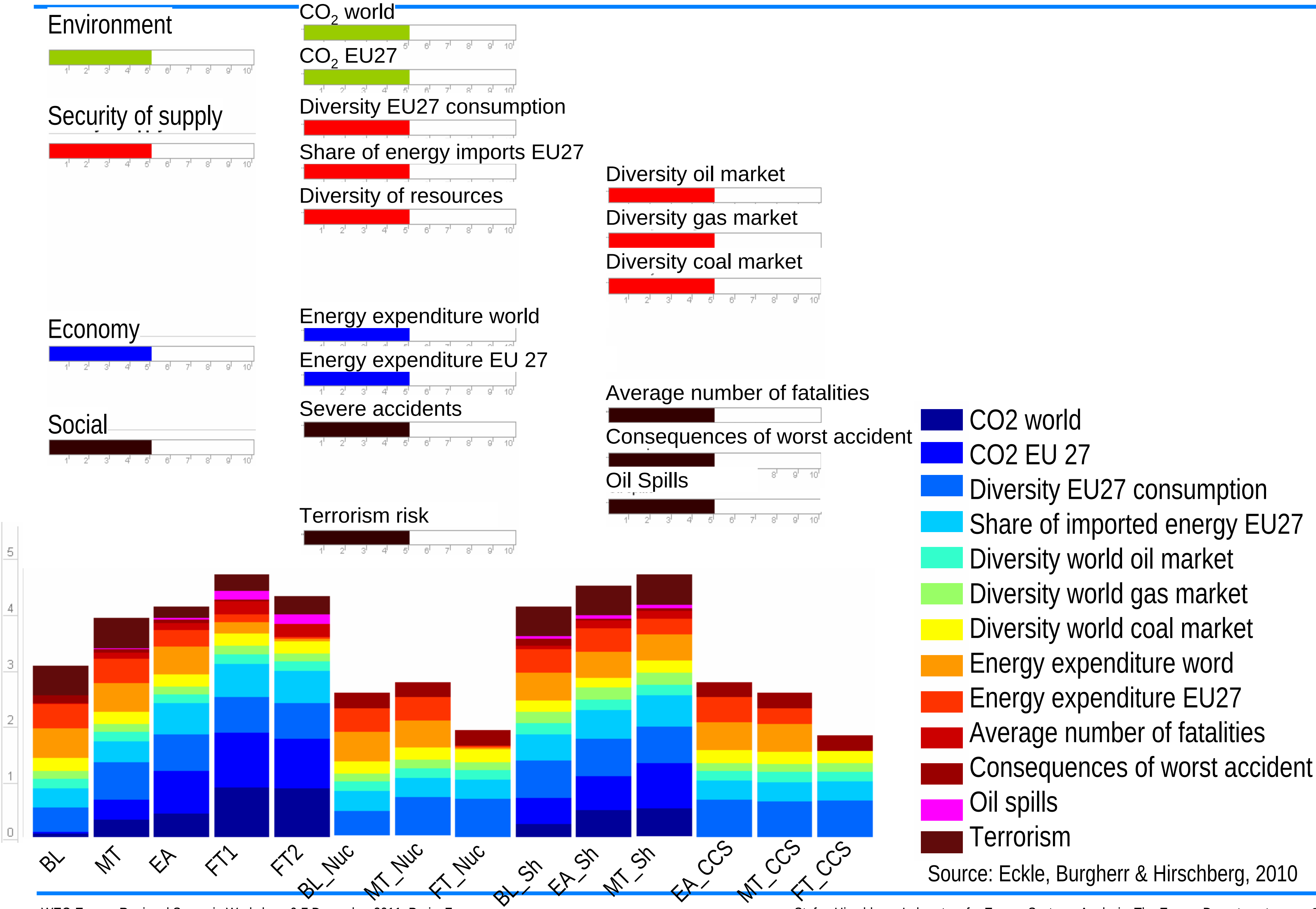






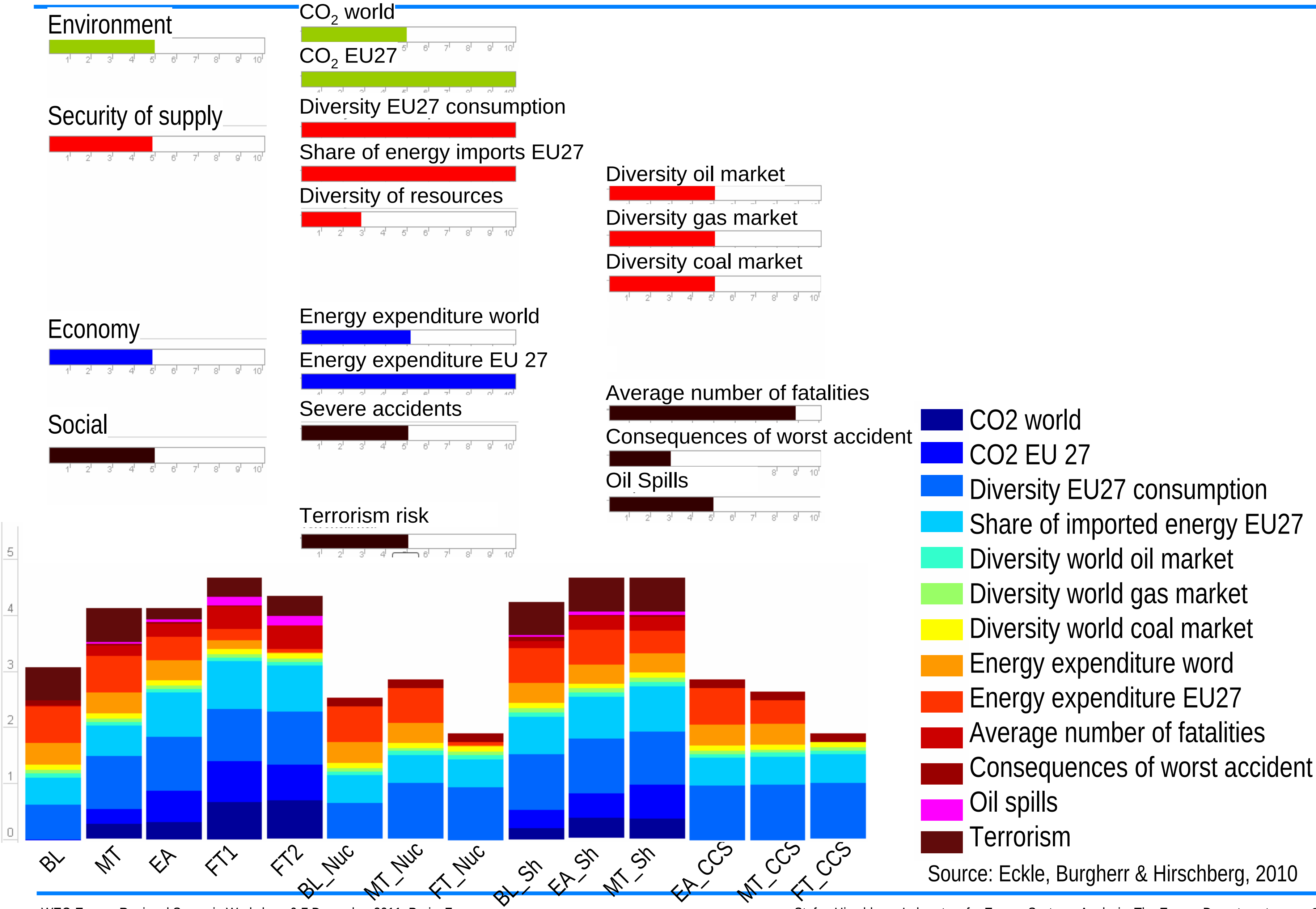
Source: LEPII/POLES

Equal weights case



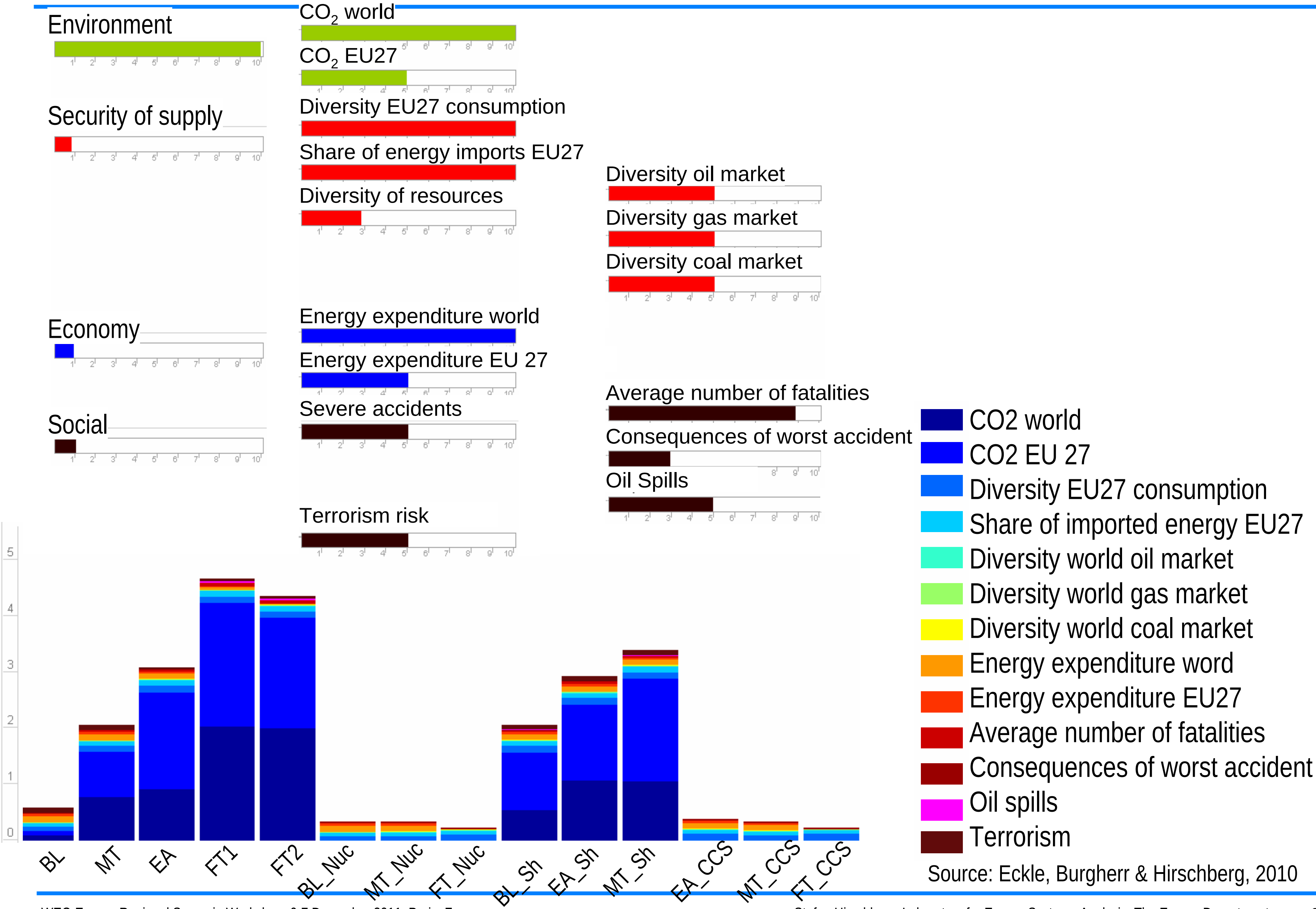
Source: Eckle, Burgherr & Hirschberg, 2010

Balanced/differentiated case



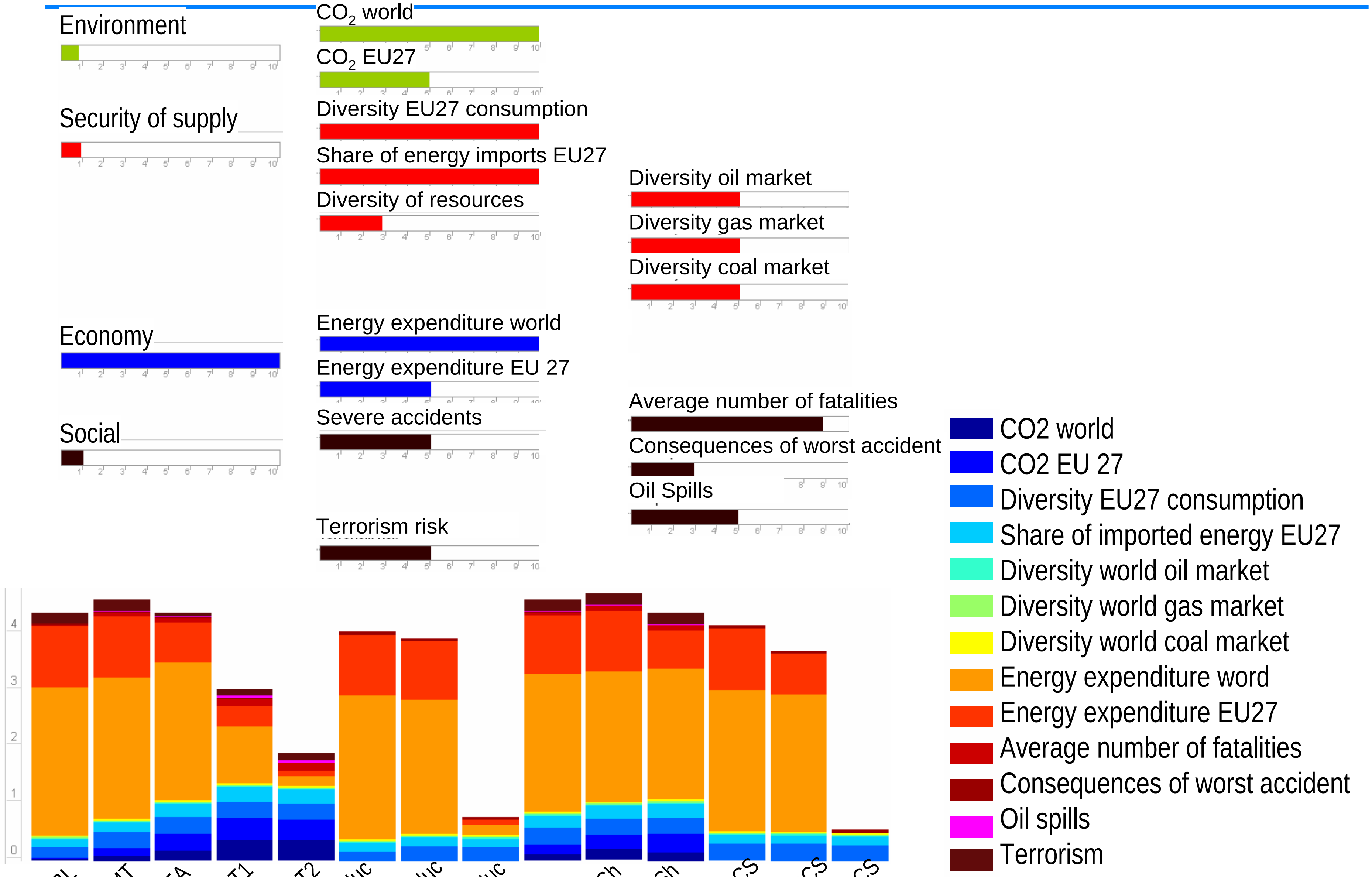
Source: Eckle, Burgherr & Hirschberg, 2010

Environmentally-centered case



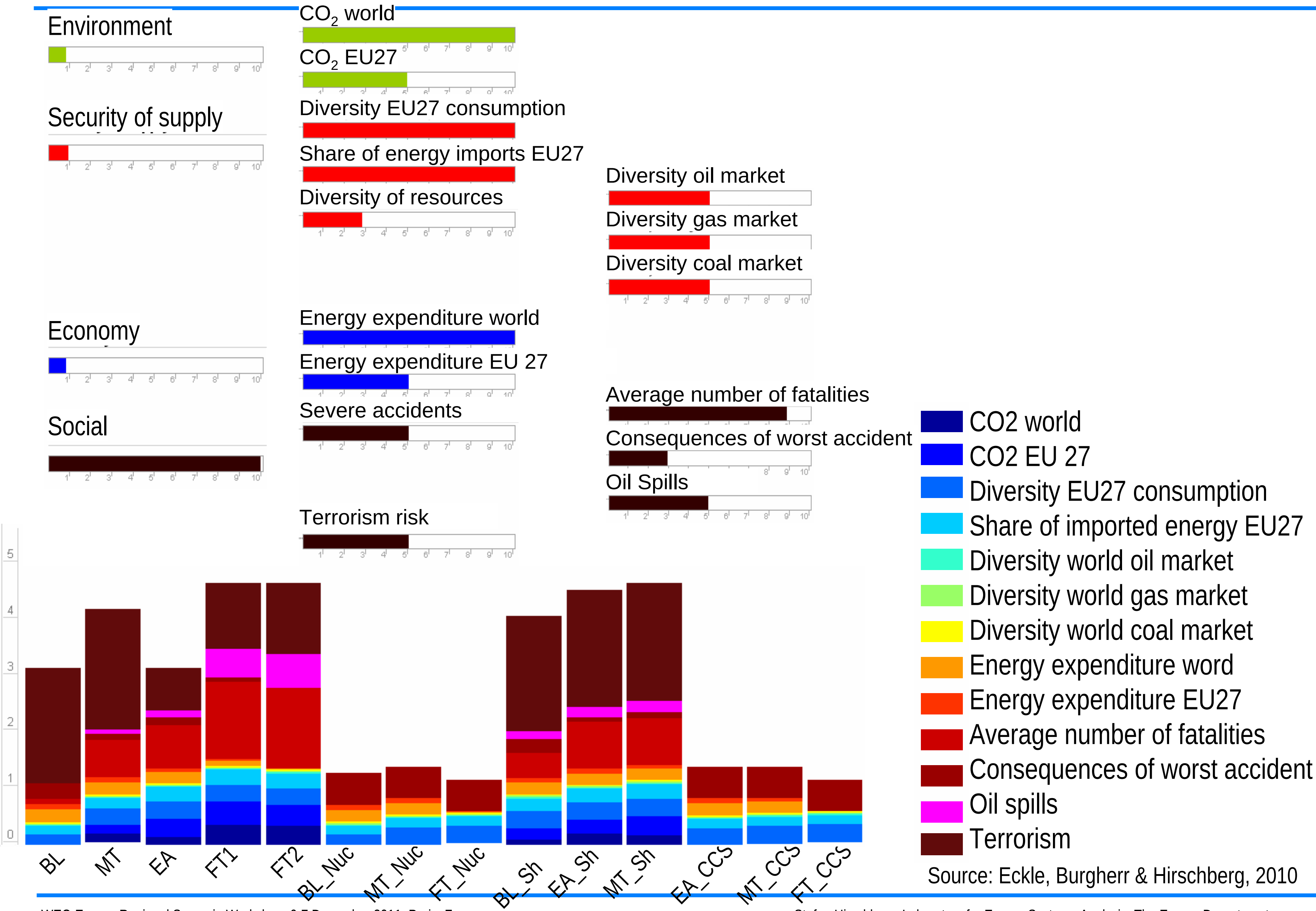
Source: Eckle, Burgherr & Hirschberg, 2010

Economy-centered case

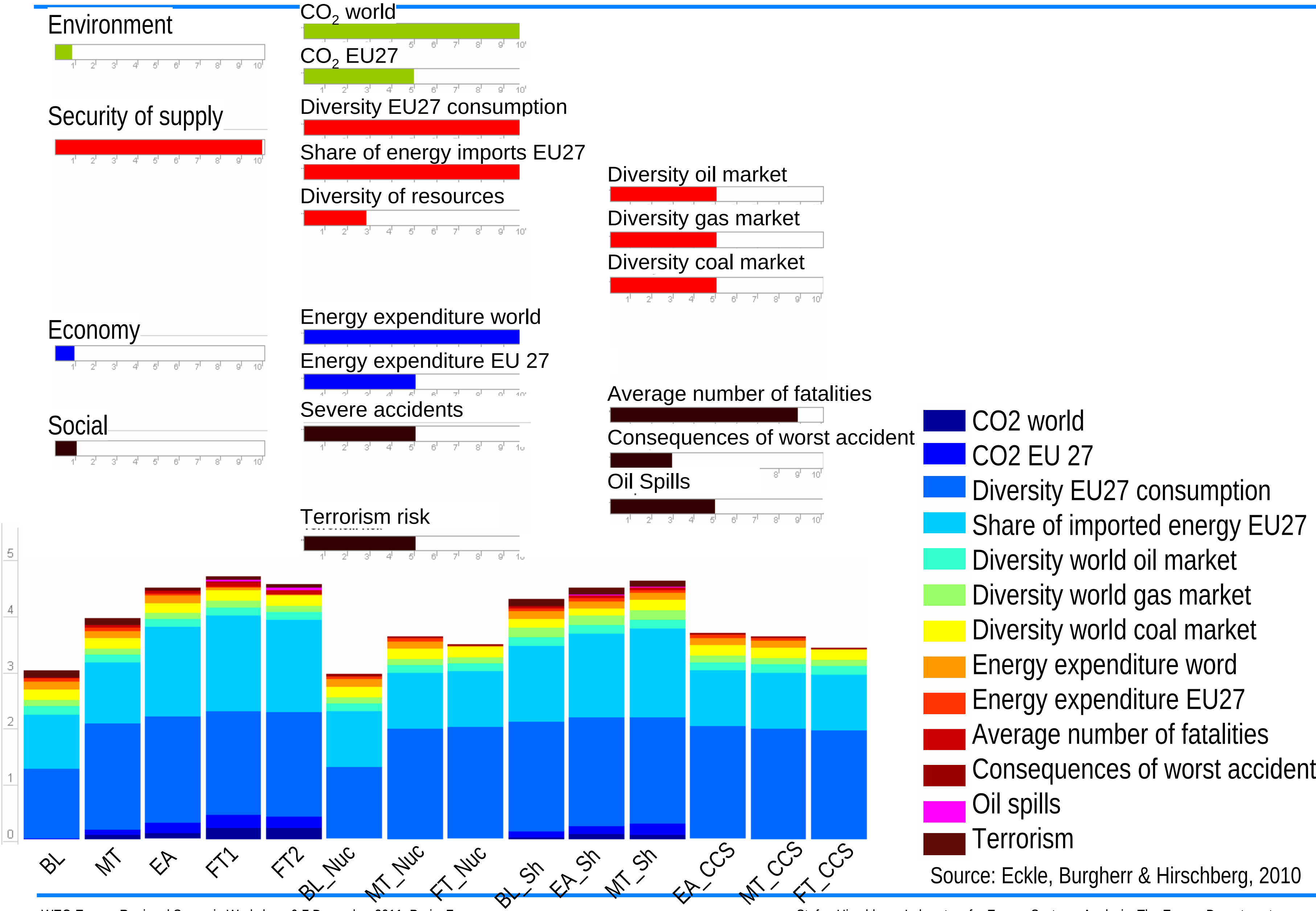


Source: Eckle, Burgherr & Hirschberg, 2010

Socially-centered case

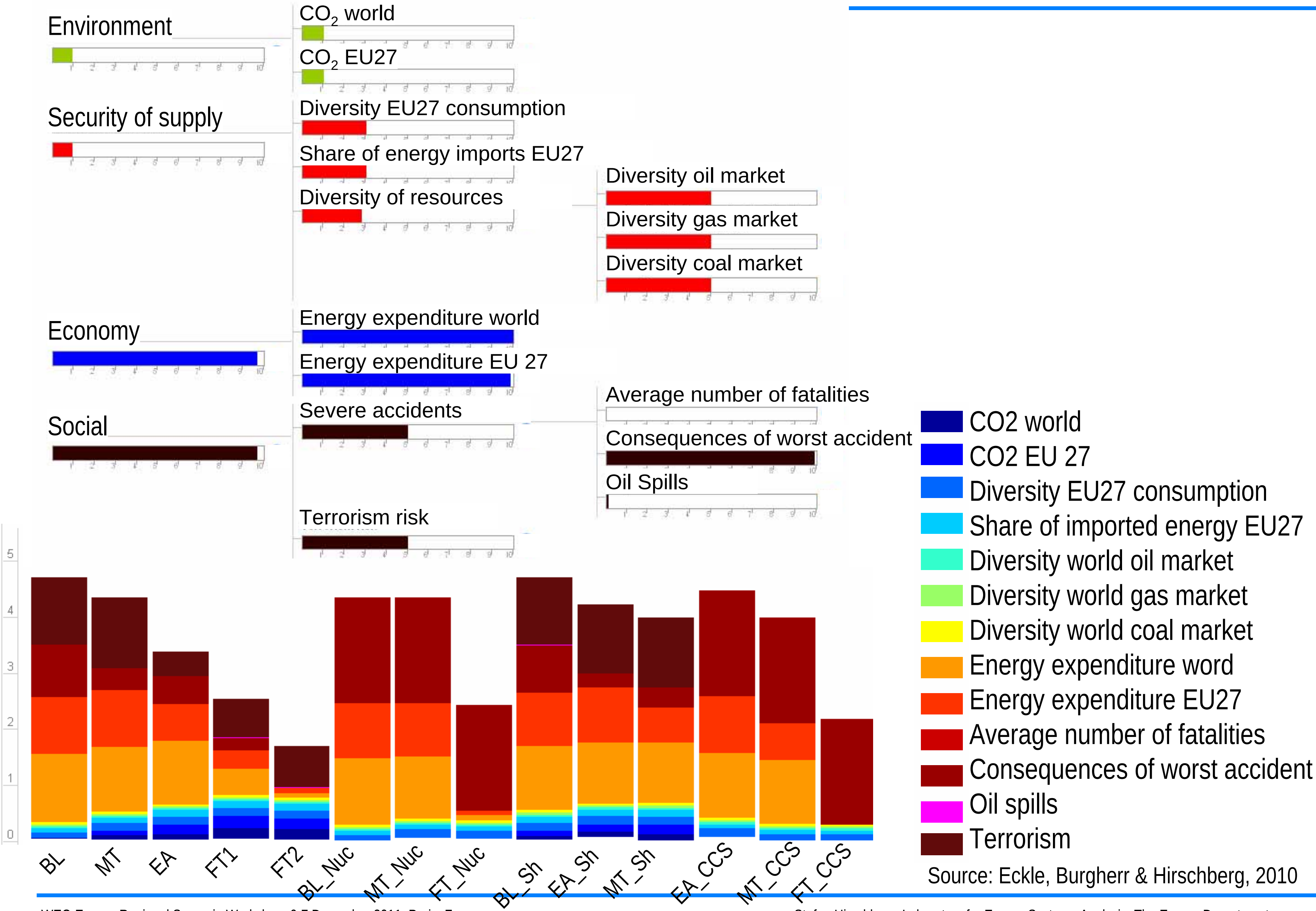


Security of supply centered case



Source: Eckle, Burgherr & Hirschberg, 2010

When is Baseline top ranked?

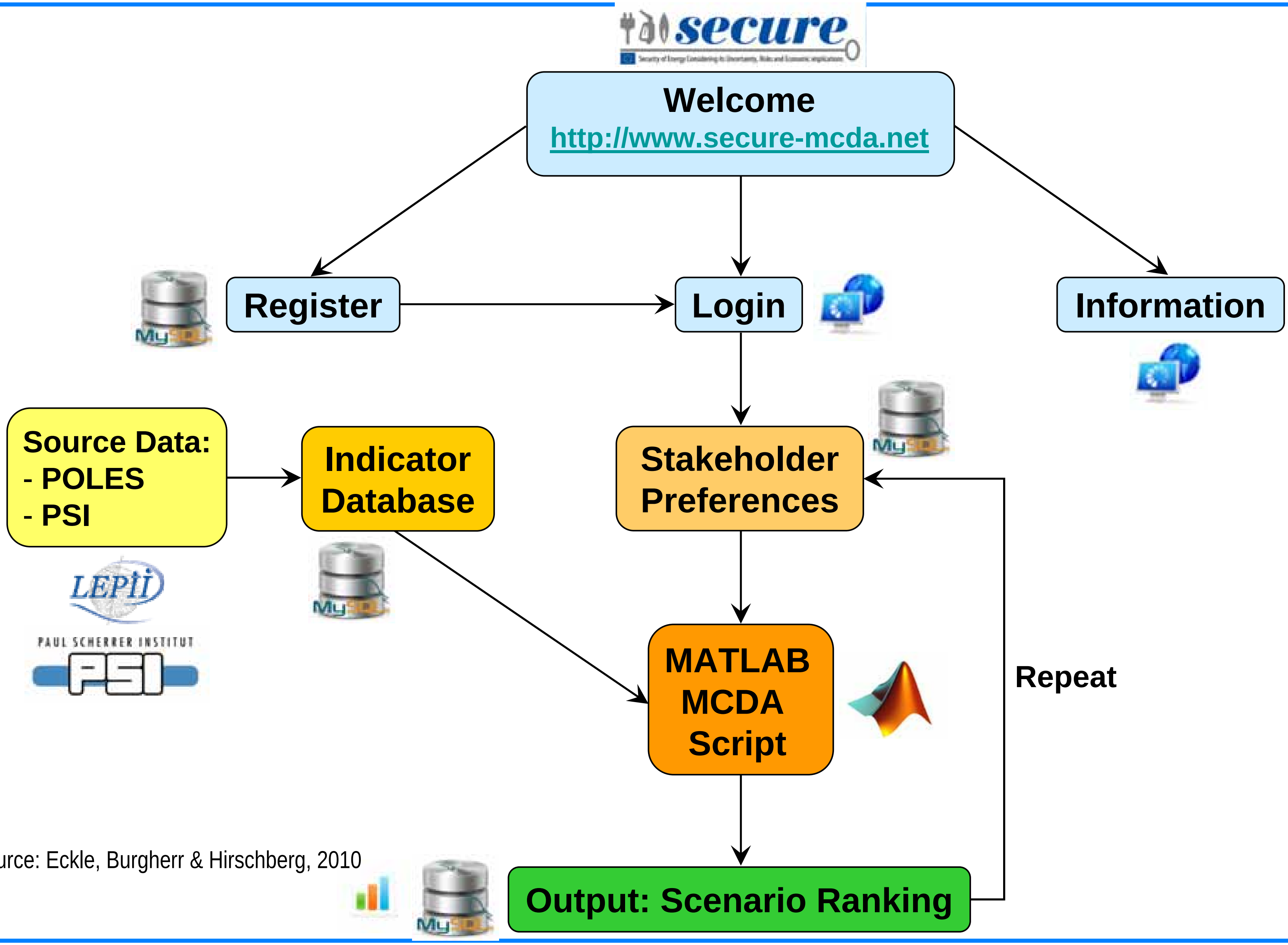


Source: Eckle, Burgherr & Hirschberg, 2010

Conclusions

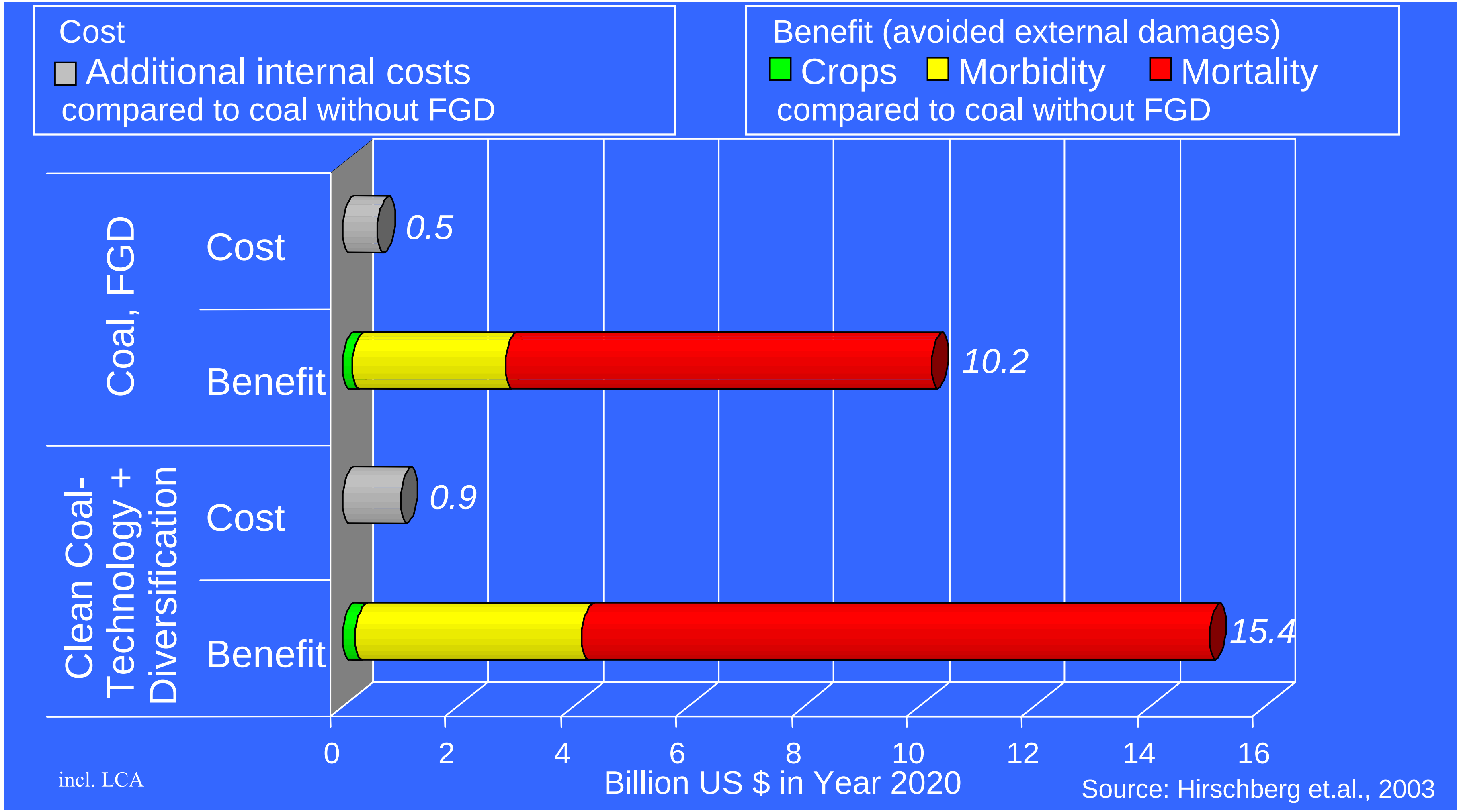
- No single scenario meets all sustainability and security of supply criteria used in SECURE; thus, trade-offs are inevitable,
- Given balance between environmental, economic, social and security of supply criteria, the **global regime climate regime scenarios (without shocks) perform best while the baseline scenario is consequently worst.**
- This result is with two exceptions quite stable with respect to the variations of preferences. **The exceptions are economy-centered profiles and/or high importance assigned to the aversion towards worst consequences of severe accidents.**
- **Under the assumptions made in the SECURE project the global regime scenarios are highly vulnerable to shocks in form of a very severe nuclear accident** and/or failure to implement carbon capture and storage on a large scale.
- **There are clear synergies between protection of climate and security of supply.** Meeting ambitious GHG-emission reduction goals by means of successful decarbonisation of the energy supply system through expansion of renewables, nuclear and CCS, combined with very extensive efficiency improvements, is also highly beneficial for security of supply.

On-line tool open for stakeholder evaluations



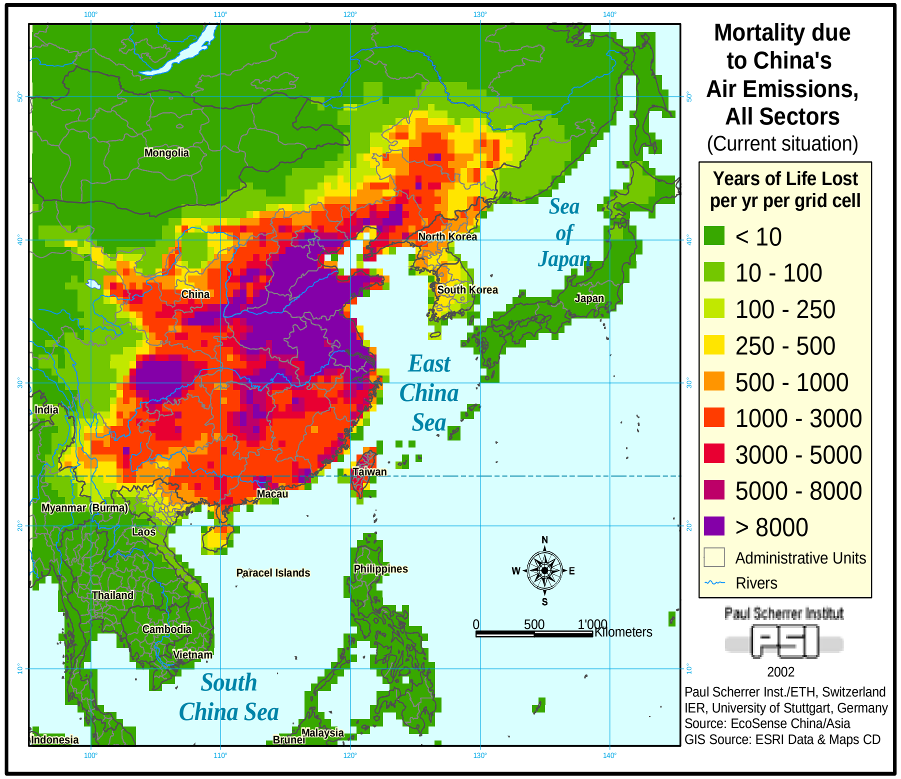
Source: Eckle, Burgherr & Hirschberg, 2010

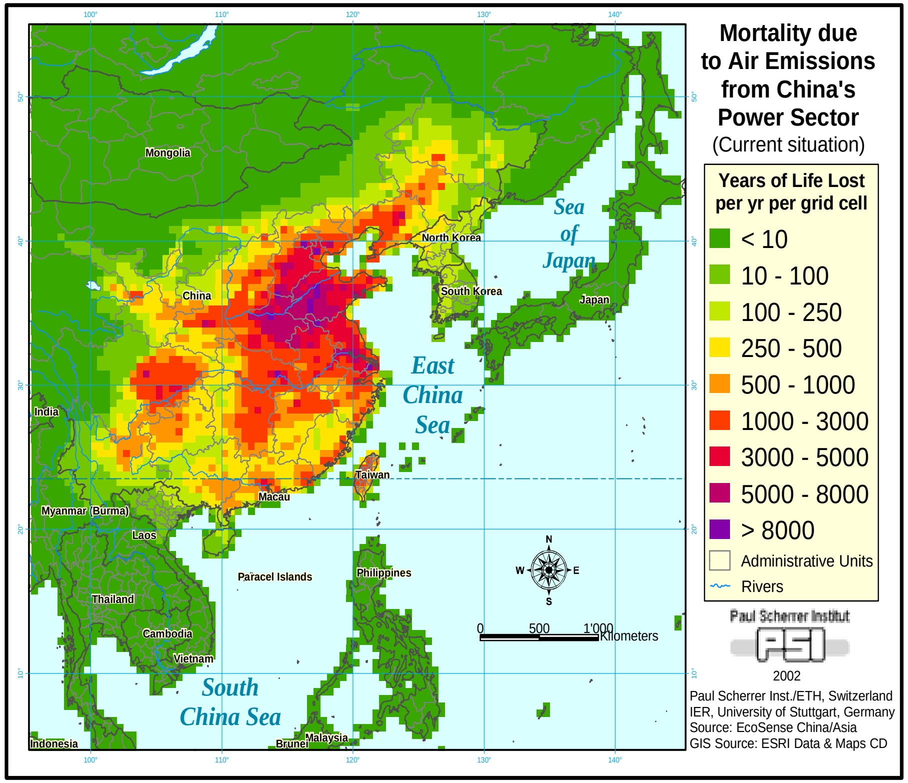
Cost-Benefit Analysis for Selected Electric Sector Simulation Scenarios, Province Shandong in Year 2020



Mortality in China due to Air Pollution

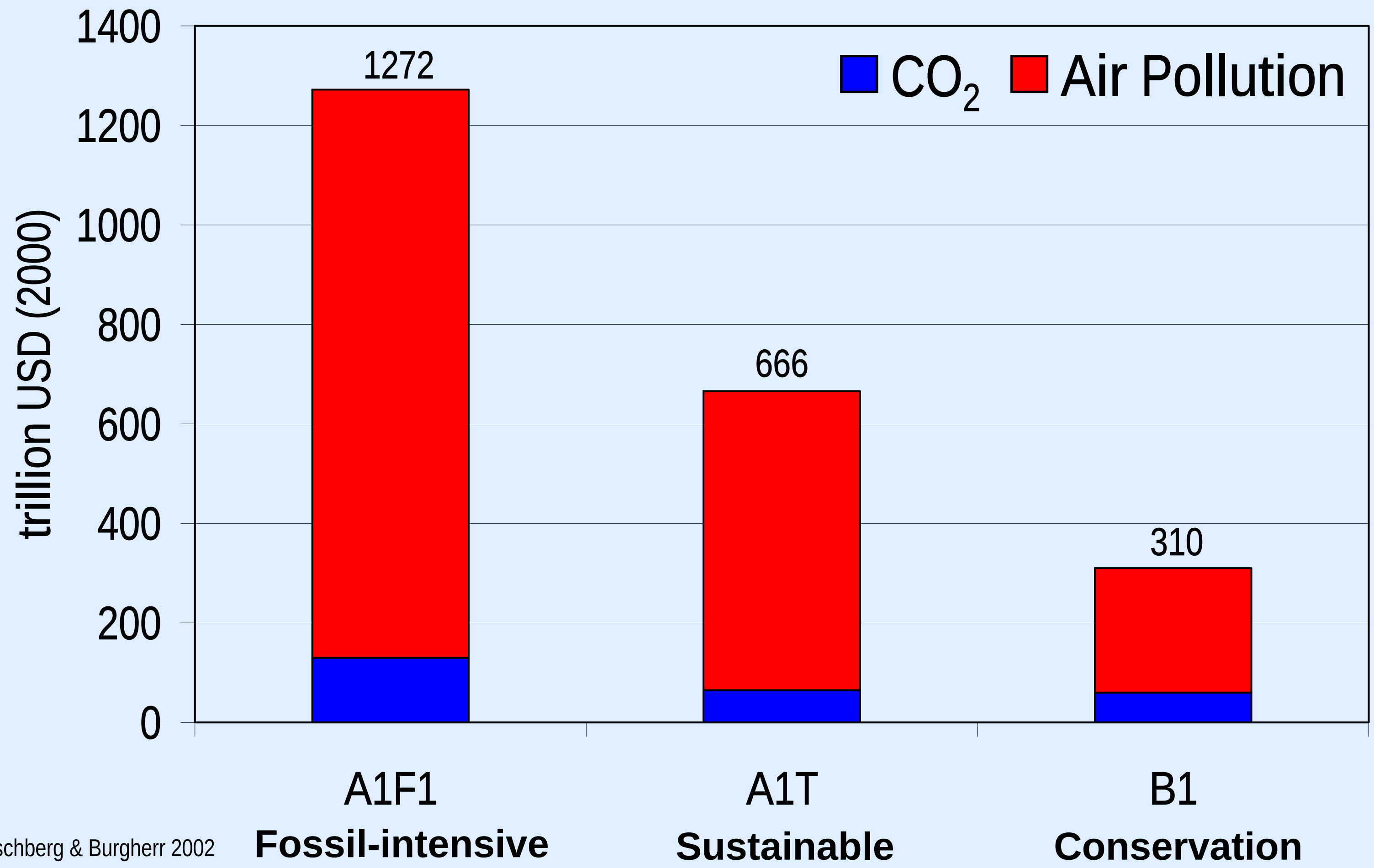
Emissions from all Sectors	Emissions from Power Sector





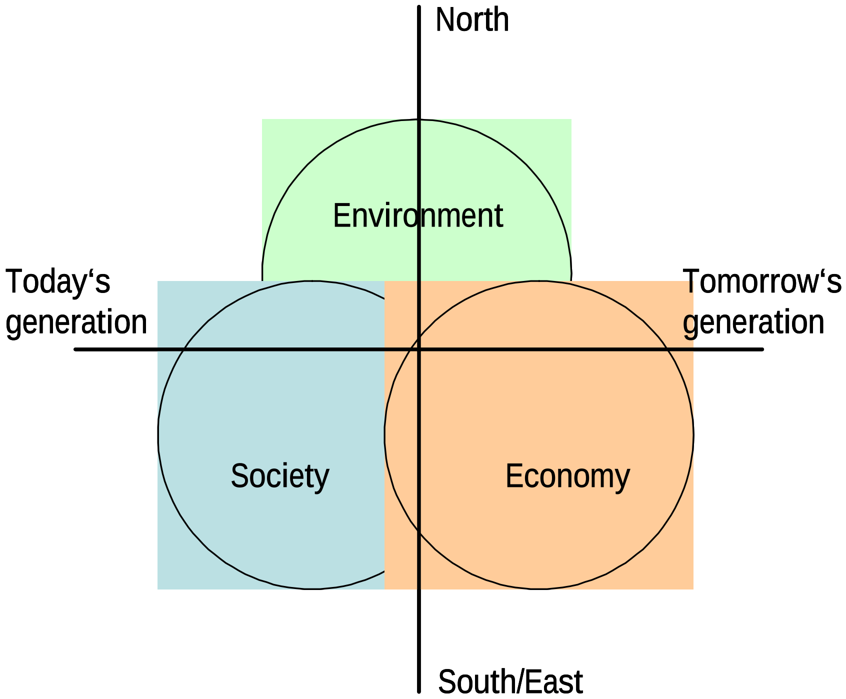
Source: Hirschberg et al., 2003

Total Cumulative Damage (1990 – 2100) for Selected IPCC Scenarios



Source: Hirschberg & Burgherr 2002

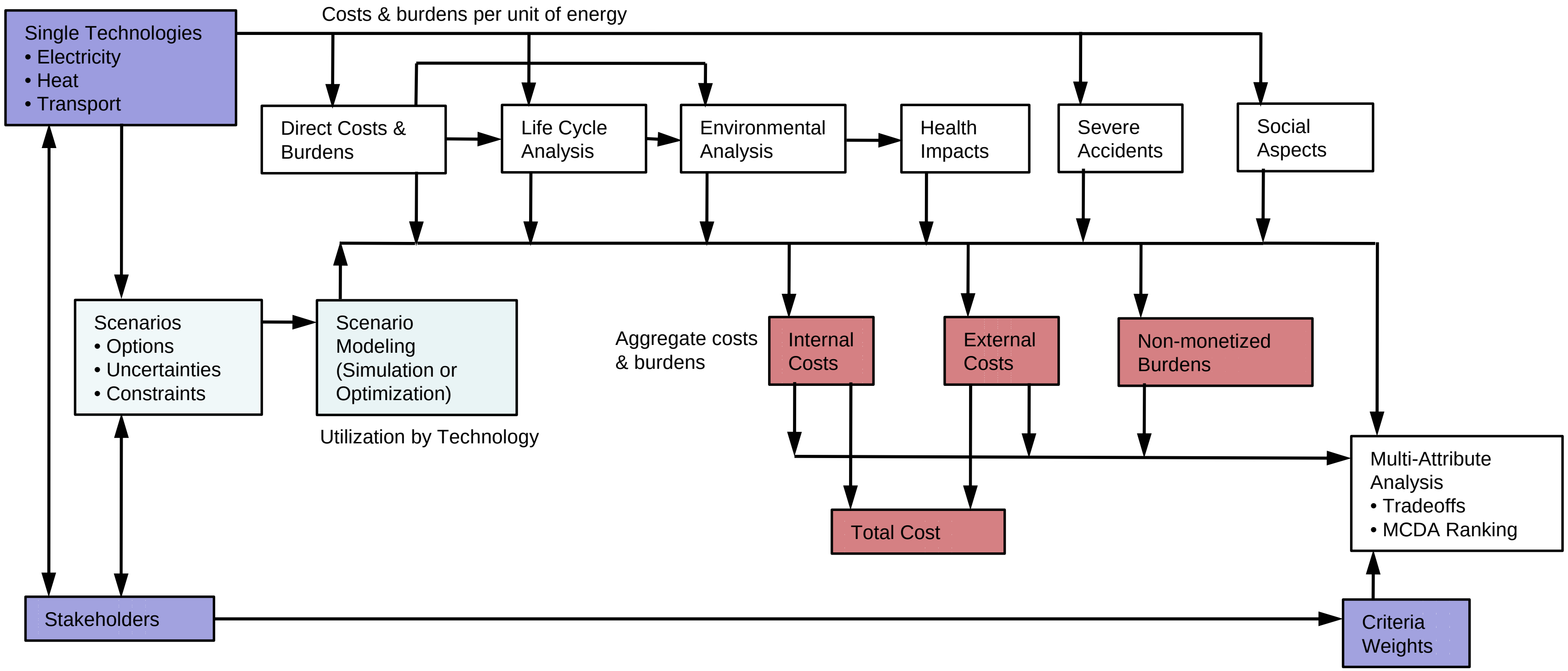
Sustainability Criteria



	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

PSI's General Analysis Framework



For electric vehicle analysis:

Vehicle (technology) characterization requires

- Drivetrain simulation

Scenario analysis requires

- Traffic forecasting/simulation
- Grid modeling (demand/generation/transmission)

Implications for decision-making I

The scenario approach has strengths and limitations which affect its suitability for supporting decision-makers:

Strenghts	Limitations
Scenarios are used to explore alternative futures.	Scenarios are not predictions, i.e. they serve as explorative tools.
Different pathways to achieve certain targets can be assessed.	Short-term changes of parameters and shocks are usually not represented in detail.
Critical trade-offs can be understood, e.g. between technology or mitigation options.	Historically, energy models have not dealt in detail with spatial and actor heterogeneity.
Crucial parameter assumptions can be detected.	The range of scenarios is limited to the imagination of scenario developers; subjective opinions determine the choice of scenarios.
Consequences of certain decisions can be anticipated.	Only a limited range of uncertainty can be taken into account.
Uncertainty can be explored.	Scenario studies often have a simplified representation of technology characteristics.
	Well-quantified scenarios may have a quantification bias: soft factors are difficult to quantify and not well represented.

Implications for decision-making II

- **Some real-world factors are not well represented**, primarily related to the interface between the energy system and other human and natural systems (for example, related to non-energy resources, such as water, agricultural land, minerals, manufacturing and human capacity and so on)
- Energy scenarios are **less suitable for accounting for factors important for very immature or speculative technologies**, where major technological breakthroughs are needed
- The breadth of this range of perspectives can be understood in the context of **significant uncertainty** about future technological development and political, social and economic factors
- This wide range of perspectives necessitates **better communication and interaction between scenario developers and the audience** of these studies
- There is **no single option or single combination of options** for responding to climate change and policy makers have some flexibility to pursue different combinations of energy efficiency, electrification, renewables, nuclear power, and CCS to meet long-term targets, at least during the period to 2030
- However, the scenario literature has a somewhat **limited discussion of costs and trade-offs associated with different technology options** (although some exceptions, such as ETP).

PAUL SCHERRER INSTITUT

Recommendations on energy scenario development

The scenario analysis can be improved in the following areas to increase the usefulness for decision-makers:

1. Emphasize key question to be investigated
2. Motivate the choice of certain scenarios (i.e. the importance and uncertainty of scenario drivers)
3. Investigate scenarios with different levels of energy security
4. Define conventions on what current cost and capacity data should be used
5. Assess the likelihood of outcomes (i.e. conditions, feasibility and risks of solutions)
6. Make assumptions and constraints transparent and accessible for the audience
7. Develop multi-stakeholder sets of scenarios (e.g. involve green, industry, or government perspectives)
8. Consider further approaches to technology assessment (e.g. combine with LCA and MCDA approaches)
9. Increase spatial and time resolutions
10. Improve consistency and transparency

PAUL SCHERRER INSTITUT

Thank you for your attention

stefan.hirschberg@psi.ch