SCCER SoE

SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

Global observatory of electricity resources (Task 4.2)

Peter Burgherr, Paul Scherrer Institut (PSI)
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In cooperation with the CTI

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Persons Involved

PIs:

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Energy Economics (EE) group:

Dr. Martin Densing
EE

Dr. Evangelos Panos
EE

CO = Coordination
LCA = Life Cycle Assessment
EIA/EC = External Impact Assessment / External Costs
RA = Risk Assessment
TC = Technology Characterization
IA = Integrated Assessment
MCDA = Multi-Criteria Decision Analysis
EE = Energy Economics

Goals and Tasks

Short-term (to 2016):

- Trend-based and comparative perspective on the prospective developments of technologies
  - TA: Characterization and sustainability assessment of current and future technologies
  - EE: Evaluation of existing trends, projections and scenarios
  - **Milestone T4.2.1**: Report on global evolution of electricity resources and market

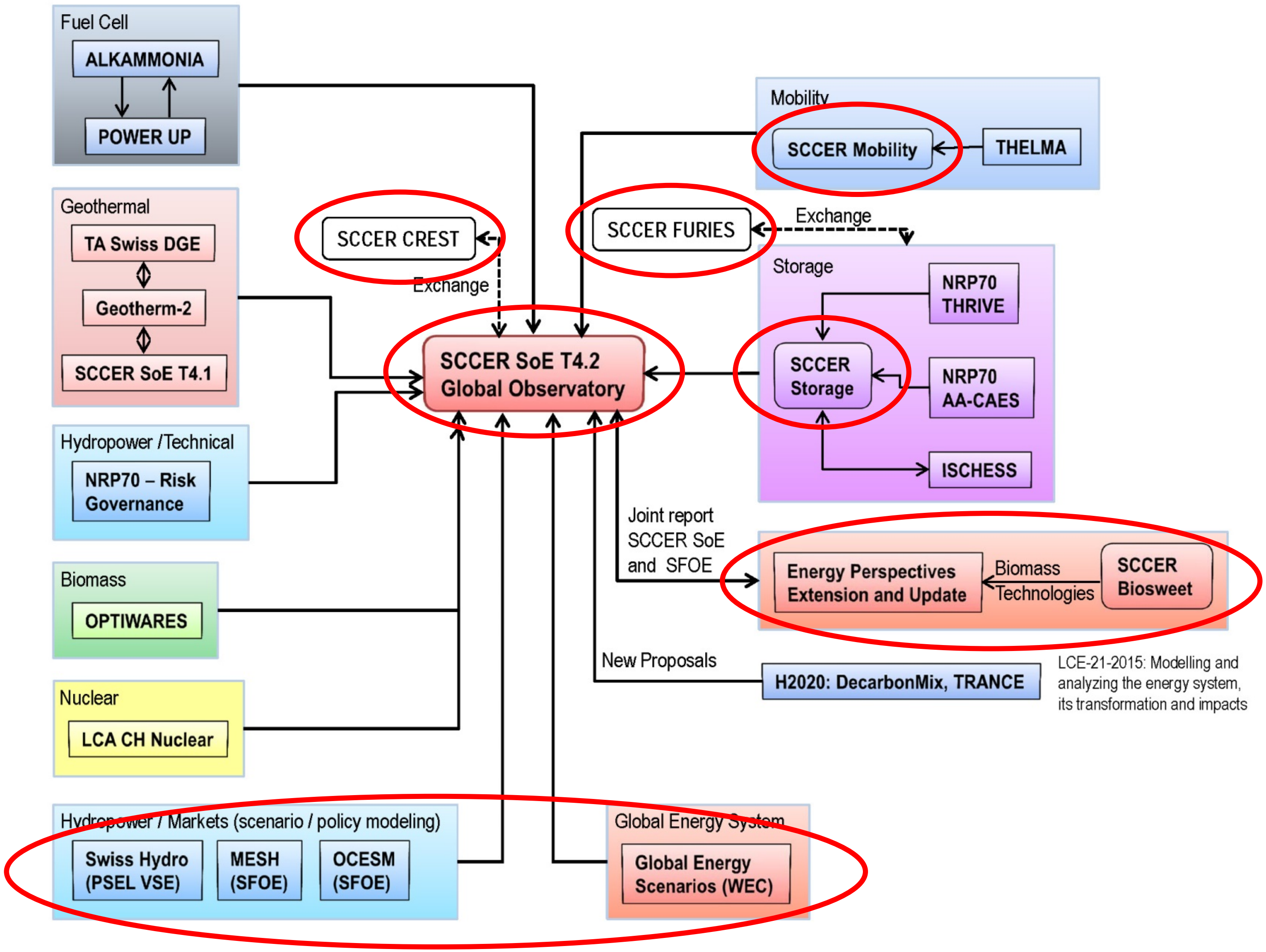
Medium term (years 5-8):

- Assess technologies emerging from SCCER activities in future trend and scenario analysis
  - TA: Refine and extend technology monitoring and horizon scanning
  - EE: Scenario analysis of technologies emerging from SCCER

Long term (years 9-12):

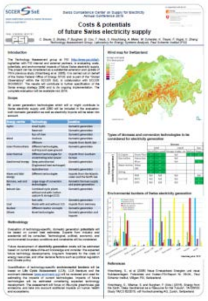
- Continuously improve technology monitoring
- Develop instruments and interactive tools for evaluation and visualization of trends in technology developments
  - TA & EE: Tool development with focus on dissemination and interactivity

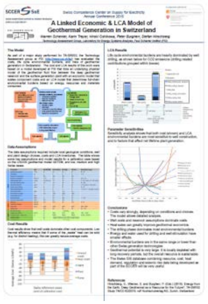
Global Observatory Project Interactions

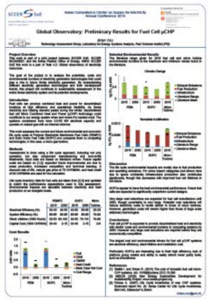


Ongoing Activities

Energy Perspectives Extension & Update

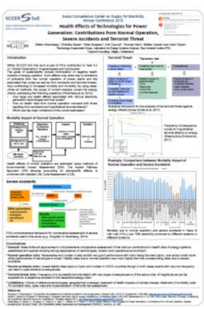






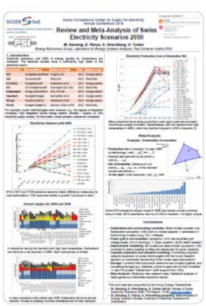
- Costs & potentials of future Swiss electricity supply
- A Linked Economic & LCA Model of Geothermal Generation in Switzerland
- Global Observatory: Preliminary Results for Fuel Cell µCHP

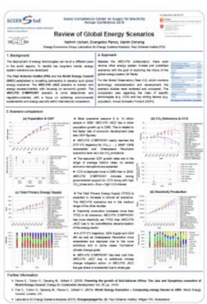
Health Effects



- Health Effects of Technologies for Power Generation: Contributions from Normal Operation, Severe Accidents and Terrorist Threat
- Comparative Risk Assessment of Accidents in the Energy Sector using PSI's ENSAD Database

Scenario Comparison





- Review of Global Energy Scenarios
- Review and Meta-Analysis of Swiss Electricity Scenarios 2050

Costs & potentials of future Swiss electricity supply

- **Substantial extension and update of PSI's previous study (Hirschberg et al. 2005*)**
- **Evaluation of costs, potentials, and environmental impacts of future Swiss electricity supply**
- **Carried out on behalf of the SFOE and is part of the "Global Observatory" within the SCCER SoE**
- **Collaboration with SCCER BIOSWEET for biomass technologies**

* Hirschberg, S., et al (2005) Neue Erneuerbare Energien und neue Nuklearanlagen: Potenziale und Kosten. PSI-Report Nr. 05-04., Paul Scherrer Institut, Villigen PSI, Switzerland.

- **May 2015: 1st interim report**
- **Dec 2015: 2nd interim report**
- **Jun 2016: final report**

Analyzed Technologies

Energy carrier	Technology	Location
Hydro	Small hydro	Domestic generation
	Reservoir	Domestic generation
	Run-of-river	Domestic generation
Wind	Onshore	Domestic generation
	Offshore	Imports from North Sea
Solar Photovoltaics	Different technologies, roof-top and open ground	Domestic generation
Solar thermal	Different technologies for oncentrating solar power	Imports from Southern Europe
Geothermal energy	Deep petrothermal (Engineered heat exchanger)	Domestic generation
	Hydrothermal	Domestic generation
Wave and tidal energy	Different technologies	Imports from the Atlantic ocean and the North Sea
Biomass, wet and dry	Large range of conversion technologies	Domestic biomass supply and power generation
Natural Gas	Combined cycle plants without and with Carbon capture & storage (CCS)	Domestic generation
	Fuel cells	Domestic generation
Coal	Plants with and without CCS	Imports from Germany
Nuclear	Different reactor concepts	Domestic generation
Others	Novel technologies	Domestic generation and imports

Approach

Potentials:

- Based on latest available estimates and expert consultation
- Considering technological, political, economic, and environmental boundary conditions and constraints

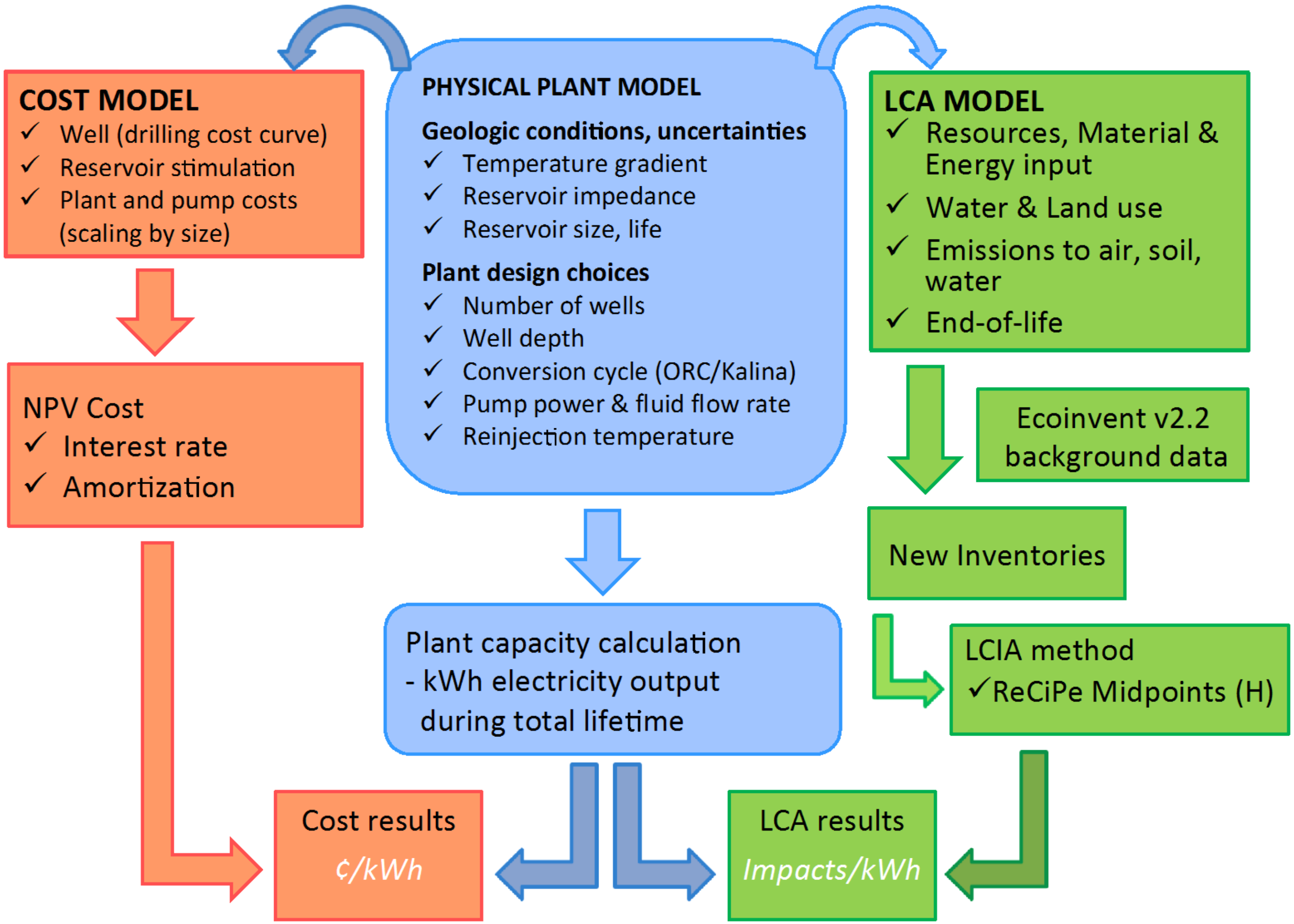
Costs:

- Estimates based on expected technology development and learning curves
- Considering political regulation, climate policy, etc

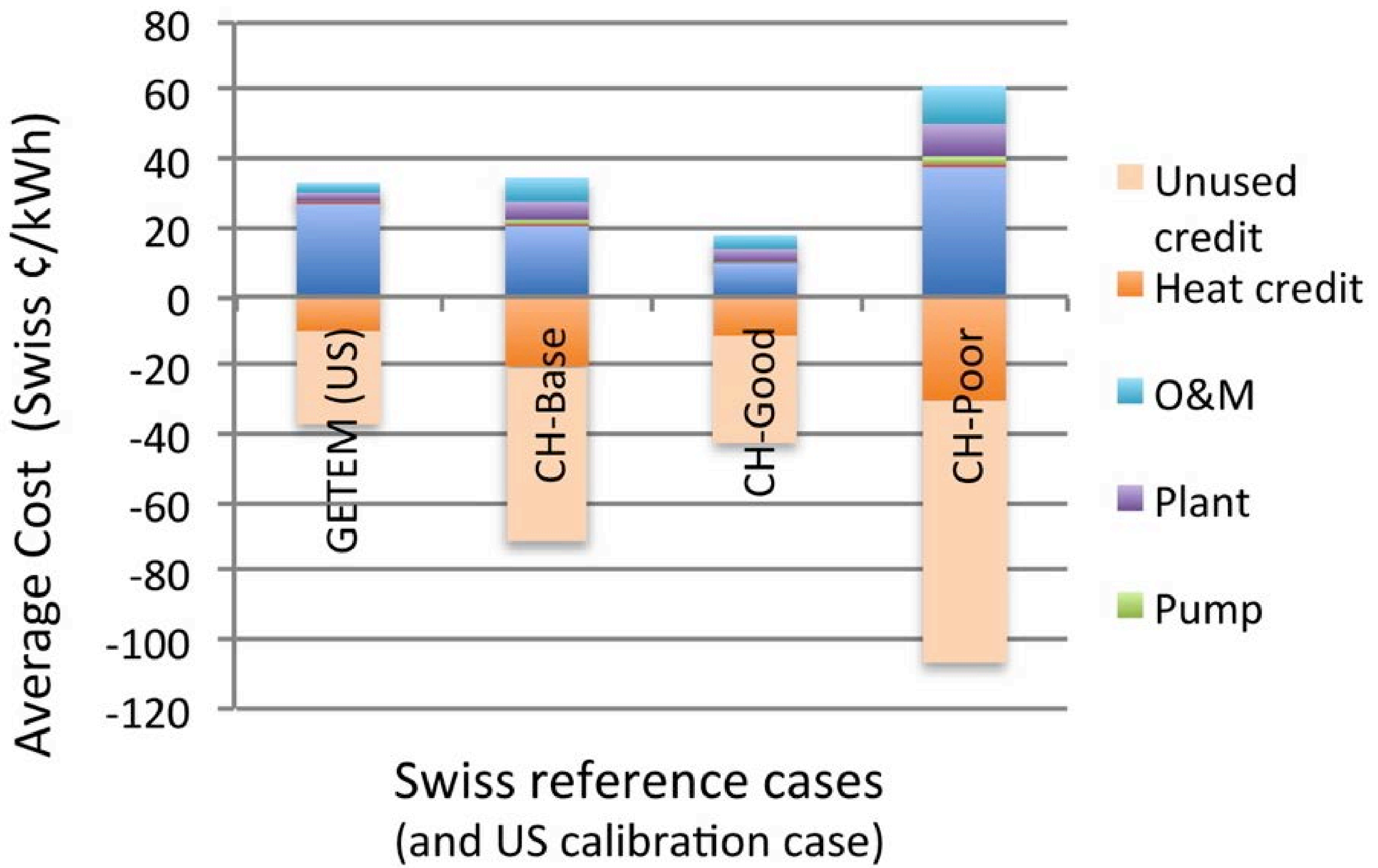
Environmental aspects:

- Based on Life Cycle Assessment (LCA)
- Based on expected technology development and learning curves

Linked Cost & LCA Geothermal Model

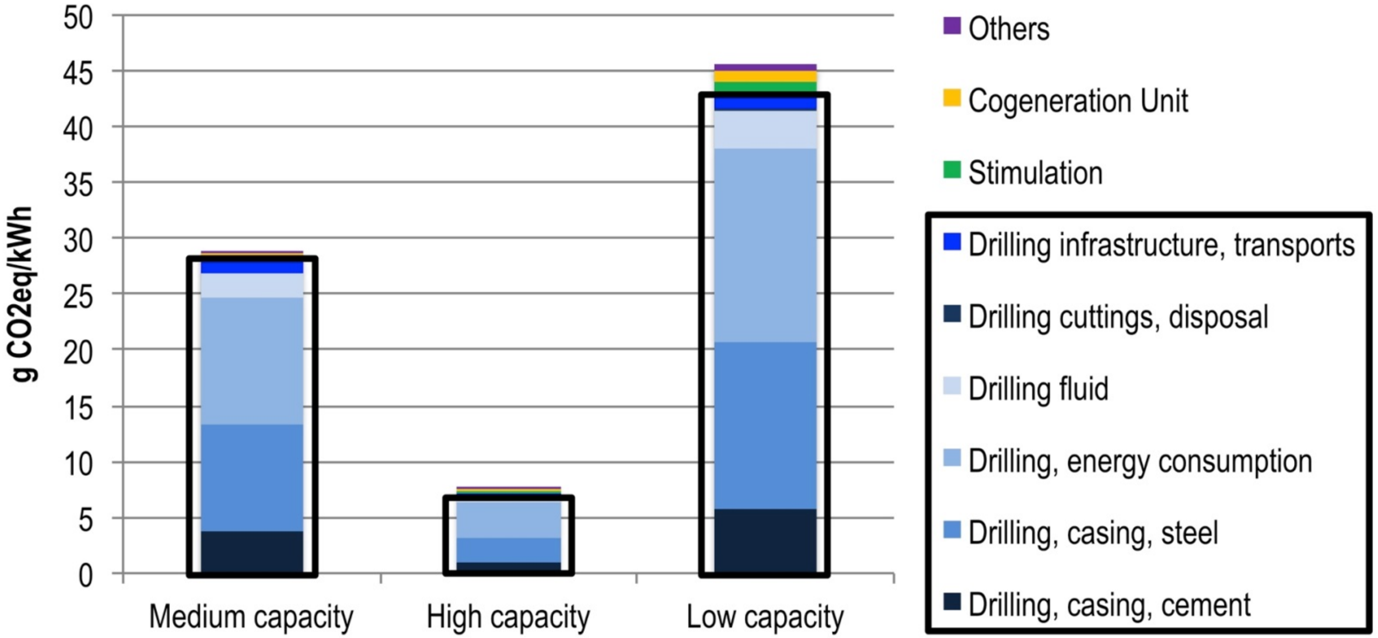


Cost Results – Average Cost by Components



- **Well costs dominate other cost components.**
- **Low thermal efficiency means that if some of the „waste“ heat can be sold (e.g. for district heating), this can greatly reduce average costs.**

LCA Results – CO2 Emissions



Plant net capacity [Mwel]	**5.5**	**14.6**	**2.9**
Gradient [°C/km]	35	40	30
Depth of wells [km]	5	6	5
Number of wells	6 (2 well triplets)	3 (1 well triplet)	3 (1 well triplet)
Surface plant life time [years]	30	30	20
Well life time [years]	20	3	20
Production flow rate [l/s]	147 (2*73.5)		
Surface system	Organic rankine cycle (ORC)		
Cooling system	Air cooling		
Rig power source	Electricity		

«Others»: Refrigerant loss during operation, pump material, land use

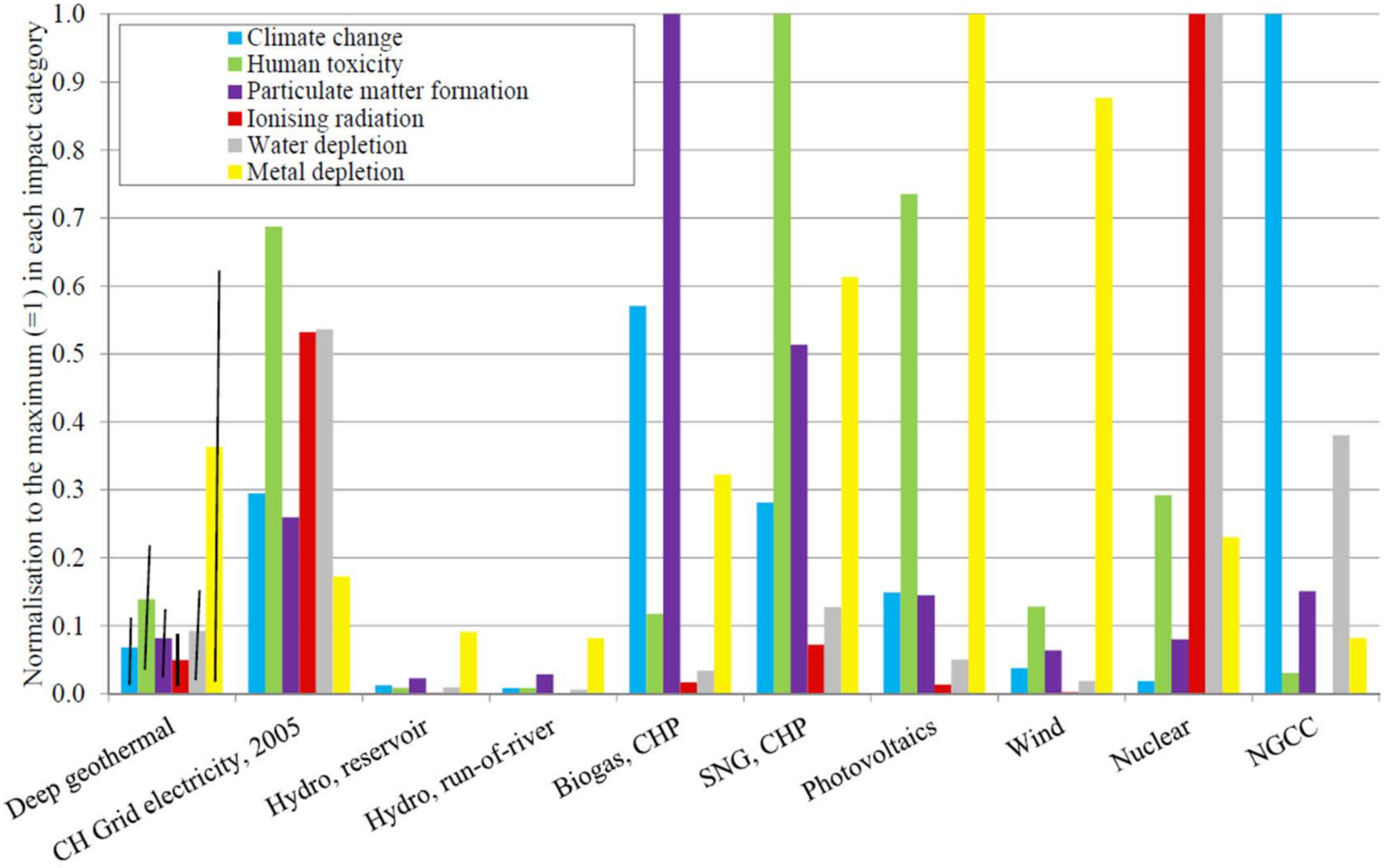
- **Life cycle environmental burdens are heavily dominated by well drilling, as shown below for CO_2 emissions (drilling related contributions grouped within boxes).**

Overview, which fuel/technology mix is considered in SFOE/SCCER study

Electricity generation from fuels			Fuel							
			NG	Dual Fuel	Biomasse					
			Gas	-	Gas	Solide		Liquid		
				Gas/Gas	Biogas	Wood	Non-wood	Biofuel	Sewage sludge	Manure, etc.
Energy converter (electricity generator)	IC Engine	Power Plant		-					-	
	Gas turbine	Heavy duty			-			-	-	-
		Micro		-				-	-	
	Steam turbine	Water	?	-	-			-		-
		ORC	-	-	-			-	-	-
	Stirling		-	-	-			-	-	-
	Fuel Cell	PEM		-		?	?	-	-	-
		MCFC		-		?	?	-	-	-
		SOFC		-					-	-
Biomethane production			-	-				-		

- Good data basis available for implemented bioenergy technologies
- Challenging data base for new, innovative technologies

Environmental Performance of Various Electricity Generation Technologies



Hirschberg et al., 2015

- **The results for geothermal power are similar to those of the “cleanest” renewables such as hydro and wind power.**

Comparison of Swiss electricity studies 2050

Author	Full name	Modeller	Year	System scope
BFE	Energieperspektiven für die Schweiz bis 2050	Prognos AG	2012	Energy system
VSE	Stromzukunft Schweiz	Pöyry AG	2012	Electricity system (also AT/IT/DE/FR)
ETH / ESC	Energiezukunft Schweiz	G. Andersson, K. Boulouchos, L. Bretschger	2011	Energy system
SCS	SCS-Energiemodell	A. Gunzinger	2013	Electricity system
Greenpeace	Energy [r]evolution	S. Teske, G. Heiligtag (DLR)	2013	Energy system
Cleantech	Energiestrategie	F. Barmettler et al.	2013	Energy system
PSI / ETH (-system)	Energy-economic scenario analysis of Swiss energy system	N. Weidmann	2013	Energy system
PSI (-electricity)	Energie-Spiegel 21	R. Kannan, H. Turton	2012	Electricity system

M. Densing, S. Hirschberg (2015): ***Review of Swiss Electricity Scenarios 2050***, PSI-Report, **http://www.psi.ch/eem/** **→ See poster for selected comparison results!**

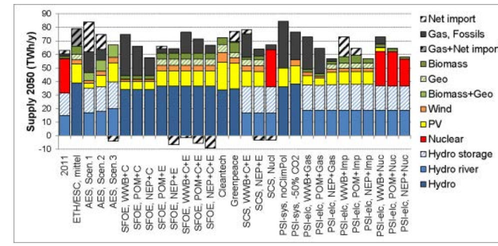
Meta-Analysis
(Example of supply mix 2050)

Target year 2050 has relatively low annual imports across scenarios (situation different in 2030; see poster)

Goals of Meta-Analysis:

1. Identification of **key scenarios,** which can be used for:
   - Simplified view for policy makers
   - Input to other models that require low-dimensional data (e.g. large economic-wide models with many other data inputs to keep model sizes small, or stochastic scenario generation)
2. Removal of `superfluous' scenarios

Meta-Analysis
(Example: Supply Mix 2050)



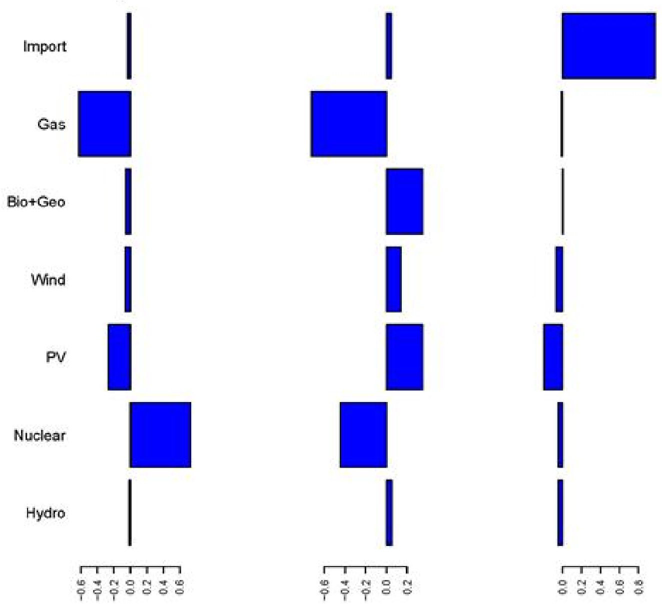
1. **Key scenarios** may be determined by either:
   a) Principal Component Analysis (PCA)
   b) Minimal set of scenarios selected by distance measure
2. **Scenarios may be removed** having zero distance

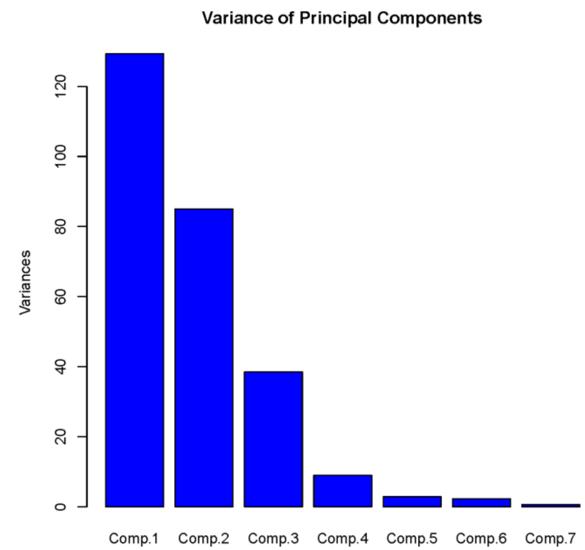
1a) PCA yields major policy decision in Switzerland →

1st Principal Component: Nuclear vs. all other options

2nd PC: Centralized vs. decentralized

3rd PC: Import vs. domestic production





79% of the cumulative variance of the scenarios is explained by the first three PCs. → Variation over all scenarios can be represented by a linear combination of independent movements of three PCs.

Global Observatory Summary

Approach:
- Spatial scale of the GO stretches from Switzerland to European and global coverage.
- Detailed technology characterization forms the basis for a holistic sustainability assessment of electricity generation options.

Challenges:
- The key challenge is to evaluate the current status and innovation potential of emerging and future highly advanced technologies with regard to their costs, environmental and social performance aspects, resource potentials, and possible future deployment scenarios.

Main impact:
- Develop a framework that allows establishment of a trend-based and partially quantitative comparative perspective on the prospective developments of electricity technologies.
- Establish a common format of a status report that is published in regular intervals.