LEA strategic goals

- Developing, implementing and applying integrated framework for inter-disciplinary technology assessment.

- Developing, maintaining and extending comprehensive and consistent databases relevant for inter-disciplinary systems analysis.

- Developing analytical models and tools to improve understanding of energy technology development and policy strategies for realizing sustainable energy systems at the Swiss, European and global levels.

- Addressing current and emerging safety issues, through the development, evaluation and application of risk analysis and human reliability analysis methods, and the collection and analysis of data and operating experience.
### Personnel
- Currently 17 staff scientists (including Lab-head); thereof 5.8 PSI positions
- 3 Post-docs, 5 Ph.D. students
- 4 vacancies (+ 9 Future Resilient Systems Singapore)
- High number of Master/Bachelor students and internships
- Inter-disciplinary and multi-national (15 countries)
- Personnel with German as mother tongue (6), Swiss (4) and women (7)

### Scope
- Current and future fossil, nuclear and renewable technologies; current and future mobility
- National, regional and global energy issues
- Risk-based perspective on human-related safety issues and innovative PSA applications

---

### Technology Assessment (TA)
- P. Burgherr
  - 9 staff scientists
  - 1 Ph.D. student
  - 1 vacancy (Ph.D. student)

### Energy Economics (EE)
- Vacancy
  - 2 staff scientists
  - 2 post-docs
  - 3 Ph.D. students
  - 2 vacancies (GL + Ph.D. st.)

### Risk & Human Reliability (RHR)
- V. N. Dang
  - 5 staff scientists
  - 1 post-doc
  - 1 Ph.D. student
  - 1 vacancy (Ph.D. student)
A. Basic, classical HRA: Identify, Characterize, Quantify
- Situation assessment (decision) + implementation

B. “2nd order” issues: “Errors of commission”. Undesired, aggravating actions, not foreseen in design, emergency procedures, training
- Can be postulated almost anywhere – need efficient screening
- Predicting these decision failures and estimating their probabilities even more difficult

C. Dynamic PSA: Simulation-based risk assessment
- Eliminate (some) simplifications made in order to handle numerous combinations of initiating events and failures, e.g., quasi-static model above
- Dynamic event trees – simulation model combined with failure model generates order of headers, considers variability of timing. Also allows propagation of physical uncertainties.
Fukushima – analysis from an HRA view

Questions

• What did decision-makers know about state of the units, over time?
• When were decisions made?
• What procedural guidance (EOPs, SAMG, AM) was available?
• How long did implementation require?
• Was implementation successful? (why not?)
• Personnel and equipment resources?

“Action” phases

1. Timelines per function/action

2. Site-wide, 6-hour snapshot

3. Day-to-day summary

- Decisions, outcomes of actions, contributors to delays
- Shortcomings of procedures and guidance
- Performance issues

Pre-decision (evaluate/develop options)

Strategy (set or change goal)

Plan (develop/adapt implementation plan or procedure)

Decision - initiate

Pre-implementation (collect and stage equipment)

Implementation - start

Implementation – completion of actions

Implementation – outcome (effective, failed, etc)
## Site-wide, 6-hour snapshot (excerpt)

<table>
<thead>
<tr>
<th>Day</th>
<th>Time</th>
<th>Events</th>
<th>Goals</th>
</tr>
</thead>
</table>
| 03-11| 1800-0000  | 1830 U1 freshwater inj. ready but reactor pressure is too high  
2007 U1 reactor pressure read locally  
2049, 2158 U1&U2 CR temporary lighting;  
U3&U4 temporary lighting  
2350 U1 containment pressure read, near design pressure | From afternoon, batteries collected from buses etc. to power instrumentation; small generators collected (for temporary lighting, and for instruments). |
|      |            | 2007 U1 reactor pressure read locally  
2049, 2158 U1&U2 CR temporary lighting;  
U3&U4 temporary lighting  
2350 U1 containment pressure read, near design pressure | From afternoon, batteries collected from buses etc. to power instrumentation; small generators collected (for temporary lighting, and for instruments). |
|      | 0000-0600  | 0000-0400 aftershocks delay actions  
0400 U1 – fire engine connected (higher discharge head than D/D fire pump)  
0430 Tsunami warning and suspension of field work (duration unclear)  
Arrival of power supply trucks from offsite. | 0006 U1 decision to prepare venting plan  
0130, U1 venting strategy decided, pending (offsite) evacuations  
0245 U1 decision to use fire engine for inj. |
|      | 0600-1200  | 0546-1430 U1 freshwater inj. at low rates  
0720 Low voltage for U1 provided | Cabling of power for U1 & U2  
0905 U1 venting decision (alignments begin 0915) |
|      | 1200-1800  | 1430 U1 venting succeeds (rupture disk ruptures)  
1453 U1 freshwater runs out  
1530 High voltage for U2 provided  
**1536 U1 explosion**  
1800-0000  | 1800-0000  | 1904 U1 successfully inj. seawater  
2036 loss of U3 reactor level indication due to instrumentation batteries. | [Note: 2045 end of main U1 timeline from INPO] |
|      |            | 0242 U3 HPCI manually tripped.  
Communicated to ERC at 0355. | 0355 U3 depress (SRVs), batteries,  
seawater injection decisions  
0515 U3 venting decision  
0700 U3 freshwater prioritized |
<table>
<thead>
<tr>
<th>Day</th>
<th>Goals</th>
<th>Key events (completion, setbacks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-11 (Day 1)</td>
<td>U1 injection, depressurization</td>
<td>1830 U1 freshwater inj ready but RV press too high</td>
</tr>
<tr>
<td>3-12 (Day 2)</td>
<td>U1 injection, venting</td>
<td>0000-0400 21 aftershocks&lt;br&gt;0546 U1 injection but low flowrate due to press&lt;br&gt;1430 U1 venting, allowing injection (freshwater) by fire engine, <em>success</em>&lt;br&gt;1536 U1 explosion (damage to fire engine used for U1 freshwater injection; suspension of field work until 1720)&lt;br&gt;1904 U1 injection (seawater) by restaging to use fire engine connected to FPS</td>
</tr>
<tr>
<td>3-13 (Day 3)</td>
<td>U3 venting, injection&lt;br&gt;U2 venting, RV depress., injection&lt;br&gt;Scavenging batteries for U3 (a.m.)</td>
<td>0920 U3 venting successfully started, <em>noted by ERC</em>&lt;br&gt;0925 U3 injection (freshwater)&lt;br&gt;1100 U2 venting failed&lt;br&gt;12—aftershocks with evacuation&lt;br&gt;1313 U3 injection (switchover to seawater)&lt;br&gt;2100 U2 venting (2\textsuperscript{nd} attempt) failed</td>
</tr>
<tr>
<td>3-14 (Day 4)</td>
<td>Seawater level in U3 condenser pit&lt;br&gt;U3 restore/maintain injection&lt;br&gt;U2 venting, RV depress., injection</td>
<td>0110 low seawater level&lt;br&gt;0900 condenser pit seawater level restored, <em>success</em>&lt;br&gt;1101 U3 explosion&lt;br&gt;1443-1630 aftershocks [<em>p. 253-254 Hatamura interim</em>]&lt;br&gt;1630 U3 restoration of seawater injection&lt;br&gt;1800 U2 SRV opened, decrease of RV level&lt;br&gt;1954 U2 injection (seawater) at low rate&lt;br&gt;2130 U2 2\textsuperscript{nd} SRV opened</td>
</tr>
<tr>
<td>3-15 (Day 5)</td>
<td>Spent Fuel Pool</td>
<td>0600 U4 explosion <em>(0600 U2 containment breach suspected)</em></td>
</tr>
</tbody>
</table>
### Actions: Outcomes, durations, delays

<table>
<thead>
<tr>
<th>Function/action</th>
<th>Decision</th>
<th>Outcome/operation</th>
<th>Time to achieve</th>
<th>Additional details</th>
</tr>
</thead>
<tbody>
<tr>
<td>U2 freshwater and seawater inj (preparation)</td>
<td>03-12/early hours ~0255</td>
<td>The seawater equipment is damaged by the U1 explosion at</td>
<td></td>
<td><strong>U1 venting had priority from 03-12/0255.</strong> In parallel, workers at U2 worked to stage injection, planning to use fire pumps for freshwater and seawater.</td>
</tr>
<tr>
<td></td>
<td>(staging only)</td>
<td>03-12/1536.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U2 containment venting (strategy and preparation)</td>
<td>03-12/1730 (prioritized)</td>
<td>03-13/0810 first alignment took place, with opening of MO</td>
<td></td>
<td>U2 containment venting was prioritized.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>containment vent valve.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U2 venting (1)</td>
<td>03-13/1015</td>
<td><strong>03-13/1100 (venting not successful)</strong></td>
<td>45’</td>
<td><strong>03-13/1015 is the actual order to vent, presumably the opening of the AO drywell and/or suppression chamber vent valve.</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Containment pressure below rupture disk setpoint and inability to keep vent valves open.</strong></td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>U2 seawater inj (1)</td>
<td>03-13/1205</td>
<td>Ready by 03-13 late afternoon.</td>
<td></td>
<td><strong>03-13 evacuation orders due to aftershocks</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lack of seawater 03-14/0110-0900 with priority for U3, U3 explosion damage at 03-14/1101.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U2 venting (2)</td>
<td>03-14/1230</td>
<td>03-14/2100 (not successful)</td>
<td>8.5h</td>
<td><strong>U3 explosion at 03-14/1101 and aftershocks, both leading to suspensions of field work until 1600.</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U2 RPV depress</td>
<td>03-14/1230</td>
<td>03-14/1800 (1\textsuperscript{st} SRV) and 2120 (2\textsuperscript{nd} SRV)</td>
<td>5.5h then 3h</td>
<td><strong>Evacuation order in force until 03-14/1600</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U2 seawater inj (3)</td>
<td>03-14/1230 or 1325</td>
<td>03-14/1954 (actual start but no injection due to reactor</td>
<td>7h</td>
<td><strong>U3 explosion at 03-14/1101 damaged equipment staged for U2, and evacuation order in force until 1600.</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>pressure) 03-14/2120 (limited success after 2\textsuperscript{nd} SRV opened)</td>
<td></td>
<td><strong>03-14/1630-1800 attempt to open an SRV and to align seawater injection.</strong> No seawater available (prioritized for U1 and U3 until 03-14/1957)</td>
</tr>
</tbody>
</table>
Fukushima analysis

Background
• Shortcomings of emergency preparedness were identified by many organizations relatively quickly
  – Inadequacy of protections against tsunamis exceeding the design basis
  – Design basis for Loss of Offsite Power: assumed short-term AC power only
  – Severe Accident Management assumed AC power available within 30 minutes, including credit for AC power from neighboring unit
• Not analyzed
  – Design basis exceedance curve for tsunami (and, correspondingly, no PSA treatment of tsunami as consequence of earthquake)
  – SAMG based on internal events PSA only (no seismic, no tsunami, no area events affecting multiple units)

Became assumptions underlying Accident Management guidelines and procedures
Fukushima analysis - Findings

• Critical assumptions of AM guidance and procedures were not satisfied in event
  • AC available within 30 min
  • DC available 8 hours
  • Operability from control room
  • Instrumentation available in control room
  • Loss of most on-site communications

• Power for instrumentation and actuation of equipment had to be improvised.
  • Scavenged batteries shared between instrumentation and actuation (10 car batteries = 120 V DC)
  • Compressors for actuation power

• “Foreseen” AM measures included no contingency for loss of all power, so plans needed to be developed ad hoc
  – Reactor depressurization (opening of SRVs)
  – Containment venting

• Essential AM measures that were needed in event were not foreseen, also had to be developed ad hoc
  – Water injection using fire engine
  – Injection of seawater

• Not foreseen => no procedure, no training, documentation not readily available (P&IDs), no equipment (hoses, connectors, etc.)

Major delays

• Suspensions of field work due to tsunami warnings and earthquake aftershocks
  • Unit 1 and Unit 3 reactor building explosions, scattering radioactive debris
    o led to suspensions of work
    o damaged staged equipment, e.g. U2 injection

➢ Lack of resources (people, batteries) to pursue additional strategies in parallel, e.g. U2 and U3 venting / depressurization
  – Reports confirm that RCIC (U2) and HPCI (U3) operation explicitly used by ERC to prioritize implementation

➢ Strategies selected early (containment venting as well as seawater injection) but massively hindered by loss of all AC and DC and no anticipation of this condition
Health impacts of electricity generation: Normal operation, accidents, terrorism

- Minimization of health impacts is one of the goals of sustainable energy policies.

- High public interest but serious misunderstandings and deficiencies of available analyses.

- Questions addressed:
  - How large are health effects associated with various electricity generation technologies and fuel cycles?
  - How do health risks from normal operation compare with those resulting from accidents and hypothetical terrorist attacks?
  - Which are the major limitations of the current estimates?
YOLL = Years of Life Lost

Sources: after Hirschberg et al., 2003; Heck & Hirschberg, 2011; Roth et al., 2009; Hirschberg et al., 2014
Severe accident fatality rates and maximum consequences

Sources: after Burgherr, 2011; Burgherr et al., 2013; Burgherr et al., 2014; Burgherr & Hirschberg, 2014

Sources: after Burgherr et al., 2013; Burgherr & Hirschberg, 2014; Hirschberg et al., 2014

- **Nuclear PWR**
- **Nuclear EPR**
- **Chernobyl (immediate fat.)**
- **Chernobyl (latent fat.)**


**Notes:**
- (*) non-OECD w/o China
Frequency-consequence curves for hypothetical terrorist attacks

Source: Eckle, Cazzoli, Burgherr & Hirschberg, 2010
Conclusions: Health effects

• **General:**
  - State-of-the art approaches to comprehensive comparative assessment of the various contributions to health risks of energy systems established and applied
  - Importance of covering full energy chains
  - Strong dependence on technologies, location and operational environment
  - Dominance of health impacts from normal operation

• **Normal operation risks:** Renewables and nuclear mostly exhibit very good performance with hydro being the best option; coal ranks mostly worst while performance of natural gas is mixed.

• **Severe accidents risks:** Lowest fatality rates apply to hydro and nuclear in OECD countries though in both cases events with very low frequency can lead to quite extreme consequences.

• **Terrorist threat risks:** Frequency of a successful terrorist attack with very large consequences is of the same order of magnitude as can be expected for a disastrous accident in the respective energy chain.

• **Limitations:** Choice of reference technologies, geographical coverage, treatment of health impacts of climate change, solar PV accident risks, cyber risks and implementation of terrorist risk assessment.

Source: Hirschberg et al., 2014
TA-SWISS project on deep geothermal energy

- Research consortium: 4 organizations, 32 scientists
- Highly inter-disciplinary competences
- Effort: ~5 person-years
- Duration: ~18 months
- Report: ~500 pages
- Very high media echo
- Recognition (BFE etc.)
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Costs of deep geothermal power vs. other technologies

Average Generation Cost (rp/kWh)

- Geothermal w/o heat credit
- Geothermal w/ heat credit
- Biogas CHP
- Solar PV
- Onshore wind
- Offshore wind

Source: Schenler, 2014
Impact assessment results – Climate change

![Graph showing CO2 emissions for medium, high, and low capacity scenarios.]

- **Others**: Refrigerant loss during operation, pump material, land use

### Plant net capacity
- Medium capacity: 5.5 MWel
- High capacity: 14.6 MWel
- Low capacity: 2.9 MWel

### Gradient
- Medium capacity: 35°C/km
- High capacity: 40°C/km
- Low capacity: 30°C/km

### Depth of wells
- Medium capacity: 5 km
- High capacity: 6 km
- Low capacity: 5 km

### Number of wells
- Medium capacity: 6 (2 well triplets)
- High capacity: 3 (1 well triplet)
- Low capacity: 3 (1 well triplet)

### Surface plant life time
- Medium capacity: 30 a
- High capacity: 30 a
- Low capacity: 20 a

### Well life time
- Medium capacity: 20 a
- High capacity: 30 a
- Low capacity: 20 a

### Production flow rate
- Medium capacity: 147 l/s (2*73.5)

### Surface system
- Medium capacity: Organic rankine cycle (ORC)
- High capacity: Organic rankine cycle (ORC)
- Low capacity: Organic rankine cycle (ORC)

### Cooling system
- Medium capacity: Air cooling
- High capacity: Air cooling
- Low capacity: Air cooling

### Rig power source
- Medium capacity: Electricity
- High capacity: Electricity
- Low capacity: Electricity

**Source**: Treyer et al., 2014
Selected conclusions on Enhanced Geothermal Systems

• The EGS potential is large provided a combination of cost reductions, heat sales and efficient use of the resource.

• It has so far proved difficult to create a petrothermal reservoir to allow commercial flow rates, without the benefit of pre-existing, highly-permeable fracture zones and faults.

• EGS technology is not mature and requires a program of basic research before it is ready for large-scale deployment.

• Environmental burdens of EGS are lower or of the same order as those of other electricity generation technologies in Switzerland.

• The contribution of geothermal to the security of energy supply should be more strongly emphasized.

• Earthquake risks can be controlled, but not eliminated. The success and economy of geothermal energy will depend on the level of socially acceptable risk.
TIMES model developments

- STEM-E
  - ELECTRA
  - CROSSTEM
  - INSIGHT-E
  - CROSSTEM-EU
- STEM
  - CHP-Swarm
  - ISCHESS
  - STEM-SCCER-Mobility
  - i4City
  - ESI-P2G
- SMM

Projects:
- Grid representation
- Storage
- Non-car fleet
- Power to gas
- Electricity storage
- CCS module

Modules:
- CHP
- Distributed generation
- Electricity marginal prices
- Electricity dispatch
- TIMES elastic demand
- TIMES Macro

Outlook

External model (soft links or data flow)

Funding: PSI, BFE, SER, CCEM, KIT, SwissGrid, EU
CROSs border Swiss TIMES Electricity Model

Extension of the STEM-E model to include the four neighbouring countries

Time horizon: 2010 – 2070

An hourly timeslice (288 timeslices)

Detailed reference electricity system with resource supply, renewable potentials and demands for 5 countries

Calibrated for electricity demand and supply data between 2000-2010

Endogenous electricity import / export based on costs and technical characteristics
### CROSSTEM Scenarios

| Sc.1 | Baseline scenario  
|      | No particular constraints in technology investment*  
|      | Trade constraints applied – net exporter (France, Germany) cannot  
|      | become net importer (Italy, Austria) and vice versa  
|      | Switzerland self-sufficient  
|      | CO₂ prices for allowances in the ETS as in WWB (SES 2050) |
| Sc.2 | De-carbonization of power sector (95% CO₂ reduction by 2050 from  
|      | 1990 levels) for all five countries together  
|      | All other conditions same as Sc.1 (including trade constraints) |
| Sc.3 | No gas based generation in Switzerland  
|      | Trade constraints relaxed for CH only (allowed to be a net importer)  
|      | All other conditions same as Sc.2 |

* except where already part of policy: e.g., Nuclear phase-out in Switzerland (CH) and Germany (DE), no nuclear investment in Italy (IT) and Austria (AT). No Coal investment in Switzerland (CH).
- No Solar PV in CROSSTEM, more flexible gas plants
- Import/Export costs as well as surrounding country electricity profiles cause this difference

Source: Pattupara & Ramachandran, 2014
Switzerland – All CROSSTEM scenarios

- **Sc2** – Gas plants replaced by gas CCS + renewables, lower pump hydro (higher electricity price)
- **Sc3** – Imports preferred to investments in renewables, Investments made elsewhere

Source: Pattupara & Ramachandran, 2014
Results – Electricity generation mix

Electricity generation mix 2050

- Sc1
- Sc2
- Sc3

- Italy
- Austria
- France
- Germany
- Switzerland

- Imports
- Renewable
- Oil
- Gas
- Gas CCS
- Coal
- Coal CCS
- Nuclear
- Hydro
## Comparison of Swiss electricity supply scenario studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Full name</th>
<th>Author (Modeller)</th>
<th>Year</th>
<th>System scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>BFE</td>
<td>Energieperspektiven für die Schweiz bis 2050</td>
<td>BFE (Prognos AG)</td>
<td>2012</td>
<td>Energy system</td>
</tr>
<tr>
<td>VSE</td>
<td>Stromzukunft Schweiz</td>
<td>VSE (Pöyry AG)</td>
<td>2012</td>
<td>Electricity</td>
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<tr>
<td>ETH / ESC</td>
<td>Energiezukunft Schweiz</td>
<td>G. Andersson, K. Boulouchos, L. Bretschger</td>
<td>2011</td>
<td>Energy system</td>
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<td>SCS</td>
<td>SCS-Energiemodell</td>
<td>A. Gunzinger (SCS AG)</td>
<td>2013</td>
<td>Electricity</td>
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<tr>
<td>Greenpeace</td>
<td>Energy [r]evolution</td>
<td>S. Teske, G. Heiligtag (DLR, SCS AG)</td>
<td>2013</td>
<td>Energy system</td>
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<td>Cleantech</td>
<td>Energiestrategie</td>
<td>F. Barmettler, N. Beglinger, C. Zeyer</td>
<td>2013</td>
<td>Energy system</td>
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<tr>
<td>PSI-sys</td>
<td>Transformation strategies towards a sustainable Swiss energy system – energy-economic scenario analysis</td>
<td>N. Weidmann</td>
<td>2013</td>
<td>Energy system</td>
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<td>PSI-elc</td>
<td>Swiss electricity supply options (Energie-Spiegel 21)</td>
<td>R. Kannan, H. Turton</td>
<td>2012</td>
<td>Electricity</td>
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## Overview of models

<table>
<thead>
<tr>
<th>Study (electricity only)</th>
<th>Electricity demand model (if no model: data from)</th>
<th>Capacity expansion model</th>
<th>Dispatch model</th>
<th>Modelling of energy system network</th>
<th>Speciality</th>
</tr>
</thead>
<tbody>
<tr>
<td>BFE</td>
<td>Simulation</td>
<td>Simulation</td>
<td>Simulation</td>
<td>na</td>
<td></td>
</tr>
<tr>
<td>VSE (elc)</td>
<td>Simulation</td>
<td></td>
<td>Simulation</td>
<td>na</td>
<td>Cap./Disp. model also <strong>for neighbouring countries</strong></td>
</tr>
<tr>
<td>ETH/ESC</td>
<td>Simulation</td>
<td>Simulation</td>
<td>na</td>
<td>na</td>
<td>3rd model used for the whole economy (labour, capital, energy)</td>
</tr>
<tr>
<td>SCS (elc)</td>
<td>(from BFE)</td>
<td>na</td>
<td>Simulation</td>
<td>na</td>
<td>Model is only for year 2050</td>
</tr>
<tr>
<td>Greenpeace</td>
<td>Simulation</td>
<td>Simulation</td>
<td>(from SCS)</td>
<td>yes</td>
<td>Electricity demand is endogenous (?)</td>
</tr>
<tr>
<td>Cleantech</td>
<td>Simulation</td>
<td>Simulation</td>
<td>na</td>
<td>na</td>
<td><strong>no costs</strong> (not even ex-post)</td>
</tr>
<tr>
<td>PSI-sys</td>
<td><strong>Optimization</strong></td>
<td>na</td>
<td>yes</td>
<td>Electricity demand is endogenous</td>
<td></td>
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<tr>
<td>PSI-elc (from BFE)</td>
<td><strong>Optimization</strong></td>
<td></td>
<td>na</td>
<td>«typical hour» for dispatch</td>
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</table>
Production cost of generation mix

Sources: Densing et al., 2014
**Comparison:** CO₂ from energy sector (+transport) today: ~40 Mio. tons/Jahr

- BFE, NEP+E and BFE, POM+E have same domestic emissions, but POM-E has more imports

**Sources:** Densing et al., 2014
Cluster 1. Interdependent Critical Infrastructure
M1.1 Interdependencies
M1.2 Modeling
M1.3 Consequences
M1.4 Improving CI systems

Cluster 2. Energy Systems & Comparative Assessment
M2.1 Energy System Resilience
M2.2 People and Operations

Cluster 3. Social and Behavioral Factors in Decision-Making
M3.1 Human Decision-Making
M3.2 Sustainable Energy Demand

Technology Assessment Projects

<table>
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<tr>
<th>Sing. SNF (for PSI in C2)</th>
<th>PSI in-kind</th>
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<tr>
<td>Staff &amp; students</td>
<td>3.1 MSGD</td>
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<td>(2.1 MCHF)</td>
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</table>

3 PhDs
4 Postdocs
2 specialists
(based in SNG)

In-kind: PIs, staff
Thank you for your attention!

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lea.web.psi.ch