PAUL SCHERRER INSTITUT

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SWISS COMPETENCE CENTER for ENERGY RESEARCH

SUPPLY of ELECTRICITY

Development of methods and tools responding to the needs of energy transition: PSI perspective

In cooperation with the CTI

Energy funding programme
Swiss Competence Centers for Energy Research

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

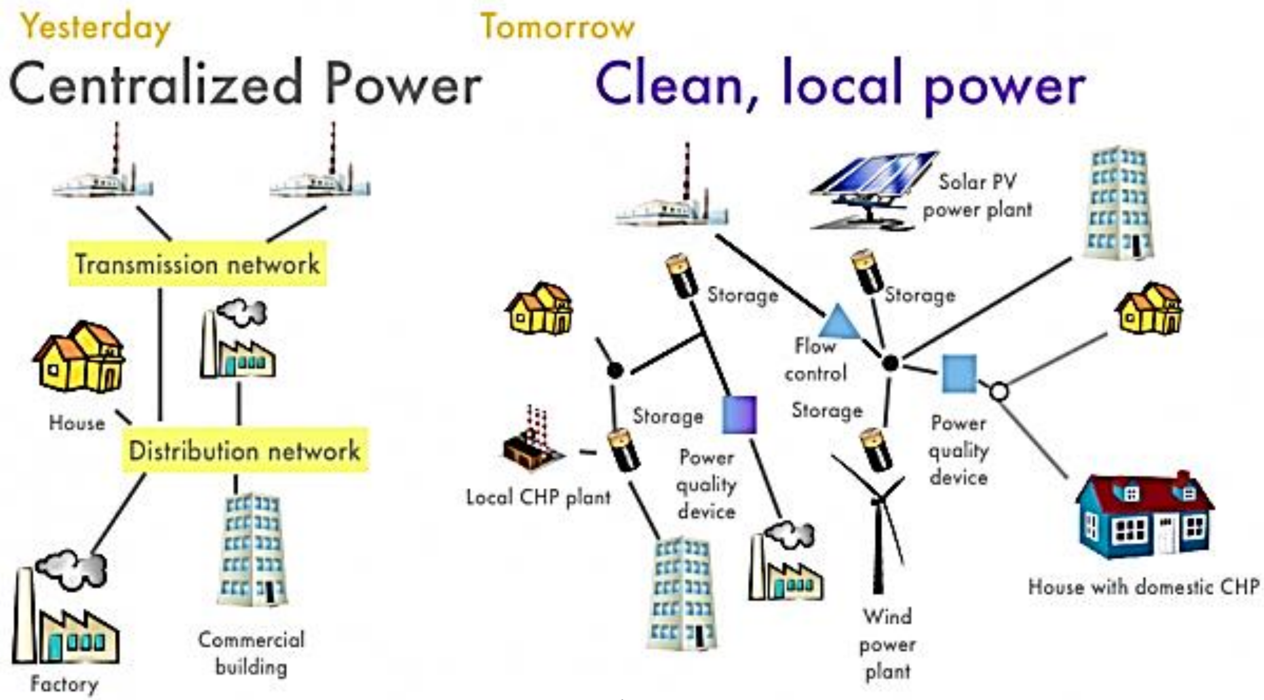
Swiss Confederation

Commission for Technology and Innovation CTI

S. Hirschberg, P. Burgherr, E. Panos

14.9.2017

Renewable energy changes the electricity system



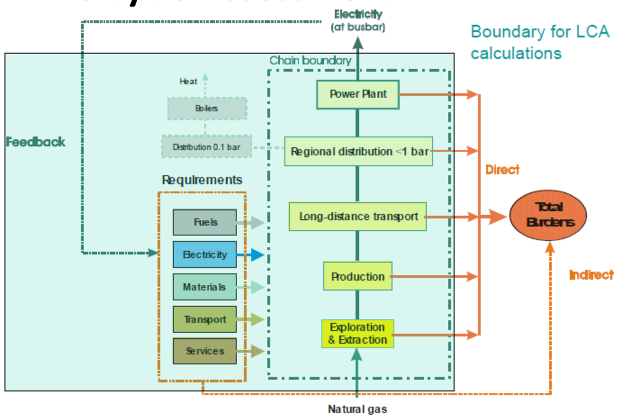
Source: http://ilsr.org/challenge-reconciling-centralized-v-decentralized-electricity-system/

Main challenges in electricity modelling but very important to model the full energy system since (1) electricity is fundamental for the overall efficiency improvement; (2) necessary for optimal (with view to efficiency, cost, climate protection goals, etc.) allocation of electricity to specific demand sectors:

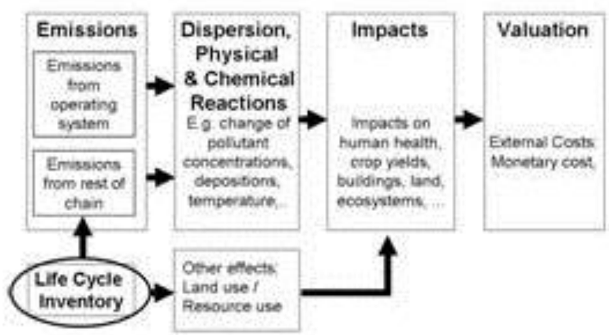
- Distinguishing between centralized and decentralized generation
- Representing electricity grid from high to low voltage
- Identifying storage options and new business models, e.g. prosumers
- Capturing the intra-annual variability of renewable generation and demand
- Assessing interactions between demand and supply

Methods, Models and Databases

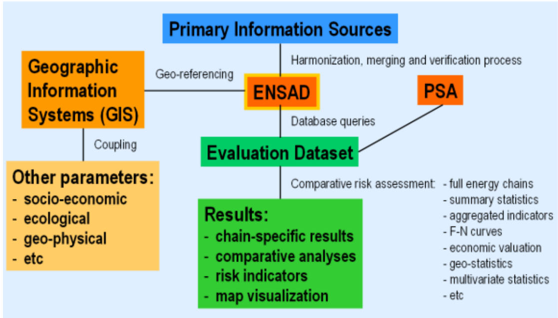
Life Cycle Assessment



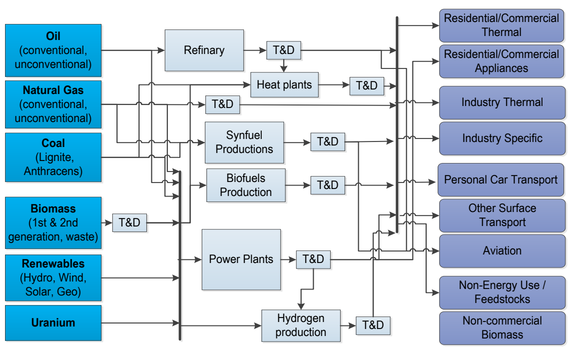
Impact Pathway Approach



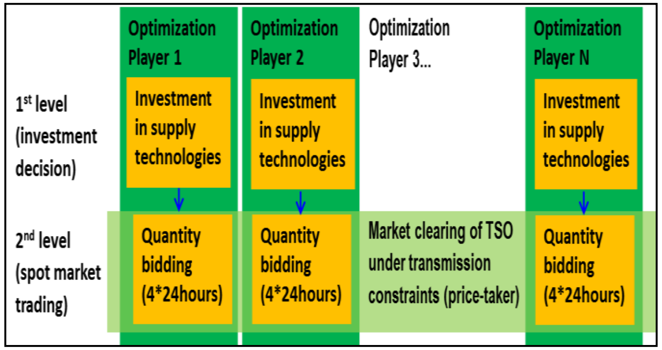
Risk Assessment



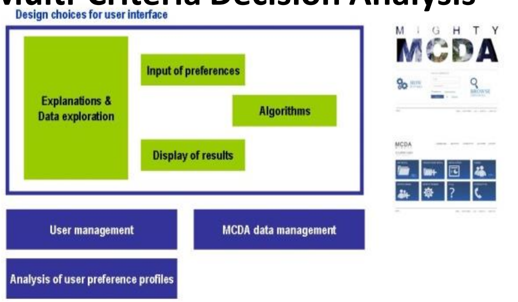
Swiss TIMES energy systems model



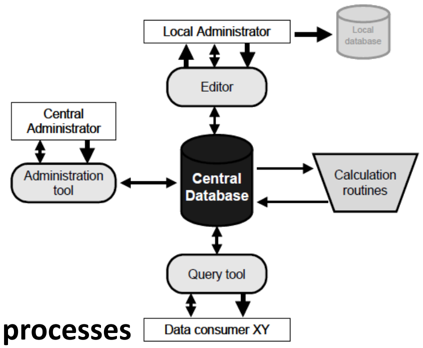
Bilevel Electricity Market Model



Integration: Multi-Criteria Decision Analysis

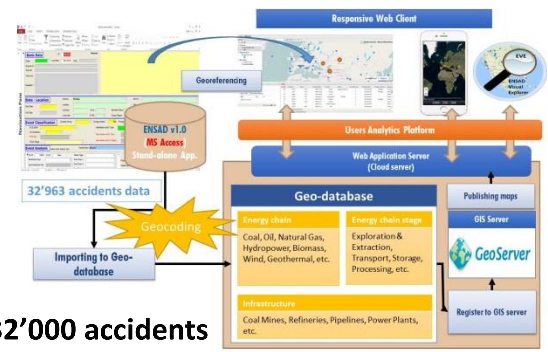


Ecoinvent Database



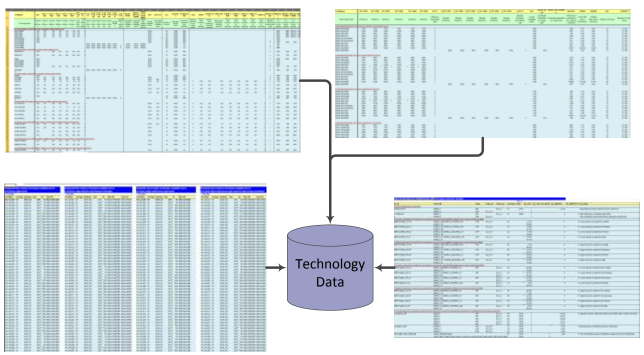
> 12'000 processes

ENSAD Database

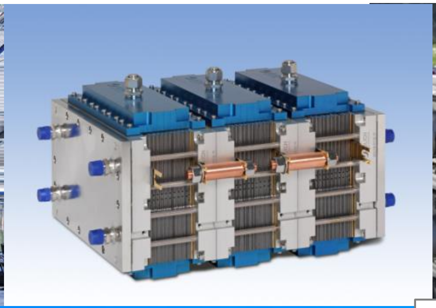


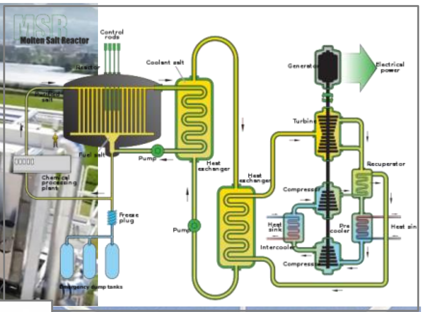
> 32'000 accidents

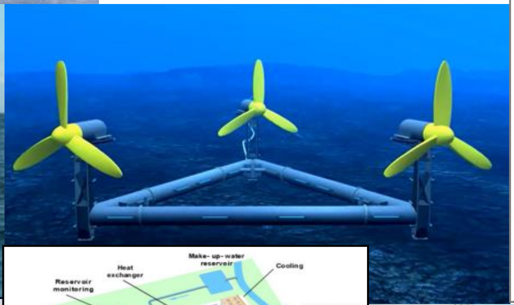
Technology Database

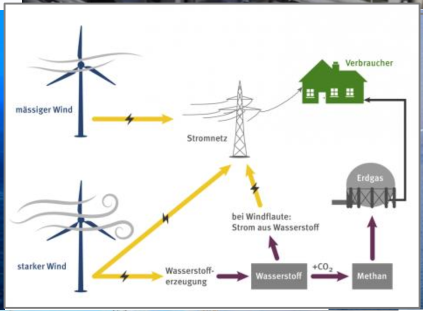


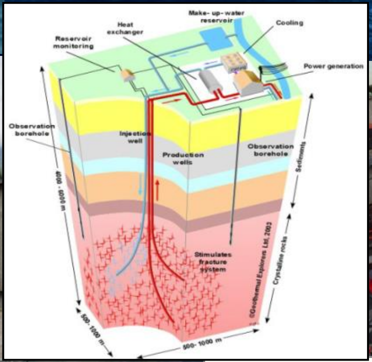
New Technologies

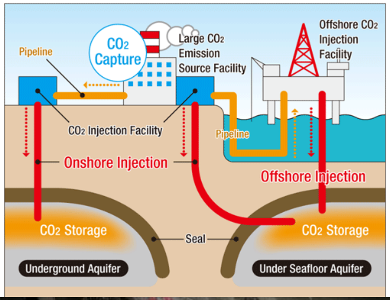


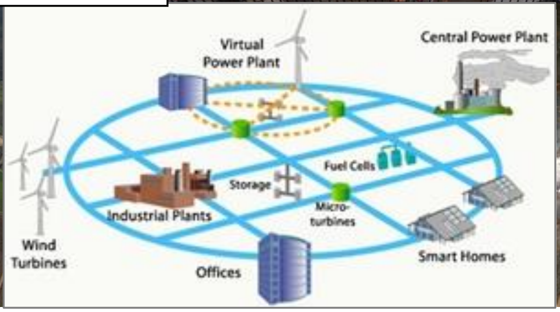




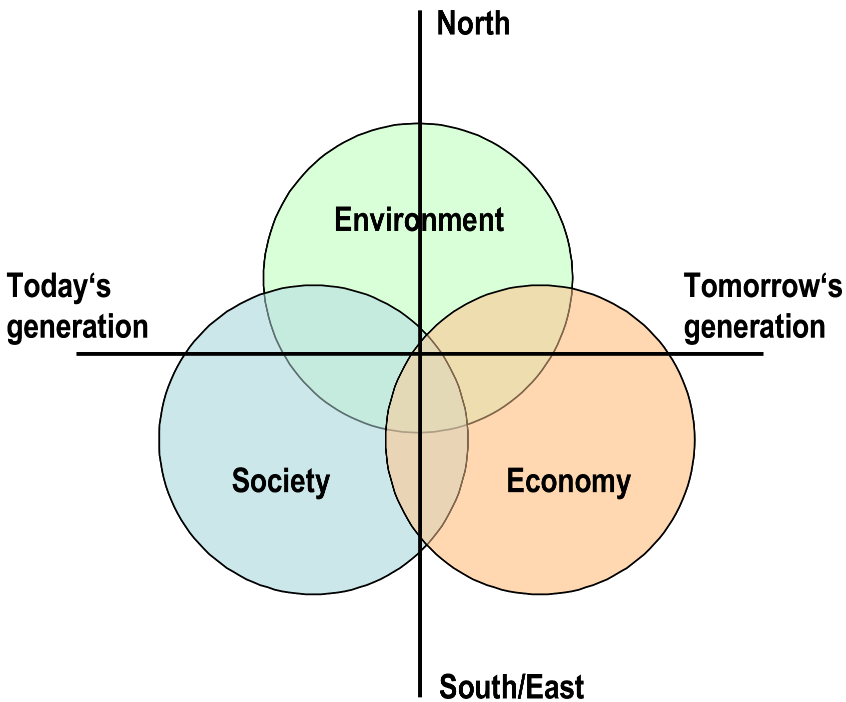








Sustainability Criteria

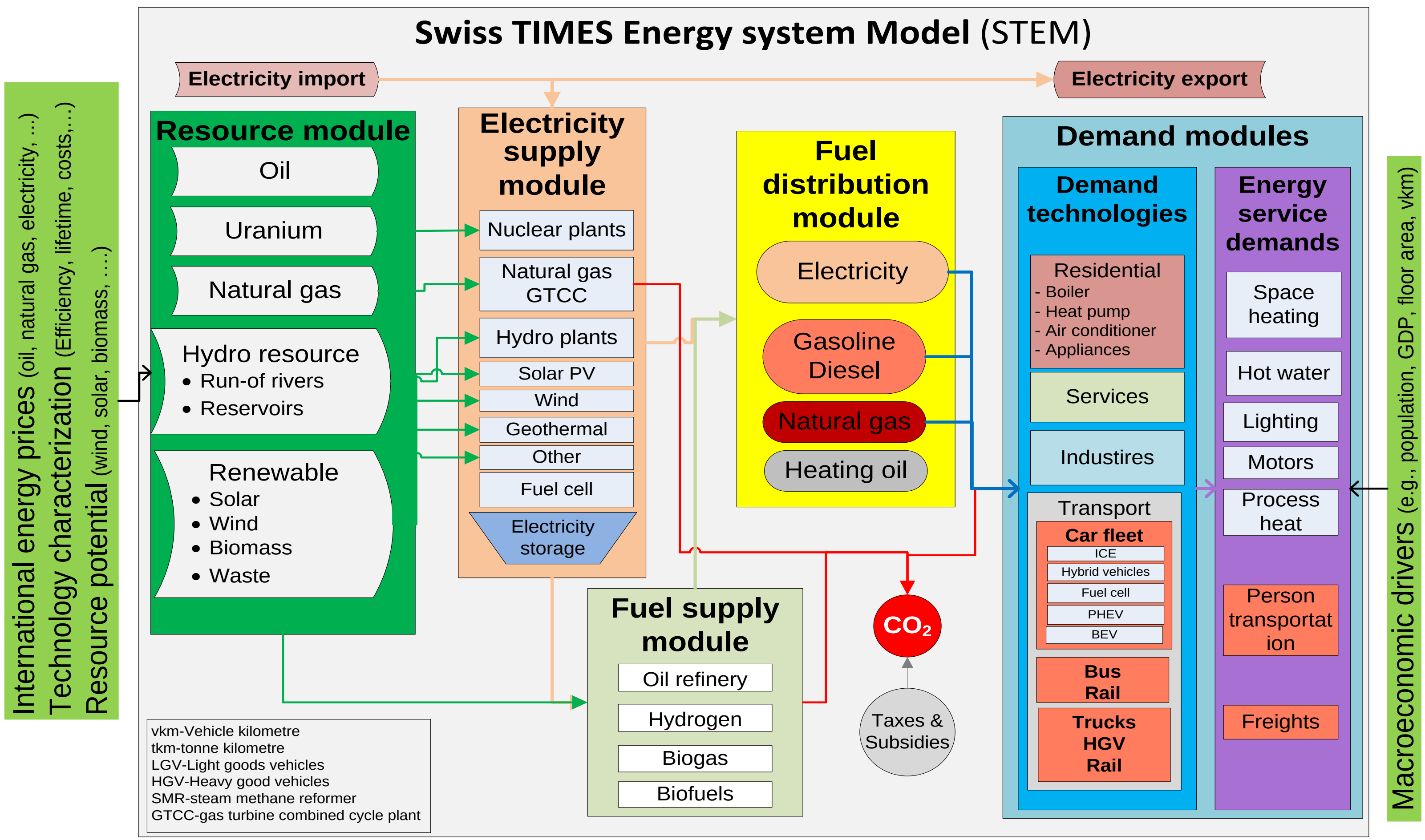


	Criterion
ENVIRONMENTAL DIMENSION	**RESOURCES**
	Energy Resources
	Mineral Resources (Ores)
	CLIMATE CHANGE
	IMPACT ON ECOSYSTEMS
	Impacts from Normal Operation
	Impacts from Severe Accidents
	WASTES
	Special Chemical Wastes stored in Underground Depositories
	Medium and High Level Radioactive Wastes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

The Swiss TIMES energy systems model (STEM)

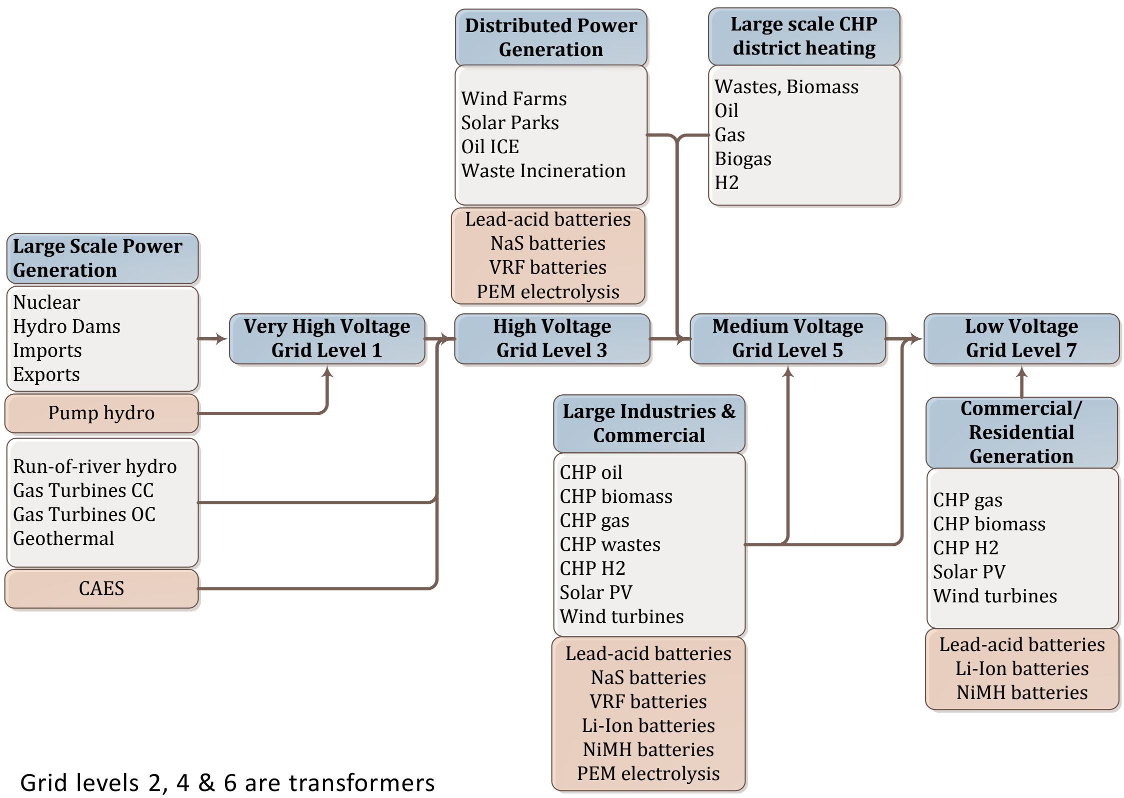
- Energy systems models are the main tool for assessing long-term transformation strategies
- The STEM model represents the Swiss energy system from resource extraction to end-uses
- It is a bottom-up cost optimization model with long time horizon (2015 – 2100)
- It has high hourly resolution and high technological detail (> 350 processes/technologies)
- Significant development has been done in STEM to respond to the electricity sector’s challenges



Centralized vs decentralized supply & grid levels

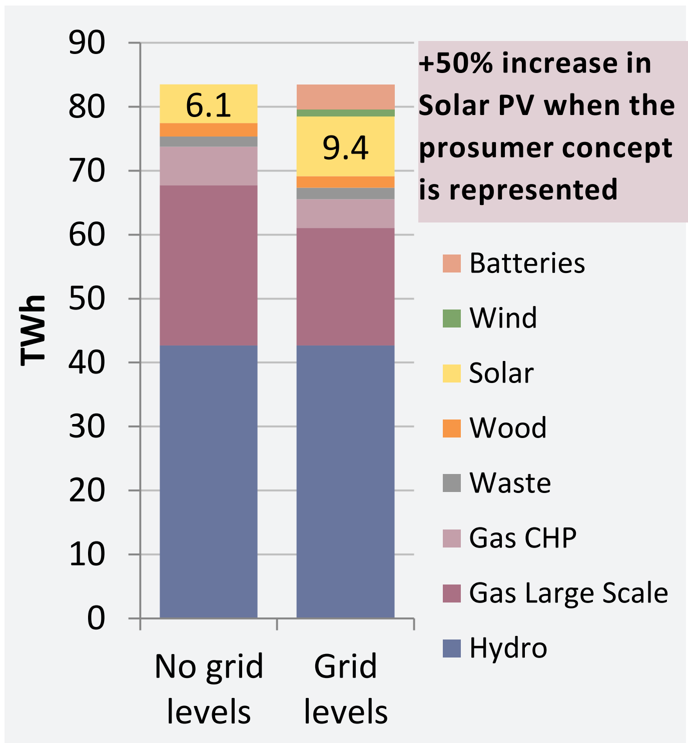
- Each grid level is differentiated in terms of transmission cost and losses
- Different types of power plants and storage options can be connected to each level
- A linearized approximation of the power plant unit commitment problem (dispatch) is formulated
- This structure allows for capturing the effect of incentives for decentralized generation and the benefits of own consumption and/or selling excess supply to upper grid levels (**prosumers**)

REPRESENTATION OF CENTRALIZED/DECENTRALIZED GENERATION AND DIFFERENT GRID LEVELS IN THE STEM MODEL



Grid levels 2, 4 & 6 are transformers

ELECTRICITY GENERATION MIX IN 2050 REFERENCE SCENARIO

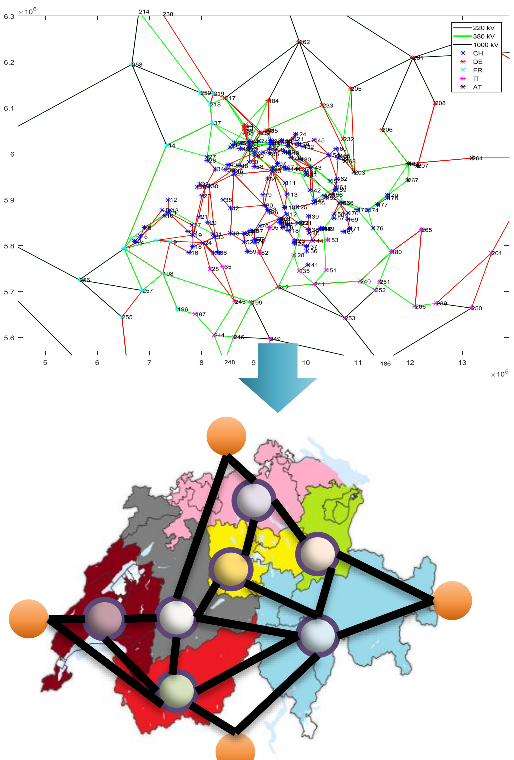


Source: PSI/Kannan & Panos, 2017

Representation of transmission grid

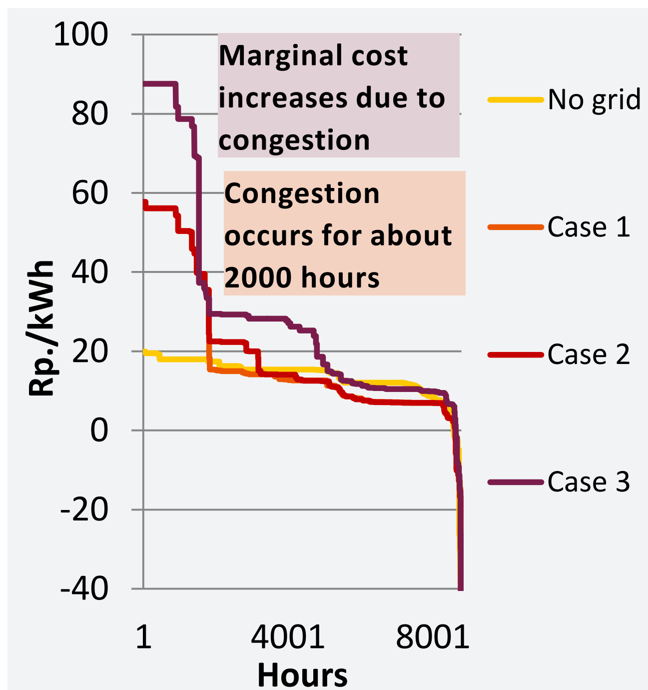
- The detailed transmission grid is mapped to an aggregated grid with 15 nodes and 319 lines
- The mapping is based on a fix disaggregation of the reduced network injections to detailed network injections, by taking into account the grid transmission constraints
- This structure allows for evaluating the impact of grid congestion on electricity supply and demand

REPRESENTATION OF AGGREGATED ELECTRICITY TRANSMISSION GRID



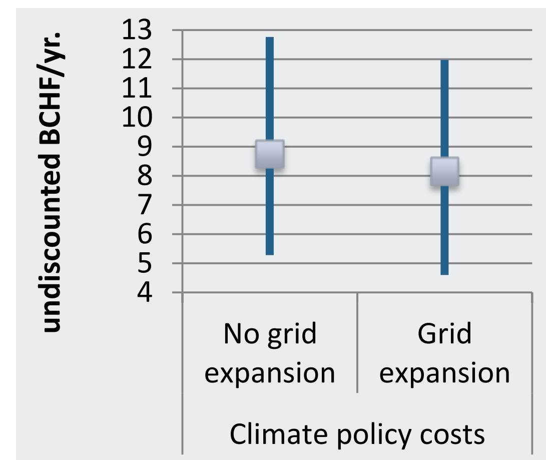
7 regions + 4 nodes for At/DE/IT/FR + 4 nodes for the existing nuclear plants

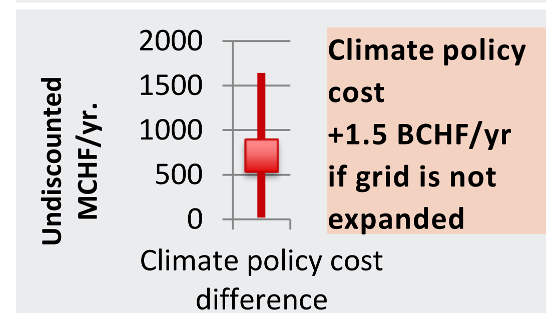
IMPACT OF GRID CONGESTION IN MARGINAL COSTS OF ELECTRICITY, 2050 (Reference)



No grid means no representation of grid constraints
The different cases correspond to different locations of large gas power plants; grid expansion is limited to 2025 plans

IMPACT OF GRID EXPANSION IN CLIMATE CHANGE COSTS, 2020-50





Transport is excluded in cost calculations

Capturing the variability of renewables

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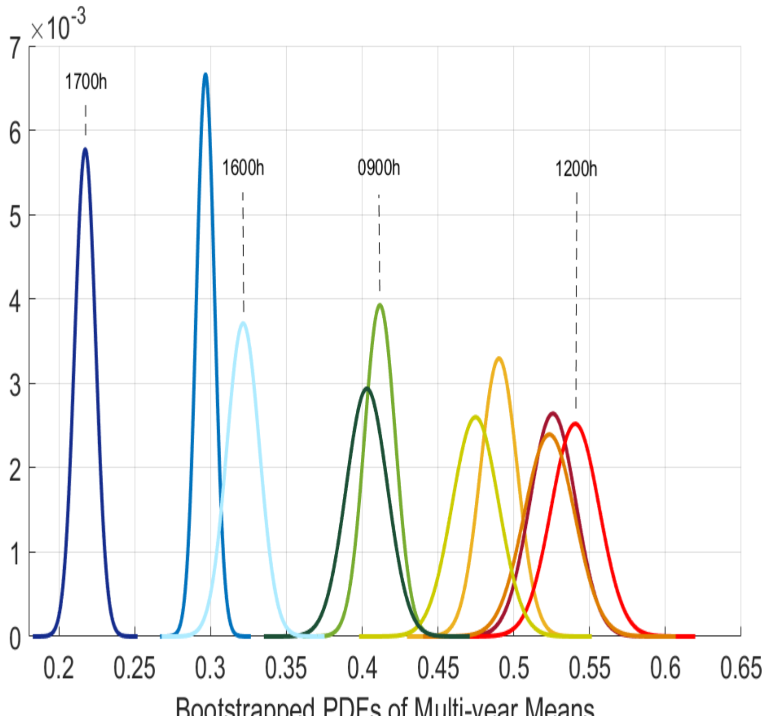
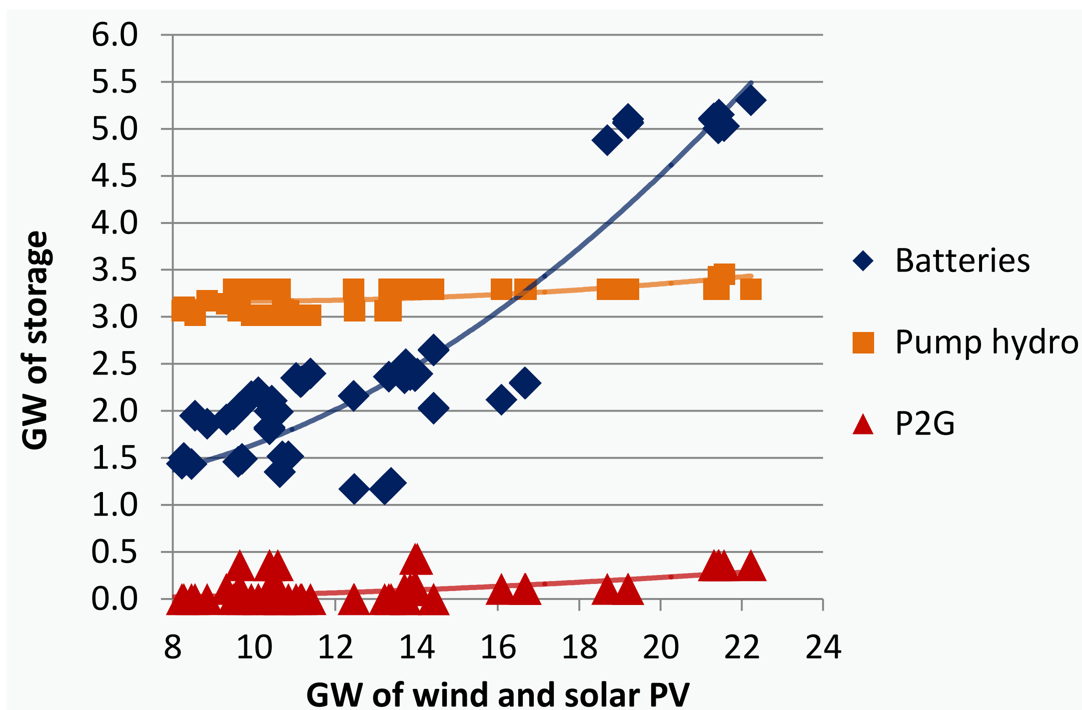
- The variability of RES is based on the variance of mean RES production in each hour and for each typical day represented in the model over a 20-year bootstrapped sample
- This allows to assess the storage requirements to balance the RES production
- High shares of VRES require electricity storage peak capacity of ca. 30 – 50% of the installed capacity of wind and solar PV (together)
- About 13% of the excess summer VRES production is seasonally stored in P2G

VARIABILITY OF SOLAR PV GENERATION IN A SUMMER TYPICAL DAY IN THE STEM MODEL



ELECTRICITY FROM WIND AND SOLAR PV VS INSTALLED PEAK STORAGE CAPACITY IN DIFFERENT SCENARIOS AND YEARS



Each data point corresponds to a different long term scenario and year

Features of PSI's analytical framework for comprehensive energy systems modeling

- Strong technological basis
- Scope covers environmental, economic and social dimensions
- Variety of methods, models and databases
- Inter-disciplinary technology assessment coupled with system models
- Integrative approaches combining knowledge with stakeholder preferences
- Systematic approach to modeling and assessing prospective tchnological advancements
- Endogenous capacity expansion
- Systematic extension of system models within a modular framework
- Representation of whole energy system with detailed modeling of demand sectors (e.g. mobility)
- Coupling of bottom-up technology rich system models with grid
- Geographic coverage (CH, Europe, China and other regions, global)
- Temporal resolution and striving for increased spatial resolution
- Ongoing developments towards integrating behavior in system models
- Continuity and expandability

Thank you for your attention!

Acknowledgements:

Kannan Ramachandran
Tom Kober