Task 4.4

Title

Joint Activity Scenarios & Modeling (JA-S&M)

Project (presented on the following page)

Joint Activity Scenarios & Modelling
JASM-team

Distributional trade-offs of renewable electricity generation, transmission and storage in Europe
Jan-Philipp Sasse, Evelina Trutnevyte

Models on the wrong track: Model-based electricity supply scenarios in Switzerland are not aligned with the perspectives of energy experts and the public
Georgios Xexakis, Ralph Hansmann, Sandra P. Volken, Evelina Trutnevyte

SCCER-SoE Annual Conference 2019

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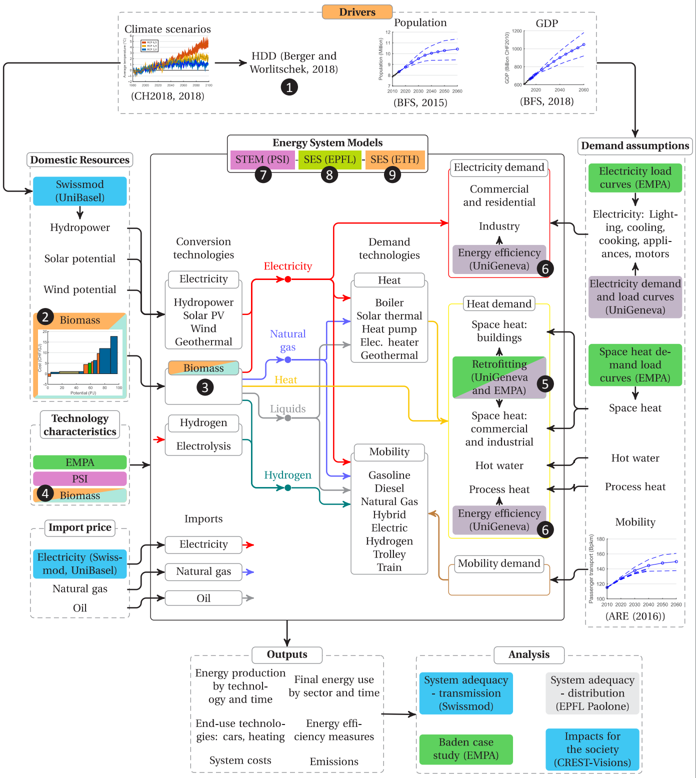
Joint Activity Scenarios & Modelling

JASM-team (contact: Adriana Marcucci, madriana@ethz.ch)

JASM-structure: How do the models fit?

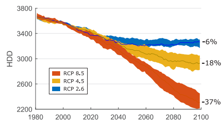
Modelling groups of 8 SCCERs work together to analyse scenarios for the realization of the Swiss Energy Strategy 2050



Modelling Highlights

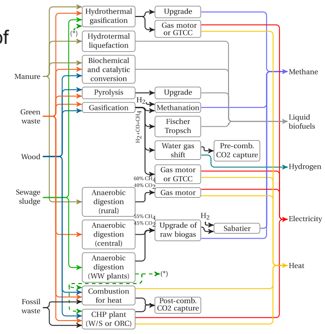
Impact of climate change

1. Heating and cooling demand (Berger and Worlitschek, 2018)



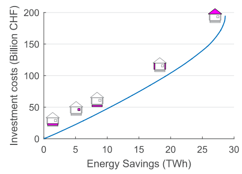
Biomass

2. Updated assessment of biomass and waste resources
3. Biomass roadmap
4. Expert elicitation on biomass technologies



Energy efficiency

5. Buildings: Investment cost for building retrofitting (Streicher et al., 2018, 2019)
6. Industry: Energy efficiency for heat and electricity demand (Zuberi et al., 2017, 2018)



STEM 7

→ Updated costs of Mobility technologies

→ Detailed model of industrial subsectors

→ Model of demand-side management mechanisms

SES

8. Industry: Detailed model of chemicals and plastics

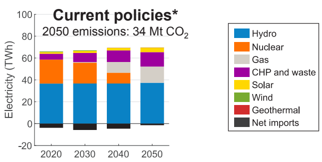
8 9 Integration of new biomass technologies (from JASM roadmap)

Selected results

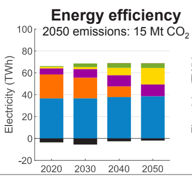
STEM-PSI

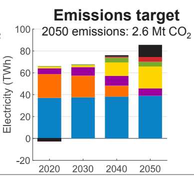
Alternative policy scenarios

Electricity supply 2020-2050 pathways



* no efficiency or climate policies and targets

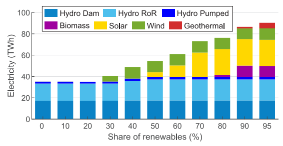




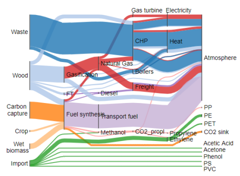
SES-EPFL

2050 electricity production and carbon flow for climate scenario

→ Electricity technologies with the increase in the share of renewables



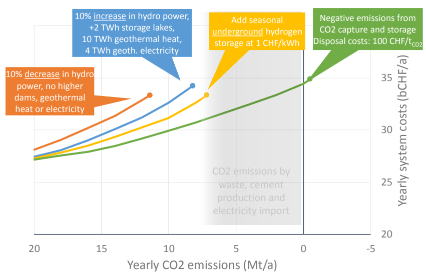
→ 2050 Carbon flow in climate scenario with 1.5 t CO_2 per capita



SES-ETHZ

Role of SCCER-SoE technologies

Pareto frontiers of scenarios for 2050 with or without certain technologies



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Distributional trade-offs of renewable electricity generation, transmission and storage in Europe

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Introduction

- Expansion of decentralized renewable electricity generation (DREG) is the key requirement for climate protection, energy security and economic growth [1].
- To reach net-zero emissions by 2050 in the EU, the share of electricity supply from renewables has to increase from 21% (2010) to 57% (2050) [2] (Fig. 1).
- Previous research showed that such clean energy transition risks creating new patterns of spatially uneven regional development, e.g. clustering of renewable energy investments to few locations and regionally uneven impacts on emissions, electricity generation costs, health and employment [3, 4, 5].
- The appropriate spatial allocation of renewable electricity generation and potentially emerging inequities is a new and recently noticed policy challenge [4, 6, 7].

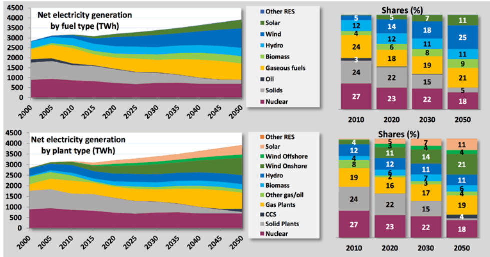

Figure 1. *Share (%) of DREG net electricity generation by fuel type and by plant type. This figure is reproduced from [2]*

Research questions

1. What are the distributional impacts (i.e. additionally installed renewable capacity, storage, transmission infrastructure, and its impact on electricity generation cost) for reaching net-zero emissions in Europe at NUTS-3 level by 2050?
2. How do these distributional impacts vary when increasing levels of regional equity (i.e. equitable spatial allocation of DREG) compared to the cost-efficient spatial allocation?
3. How do NUTS-3 regions in Europe (today and in future scenarios) compare in terms of regional equity of DREG spatial allocation?

Methods and materials

- Study region: Europe at high NUTS-3 spatial resolution (Fig. 2).
- We setup the model by hard-linking the PyEXPANSE and PyPSA models (Fig. 3):
  - PyEXPANSE to assess long-term capacity expansion requirements by generating equitable scenarios with Modeling to Generate Alternatives (MGA) method [4,8].
  - PyPSA [9] to assess short-term economic dispatch, storage and transmission requirements and costs.
- Each scenario is compared in terms of distributional impacts for multiple levels of regional equity, which we measure with an adapted concept of the Gini coefficient [4,10].
- We develop an energy justice framework in which we embed our equity analysis [4] (Fig. 4).
- We include multiple equity or "effort-sharing" principles to assess the equitable spatial allocation of renewable electricity generation as proposed by Höhne et al. [11].
  - Equality: e.g. equal per capita renewable capacity allocation.
  - Cost-efficiency: e.g. least-cost allocation by total system cost (generation, storage & transmission).
  - Capability: e.g. allocation of renewable capacity weighted by GDP.
  - Responsibility: e.g. allocation of renewable capacity weighted by historic emissions.

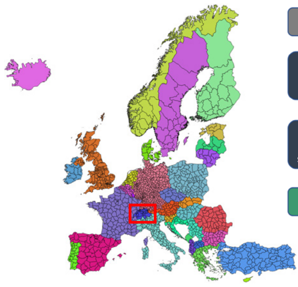

Figure 2. *Study regions (Switzerland in red)*

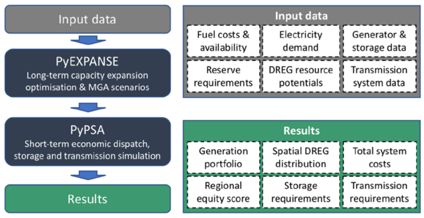

Figure 3. *Overview of the modelling methodology*

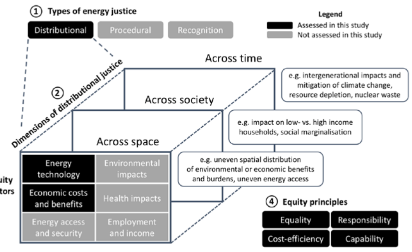

Figure 4. *Energy justice framework. This figure is reproduced from [4]*

Preliminary results for one country (Switzerland)

- Least-cost DREG allocation leads to highest electricity storage and net import costs; but still has low total system costs (Fig. 5).
- Most regionally equitable scenarios lead to high total system costs (Fig. 5 & 6).
- There is a significant trade-off between equity, levelized cost of electricity (LCOE) and total system cost found in Switzerland: 100% increase in regional equity when allocating DREG leads to 20% higher LCOE and 35% higher total system costs (Fig. 6).
- Existing transmission line capacity is sufficient to achieve Swiss 2035 DREG capacity targets (n-1 security approximation) (Fig. 5).
- Pumped hydro and battery storage plants are able to balance high solar PV power supply and demand (Fig. 7 & 8).

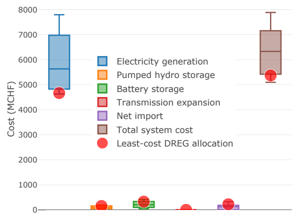

Figure 5. *Boxplot of total system cost components (annualized) for least-cost DREG allocation and 200 MGA scenarios*

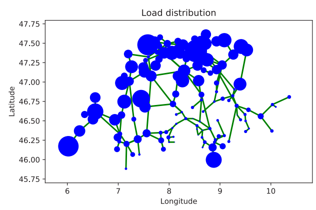

Figure 7. *Hourly load distribution with ENTSO-E transmission grid infrastructure extracted with GridKit model [12]*

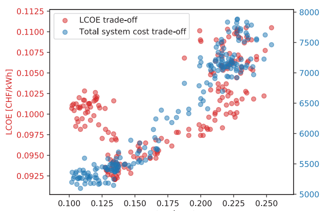

Figure 6. *Equity trade-off between LCOE and total system costs for 200 MGA scenarios*

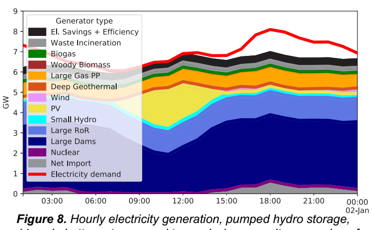

Figure 8. *Hourly electricity generation, pumped hydro storage, grid-scale battery storage and transmission capacity expansion of least-cost DREG allocation scenario*

Next steps

- Expand analysis to further 4 countries: France, Germany, Netherlands and Austria, and later to all regions from Fig. 2.
- Assess distributional trade-offs of total system cost for varying degrees of regional equity for these regions.
- Assess distributional trade-off for a range of equity principles: equality, cost-efficiency, responsibility and capability (Fig. 4).

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UNIGE RES

Models on the wrong track: Model-based electricity supply scenarios in Switzerland are not aligned with the perspectives of energy experts and the public

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Introduction

- Model-based scenarios have become the key method to explore uncertainties and decision alternatives in the electricity supply transition of many countries [1-3].
- In Switzerland, such scenarios have been developed by many different organisations, including public administration (e.g. Swiss Federal Office of Energy [4]), research institutes (e.g. Paul Scherrer Institute [5]), universities (e.g. ETH Zurich [6]), and non-governmental organizations (e.g. Cleantech [7]).
- Combining scenarios in multi-organization, multi-model scenario ensembles increases the diversity of considered uncertainties [3].
- However, it is unclear whether such ensembles align with the perspectives of stakeholders, including the wider public [8-9].

Methods and Materials

- We collected model-based scenarios by reviewing published scenario studies that provided electricity supply results for 2035 (Table 1).
- We elicited preferred scenarios using the interactive web-tool Riskmeter (Figure 1) from three samples of participants in Switzerland:
  1. non-experts ("citizens", N=61)
  2. non-experts that received balanced information and participated in informational workshops about the electricity supply topic prior to giving their preferred scenarios ("informed citizens", N=46)
  3. participants that were mainly working in or studying about energy topics in Switzerland ("energy experts", N=60)
- We compared model-based and preferred scenarios in terms of technology-specific electricity supply and the whole supply system.

Pub. year	Organisation	Study	Cost-optimization used?	Scenario diversity method used?	Uncertainties explored: Related to nuclear, fossil fuels or imports	Uncertainties explored: Related to domestic renewable sources	Electricity supply excl. hydro (TWh/year)
2019	PSI	[11]	✓				
2018	EPFL - LEURE	[12]	✓		✓		
2017	VSE	[13]		✓			
	ETHZ - TD	[2]		✓			
	ETHZ - FEN & PSI	[14]	✓		✓	✓	
	ETHZ - CP	[15]			✓	✓	
2016	PSI	[16]	✓		✓	✓	
	PSI	[17]	✓		✓		
2015	Econability & PSI & EPFL - LEURE	[18]	✓		✓		
	ETHZ - CP	[19]			✓		
2014	PSI	[20]	✓		✓		
2013	PSI	[21]	✓		✓		
	Cleantech	[7]				✓	
	Greenpeace	[22]				✓	
2012	VSE	[23]	✓			✓	
	PSI	[5]	✓		✓		
	SFOE	[4]			✓		
2011	ETHZ - ESC	[6]					

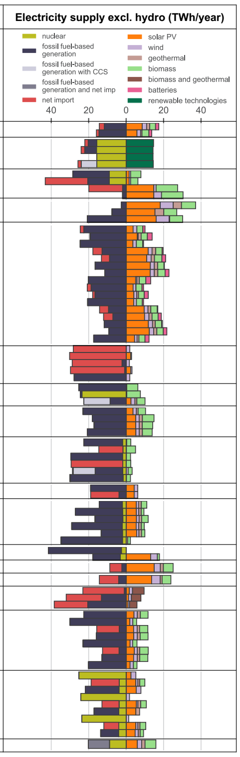

Table 1. Scenario development details for all studies included in the review. Acronyms used: PSI (Paul Scherrer Institute), LEURE (Laboratory of Environmental and Urban Economics), VSE (Verband Schweizerischer Elektrizitäts-unternehmen), FEN (Research Center for Energy Networks) CP (Climate Policy group), TD (Transdisciplinarity lab), SFOE (Swiss Federal Office of Energy), ESC (Energy Science Center).

Aim and research questions

We compare a multi-organization, multi-model ensemble of 80 Swiss electricity supply scenarios for 2035 from 18 studies between 2011-2018 with the preferred scenarios from three samples of stakeholders: citizens (N=61), informed citizens (N=46), and energy experts (N=60). Our study aims to answer the following questions:

1. How does an ensemble of multi-organization, multi-model electricity scenarios compare to the preferred scenarios from citizens, informed citizens, and energy experts?
2. What are the key factors of scenario development that may explain the alignment or misalignment between the model-based scenarios and the preferred scenarios?
3. Does the difference in energy knowledge level of the three samples result in differences in preferred scenarios?

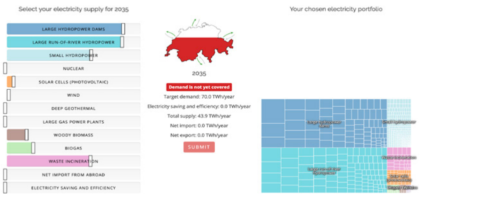

Figure 1. The interactive web-tool Riskmeter for building Swiss electricity supply scenarios for 2035 [10]

Results

- Most informed citizens and experts preferred an almost 100% domestic renewable electricity supply in Switzerland in 2035 (Figure 2).
- Most model-based scenarios relied significantly more on fossil fuel-based generation and net electricity imports (Figure 2).
- Possible reasons for this misalignment are the lack of broad stakeholder participation in scenario development, the wide use of cost-optimization models that are known to underrepresent renewable electricity [8], and the limited diversity due to a focus on specific uncertainties (Table 1).
- The energy knowledge level affected preferred scenarios. Citizens preferred statistically significantly lower supply from domestic renewable electricity than informed citizens and experts (Figure 2).

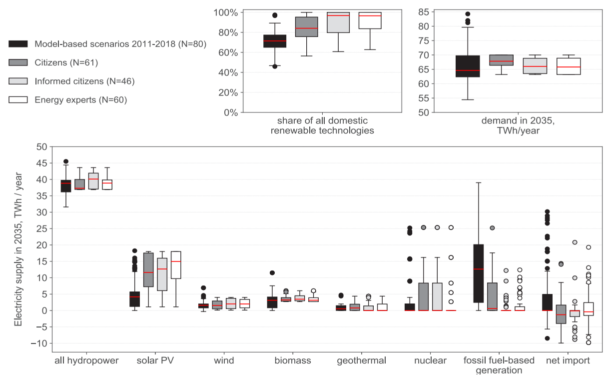

Figure 2. Comparison of annual electricity supply for 2035 between model-based and preferred scenarios. The boxplots depict median, 25th and 75th quartiles, and 1.5 interquartile range.

Implications

- For scenario developers and users: even multi-model scenario ensembles can focus on alternatives that are not preferred by stakeholders; diverse stakeholder and public perspectives can enrich scenarios.
- For the electricity supply transition in Switzerland: more scenarios with large-scale deployment of renewable electricity before 2035 should be modelled in the future.

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