School of
Management and Law

# Economic assessment of bottom-up energy system model results

## Coupling SES-ETH with GemEne

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30 January 2025

# Background

- Computable General Equilibrium (CGE) models allow for **economy-wide** analysis of policy issues but are **ill-suited** to predict consequences of **fundamental transformation** of the energy sector.
  - CES framework for production functions not easily amenable to full phase-out of production inputs like fossil fuels
  - Good accounting of *values* but inconsistent accounting of *physical quantities*
- Energy system models give more credible representation of technological substitutability, but lack economy-wide perspective.
- Model coupling allows to draw on strengths of both model types.
- Nexus-e: provide tight coupling link between *electricity* investment and electricity market modeling and CGE model (Gjorgiev et al. 2022)[1]
- Goal: work towards a tight model link between *energy* system modeling and CGE model.

[1] Blazhe Gjorgiev et al. (2022). "Nexus-e: a platform of interfaced high-resolution models for energy-economic assessments of future electricity systems". In: *Applied Energy* 307. DOI: https://doi.org/10.1016/j.apenergy.2021.118193.

# Method

Attempt a model-coupling between

- SES-ETH (Marcucci, Guidati and Giardini 2021)[2]
  - energy system model
  - minimizes total cost given
    - demand for energy services
    - constraints on emissions
- CGE model of Switzerland (GemEne)
  - General equilibrium
    - prices such that markets are balanced
    - activity levels such that zero-profits hold
  - Production functions allow for substitution of inputs when prices change.
  - Firms participating in markets minimize production costs → demand functions of firms

[2] Adriana Marcucci, Gianfranco Guidati and Domenico Giardini (2021). *Swiss Energy Scope – ETH: Swiss Energy Scope with hourly resolution*. Report. Accepted: 2022-04-05T05:08:47Z. ETH Zurich. DOI: 10.3929/ethz-b-000540917.

# Data: Structure of Swiss economy

Input–Output-Table of Swiss economy:

- "Energiebezogene Differenzierung der Input-Output-Tabelle 2014" von aramis Projektdatenbank[3]
- 77 economic sectors;
  sectors of particular interest:
  - (23) Manufacture of other non-metallic mineral products
  - (35a–35h) diverse sources of electricity generation
  - (35i) Electricity distribution and trade
  - (49a, 49d, 49e) Passenger land transport
  - (49b) Freight rail transport
  - (49f) Freight transport by road
  - (35j) Steam and hot water supply
  - (38b) Heat from waste incineration
- Energy demand for 22 energy commodities by sector in TJ

[3] https://www.aramis.admin.ch/Grunddaten/?ProjectID=43188

# Data: Energy sector according to SES-ETH

SES-ETH:

- Rich set of technologies and energy goods
- $CO_2$ accounting
- Minimize syste cost s.t. fix energy demand and climate target are met

Small-scale version in GemEne:

- 7 final energy goods: heat, electricity, four modes of transport, cement
- 4 inputs: investments (capital), biomass, natural gas, carbon transportation and storage services, electricity imports
- 12 activities: cement, 4 modes of transport, electricity generation, combined-heat-and-power, heat, $H_2$, biomass, gas, CCS
- 4 grids: electricity, heat, $H_2$, gas
- activities (and grids) integrate in CGE as fixed-factor production functions

# Correspondance of energy activities and economic sectors

| | ESM energy good | CGE sector |
|---|---|---|
| Transport | Individual transport | Private transport |
| | Public transport | (49a, 49d, 49e)Passenger land transport |
| | Freight road transport | (49f) Freight transport by road |
| | Freight rail transport | (49b) Freight rail transport |
| Electricity | Electricity | (35a–35h) diverse sources of electricity generation |
| Cement | Cement | (23) Manufacture of other non-metallic mineral products |
| Heat | Heat | (35j, 38b) heat supply<br>& *all* sectors with heating fuel inputs |

# Forward calibration: BaU energy sector

| | Heat | H2 | Public Transport | Private Transport | Road freight transpor | Rail freight transport | CHP | Electricity generation | Biomass | Natural gas | Cement | CCS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| v_cr | −2.78 | | −0.47 | −1.99 | −3.18 | | −0.37 | −5.45 | | −0.44 | | |
| v_ng | | | | | | | | | | −3.11 | | |
| v_el | | | | | | | −0.00 | −0.00 | | | | |
| v_bm | | | | | | | | | −0.33 | | | |
| v_cs | | | | | | | | | | | | |
| e_h2 | | | | | | | | | | | | |
| e_bm | −0.12 | | | | | | −0.21 | | **0.33** | | | |
| e_ng | −0.52 | | −0.03 | −0.37 | −0.37 | | −0.90 | −1.35 | | **3.55** | | |
| e_cc | | | | | | | | | | | | |
| f_ht | **4.88** | | | | | | **0.97** | | | | −0.17 | |
| f_cem | | | | | | | | | | | **0.21** | |
| f_ele | −1.46 | | −0.28 | −1.26 | −0.08 | −0.08 | **0.50** | **6.81** | | | −0.04 | |
| f_frd | | | | | **3.64** | | | | | | | |
| f_frl | | | | | | **0.08** | | | | | | |
| f_tpr | | | | **3.63** | | | | | | | | |
| f_tpb | | | **0.78** | | | | | | | | | |

# Counterfactual: Carbon net-negative energy sector

| | Heat | H2 | Public Transport | Private Transport | Road freight transpor | Rail freight transport | CHP | Electricity generation | Biomass | Natural gas | Cement | CCS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| v_cr | −4.98 | −0.36 | −0.47 | −1.99 | −3.18 | | −0.23 | −7.08 | | −0.23 | | −0.17 |
| v_ng | | | | | | | | | | −1.14 | | |
| v_el | | | | | | | −0.00 | −0.00 | | | | |
| v_bm | | | | | | | | | −1.49 | | | |
| v_cs | | | | | | | | | | | | −2.85 |
| e_h2 | −0.32 | **1.31** | −0.04 | −0.46 | −0.50 | | | | | | | |
| e_bm | −0.10 | −0.23 | | | | | −0.23 | | **0.56** | | | |
| e_ng | −0.26 | −0.29 | | | | | | −0.70 | | **1.25** | | |
| e_cc | −0.47 | −0.05 | | | | | −0.75 | −0.58 | | | −0.32 | **2.17** |
| f_ht | **5.61** | | | | | | **0.51** | | | | −0.17 | −0.27 |
| f_cem | | | | | | | | | | | **0.21** | |
| f_ele | −1.50 | −0.05 | −0.28 | −1.26 | −0.08 | −0.08 | **0.14** | **7.42** | | | −0.04 | −0.16 |
| f_frd | | | | | **3.64** | | | | | | | |
| f_frl | | | | | | **0.08** | | | | | | |
| f_tpr | | | | **3.63** | | | | | | | | |
| f_tpb | | | **0.78** | | | | | | | | | |

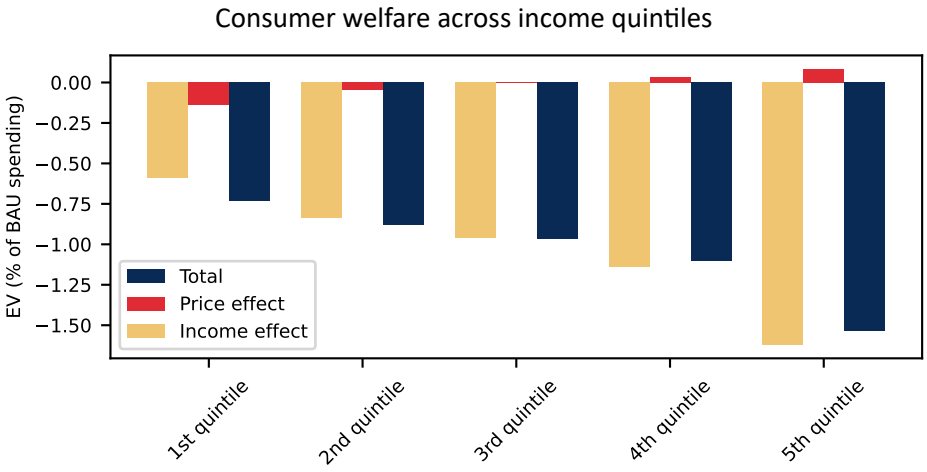
# Findings: Demand response

| | | SES-ETH | | GemEne | |
|---|---|---|---|---|---|
| | | BAU | Decarb | BAU | Decarb |
| Supply (bn CHF) | Heat | 5.68 | ” | 5.68 | 4.43 |
| | Cement | 0.21 | ” | 0.21 | 0.19 |
| | Electricity | 4.10 | ” | 4.10 | 3.17 |
| | Freight road | 3.64 | ” | 3.64 | 3.57 |
| | Freight rail | 0.08 | ” | 0.08 | 0.08 |
| | Persons road | 3.63 | ” | 3.63 | 3.55 |
| | Persons rail | 0.78 | ” | 0.78 | 0.76 |
| ES Cost (bn CHF) | Total | 18.16 | 24.21 | 18.15 | 20.66 |

# Findings: Macroeconomic results

| | | SES-ETH | | GemEne | |
|---|---|---|---|---|---|
| | | BAU | Decarb | BAU | Decarb |
| ES Cost | Total (bn CHF) | 18.16 | 24.21 | 18.15 | 20.66 |
| | Change (bn CHF) | | 6.05 | | 2.50 |
| GDP | Total (bn CHF) | | | 975.34 | 967.59 |
| | Change (bn CHF) | | | | −7.75 |
| | Change (%) | | | | −0.79 |
| Real consumption | Total (bn CHF) | | | 501.37 | 495.68 |
| | Change (bn CHF) | | | | −5.69 |
| | Change (%) | | | | −1.13 |
| Consumer price | Change (%) | | | | −0.01 |
| Wages | Change (%) | | | | −0.92 |
| Capital rents | Change (%) | | | | −0.60 |

# Findings: Households



# Conclusion and Outlook

Achievements and insights:

- 1-to-1 integration of energy system modelling results in CGE analysis
- Demand response in CGE reduces energy system costs
- Allows for an analysis of which sectors and households are affected by more expensive energy
- Analysis corresponds to “regulation by technology standards”

Caveats and outlook:

- Policies (like subsidies or carbon prices) or targets (like emissions caps) not in CGE model, but need to be reflected in energy system model
- Effects of demand response should be reassessed in energy system model:
  - Loop between models for a “tight” model coupling link.
  - Current demand response (behavior of stylistic ES model) is based on cost structures but sees no carbon constraint.

# Thank you for your attention

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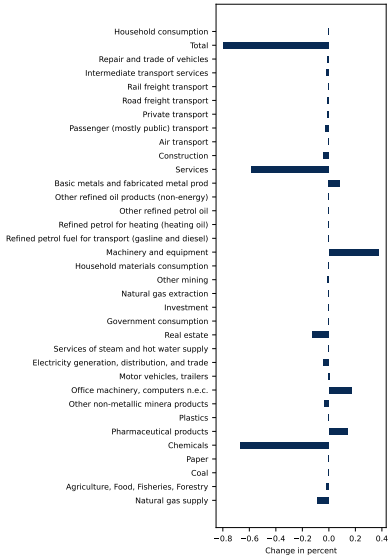
# Sector results: GDP composition



# Sectoral energy demand: Efficiency v. activity levels

# Sector results: Output prices