Presenter's Profile

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Michel Dominik Obrist :: PhD Student :: Paul Scherrer Institut

Long-term energy and emission pathways for the Swiss industry

PhD Project :: Frontiers in Energy Research :: 28.04.2020

Swiss industry in a nutshell

- Swiss industry produces products we use every day
- Most important industries in Switzerland:


Pharmaceutical


Machinery


Food


Watches

Precision instruments


Medical technology

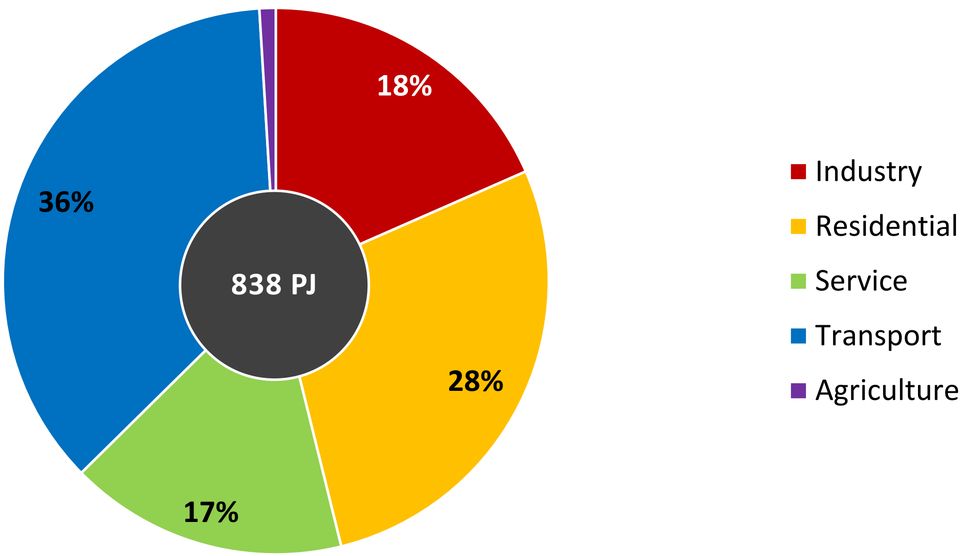
Importance of industry for Switzerland

- **Swiss GDP: 679.3 BCHF**[1]
- 74% of Swiss GDP is generated by the service sector and **25% by industry**[1]
- **1.0 Mio employees** are working in the Swiss industry (full time equivalent)[2]

[1] Swiss Federal Departement of Foreign Affairs FDFA, Swiss Economy – Facts and Figures
[2] Swiss Federal Statistical Office, Full-time job equivalent per sector

Final energy consumption in industry

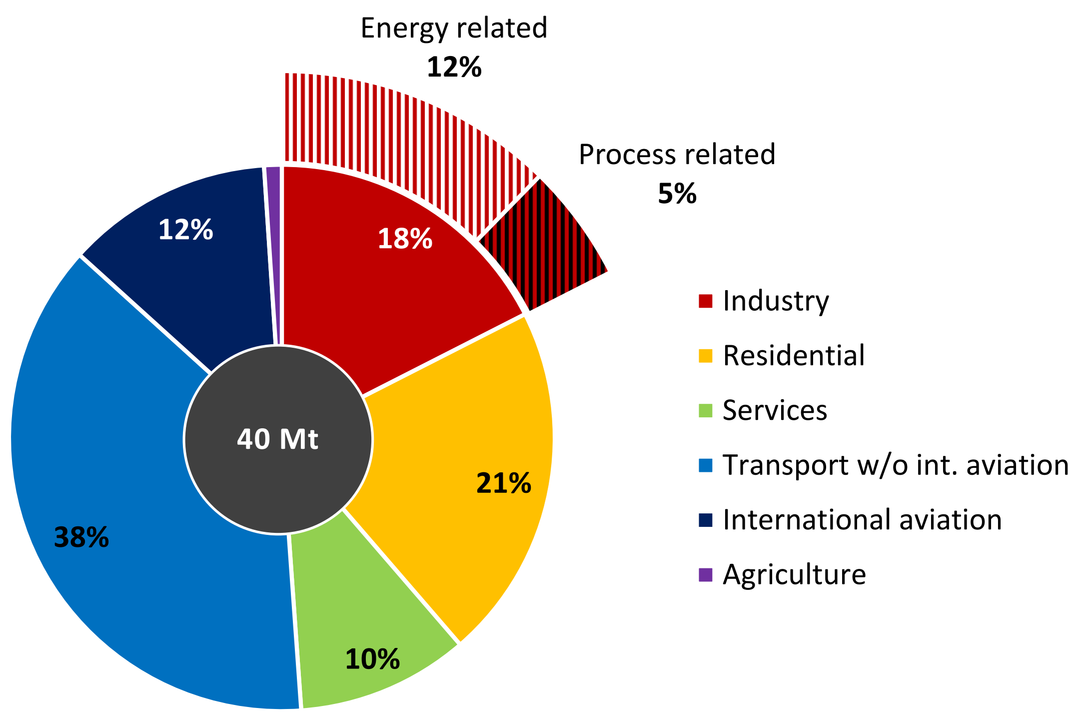
- Swiss final energy consumption in 2015 by sector[1]



[1] Swiss Federal Office of Energy SFOE, Schweizerische Gesamtenergiestatistik

CO_2 emissions in Swiss industry

- Swiss direct CO_2 emissions in 2015[1] without indirect emissions associated to purchased electricity and heat



[1] United Nations Climate Change UNFCCC, Inventory 2015 Switzerland

Swiss energy policy

- Energy strategy 2050 indicative targets
  - Energy reduction per capita of 43% from 2000 levels
  - Electricity reduction per capita of 13% until 2035 compared to 2000 levels
- Paris agreement
  - Pursue efforts to **limit the global temperature increase to 1.5 degrees Celsius** above pre-industrial levels

Main research question:

How can the climate and energy policy goals be reached and what are the implications for the Swiss industry sector?

Current significance

- Swiss parliament is debating about the revision of the **CO_2 regulation after 2020**
- Communication from BAFU (15.04.2020)[1]:
  - **GHG emissions** from 1990 until 2018:
    - **Overall 14% reduction** to 46.4 Mt $CO_{2\text{-eq}}$
    - **Industry 14% reduction** to 11.2 Mt $CO_{2\text{-eq}}$
  - **Goal** until 2020 (compared to 1990):
    - **Overall 20% reduction**
    - **Industry 15% reduction**

[1] Schweizer Treibhausgasemissionen 2018 nur leicht gesunken, BAFU, 15.04.2020

Agenda

Energy System Models

- Introduction
- Methodology
- ESM for Industry

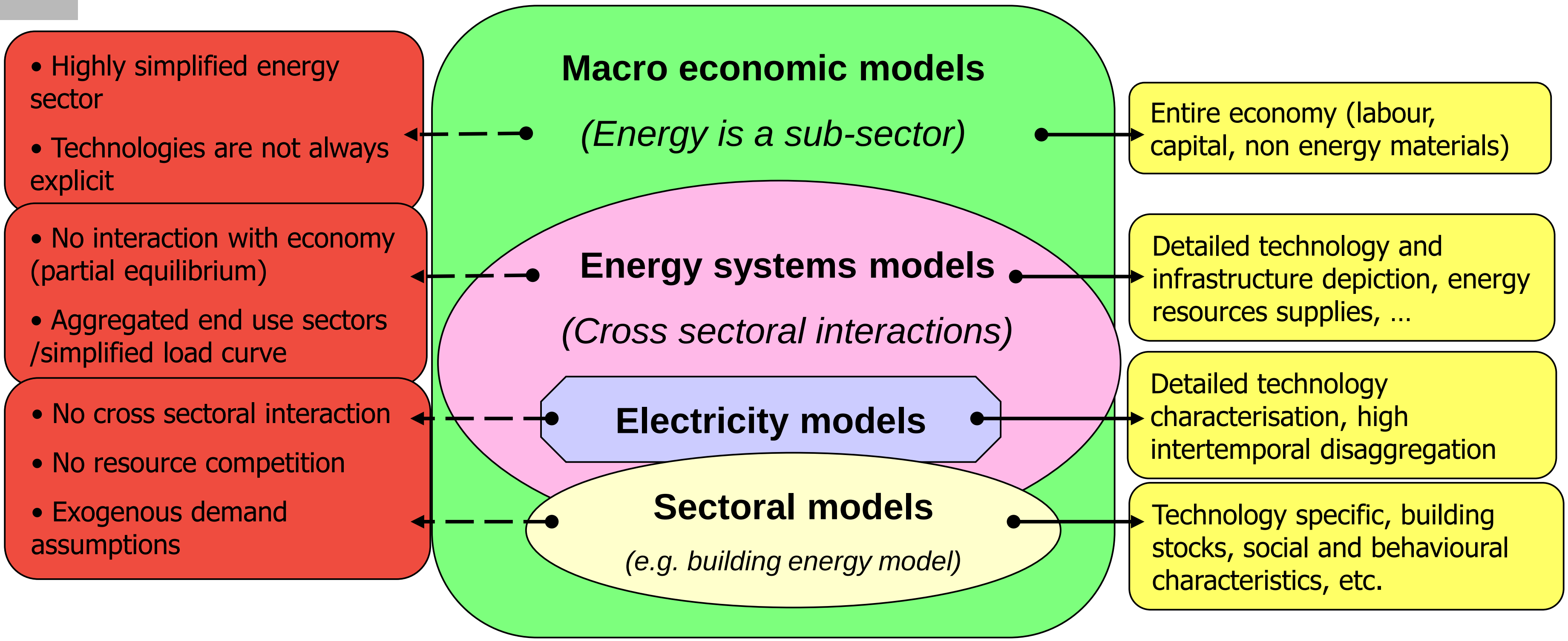
PhD Project

- Objectives
- Research gap
- Methodology

Focus: Cement industry

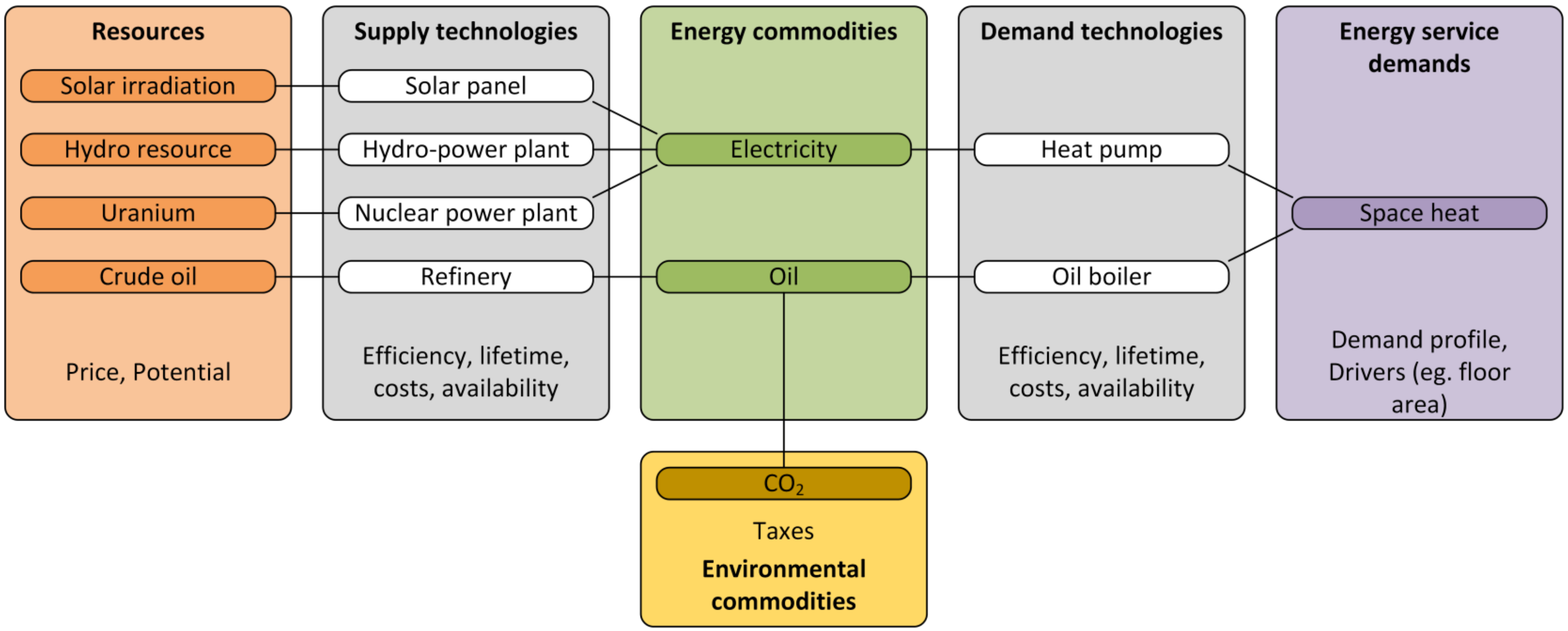
- Background
- Applied Methodology
- Preliminary results
- Key messages

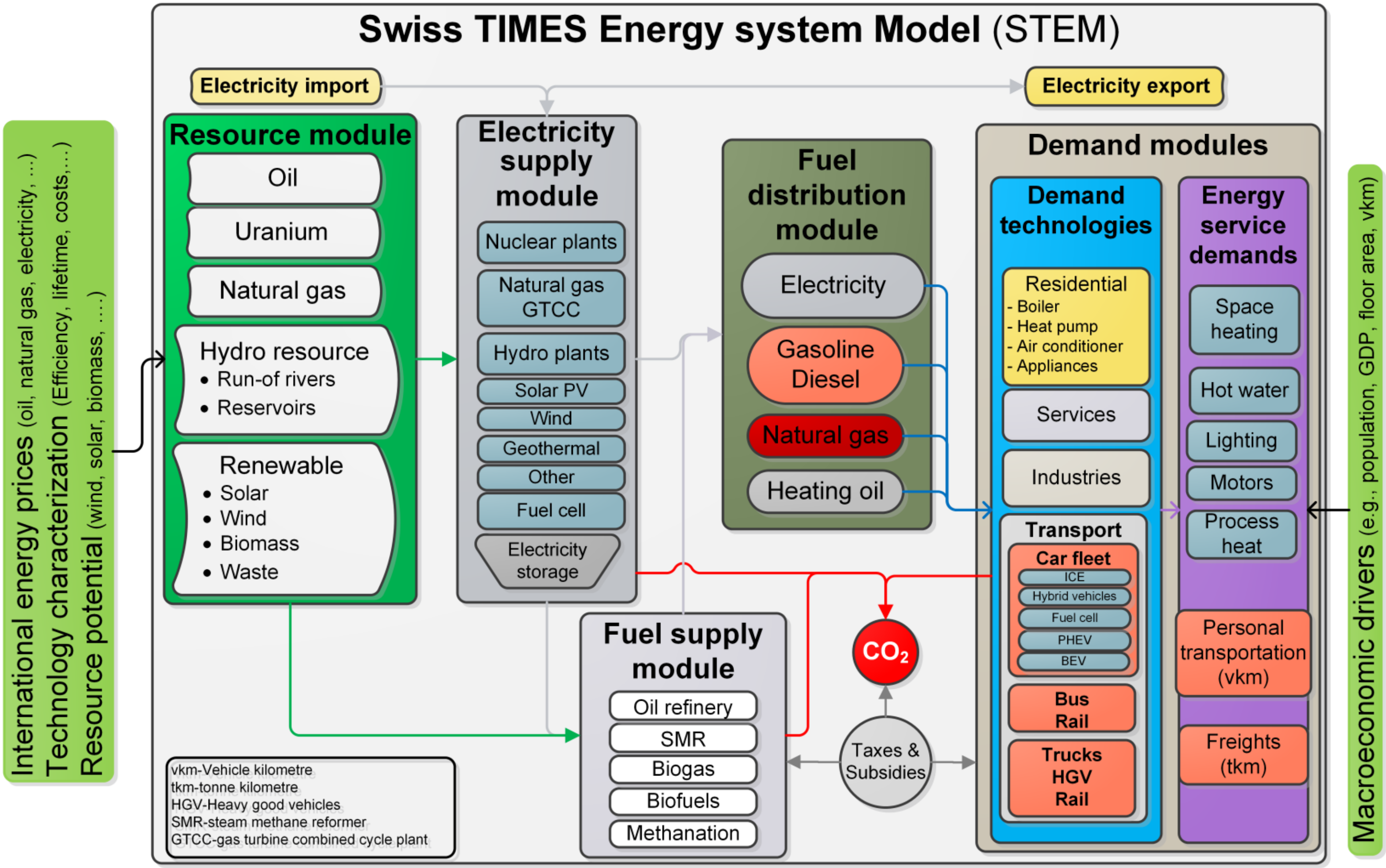
Types of Energy System Models[1]



[1] Kannan, R. and H. Turton (2013). A long-term electricity dispatch model with the TIMES framework, Environment Modeling and Assessment, 18 (3): 325-343, DOI: 10.1007/s10666-012-9346-y

Energy System Models




Swiss TIMES Energy system Model (STEM)
Electricity import
Electricity export
International energy prices (oil, natural gas, electricity, ...)
Technology characterization (Efficiency, lifetime, costs,...)
Resource potential (wind, solar, biomass, ...)
Resource module
Oil
Uranium
Natural gas
Hydro resource
• Run-of rivers
• Reservoirs
Renewable
• Solar
• Wind
• Biomass
• Waste
Electricity supply module
Nuclear plants
Natural gas GTCC
Hydro plants
Solar PV
Wind
Geothermal
Other
Fuel cell
Electricity storage
Fuel distribution module
Electricity
Gasoline Diesel
Natural gas
Heating oil
Demand modules
Demand technologies
Residential
- Boiler
- Heat pump
- Air conditioner
- Appliances
Services
Industries
Transport
Car fleet
ICE
Hybrid vehicles
Fuel cell
PHEV
BEV
Bus Rail
Trucks HGV Rail
Energy service demands
Space heating
Hot water
Lighting
Motors
Process heat
Personal transportation (vkm)
Freights (tkm)
Macroeconomic drivers (e.g., population, GDP, floor area, vkm)
Fuel supply module
Oil refinery
SMR
Biogas
Biofuels
Methanation
CO_2
Taxes & Subsidies
vkm-Vehicle kilometre
tkm-tonne kilometre
HGV-Heavy good vehicles
SMR-steam methane reformer
GTCC-gas turbine combined cycle plant

Cost minimization

- The model aims to supply energy services at minimum global cost by making decisions on:
  - Investment and operation
  - Primary energy supply
  - Energy trade

Objective function

$$Min \ \ c \cdot X$$

$$s.t.$$

$$\sum_k VAR\_ACT_{k,i}(t) \geq DM_i(t)$$

$$B \cdot X \geq b$$

c: cost vector
X: decision variables
DM: demand
k: process
i: demand categories
t: time slices
B: constraint vector
b: constraint RHS

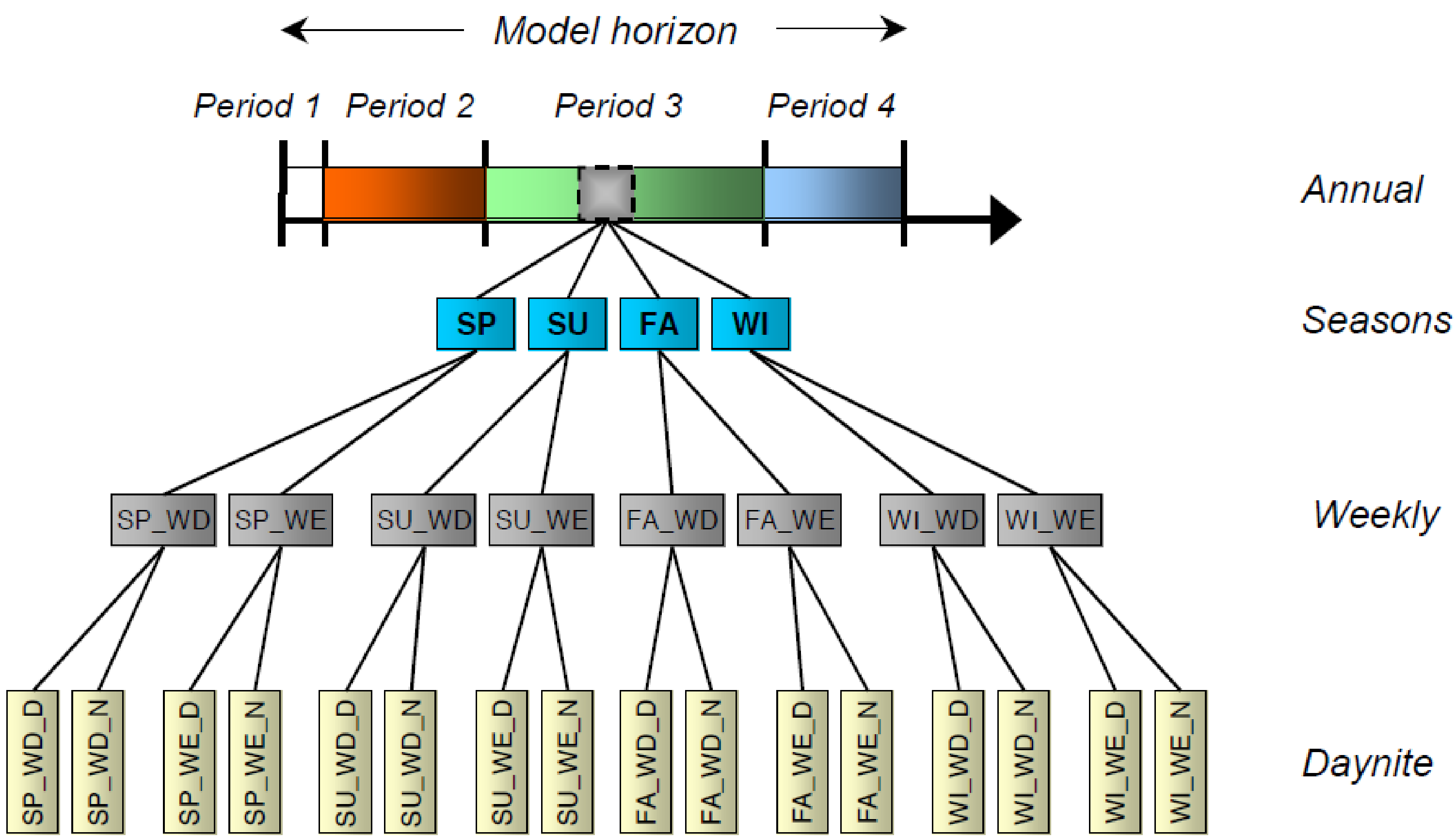
Cost vector
Includes all costs eg. investment costs, variable costs, import/export costs, taxes

Decision variables
eg. new capacity addition, capacity retirement, process activity

Demand satisfaction
Demand for i must be satisfied at all times by the process activity (decision variable) of process all processes k that produce i

Constraints
Numerous constraints eg. ramp up constrains on activity, conservation of investment, use of capacity, user constraints

Model horizon



[1] IEA-ETSAP, Documentation for the TIMES Model, July 2016

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Research objectives

- How can the **climate and energy policy goals be reached** and what are the implications for the Swiss industry sector?
- How can **new energy technologies** in industry can contribute **to reduce CO_2 emissions** and **improve energy efficiency**?
- What is the impact of **energy policy** and **energy price scenarios** for the energy demand of the industry?
- What are the **implications to the broader energy system** in terms of costs?

Research gap

- Previous studies focused on **potentials for specific technologies** or **energy efficiency improvements** and CO_2 abatement on a process level
- Shortcomings:
  - Do not investigate **transformation pathways to reach climate policy goals**
  - No detailed **long-term scenario analysis**
  - **Neglects interaction** with the rest of the energy sector

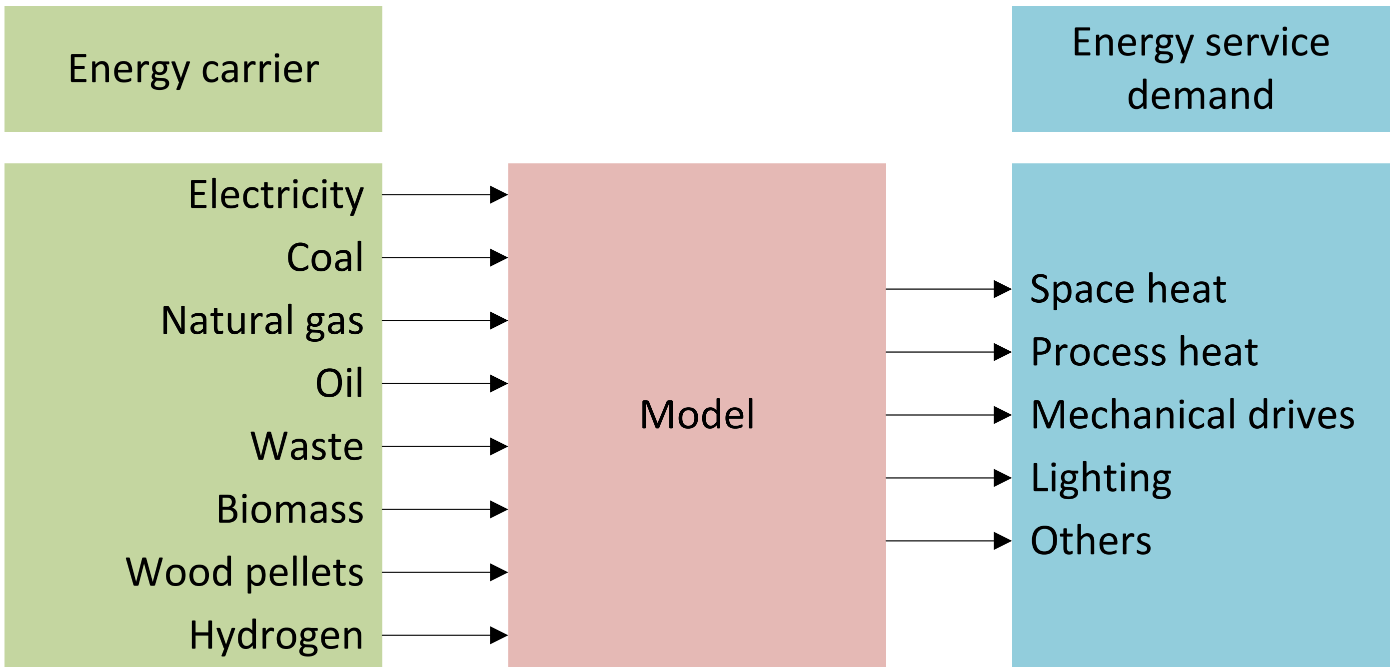
- Scenario analysis with **energy system models** (for example STEM) contributed to the understanding of **energy technology development** and identified **policy strategies** to reach the climate goals
- Shortcomings:
  - No investigation of the industry sector on a **production process level**
  - Very general view on **technology developments** and **process improvements**

Research gap

- STEM is expanded with an advanced industry module with a new modelling technique
  - Includes **production process** and **product flows**
  - Gives possibilities to include **process improvements** and **efficiency improvements** of single process steps
  - Enables options to **include process related emissions**
  - Allows a more detailed and accurate analysis

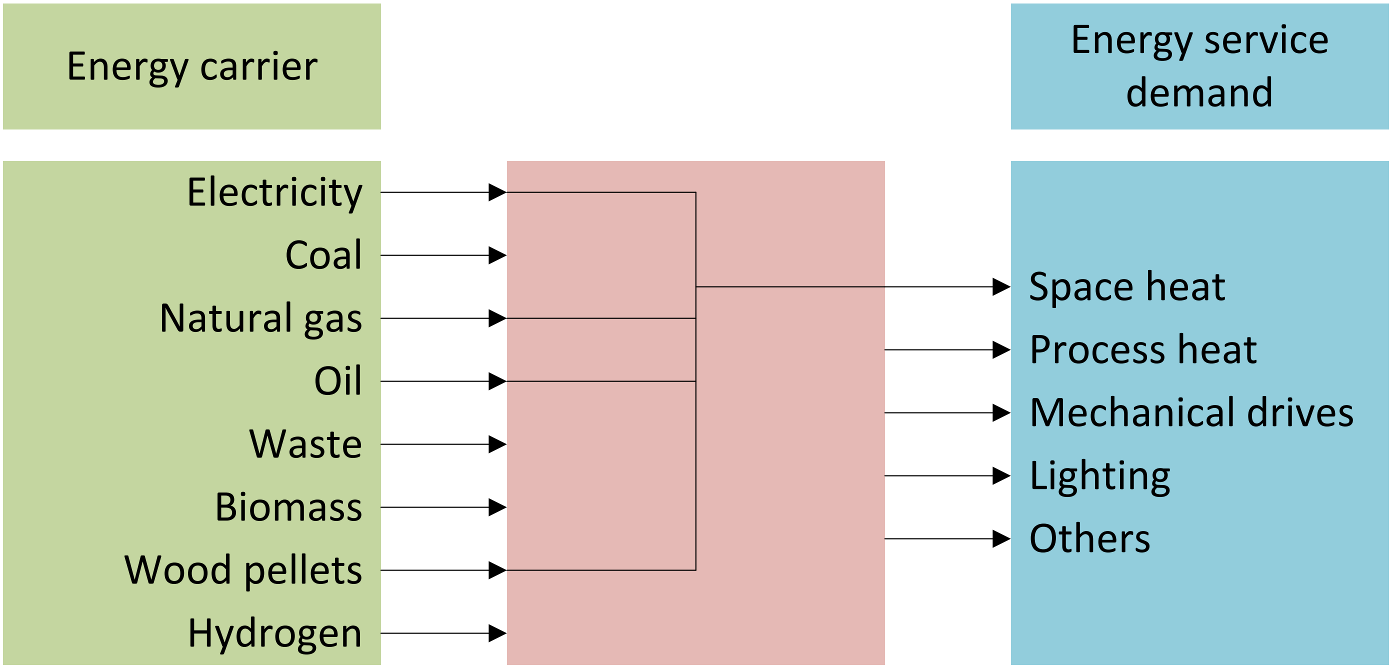
Methodology – Modelling technique

- Previous modelling technique

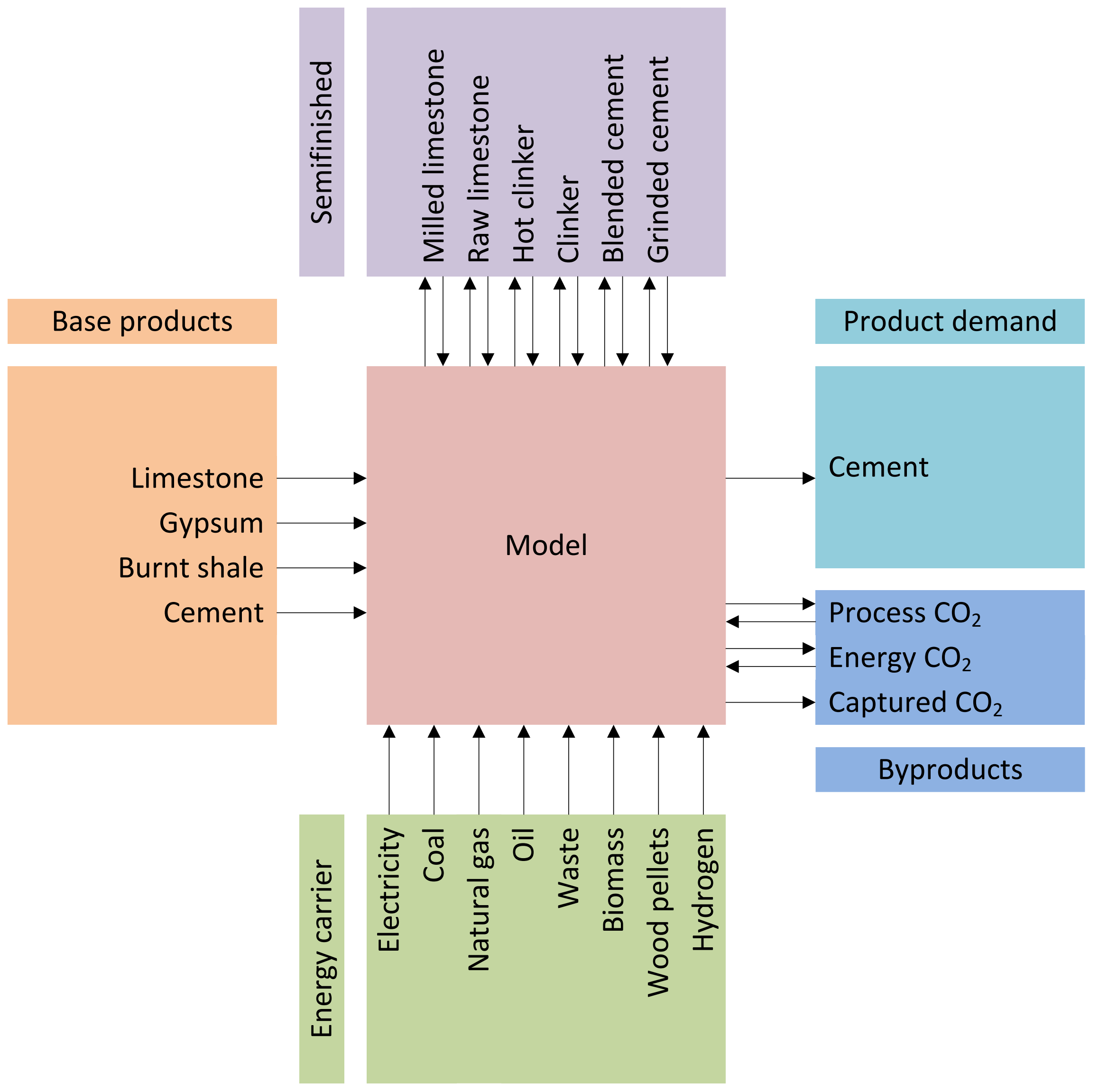


Methodology – Modelling technique

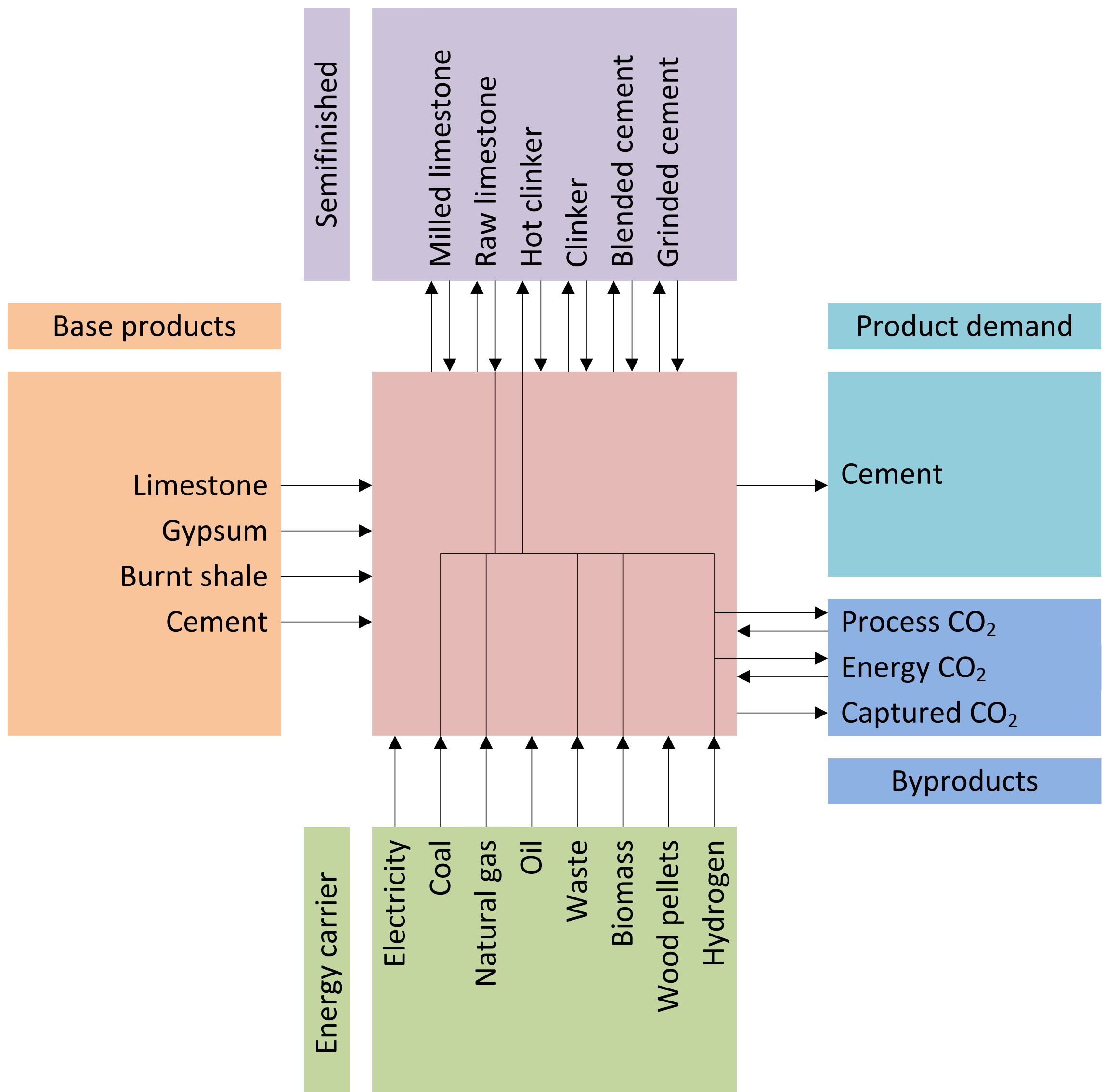
- Previous modelling technique



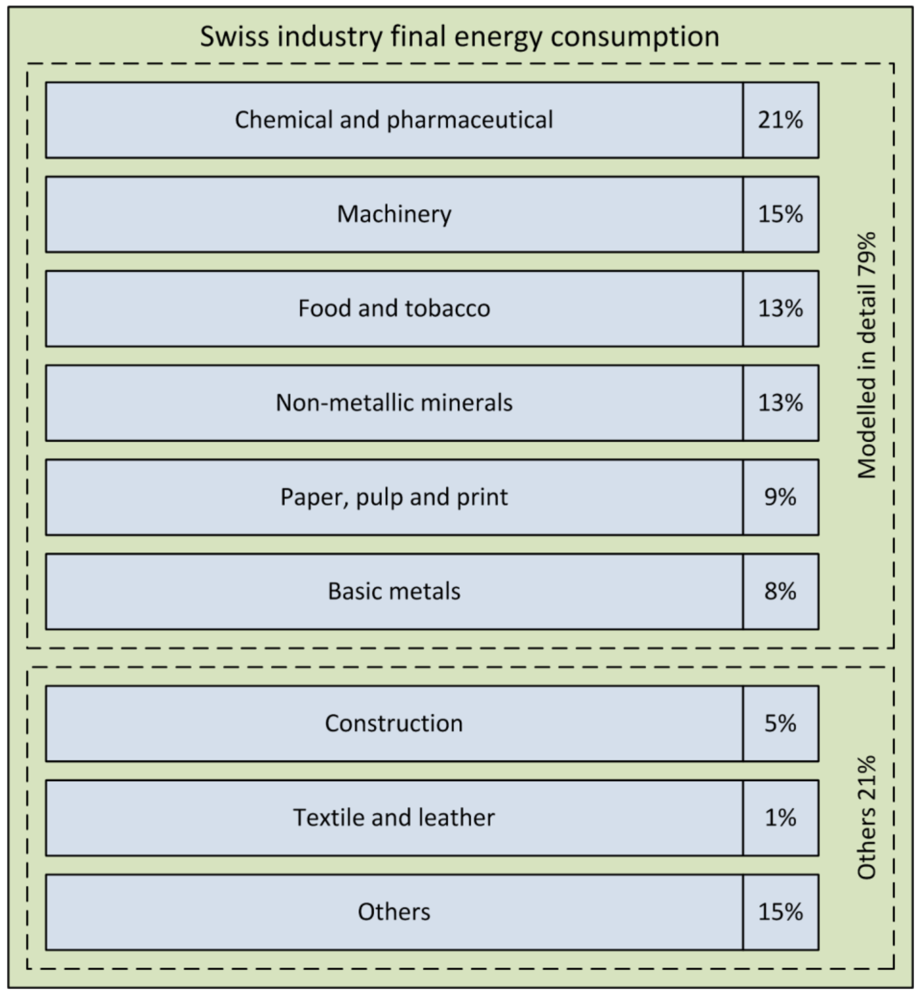
Methodology – Modelling technique



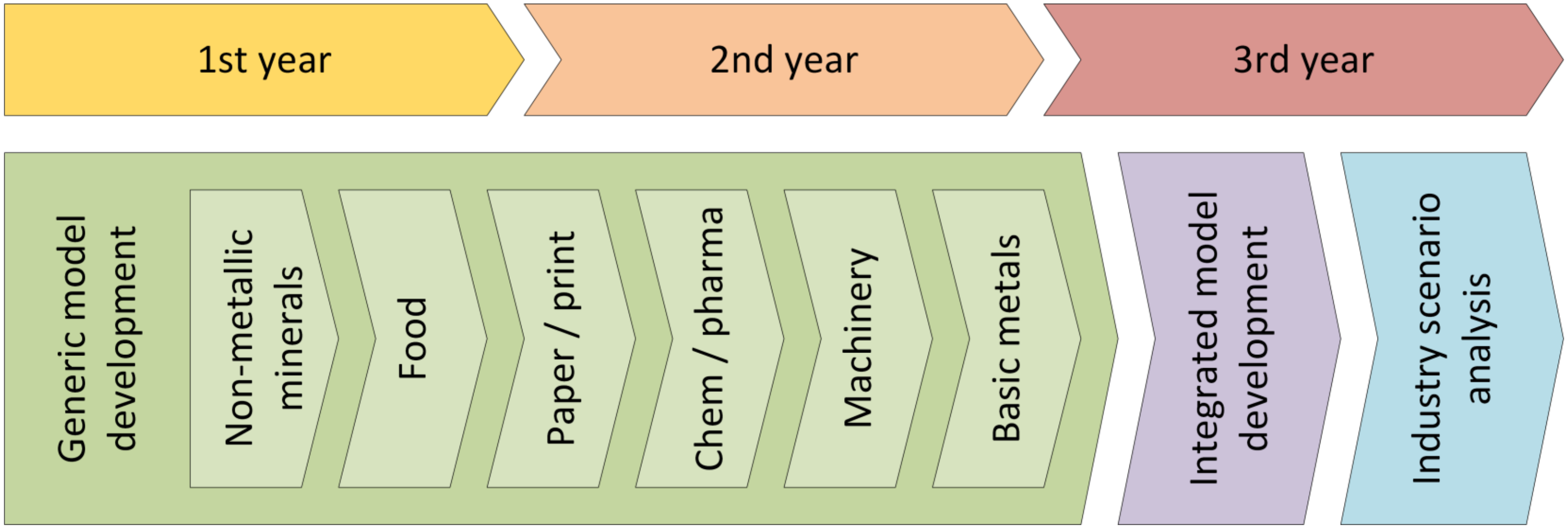
Methodology – Modelling technique



Methodology



PhD plan


1st year
2nd year
3rd year
Generic model development
Non-metallic minerals
Food
Paper / print
Chem / pharma
Machinery
Basic metals
Integrated model development
Industry scenario analysis

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Introduction to cement

“Cement is the second most consumed commodity in the world after water”[1]

[1] Global Cement Magazine, CEMENT 101 – An indtroduction to the World’s most important building material

PAUL SCHERRER INSTITUT

Introduction to cement

[1] Global Cement Magazine, CEMENT 101 – An indtroduction to the World's most important building material

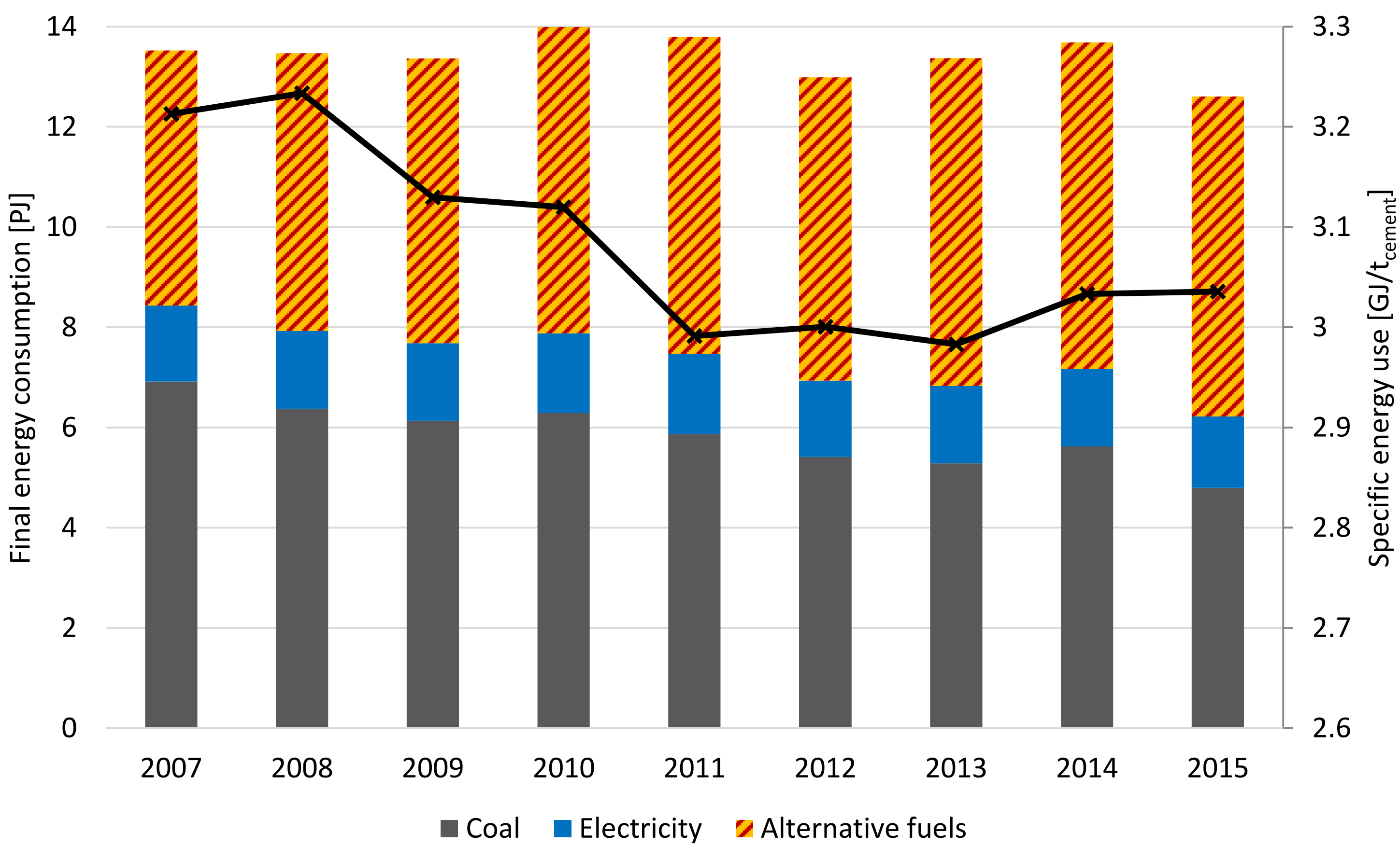
Energy and CO_2 in Swiss cement plants

- Cement production accounts for
  - **8% of the final energy consumption** of the Swiss industrial sector (12.8 PJ)[6]
  - **36% of the CO_2 emissions** of the Swiss industrial sector (2.5 Mt)[6]
    - Around **two-thirds the CO_2 emissions are related to the process** of converting limestone into clinker
    - Remaining emissions are related to fuel combustion
- Specific final energy use
  - Swiss cement plants 2.65 GJ/t_{cement} or 3.6 $GJ/t_{clinker}$[6]
  - Global cement industry between 3.4 and 4.7 $GJ/t_{clinker}$[7]
  - Best available techniques (BAT) 3.3 $GJ/t_{clinker}$[8]
- Specific CO_2 emissions
  - Swiss cement plants 787 $kg_{CO2}/t_{clinker}$[6]
  - EU cement industry 825 $kg_{CO2}/t_{clinker}$[7]
  - Global cement industry 843 $kg_{CO2}/t_{clinker}$[7]

[6] Cemsuisse, Kennzahlen 2018
[7] Cement Sustainability Initiative (CSI), 2016, Cement Industry Energy and CO2 Performance – Getting the Numbers Right
[8] European Commission, 2013, Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide

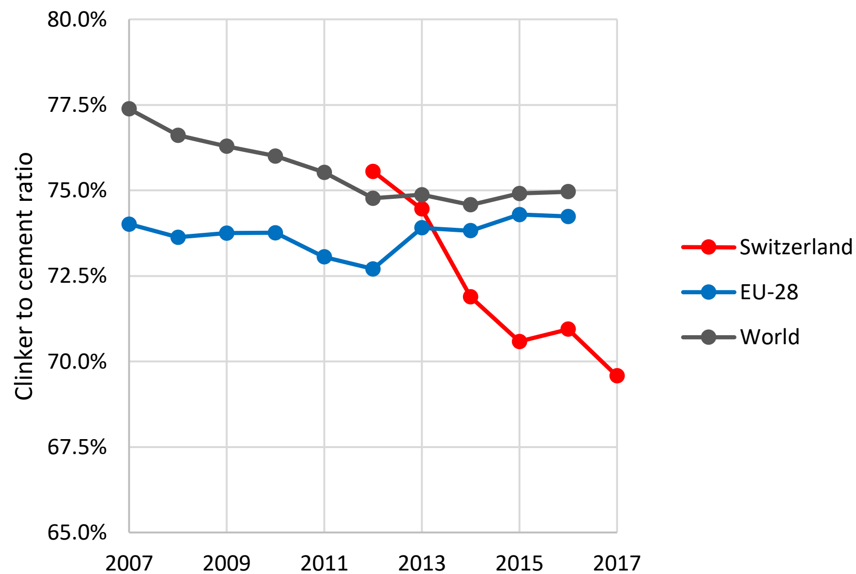
Energy consumption in Swiss cement plants

- Recent developments of energy use[6]



Based on [6] Cemsuisse, Kennzahlen 2018

Clinker content in Swiss cement plants



Based on [6] Cemsuisse, Kennzahlen 2018

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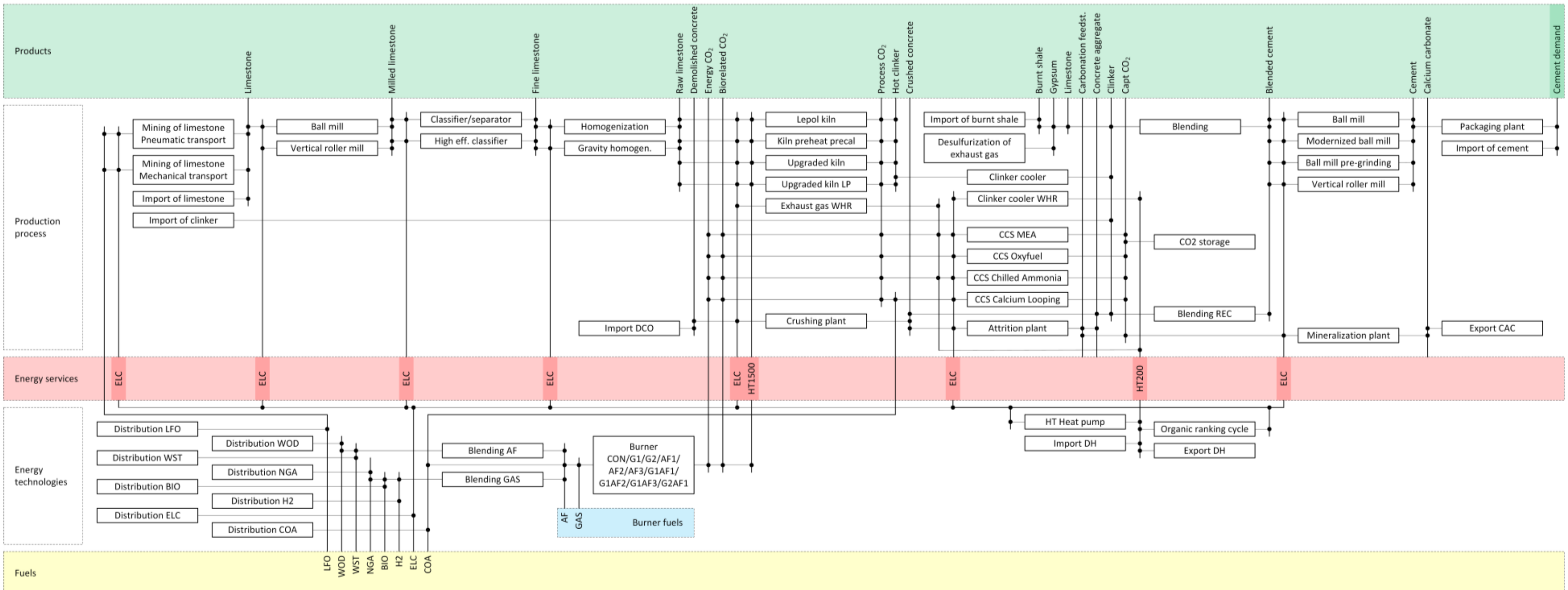
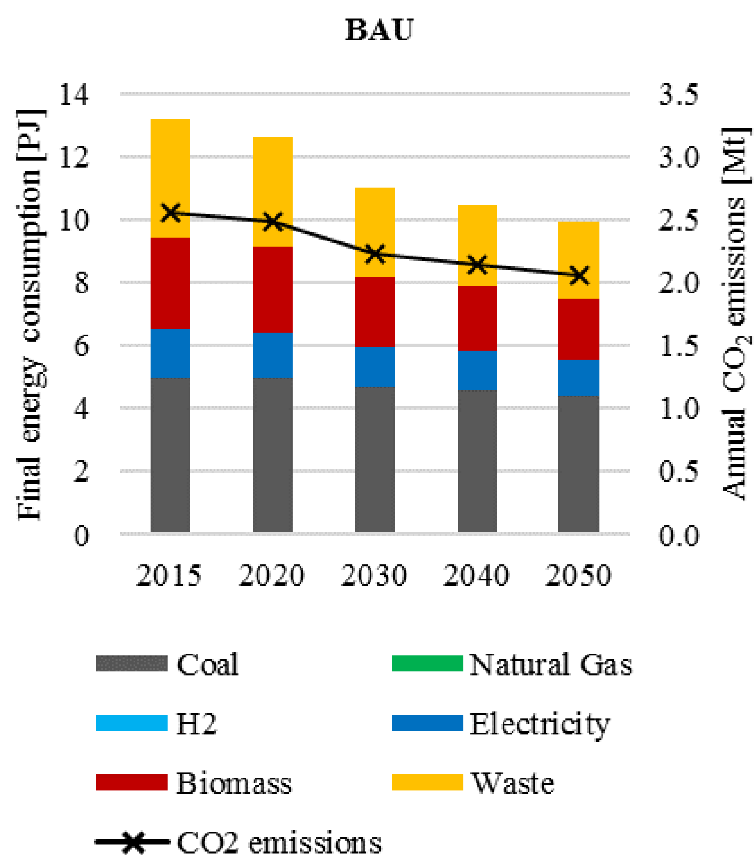
Cement process (model)



Scenario definition

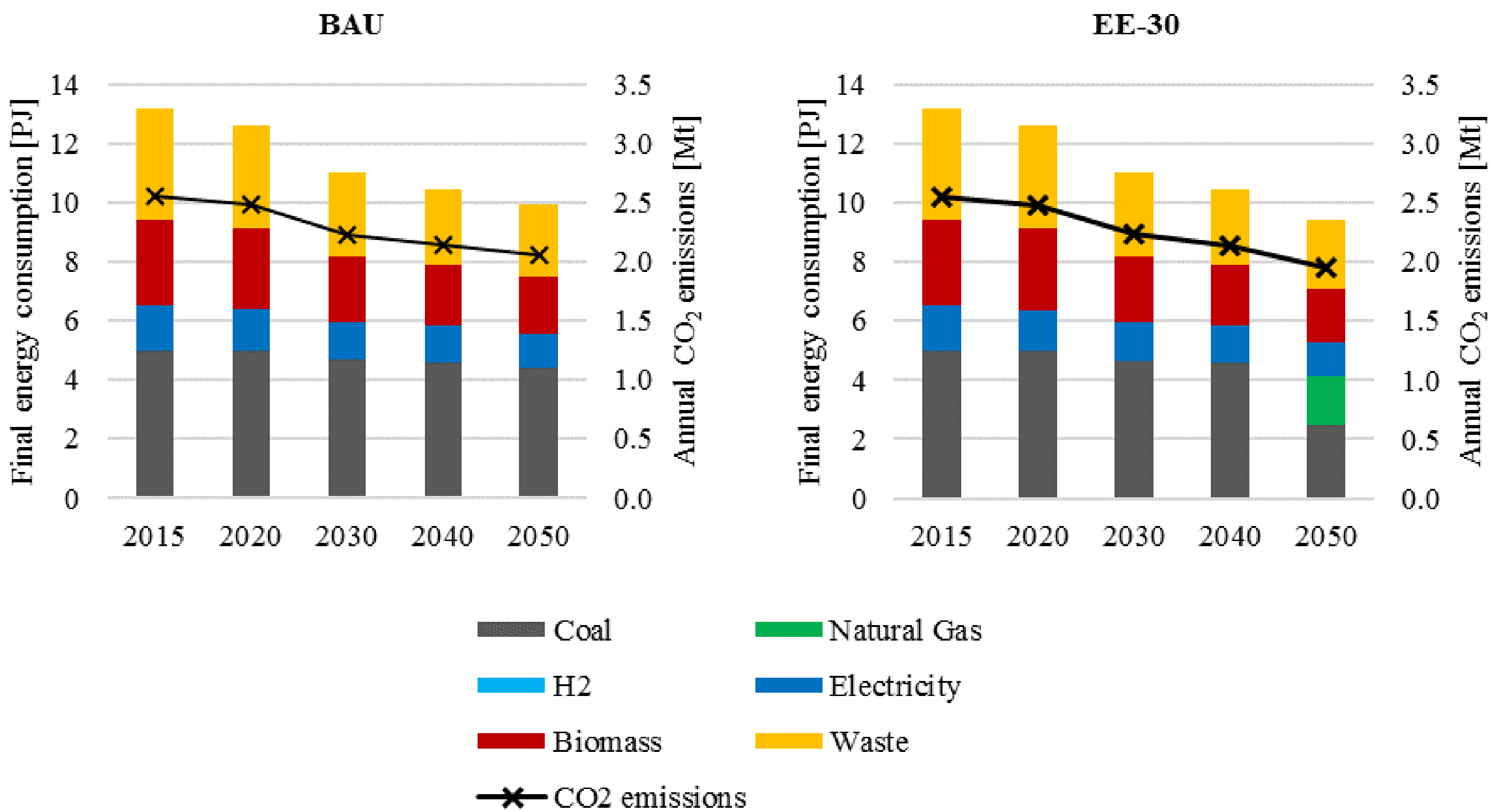
- **BAU** - Business as usual
  - Frozen policy and unchanged market environment
  - Demand for cement to remains stable
  - Average clinker content decreasing to 60% until 2050
  - CO_2 tax is held constant at a level of 20 EUR/t_{CO2}
- **CAP** - CO_2 Cap scenario group
  - Linear reduction of the CO_2 emissions by 2050 compared to 2015.
  - Four emissions reduction trajectories, which aim at an emissions reduction in 2050 of 40%, 60%, 80% and 100% compared to 2015
- **EE** - Energy efficiency scenario group
  - Specific energy reduction per ton of cement until 2050 from 2015 levels of 30% and 35%
- **TAX** – CO_2 tax scenario group
  - Different CO_2 tax policies from 20 EUR/tCO_2 (in 2015) to 70 to 100 CHF/tCO_2 in 2050

Results - BAU



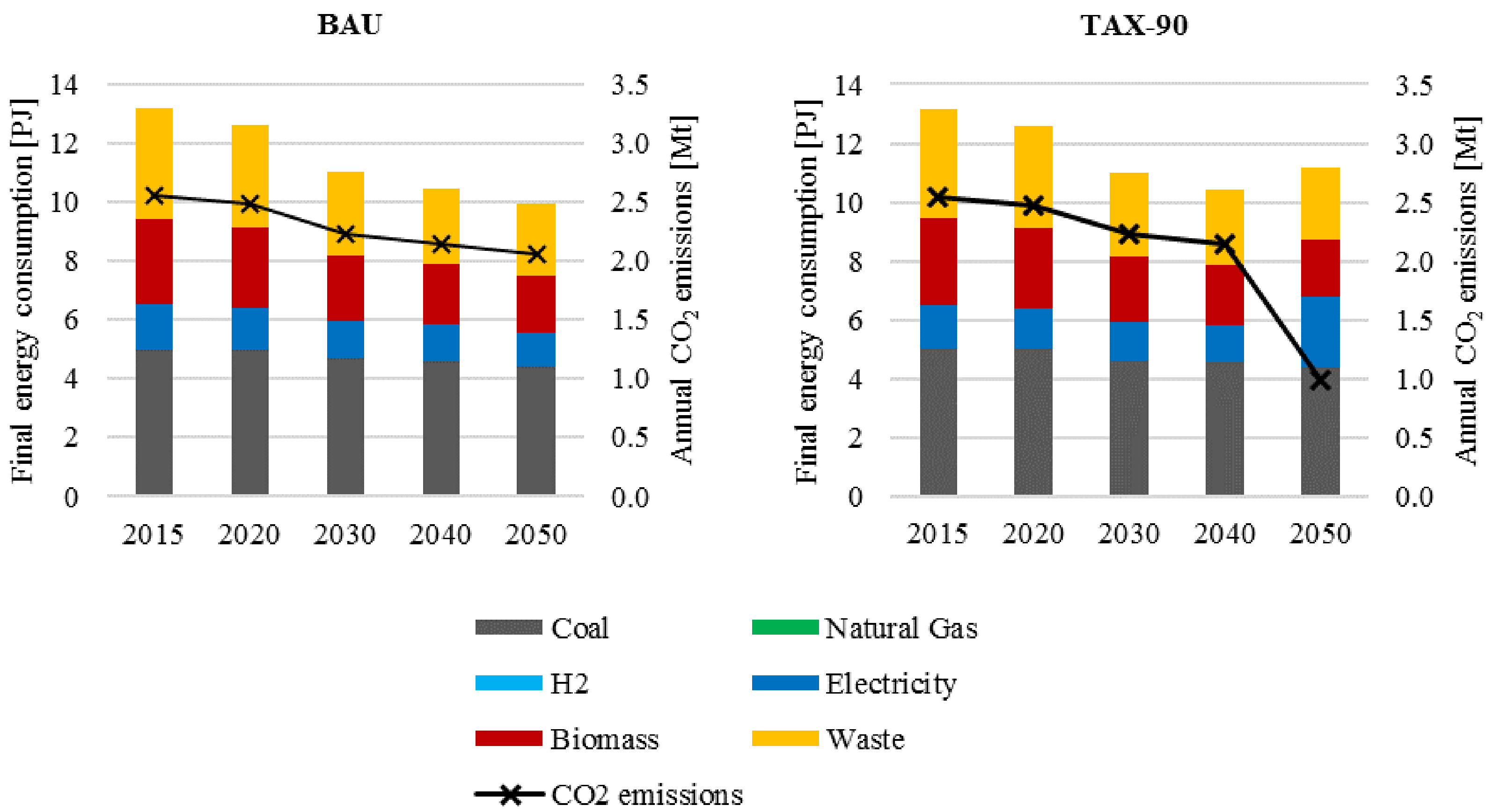
[1] Obrist et al., 2020, Decarbonization pathways of the Swiss cement industry towards net zero emissions (in preparation)

Results – EE-30



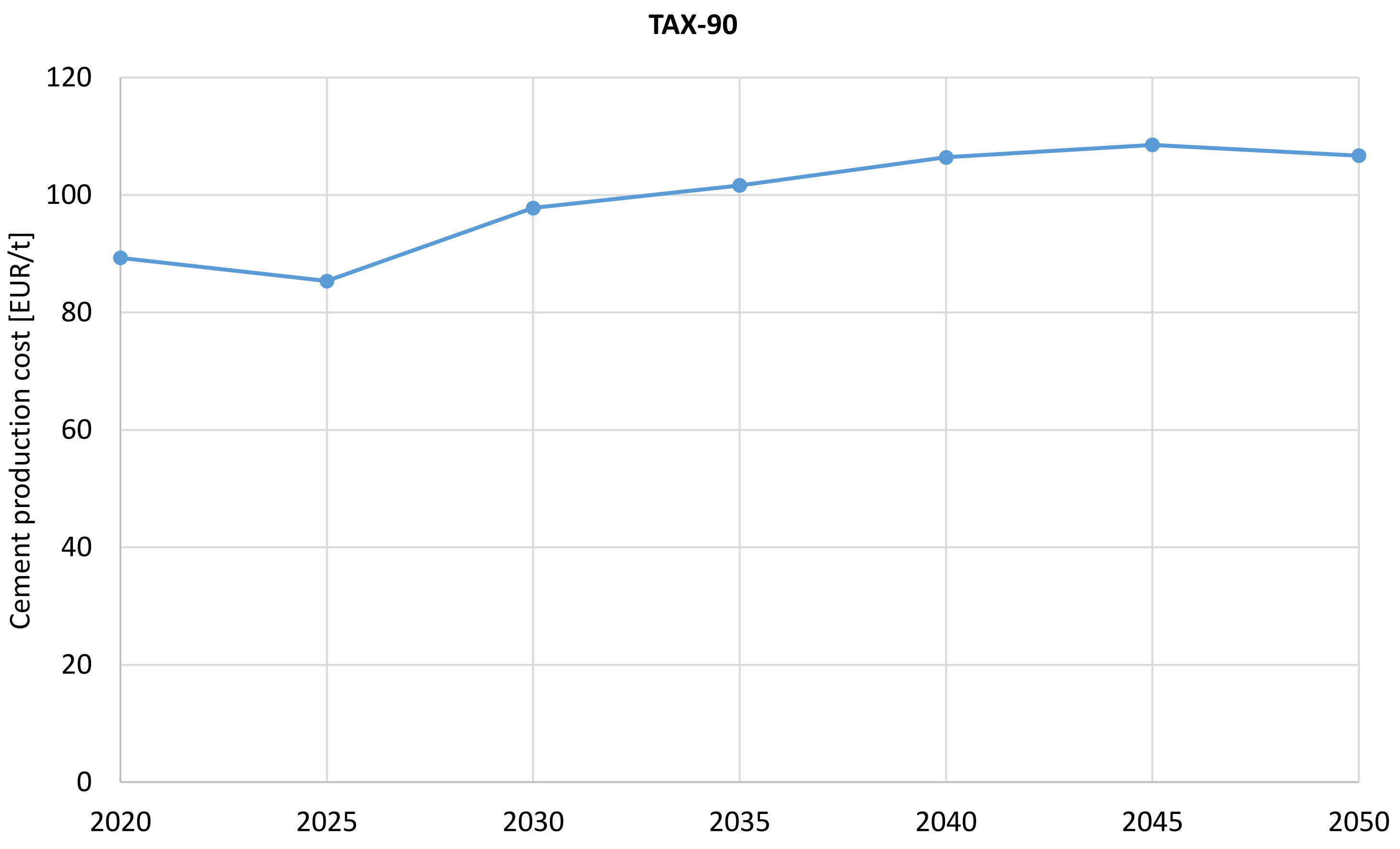
[1] Obrist et al., 2020, Decarbonization pathways of the Swiss cement industry towards net zero emissions (in preparation)

Results – TAX-90

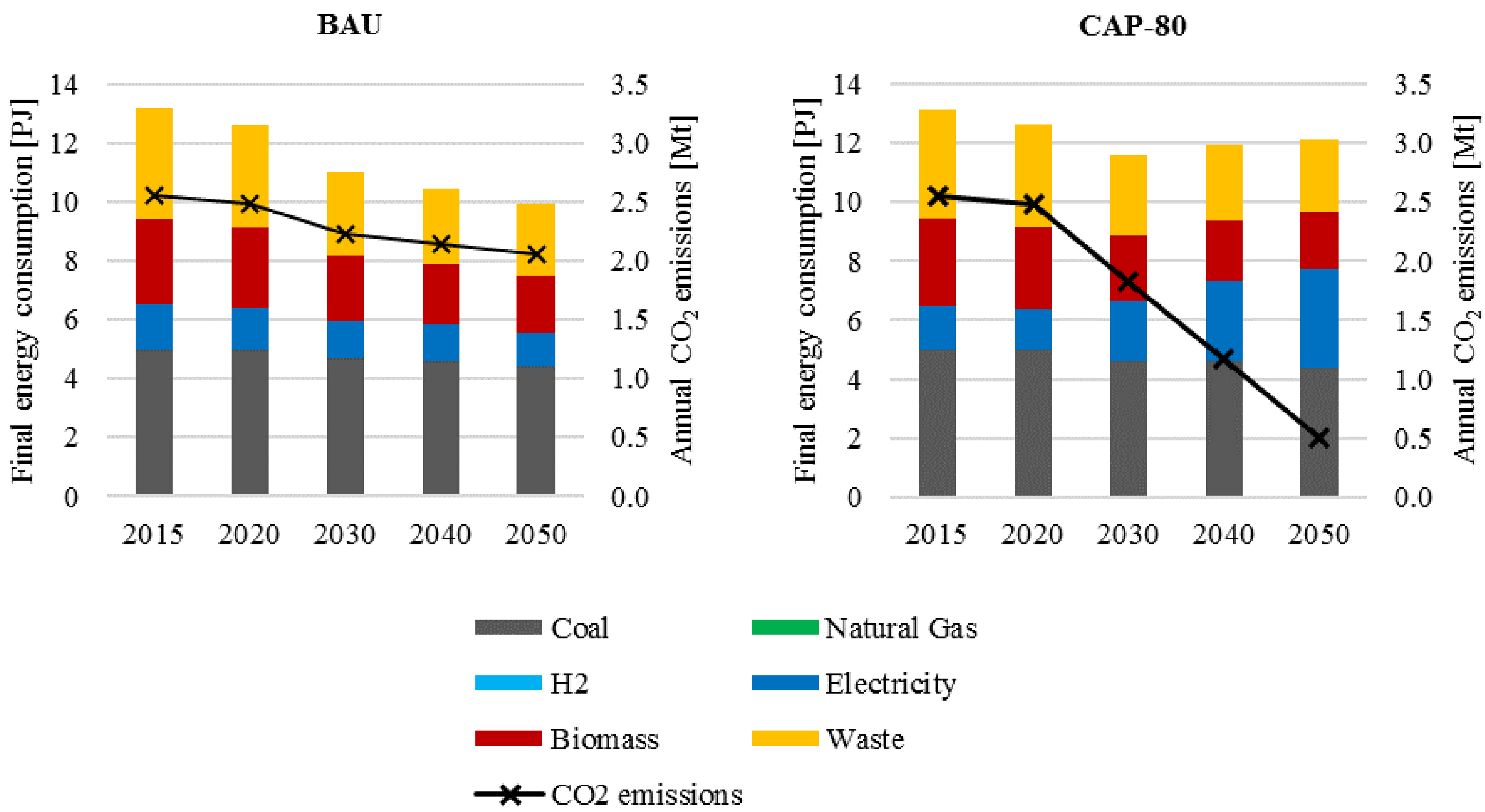


[1] Obrist et al., 2020, Decarbonization pathways of the Swiss cement industry towards net zero emissions (in preparation)

Results – TAX-90

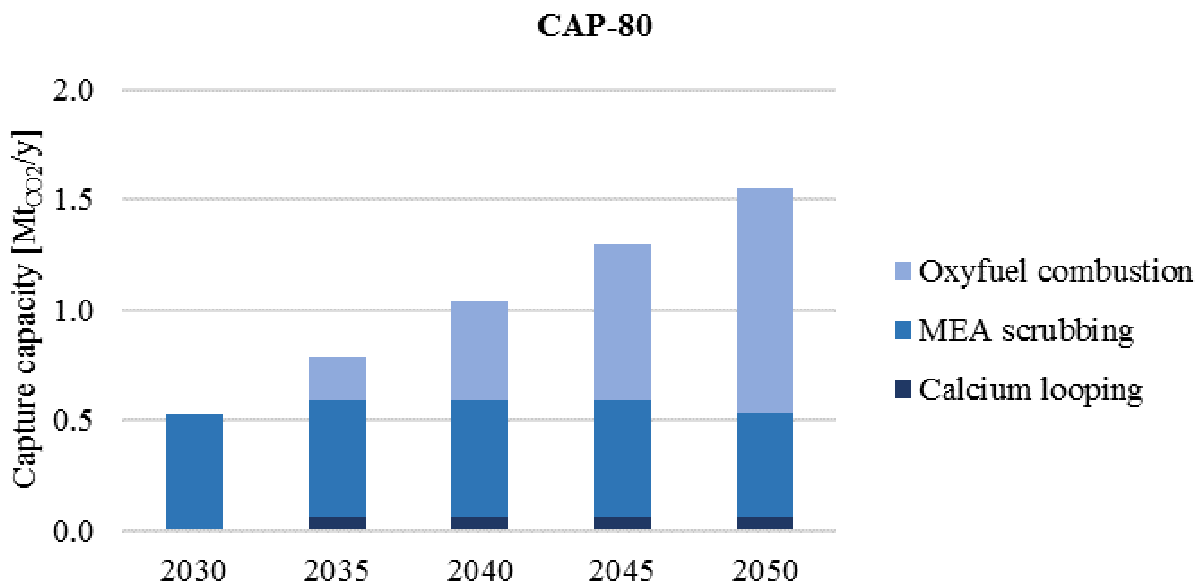


Results – CAP-80



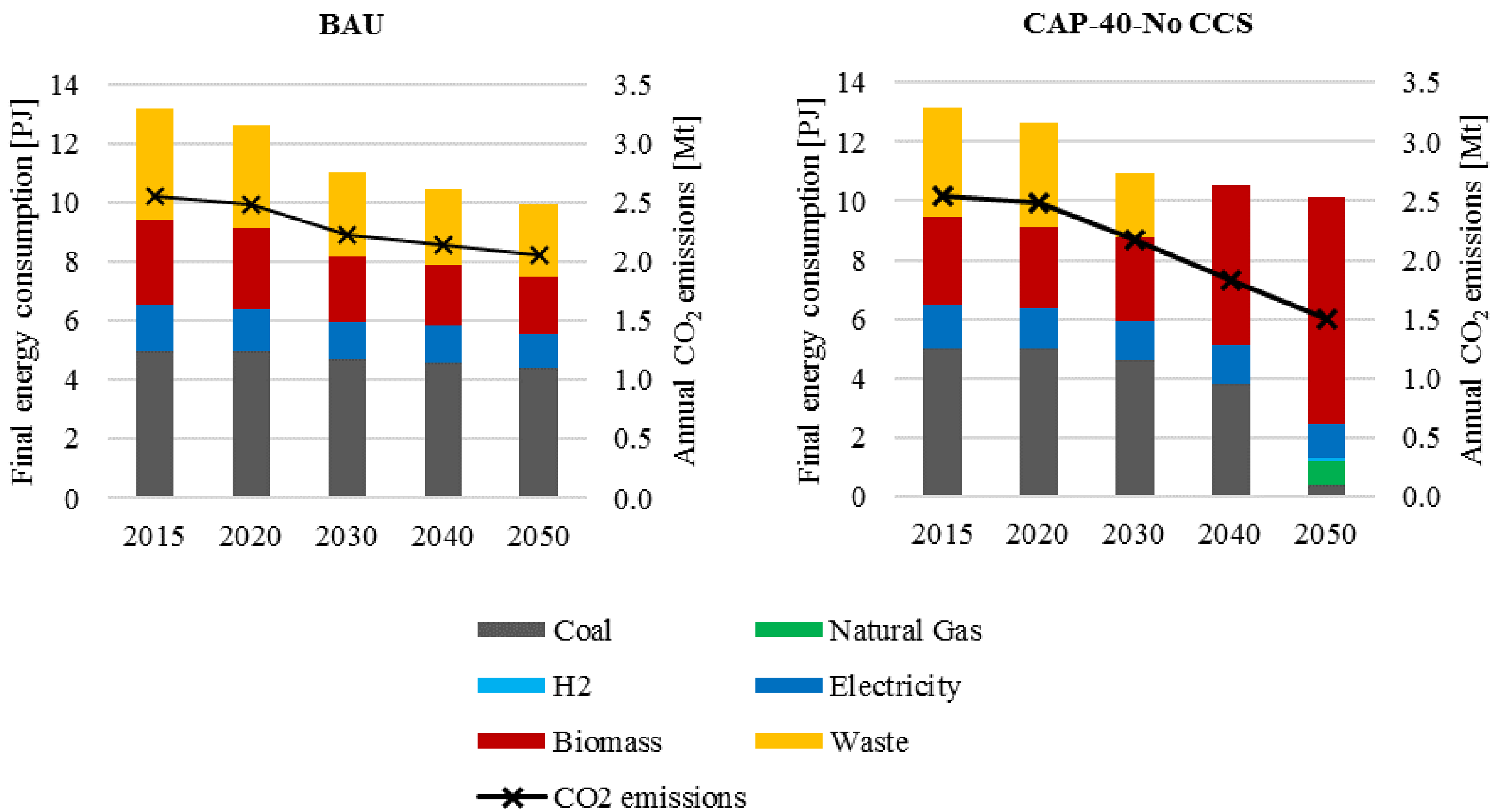
[1] Obrist et al., 2020, Decarbonization pathways of the Swiss cement industry towards net zero emissions (in preparation)

Comparison of CCS technologies



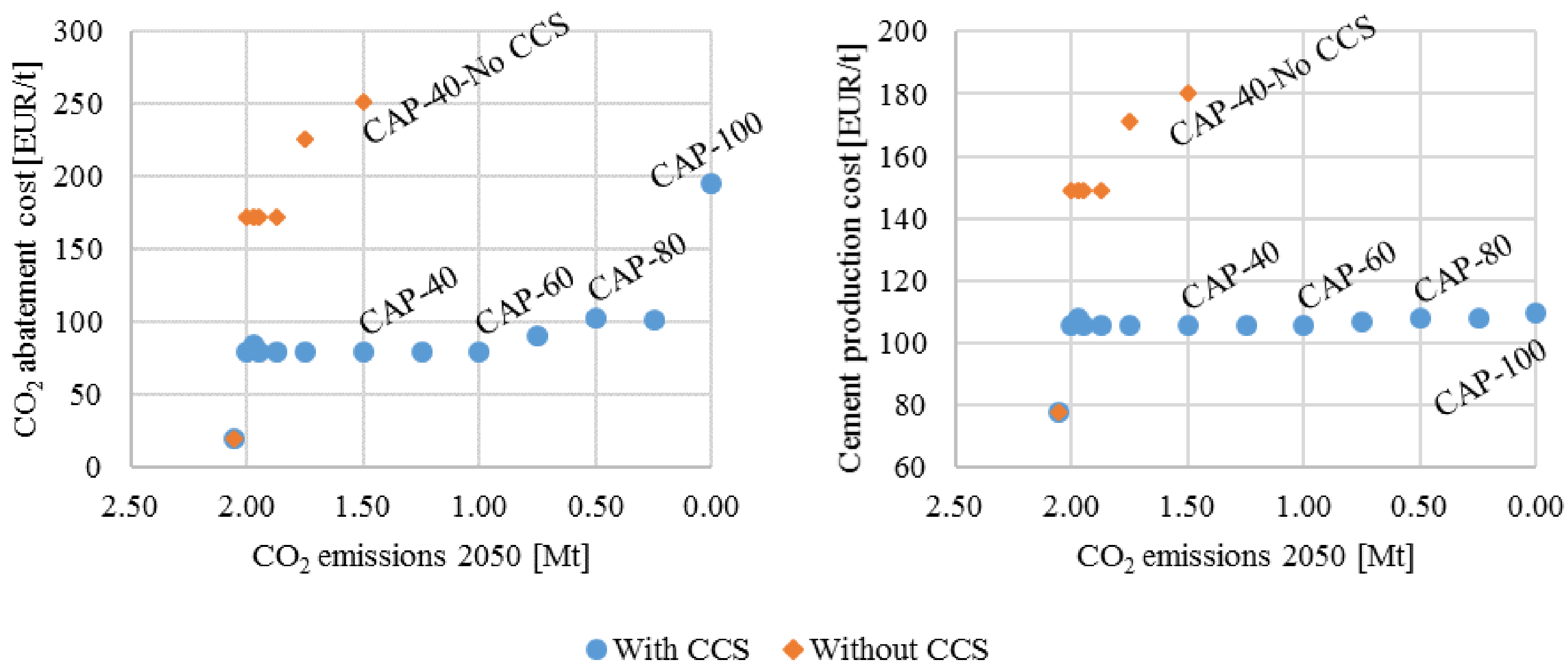
[1] Obrist et al., 2020, Decarbonization pathways of the Swiss cement industry towards net zero emissions (in preparation)

Results – CAP-40 without CCS



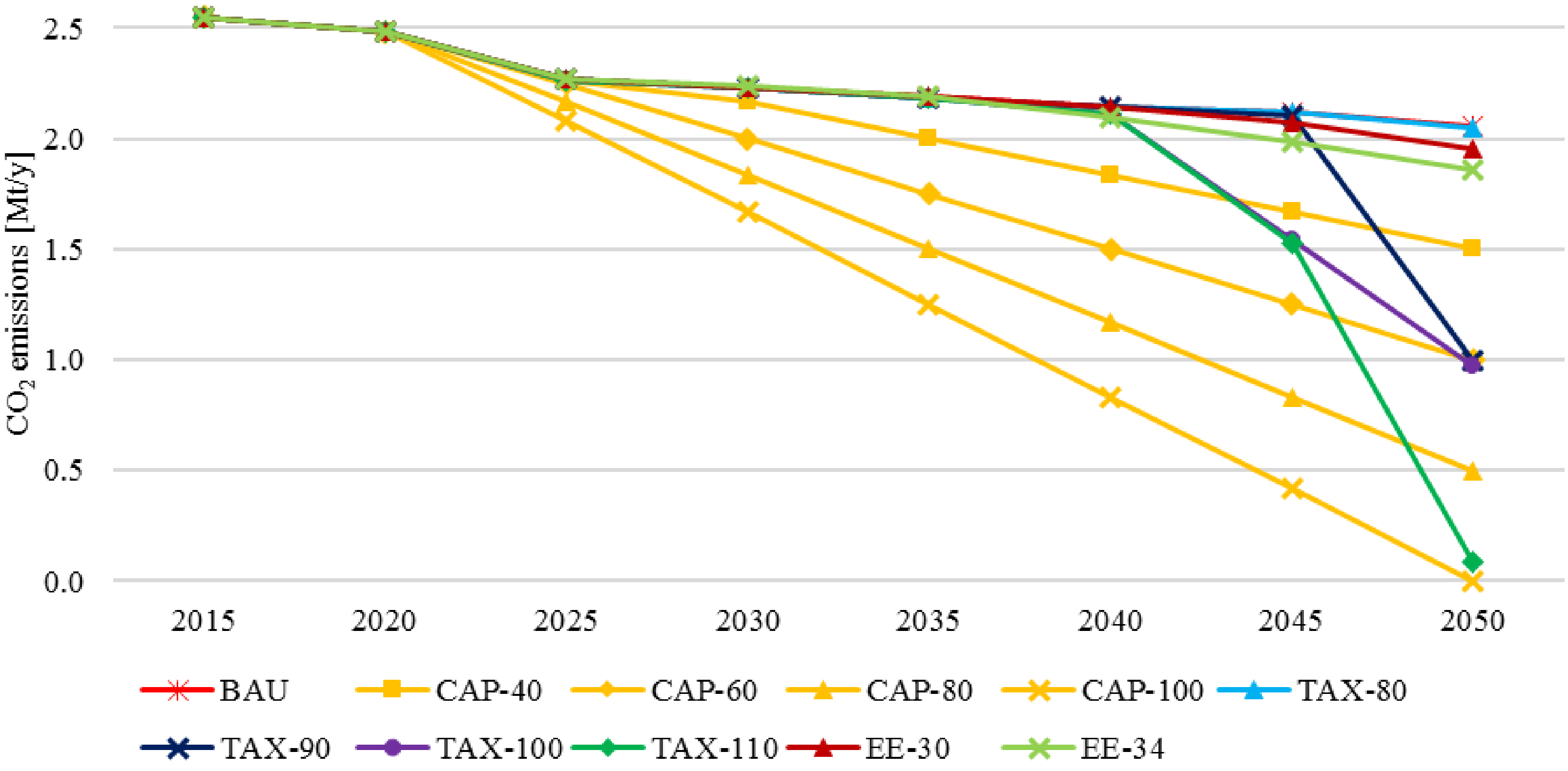
[1] Obrist et al., 2020, Decarbonization pathways of the Swiss cement industry towards net zero emissions (in preparation)

Results – CO_2 price in 2050



[1] Obrist et al., 2020, Decarbonization pathways of the Swiss cement industry towards net zero emissions (in preparation)

Results – CO_2 emissions



[1] Obrist et al., 2020, Decarbonization pathways of the Swiss cement industry towards net zero emissions (in preparation)

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Key messages

- Future cement production **improves its energy efficiency and decreases its CO_2 emissions even without policy action** mainly due to the decreasing clinker content in cement and deployment more efficient technologies (to replace existing technologies)
- Although a CO_2 tax up to 80 EUR/t_{CO2} results in a more expensive cement production, the total CO_2 emissions will not be reduced significantly
- **A CO_2 tax between 80 and 100 EUR/t_{CO2} makes it economically attractive to avoid CO_2 emissions with carbon capture technologies** with the benefit of avoiding both, energy and process-related CO_2 emissions
- Carbon capture will increase the specific electricity consumption of the cement industry
- From an economic point of view, **fuel switching is only a limited option to decrease the CO_2 emissions** of the cement industry because of the high share of process related emissions and limitations with regards to switching of burner technologies in the complex process setting of a cement plant

Key messages

- No **significant reduction of the CO_2 emissions** is possible in the cement sector **without carbon capture** and the corresponding infrastructure to transport and sequestrate CO_2

My thanks go to my supervisors

- Dr. Tom Kober
- Dr. Kannan Ramachandran
- Prof. Dr. Thomas Schmidt

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