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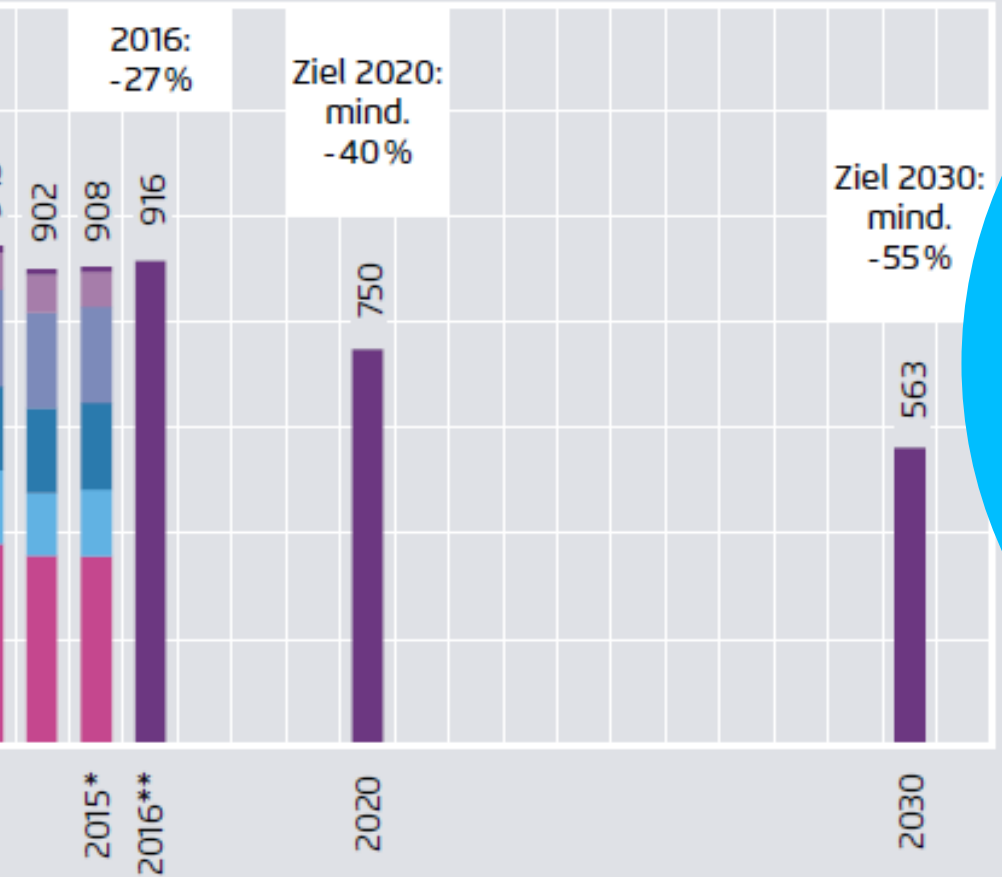


Analysis of Instruments for Decarbonisation and their Impact on the German Electricity Sector

Annika Münkel

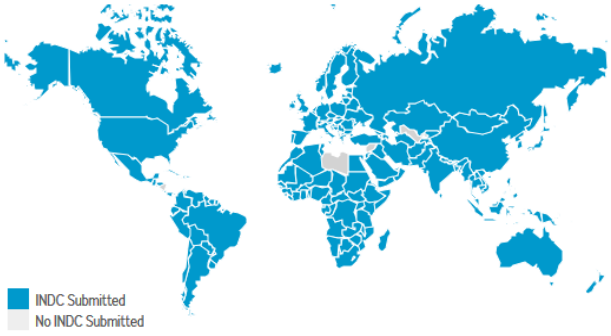
Source: [12] Graichen et al. (2017)

Content

- Motivation
- Methodology: E2M2 model description and configuration
- Preliminary results and hypotheses
- Validation of results and next steps

Motivation

Changing Targets in Climate Policy



164 INDCs have been submitted under the Paris Agreement, representing 191 countries and 98.9% of global GHG emissions. [1]

→ Implementation of new climate policies and instruments required all over the world!

Most countries had policies and instruments in place before, with

- different targets,
- different working mechanisms,
- on different levels (regional to international),
- focussing on different sectors.

GHG: Greenhouse Gas; INDC: Intended Nationally Determined Contributions

Motivation

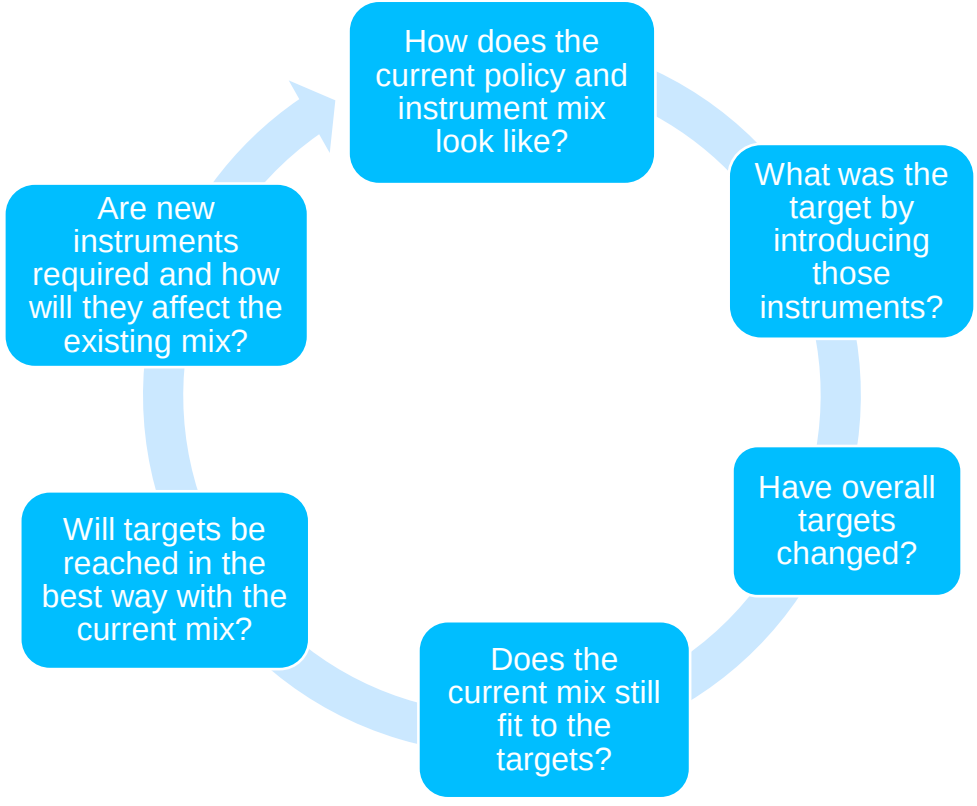
Climate Policy Mix

Literature review:

1. Implementation of more than one instrument useful [9]

2. BUT: interactions need to be taken into account when analysing policy instruments

3. Regular monitoring and evaluation of existing policy and instrument mixes required [3] [9]



Motivation

Climate Policy Mix in Germany

GHG targets relative to 1990 emissions

2016: -27%, power generation -16%
2020: -40%
2030: -40% (NDC), nationally more ambitious
2050: -80 to 95%, towards GHG neutrality

Source: [12],[10],[6],[13]

3 instruments with major effect on the power sector will be analysed:

	Overall Target	Instrument in Germany	Working mechanism
Renewable Energy Target	Supporting the development of technologies for power generation from RE	EEG (Erneuerbare-Energien-Gesetz)	Feed-in tariffs or quotas on generation from RE; works as subsidy for selected technologies
Cap and Trade	Limiting overall emissions	EU-ETS (European Emission Trading Scheme)	Sum of emissions covered is limited by a cap, emission rights can be traded between participants
Coal phase-out	Accelerating emission reduction in the power sector	in discussion	Coal and lignite power plants will legally be forced to shut down according to a preset phase-out plan

RE: Renewable Energy

Motivation

Interim Research Question

What effects do these 3 instruments have on the German power sector, especially regarding:

- Total costs
- Emission reduction (cumulated and share until 2050)
- Power and emission prices
- Distributional effects through costs and profits
- Investments: type and rentability
- Security of supply

Related Project: Kopernikus ENavi (https://www.kopernikus-projekte.de/projekte/systemintegration)

RES: Renewable Energy Sources; Enavi: Energiewende Navigationssystem

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Methodology

Modelling Policy Instruments

Evaluation criteria for instruments:

- Total costs
- Emission reduction (cumulated and share until 2050)
- Power and emission prices
- Distributional effects through costs and profits
- Investments: type and rentability
- Security of supply

First step: electricity market model E2M2

Literature: one modelling approach can only cover parts of a policy instrument analysis [4]

Methodology

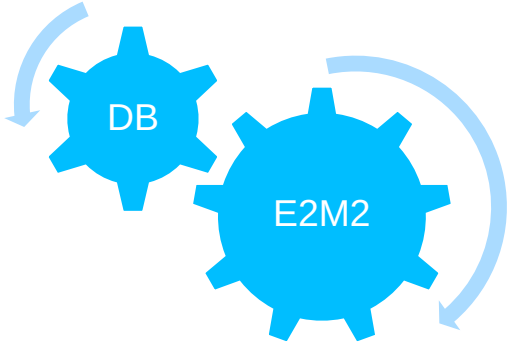
European Electricity Market Model – E2M2

- Bottom-up fundamental electricity market model (objective: minimizing system costs)
- Linear (LP) or mixed-integer (MIP) optimization problem
- Endogenous optimization of plant dispatch and investment

$$Min. \quad c_{ges} = \sum_{t,u,s} (c_{fix} + c_{var} + c_{inv})$$

Input

- Primary energy prices
- CO_2-cap or prices
- Power and heat demand profiles
- RE generation profiles
- Installed plant capacities
- Installed storage capacities
- Investment options including costs (plants, transmisison grid, storage, DSI, Power-to-X)
- Import and export capacities



Output

- Cost optimal dispatch (plants, transmission grid, storgae, DSI, Power-to-X)
- Cost optimal investment
- Wholesale prices
- Import and export flows
- Fuel consumption
- CO_2 emissions

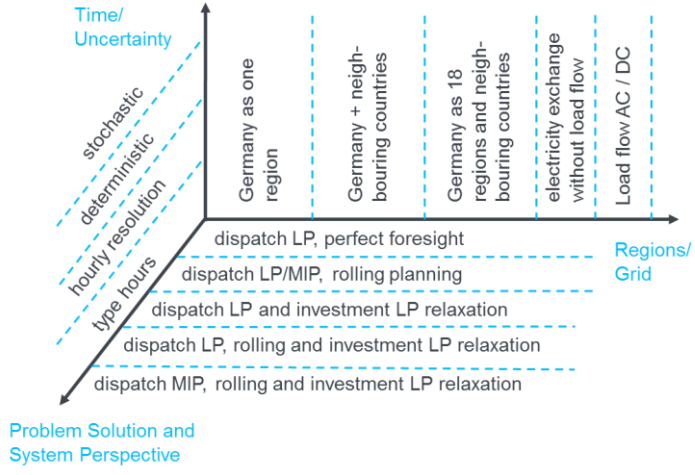
RE – renewable energies; DSI – Demand Side Integration; DB – database

Methodology

E2M2 – Key Assumptions

Basic model set-up with high resolution in time and power plants, to focus on basic effects:

Period + resolution	2015 to 2050, 2 hours time resolution
Regional	Germany as one region without import and export
Power plants	breakdown to plant level
Investment	• 4 conventional power plants, 3 types of storage, 2 photovoltaik, wind onshore and offshore • cost from WEO 2016, constant • no upper bounds
Power demand	constant until 2050
Technology	nuclear phase-out in all scenarios no CCS
Primary energy prices	from WEO 2016
RE shedding	no
Transmission grid	not considered



WEO – World Energy Outlook; CCS – Carbon Capture and Storage

Methodology

Scenarios

1. RES – Renewable Energy Share →
2. CAT – Cap and Trade
3. CPO – Coal Phase-Out
4. MIX – combination of all 3 measures

Target: 80% of power generation from renewable sources in 2050 [5]

Modelling:

- Share of demand covered by RE plants fixed for every year until 2050
- Installed capacities for PV, biomass and wind offshore fixed, endogenous investment in wind onshore to comply with RE share

Methodology

Scenarios

1. RES – Renewable Energy Share
2. CAT – Cap and Trade
3. CPO – Coal Phase-Out
4. MIX – combination of all 3 measures

<u>Target:</u> 95% emission reduction for the German electricity sector in 2050 [6]

<u>Modelling:</u>

- fix upper bound on yearly emissions
- all investments possible

Methodology

Scenarios

1. RES – Renewable Energy Share
2. CAT – Cap and Trade
3. CPO – Coal Phase-Out
4. MIX – combination of all 3 measures

<u>Target:</u> No power generation from coal or lignite plants after 2035 acc. WWF ambitious scenario [7]

<u>Modelling:</u>

- fix shut-down date for all coal and lignite plants
- no new investments in coal or lignite plants

Methodology

Scenarios

1. RES – Renewable Energy Share

2. CAT – Cap and Trade

3. CPO – Coal Phase-Out

4. MIX – combination of all 3 measures → RES + CAT + CPO

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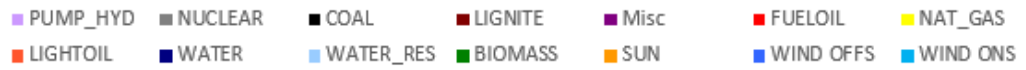
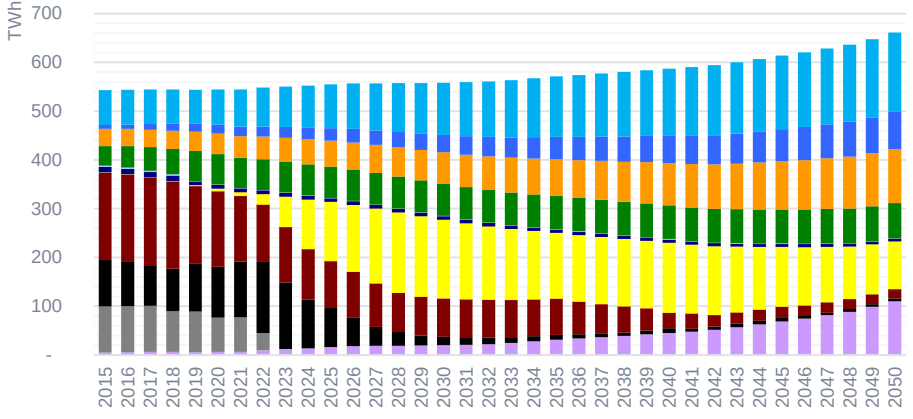
Preliminary Results

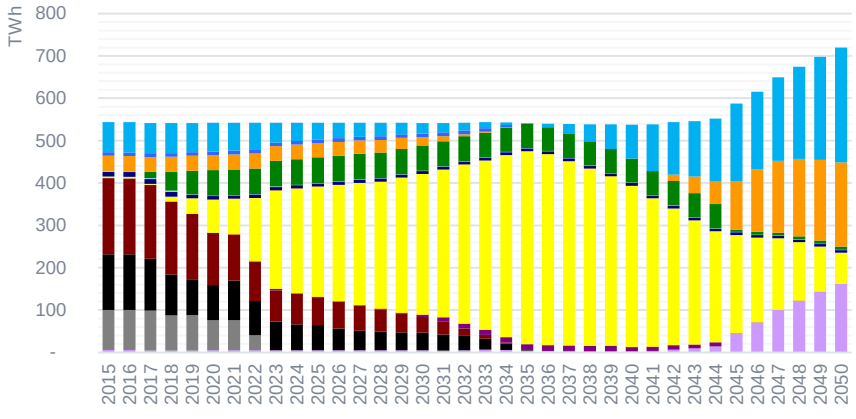
Electricity Production



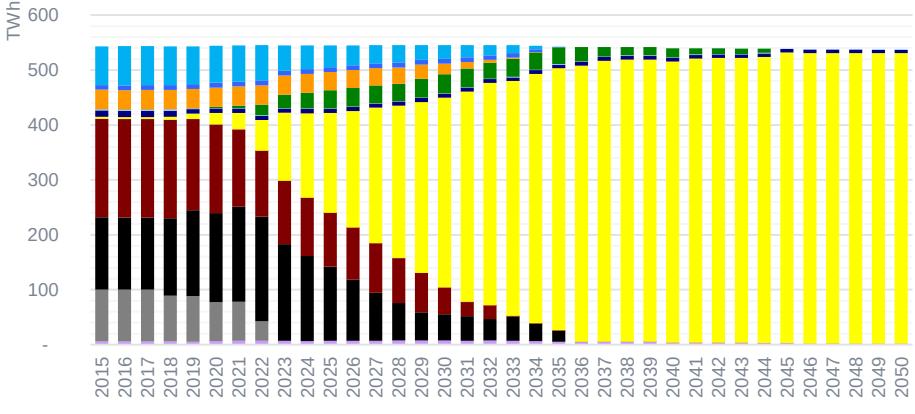
RES



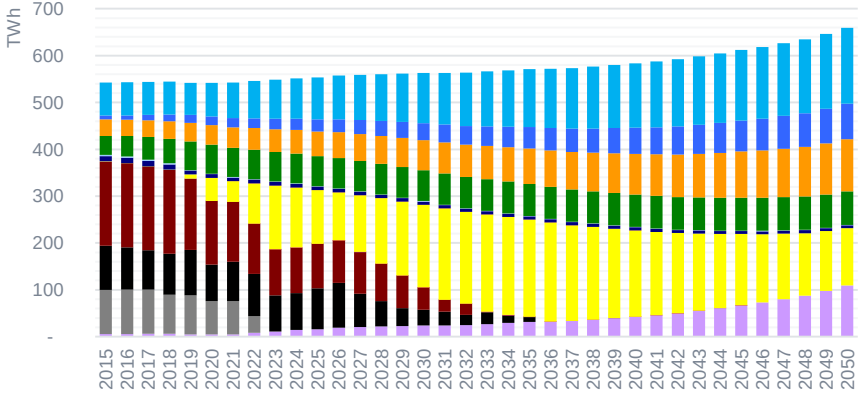
CAT



CPO

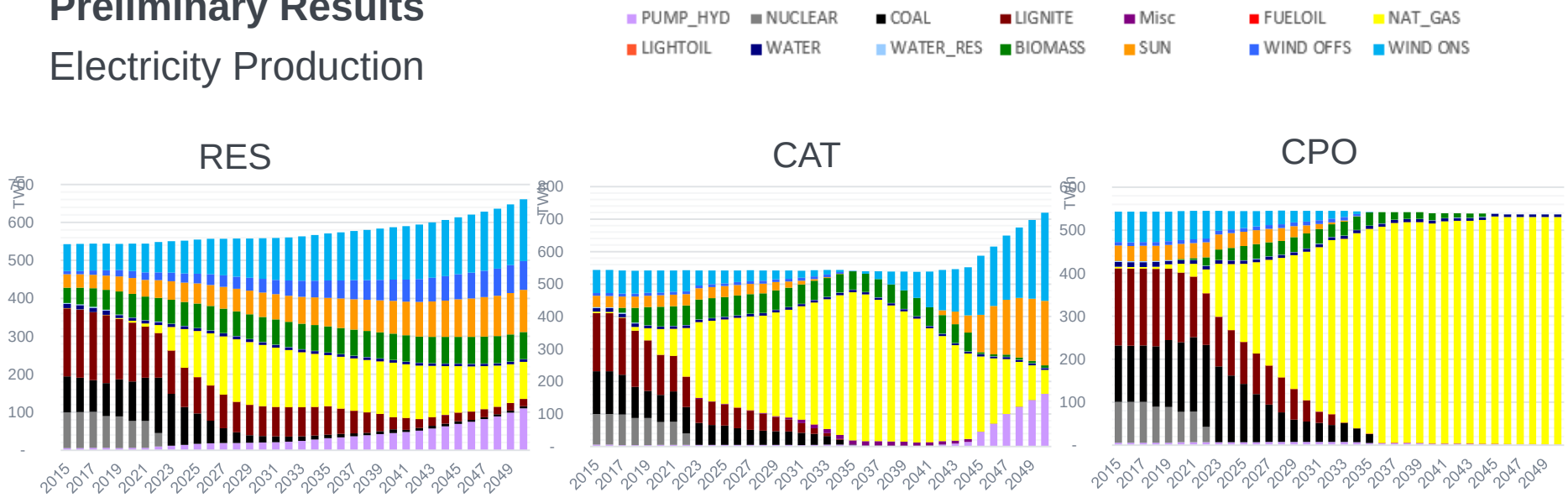


MIX



Preliminary Results

Electricity Production

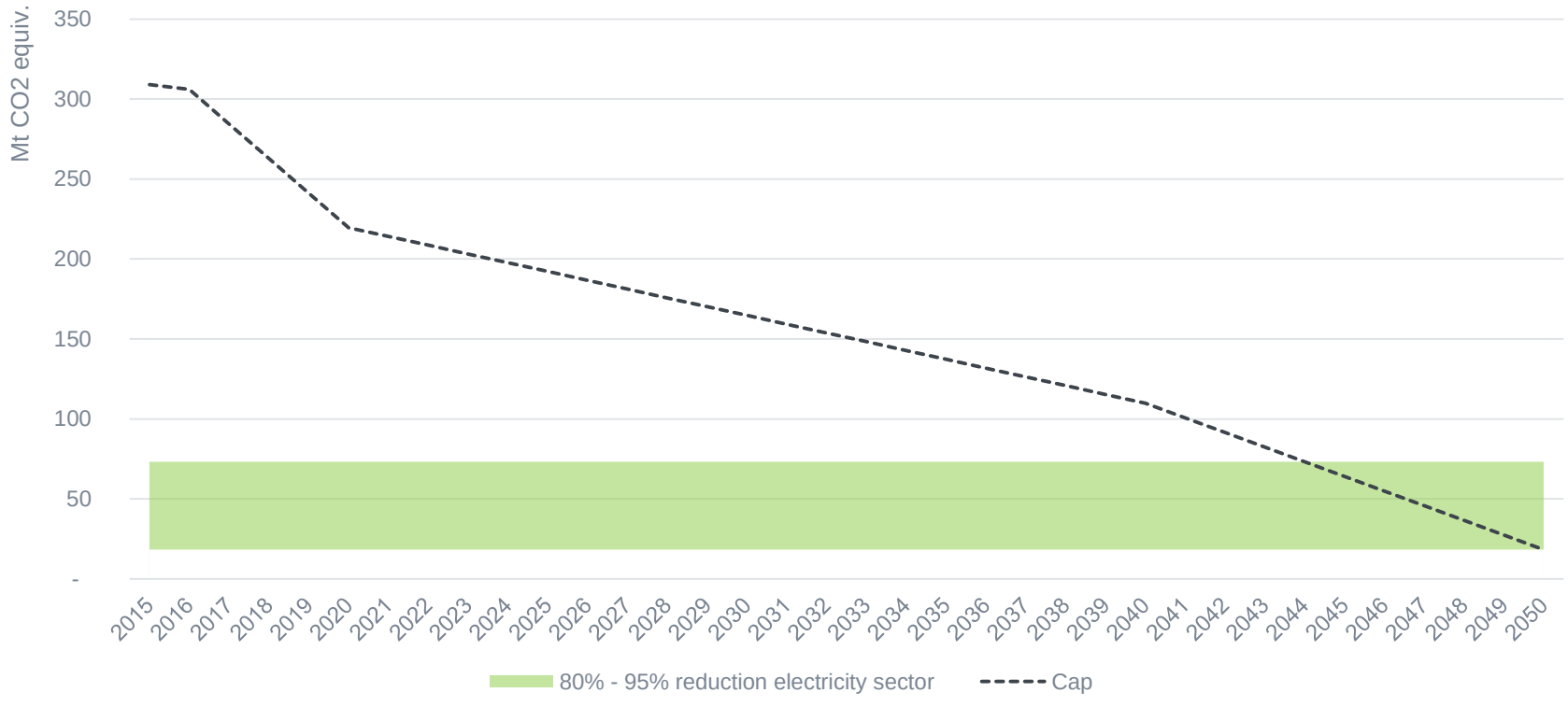


→ CAT: If they are not supported, renewables „die on the way“ until cap is tight enough
→ Current cap results in a „natural“ coal phase-out for lignite in 2041 and coal in 2045
→ Power mix 2050 similar, except CPO
→ Main differences: phase-out of coal and amount of invested gas capacities

Remark: Model generates cost optimal solution, but only on a yearly basis

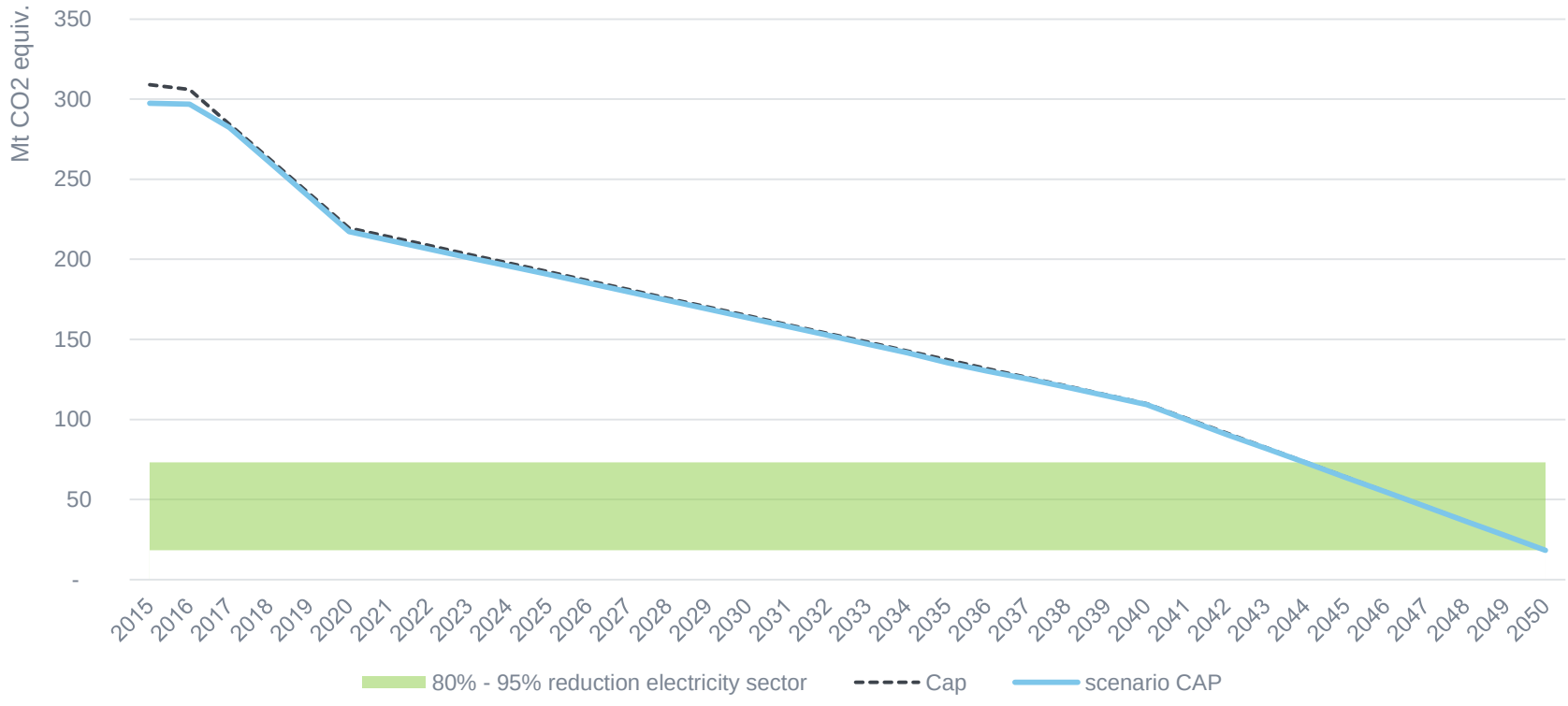
Preliminary Results

Comparison: Yearly Emissions



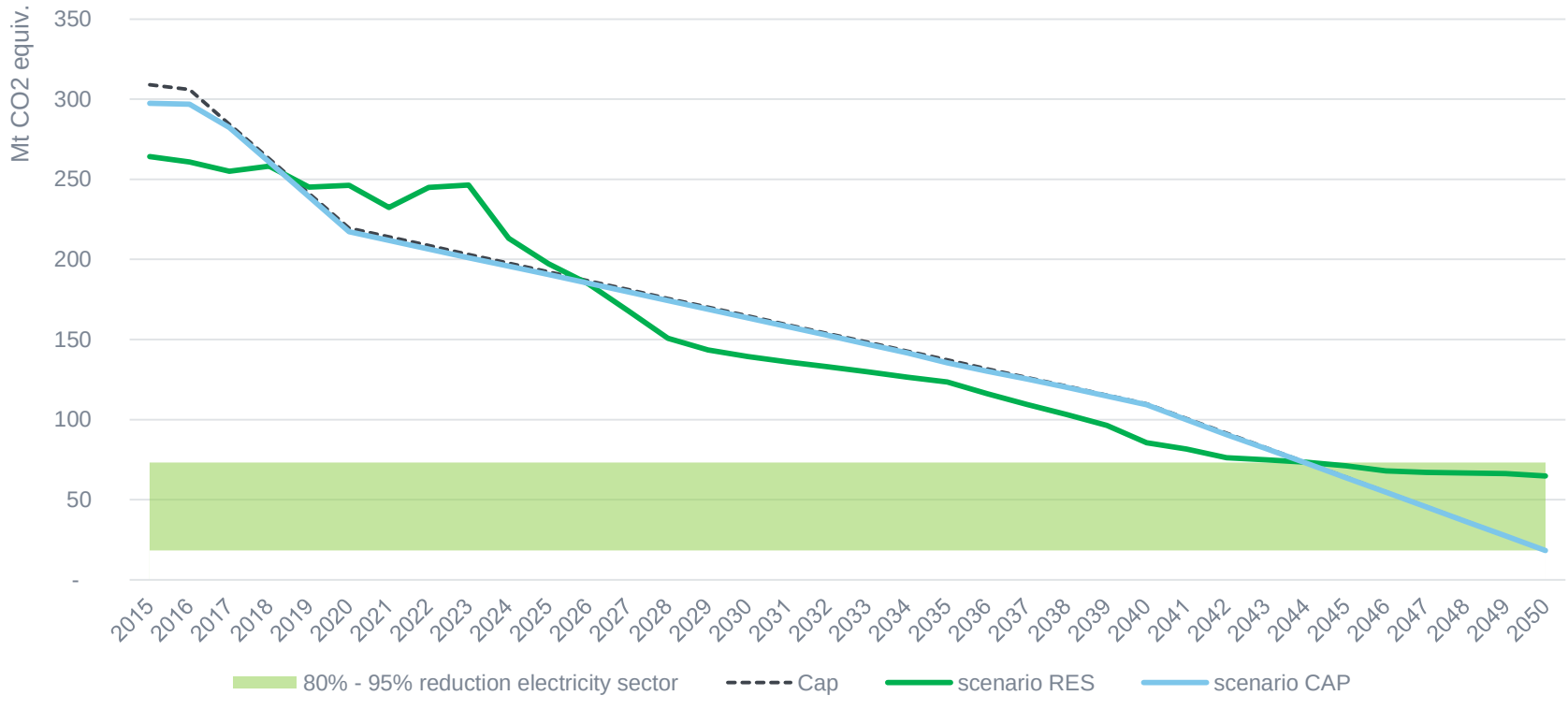
Preliminary Results

Comparison: Yearly Emissions



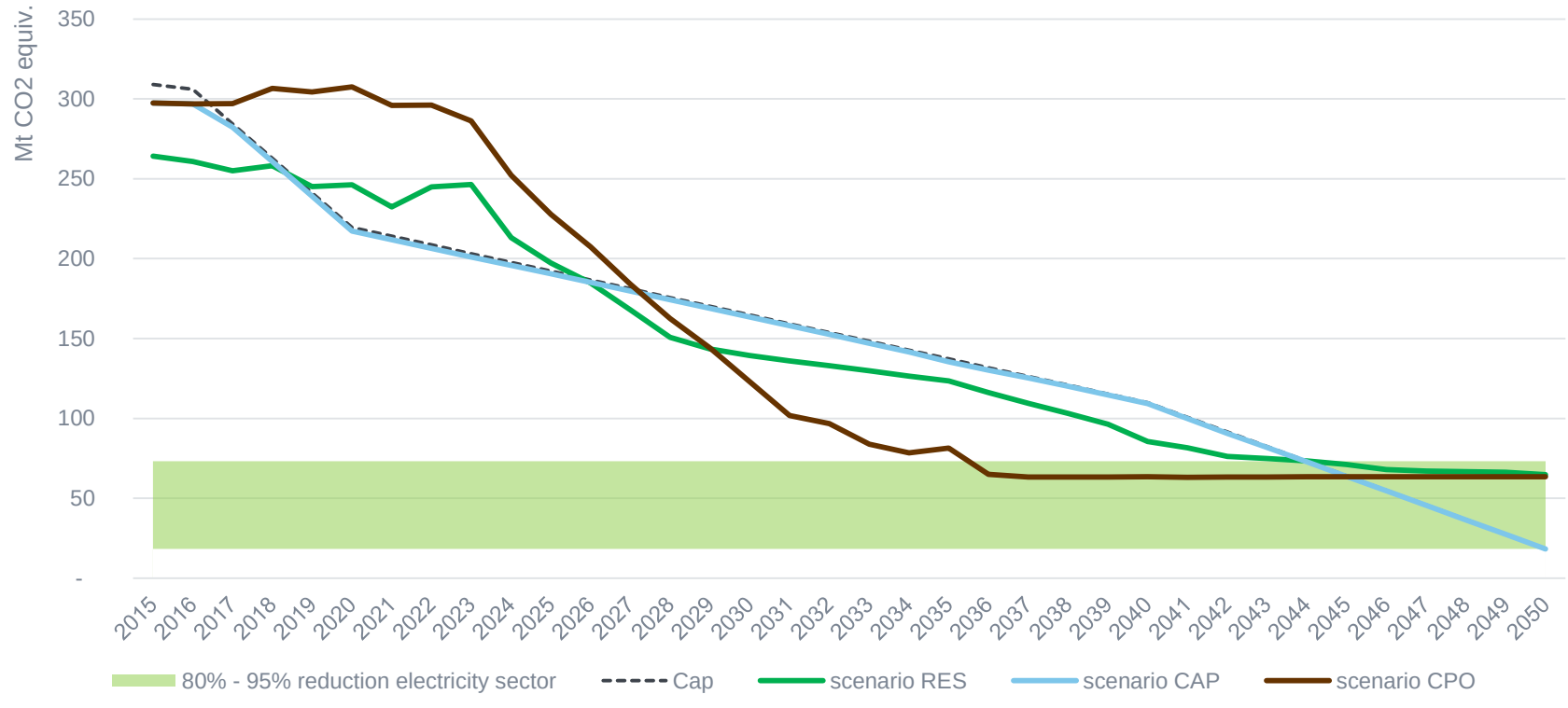
Preliminary Results

Comparison: Yearly Emissions



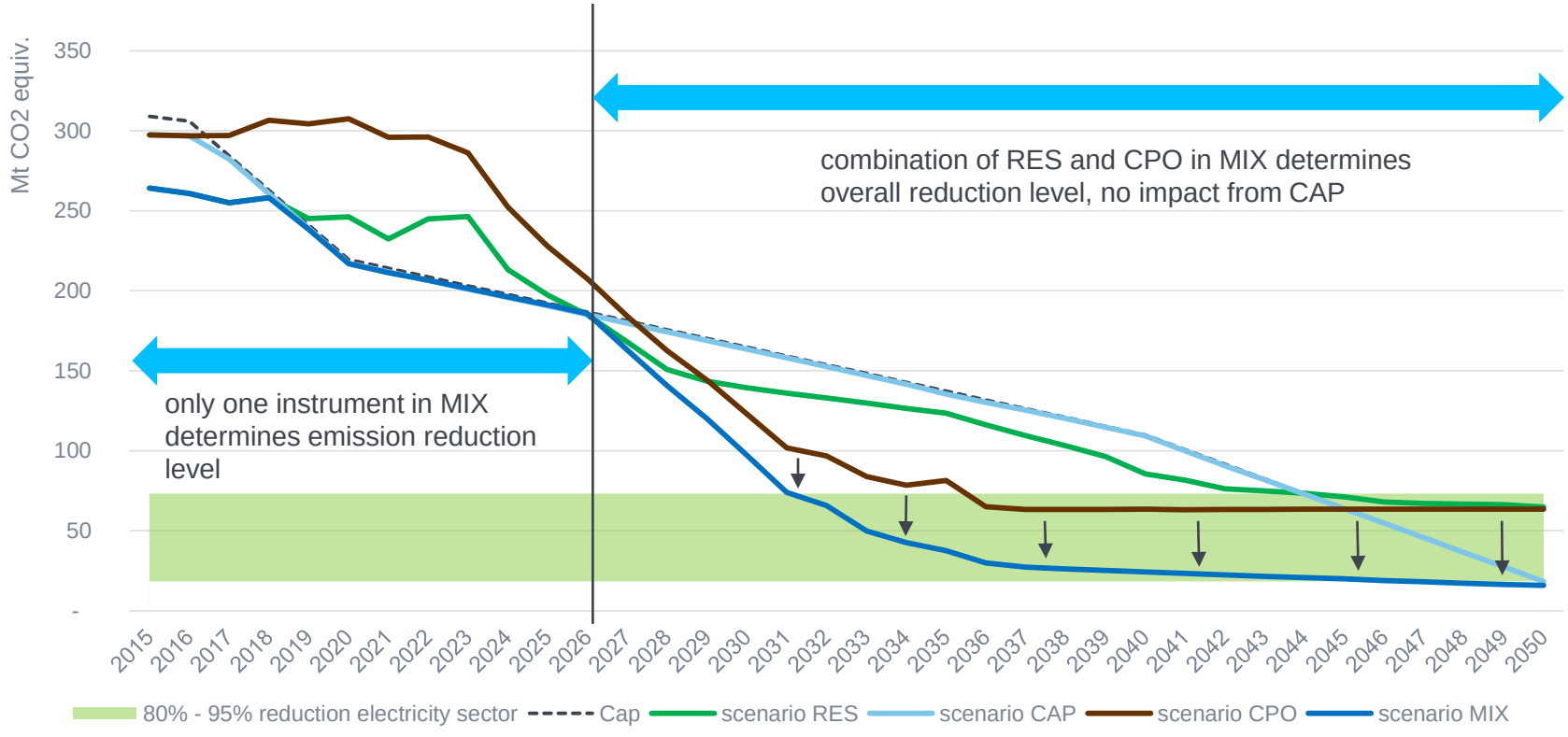
Preliminary Results

Comparison: Yearly Emissions



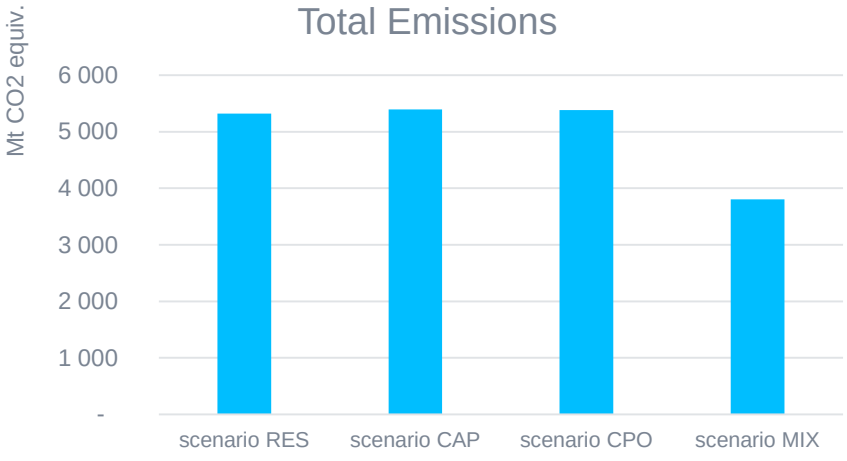
Preliminary Results

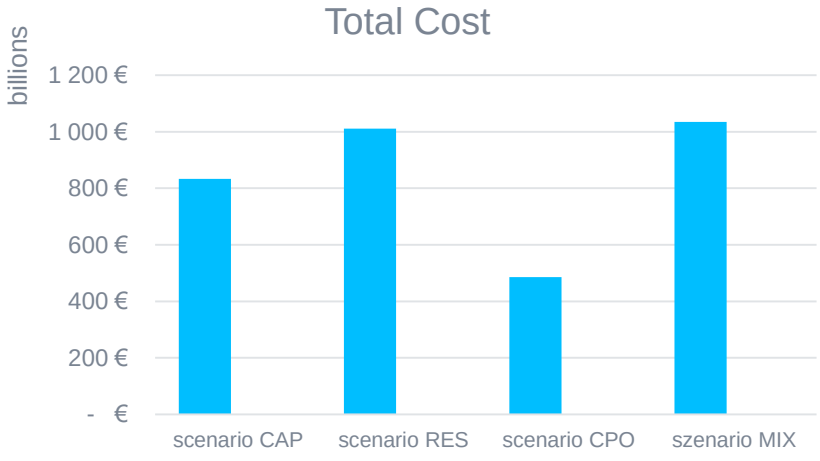
Comparison: Yearly Emissions



Preliminary Results

Comparison: Total Costs and Emissions until 2050





→ Cumulated emissions for isolated scenarios similar
→ 4 Gt only reached in MIX scenario (with constant electricity demand!)

→ MIX: lowest cumulated emissions, but highest costs

Carbon budget German electricity sector acc.WWF [8]

	CO_2-Budget ab 2015	
	national	Stromsektor
	Gt CO_2	
1,5°C bei 66 % der Modellläufe	2,7	1,1
1,5°C bei 50 % der Modellläufe	4,4	1,7
1,5°C bei 33 % der Modellläufe	7,7	3,1
2°C mit 66 % Wahrscheinlichkeit	9,9	4,0
2°C mit 50 % Wahrscheinlichkeit	11,2	4,5
2°C mit 33 % Wahrscheinlichkeit	14,4	5,8

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Outlook

Validation of Results and Next Steps

Run several MIX scenarios to find total cost optimal solution

Validation of results through impact of:

- neighbouring countries
- Shedding, renewable integration costs
- back-up capacity
- technology cost decrease
- heat
- Power-to-X (esp. power-to-gas-to-power)
- CCS
- sector linking effects, etc.

Adress other evaluation criteria:

- Total costs — assessed with E2M2
- Emission reduction (cumulated and share until 2050) — assessed with E2M2
- Power and emission prices — to be done with E2M2
- Distributional effects through costs and profits — to be defined
- Investments: type and rentability
- Security of supply

DSM: Demand Side Management, CCS: Carbon Capture and Storage

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[2] Paris Agreement, Article 2, 1.(a), United Nations
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Thank you!

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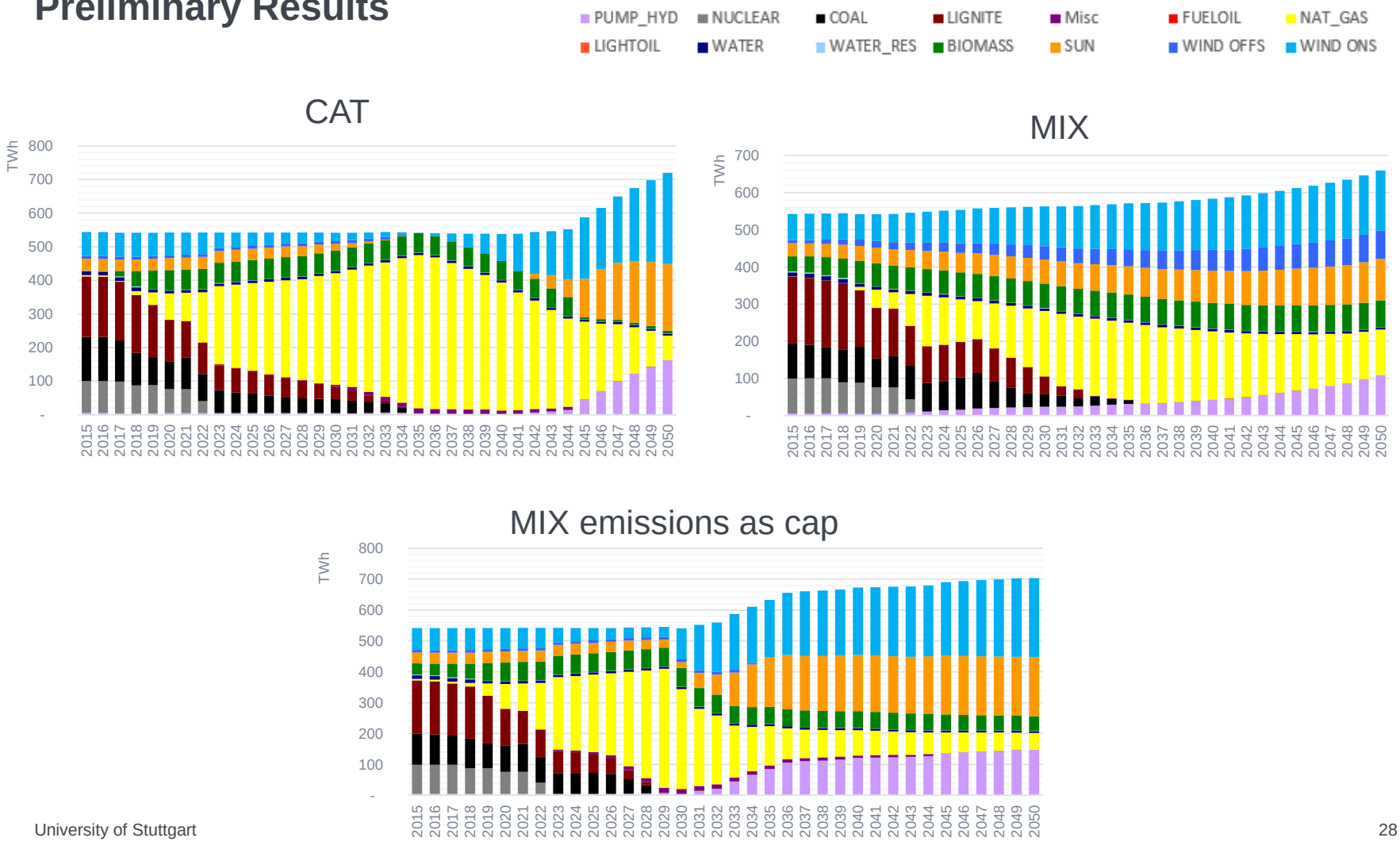
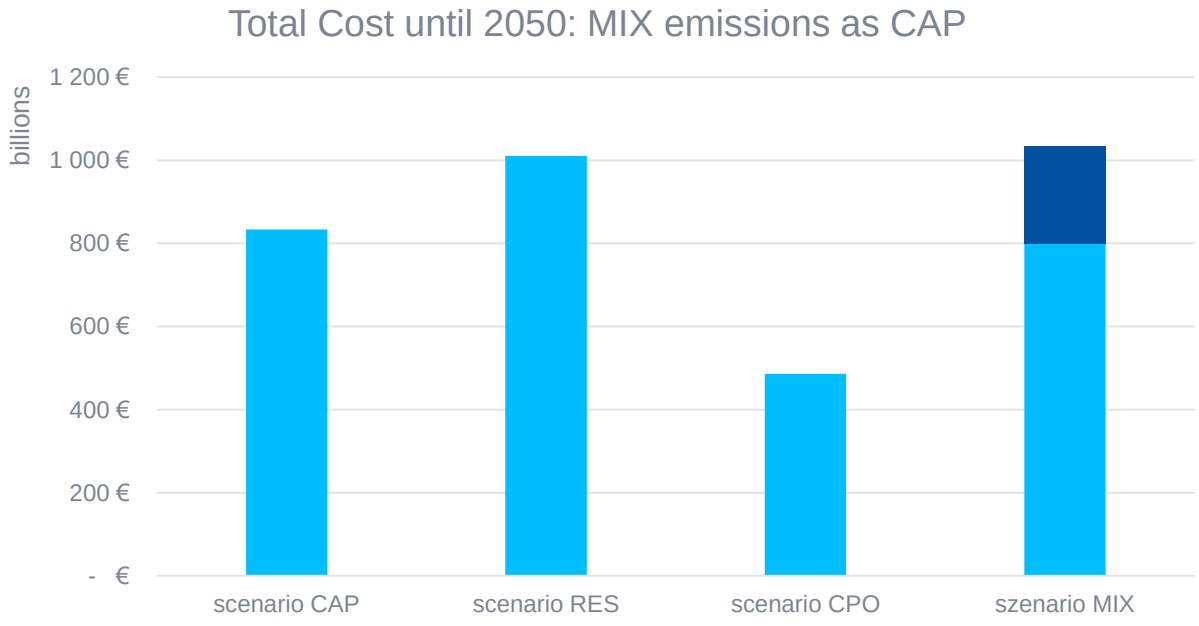
Preliminary Results



Preliminary Results

Comparison: Total Costs



Cost effect needs to be validated!

Back-up: Time resolution