

Power system and carbon capture under climate policy: a water impact analysis with TIAM-FR

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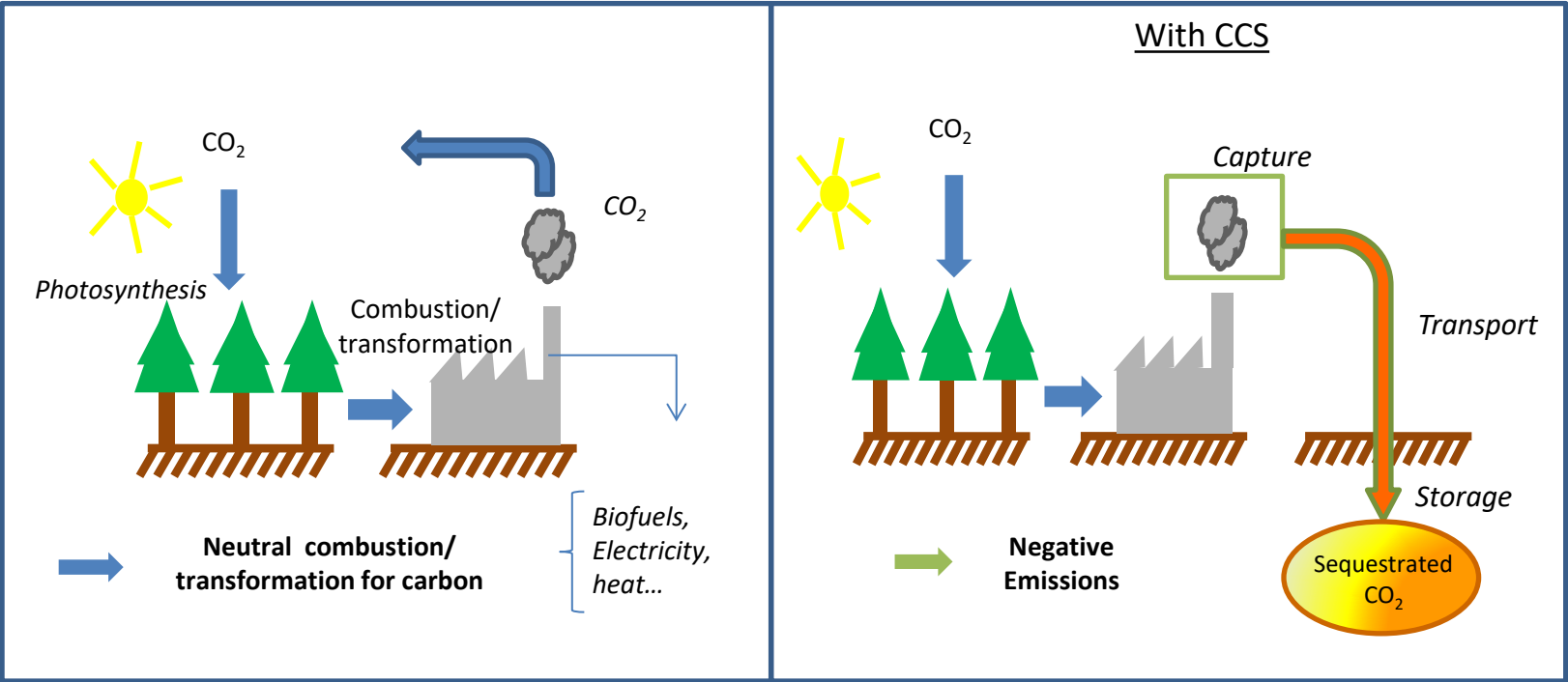
MINES ParisTech/Center for Applied Mathematics
ParisTech Chair Modeling for Sustainable Development

Overview

- Context of Energy/Climate issues
- The attainability of stringent CO₂ mitigation targets depends notably on
 - A wide range of different reduction options
 - The technology « readiness » of advanced technologies
- Among these options : Carbon capture and storage
 - Fossil fuels: dominant source of energy over the next decades (CO₂ emissions will drastically increase: unsustainable level)
 - Bioenergies + CCS (BECCS) : opportunity for a net carbon removal from the atmosphere (negative emissions)

Bioenergy + CCS

$\frac{1}{(1 + \alpha)^{n(t-1)}} \sum_{i \in TCH} in$
 $\times \left(\sum_{i \in TCH} fixom_i(t) \right)$
 $+ \sum_{i \in ELLA} \sum_{z \in Z} \sum_{y \in Y} varc$
 $+ \sum_{k \in ENC} \sum_s com_s$
 $+ \sum_s \sum_{z \in Z} \sum_{y \in Y} price$
 $- \sum_s \sum_{z \in Z} \sum_{y \in Y} price$



Tools: TIAM-FR

$$\frac{1}{(1 + \alpha)^{n(t-1)}} \sum_{i \in TCH} in$$
$$\times \left(\sum_{i \in TCH} fixom_i(t) \right)$$
$$+ \sum_{i \in E, LA} \sum_{z \in Z} \sum_{y \in Y} var$$
$$+ \sum_{k \in EN, C} \sum_s co$$
$$+ \sum_s \sum_{z \in Z} \sum_{y \in Y}$$
$$- \sum_s \sum_{z \in Z} \sum_{y \in Y}$$

- **T**IMES **I**ntegrated **A**ssessment **M**odel
 - ETSAP (Energy Technology Systems Analysis Program) from IEA
- Bottom-up optimization model
 - Minimization of the total discounted cost of the system
- Based on the concept of Reference Energy System (RES)
 - Detailed description of existing and future technologies
 - From extraction to energy services demands

Simplified RES

$$\frac{1}{(1 + \alpha)^{n(t-1)}} \sum_{i \in TCH} in$$

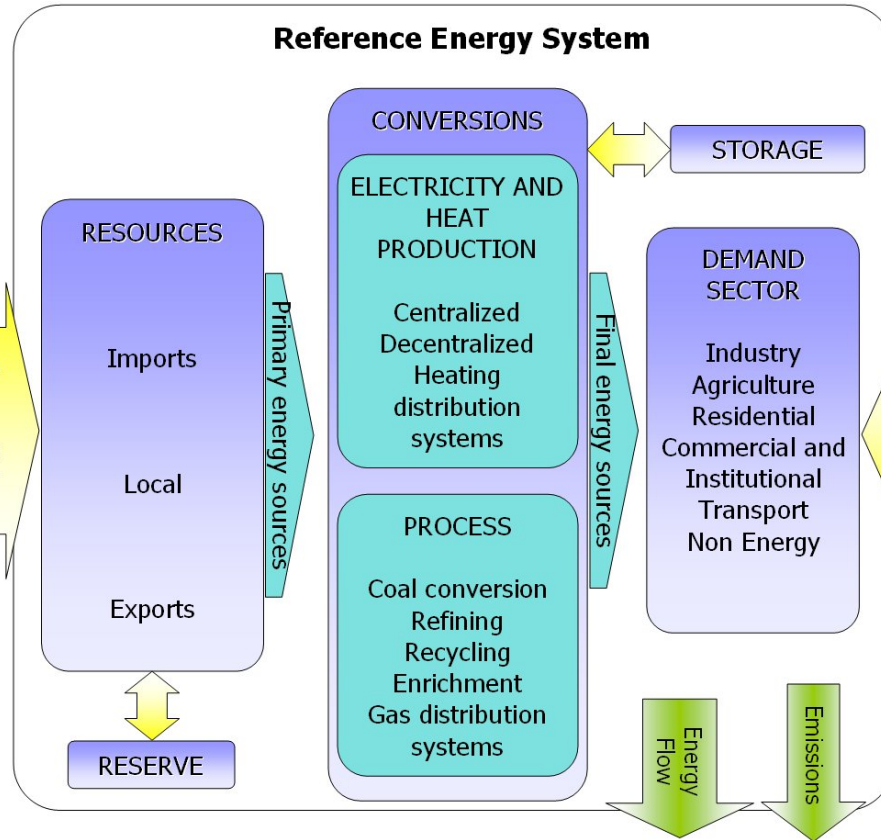
$$\times \left(\sum_{i \in TCH} fixom_i(t) \right)$$

$$+ \sum_{i \in ELA} \sum_{z \in Z} \sum_{y \in Y} var$$

$$+ \sum_{k \in ENC} \sum_s com$$

$$+ \sum_s \sum_{z \in Z} \sum_{y \in Y}$$

$$- \sum_{z \in Z} \sum_{y \in Y}$$



Inputs, exogenous

- Extraction costs
- Reserves of fossil
- Potential of biomass

Thousands of technologies for each region

Agriculture

Energy needs

Commercial

Cooling

Refrigeration

Cooking

Space heat

Hot water

Lighting

Office equipment

Other

Industry

Chemicals

Iron and Steel

Pulp and Paper

Non-ferrous metals

Non Metals

Other

Residential

Cooling

Clothes drying

Clothes washing

Dishwashing

Space heat

Hot water

Cooking

Lighting

Refrigeration

Other

Transport

Aviation: domestic

Aviation: international

Road: bus

Road: commercial trucks

Road: three wheels

Road: heavy trucks

Road: light vehicle

Road: medium trucks

Road: auto

Road: two wheels

Rail: freight

Rail: passengers

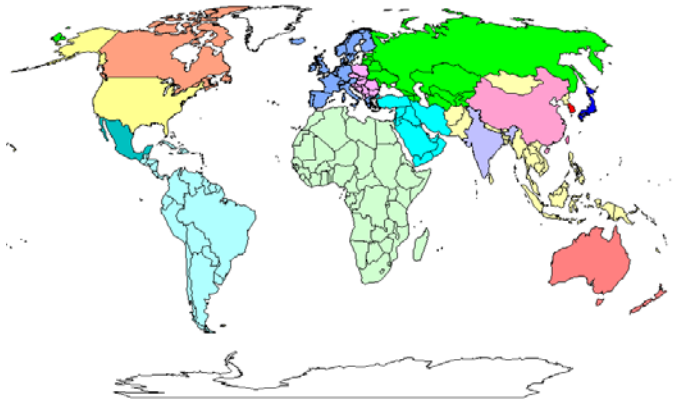
Navigation: domestic internal

Navigation: international

Demand for energy services

Tools: TIAM-FR (2)

- World integrated model in 15 regions



- Time horizon: 2005-2050
- GHG emissions and climate module
 - CO₂, CH₄ and N₂O
 - Atmospheric concentration, temperature change and radiative forcing
- Carbon capture and sequestration technologies
 - Fossil and Bioenergy
- Water consumption of processes

$$\frac{1}{(1 + \alpha)^{n(t-1)}} \sum_{i \in TCH} in$$

$$\times \left(\sum_{i \in TCH} fixom_i(t) \right)$$

$$+ \sum_{i \in EEA} \sum_{z \in Z} \sum_{y \in Y} var$$

$$+ \sum_{k \in ENC} \sum_s com_{ks}$$

$$+ \sum_s \sum_{z \in Z} \sum_{y \in Y} price_{zy}$$

$$- \sum_s \sum_{z \in Z} \sum_{y \in Y} price_{zy}$$

Simplified RES

$$\frac{1}{(1 + \alpha)^{n(t-1)}} \sum_{i \in TCH} in$$

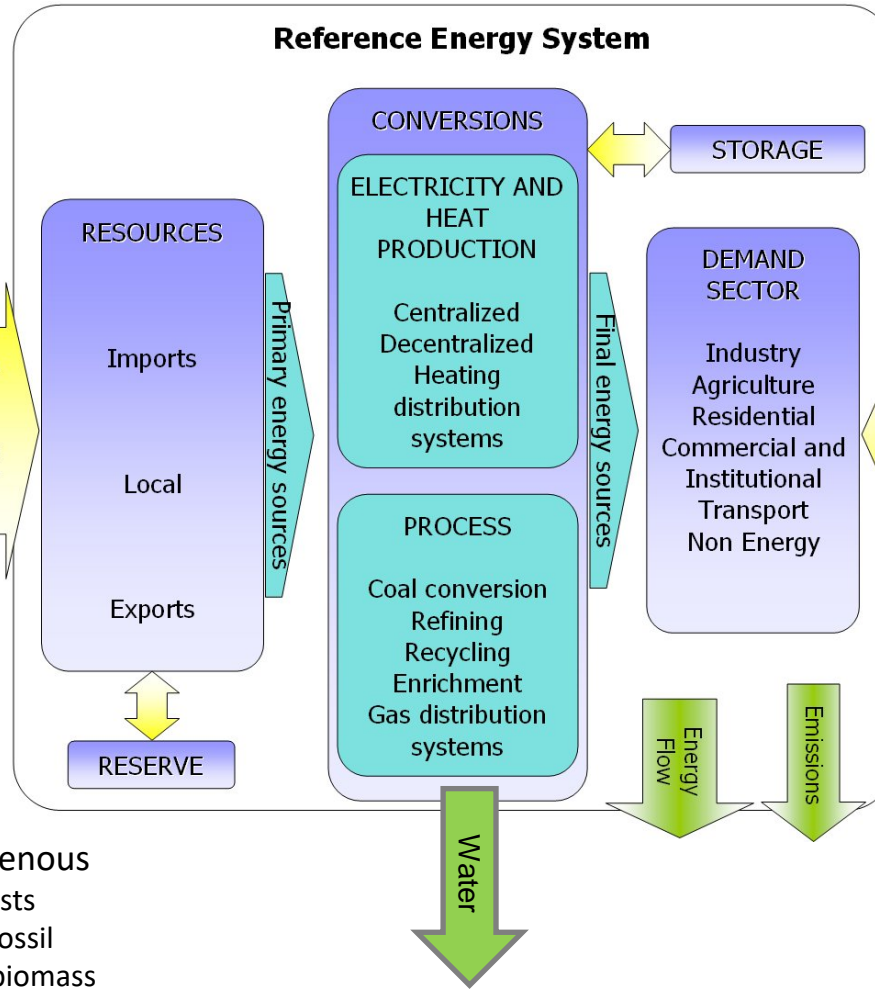
$$\times \left(\sum_{i \in TCH} fixom_i(t) \right)$$

$$+ \sum_{i \in ELA} \sum_{z \in Z} \sum_{y \in Y} var$$

$$+ \sum_{k \in ENC} \sum_s com$$

$$+ \sum_s \sum_{z \in Z} \sum_{y \in Y}$$

$$- \sum_{z \in Z} \sum_{y \in Y}$$



Inputs, exogenous

- Extraction costs
- Reserves of fossil
- Potential of biomass

- Agriculture**
- Energy needs
- Commercial**
- Cooling
- Refrigeration
- Cooking
- Space heat
- Hot water
- Lighting
- Office equipment
- Other
- Industry**
- Chemicals
- Iron and Steel
- Pulp and Paper
- Non-ferrous metals
- Non Metals
- Other
- Residential**
- Cooling
- Clothes drying
- Clothes washing
- Dishwashing
- Space heat
- Hot water
- Cooking
- Lighting
- Refrigeration
- Other
- Transport**
- Aviation: domestic
- Aviation: international
- Road: bus
- Road: commercial trucks
- Road: three wheels
- Road: heavy trucks
- Road: light vehicle
- Road: medium trucks
- Road: auto
- Road: two wheels
- Rail: freight
- Rail: passengers
- Navigation: domestic internal
- Navigation: international

Demand for energy services

Assumptions

- Climate policies
 - Radiative forcing : 2.6 W/m² (450 ppm CO₂-eq)
 - Radiative forcing : 3.7 W/m² (550 ppm CO₂-eq)
- Technology availability
 - Scenario without BECCS with co-firing (coal/biomass)
 - Scenario without BECCS without co-firing
 - Scenario without CCS
- Resources availability
 - Biomass potential: 234 EJ/yr in 2050
 - Carbon sink potential: 9 392 Gt CO₂
 - Water consumption



$$\frac{1}{(1 + \alpha)^{n(t-1)}} \sum_{i \in TCH} in$$

$$\times \left(\sum_{i \in TCH} fixom_i(t) \right)$$

$$+ \sum_{i \in ELA} \sum_{z \in Z} \sum_{y \in Y} varc$$

$$+ \sum_{k \in ENC} \sum_s com_s$$

$$+ \sum_s \sum_{z \in Z} \sum_{y \in Y} price$$

$$- \sum_s \sum_{z \in Z} \sum_{y \in Y} price$$

Results

World power generation (TWh)

Under climate constraint

$$\frac{1}{(1+\alpha)^{n(t-1)}} \sum_{i \in TCH} in$$

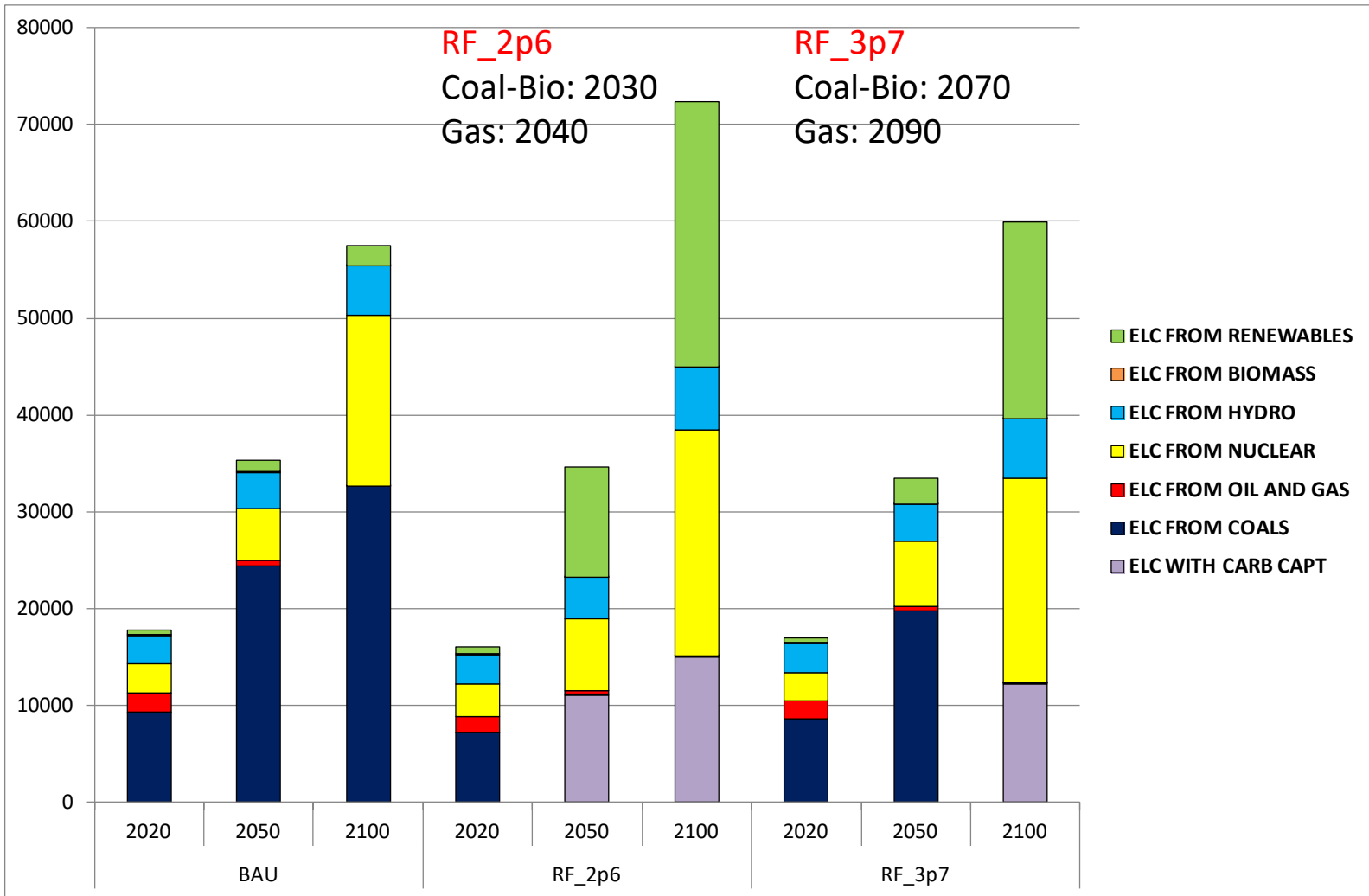
$$\times \left(\sum_{i \in TCH} fixom_i(t) \right)$$

$$+ \sum_{i \in EEA} \sum_{z \in Z} \sum_{y \in Y} var$$

$$+ \sum_{k \in ENC} \sum_s com_k(s)$$

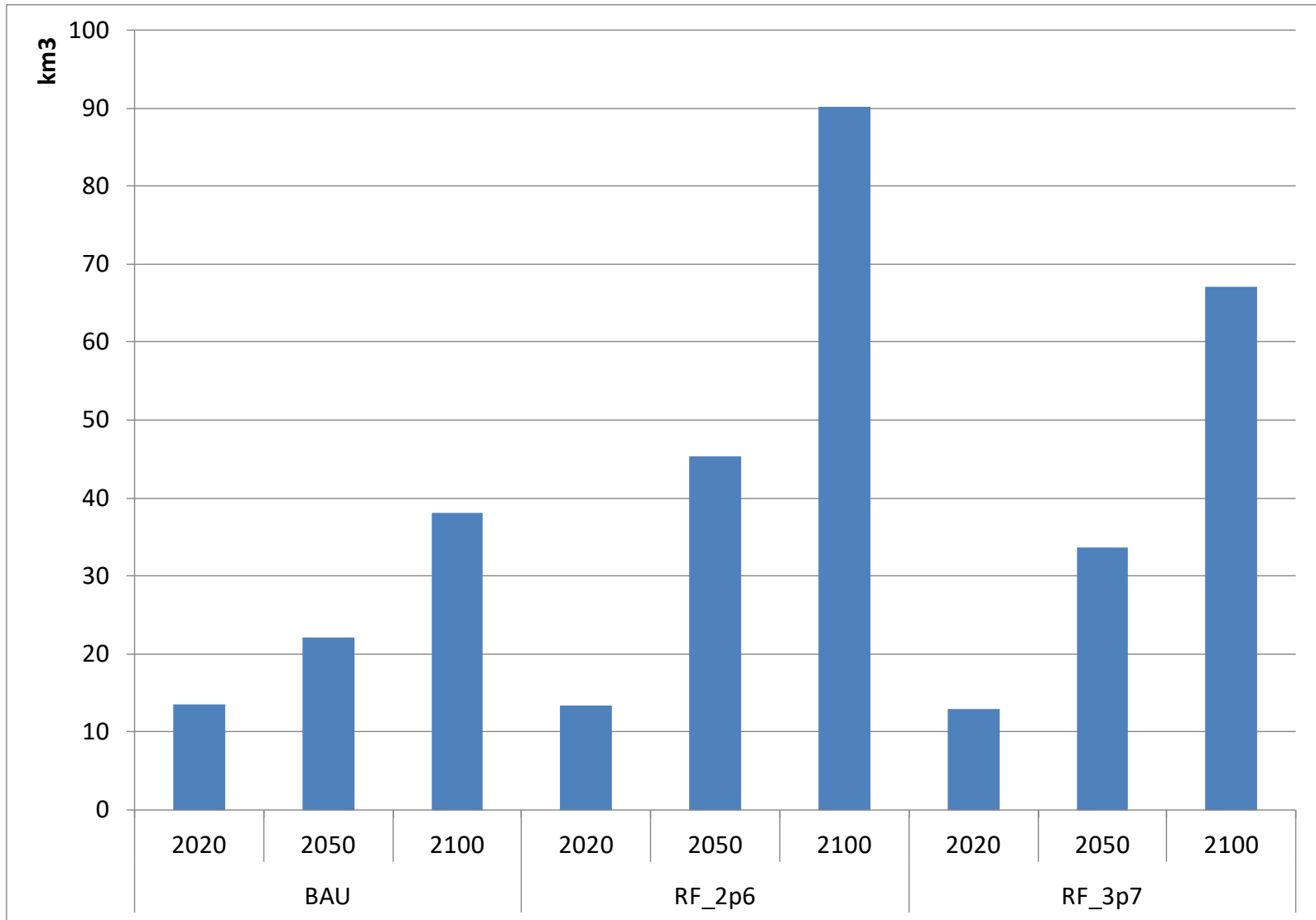
$$+ \sum_s \sum_{z \in Z} \sum_{y \in Y} price$$

$$- \sum_s \sum_{z \in Z} \sum_{y \in Y} price$$



Fresh water consumption (km³)

World – Power plants





Technological sensitivity

World power generation (TWh)

No BECCS

$$\frac{1}{(1 + \alpha)^{n(t-1)}} \sum_{i \in TCH} in$$

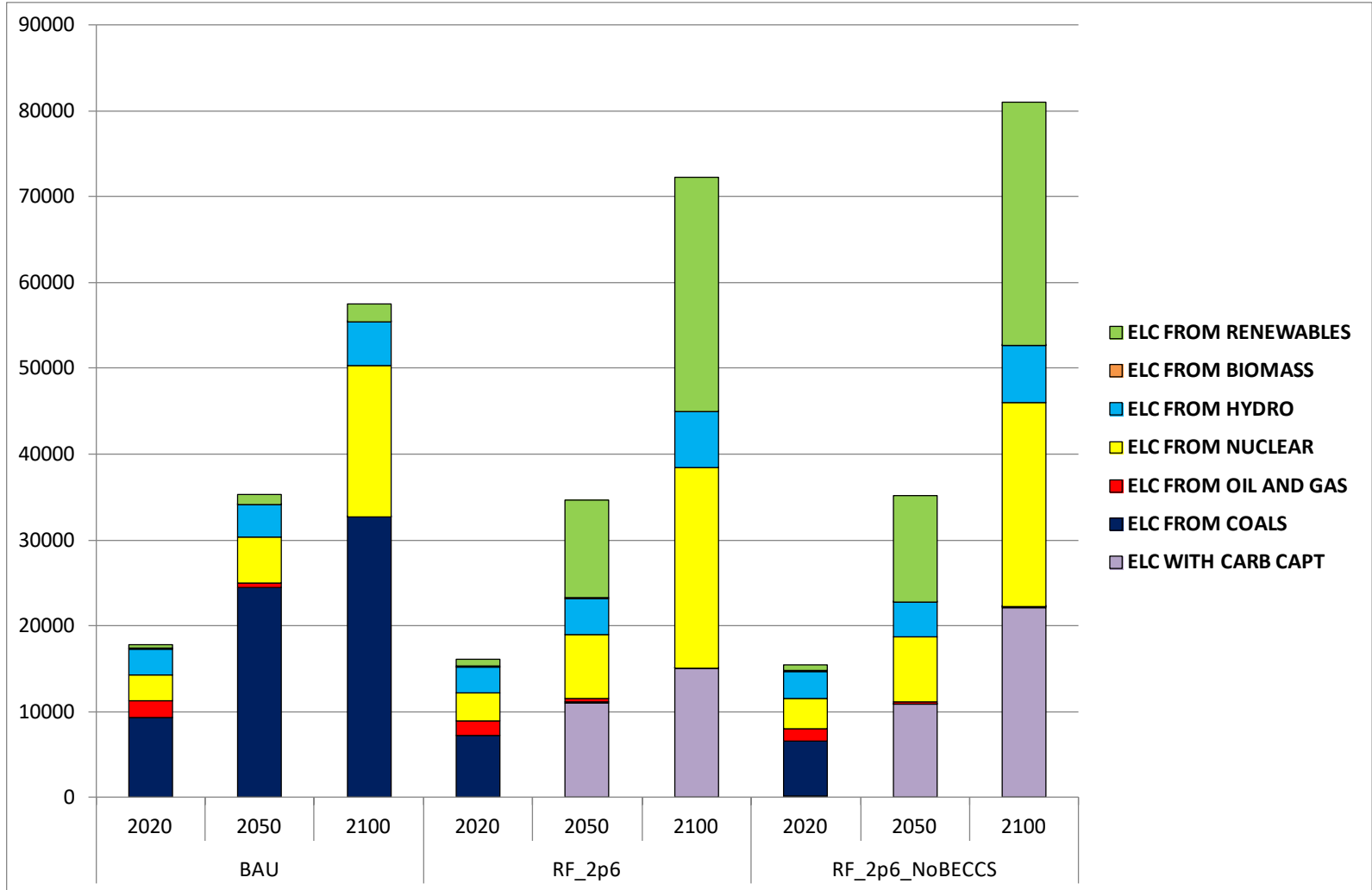
$$\times \left(\sum_{i \in TCH} fixom_i(t) \right)$$

$$+ \sum_{i \in EEA} \sum_{z \in Z} \sum_{y \in Y} varc$$

$$+ \sum_{k \in ENC} \sum_s com_s$$

$$+ \sum_s \sum_{z \in Z} \sum_{y \in Y} price$$

$$- \sum_s \sum_{z \in Z} \sum_{y \in Y} price$$



World power generation (TWh)

No BECCS – No co-firing

$$\frac{1}{(1 + \alpha)^{n(t-1)}} \sum_{i \in TCH} in$$

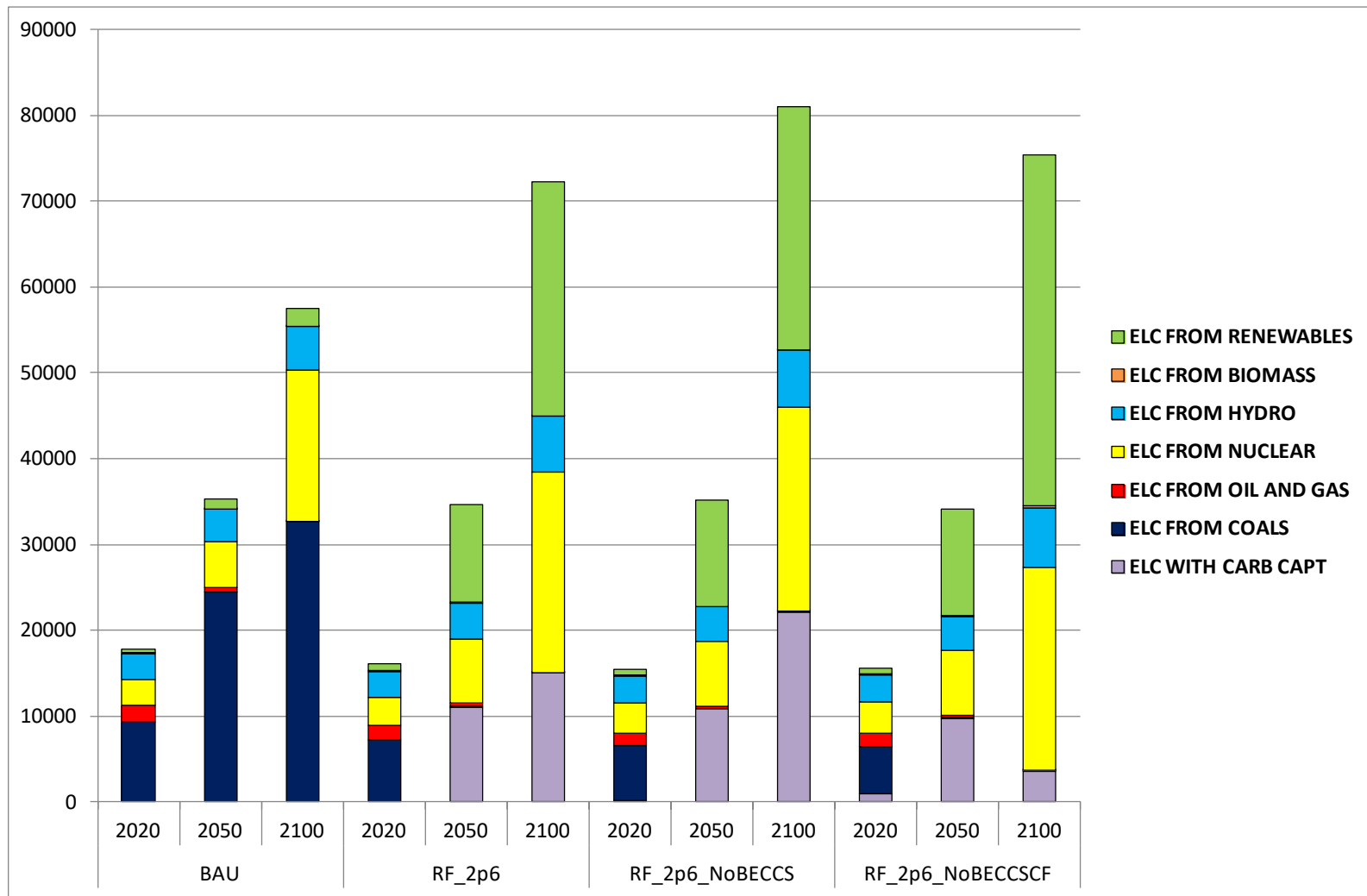
$$\times \left(\sum_{i \in TCH} fixom_i(t) \right)$$

$$+ \sum_{i \in EELA} \sum_{z \in Z} \sum_{y \in Y} varc$$

$$+ \sum_{k \in ENC} \sum_s com_s$$

$$+ \sum_s \sum_{z \in Z} \sum_{y \in Y} price$$

$$- \sum_s \sum_{z \in Z} \sum_{y \in Y} price$$



World power generation (TWh)

No BECCS – No co-firing – No CCS

$$\frac{1}{(1 + \alpha)^{n(t-1)}} \sum_{i \in TCH} in$$

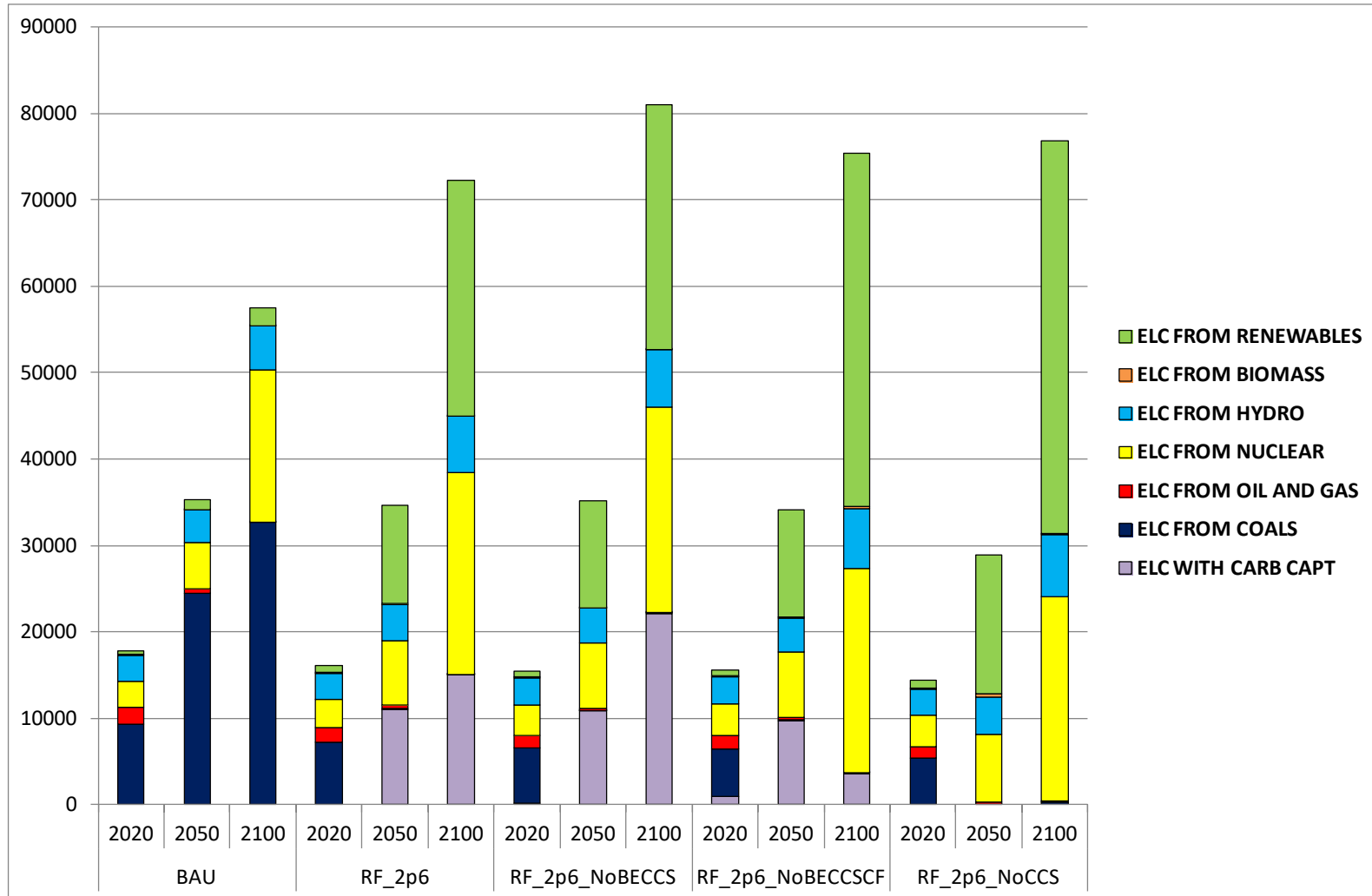
$$\times \left(\sum_{i \in TCH} fixom_i(t) \right)$$

$$+ \sum_{i \in EELA} \sum_{z \in Z} \sum_{y \in Y} var$$

$$+ \sum_{k \in ENC} \sum_s co$$

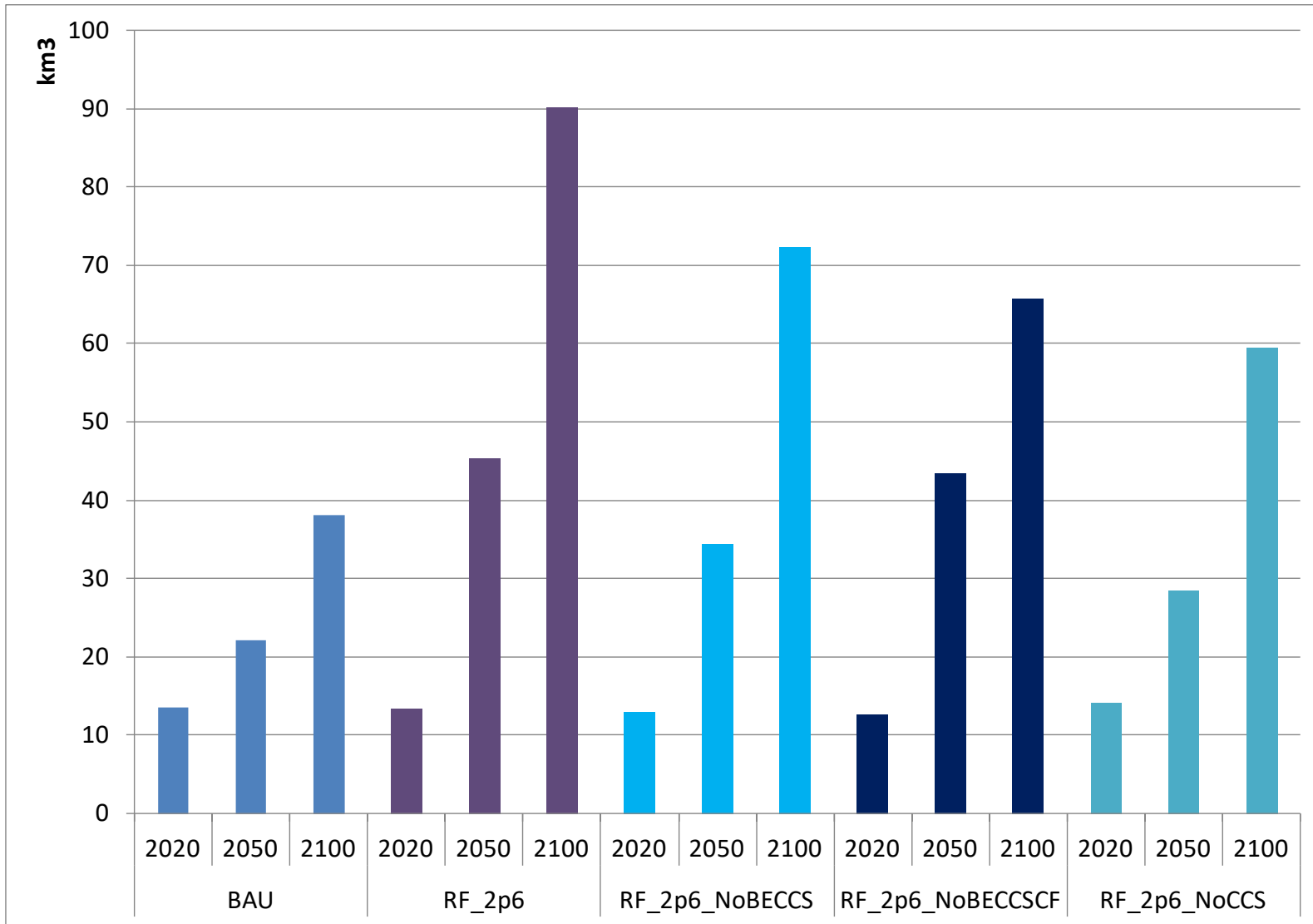
$$+ \sum_s \sum_{z \in Z} \sum_{y \in Y}$$

$$- \sum_s \sum_{z \in Z} \sum_{y \in Y}$$




Fresh water consumption (km³)

World – Power plants -





Conclusion



CCS/BECCS technologies: an increasing option
But their contribution to the CO₂ mitigation policy depends on the interplay of several factors:

- The large scale availability of technologies
- Cost/advantages according to alternatives
- Political choices
 - Incentives to CCS/BECCS
 - Climate change stake versus social objectives (social acceptance about storage sites)
- Water consideration with higher consumption
 - Regional perspectives (CO₂ mitigation targets and water scarcity)



$$\frac{1}{(1 + \alpha)^{n(t-1)}} \sum_{i \in TCH} in$$
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Annex

Reference energy system

$$\frac{1}{(1 + \alpha)^{n(t-1)}} \sum_{i \in TCH} in$$

$$\times \left(\sum_{i \in TCH} fixom_i(t) \right)$$

$$+ \sum_{i \in EEA} \sum_{z \in Z} \sum_{y \in Y} var$$

$$+ \sum_{k \in ENC} \sum_s co$$

$$+ \sum_s \sum_{z \in Z} \sum_{y \in Y}$$

$$- \sum_s \sum_{z \in Z} \sum_{y \in Y}$$

