**MERCURY – Modeling the European power sector evolution: low-carbon generation technologies (renewables, CCS, nuclear), the electric infrastructure and their role in the EU leadership in climate policy**

# Assessing the techno-economic effects of the delayed deployment of CCS power plants

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# Project outline

- WP 1 – Power sector modeling improvements (UC Berkeley → *interactions/integration with SWITCH*)
  - Task 1.1 – Training on the SWITCH model (months 1-2)
  - Task 1.2 – System integration of Variable Renewable Energies (VRE) (months 3-4)
  - Task 1.3 – Electricity storage (months 5-6)
  - Task 1.4 – Electrical grid (months 7-8)
  - Task 1.5 – ~~Electricity trade (months 9-12)~~ → Interactions/integration with SWITCH
- WP 2 – Low-carbon technologies prospects and scenarios (FEEM)
  - Task 2.1 – Study of the state of the art of renewables, nuclear and CCS in the European Union (month 13)
  - Task 2.2 – Scenario definition (month 14)
  - Task 2.3 – Scenario run and analysis (months 15-18)

Today's presentation

- WP 3 – Regional participation in climate policies (FEEM)
  - Task 3.1 – Study of the state of the art of current EU and global climate policies (month 19)
  - Task 3.2 – Scenario definition (month 20)
  - Task 3.3 – Scenario run and analysis (months 21-24)

# Introduction

- Carbon Capture & Storage (CCS) has widely been recognized as one of the main technological solutions to decarbonize the energy sector, especially if the target is to stay below 2°C (→ importance of negative emissions)
- Main advantage → (theoretically) zero or negative $CO_2$ emissions (→ BECCS, i.e. biomass CCS) without changing the fossil-based generation paradigm (→ plant dispatchability)
- However, large-scale CCS deployment is yet to come
  → globally, 30 $MtCO_2$/yr storage capacity vs. 37 $GtCO_2$/yr emissions
- Main obstacles to CCS diffusion:

  - safety concerning the stability of storage sites

  - public acceptance

  - high technology costs

  - incomplete or unclear regulatory framework

  - absence of business models

# Objective and scenario design

## Objective

- Assess the impacts that a progressively delayed CCS deployment can have both in terms of re-arrangement of the energy mix, focusing on the power sector (technical dimension) and in terms of policy costs (economic dimension).

  → Alternatively, how urgent is the installation of CCS plants for the techno-economic feasibility of more and more stringent climate targets?

## Scenario design

- 26 scenarios: BAU + 5 climate targets x 5 “starting years” when CCS deployment is allowed
- BAU → 4°C
- [3.5°C, 3°C, 2.5°C, 2°C, 1.5°C] x [2020 (i20), 2040 (i40), 2060 (i60), 2080 (i80), no CCS (ioff)]



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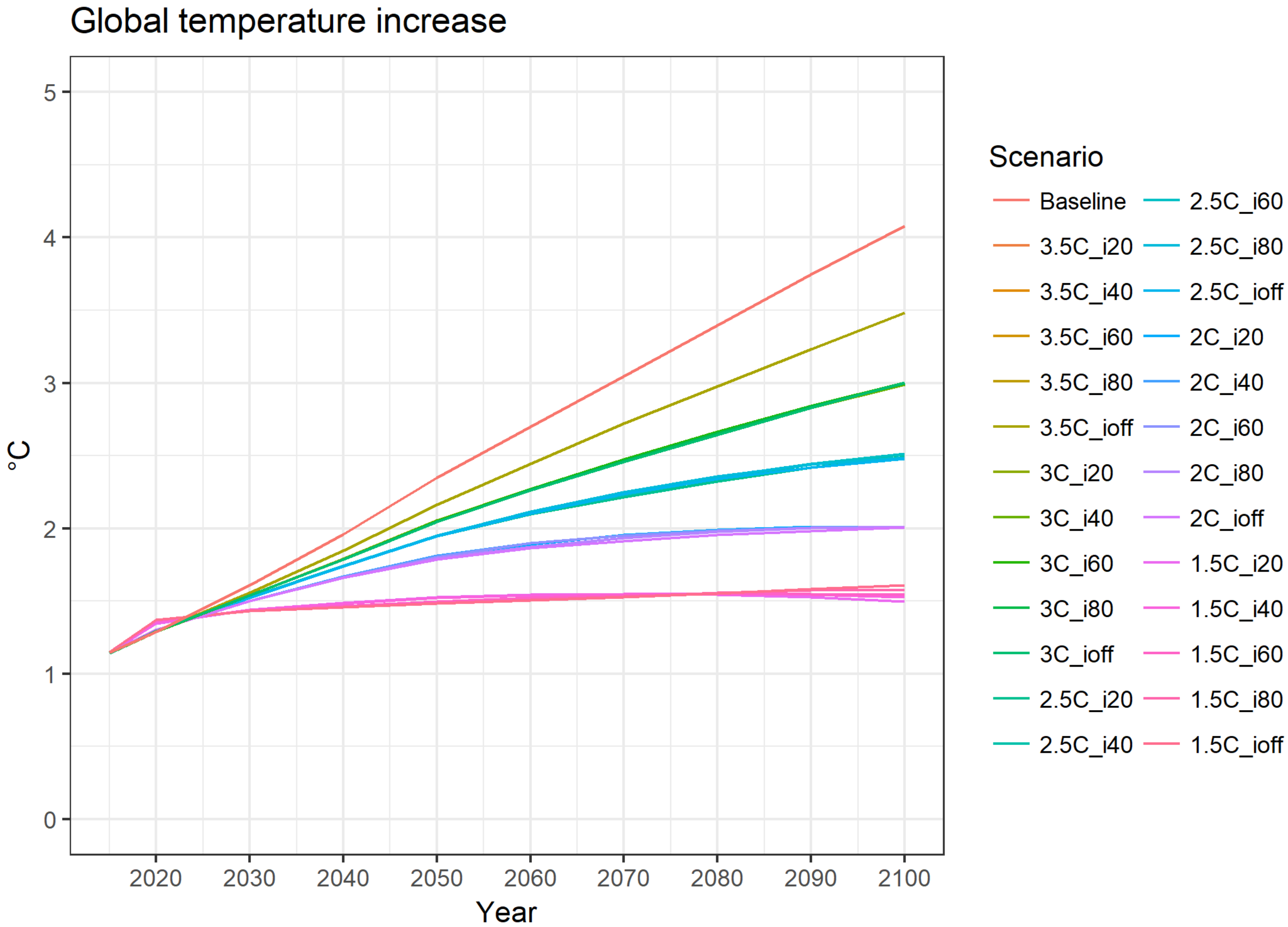

Global temperature increase
°C
5
4
3
2
1
0
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year
Scenario
Baseline
3.5C_i20
3.5C_i40
3.5C_i60
3.5C_i80
3.5C_ioff
3C_i20
3C_i40
3C_i60
3C_i80
3C_ioff
2.5C_i20
2.5C_i40
2.5C_i60
2.5C_i80
2.5C_ioff
2C_i20
2C_i40
2C_i60
2C_i80
2C_ioff
1.5C_i20
1.5C_i40
1.5C_i60
1.5C_i80
1.5C_ioff

# The WITCH model: Overview

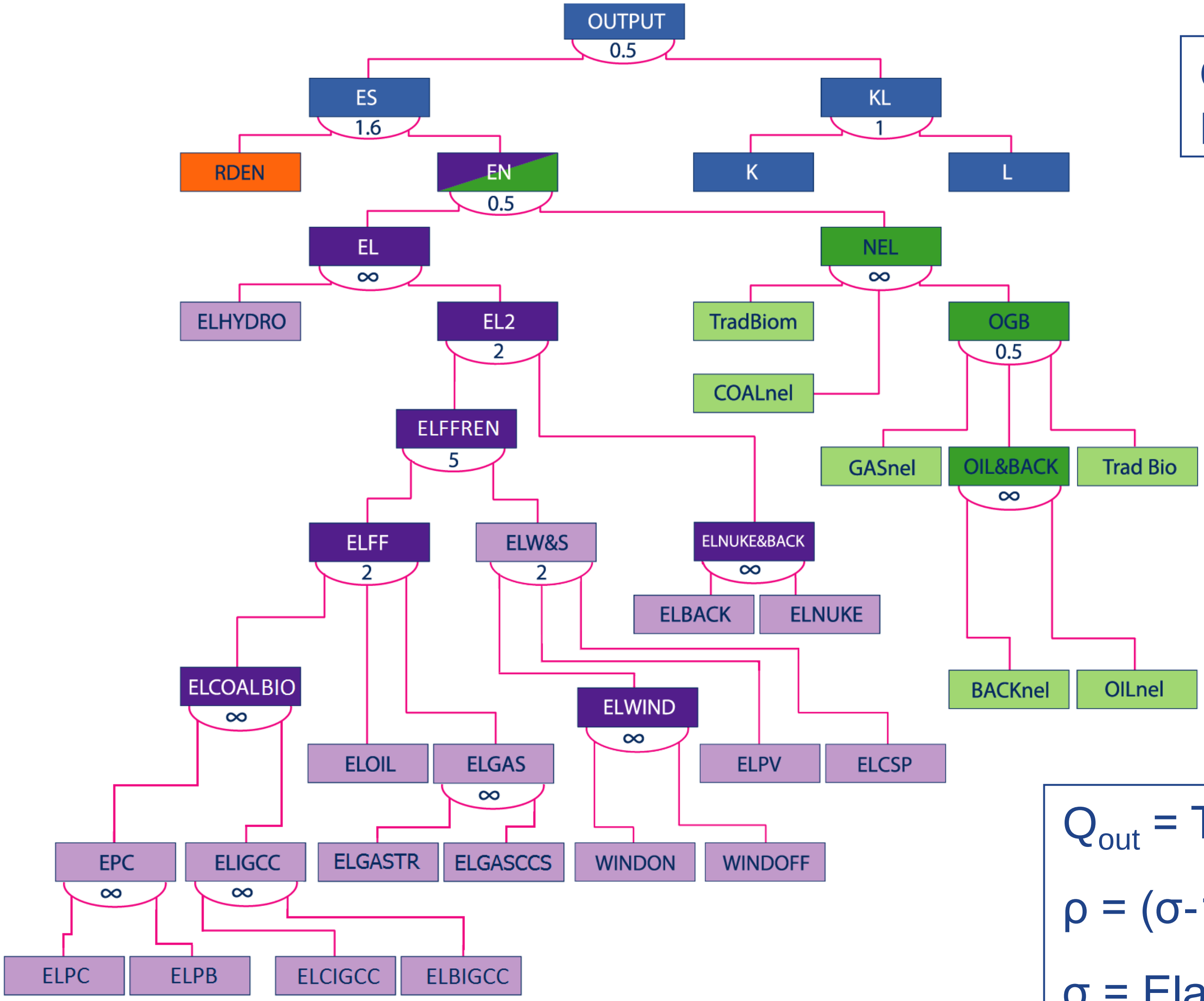
**WITCH – World Induced Technical Change Hybrid**

- Climate-energy-economic IAM (Integrated Assessment Model) → Socio-economic impacts of climate change
- Hybrid: aggregated, top-down, inter-temporal optimal-growth model + disaggregated description of the energy sector


CAJAZ
(Canada, Japan,
New Zealand)

KOSAU
(R. of Korea, South Africa,
Australia)

# The WITCH model: CES structure




CES = Constant Elasticity of Substitution

$$Q_{out} = TFP \cdot (a \cdot Q_{in,1}{}^{\rho} + (1-a) \cdot Q_{in,2}{}^{\rho})^{(1/\rho)}$$

$$\rho = (\sigma-1) / \sigma$$

σ = Elasticity of Substitution

# CCS modeling in WITCH

- $CO_2$ sequestration, transport, and storage are modeled via regional supply cost curves, which depend on site availability.
- The unit cost curve $C_{CCS}$ has a convex shape:

$$C_{CCS}(t,n) = a_{CCS}(n) \cdot \exp(\alpha_{CCS}(n) \cdot M_{CCS}(t,n)^{\beta_{CCS}(n)})$$

- t: time step

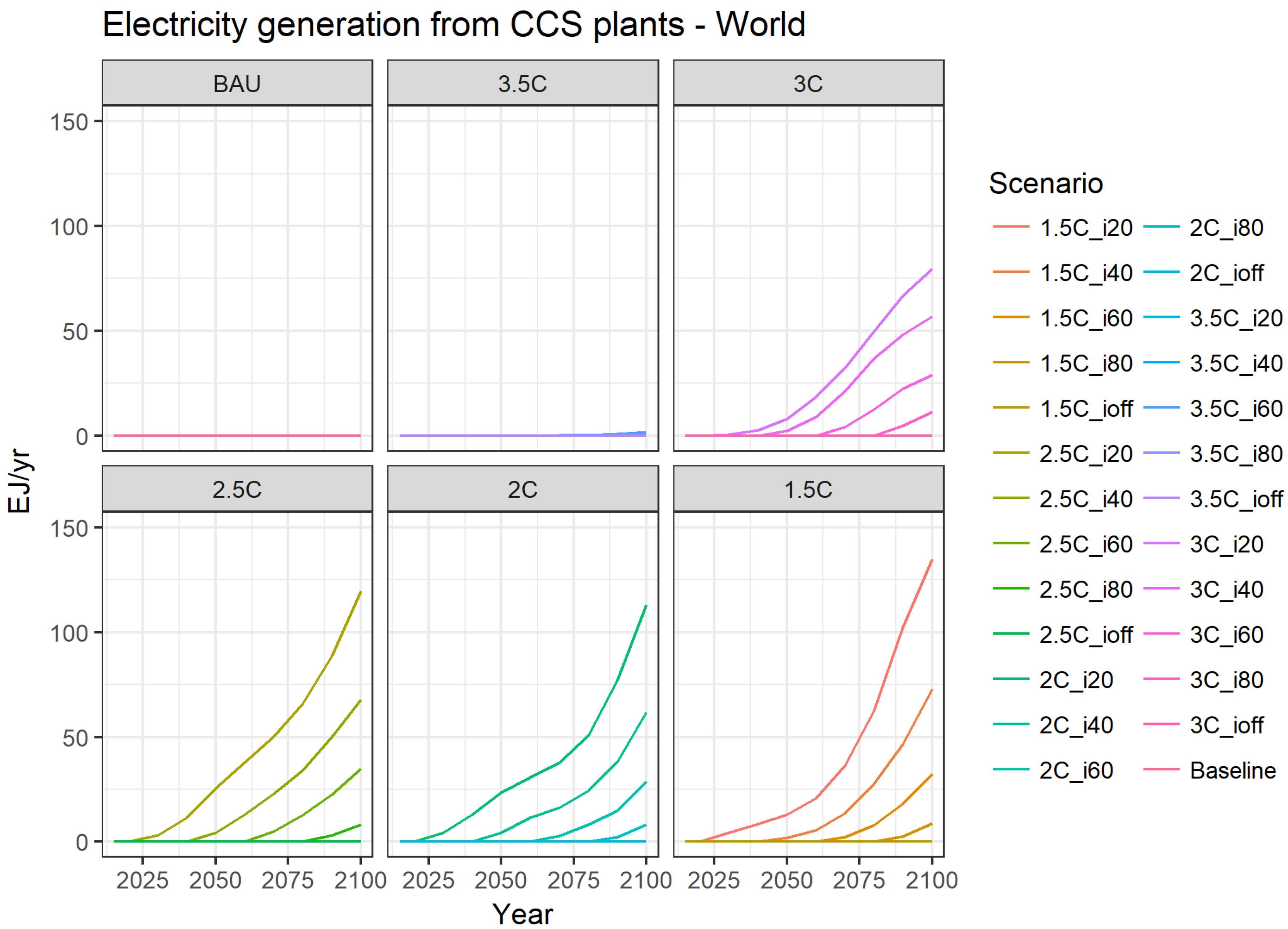
- n: region

- $M_{CCS}(t,n)$: cumulated amount of $CO_2$ captured over the years

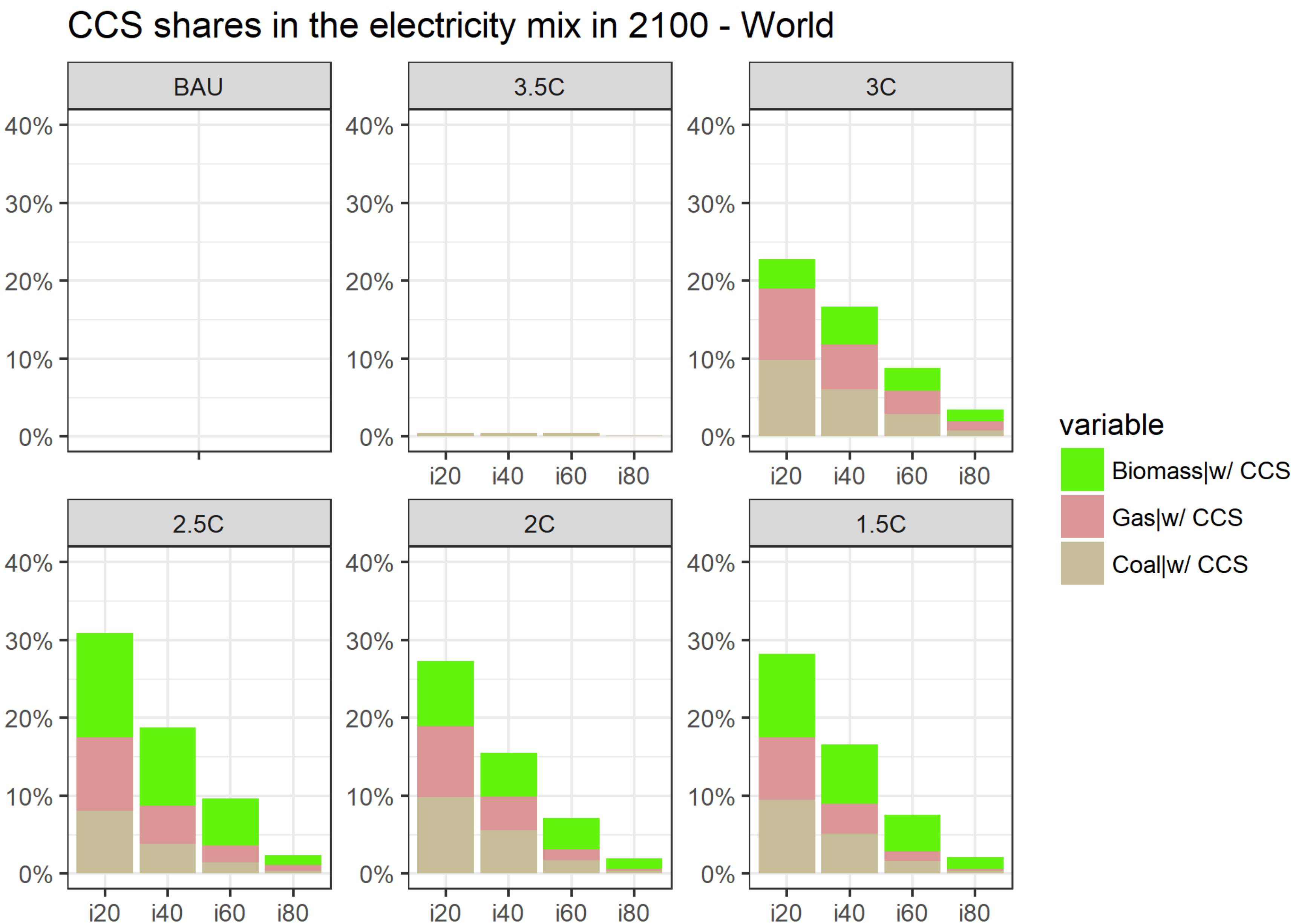
- a, α, β: parameters calibrated on the storage capacities in the different regions (→ global estimated capacity: 1678-11100 $GtCO_2$ according to the IPCC)

- The total CCS cost is finally computed by multiplying the unit cost $C_{CCS}$ by the amount of fuel burnt in the relevant power plants.

**Refined modeling** → Vinca, A., Rottoli, M., Marangoni, G., and Tavoni, M. (2018). The role of carbon capture and storage electricity in attaining 1.5 and 2 °C, International Journal of Greenhouse Gas Control, Vol. 78, pp. 148-159



Electricity generation from CCS plants - World
BAU
3.5C
3C
2.5C
2C
1.5C
EJ/yr
150
100
50
0
2025
2050
2075
2100
Year
Scenario
1.5C_i20
1.5C_i40
1.5C_i60
1.5C_i80
1.5C_ioff
2.5C_i20
2.5C_i40
2.5C_i60
2.5C_i80
2.5C_ioff
2C_i20
2C_i40
2C_i60
2C_i80
2C_ioff
3.5C_i20
3.5C_i40
3.5C_i60
3.5C_i80
3.5C_ioff
3C_i20
3C_i40
3C_i60
3C_i80
3C_ioff
Baseline


CCS shares in the electricity mix in 2100 - World
BAU
3.5C
3C
2.5C
2C
1.5C
40%
30%
20%
10%
0%
i20
i40
i60
i80
variable
Biomass|w/ CCS
Gas|w/ CCS
Coal|w/ CCS



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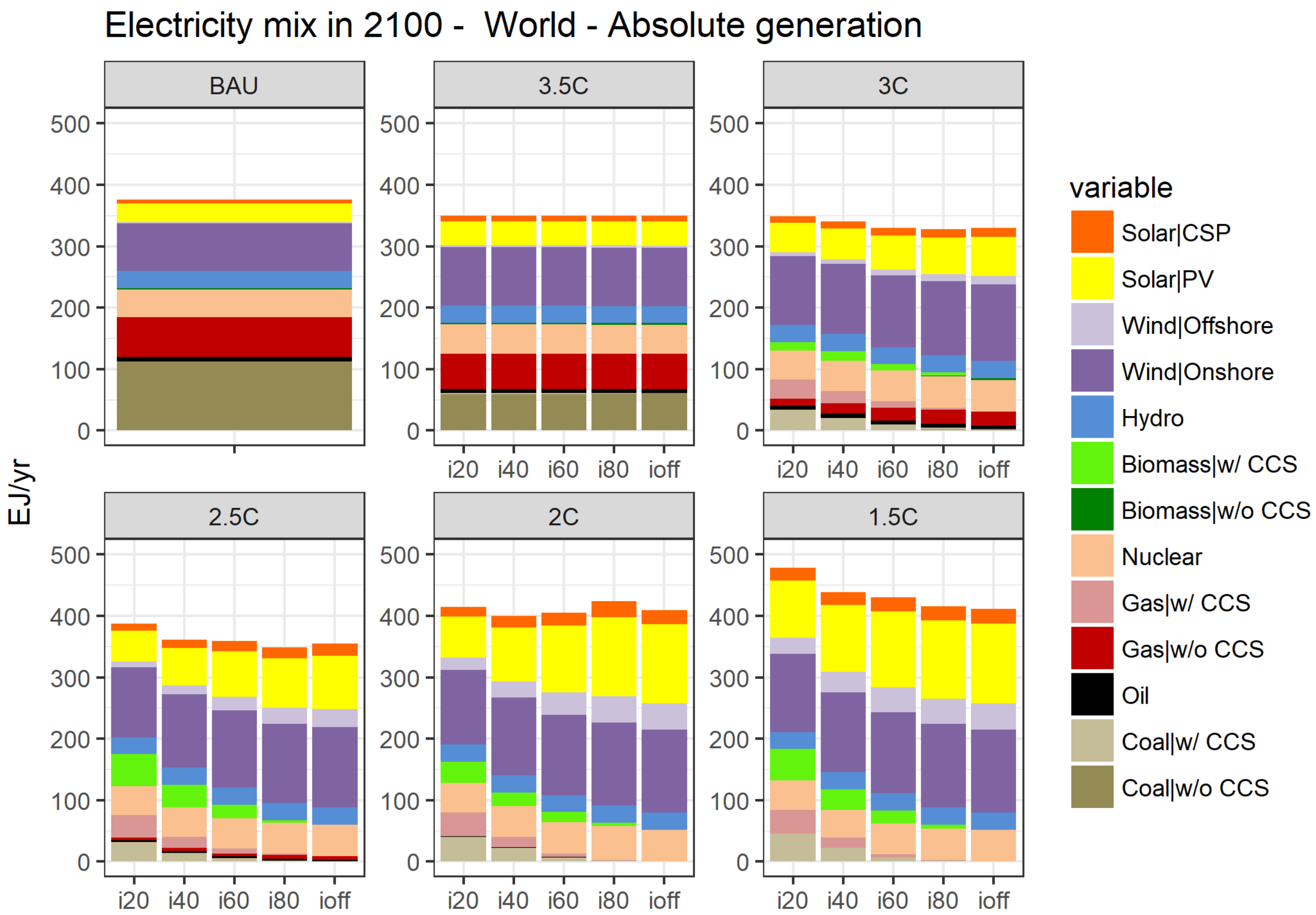
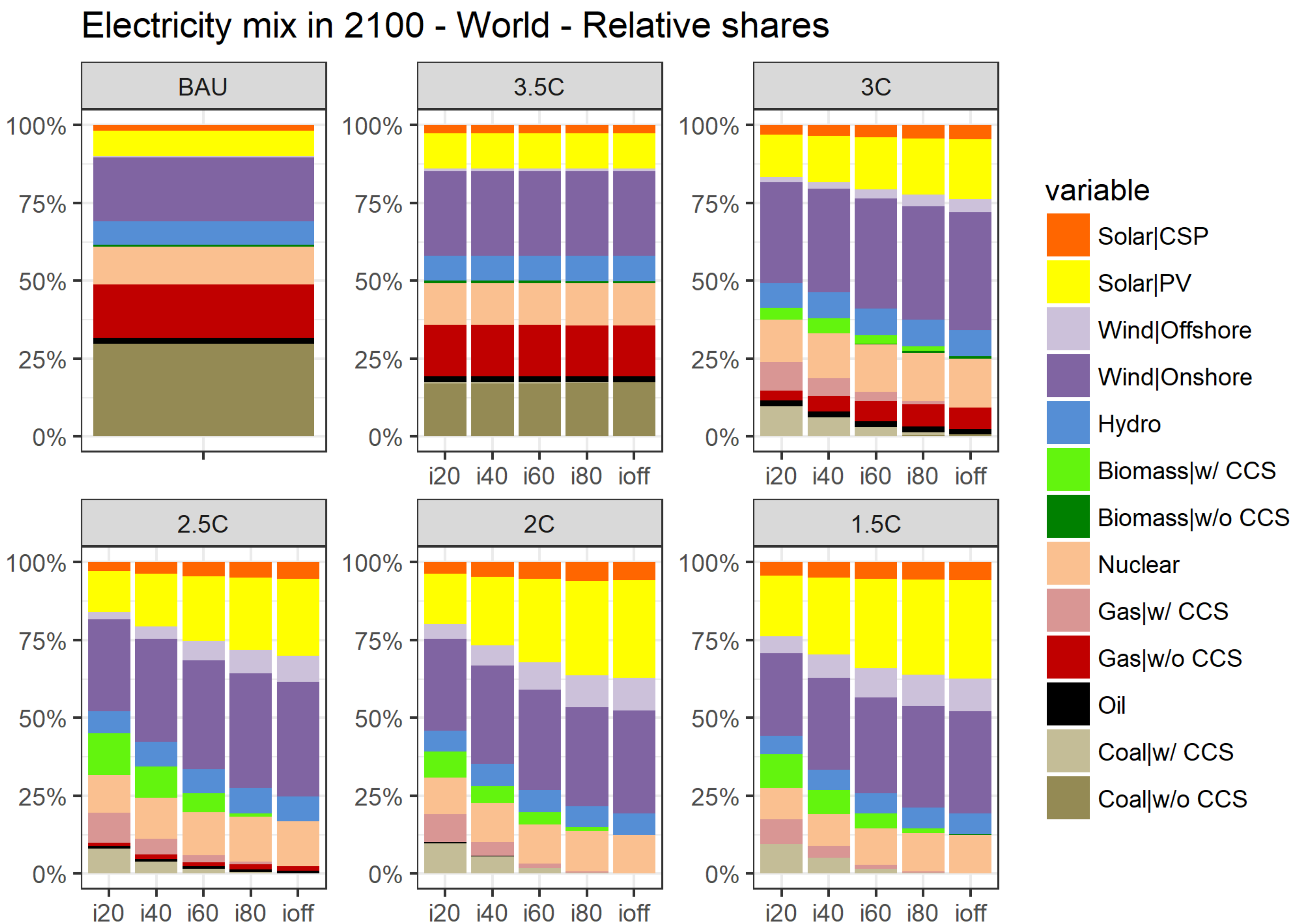


Electricity mix in 2100 - World - Absolute generation
BAU
3.5C
3C
2.5C
2C
1.5C
EJ/yr
0
100
200
300
400
500
i20
i40
i60
i80
ioff
variable
Solar|CSP
Solar|PV
Wind|Offshore
Wind|Onshore
Hydro
Biomass|w/ CCS
Biomass|w/o CCS
Nuclear
Gas|w/ CCS
Gas|w/o CCS
Oil
Coal|w/ CCS
Coal|w/o CCS


Electricity mix in 2100 - World - Relative shares
BAU
3.5C
3C
2.5C
2C
1.5C
100%
75%
50%
25%
0%
i20
i40
i60
i80
ioff
variable
Solar|CSP
Solar|PV
Wind|Offshore
Wind|Onshore
Hydro
Biomass|w/ CCS
Biomass|w/o CCS
Nuclear
Gas|w/ CCS
Gas|w/o CCS
Oil
Coal|w/ CCS
Coal|w/o CCS



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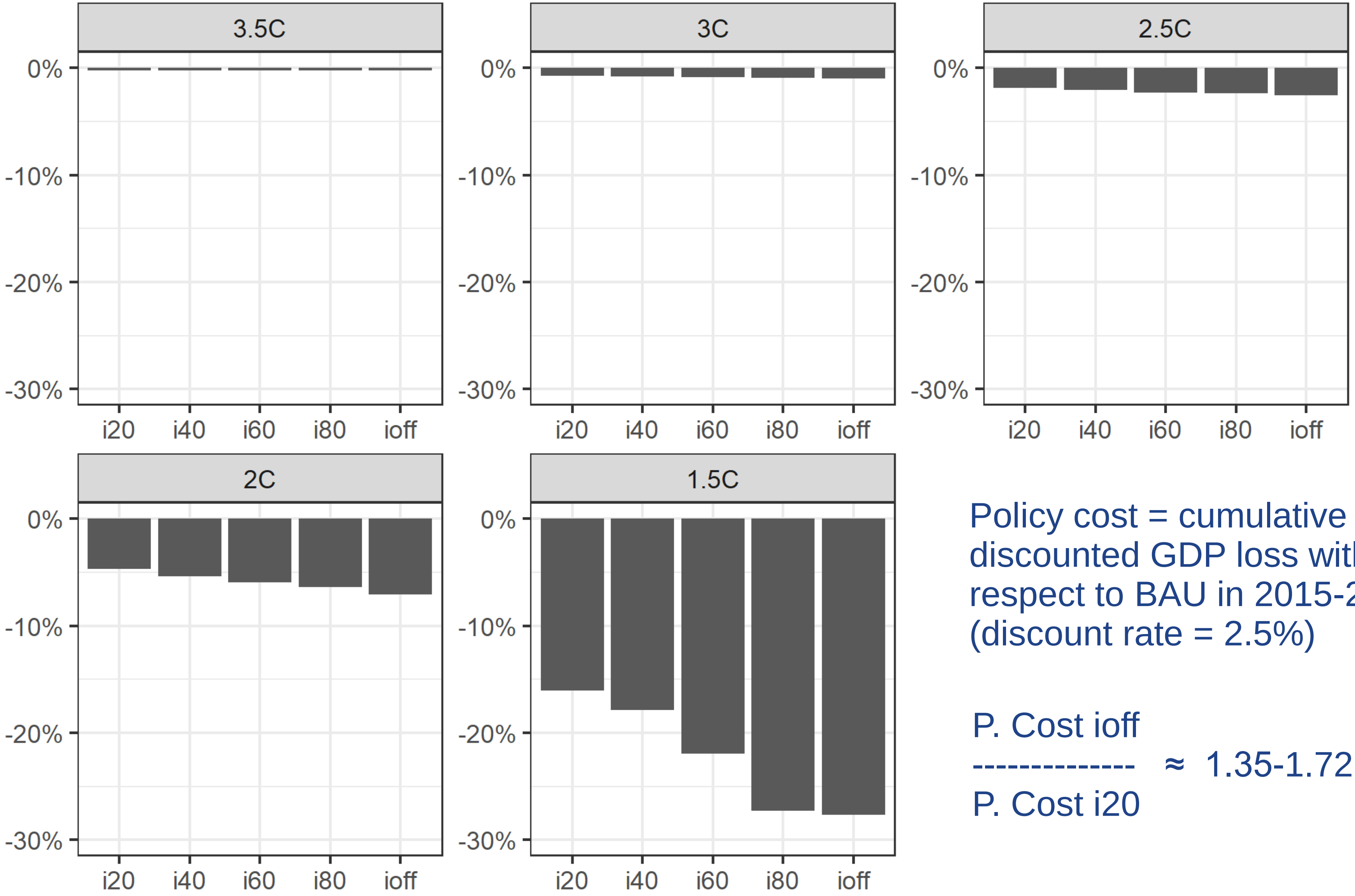
Cumulative policy cost 2015-2100 - Discount rate 2p5 - World




Policy cost = cumulative discounted GDP loss with respect to BAU in 2015-2100 (discount rate = 2.5%)

$$\frac{\text{P. Cost ioff}}{\text{P. Cost i20}} \approx 1.35\text{-}1.72$$



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# Conclusions

- CCS is likely to play a major role in the decarbonization of the electricity sector at a global level, as it is installed in all scenarios with a policy target equal to 3°C or less.
- As soon as the investment in CCS is allowed, this option is immediately activated by the optimization model. Due to expansion constraints, the delayed installation prevents CCS from reaching the optimal level which would be achieved in the unconstrained scenarios.
- This implies a progressively lower penetration in the electricity mix as the deployment is delayed: global CCS penetration achieves around 25-30% in 2100 in all scenarios from 1.5°C to 3°C, gradually decreasing to zero as the deployment is delayed or not allowed.
- The lower or no CCS generation is mostly compensated by renewables (notably wind and solar), also with a slight increase in nuclear.
- The overall electricity demand tends to slightly diminish with the progressively delayed CCS deployment (more markedly in the 1.5°C scenarios).
- Delaying or removing CCS from the optimal electricity mix has negative effects on the overall economic performance: globally, the no CCS scenario is characterized by a cumulative GDP loss which is from 35% to 72% higher than the corresponding unconstrained CCS scenario.

# THANK YOU
# FOR YOUR ATTENTION

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