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Chapter 3:
Modelling the electricity sector using FTT:Power

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- 4CMR: at the crossroads of disciplines
  Integrating economics, engineering, climatology, geography, social sciences…
- Study Energy-Economy-Environment interactions
  Strongly data led (econometrics) and/or focus on systems dynamics,
- Focus on impact assessments of climate change policy
  Projections of global greenhouse gas emissions and environmental impacts
  - Energy systems modelling at the global scale
    Fuel combustion emissions, technological change,
    the diffusion of innovations

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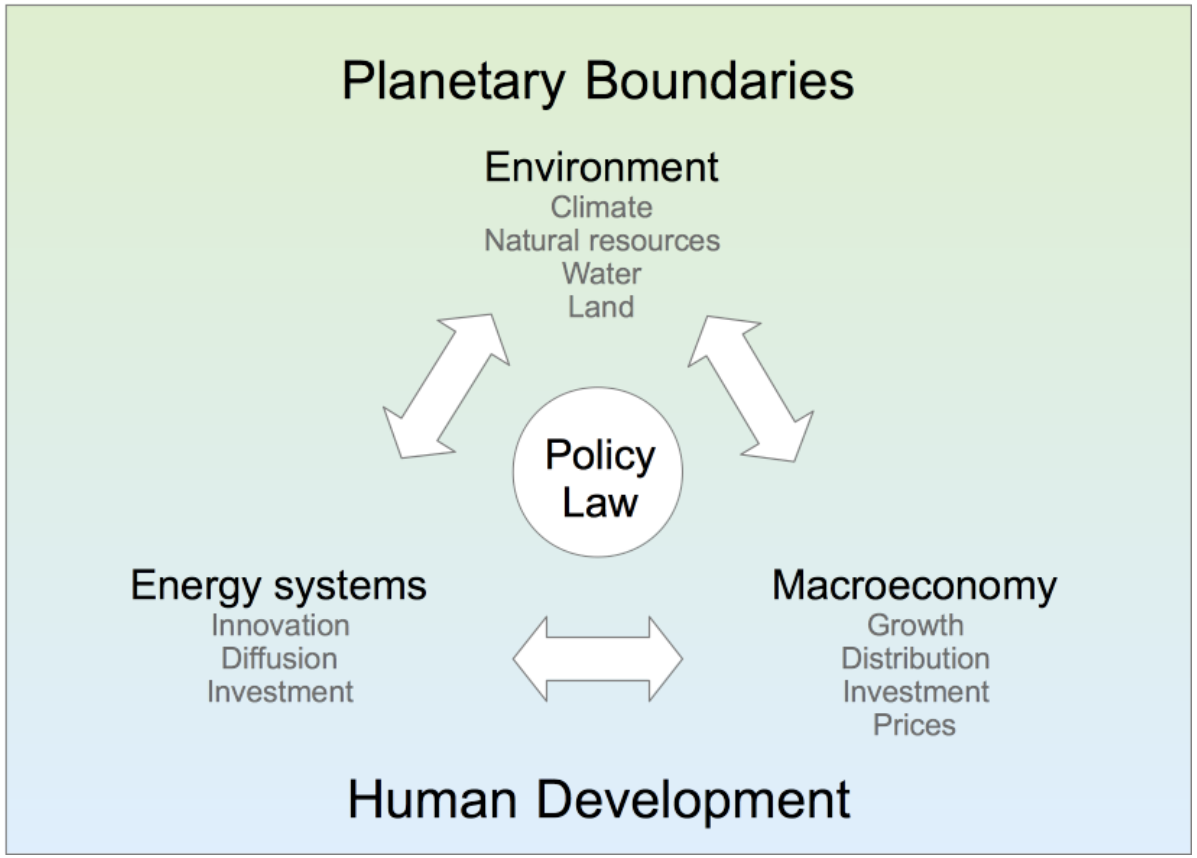
Global Energy-Economy-Environment system



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De-nuclearisation or emissions reductions?

East-Asia currently faces difficult choices for energy generation.

1- After the Fukushima accident, questions are raised with nuclear
2- With climate change, questions are raised with fossil fuels

Research questions:

-What is the impact on the energy sector of phasing out nuclear?

-What is the impact on the energy sector of phasing out coal?

- Do emissions increase or decrease?
- Do costs increase or decrease?

Future Technology Transformations Project (FTT)

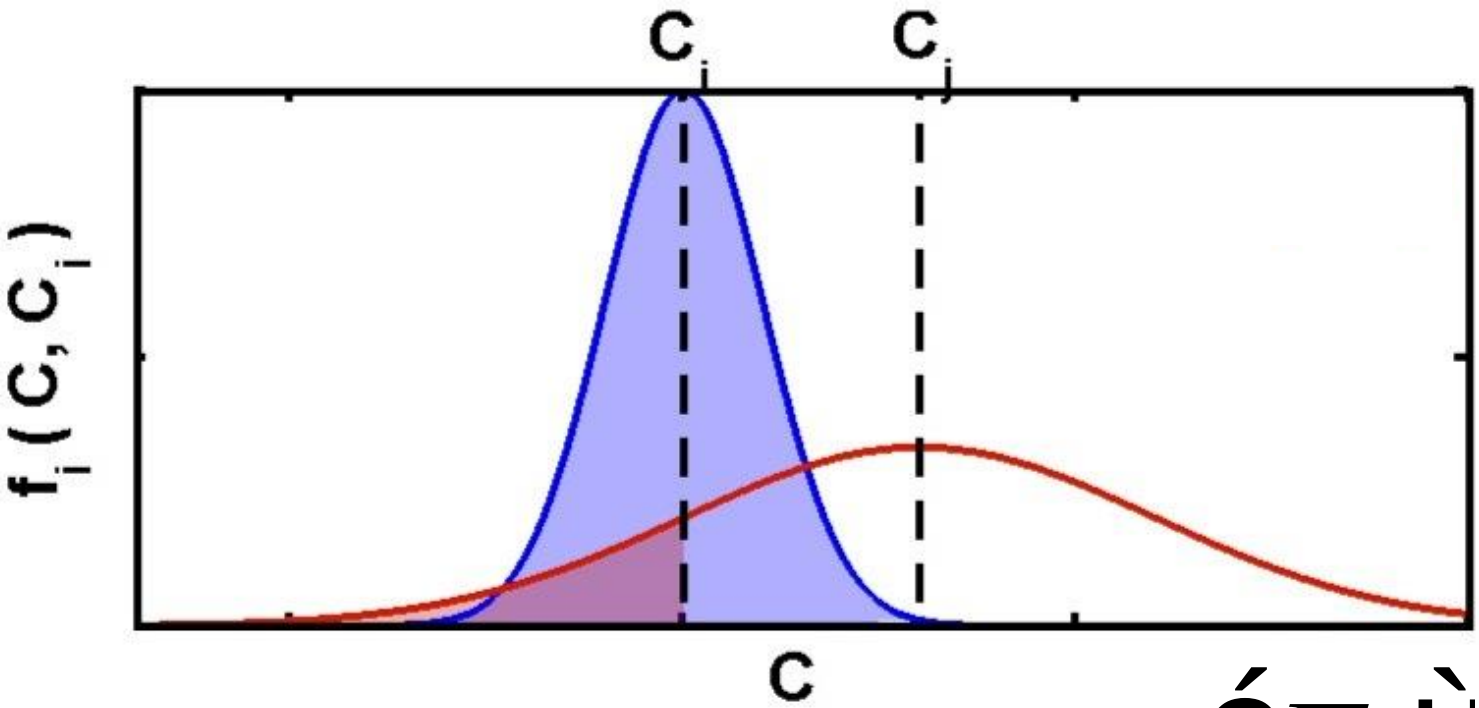
Problem of modelling technology choice:
Discrete choice theory, innovation-selection-diffusion

$t \longrightarrow t + \Delta t$

J.-F. Mercure, Energy Policy 48, 799-811 (2012)

Defining a driver for technology substitutions

Separating choice from industrial dynamics:

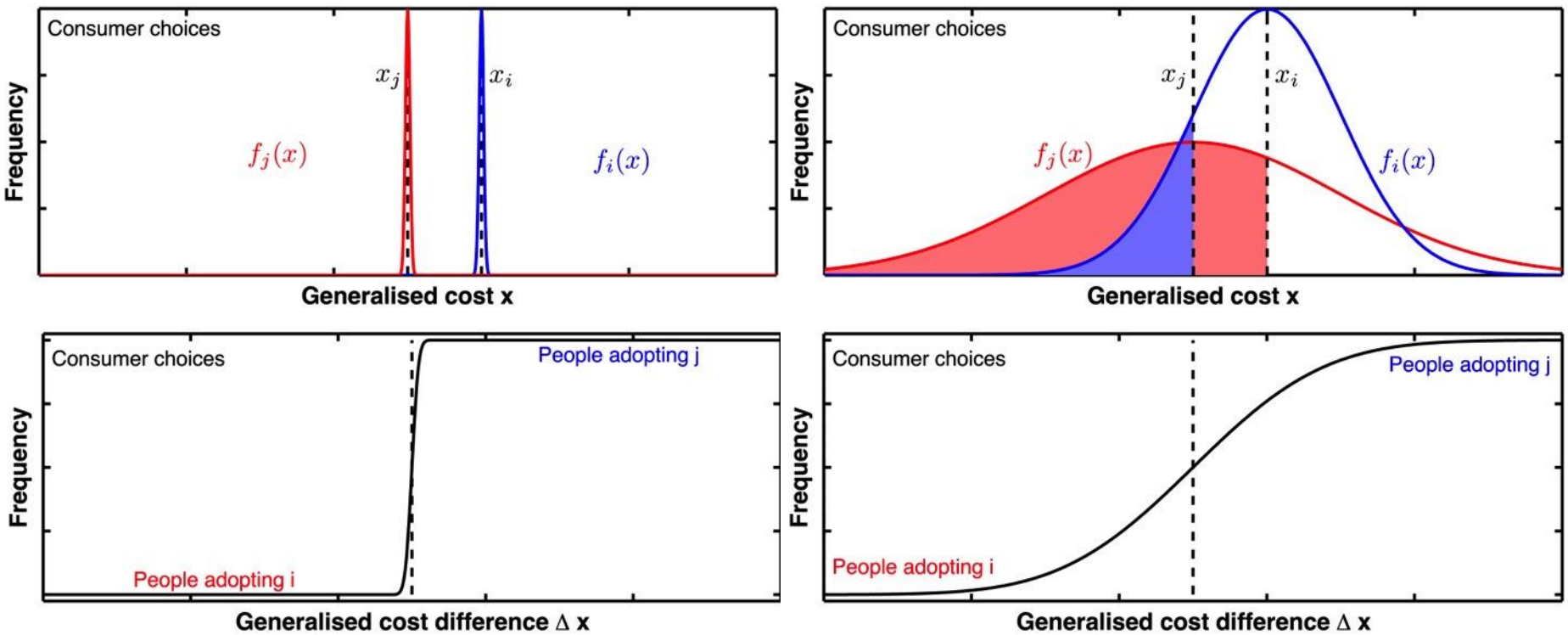


Probabilistic Choice matrix: $\left[e^{-F_{ij}} \right]$

J.-F. Mercure, Energy Policy 48, 799-811 (2012)

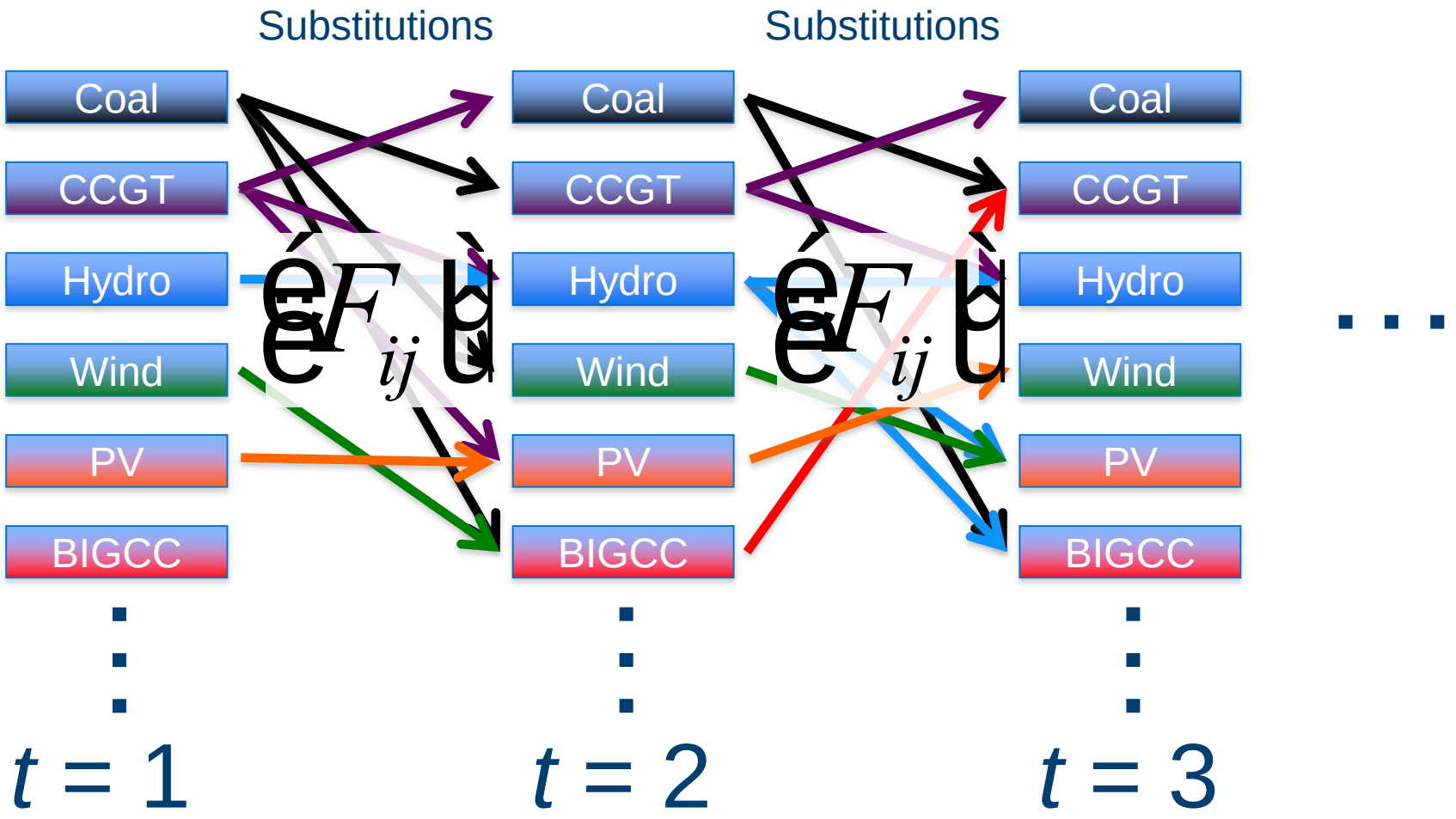
Modelling decision-making

Revealed preferences integrates agent diversity



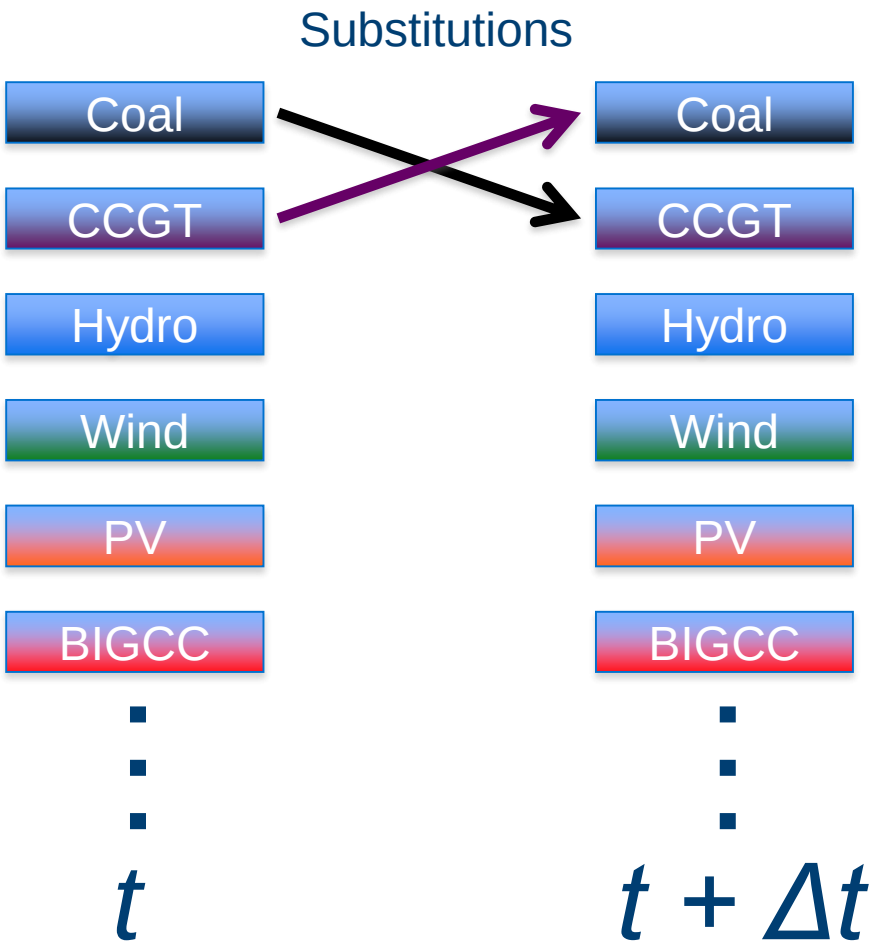
Probabilistic Choice matrix: $\left[F_{ij}\right]$

Modelling technology substitution

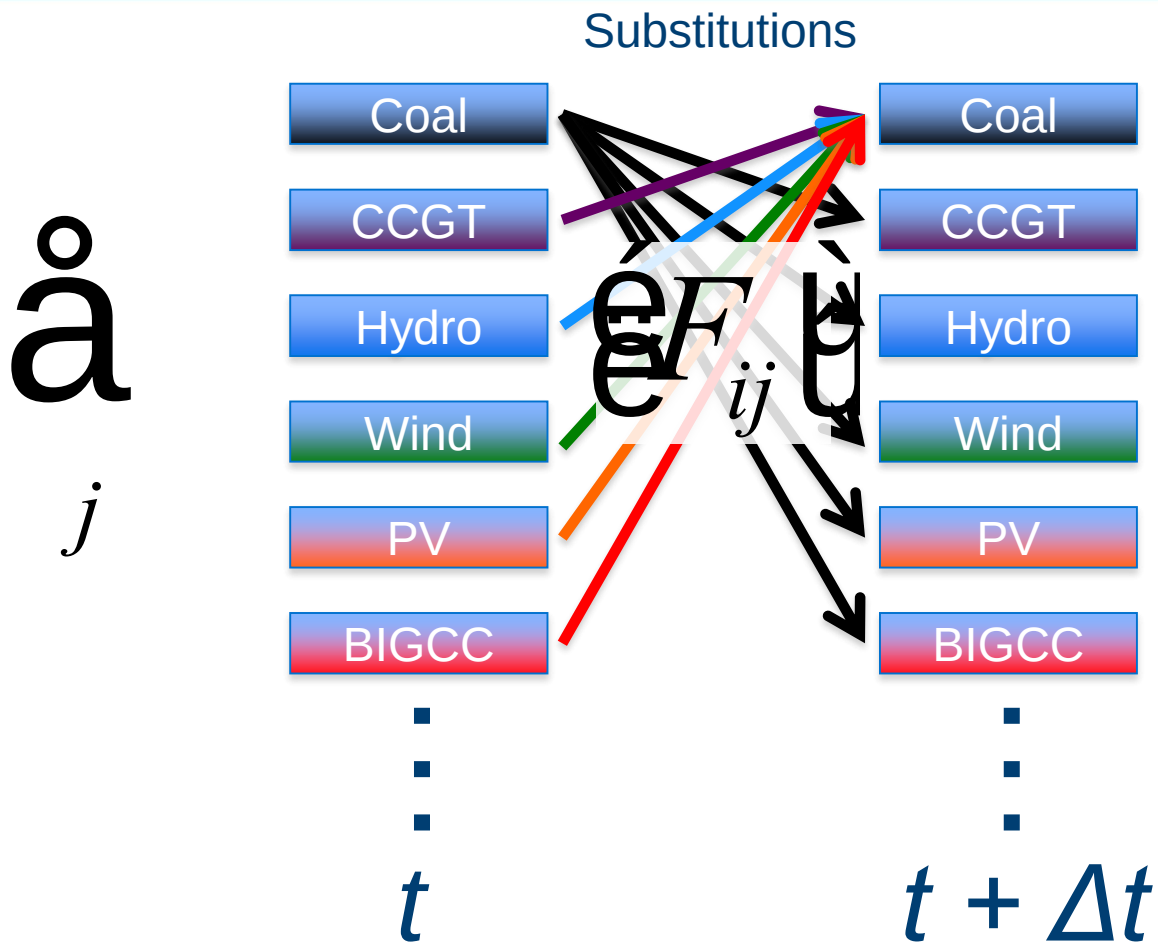


J.-F. Mercure, Energy Policy 48, 799-811 (2012)

Modelling technological change

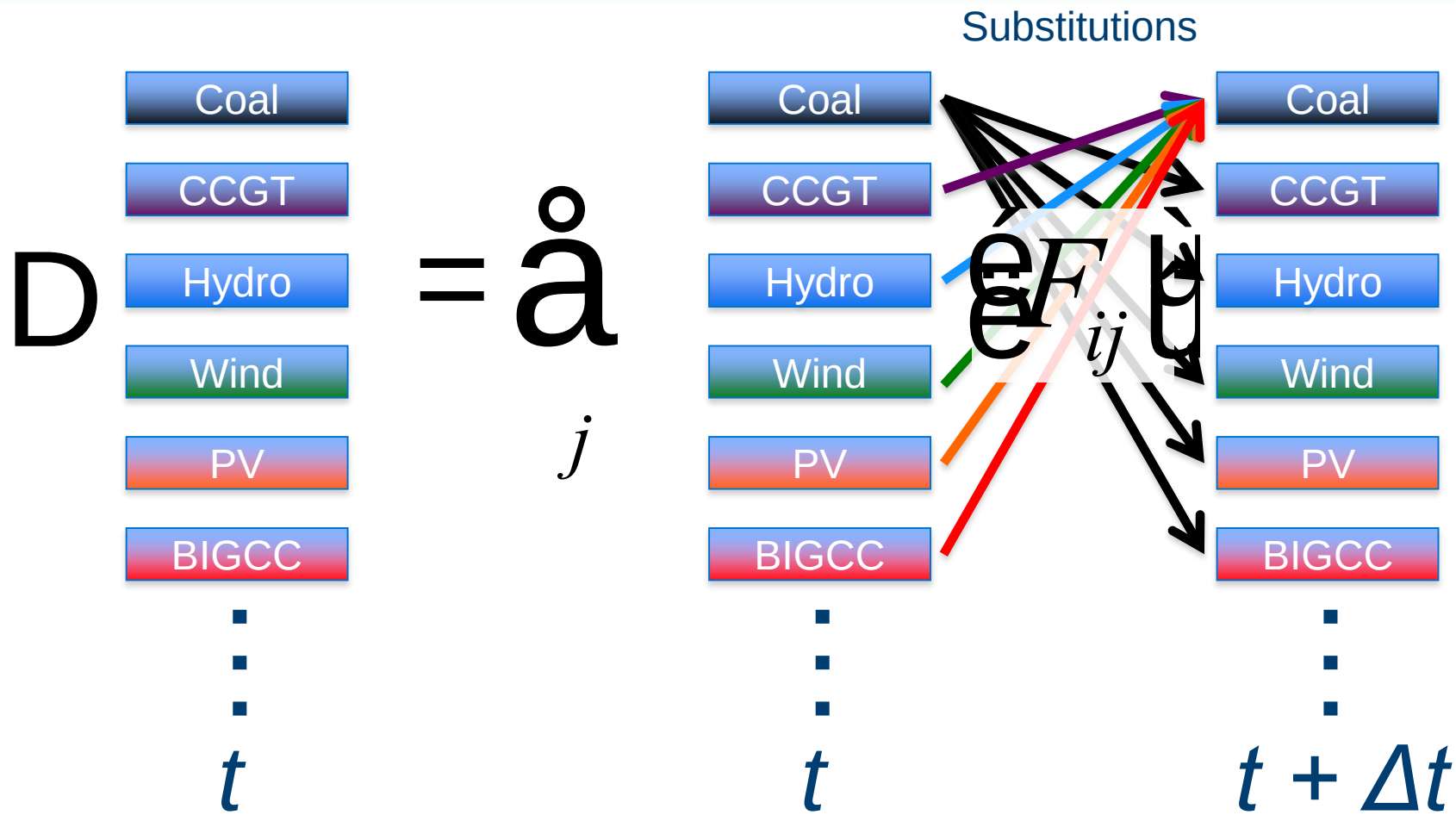


Counting technology substitutions



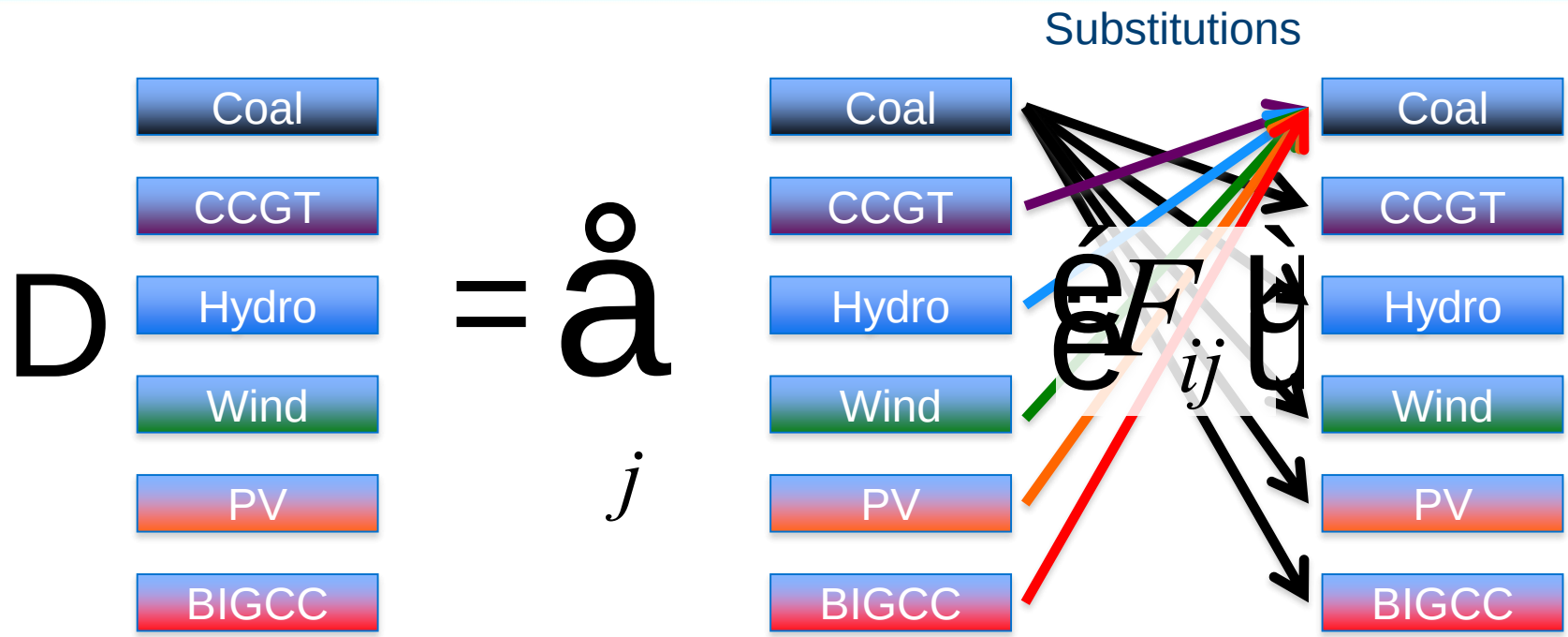
J.-F. Mercure, Energy Policy 48, 799-811 (2012)

Counting technology substitutions



J.-F. Mercure, Energy Policy 48, 799-811 (2012)

The Lotka-Volterra equation of population dynamics

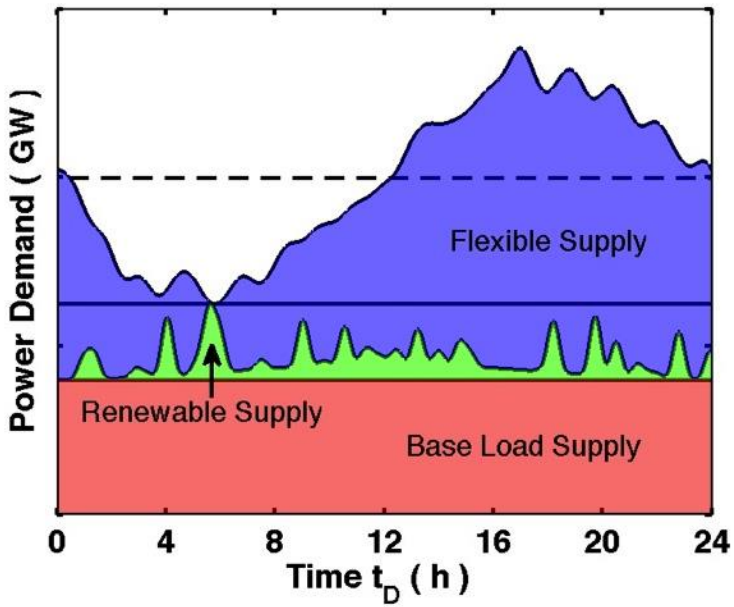


$$\Delta S_i = \sum_j S_i S_j \left(A_{ij} F_{ij} - A_{ji} F_{ji} \right) \Delta t$$

J.-F. Mercure, Energy Policy 48, 799-811 (2012)

Constraints of the system

Peak demand and storage capacity



$$\Delta S_i = \sum_j S_i S_j \left(A_{ij} F_{ij} G_{ij} - A_{ji} F_{ji} G_{ji}\right) \frac{1}{\bar{\tau}} \Delta t. \quad (1)$$

$$S_{flex} CF_{flex} + S_{var} CF_{var} + S_{base} CF_{base} = \overline{CF} \leq \overline{CF}_{rated}, \quad (2)$$

$$S_{flex} CF_{flex} + S_{var} CF_{var} \geq \overline{CF} \left(\frac{\Delta D}{D} + \frac{U_{var} T_D}{D} + \frac{E_s}{D}\right), \quad (3)$$

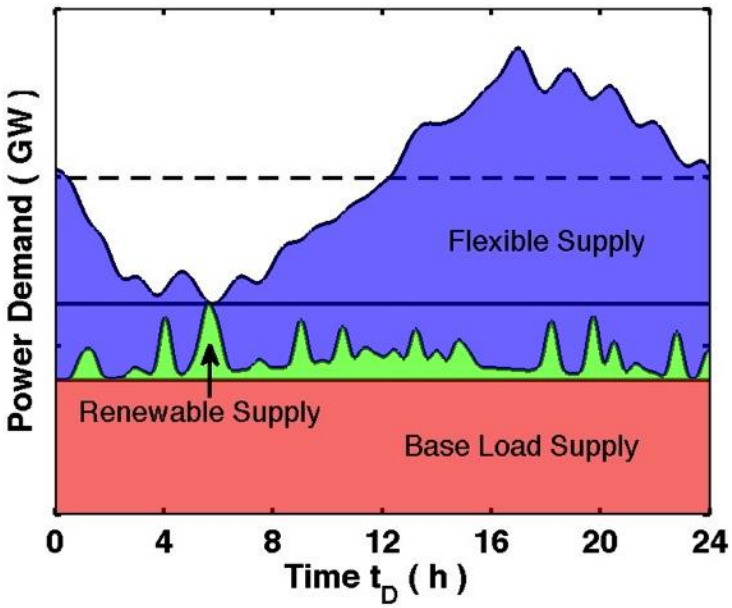
$$S_{flex} - S_{var} \geq \left(\frac{\Delta U_D}{U_{tot}} - \frac{U_s}{U_{tot}}\right), \quad (4)$$

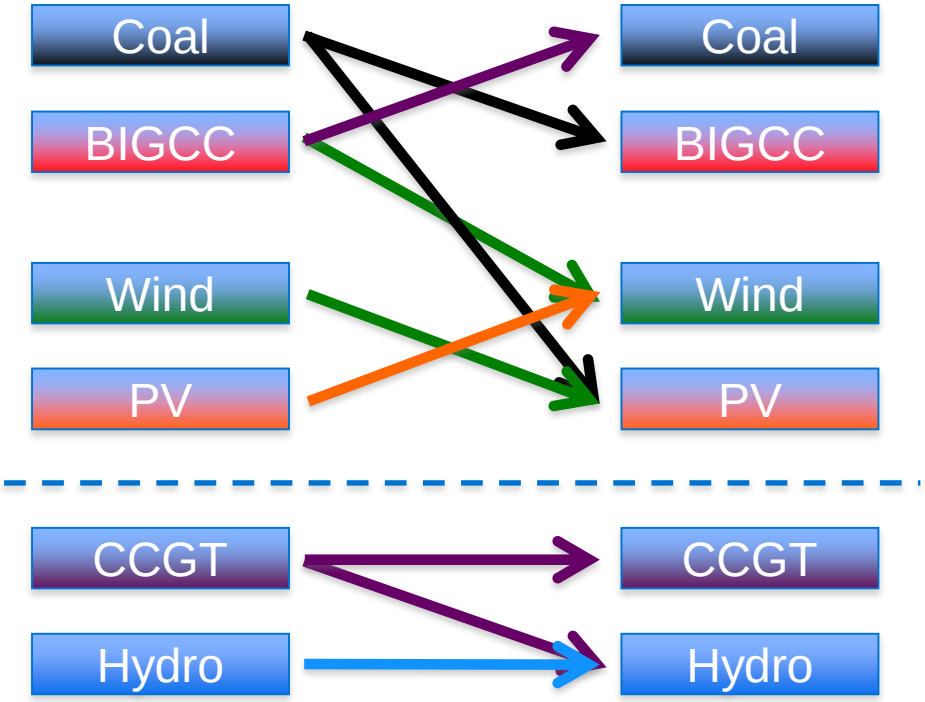
$$S_{base} + S_{var} \leq \left(\overline{CF} - \frac{1}{2}\frac{\Delta U_D}{U_{tot}} + \frac{U_s}{U_{tot}}\right), \quad (5)$$

Constrains growth of certain technologies
In situations of scarcity of flexibility
e.g. renewables in China

Constraints of the system

Base load vs peak load demand: splitting of the market





Results: electricity generation and emissions

Assumptions:

-Exogenous nuclear, and oil plant capacity

-All other generator types endogenous

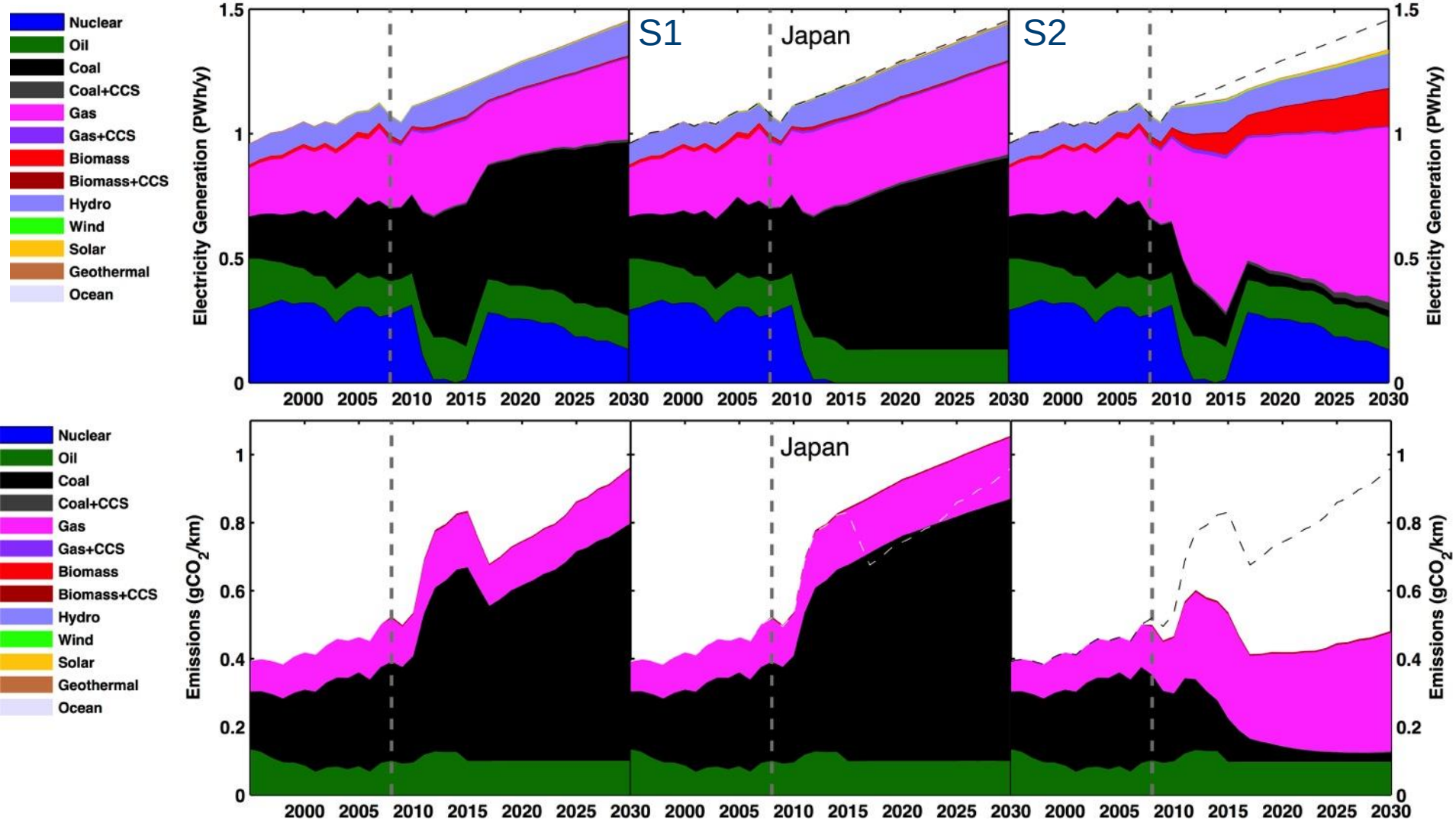
-S1: No new nuclear builds, existing plants remain until retirement

-S2: No new coal builds, existing plants remain until retirement

-All scenarios:

- FiTs for biomass, biogas, onshore+offshore wind and PV solar
- No subsidies or carbon taxes

Results: electricity generation and emissions



Results: electricity generation and emissions

Japan:

-Slow demand growth rate

-Nuclear shut down replaced by fossil fuels → emissions ↗

-Baseline: emissions go back to original trajectory when nuclear restarts

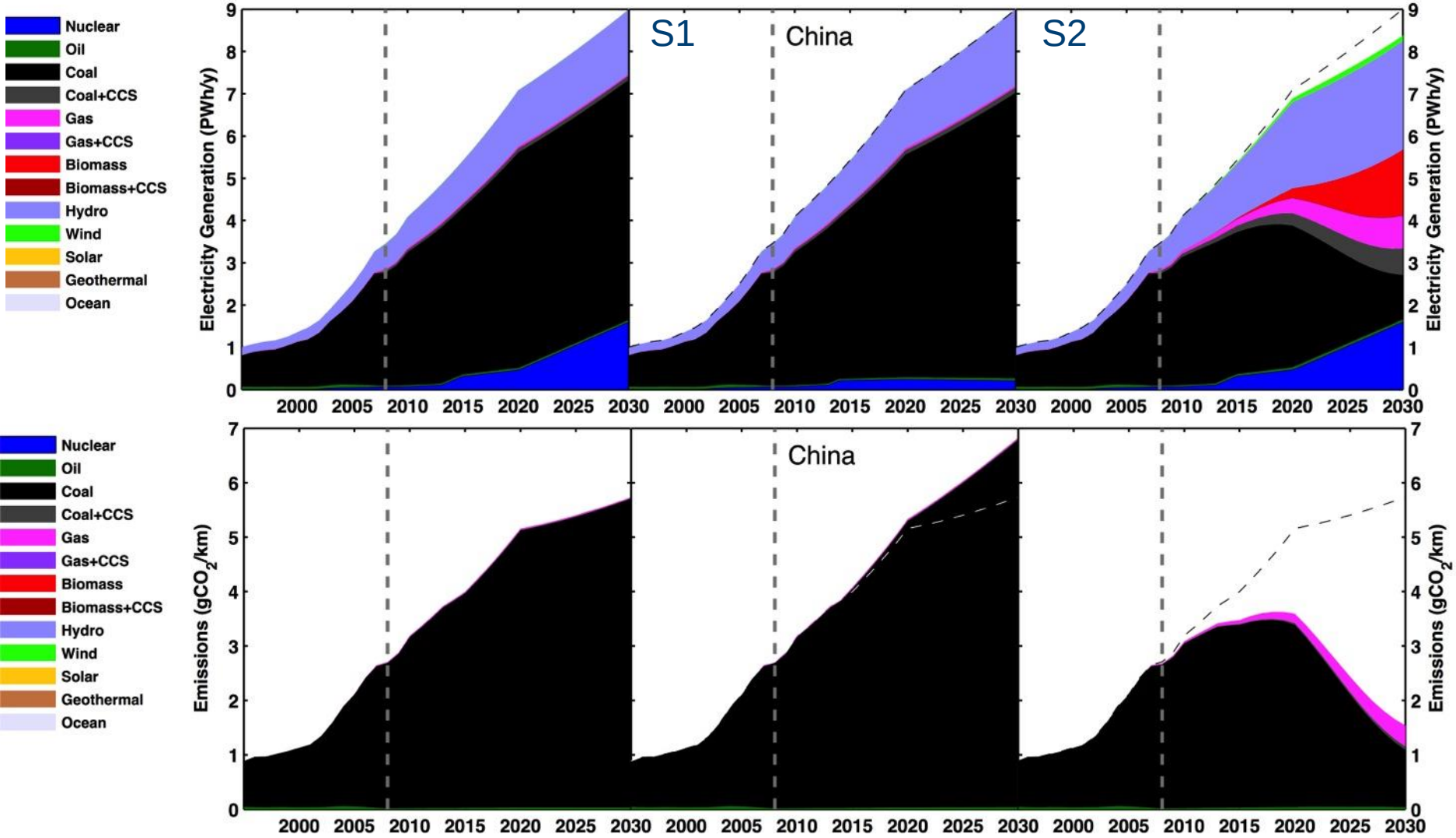
-S1: nuclear replaced by coal, emissions higher than Baseline

- Double 2008 emissions level in 2030
- Electricity consumption unchanged

-S2: coal replaced by gas + renewables,

- Emissions in 2030 ~ 2008 level
- Electricity consumption reduce (~8%) due to higher price

Results: electricity generation and emissions



Results: electricity generation and emissions

China:

- Fast demand growth, fast rise in emissions mostly from coal

-Baseline:

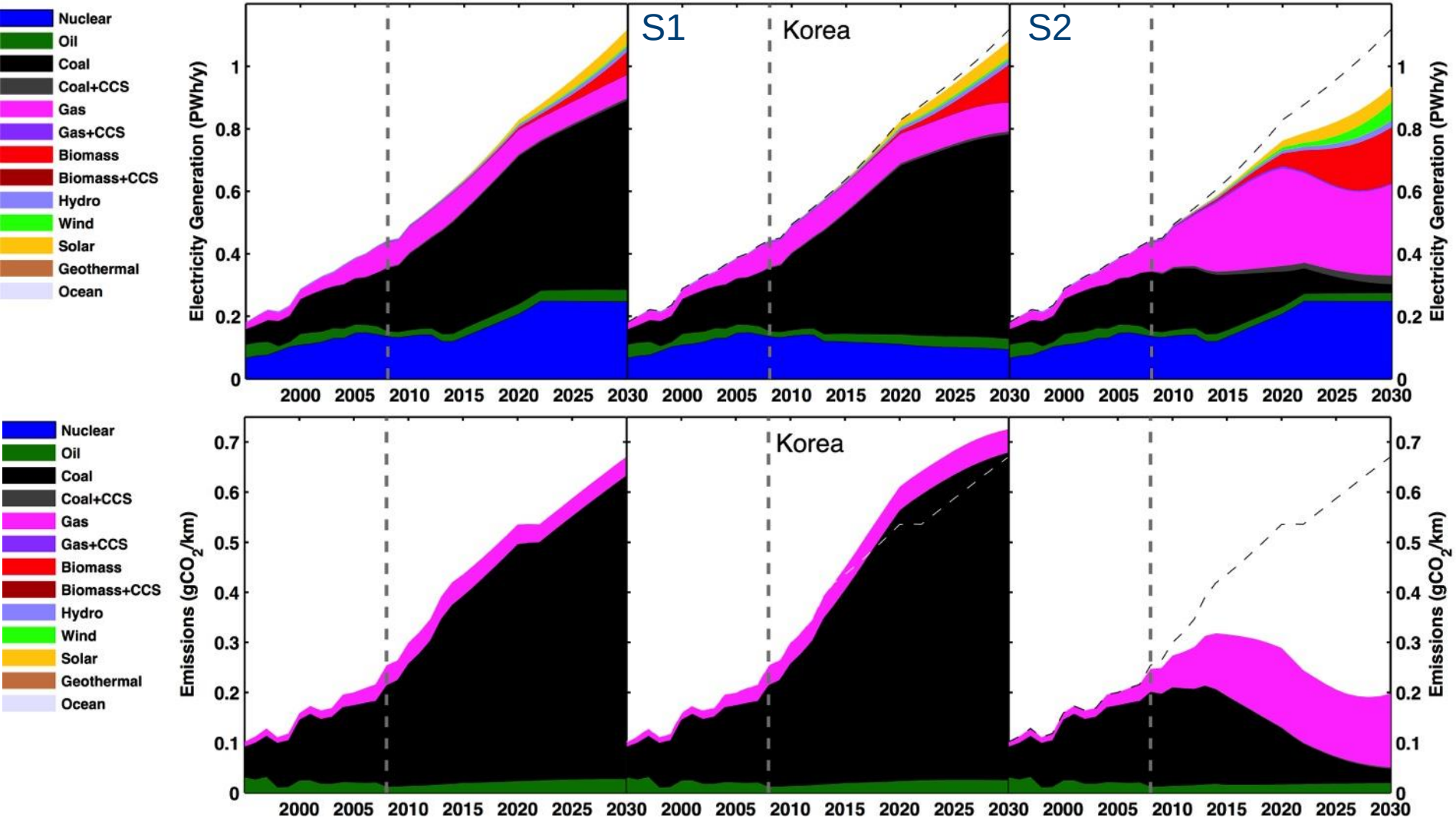
- large nuclear capacity rise (assumption)
- Hydro resources generally near the limit (FTT cost-supply curve)
- Other renewables quite insignificant

-S1: nuclear entirely replaced by coal, → emissions higher than Baseline
~ 2.5 times higher in 2030 than in 2008

-S2: coal replaced by expensive hydro projects + large scale biomass + gas

- Consumption reduced (~9%) due to higher price
- Emissions *below 2008 level* (~50%)

Results: electricity generation and emissions



Results: electricity generation and emissions

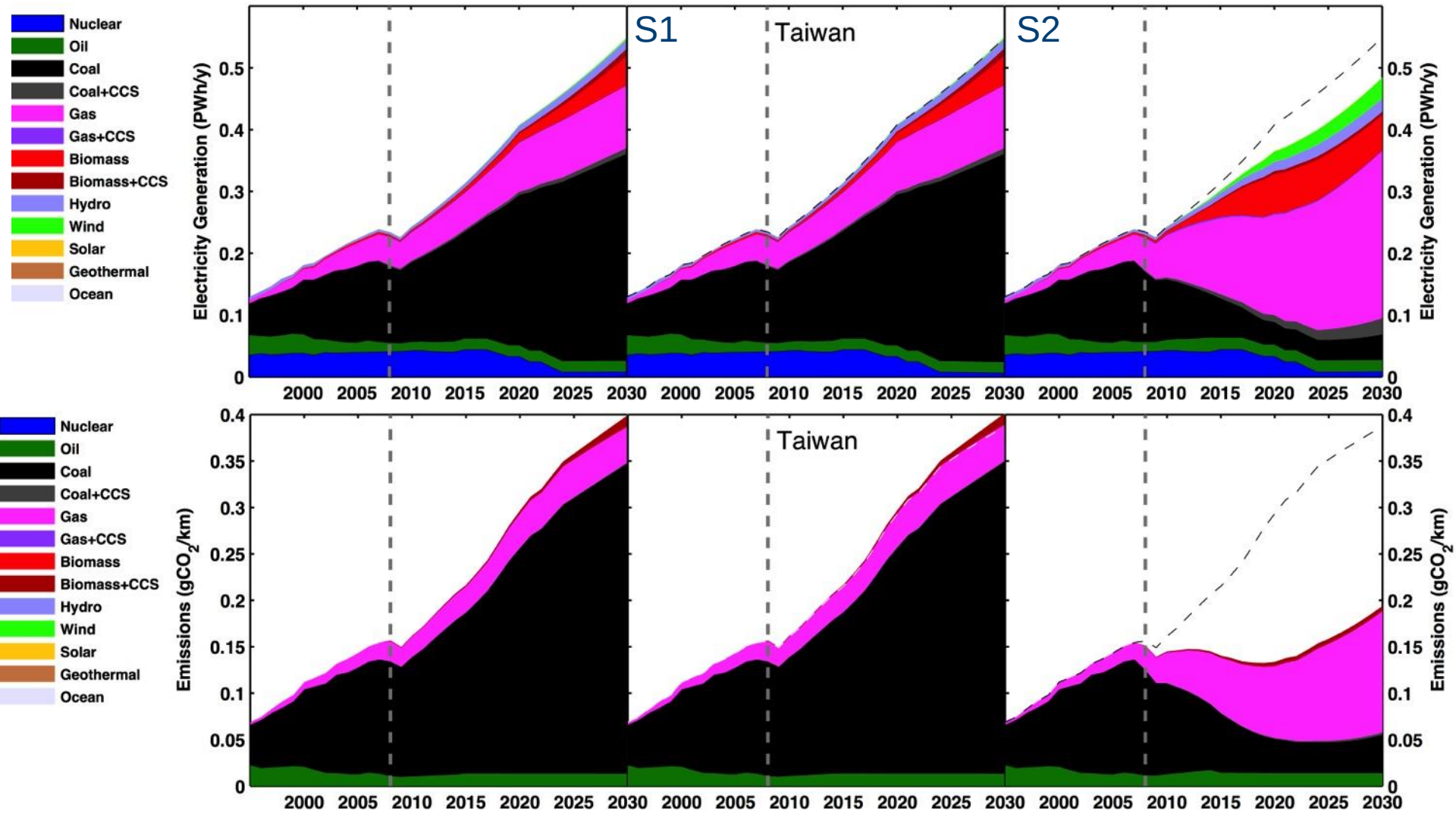
Korea:

-Fast growth rate of demand and emissions, large amounts of coal

-Important share of nuclear

- Baseline: fast rise of coal, some renewables (due to FiT)
    - Rise in nuclear (assumption)
- S1: nuclear replaced by coal → emissions higher than baseline
- S2: coal replaced by gas + renewables + nuclear,
    - Emissions in 2030 ~ 2008 level
    - Electricity consumption reduce (~15%) due to higher price

Results: electricity generation and emissions



Results: electricity generation and emissions

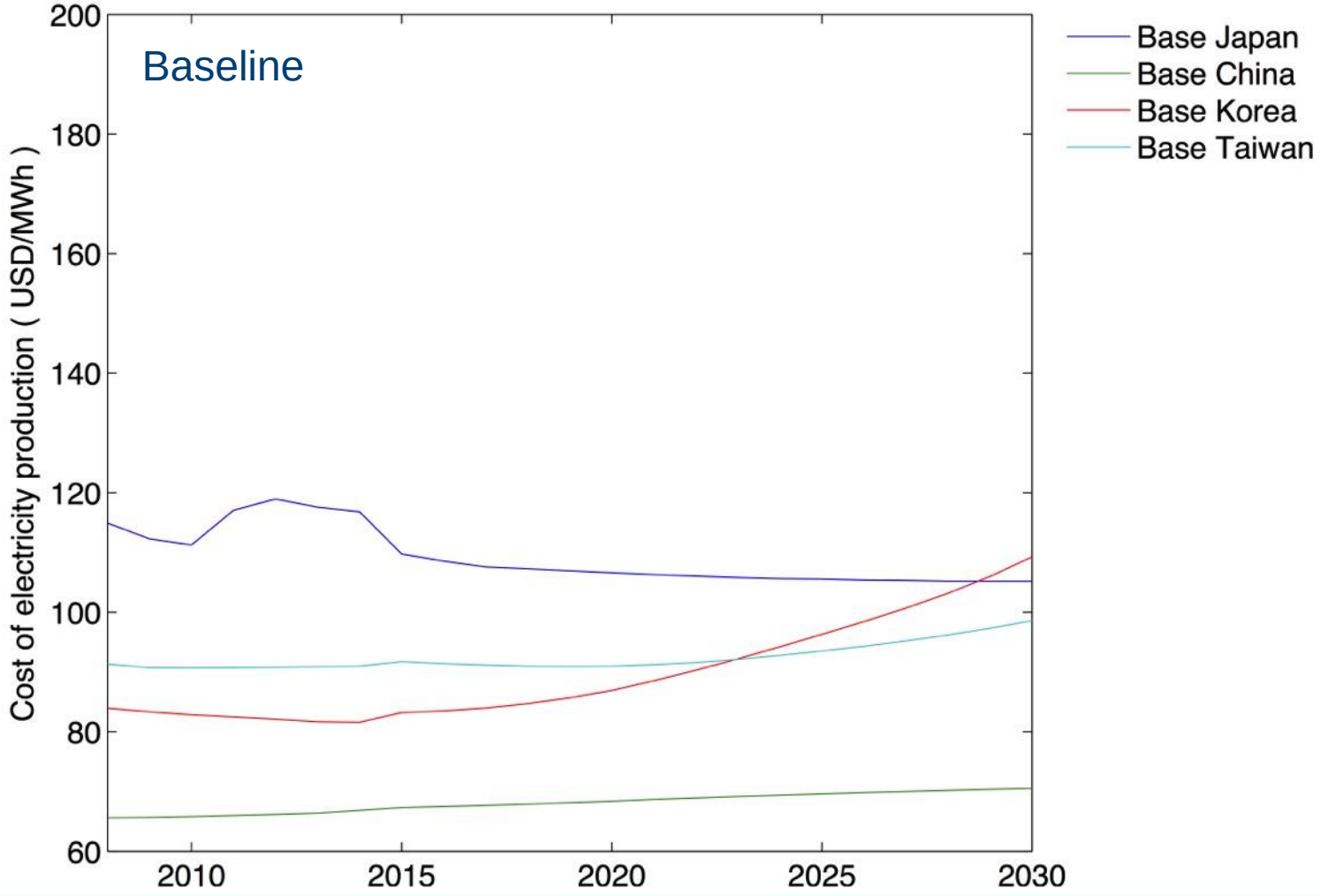
Taiwan:

-Fast growth rate of demand and emissions, large amounts of coal

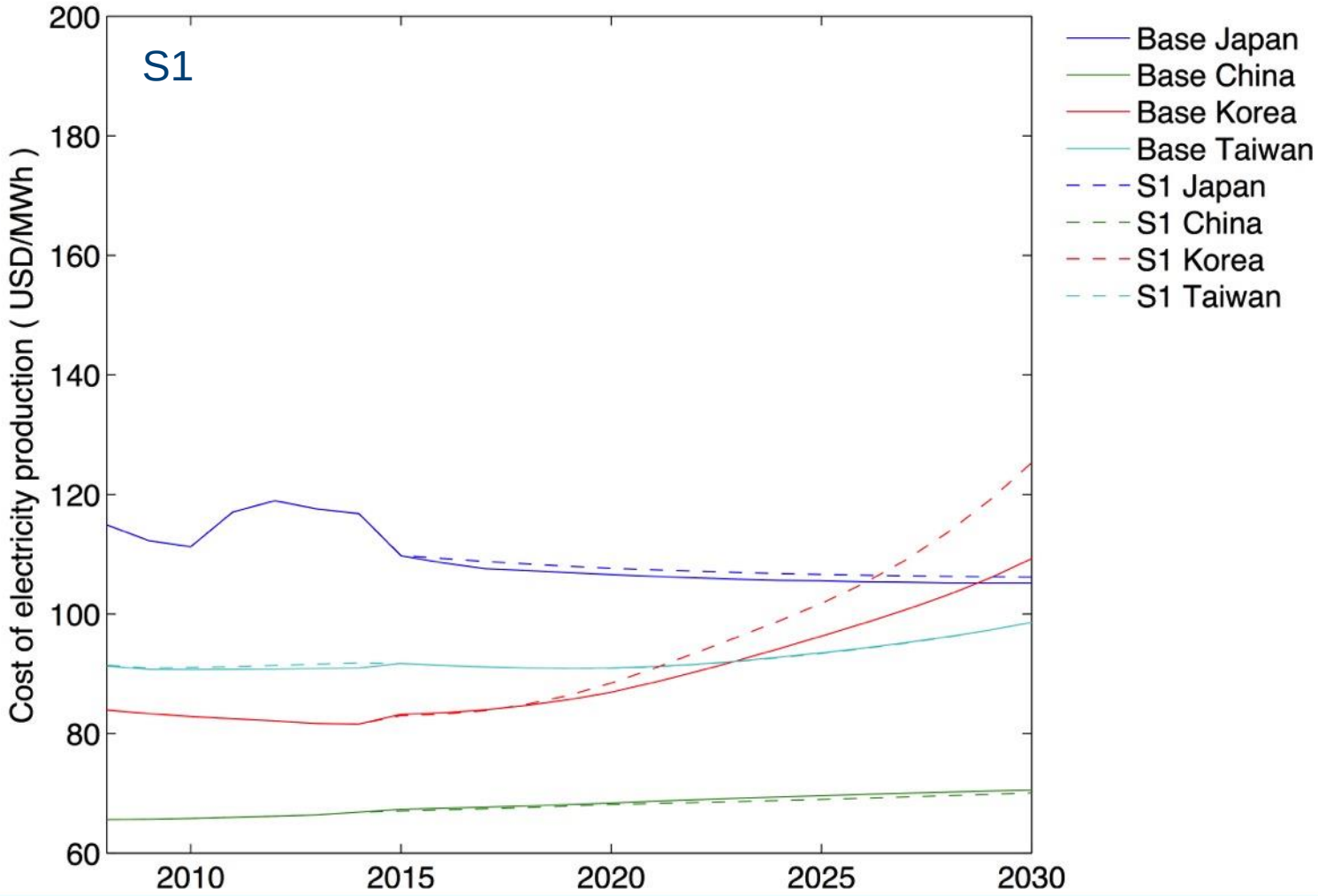
-Important share of nuclear

- Baseline: fast rise of coal, some renewables (due to FiT)
    - Rise in nuclear (assumption)
- S1: nuclear replaced by coal → emissions higher than baseline
- S2: coal replaced by gas + renewables + nuclear,
    - Emissions in 2030 ~ 2008 level
    - Electricity consumption reduce (~15%) due to higher price

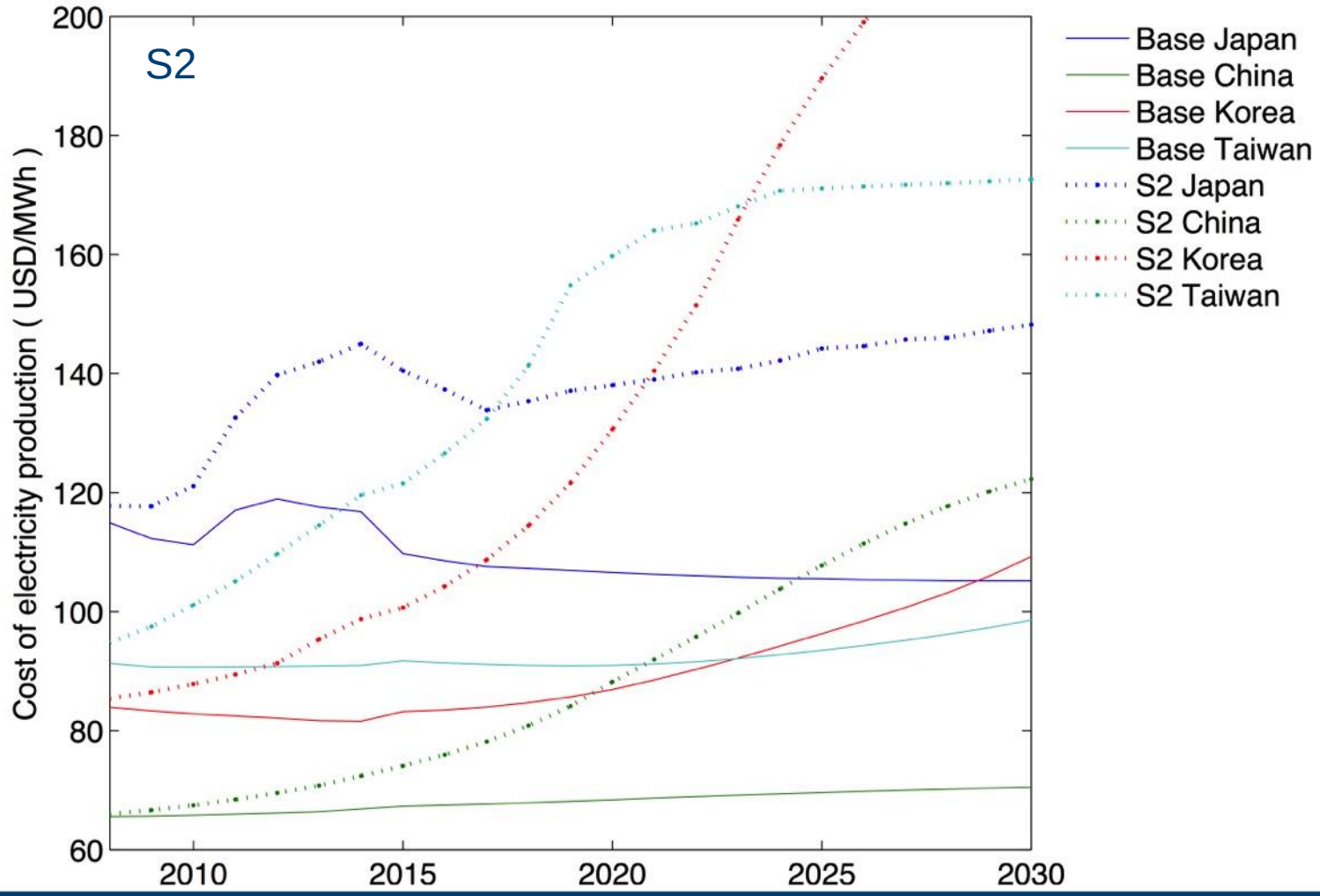
Results: electricity generation costs



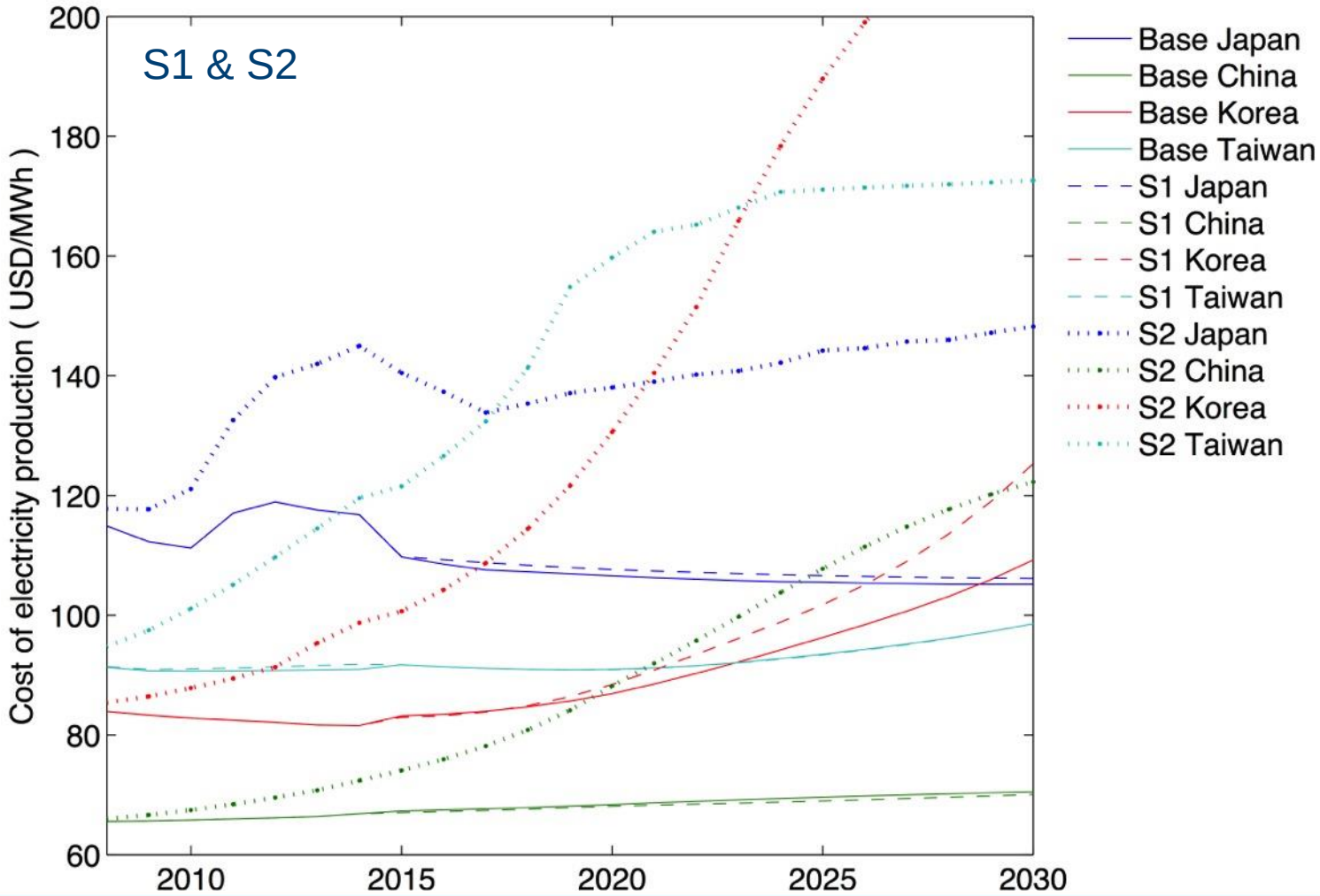
Results: electricity generation costs



Results: electricity generation costs



Results: electricity generation costs



Results: electricity generation costs

Baseline:

- Costs are nearly constant throughout the period

S1:

- Costs are nearly unchanged in all cases,
    - nuclear is replaced by coal

S2

- Costs increase significantly in all cases:
    - Coal is the least cost option, which we phase out
    - FiT costs are added to total system costs
        - Uptake of renewables expensive
    - Grid balance provided by more hydro + gas turbines

List of model references

- Data exploration on the 4CMR website:
  http://www.4cmr.group.cam.ac.uk/research/FTT/fttviewer
- Definition of FTT:Power: J-F Mercure, Energy Policy, **48** 799-811 (2012)
- Energy resources database: Mercure & Salas, Energy, **46** 322-336 (2012)
- Consumption of non-renewable resources: Energy Policy, **63**, 469-483 (2013)
  See also 4CMR working papers: http://ideas.repec.org/p/ccc/wpaper/002.html
- Technology diffusion theory: http://arxiv.org/abs/1304.3602
- Electricity sector scenarios and policy analysis: Energy Policy **73** 686-700 (2014)
- Economic impacts of decarbonisation: http://arxiv.org/abs/1310.4403