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Decarbonizing the East Asian Steel Industry in 2050 – An analysis performed using E3ME-FTT:Steel

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clarity from complexity

Research question and objective

Research goal:

It is the goal of this research to provide **policymakers** in **China**, **Japan**, **Korea**, and **Taiwan** with valuable insights on how **low carbon policies** such as carbon taxes affect **technological diffusion** and **emission reduction** until 2050 in the iron and steel industry.

Research Question:

*What kind of **decarbonisation** can be achieved for the **Chinese**, **Japanese**, **Korean**, and **Taiwanese iron and steel industries** up to **2050** by imposing varying **carbon taxes**?*

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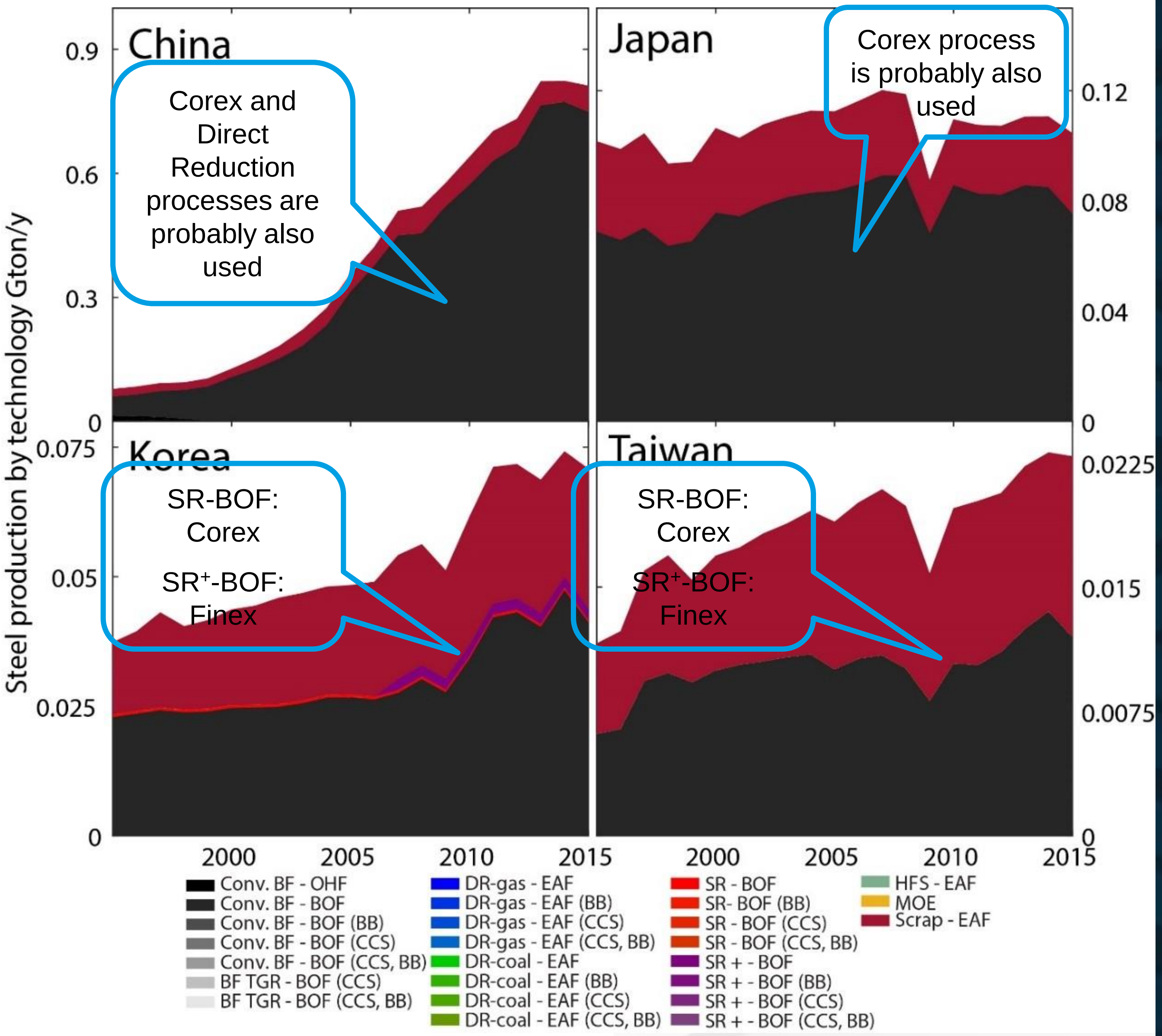
The Steel Industry's contribution to GHG emissions

- Iron and Steel industry emitted ~5% of <u>global</u> CO_2 emissions, ~32% of <u>industrial</u> CO_2 emissions, and consumed ~30% of all <u>coal</u>
- East Asian countries produce most of all steel (<u>61%</u>)
  - China: 49.2% (832 Mt of crude steel)
  - Japan: 6.2% (105 Mt of crude steel)
  - Korea: 4.2% (71 Mt of crude steel)
  - Taiwan: 1.3% (22 Mt of crude steel)

Development of steel production



China's crude steel output was on par with Japan's output in 1995, but has since surpassed Japan and any other country

Korea and Taiwan gradually increased their output.

Japan's output remained constant

Due to data gaps several uncommon technologies are not represented (e.g. technologies that use SR or DR)

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Possible ways to decarbonise the iron and steel industry

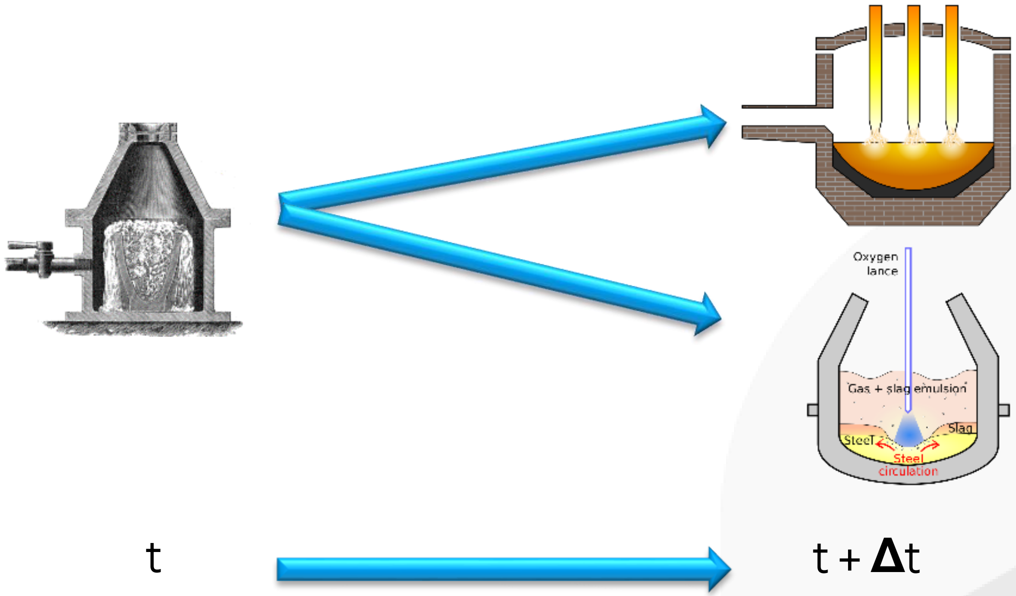
- **Incremental** innovation: Improving **energy efficiency** through **learning**
- Switch fuel source: Fossils → **Biomass**
- **Radical** innovation:
  - Switch reducing agent:
    - Carbon-based → **Hydrogen-based**
    - Carbon-Based → **Direct electrolysis** of iron ore
  - **Carbon Capture and Storage/Utilisation** (+ Biomass = negative nett emissions)
- **Recycling** (i.e. Secondary production)

Policies to incentivise decarbonisation of the steel industry

- Market pull policies:
  - Regulations
  - Carbon tax
  - Material tax / subsidy
- Technology push policies:
  - Subsidies on capital investment
  - Planned capacity additions
  - Energy efficiency investments (prototype)
  - R&D investments (prototype)
- Miscellaneous policies:
  - Capacity utilisation regulation

Future Technology Transformations

- First developed by Jean-Francois Mercure for the power sector (**FTT:Power**)
- Followed by **FTT:Transport** (Aileen Lam), **FTT:Heat** (Florian Knobloch), **FTT:Steel** (me), and soon by **FTT:Agri** (Soeren Lindner)
- FTT simulates technological diffusion in a given sector by taking into account external influences (**E3ME**)



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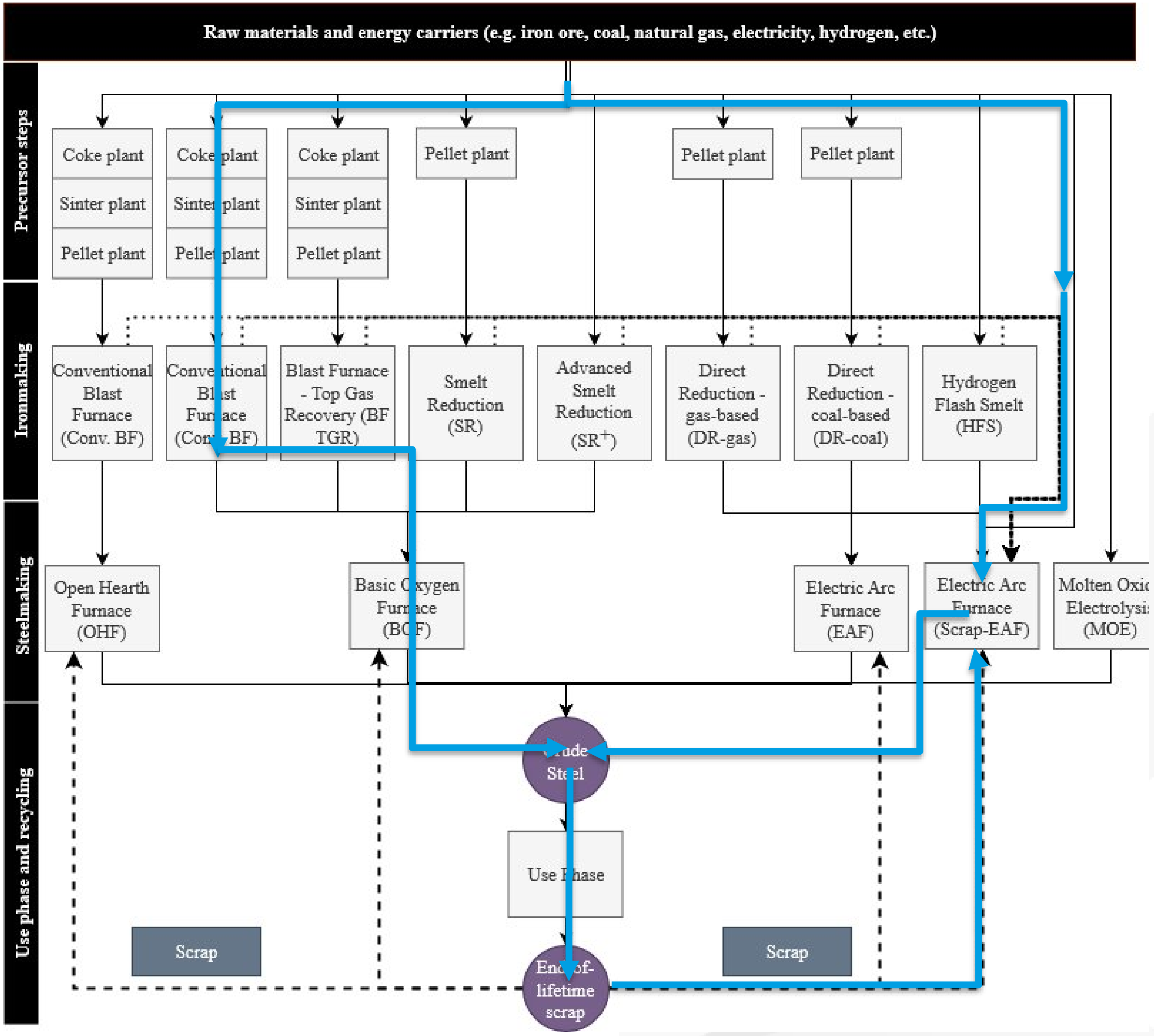
Domain of FTT:Steel



In FTT:Steel, the pathways illustrated on the left were identified.

We assume that all precursor processes (e.g. coking of coal, or pelletising iron ore), and ironmaking occurs on-site.

For each integrated steelmaking route, several variants exists (see next slide).

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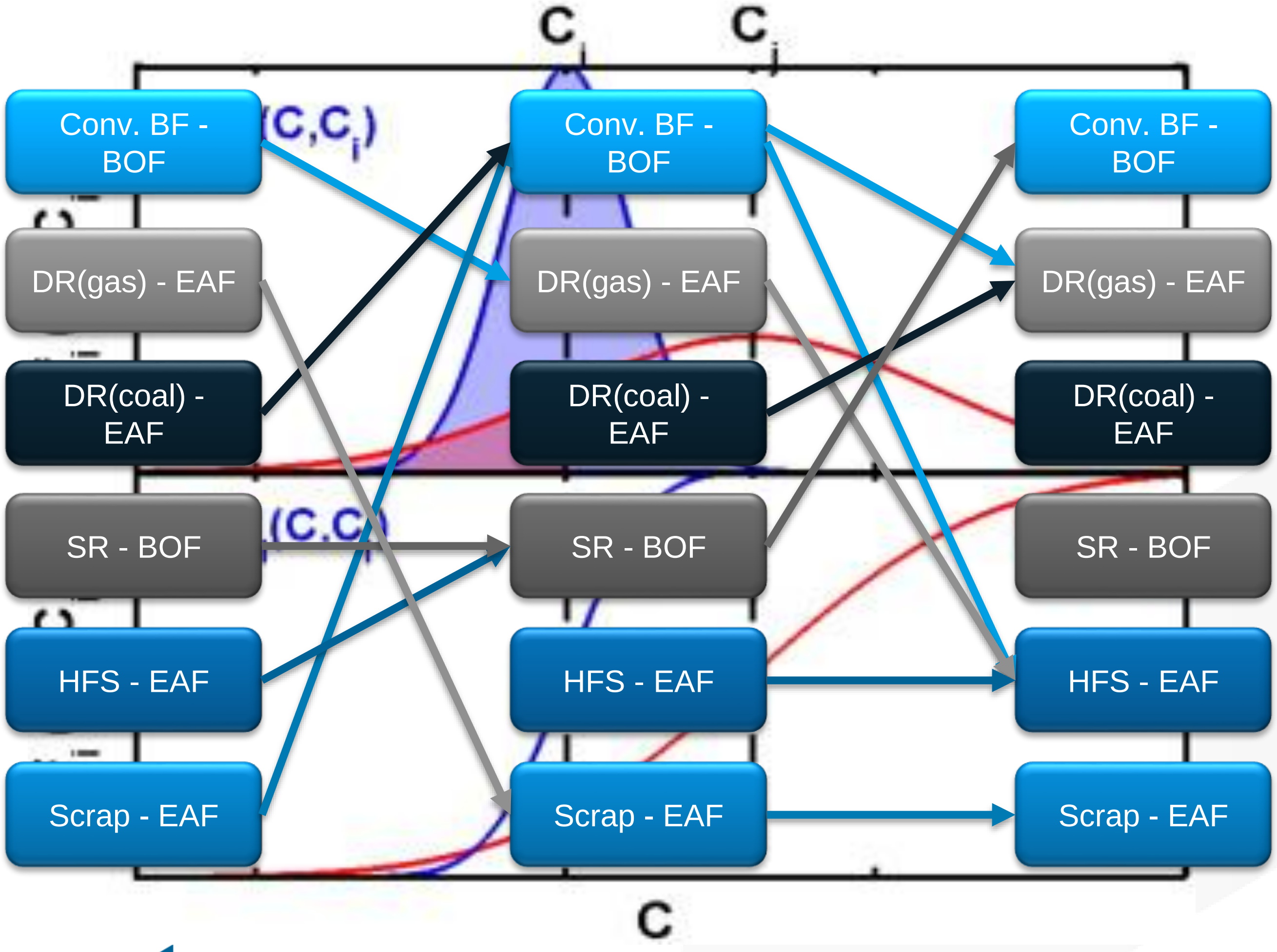
Integrated steelmaking routes included in FTT:Steel

Ironmaking technology	Steelmaking technology	Integrated steelmaking designation	# of variations
Conv. BF	OHF	Conv. BF-OHF	1 (D)
Conv. BF	BOF	Conv. BF-BOF	4 (D,BB,CCS,CCSBB)
BF TGR	BOF	BF TGR-BOF	2 (CCS, CCSBB)
DRI (gas)	EAF	DRI (gas) -EAF	4 (D,BB,CCS,CCSBB)
DRI (coal)	EAF	DRI (coal) -EAF	4 (D,BB,CCS,CCSBB)
SRI	BOF	SRI-BOF	4 (D,BB,CCS,CCSBB)
SRI+	BOF	SRI+-BOF	4 (D,BB,CCS,CCSBB)
HFS	EAF	HFS-EAF	1 (D)
-	MOE	MOE	1 (D)
-	EAF	Scrap-EAF	1 (D)
Total No. of technologies in FTT:Steel			26

D = Default; BB = Bio-based; CCS = Carbon capture and storage/utilisation; CCSBB = Carbon capture and storage/utilisation in combination with bio-based production

FTT Methodology



FTT calculates the Levelised Cost of Steelmaking (LCOS) → (imperfect) Investor preferences → Can be affected by:

- Learning-by-doing
- Prices of raw materials
- (Un)availability of scrap
- Emissions (when carbon taxes are applied)

Market share changes are then proportional to investor preferences, and technological and sectoral constraints

E3ME: Key Features

Comprehensive

- integrated treatment that places the economy inside the constraints of society and the natural environment
- global coverage but highly disaggregated at national and sectoral level
- wide coverage of economic, social and environmental indicators

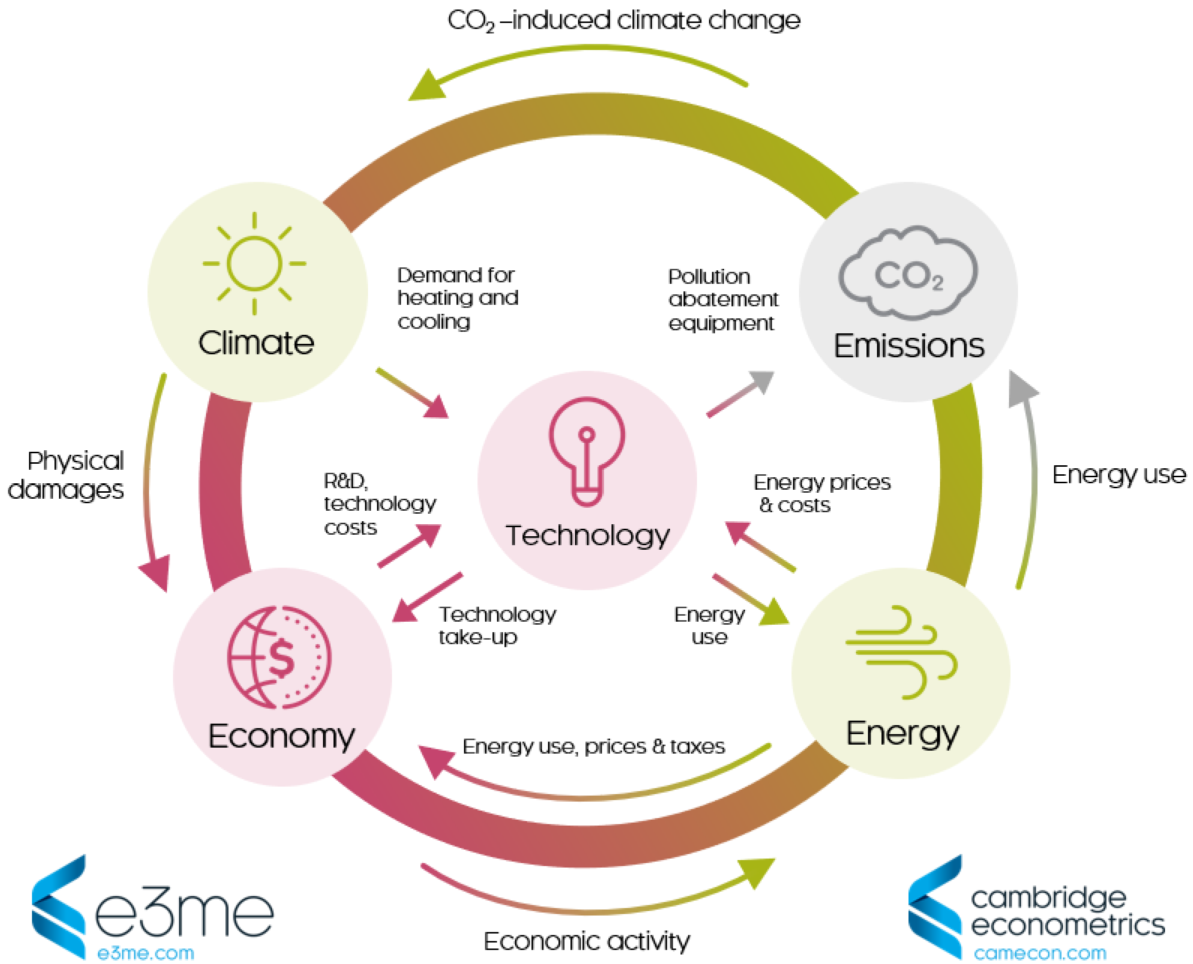
Adaptable

- well-suited to both short-term and long-term analysis
- dynamic modelling of technology take-up
- designed to assess the key challenges facing policy makers
- flexibility to test a diverse range of policies

Robust and transparent

- strong empirical grounding through its econometric equations
- a track record of application over 25 years
- a publicly available model manual

Structure of E3ME



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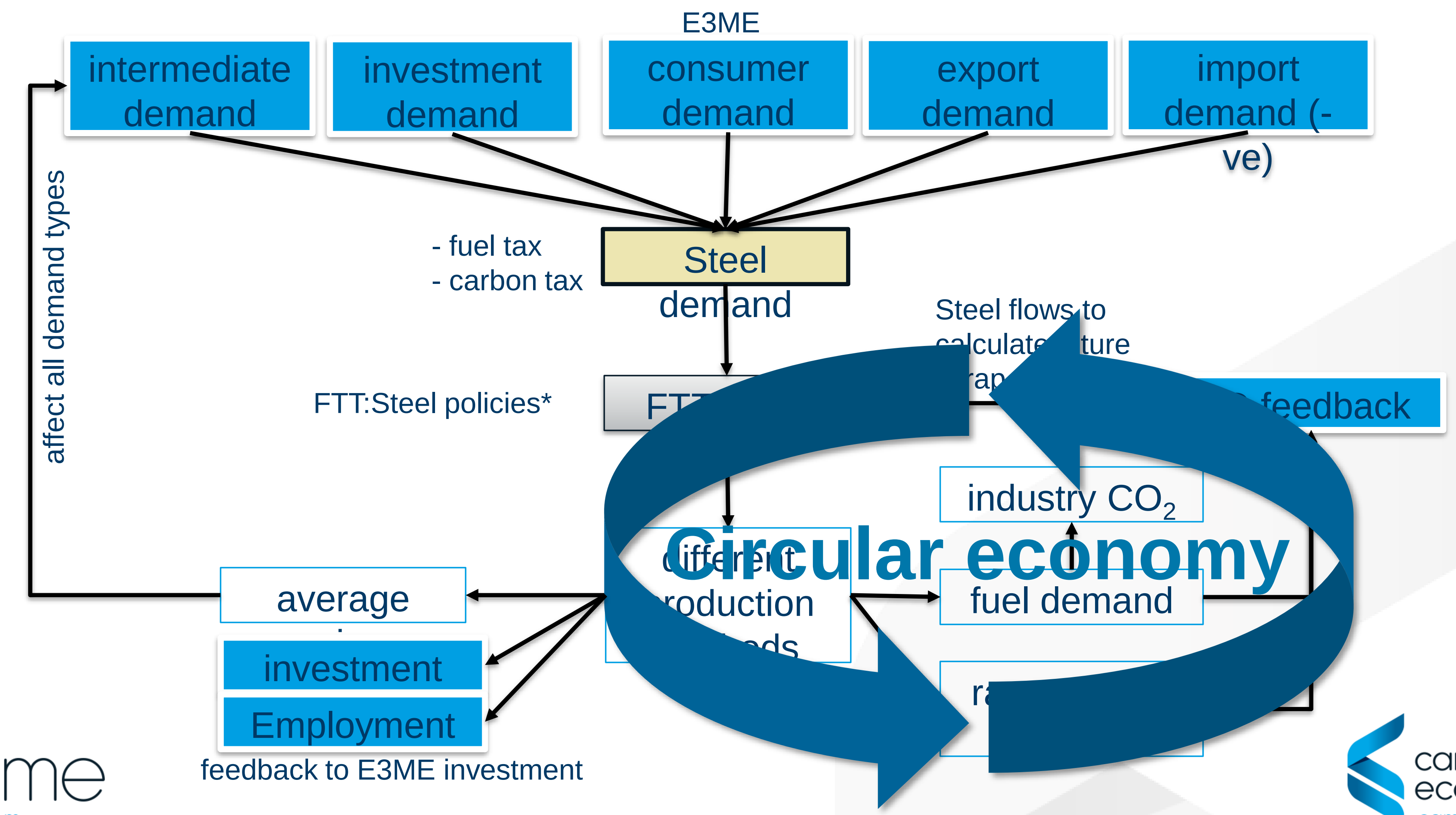
E3ME is a macro-econometric model designed to assess global policy challenges.

It connects Energy, Economy, and Environment. The innovation part is done via FTT for specific sectors.

How does FTT:Steel fit within E3ME?

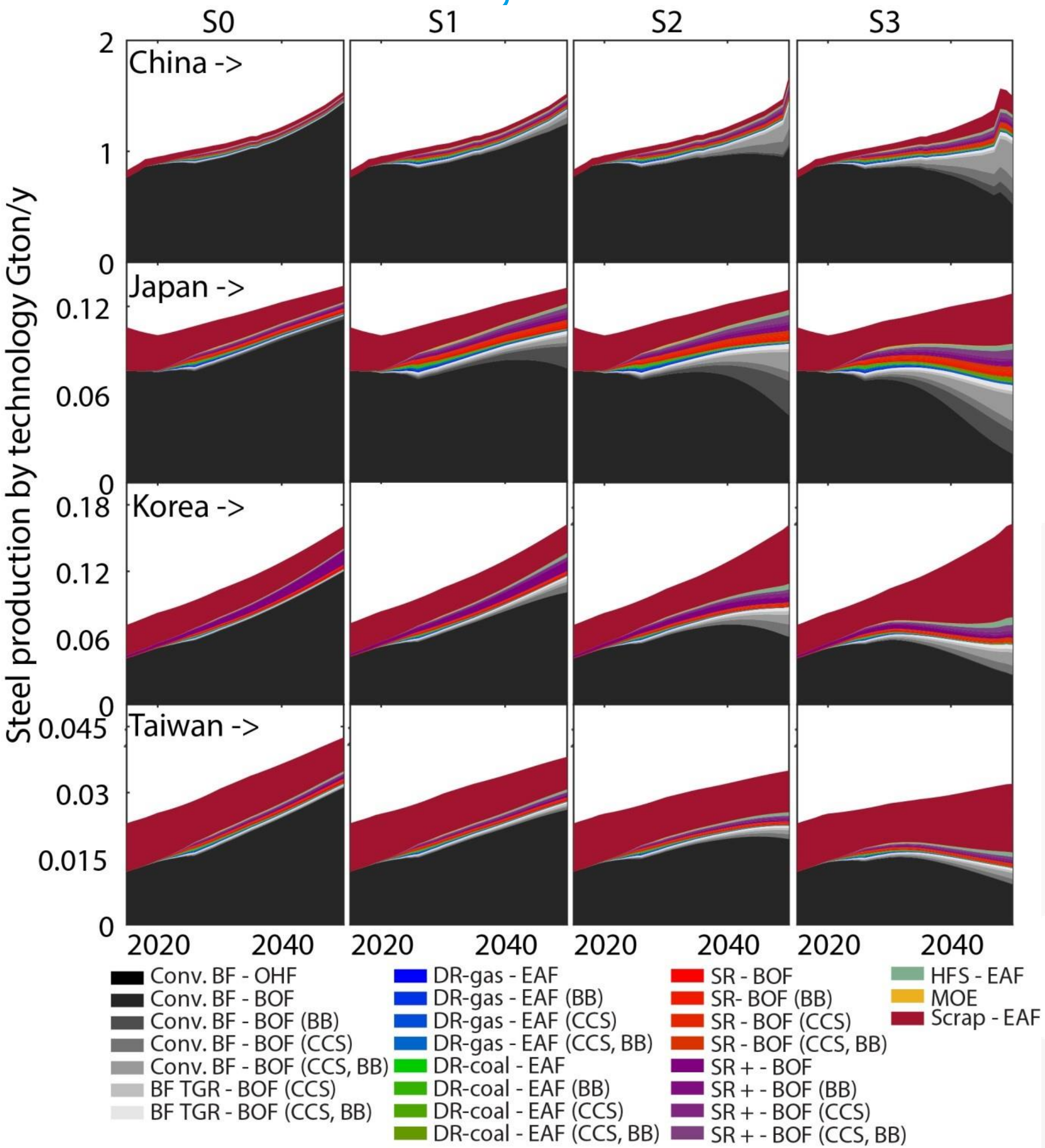


Decarbonisation scenarios

Baseline scenario	No policies	-
Scenario a	Low carbon tax case	$10\$_{2008}$ to $50\$_{2008}$ (2020-2050)
Scenario b	Medium carbon tax case	$10\$_{2008}$ to $100\$_{2008}$ (2020-2050)
Scenario c	High carbon tax case	$10\$_{2008}$ to $200\$_{2008}$ (2020-2050)

Policies apply economy wide!

Technological diffusion



Investors in China mainly choose for variations of the Conv. BF – BOF.

In Japan, the diffusion of SR and SR+ (-BOF) and HFS-EAF gain minor market shares

Korea and Taiwan mainly switch towards the Scrap-EAF route (~50% market share) and, to a smaller degree, towards HFS-EAF (~4%)

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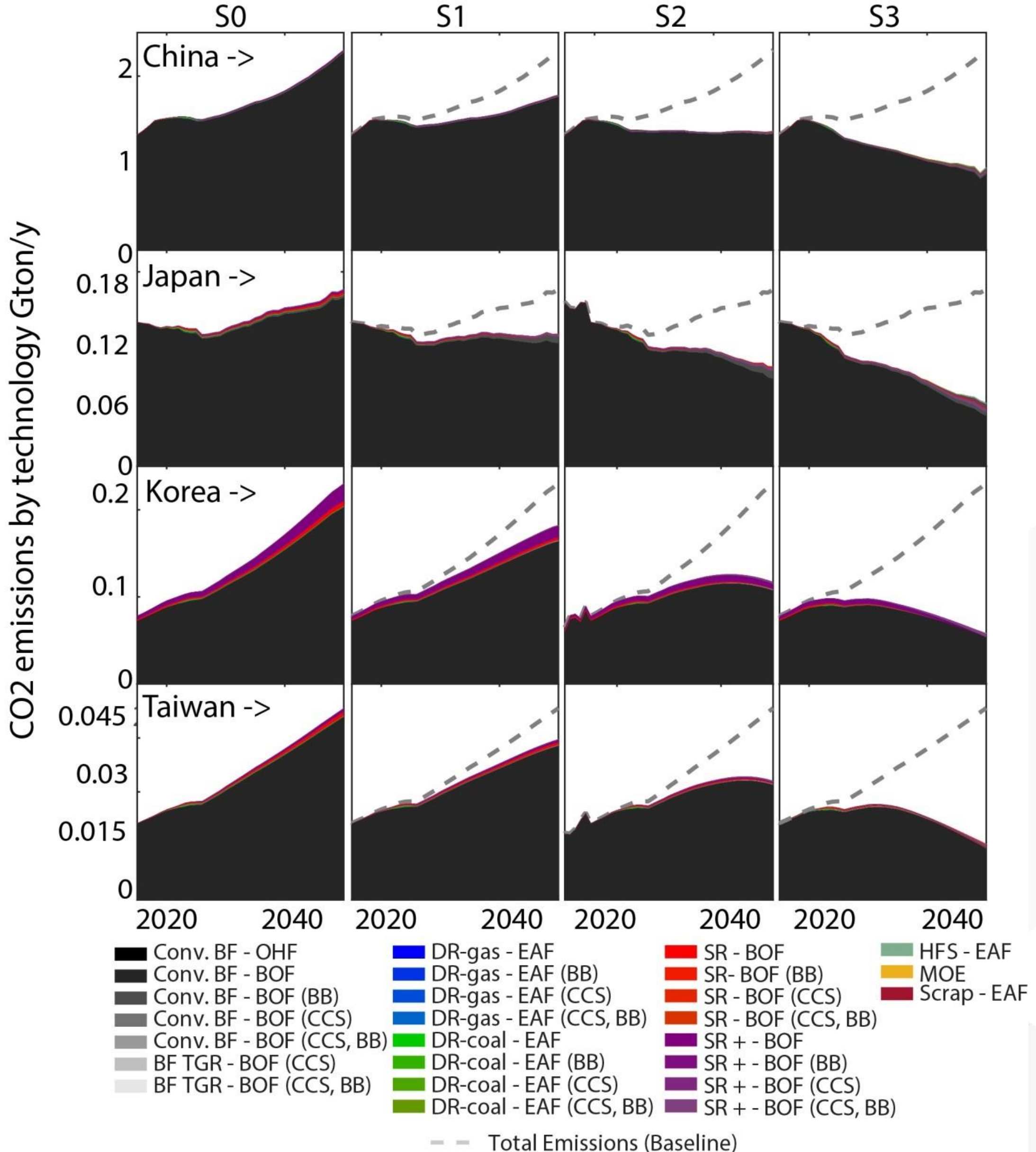
CO_2 Emissions



Compared to	China			Japan		
	S1	S2	S3	S1	S2	S3
2005 levels (%)	251	191	49	-23	-49	-62
2050 baseline (%)	-13	-51	-63	-26	-51	-68
Total averted (Gt CO_2)	**3.5**	**7**	**13.6**	**0.5**	**0.9**	**1.4**

Compared to	Korea			Taiwan		
	S1	S2	S3	S1	S2	S3
2005 levels (%)	272	117	-27	160	91	-34
2050 baseline (%)	-16	-51	-83	-11	-35	-77
Total averted (Gt CO_2)	**0.4**	**1**	**2**	**<0.1**	**0.2**	**0.4**

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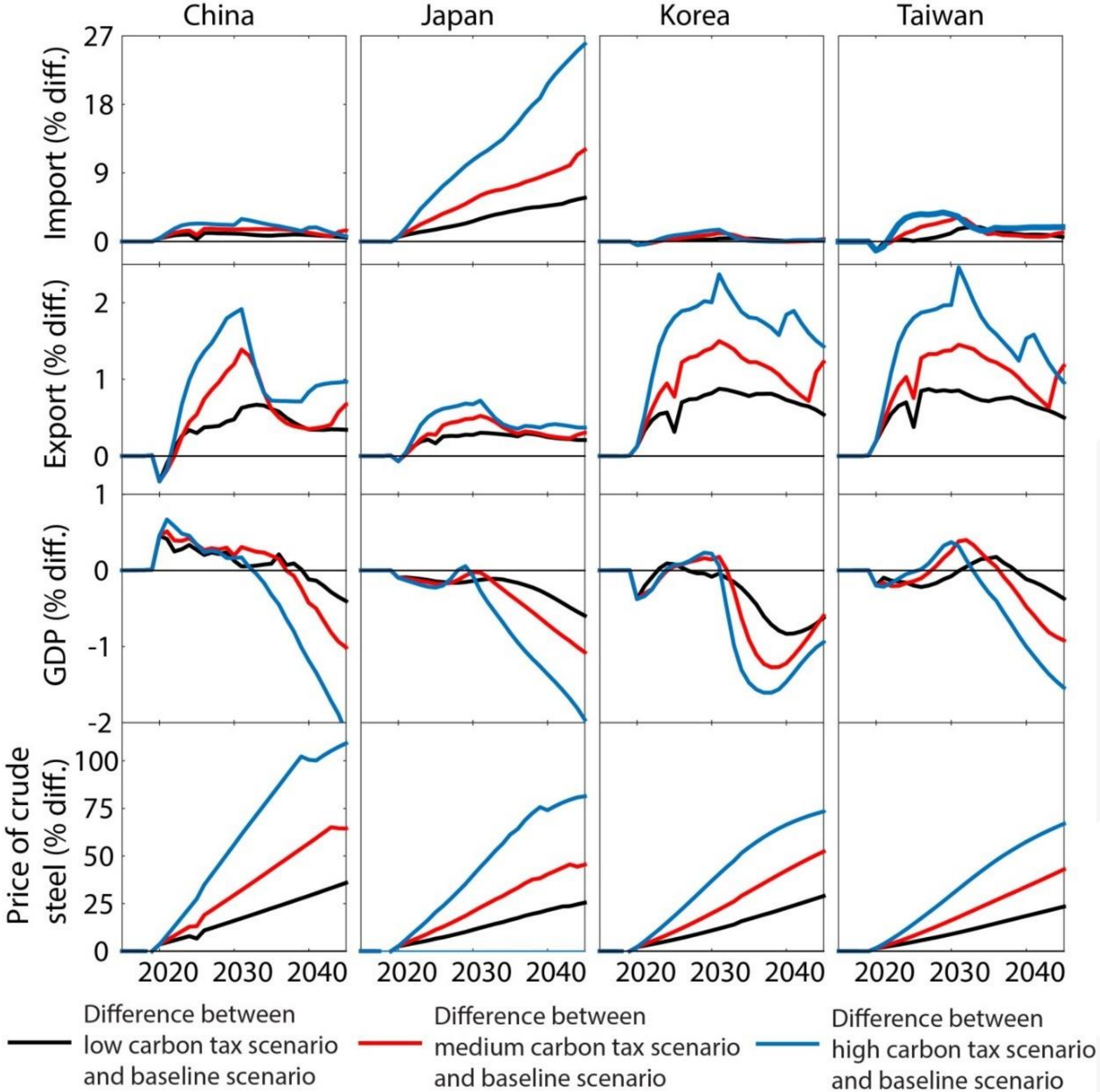
Economic indicators



Steel import increases, especially in Japan

Steel export increases as well, most likely due to exports to each other

GDP increases in the period after implementation of carbon taxes (except Japan), but decreases afterwards

China takes the largest hit to GDP. Probably due to its vast steel industry being required to transform

The prices of steel go up, in particular in China

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Key messages

- Climate
  - large scale decarbonisation, but not <u>complete</u> decarbonisation, can be achieved through carbon taxes
- Economy
  - the East Asian countries can maintain a large-scale iron and steel industry
  - carbon taxes: positive effects at first, negative effects later on
- Policies
  - carbon taxes are not enough
  - technology-push policies and regulations should be considered

This is a general conclusion of E3ME!!!

Limitations of FTT:Steel

- Bad input parameters
  - FTT is path-dependent and therefore susceptible to bad data that feed into the initial parameters
  - presently uncommon technologies are not well reported

- Bad assumptions
  - the iron and steel industry may not always follow an integrated route (e.g. in Brazil there are a few independent ironmakers that supply to the independent steelmakers)
  - due to lack of data, no variation in regional data on material consumption or capital investment costs was applied
  - biomass prices are poorly represented in the model

An update of FTT:Steel

- Increased the number of regions (59 to 61)
- Historical data was updated to 2018
- Bottom-up description of employment
- Endogenous estimation of scrap availability
- Crude form of steel scrap trade

Any questions?

Calculation of LCOS

- Price of commodity based on Levelised C... ...lculation

$$NPV_{expenses} \ldots \frac{\ldots FC(t) + \ldots}{(1+r)^t}$$

$$NPV_{income} = \sum_0^{\tau} \frac{P \ldots Production(t)}{(1+r)^t} = \ldots \sum_0^{t} \frac{1}{(1+r)^t}$$

Affected by necessisty for precursor plants

Affected by learning and scrap (un)availability

Affected by learning

$$Break - even: \frac{NPV_{expenses}}{NPV_{income}} = \frac{\sum_0^{\tau} \frac{IC(t) + OM(t) + FC(t) + CO2T(t) + \cdots}{(1+r)^t}}{P * \sum_0^{\tau} \frac{1}{(1+r)^t}} = 1$$

Affected by learning (decrease in emissions), and material consumption

$$LCOS(t) = P = \frac{\sum_0^{\tau} \frac{IC(t)+OM(t)+FC(t)+CO2T(t)+\cdots}{(1+r)^t}}{\sum_0^{\tau} \frac{1}{(1+r)^t}}$$

Illustrates imperfect knowledge and difference in the perceived costs by investors

$$\mathrm{sdLCOS} = \frac{\sum_0^{\tau} \frac{\sqrt{\left(sdIC/_{CF}\right)^2 + sdOM^2 + sdFC^2 + \cdots}}{(1+r)^t}}{\sum_0^{\tau} \frac{1}{(1+r)^t}}$$

How does E3ME compare to other models?

E3ME's empirical approach means that we do not apply restrictive assumptions that are typical to CGE models…

	Standard CGE model	E3ME
Global coverage	✓	✓
Detailed sectoral coverage	✓	✓
Suitable for real-world policy analysis	✗	✓
Realistic modelling of labour markets	✗	✓
Suitable for short, medium and long term analysis	✗	✓
Path-dependent modelling of technology take-up	✗	✓
Captures environmental double-dividend	✗	✓
Captures effects of economic stimulus or austerity	✗	✓
Modelling behavior of individuals/firms	Based on theoretical assumptions	Validated against historical data

Our Areas of Work

Economy	Society	Environment
Innovation	Jobs & Skills	Energy
Infrastructure	Inequality & Poverty	Climate
Tax & Finance	Population, Migration & Housing	Circular Economy
Sectors, Trade & Competitiveness	Health & Social Care	Natural Resources
Cities, Regions & Local Areas		

What are the typical model outputs of E3ME?

Economy

- GDP and its aggregate components
- sectoral output & GVA, prices, trade & competitiveness effects
- sectoral international trade in bilateral format & can be presented by trade blocs
- consumer prices & expenditures, & implied household distributional effects

Society

- sectoral employment by gender
- labour force and participation rate by gender and age groups
- unemployment rate and level
- sectoral wage rate
- real income of different socio-economic groups
- GINI coefficients

Environment

- energy demand, by users and by fuel
- energy prices
- power sector detailed results
- CO_2 emissions by sector and by fuel
- other air-borne emissions
- material demands (DMC, DMI, DE, M, X, TMR), by users and by materials

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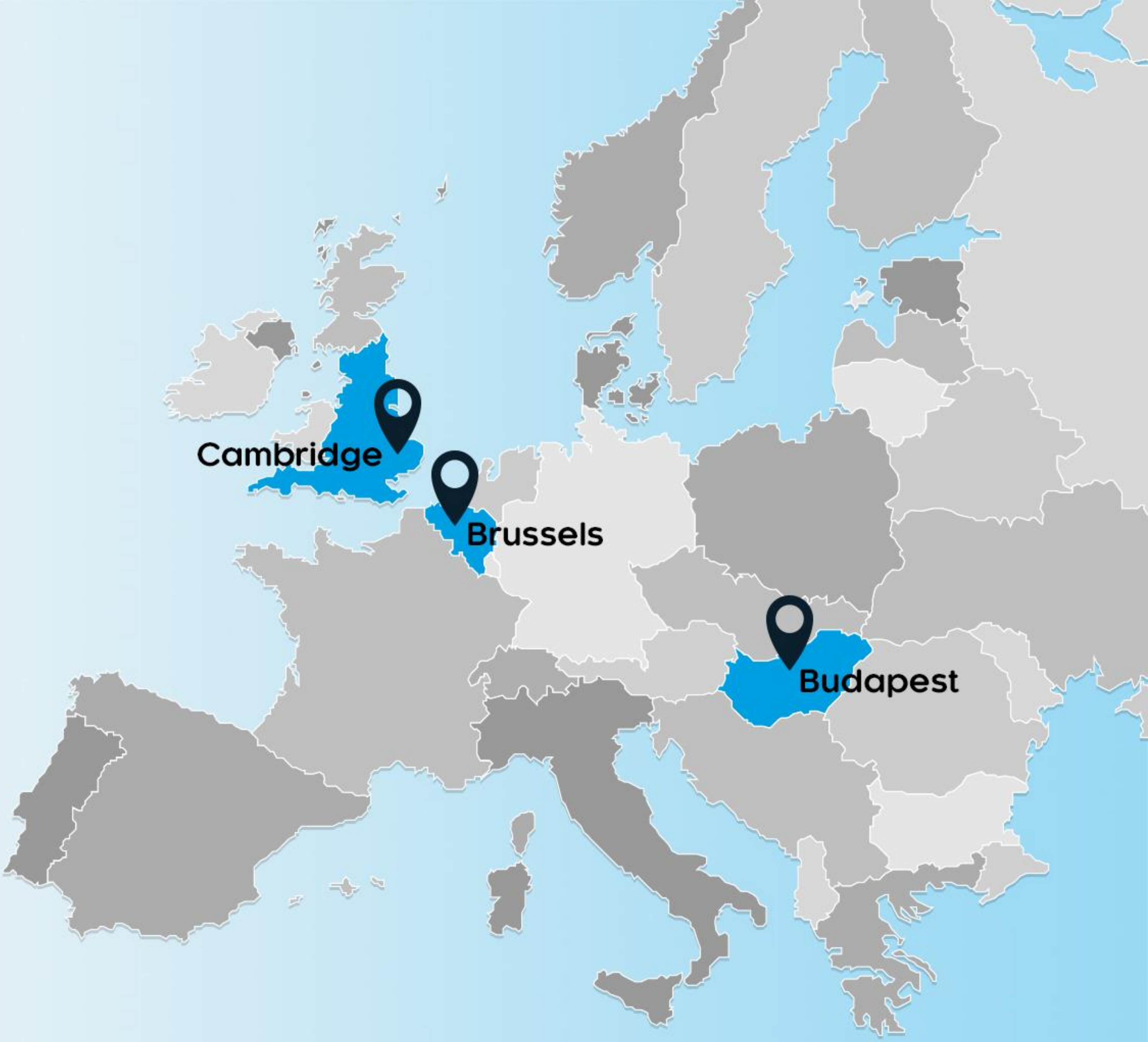

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