East-, Central- and West-China's future energy consumption and emission pathways: Insights from soft-linking two global models

Methodologies linking energy system models and economic models

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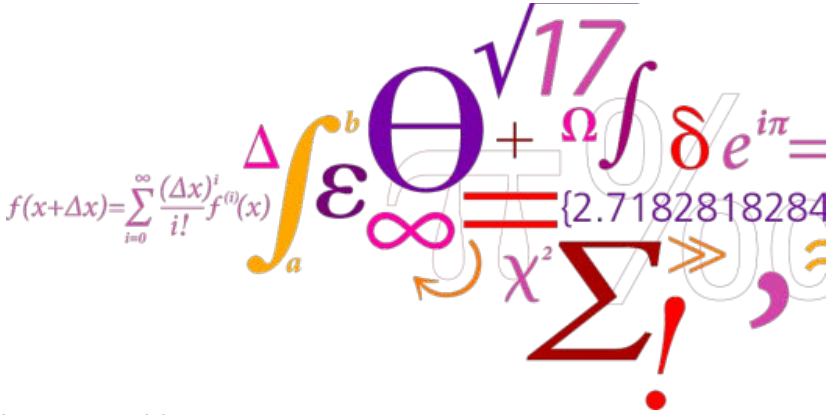


Motivation and research interest

CHINA's RISE:

An improved understanding of plausible future pathways for China's economy and energy system is becoming more important to understand global energy markets, energy security, greenhouse gas emissions and environmental impacts. As the world's largest emitter of CO_2, China is a prominent and important global and national case study for scenario analysis.

DIFFERENT ECONOMIC DEVELOPMENT STAGES IN CHINA:

China's provinces are in very different stages of economic development today. Global energy models, in particular bottom up models, that account for regional economic and energy system differences within China do hardly exist. Possible explanations are the numerous challenges in the comparison of China's energy system data in a global context.

CHINA-SPECIFIC GLOBAL MODEL LINKING FOR IMPROVED DECISION-MAKING:

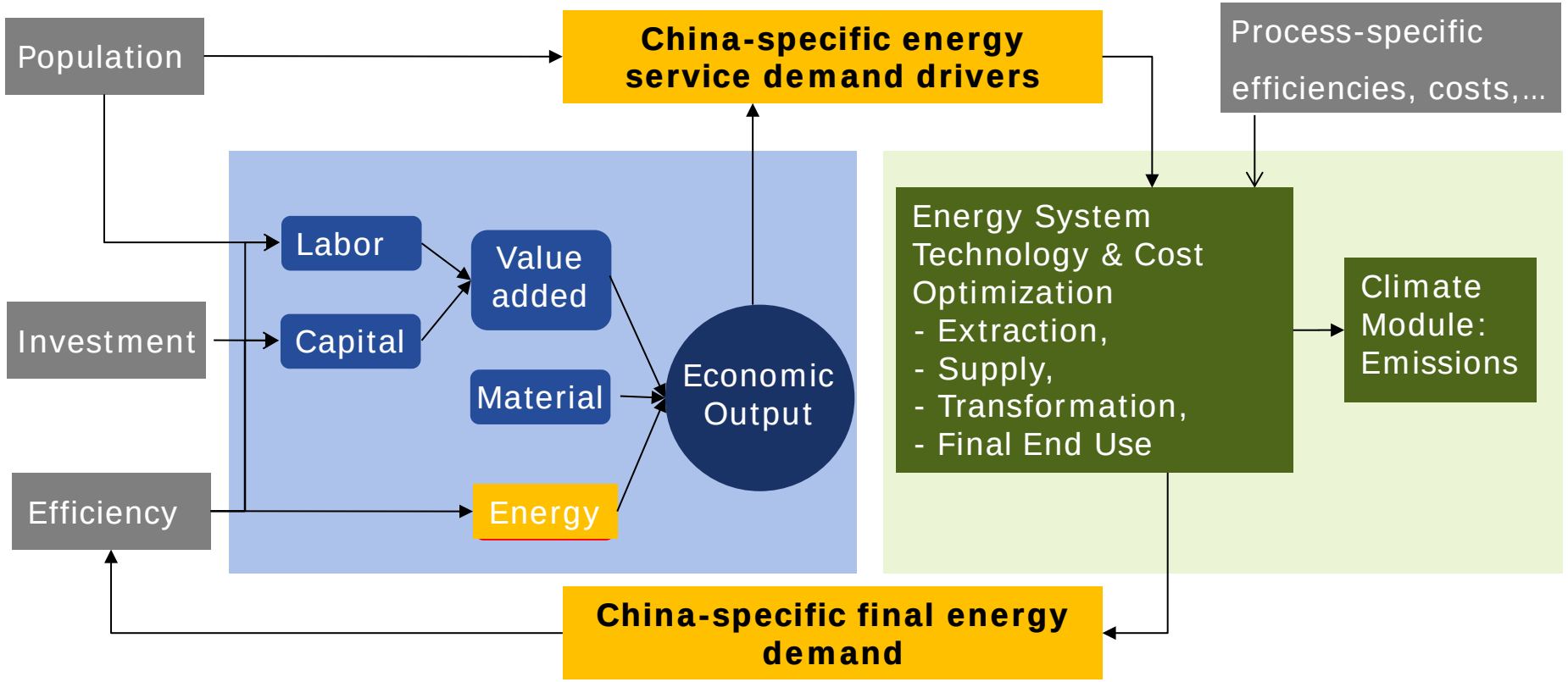
In this joint cooperation between NIES (Japan), ERI (China) and DTU (Denmark), we aim to soft-link two global models for an improved regional economy and energy system analysis of China's future energy policies.

The results from this soft-linking approach will feed into an ongoing energy policy debate in China, striving to balance global, regional and national development targets, such as energy intensity reduction goals in China's 12th Five-Year Plan (2011-2015).

Introducing the two China-specific global models

	Global Economic Model: Global-NIES-CGE-Model	Global Energy System Model: Global-DTU-ETSAP-TIAM-Model
Modelling approach:	general equilibrium model, representing the whole economy based on capital, labour, **energy** and material inputs	technology-rich, bottom-up, linear optimization model, representing the full energy system
Main underlying functions:	Individual behaviors of households, firms and government are based on optimization, e.g. budget-constrained utility maximization by households and technology-constraint profit maximization by firms, so that the demand and supply of each commodity and factor are balanced through the price mechanism.	objective function specified as discounted sum of the annual costs minus revenues; production-consumption commodity balances; share constraints on the in/outputs of processes; transformation equations; utilisation constraints
Historic model development:	NIES AIM/CGE model, **new feature: representing 30 regions of China and 15 other world regions.**	TIAM model development in collaboration with IEA ETSAP partners, open-source TIMES code, **new feature: bottom-up energy system for three economic regions within China**
Key inputs:	Population projection, Efficiency assumptions, future economic growth targets for China	population, household, economy and energy service demand projections; technology/process related cost, efficiency, emission assumptions
Key outputs:	Sectoral economic output, household income, GDP etc.	highly-detailed, cost-optimized primary and final energy use data
Global Regions:	**Same as TIAM model**	**15** (Africa, Australia-New Zealand, Canada, Central and South America, China, Eastern Europe, Former Soviet Union, India, Japan, Mexico, Middle-East, Other Developing Asia, South Korea, United States, and Western Europe)
China Regions:	**30** (administrative provinces, municipalities, autonomous regions of China, excl. Tibet)	**3** (East, Central, West China)
Time horizon:	**2002 - 2050**	**2005 - 2100**
Economic sectors:	**22 economic sectors and 3 final demand sectors**, based on China's economic structure and sectoral definitions	highly-detailed energy-relevant sectors of the economy, incl. energy resources/extraction and supply, energy transformation and final energy use in **industry, transport, commercial and public services, households and agriculture**
Fuels and energy carriers:	Coal, Crude oil, petrol oil, manufactured gas, electricity	Coal (hard coal, brown coal, coke, peat,..), Crude oil, oil products (incl. kerosene, diesel, gasoline, synthetic oils from coal,...), natural gas, electricity from various fossil and renewable sources, heat, biomass, biofuels, ethanol/methanol, hydrogen, ...
Emissions and pollutants:	CO_2, CO, NH_3, NMVOC, CH_4, N_2O, NOx, SO_2	CO_2 derrived from the carbon cycle of the TIMES climate module, CO_2 equivalents of N_2O and CH_4

Soft-linking Methodology (I) – Philosophy

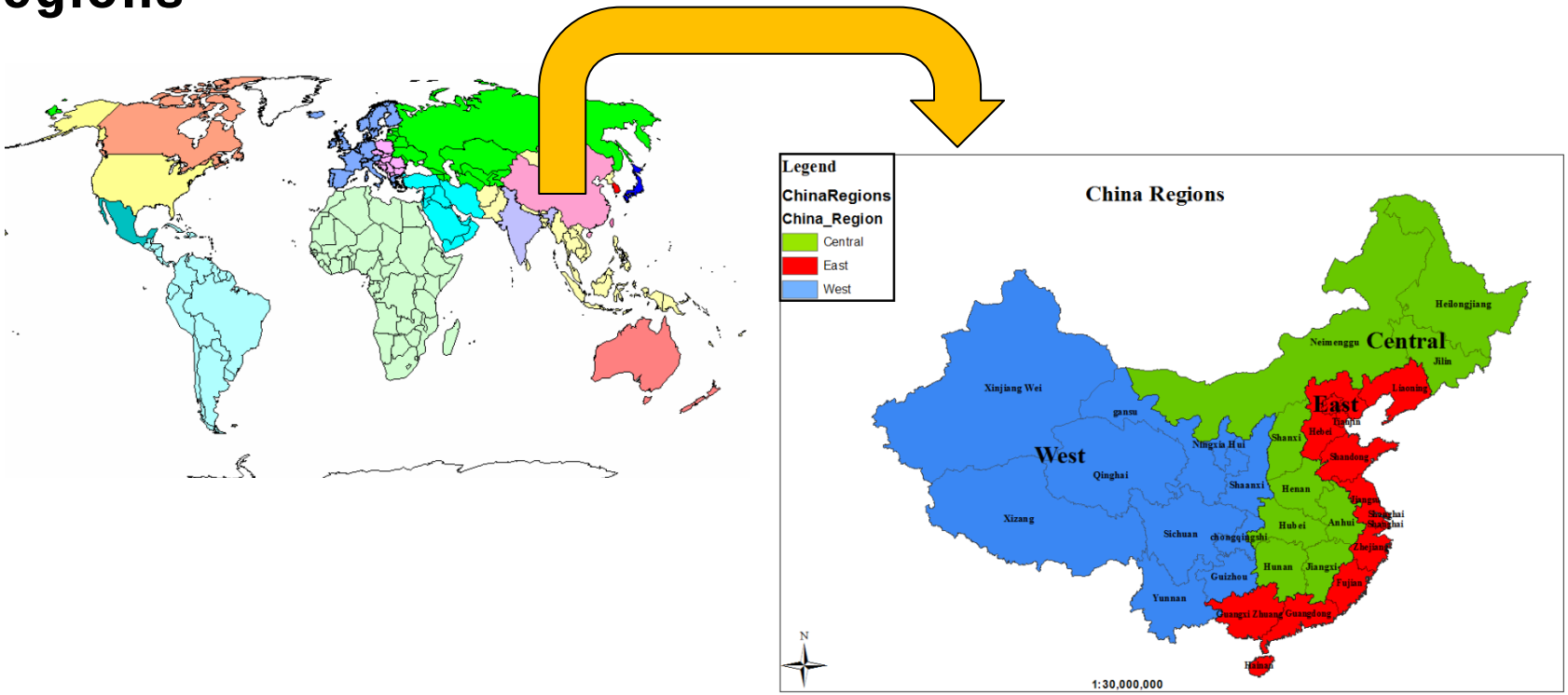


Exogenous inputs

Global-NIES-CGE-Model

Global-DTU-ETSAP-TIAM-Model

Soft-linking Methodology (II) – Global and China-specific regions



East-, Central- and West-China are defined based on the Seventh Five-Year Plan (1986–1990), which grouped the different provinces of China into three economic zones to promote economic specialization and division of labour.

Both models are able to represent economic and energy system details for these 3 regions of China. Both models are using a consistent division of the world in 15 regions. The economic model can produce more detailed results within China, at the level of 30 provinces.

Soft-linking Methodology (III) – Sectors in both models

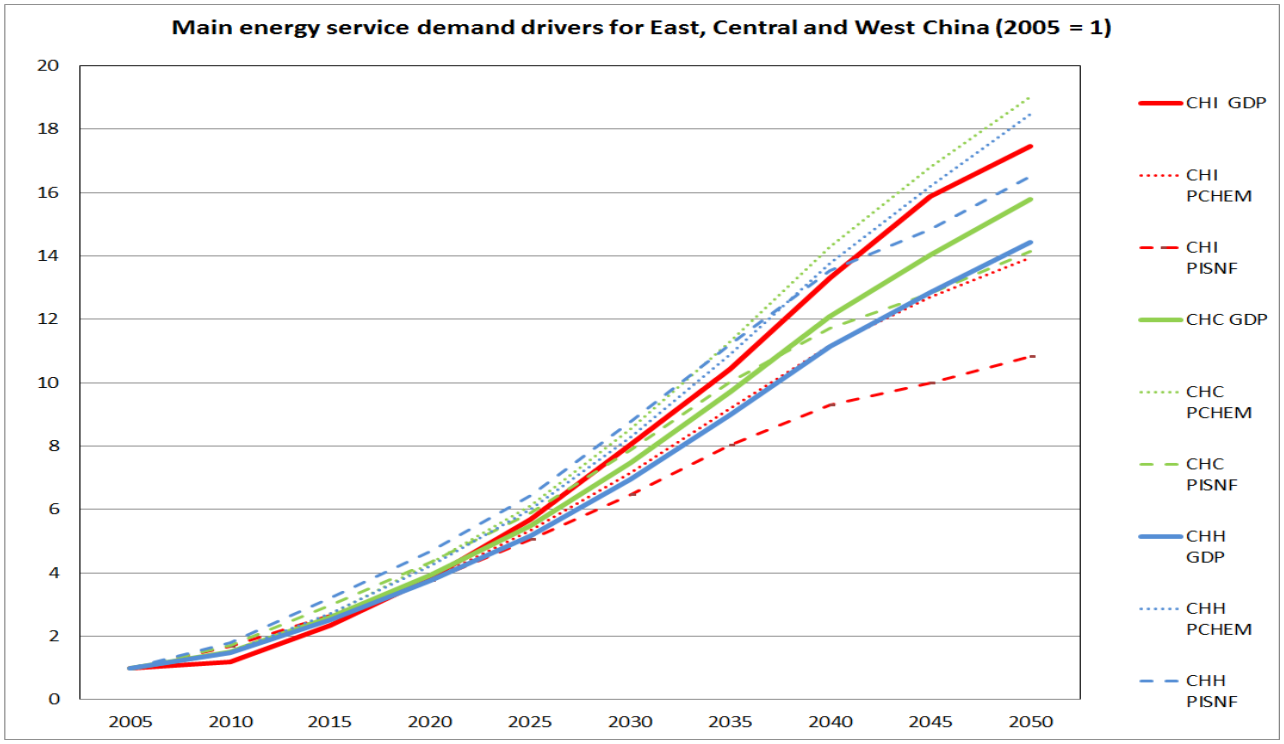
more detailed

	Global Economic Model: Global-NIES-CGE-Model		Global Energy System Model: Global-DTU-ETSAP-TIAM-Model	
Energy-intensive industries	CMetSmlt	Metal smelting and processing	IIS; INF	Iron and steel + non-ferrous metals
	Cchem	Chemicals	ICH	Chemicals
	CNonMPrd	Non Metal product	NMM	Non-metal minerals
	Cpaper	Paper	ILP	Pulp and paper
Other industries:	Cmin	Other Mining	IOI	Aggregated to other industries
	CFdTbc	Food and Tabaco	IOI	
	CTxt	Textile	IOI	
	CMetPrd	Metal Product	IOI	
	CMchn	Machinery	IOI	
	CTspEq	Transport equipment	IOI	
	CelMchn	Electronic machinary	IOI	
	CElcEq	Electronic equipment	IOI	
	CMsInstr	Mesure instrument	IOI	
	COthManuf	Other Manufacturing	IOI	
	Cwater	Water production	IOI	
	CCnst	Construction	IOI	
Transport	CTrsp	Transport	TRA	highly-detailded transport energy use by transport mode (road, rail, water, aviation)
Service	Csvc	Service	COM	highly-detailed commercial and public service energy use (e.g. space heating, cooling, refrigeration,…)
Residential Sector	hhld	Household sector	RES	highly-detailed residential energy use (e.g. space heating, cooling, refrigeration,…)
Agriculture	CAgri	Agriculture	AGR	Agriculture/Forestry

more detailed

As expected, differences in the detailed representation of economic and energy-relevant sectors exist. Both models are able to represent China's main energy-intensive manufacturing industries as single sectors.

Soft-linking Methodology (IV): economic model --> energy system model



East-China, Central-China and West-China are expected to take different future development paths.

These assumptions are in line with the government medium and long-term plans for economic restructuring.

Many energy service demand drivers **provided by the Global-NIES-CGE-Model** show differences across China's regions: While the increase in gross regional product remains larger in East-China than in Central-/West-China, the increase in outputs of chemical and iron/steel products are expected to be larger in Central-/West-China than in East China.

Soft-linking Methodology (V): energy system model → economic model

The relationship between composite energy demand and energy input in the Global-NIES-CGE-Model model can be expressed as follows:

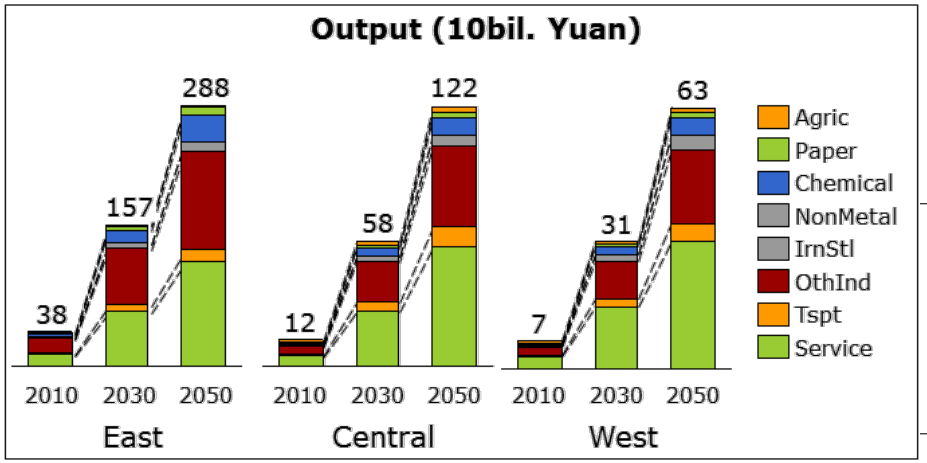
$$QE_{r,j} = \alpha_{r,j} \cdot \left(\sum_{en} \delta_{r,j}^{en} \cdot \left(\frac{\boldsymbol{QEN_{r,en,j}}}{\boldsymbol{EEI_{r,en,j}}} \right)^{-\rho_{r,j}} \right)^{-\frac{1}{\rho_{r,j}}}$$

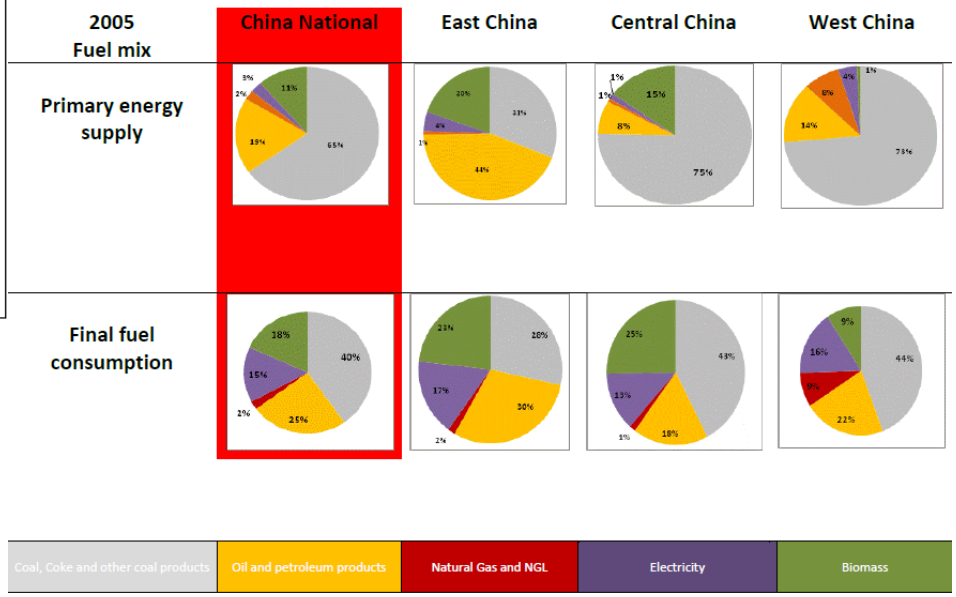
$QE_{r,j}$	Composite energy input required by the economic model;
$QEN_{r,en,j}$	**Final energy demand from the energy system model**;
$EEI_{r,en,j}$	**Energy efficiency improvement**;
$\alpha_{r,j}$, $\rho_{r,j}$	Shift and substitution parameters in the CES function;

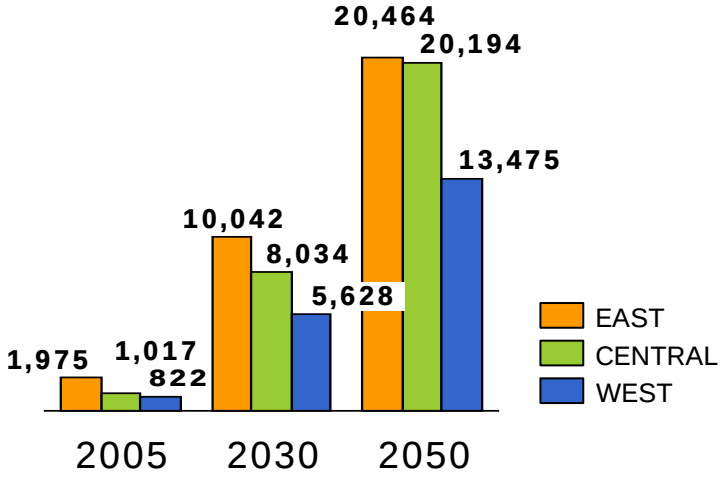
- The final energy demand $\boldsymbol{QEN_{r,en,j}}$ over the 2005-2050 period in East-, Central- and West-China is **provided by the Global-DTU-ETSAP-TIAM model**;
- Composite energy demand, $\boldsymbol{QE_{r,j}}$, is known **from the Global-NIES-CGE-Model**;
- **Energy efficiency parameters EEI** in the Global-NIES-CGE-Model are modified so that the above equation holds.

Note: This is work in progress, currently only total (rather than sectoral) energy consumption is used. Energy conversion factor: 1 PJ = 34.12 kilo ton of coal equivalent.

Reference-Scenario: before soft-linking



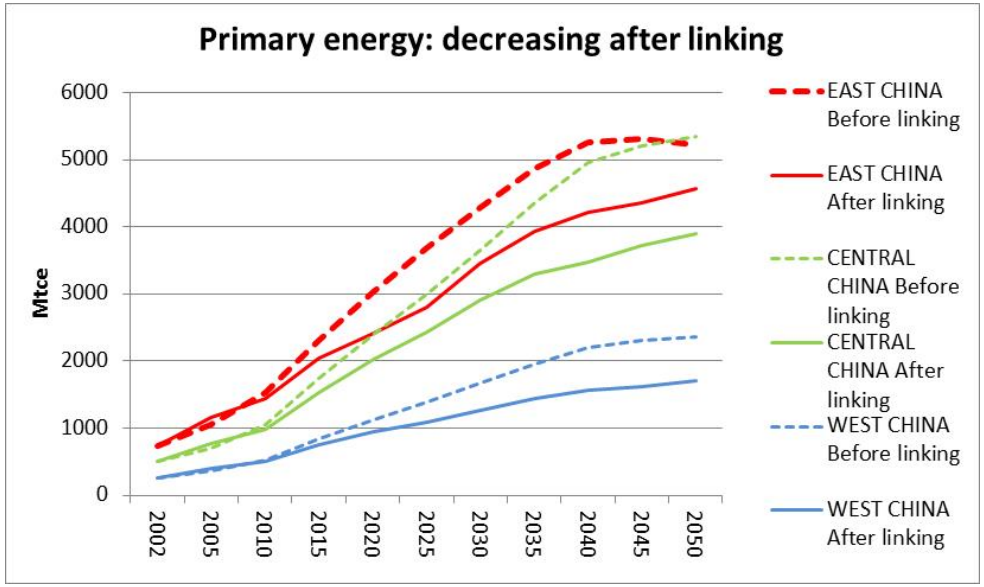


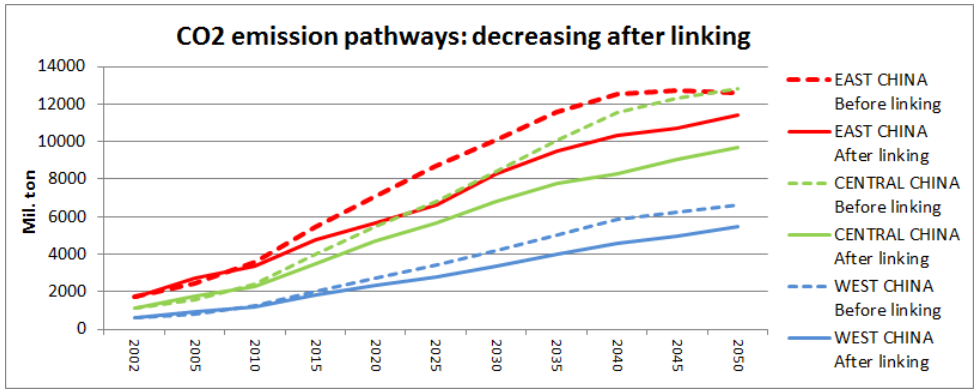


Global-NIES-CGE-Model

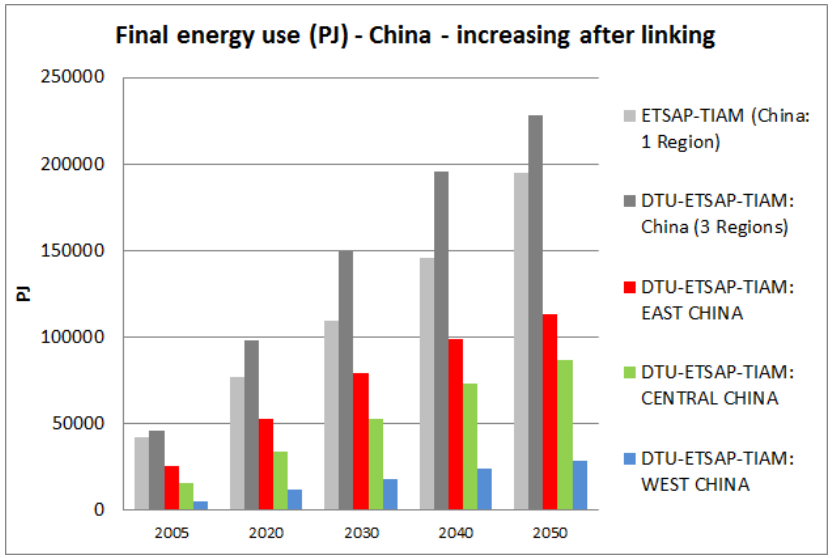
Global-DTU-ETSAP-TIAM-Model

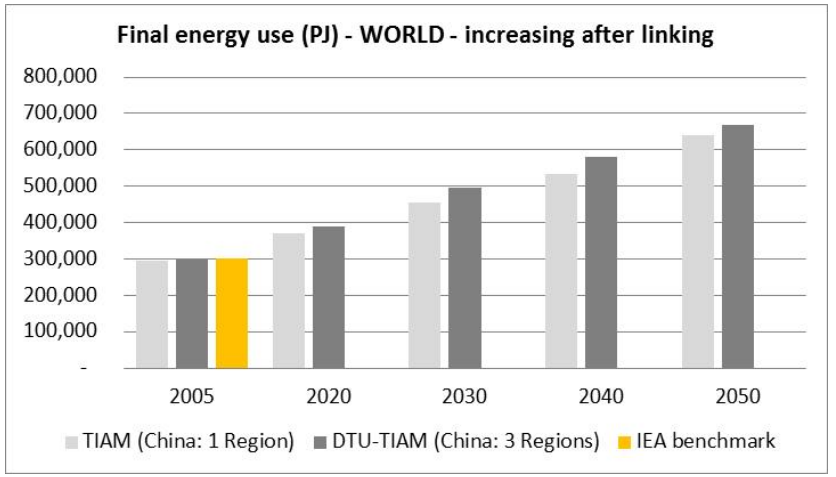
Reference-Scenario after soft-linking: Modifications after the 1st iteration





Global-NIES-CGE-Model





Global-DTU-ETSAP-TIAM-Model

Challenges and next steps

A very time consuming and complex task – some of the challenges:

- Understanding China-specific data & statistics in an international context
- Understanding the different modeling approaches, key drivers, uncertainties
- Working virtually and dealing with a 7h time difference
- Working with different cultural backgrounds, native languages and working styles

This is work in progress – next steps:

- Continue iterations and document soft-linking process and results in more details
- Document the DTU-ETSAP-TIAM-Model's reference energy system for East-, Central- and West-China
- Undertake the soft-linking excercise for a consistent set of policy/emission scenarios

→ Publish the results ☺

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Thank You! 谢谢!
Danke! Merci bcp! Gracias!

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