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China's energy revolution - measuring the status quo, modelling regional dynamics & assessing global impacts

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China's energy revolution – measuring the status quo, modelling regional dynamics & assessing global impacts

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Overview

Part I: Framework

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Part II: Publications

Summary of 7 key publications – Research gaps, Highlights, Method, Results

Part III: Conclusions

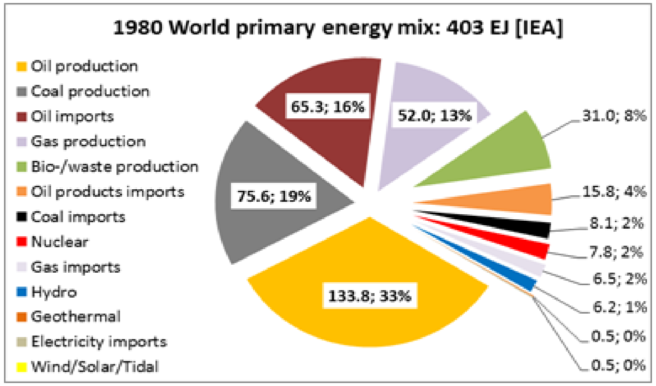
General conclusions, Outlook, Outreach

Part I: Framework

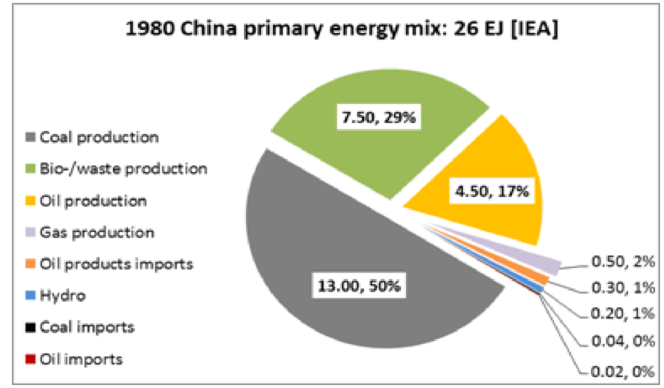
Part I: Acknowledgements

African Development Bank; Asian Development Bank; Aalborg University Denmark; the Asia Banker; Chinese Academy of Sciences; China National Renewable Energy Centre; Climate Wire Asia; Copenhagen Capacity; Danish Energy Agency; Danish Embassy Beijing; DTU UNEP partnership, formerly UNEP RISO; Energianalyse Denmark; Energy Crossroads Denmark; Energy Sector Management Assistance Program; Ecofys China; European Chamber of Commerce Shanghai; Fraunhofer Joint Centre for Innovation Research China; German Technical Cooperation China; International Energy Agency; Energy Technology Systems Analysis Program; International Energy Conservation Environmental Protection Association, International Renewable Energy Agency; King Abdullah Petroleum Studies and Research Center Saudi Arabia; MERCATOR Institute for China Studies Germany, MIT Tsinghua China Energy & Climate Project; National Institute of Environmental Studies Japan; Energy Research Institute China; Pacific Northwest National Laboratory USA; Potsdam Institute for Climate Impact Research Germany; Remnin University China; Sino-Danish Center for Innovation and Research Denmark; Sino-Danish Centre for Education and Research; Technical University of Berlin Germany; Technical University of Denmark; Tsinghua University China; University of Cambridge UK; University of Copenhagen Denmark; University of Berkeley China Energy Group USA; University of Maryland USA; Technical Research Centre of Finland; Xiamen University China; World Bank Group

Part I: Motivation – Why China?

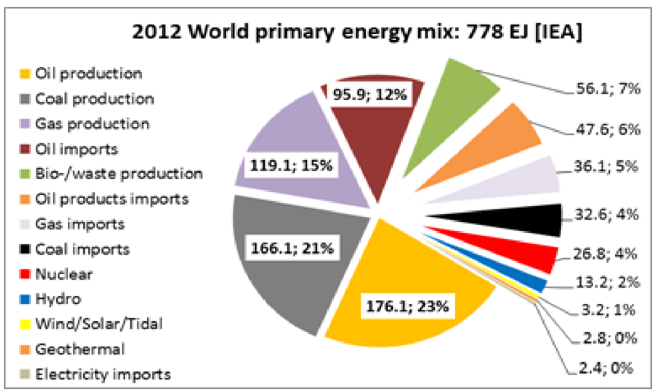


1980: China's share of global primary energy: 6 %

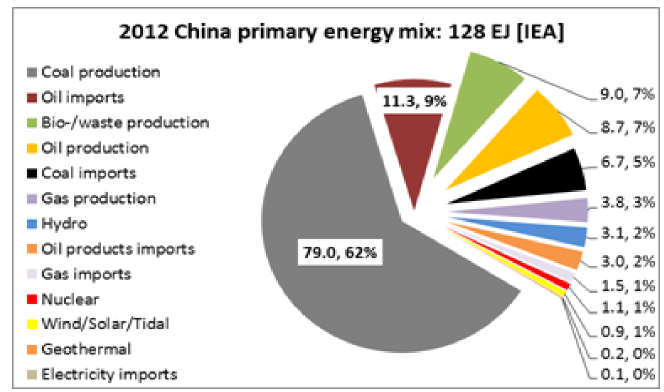


1980-2012: World's total primary energy supply increased by a factor of 1.9

1980-2012: China's total primary energy supply increased by a factor of 4.9



2012: China's share of global primary energy: 16 %



Chinese President Xi Jinping called for "... more efforts to revolutionize the country's energy production and consumption habits, in light of changing dynamics in the global energy markets. China faces challenges to cope with rising energy demand, supply restraints, huge environment costs and backward technology...." 13 June 2014, Central Leading Group on Financial and Economic Affairs Meeting, Beijing

Sources: energy supply from IEA; press news from Xinhua news agency [Xinhua, 2014], [IEA, 2012]

Part I: Objectives

- The overall aim of this research is to identify, describe and discuss the main regional characteristics China's "energy revolution".

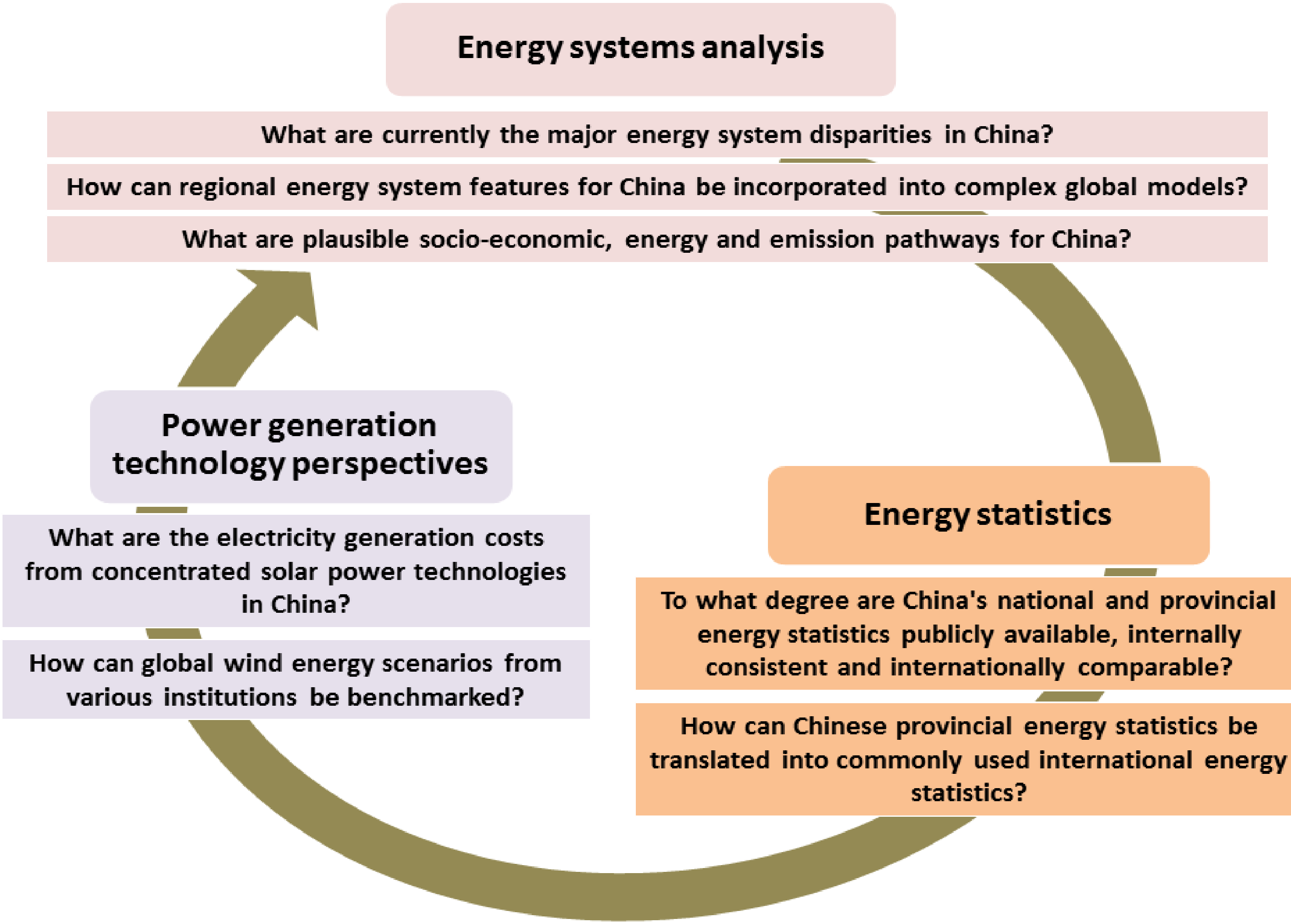
- This broad research aim will be approached by means of:

  – measuring and quantifying the current status of China's energy system with a focus on **major regional characteristics**;

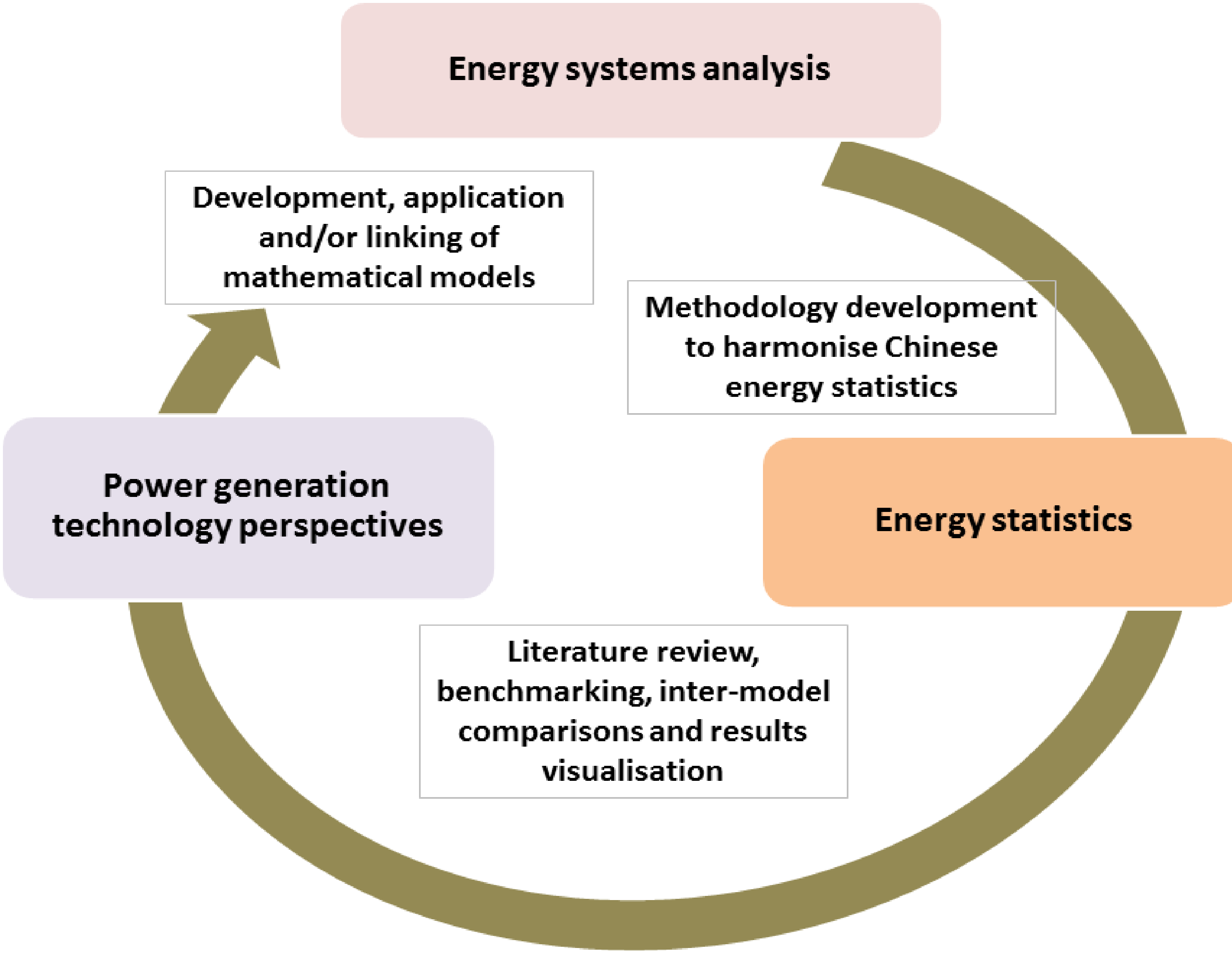
  – **modelling selected, plausible future scenarios** for China's regional energy system dynamics, including **a few perspectives for renewable power generation technologies** and

  – **benchmarking and visualizing** associated global impacts of China’s “energy revolution”.

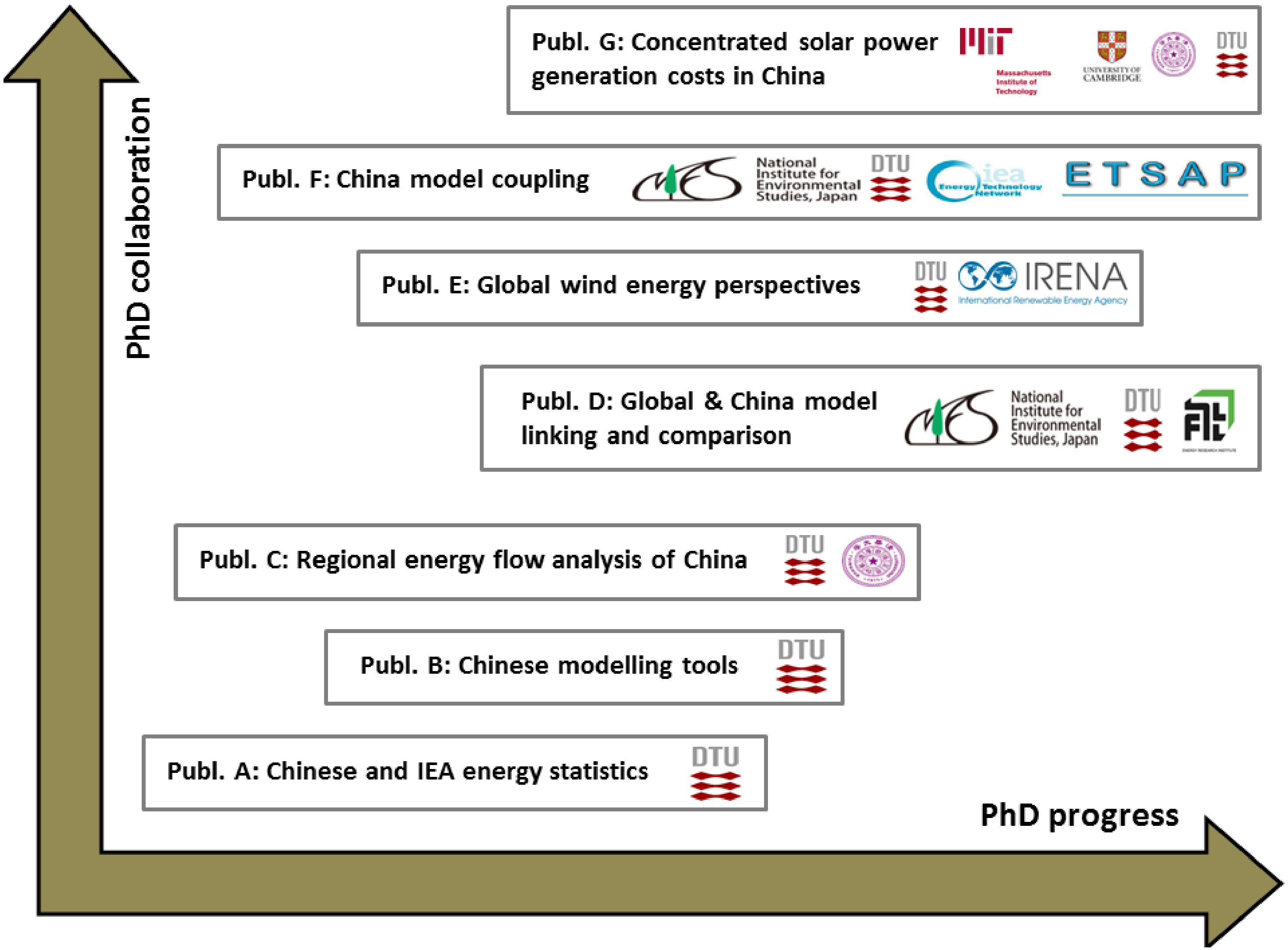
Part I: Research Questions



Part I: Methodologies

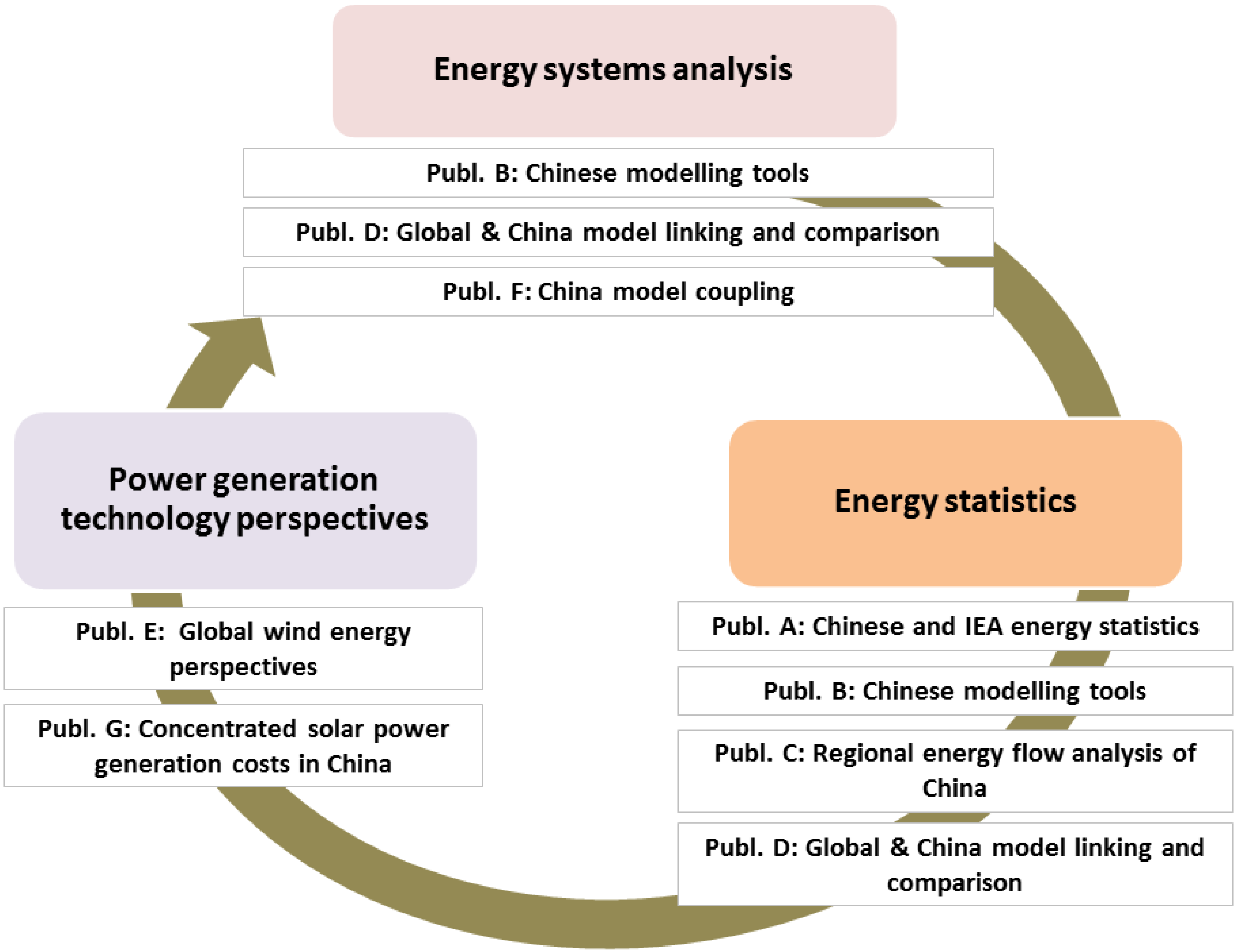


Part I: Collaborations



Part II: Publications

Part II: Key Publications



Part II: Key Publications

- P. MISCHKE (2013), ***China's energy statistics in a global context: A methodology to develop regional energy balances for East, Central and West China***. MPRA working paper 50305, available at: http://mpra.ub.uni-muenchen.de/50305
- P. MISCHKE & K. B. KARLSSON (2014), ***Modelling tools to evaluate China's future energy system - a review of the Chinese perspective***. Energy, doi:10.1016/j.energy.2014.03.019
- P. MISCHKE & W. XIONG (2015), ***Mapping and benchmarking regional disparities in China's energy supply, transformation and end-use in 2010***, Applied Energy, doi: 10.1016/j.apenergy.2015.01.011
- H. DAI, P. MISCHKE, X. XIE & T. MASUI (2015), ***Closing the gap? Top-down versus bottom-up pathways of China's regional energy demand and global CO_2 emissions***, Applied Energy, in press
- K. B. KARLSSON, P. MISCHKE, A. MIKETA & N. WAGNER (2014), ***Global energy perspectives with an emphasis on wind energy***, in: H. Hvidtfeldt Larsen & L. Sønderberg Petersen (Eds.), DTU International Energy Report 2014, Pages 19-25, Technical University of Denmark, ISBN: 978-87-550-3969-8
- P. MISCHKE & H. DAI (2015), ***From global modelling to country analysis: focus on China with ETSAP-TIAM and AIM,*** in: Giannakidis G., M. Labriet, B. Ó Gallachóir, G.C. Tosato (Eds.), *Informing energy and climate policies using energy systems models. Insights from scenario analysis increasing the evidence base*, Springer, “Energy System” series, ISBN 978-3-319-16539-4
- Z. ZHU, D. ZHANG, P. MISCHKE & X. ZHANG (2015), ***Electricity generation costs of concentrated solar power technologies in China based on operational plants***, Energy, under review

Part II: Chinese and IEA energy statistics (Publ. A)

Research gap:

- Improved understanding of the quality and reliability of Chinese economic and energy statistics is needed (national – regional – provincial) → global energy markets and China's energy / climate policies
- China's national statistical system is however still developing → some energy data remain unavailable in the public domain or are not internationally comparable

Methodology:

- A pragmatic triangulation approach to cope with lack of data harmonisation and data quality
- Review China's national and provincial energy balances, review the IEA national energy balance of China (international benchmark)
- Identify indicators to establish regional energy balances of China in the format of an IEA energy balance
- Expert judgment to check suitable energy indicators and fill a few data gaps

Key results:

- Internationally comparable regional energy balances for China, transparent approach
- Measuring the status quo of China's energy system → modelling future scenarios

Part II: Chinese and IEA energy statistics (Publ. A)

Highlights:

- An overview of the development of China's statistical system
- A discussion of the reliability, accuracy, and availability of energy data for China
- A comparison of Chinese energy statistics and IEA energy statistics
- A pragmatic methodology development to analyse regional energy trends in China

Table A-1: Regional energy balance of China – primary energy supply

Primary energy supply – IEA energy balance	Primary energy supply – NBS provincial energy balance	Primary energy supply – alternative provincial data	Key Indicator – EAST CHINA	Key Indicator – CENTRAL CHINA	Key Indicator – WEST CHINA
Coal and coal products					
Hard coal: Indigenous production International import International export	**Raw coal, cleaned coal, other washed coal, briquettes:** Production Imports (international, interprovincial) Exports (international, interprovincial)	Coal throughput of coastal ports, total coal imports; total coal exports (China Customs Bureau)	**Raw coal:** Production: 16% International import: 100% International export: 100%	**Raw coal:** Production: 59%	**Raw coal:** Production: 25%
Coke: International import International export	**Coke, other coking products:** Production Imports (international, interprovincial) Exports (international, interprovincial)		**Coke:** International import: 100% International export: 100%	n.a.	n.a.
n.a.	**Blast furnace gas, coke oven gas, converter gas, other gas:** Recovery of energy Imports (interprovincial) Exports (interprovincial)		n.a.	n.a.	n.a.
Oil and petroleum products					
Crude oil Indigenous production International import International export	**Crude oil:** Production Imports (international, interprovincial) Exports (international, interprovincial)	Crude oil production by oil field from major three SOE (Petroleum industry yearbooks)	**Crude oil:** Production incl. offshore fields: 80% International import: 86% International export: 100%	**Crude oil:** Production by field: 8%; International import: 8%	**Crude oil:** Production by field: 12% International import: 6%

Part II: Chinese modelling tools (Publ. B)

Research gaps:

- Identify, compare and review recent energy modelling tools and scenarios from Chinese institutions, between 2005 and 2013 → Chinese perspective

Methodology:

- Review of scientific literature, review of project reports, interviews in China
- Identify indicators for model and scenario comparisons
- Establish a Chinese energy model and scenario database

Key results:

- Considerable ranges in the reference scenarios of 18 modelling tools:
    GDP is projected to grow by 630-840% from 2010-2050,
    energy demand could increase by 200-300% from 2010-2050, and
    CO_2 emissions could rise by 160-250% from 2010-2050.
- Access to the modelling tools and the underlying data remains challenging,
- Chinese perspective, independently from the modelling approach and institution, suggests a rather gradual and long-term transition towards a low carbon economy in China

Part II: Chinese modelling tools (Publ. B)

Table B-1: Overview of modelling tools and institutions

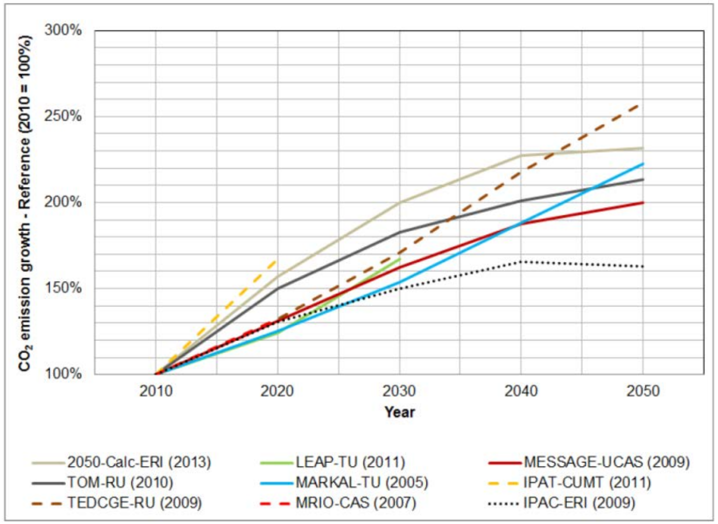
Acronym	Modelling tool	Institution
2050-Calc-ERI	China 2050 Calculator	Energy Research Institute
CGE-NCEPU	Computable General Equilibrium Model	North China Electric Power University
CREAM-ERI	China Renewable Energy Analyses Model	Energy Research Institute
DCGE-SIC	Dynamic Computable General Equilibrium Model	State Information Centre
EEM-ERI	Economic Evaluation Model	Energy Research Institute
IO-TU	Input Output Model	Tsinghua University
IPAC-ERI	Integrated Policy Assessment Model for China	Energy Research Institute
IPAT-CUMT	IPAT Model	China University of Mining and Technology
LEAP-TU	Long-range Energy Alternatives Planning Model	Tsinghua University
MARKAL-TU	Market Allocation Model	Tsinghua University
MESSAGE-UCAS	Model for Energy Supply Strategy Alternatives and their General Environmental Impact	University of the Chinese Academy of Sciences
MRIO-CAS	Multi-Regional Input Output Model	Chinese Academy of Sciences
MSCGE-DRC	Multi-Sector Computable General Equilibrium Model	Development Research Centre, State Council
PMP-TU	Power Mix Planning Model	Tsinghua University
POM-USTC	Portfolio optimization Model	University of Science and Technology of China
TEDCGE-RU	Technology oriented dynamic Computable General Equilibrium Model	Renmin University of China
TIMES-TU	The Integrated MARKAL-EFOM System	Tsinghua University
TOM-RU	Technological Optimization Model	Renmin University of China

Highlights :

- A China-specific model review
- An analysis of the Chinese perspective towards a low carbon economy
- A summary of energy planning and modelling tools in China
- An inter-model results comparison and benchmarking exercise

Modelling tool (acronym)	Institution		Access to information			Modelling approach						
	University	Non-University, State	Peer reviewed journal	Project report	Model website	Bottom Up – Simulation	Bottom Up – Optimization	Bottom Up – no further details	Hybrid	Top Down – Input Output	Top Down – CGE	Top Down – no further details
2050-Calc-ERI		√			√	√						
CGE-NCEPU	√		√								√	
CREAM-ERI		√		√					√			
DCGE-SIC		√		√							√	
EEM-ERI		√		√				√				
IO-TU	√		√							√		
IPAC-ERI		√	√	√					√			
IPAT-CUMT	√		√									√
LEAP-TU	√		√	√		√						
MARKAL-TU	√		√	√			√					
MESSAGE-UCAS	√		√				√					
MRIO-CAS	√		√	√						√		
MSCGE-DRC		√		√							√	
PMP-TU	√		√					√				
POM-USTC	√		√									√
TEDCGE-RU	√		√	√							√	
TIMES-TU	√		√				√					
TOM-RU	√		√	√				√				

Figure B-3: Comparison of China's future CO_2 emissions – reference scenarios



Part II: Regional energy flow analysis (Publ. C)

Research gaps:

- Regional disparities in China's current energy flow patterns are rarely visualised and quantified from a system-wide perspective.
- Lack of a comprehensive discussion of data quality.

Methodology:

- Statistical methodology development (national, regional and provincial energy flows, establishment of conversion factors)
- Sankey diagrams for three regions of China to visualise results, discussion of data challenges

Key results:

- Major regional disparities in 2010 visualised:

  West-China and Central-China accounts for about 89% of coal production.

  About 50% of coal fired power generation and 90% of refining : East-China.

  East-China also dominated industrial energy consumption, accounting for about 70% of oil/petroleum product use, about 58% of coal use and about 53% of electricity use.
- National – regional data differences of up to 46% for coal →statistical inconsistencies and assumptions in the methodology

Part II: Regional energy flow analysis (Publ. C)

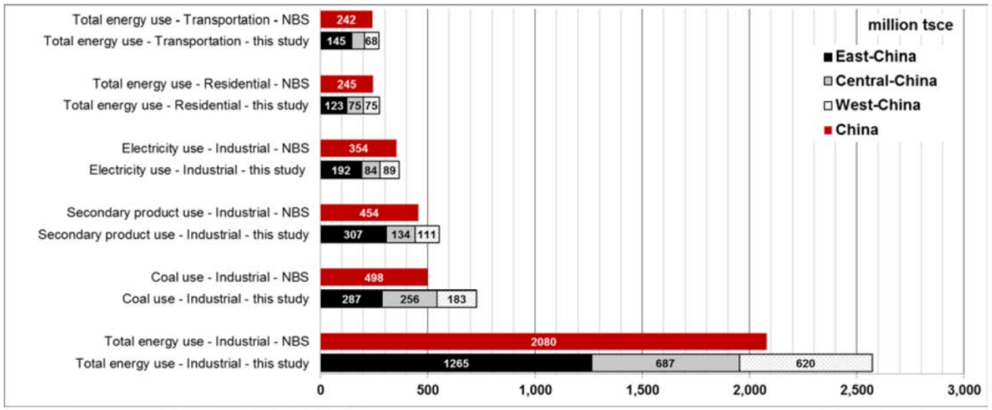


Figure C-7: Benchmarking major regional disparities in China's energy end use (million tsce, 2010)

<u>Highlights :</u>

- An energy system wide mapping of regional and national energy flows in China
- A discussion of regional energy disparities between East-, Central- and West-China
- A visualization of China's current national and regional energy balance with Sankey diagrams (fuel by fuel flow charts)

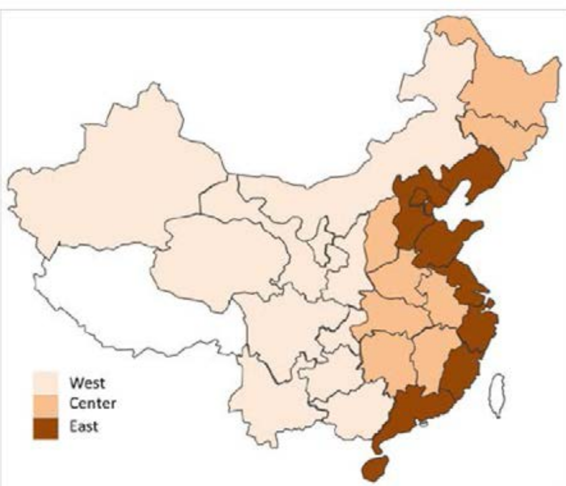


Figure C-1: Energy system boundaries of East-, Central- and West-China

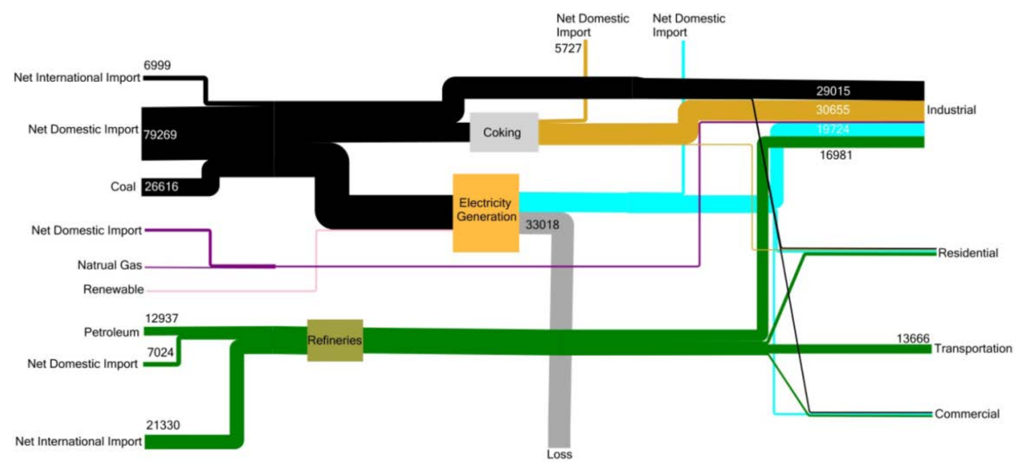


Figure C-2: Sankey Diagram of East-China in 2010 (10^4 tsce)

Part II: Chinese modelling tools (Publ. D)

Research gaps:

- As the world's largest carbon emitter, China is a prominent case study for scenario analysis. Uncertainty in China's future energy scenarios is however considerable.
- Can this be reduced by comparing, harmonising and soft-linking complex global models?

Methodology:

- Soft-linking methodology to harmonise two complex global top-down and bottom-up models with a regional China focus.
- Baseline follows the GDP and demographic trends of the Shared Socio-economic Pathways (SSP2) scenario, down-scaled for China, while the carbon tax scenario follows the pathway of the Asia Modelling Exercise.

Key results:

- Soft-linking allows "bridging the gap" between these models. Comparing this study with the Asia Modelling Exercise indicates that sub-regional China features, when incorporated into complex global models, do not increase uncertainty in China-specific modelling results further.
- Without soft-linking, baseline result ranges for China in 2050 are 240-260 EJ in primary energy, 180-200 EJ in final energy, and 15-18 Gt in carbon dioxide emissions.
- The highest uncertainty in modelling results can be mapped for China's future coal use in 2050, in particular in electricity production.

Part II: Chinese modelling tools (Publ. D)

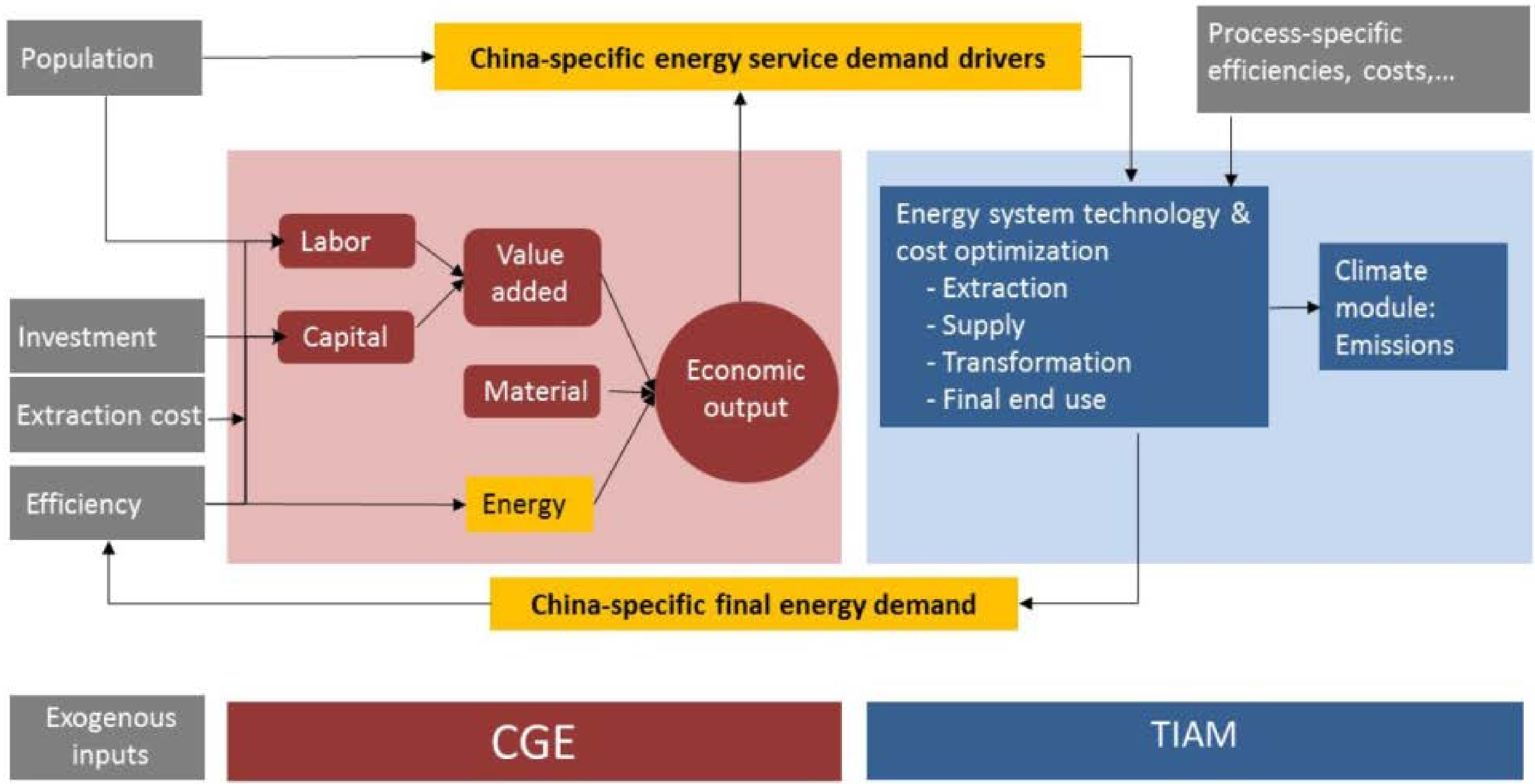


Figure D-10: Soft-linking framework between the two global models – example for the China region

Part II: Chinese modelling tools (Publ. D)

<u>Highlights :</u>

- A coupling of two complex top-down and bottom-up energy planning tools with sub-regional detail on China
- An international model harmonization, benchmarking, and results comparison exercise
- A regional analysis on China's future energy system in a global perspective
- A discussion of data uncertainty in China's energy and emission scenarios

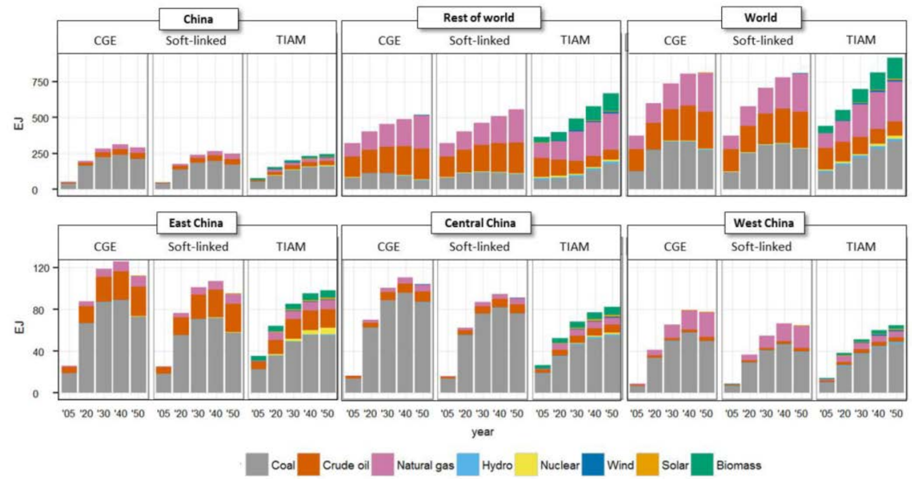


Figure D-11: Primary energy use –baseline across models (2005-2050)

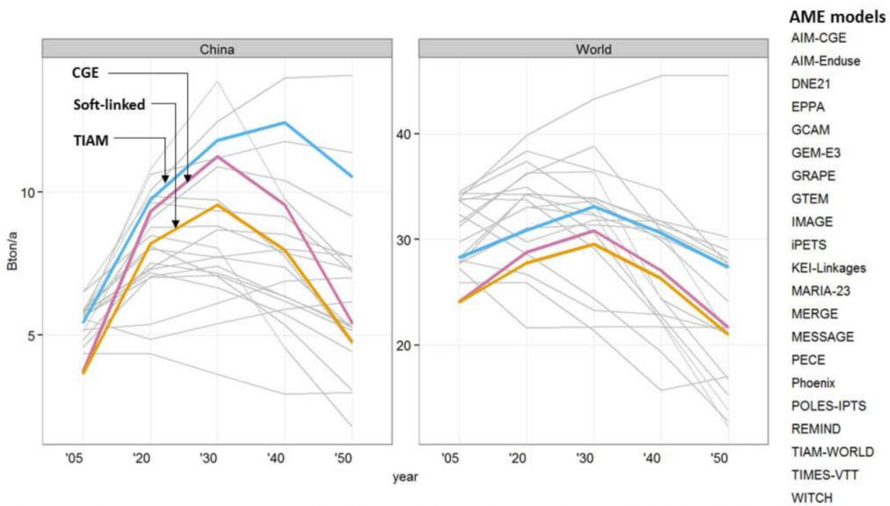


Figure D-18: Benchmarking of carbon tax scenarios in this study against global AME models (2005-2050)

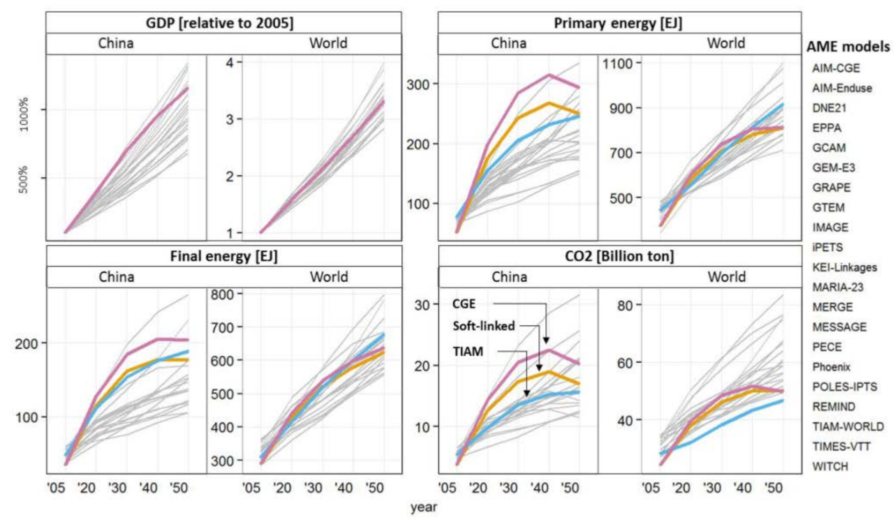


Figure D-17: Benchmarking of baseline scenarios in this study against global AME models (2005-2050)

Part II: Global wind energy perspectives (Publ. E)

Research gaps:

- Future wind electricity generation outlooks depend on many factors, projections from leading research and industry studies vary considerably
- What are key assumptions behind those studies? Can scenarios be benchmarked with regards to their ambition for future wind power generation? What's the role of China?

Methodology:

- Literature review, interviews and collaboration with IRENA
- Benchmarking and comparing various available studies for a public audience

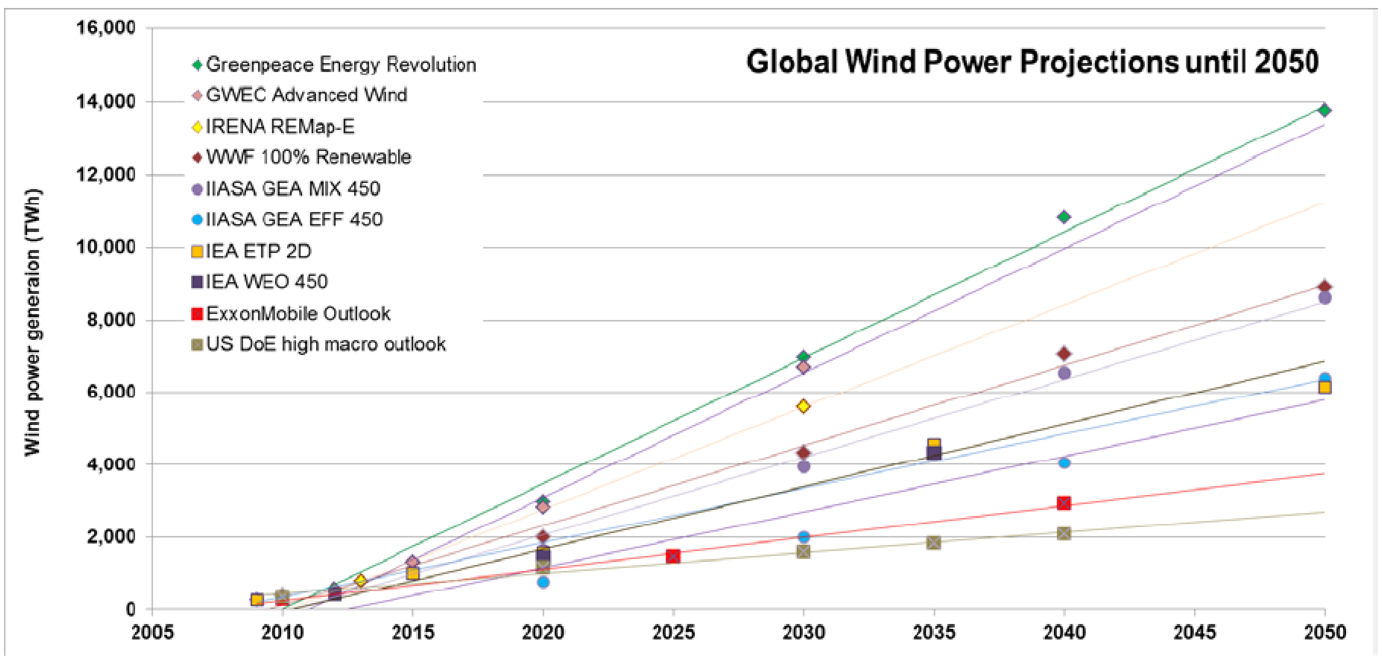
Key results:

- The most optimistic studies for wind energy are based on a strong political commitment for a future low-carbon energy system and assume a global energy transition towards keeping global mean temperature rise below 2°C by 2050.
- Wind power scenarios towards 2050 show a wide range: from a conservative 2500 TWh/y to an optimistic 14000 TWh/y.
- The most conservative global wind power projections are presented by Exxon Mobile and the US Department of Energy. The most ambitious wind power outlooks are published by Greenpeace and the Global Wind Energy Council.

Part II: Global wind energy perspectives (Publ. E)

<u>Highlights :</u>

- A comparison of future global wind power projections from 7 leading international institutions
- A summary of the role of wind power in IRENA's REMap2030 study, a global renewable energy road map towards 2030 based on country-specific analyses



Part II: China model coupling (Publ. F)

Research gaps:

- Soft-linking global models with regional China features for new, sub-regional insights into China's future economic and energy system development.
- Divergence in China-specific scenario results calculated by different modelling tools with different underlying assumptions is rather high → common frameworks needed

Methodology:

- Establishing and testing of a common reference scenario
- Define and test future scenario to analyse the potential global impacts of China-specific sub-regional and national energy and climate policies

Key results:

- China-specific modelling exercises should be sufficiently harmonised and documented first, before applying any modelling framework to study policy scenarios for China in a global context.
- To cope with the range of uncertainty in China's future energy and emission projections, future work should focus on benchmarking such a global and China-specific modelling exercise with more leading global and China-specific scenario studies.

Part II: China model coupling (Publ. F)

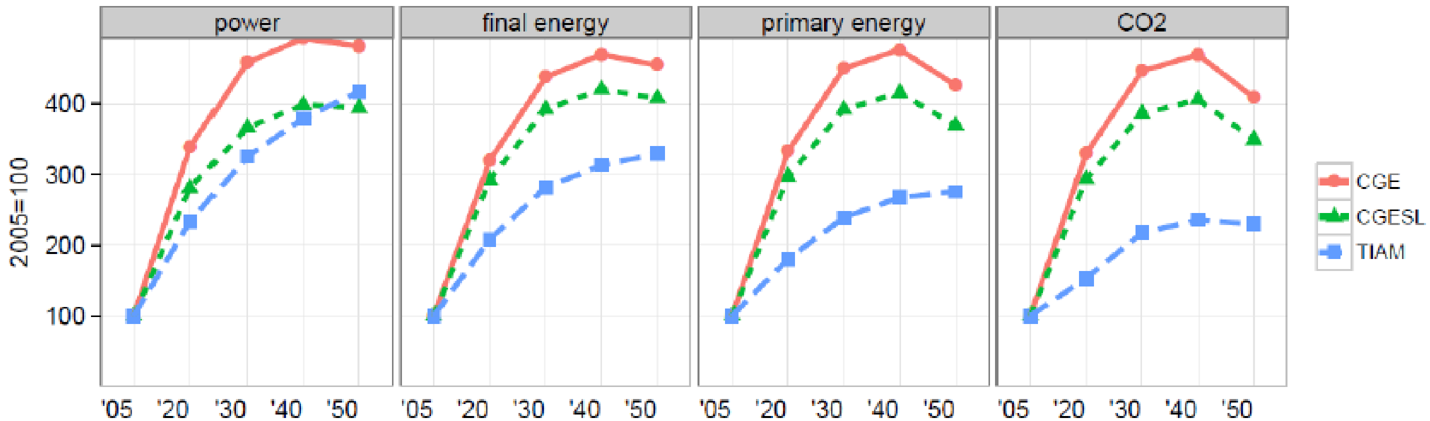


Figure F-3: East-China reference scenario in TD AIM/CGE, BU TIAM and hybrid CGE-SL models – pathways for power generation, primary and final energy use, and CO2 emissions (2005-2050)

<u>Highlights :</u>

- a discussion of baseline scenario assumptions for sub-national energy system dynamics for East-, Central and West-China until 2050
- a comparison of China-regional and global energy and emission results from three different models (top-down, bottom-up, coupled)

Part II: Concentrated solar power generation costs (Publ. G)

Research gaps:

- China's rising electricity demand, severe environmental pollution from coal-fired power plants, and favourable renewable energy policies are expected to result in a large-scale CSP deployment in the next years.
- Detailed CSP studies for China are however hardly available.

Methodology:

- Collection of plant-specific data in a national CSP database in collaboration with local CSP experts.
- Analysis and benchmarking the costs of parabolic trough CSP, tower CSP, and dish CSP technologies in China by applying a levelized cost of electricity (LCOE) model.

Key results:

- The current LCOE for the different CSP plants fall in a range of 1.2-2.7 RMB/kWh (0.19-0.43 US$/kWh).
- Among the three CSP technology variants discussed, the sensitivity analysis indicates that the tower CSP variant might have the greatest potential in China.
- Future cost reduction potential of more than 50% and a high share of local content manufacturing for tower CSP.

Part II: Concentrated solar power generation costs (Publ. G)

<u>**Highlights :**</u>

- First study that analyzes three different CSP technology variants in China
- First national CSP database for China is compiled, consisting of seven CSP plants under construction and operation
- LCOE for operational CSP plants is in the range of 1.2-2.7 RMB/kWh (0.19-0.43 US$/kWh)
- Future LCOE for the tower CSP could decline by 50% towards 2020.

Table G-2: National database of CSP projects under construction and operation in China.

CSP projects in China	1. CAS IEE –Yanqing-Parabolic plant	2. CGNPG-Delingha-Parabolic plant	3. Datang-Erdos-Parabolic plant	4. CAS IEE-Yanqing-Tower plant	5. Supcon-Delingha-Tower plant	6. Sanhua Heli-Wuhai-Dish plant	7. Huaneng-Nanshan-Fresnel plant
General information							
Location, Province	Yanqing, Beijing	Delingha, Qinghai	Erdos, Inner Mongolia	Yanqing, Beijing	Delingha, Qinghai	Wuhai, Inner Mongolia	Nanshan, Hainan
Operator	CAS IEE	CGNPG	Datang	CAS IEE	Supcon	Sanhua Heli	Huaneng
Project status: construction phase	since July 2014	construction completed	since September 2013	construction completed	construction completed	since July 2012	construction completed
Project status: operational phase	expected in 2015	Since July 2014	expected in 2017	Since July 2013	Since July 2013		Since November 2012
Technical information							
CSP technology variant	Parabolic Trough	Parabolic Trough	Parabolic Trough	Tower	Tower	Dish	Fresnel
Capacity (MW)	1	1	50	1	50	1	1.5
Project size	demonstration project	demonstration project	utility-scale project	demonstration project	utility-scale project	demonstration project	demonstration project
Direct normal insolation (DNI) (kWh/(m^2 yr)			1900	1900	1900	1900	
Electricity generation (MWh/yr)			138,700	1950	130,000	2000	
Capacity Factor			0.3167	0.2226	0.2968	0.2283	

Figure G-3: Locations of China's CSP projects.

Part III: Conclusions

Part III: General results

Publ. A: Chinese and IEA energy statistics

- an overview of the development of China's statistical system
- a discussion of the reliability, accuracy, and availability of energy data for China
- a comparison of Chinese energy statistics and IEA energy statistics
- a pragmatic methodology development to current analyse regional energy trends in China

Publ. D: Global & China model linking and comparison

- a coupling of two complex top-down and bottom-up energy planning tools with sub-regional detail on China
- an international model harmonization, benchmarking, and results comparison exercise
- a regional analysis on China's future energy system in a global perspective
- a discussion of data ranges in China's future energy and emission scenarios

Publ. B: Chinese modelling tools

- a China-specific model review
- an analysis of the Chinese perspective towards a low carbon economy
- a summary of energy planning and modelling tools in China
- an inter-model results comparison and benchmarking exercise

Publ. E: Global wind energy perspectives

- an overview of the most recent wind power investments at a global scale
- a comparison of future global wind power projections from 7 leading international institutions
- a summary of the role of wind power in IRENA's a global renewable energy road map towards 2030

Publ. C: Regional energy flow analysis of China

- an energy system wide mapping of regional and national energy flows in China
- a discussion of regional energy system disparities
- a visualization of China's energy balance with Sankey diagrams

Publ. F: China model coupling

- a discussing of baseline scenario assumptions for sub-national energy system dynamics for East-, Central and West-China until 2050
- a comparison of China-regional and global energy and emission results from three different models (top-down, bottom-up, coupled)

Publ. G: Concentrated solar power generation costs in China

- a study that analyzes three different concentrated solar power (CSP) technology variants in China
- a first national CSP database for China, consisting of seven CSP plants under construction and operation
- a calculation of the range of levelized costs of electricity for operational CSP plants in China
- a discussion of scenarios for future CSP cost reductions in China

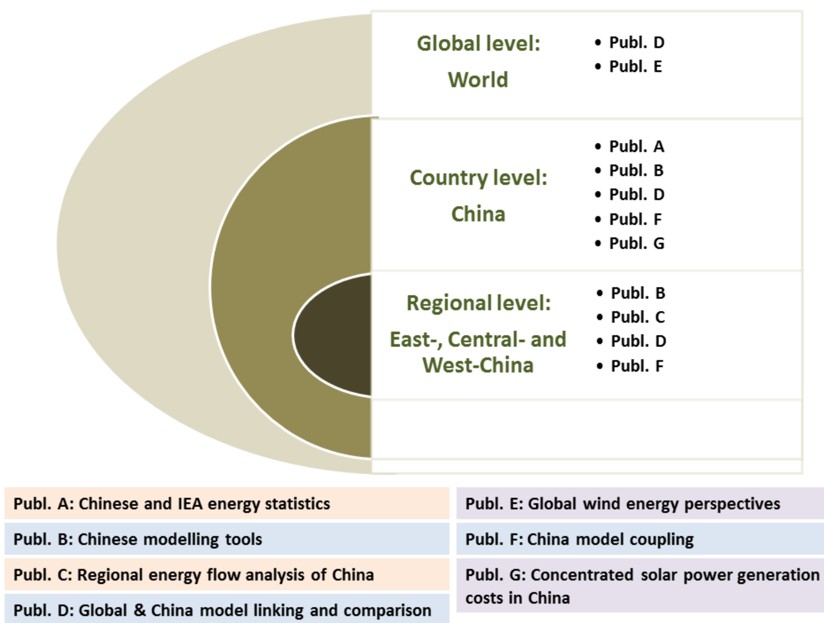
Part III: General conclusions

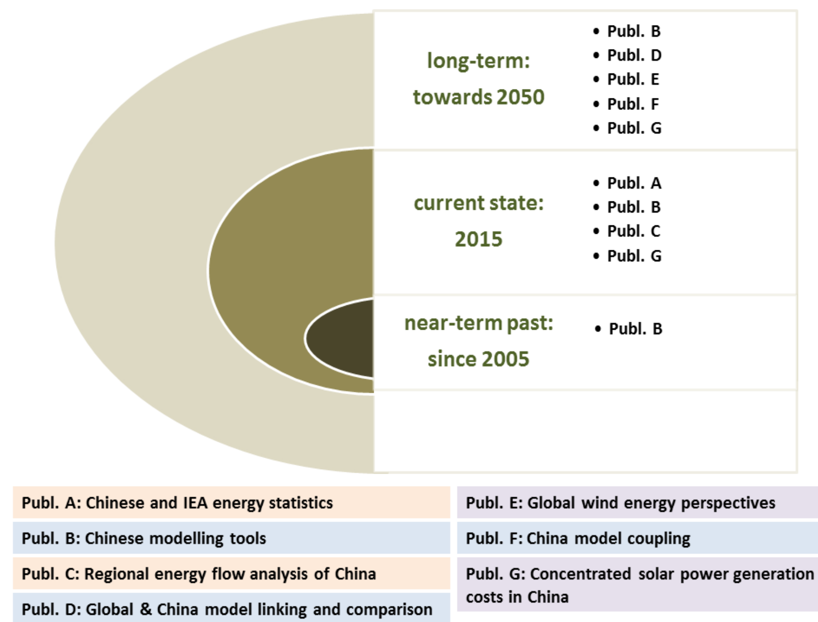
Measuring the status quo:

- China's energy sector is an interesting, challenging and quickly changing research topic, with some energy data uncertainty & complexity
- Major regional energy system disparities

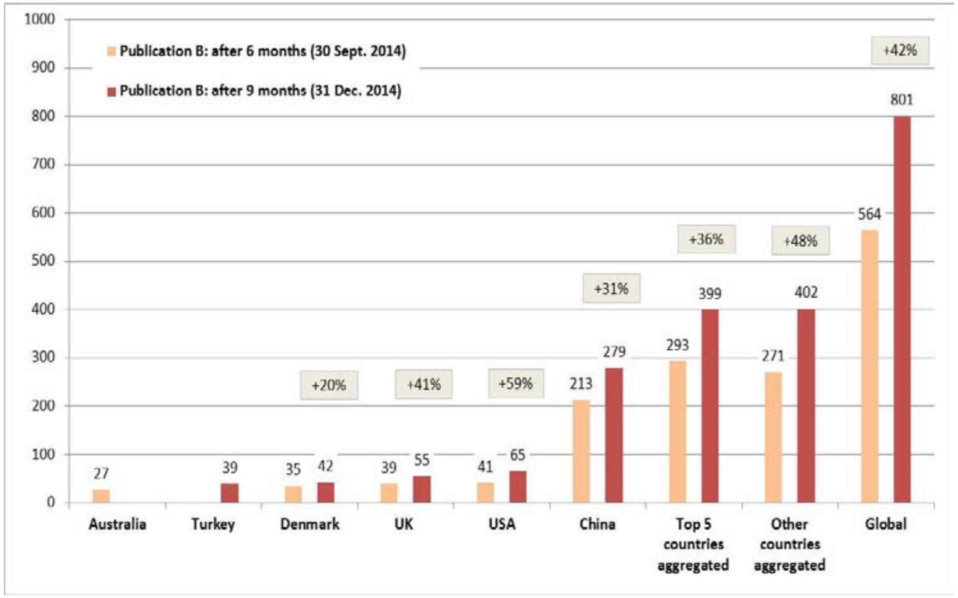
Modelling regional dynamics & assessing global impacts:

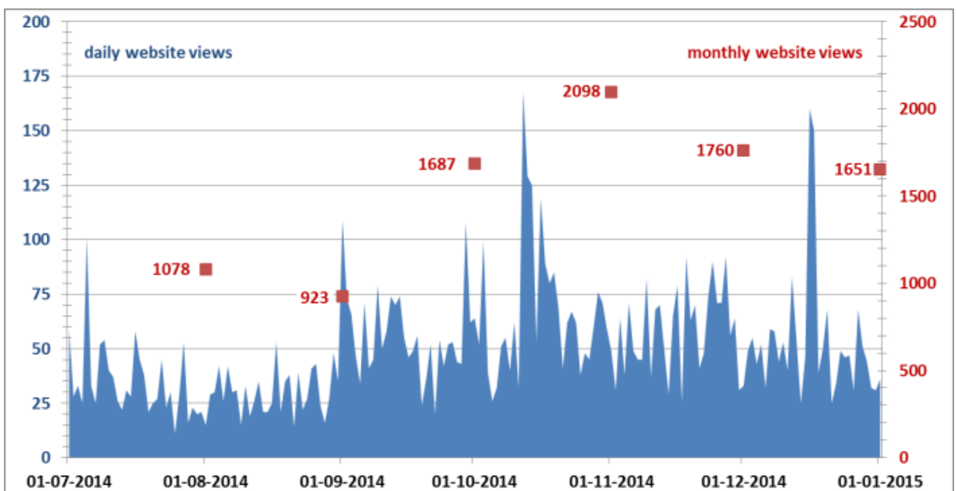
- Approaches/methodologies should be pragmatic, transparent and collaborative
- Benchmarking and visualisation of results very important
- Bridging regional China and global development scenarios is rather new

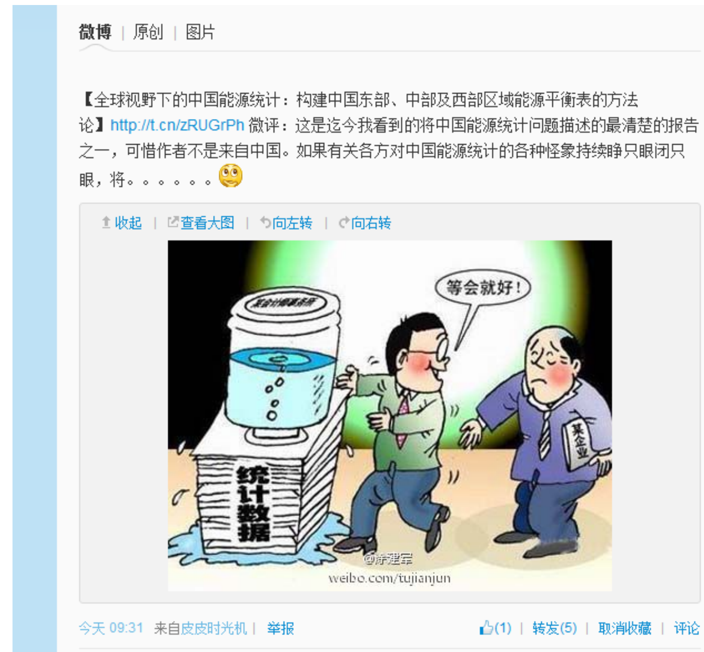




Part III: Public and scientific outreach







Part III: Outlook

Further avenues of research could include:

- more detailed sub-regional and national/global energy policy analysis, such as the recent US-China climate change commitment;
- more comprehensive, system-wide analysis in the energy / water / air quality nexus;
- more technology-specific research for different regions of China, e.g. nuclear versus renewable energy technologies versus advanced coal technologies
- more China and BRIC country comparisons with similar coal-based energy system characteristics
- ….

Thank you for your attention!
谢谢!

千里之行始于足下.

The journey of a thousand miles starts with one step.

老子.

Laozi, Chinese philosopher, 604-531 BC.

The different studies, associated conference presentations and website blog entries are also electronically available from the following website:
www.peggymischke.com