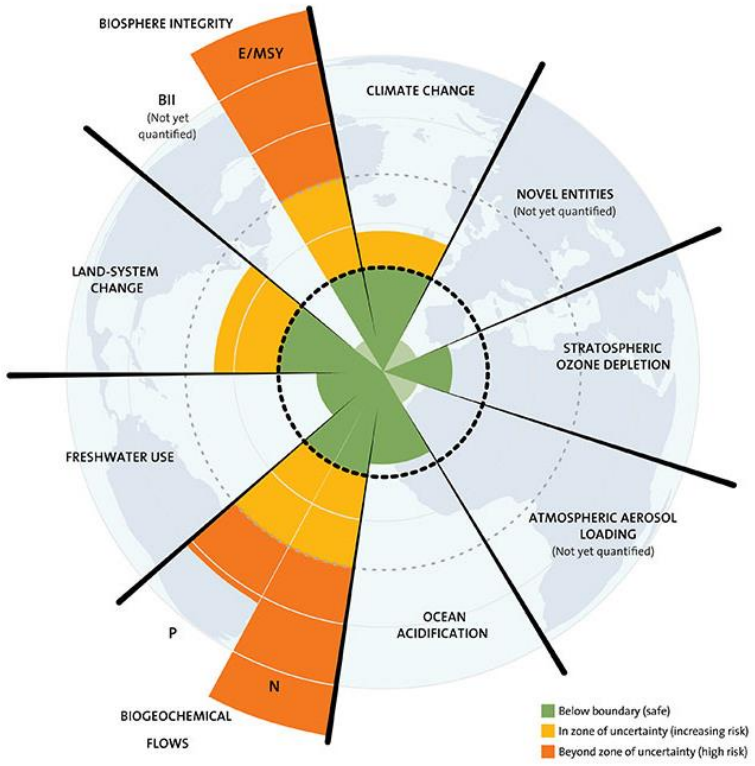
CHAPTER 10

LOOKING BEYOND: SUSTAINABLE DEVELOPMENT, RENEWABLE ENERGY, AND GEOENGINEERING

北京大学
PEKING UNIVERSITY

World's Environmental Challenges

- Climate change
- Air pollution
- 'Ozone hole'
- Water pollution
- Water shortage
- Solid pollution
- Excess nitrogen
- Biodiversity
- ……

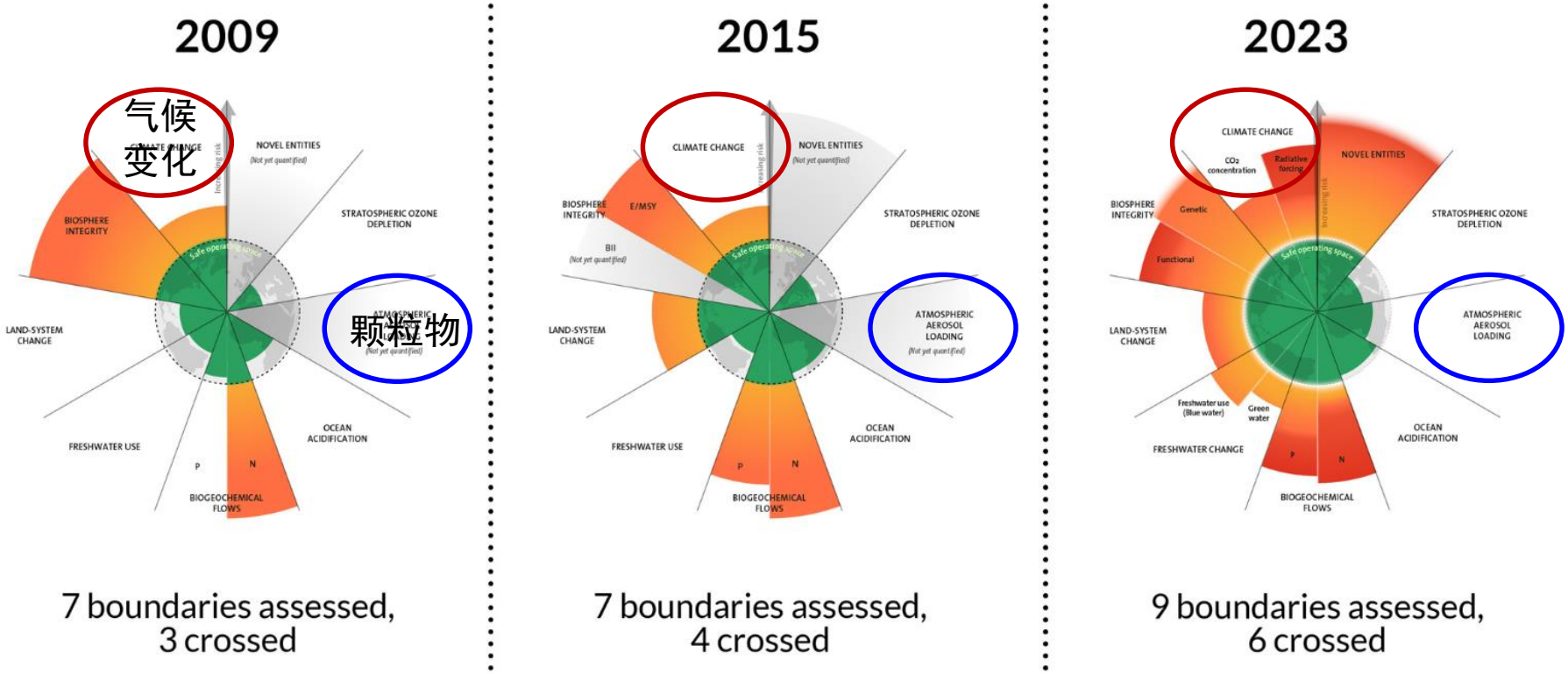


Steffen et al., Science, 2015

"Nexus" of these problems

- Synergistic versus trade-off

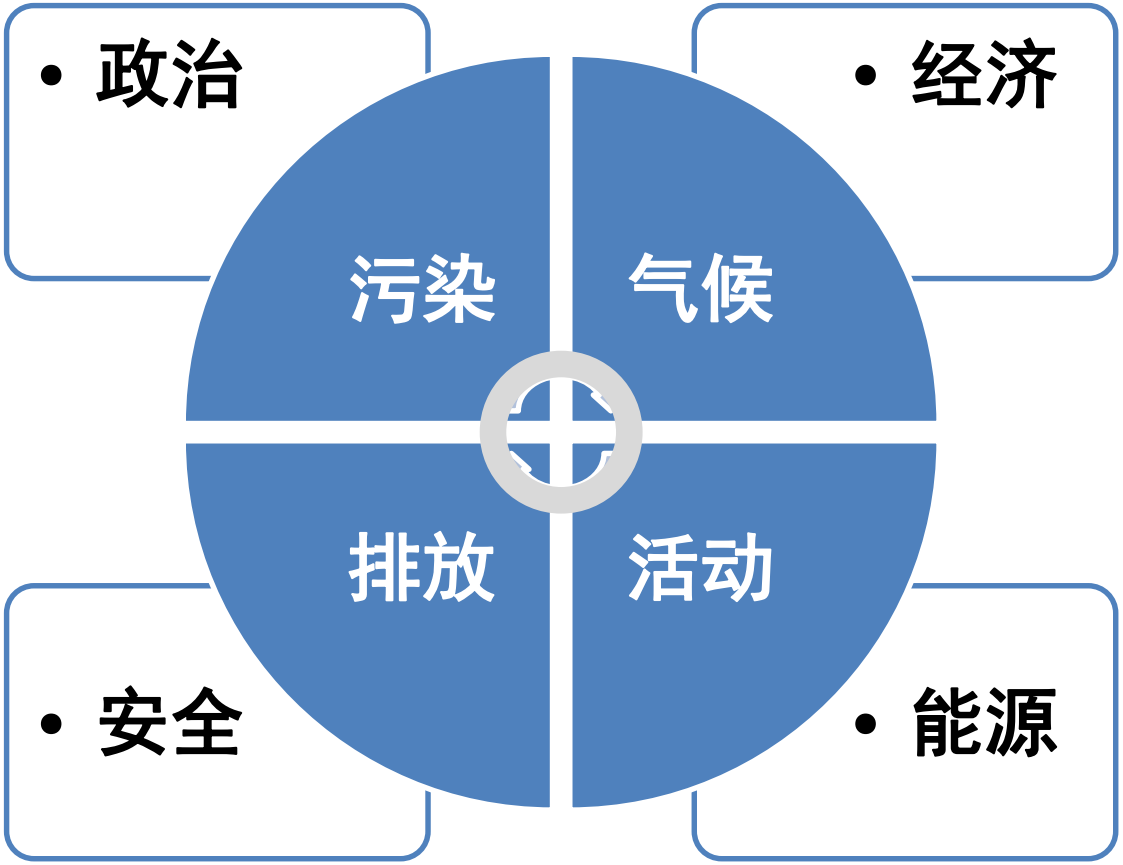
Planetary Boundaries



https://www.stockholmresilience.org/research/planetary-boundaries.html

United Nations Sustainable Development Goals

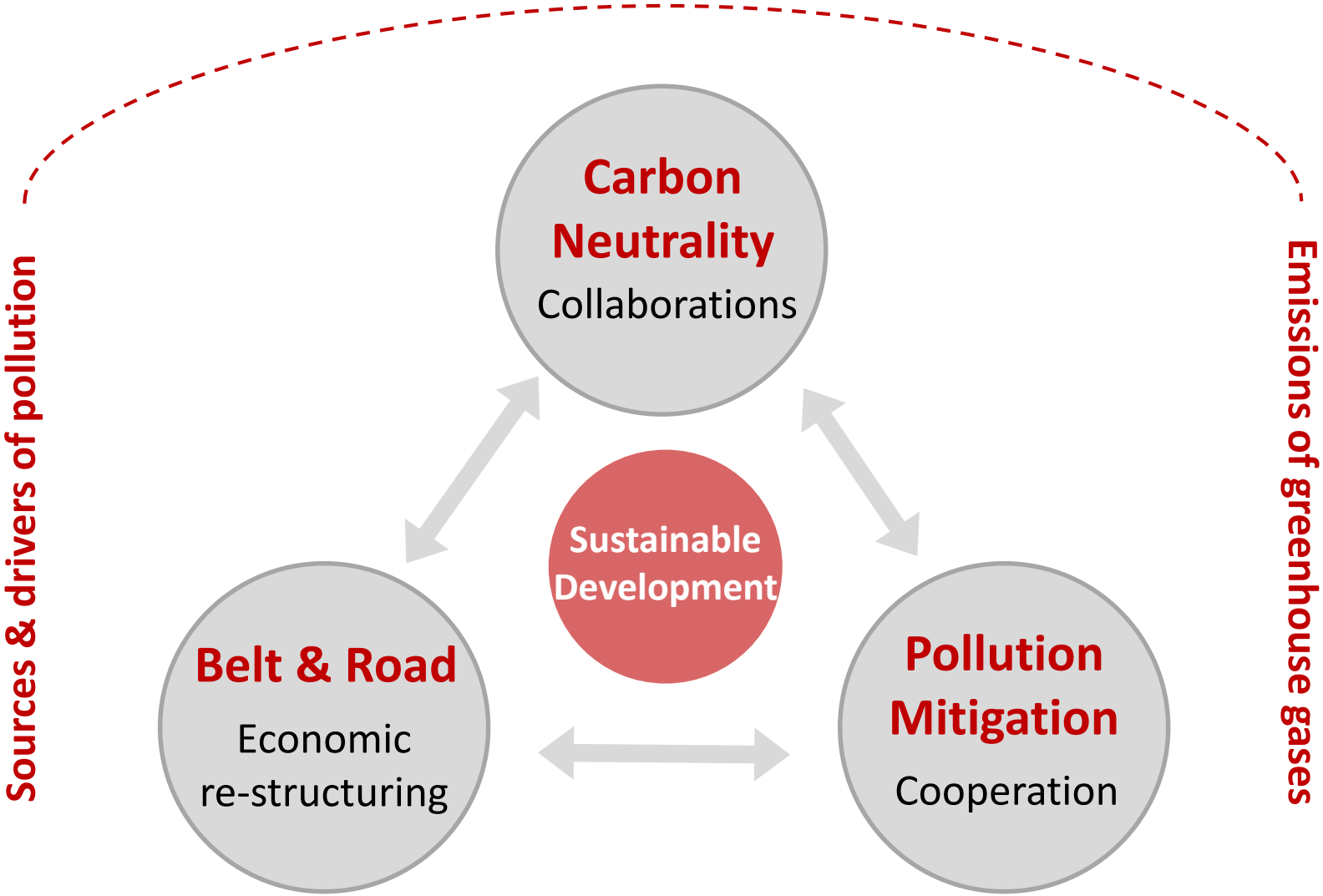
Environment in a Broader Context



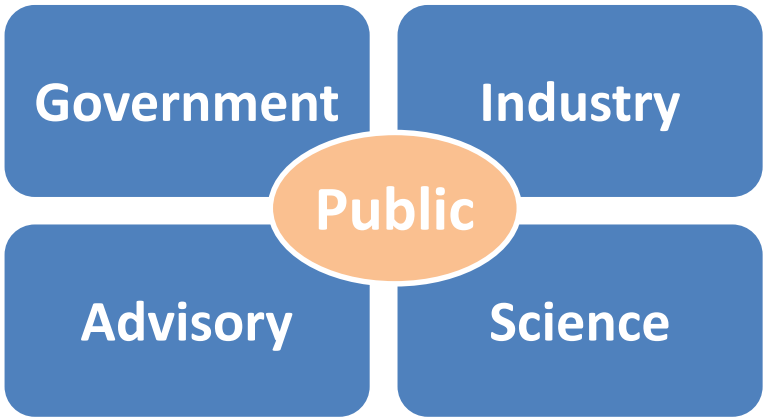
China's Energy Challenges

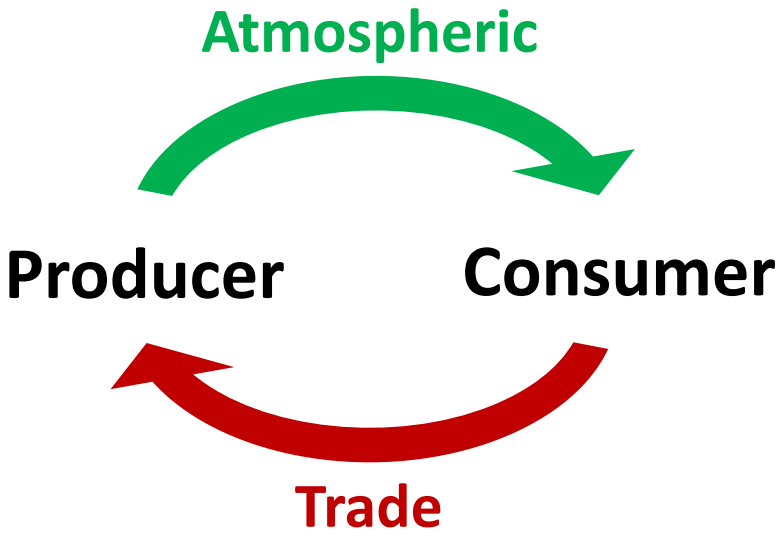
- National security
- Economic bottleneck
  - Energy shortage drives economic crisis throughout the world's history
  - China is short of liquid and gaseous fossil fuels
  - The reliance on coal is faced with great challenges, especially in the coming future
- Climate change and air pollution
  - Fossil fuels do no good for both issues
- Renewables are relatively expensive, but are our future

Science For Concerted Action Towards Sustainability



Science and Policy Making





Our Environmental Dilemma: Global Solution(s) Needed

- Climate change: GHGs (warming), aerosols (cooling)
- Air pollution: ozone, aerosols, etc.

Dilemma (trade-off):

- Environment versus economy
- For air quality: aerosols ↓ → radiative forcing ↑ → climate warming
- For regional ozone air quality: NOx ↓ → urban ozone air quality ↓
- For urban aerosol air quality: VOC ↓ → regional ozone air quality ?
- For climate: aerosols ↑ → air quality ↓
- For climate: BC ↓ → OC, SO_4 ↓ → climate?
- Environmental Kuznets Curve
- Pollution Heaven Hypothesis

Our Environmental and Energy Solutions

- Sustainable development: reduce all pollutants
- Resource & energy conservation: rely on everybody!
  - Consumption-based perspective
- Energy efficiency: decrease energy per unit of GDP
- Emission reduction
  - Regulation and policy
    - Enhance standard, penalty, and enforcement
    - Administrative versus market-based policy
    - Carbon trade versus carbon tax
    - Power, industry (?), transportation, residential (?), agr. (?)
  - Technology
    - CCUS (carbon capture, utilization, and storage)?
    - BECCS (bioenergy + CCS)?
- Renewable energy: a plausible solution
  - Hydro, wind, solar, biofuel, tidal, etc.

碳中和：中国排放约束

碳中和事关环境、科技、经济、国际合作

但是，碳中和的内涵是什么？

2015年巴黎协议：提出2℃温升目标，争取做到1.5℃温升

2015年中国NDC：
- CO_2排放于2030年左右达峰（争取提前）
- 单位GDP的CO2排放比2005年下降60-65%
- 非化石能源占一次能源消费比重达到20%左右
- 森林蓄积量比2005 年增加45 亿立方米左右
- 到2020 年天然气占一次能源消费比重达到10%以上

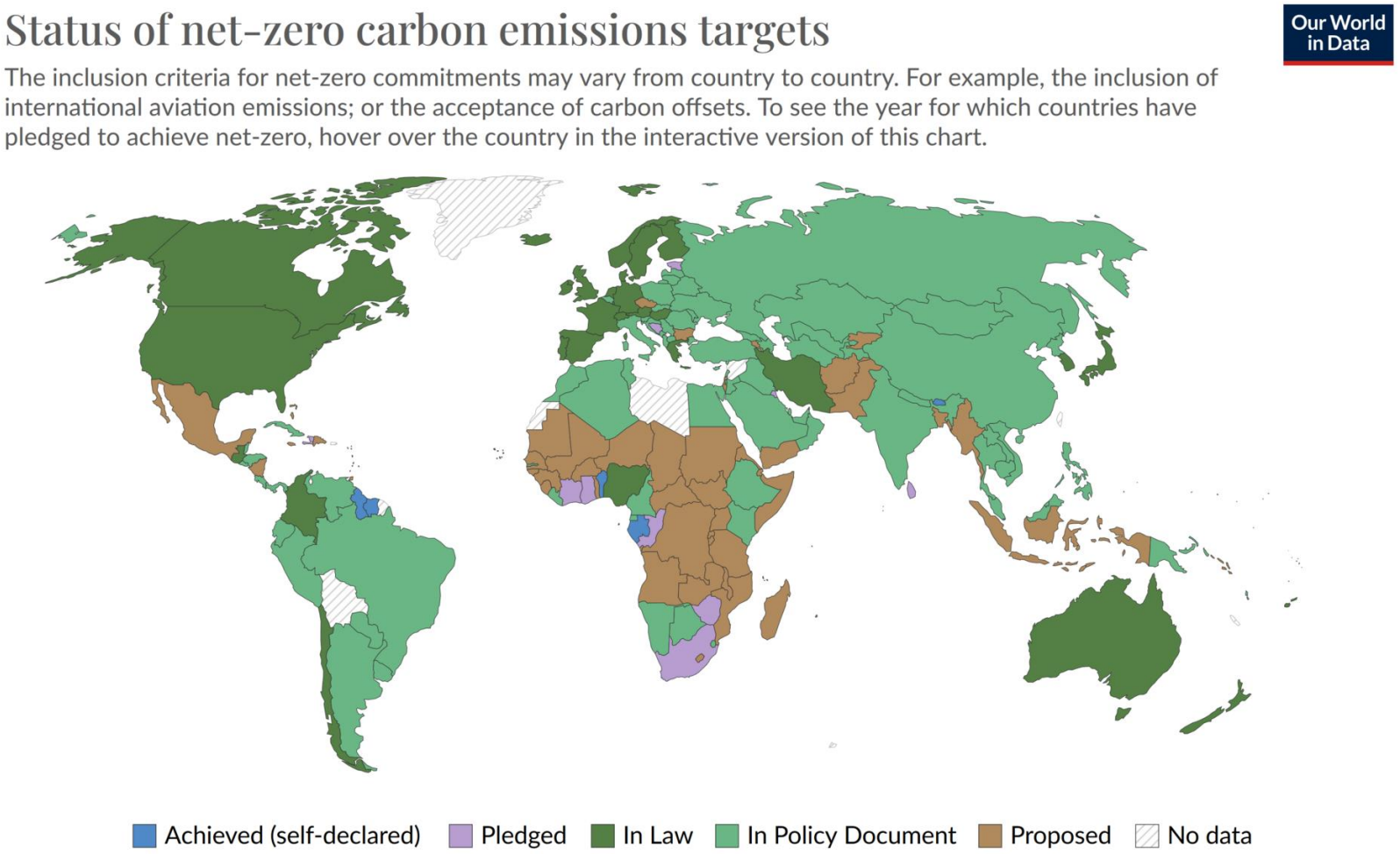
2018年10月：IPCC 1.5℃温升特别报告

2020年9月22日：2030年前实现CO_2排放达峰，2060年之前碳中和

2021年4月：中美应对气候危机联合声明

2021年11月：中美格拉斯哥联合宣言：中方争取在21世纪20年代取得控制和减少甲烷排放的显著效果

Carbon Neutrality ?



https://en.wikipedia.org/wiki/Carbon_neutrality

碳中和：中国重要机遇

碳中和事关环境、科技、经济、国际合作

但是，碳中和的内涵是什么？

社会：能源清洁化 + 终端电气化 + 可持续消费

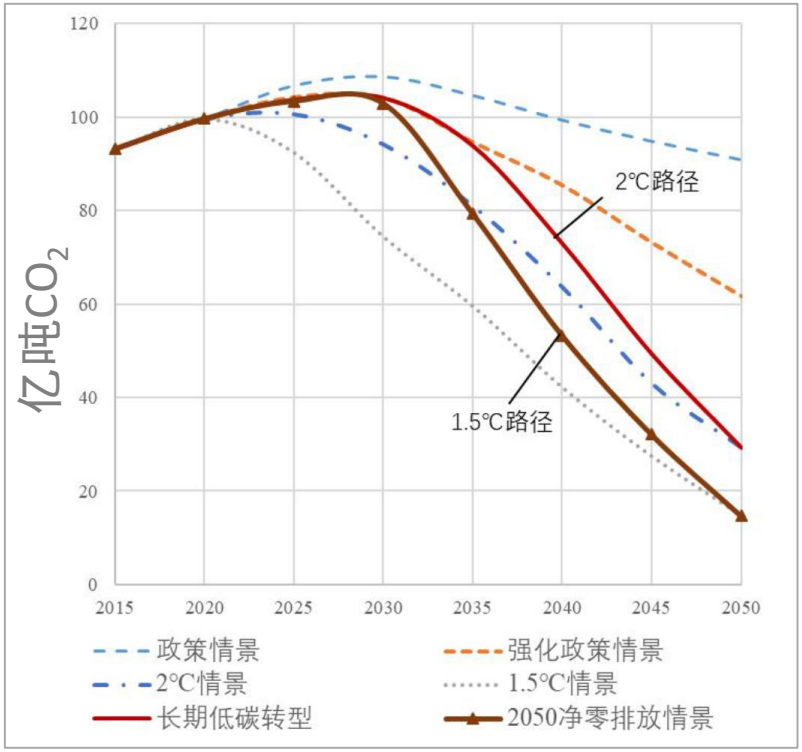
经济：弱国 → 大国 → 强国

科技：跟跑 → 并跑 → 领跑

环境：引领生态环境保护和治理

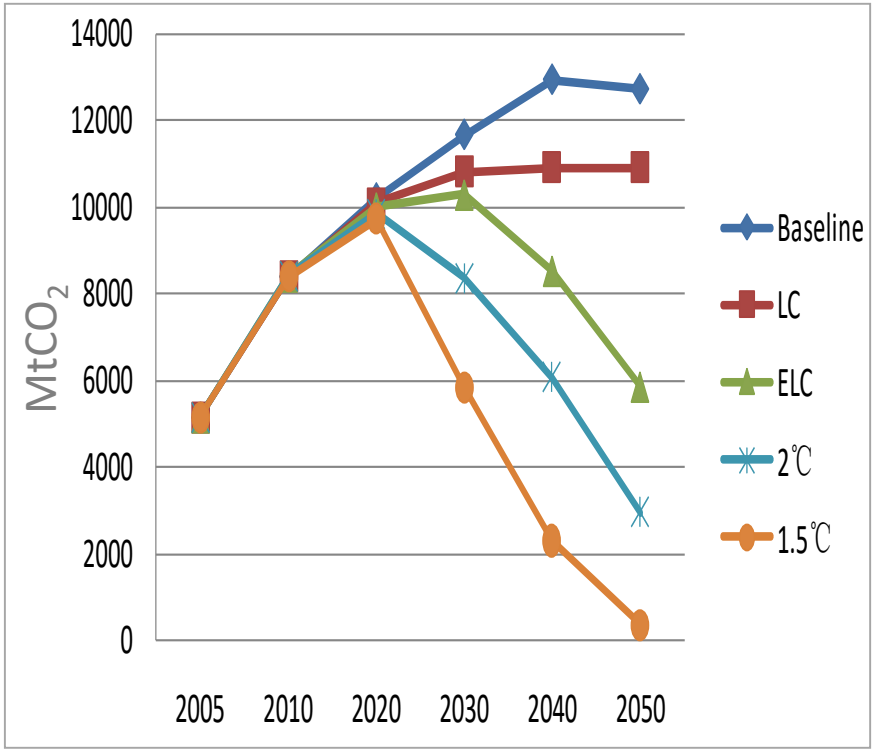
国际合作：人类命运共同体（可持续发展）

中国碳排放情景和碳中和路径



来源：清华大学气变院

vs



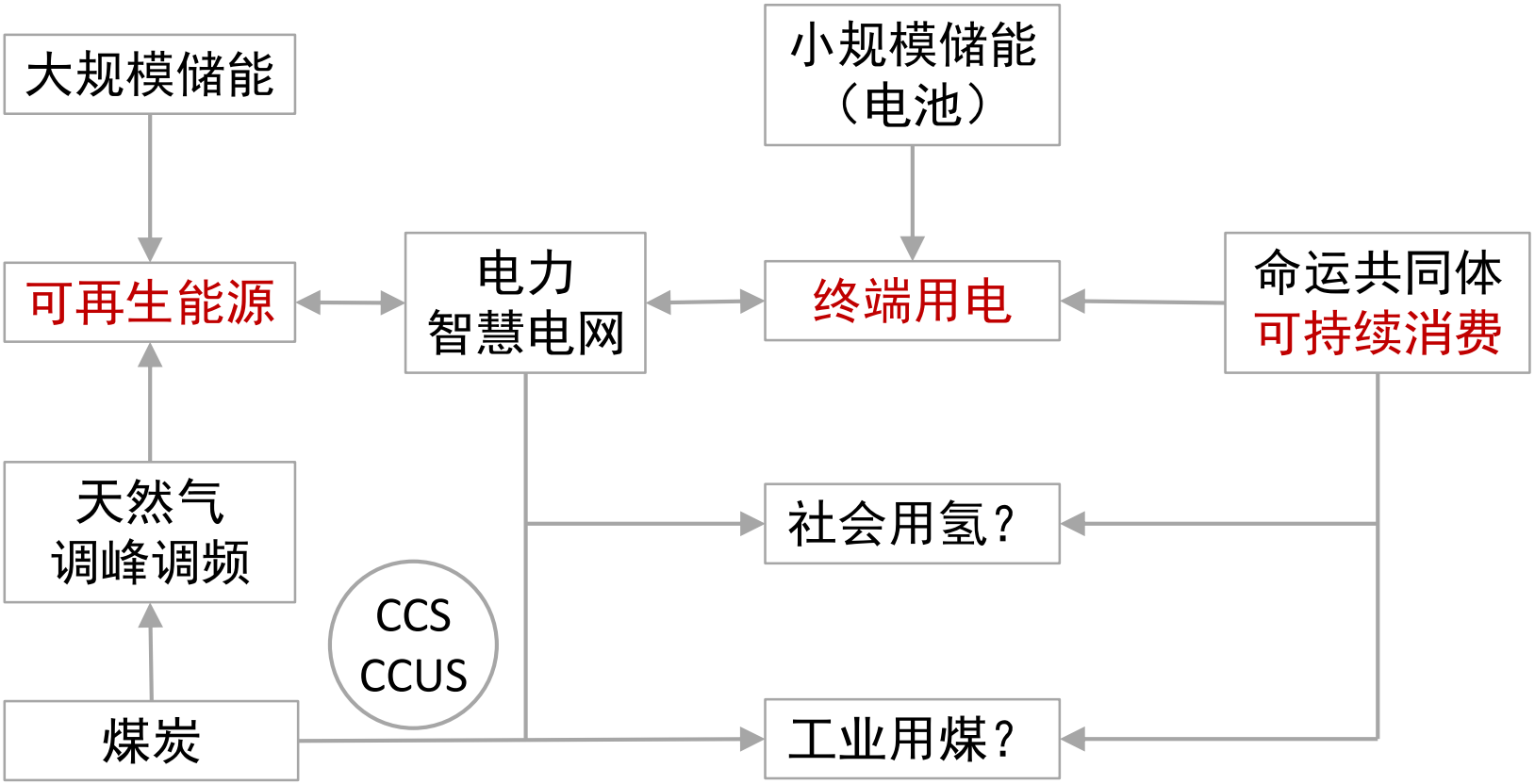
来源：姜克隽

碳中和措施

策略	措施	能源安全影响	科技影响	经济影响	气候影响	环境影响	其他制约因素
改善能源供给	减少化石燃料使用				+	+	
	发展风能	+	+	短期 - 长期 +	+	+	储能、电网
	发展太阳能	+	++	短期 - 长期 +	+	+	储能、电网
	发展水电	+		+	+	?	规模
	发展核能	+	+	?	+	?	潜在风险
减少排放	CCS、CCUS	+	+	?	短期 + 长期 ?	短期 + 长期 ?	潜在风险、可持续性
	BECCS	+	+	?	短期 + 长期 ?	短期 + 长期 ?	潜在风险、可持续性
增加碳汇	植树造林			+	+	+?	
减少能源需求	可持续消费	+	+	短期 - 长期 +	+	+	平等性

未来能源发展

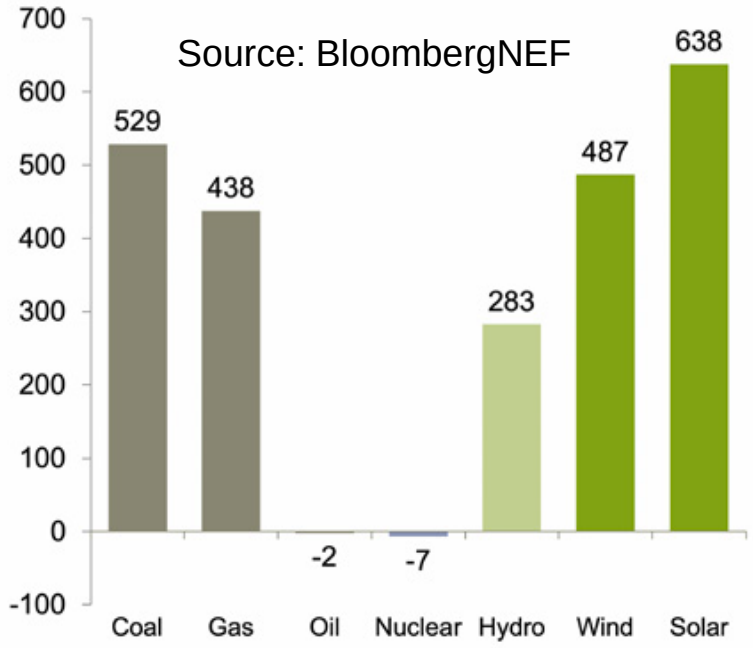
经济领导、科技领先、环保领军、国际领袖



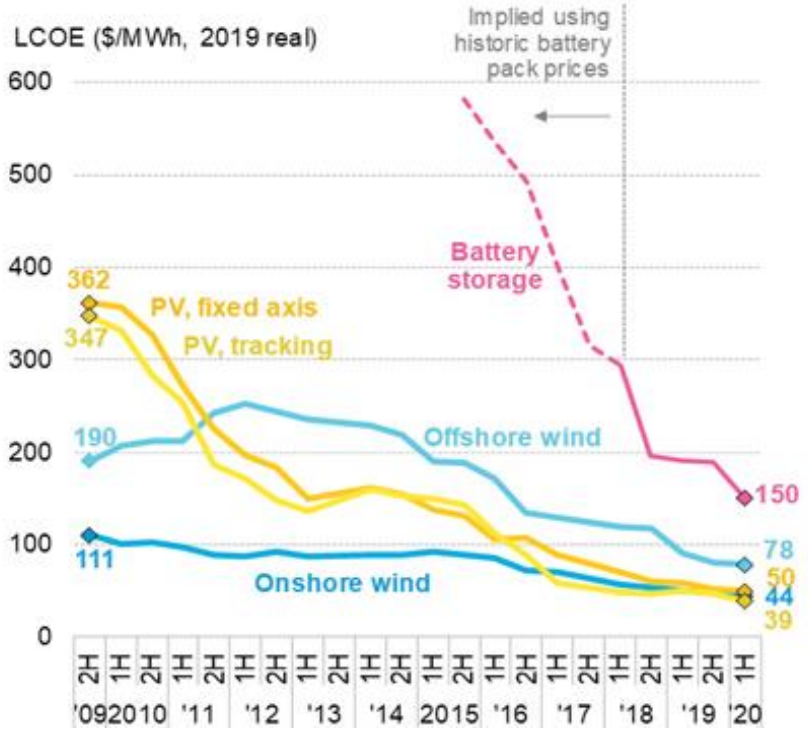
Future of Energy

- Economic costs of solar/wind electricity are close to coal-based electricity

Capacity added in the last decade (2010-2019) Unit: GW



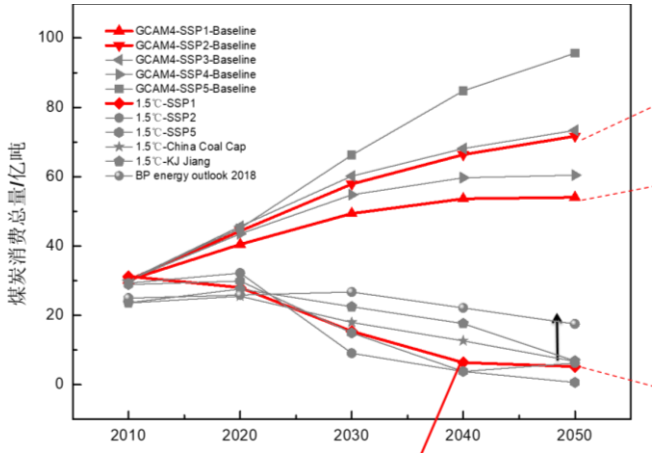
Global LCOE benchmarks



Potential Solutions to China's and World's Environmental Issues

- Energy: From fossil fuel to renewables
- Societal energy use: Electrification
- Individuals: Sustainable consumption
- Inter-regional cooperation: Financial and technological
- Carbon / environmental tax ?

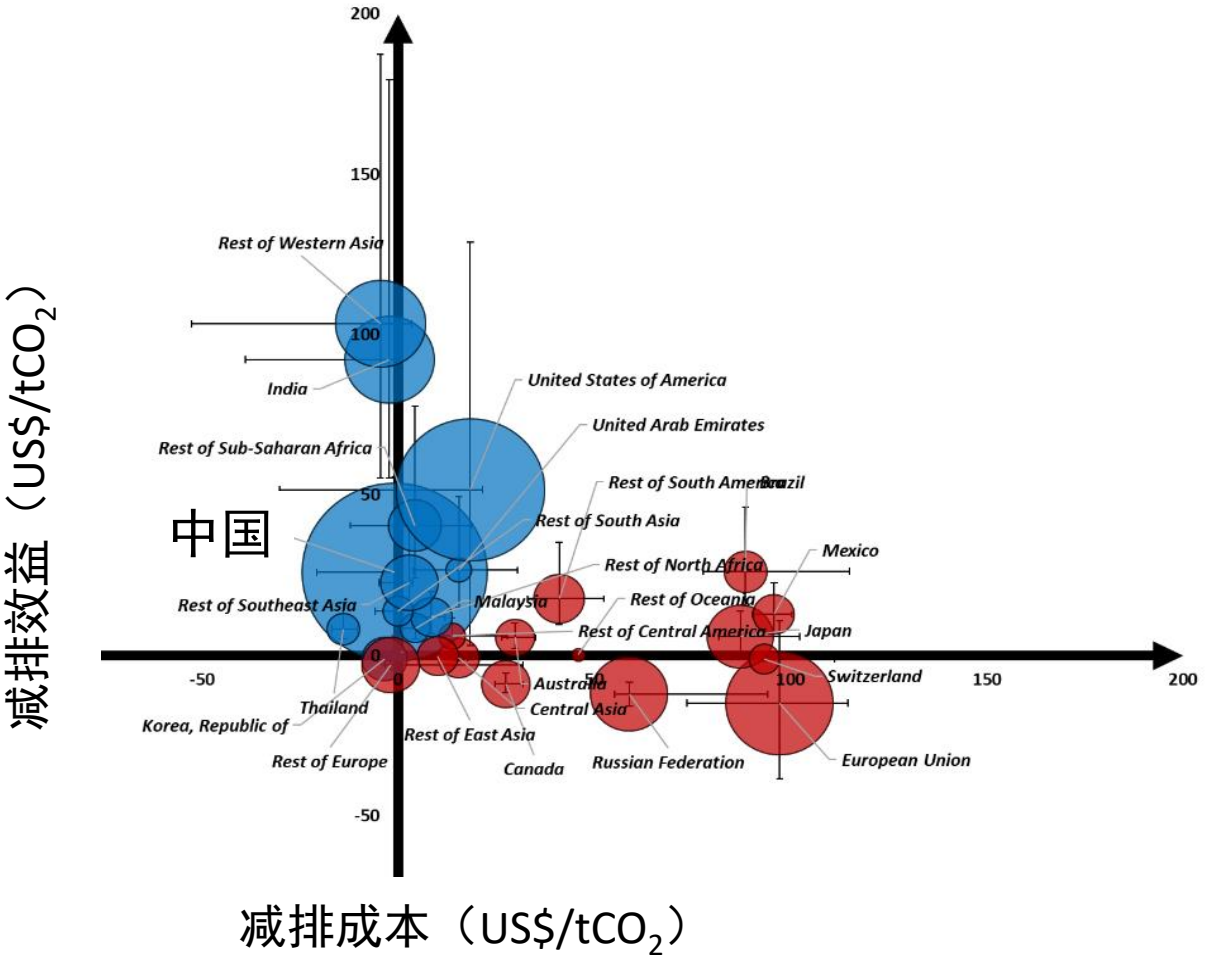
中国煤炭消费量



Source: Xiao Liu

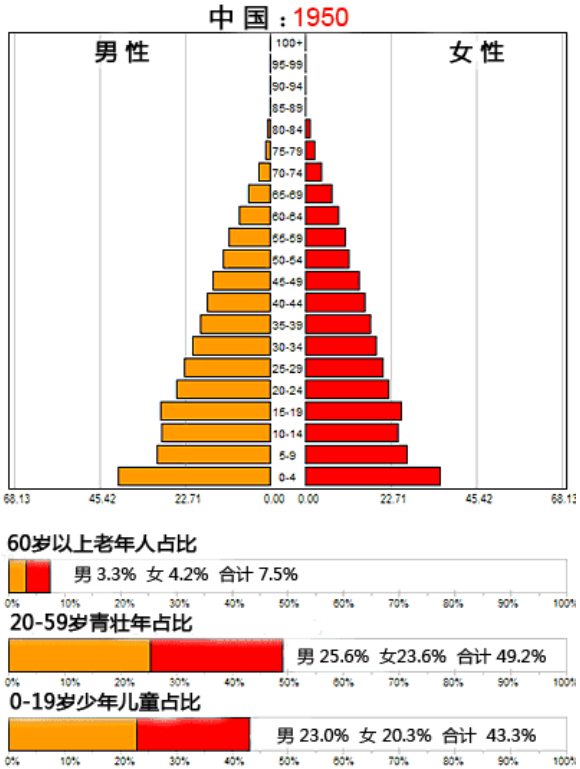
各地区碳减排成本与潜在效益呈现负相关
中国减排适合性？国际减排合作？

SSP2-RCP4.5情景相比于SSP5-RCP8.5情景的减排成本和潜在效益

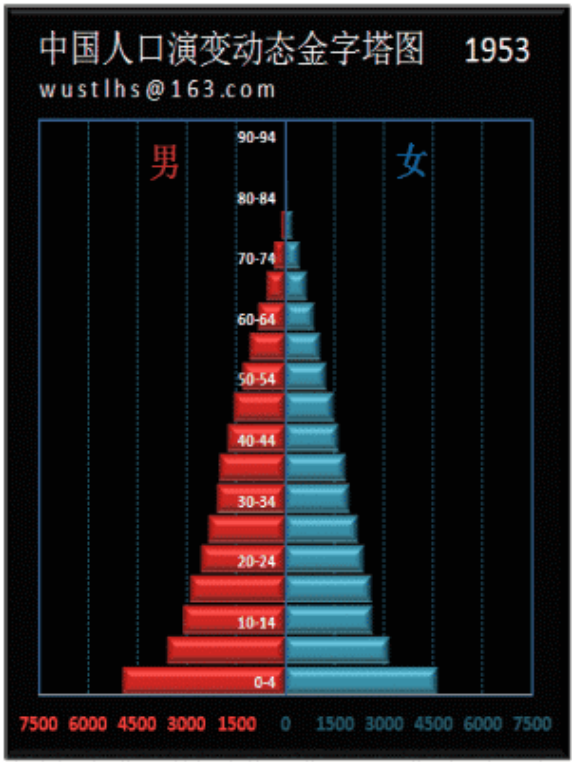


Liu et al., in review

Chinese Population Structure Change



http://www.360doc.com/content/15/0929/18/14590724_502277109.shtml

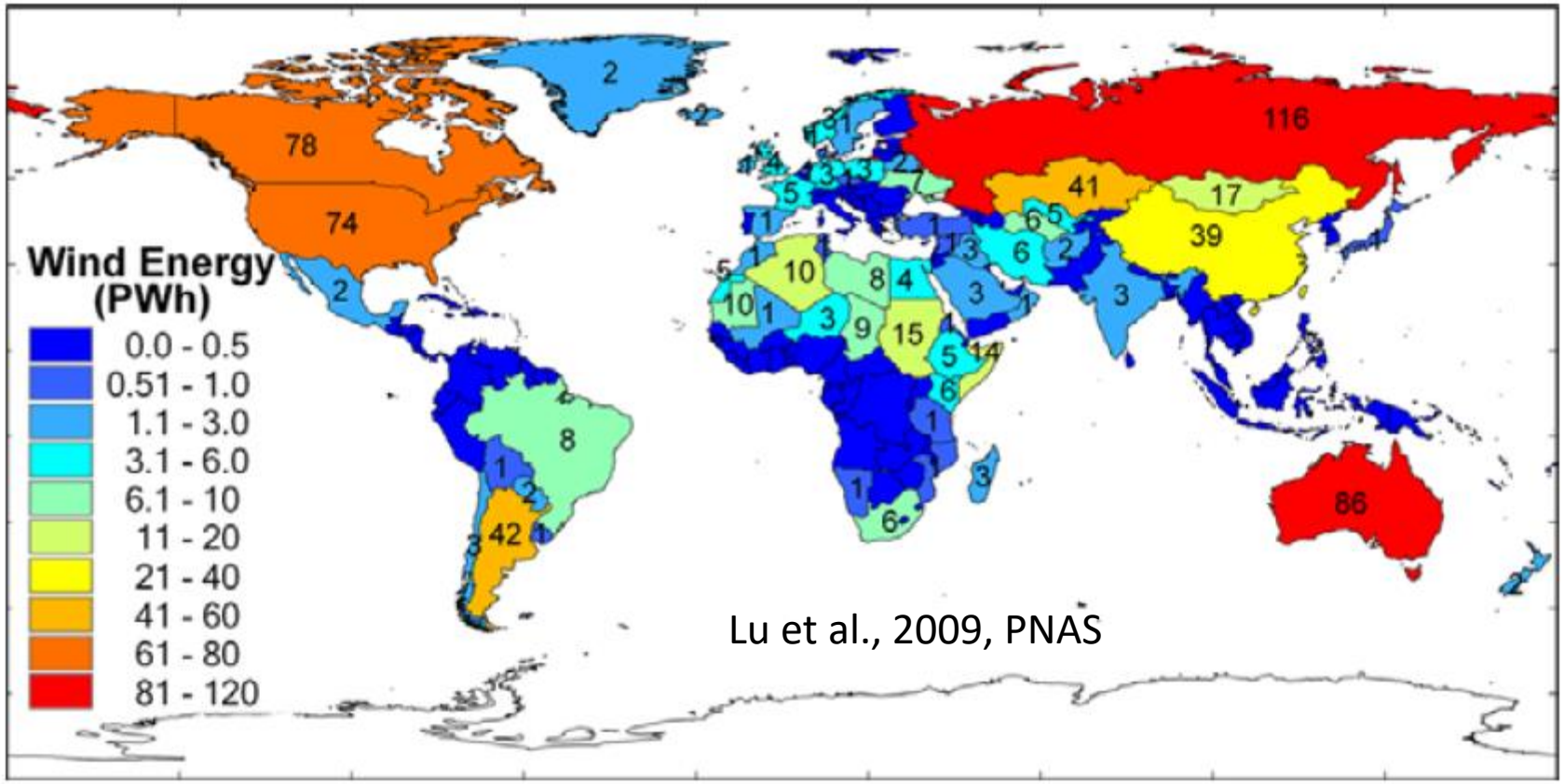


How many people will China and the world need ?

Clean Energy and Renewable Energy

- Hydro : Traditional, Ecosystem issues
- Nuclear : Safety – Not In My Backyard
- Wind : Abundant, Intermittency
- Solar : Abundant, Intermittency
- Biofuel : Energy-food-water nexus
- Geothermal: Limited exploitability
- Tidal : Limited exploitability

Annual ONSHORE Wind Energy Potential Country by Country



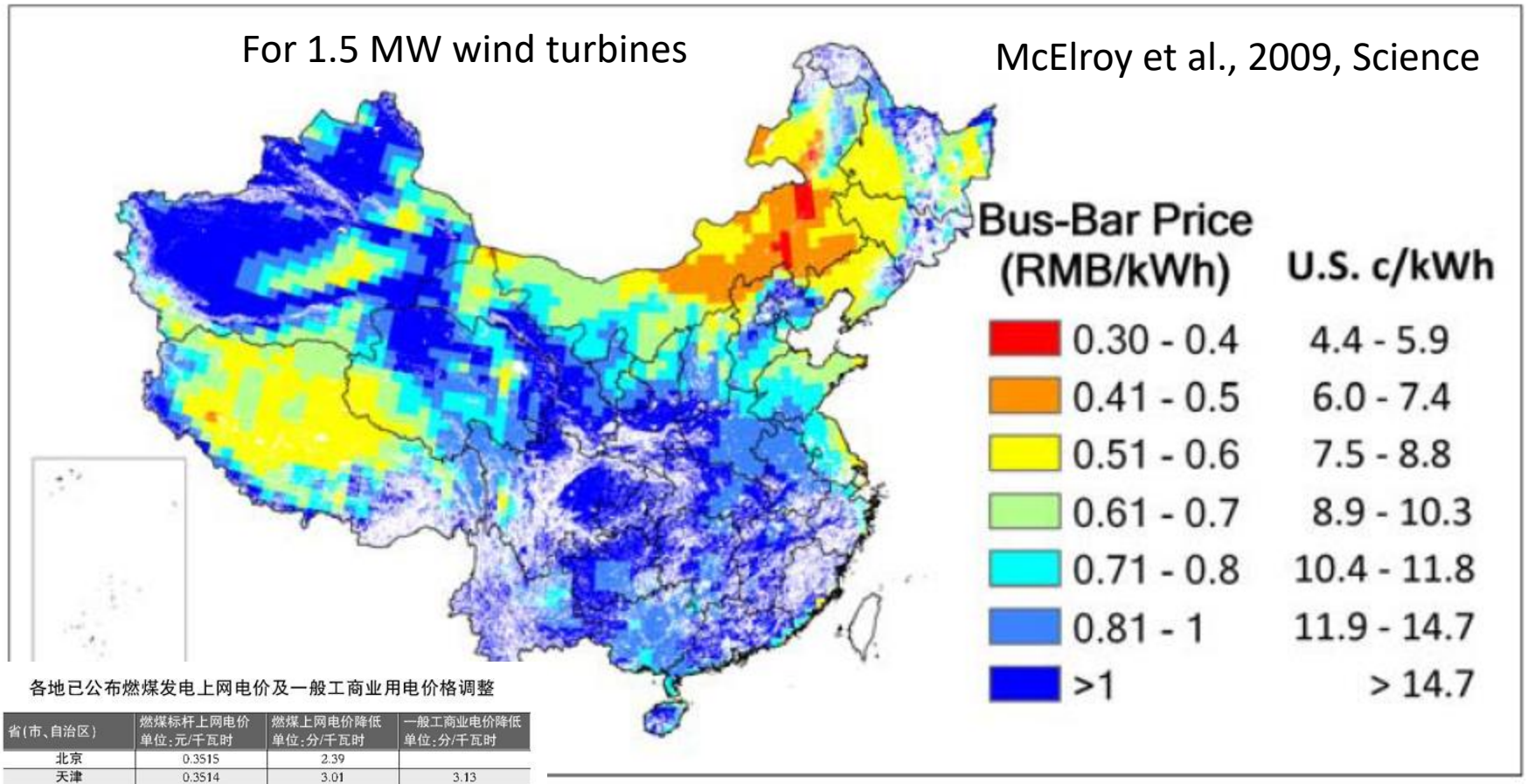
Lu et al., 2009, PNAS

- A network of land-based 2.5 MW wind turbines is assumed to be installed on **non-forested**, **ice-free**, **non-urban** land areas.
- Only those that generate ≥ 20% of their rated capacity are included.

Bus-Bar Price Estimated of Wind Electricity for China

For 1.5 MW wind turbines

McElroy et al., 2009, Science

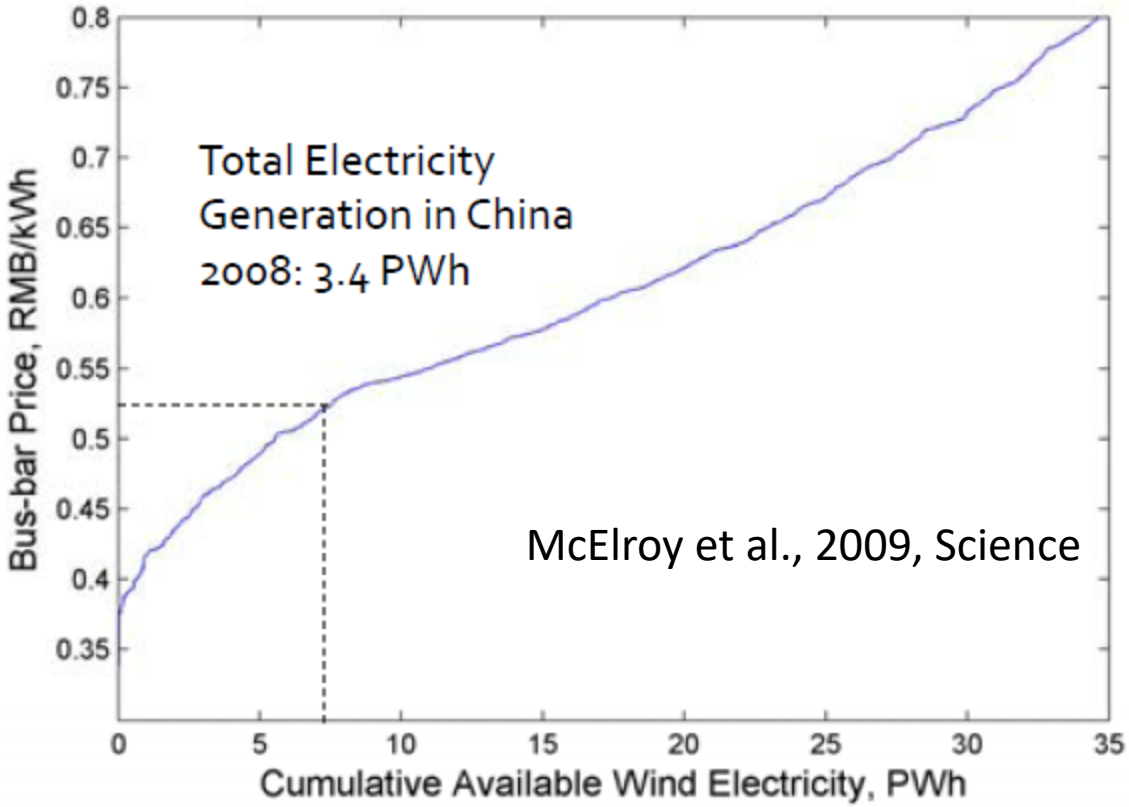


各地已公布燃煤发电上网电价及一般工商业用电价格调整

省(市、自治区)	燃煤标杆上网电价 单位:元/千瓦时	燃煤上网电价降低 单位:分/千瓦时	一般工商业电价降低 单位:分/千瓦时
北京	0.3515	2.39	
天津	0.3514	3.01	3.13
黑龙江	0.3723	1.41	1.3
河南	0.3551	4.46	5.57
山东	0.3729	4.65	4.15
山西	0.3205	3.33	6.09
四川	0.4012	3.9	0.6
甘肃	0.2978	2.72	1.39
宁夏	0.2595	1.16	3.16
江苏	0.378	3.16	3.12
浙江	0.5058	3.3/1.3(内陆)	4.47
上海	0.4048	3.11	2.12

中国能源报，2016/01/20
http://news.bjx.com.cn/html/20160120/702815.shtml

Cumulative Available Wind Electricity at Different Bus-bar Price Levels for China



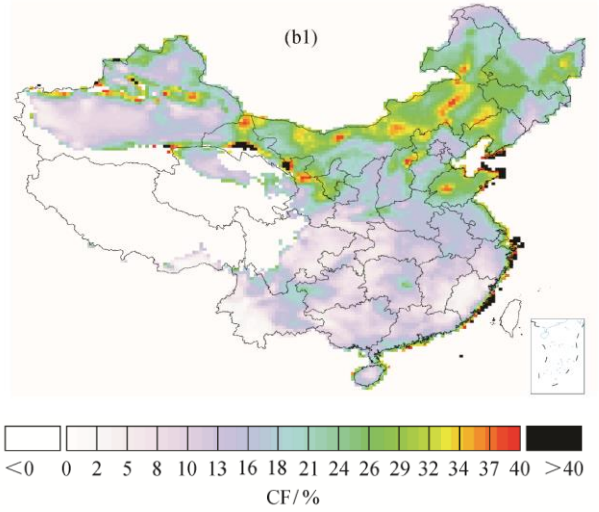
At 0.516 RMB/kWh (about 7.6 US Cents/kWh) profitable wind power would amount to 7 PWh, comparable to total electricity demand projected for 2030 in China.

Challenges for Wind Energy Development

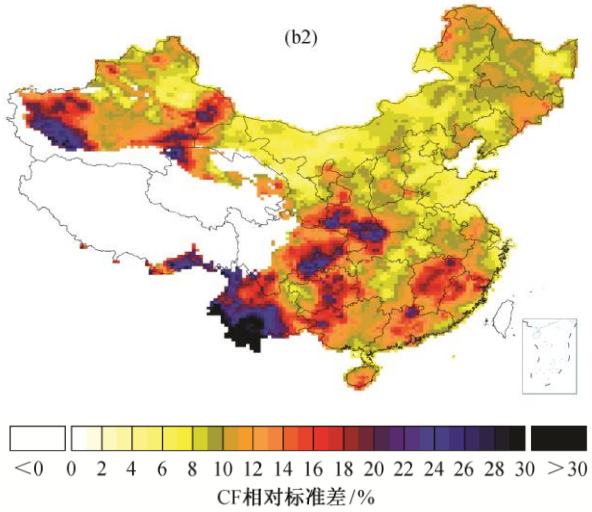
- Wind speed varies dramatically, both spatially and temporally!
  - Temporal variability within the lifetime of a wind turbine
    - Seasonal and interannual: where to set up wind turbines?
    - Hourly, daily: Can we predict wind power?
    - Storage: good wind time ≠ high demand time
  - Spatial variability
    - Good wind regions ≠ high demand regions
    - Electricity transport
    - Power storage
  - Impacts on power grids
    - Transition to 'smart grid'; bi-directional transmission
    - Role of electric cars?
  - Reliability of wind energy estimation
    - Observation based vs. model based
  - Combined with solar energy and/or hydropower ?
    - Negatively correlated diurnally and seasonally

Interannual Variability of Wind Electricity

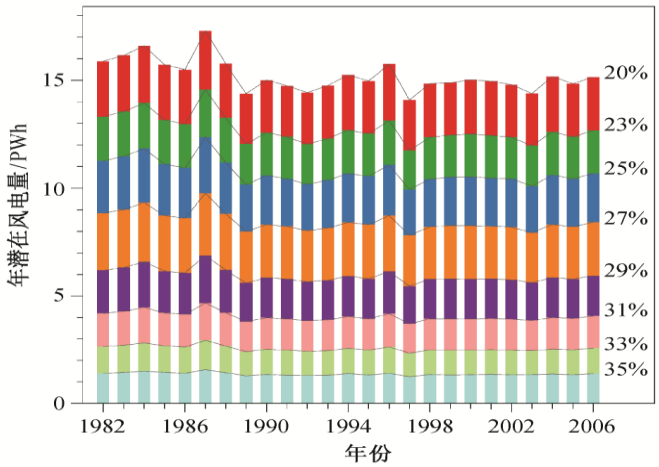
1982-2006 mean CF



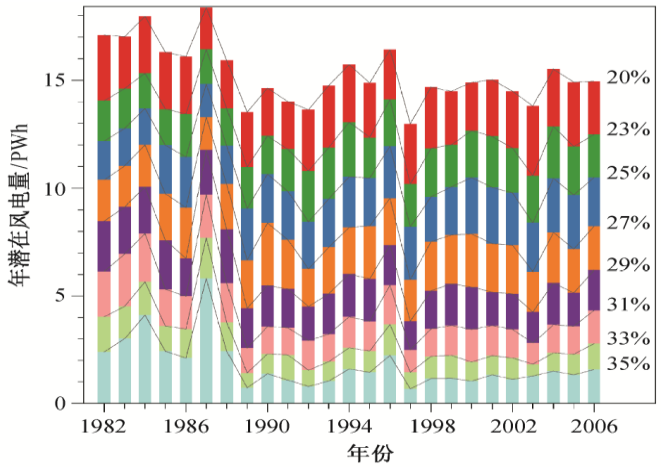
Relative STD of CF



WP wrt 25-year mean CF



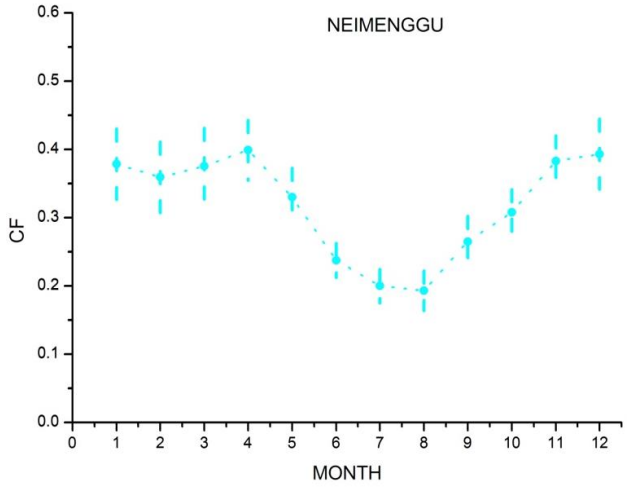
WP wrt year-specific CF

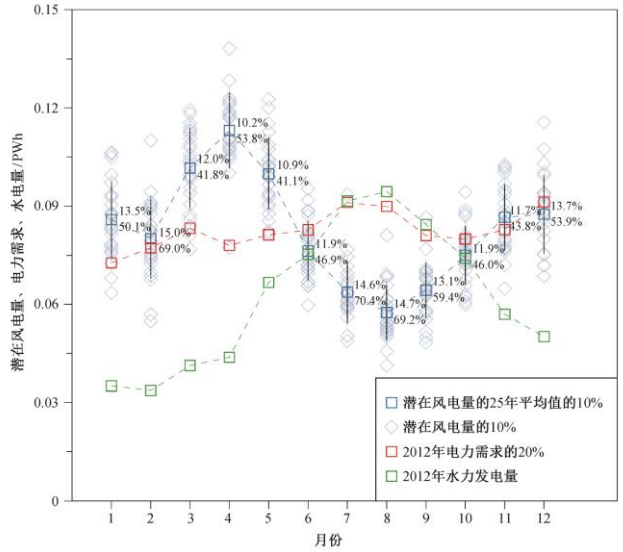


Wang et al., 2016

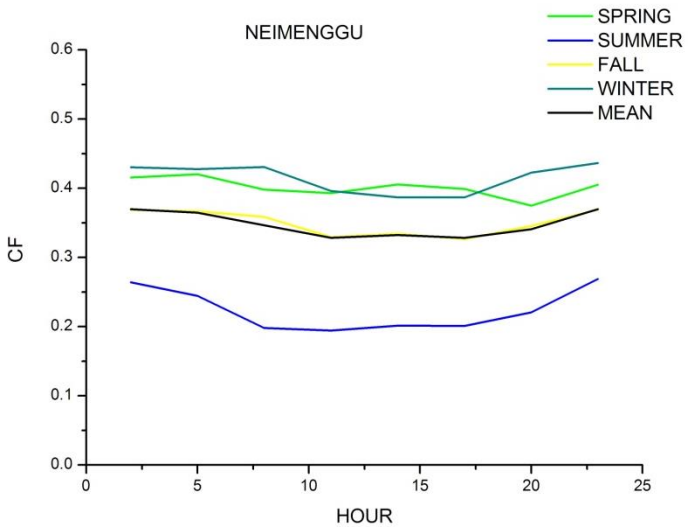
Seasonal and Diurnal Variations of Wind Electricity

Seasonal Variability





Diurnal Variability



Wang et al., 2016

A Few Cents on Geoengineering

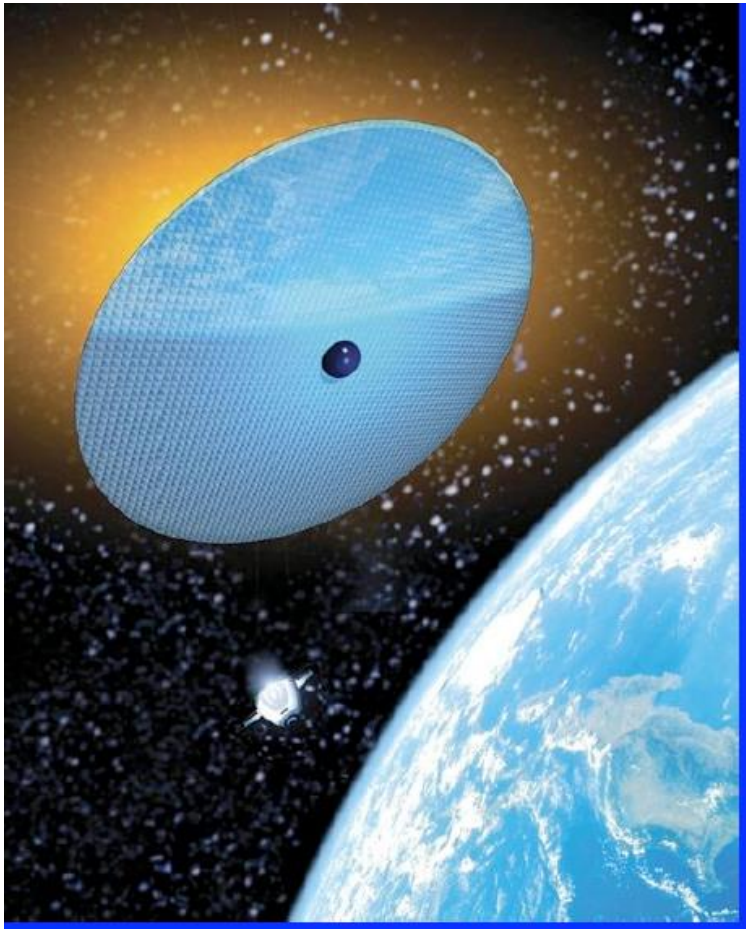
Different types of CE derived from the energy balance

- What could we do to the energy balance to decrease the present imbalance?

1. Reduction of the solar constant
2. Increase of Planetary Albedo
3. Increase of thermal emissions

Jost Heintzenberg

A Few Cents on Geoengineering



Solar constant S

Reduction of S by ca. 1.8% through:

1. autonomous mirror systems (100000 x 13000 km) at Lagrange point L1
2. Reflecting dust rings or screens in near-Earth orbits

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A Few Cents on Geoengineering

Planetary Albedo A_p

1.Suggestion:

More reflecting stratospheric aerosol

Deployment through rockets, planes, canons or hoses carried by tethered balloons

Bill Gates funds the balloon approach

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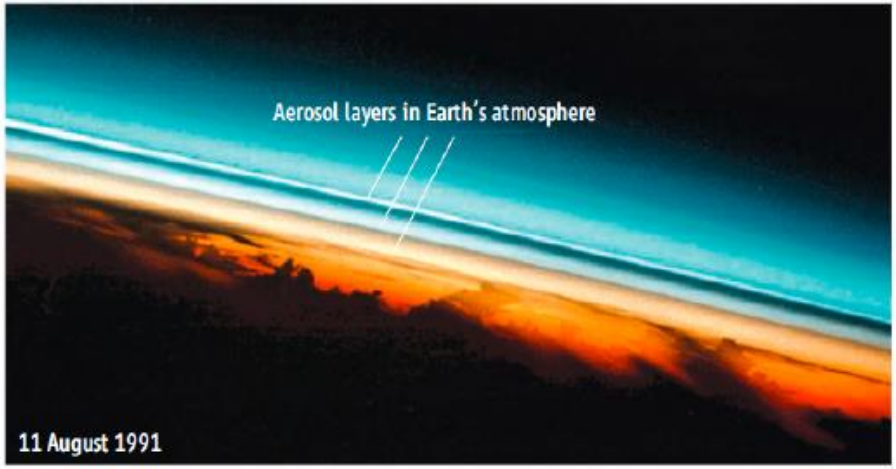
A Few Cents on Geoengineering

Comparison with volcano Pinatubo

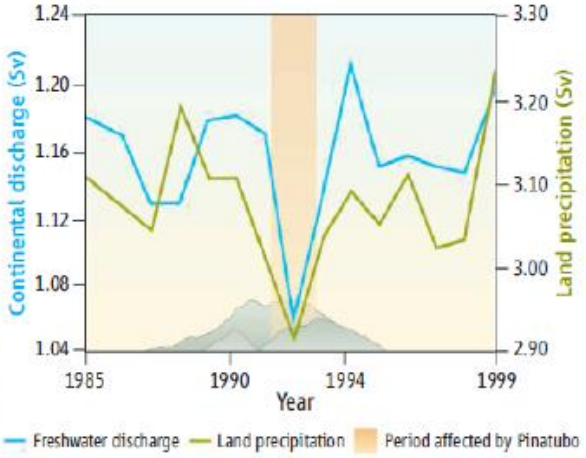
A

Pinatubo aerosols as seen from the space shuttle Atlantis



B

Pinatubo effects on precipitation



Hegerl & Solomon, 2009:
Global reduction in precipitation and continental run-off

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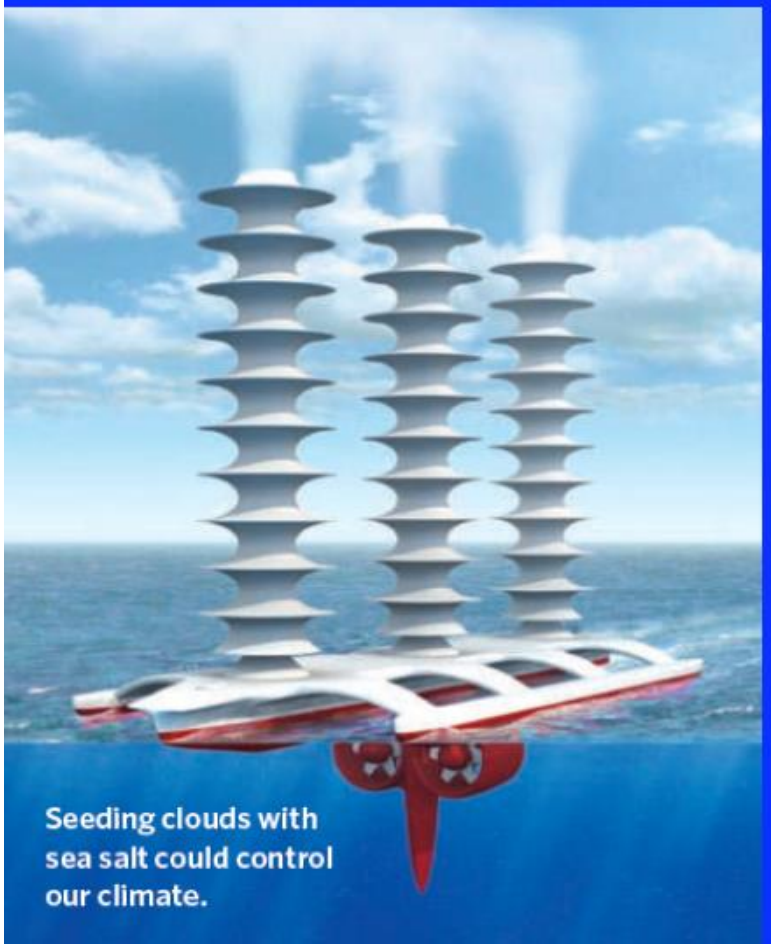
Planetary Albedo A_p



2. Suggestion:

John Latham et al.:

Brightening of low marine clouds by offering them more sea salt condensationa nuclei (and water vapor)

Bill Gates funds this idea as well

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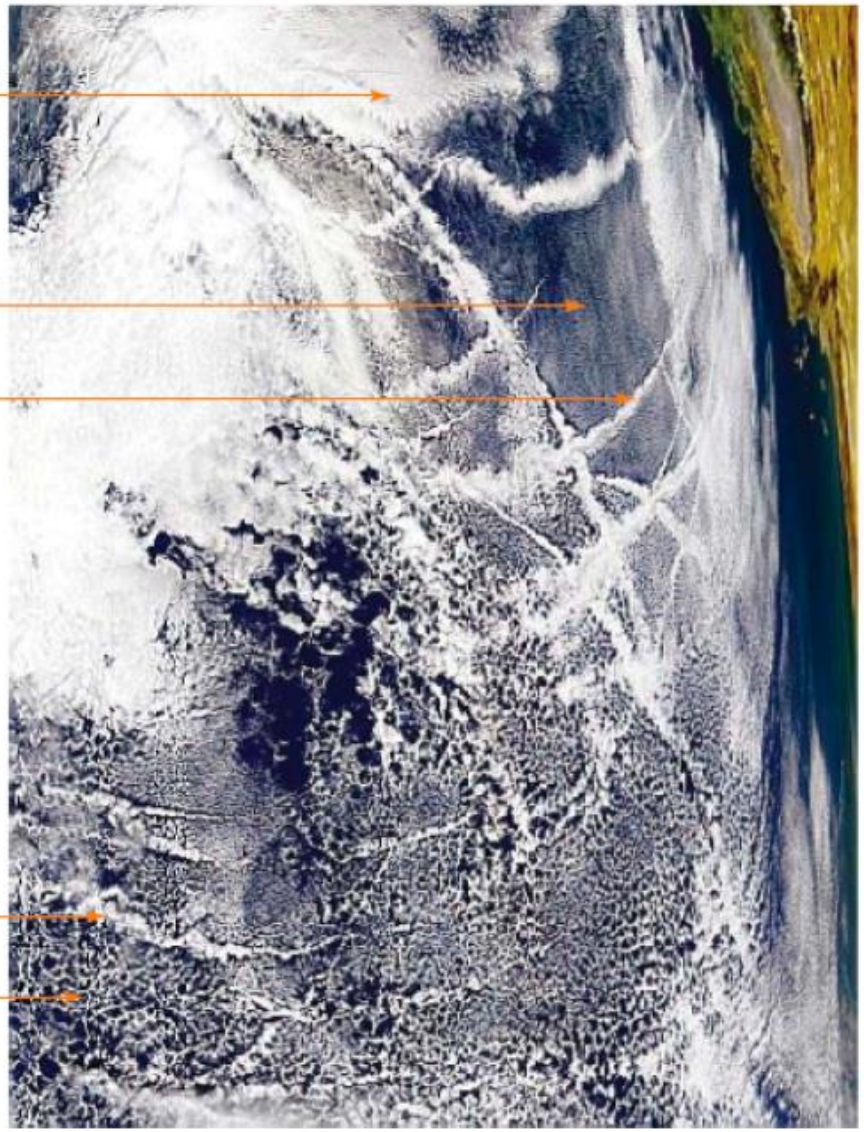

Stevens & Feingold, 2009

An example of ship tracks

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Planetary Albedo A_p

3.+ 4. Proposal
Increase of albedo of agricultural and urban land surfaces

CLIMATE ENGINEERING 24

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Planetary Albedo A_p

5. Proposal: ***Eliminate atmospheric particulate black carbon (soot)***

Advantage:

Techniques exist. Positive side effects on human health and urban ventilation. Albedo increase of previously soot covered snow and ice regions

Modeling:

Present total influence of soot on Earths energy balance is on the order of the CO_2 heating

Disadvantages:

Most filtered-out combustion particles are not soot but light reflecting particles. Ocean acidification as before

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A Few Cents on Geoengineering

Earth's thermal emission F_I

Almost all proposals want to increase F_I through the extraction of CO_2 from the atmosphere:

- Acceleration of the **physical carbon pump** in the ocean
- Acceleration of the **physico-chemical carbon pump** in the ocean
- Acceleration of the **biological carbon pump** in the ocean
- Increase of **carbon binding in terrestrial plants and plant detritus**
- Acceleration of **natural weathering**
- Technical **elimination of CO_2 from the air**

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A Few Cents on Geoengineering

The biological carbon pump

- Builds on the ***Iron hypothesis*** of Martin (1988)
- Ocean fertilization with substances that stimulate growth of algae
- **Advantage**: Reduction of CO_2 ocean acidification
- **Modeling**: Difficult because not all processes are known and because the whole marine food web is affected
  Disadvantage: After 15 field trials no clear long-term results, however measurable side effects like increased emissions of greenhouse gases
- The fate of biologically fixated carbon does also depend on physical and chemical processes in the oceans

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A Few Cents on Geoengineering

Terrestrial biological carbon fixation

- Simplest approach: **Large-scale afforestation**, e.g., the Sahara
- **Disadvantage**:
- Model simulations only show a cooling when increasing tropical forests
- The Tundra/Taiga feedback would lead to a warming when increasing boreal forests
- Afforestation of the Sahara needs to consider albedo changes, the west African monsoon and changes of the nutrition effects of Saharan dust

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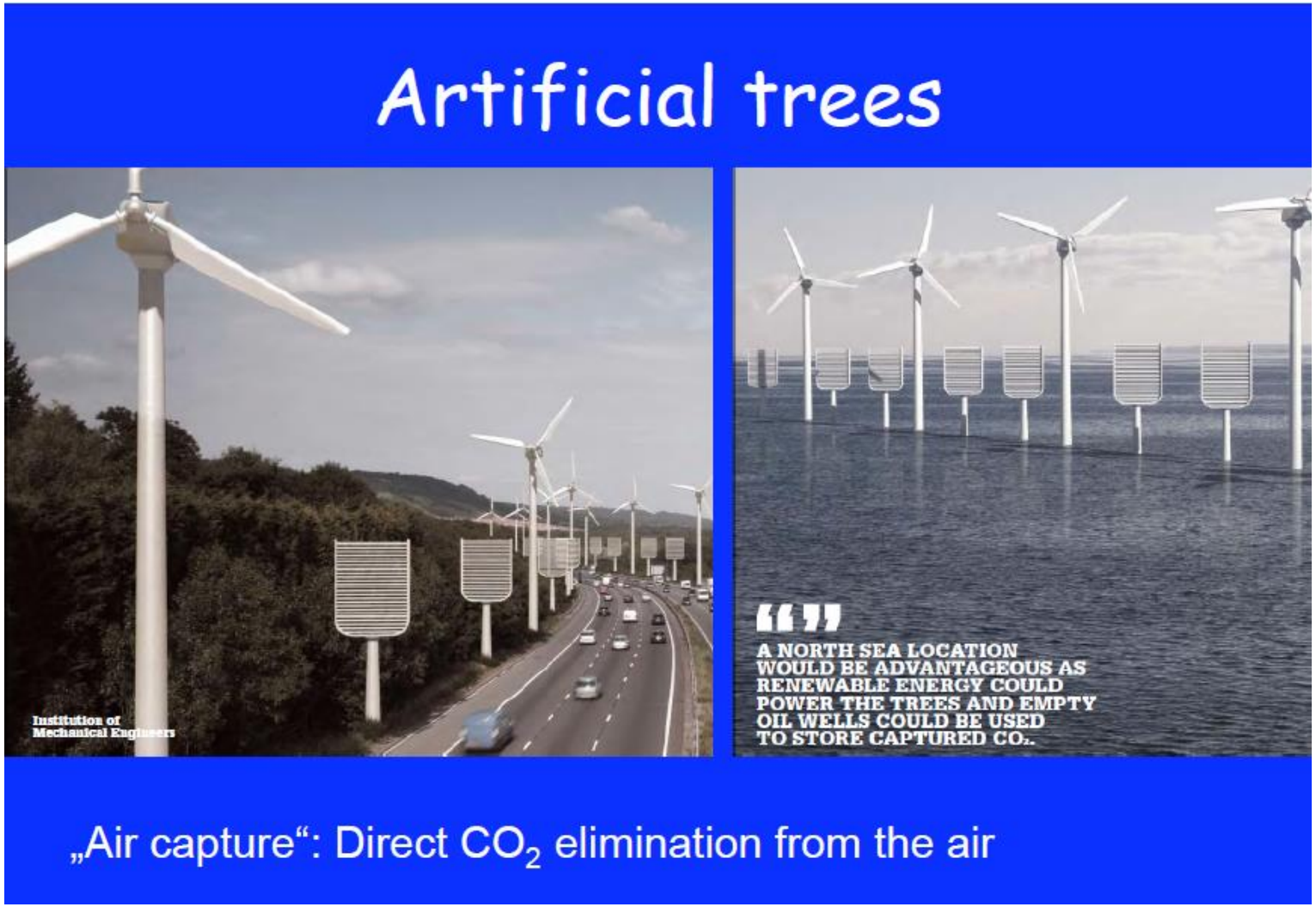
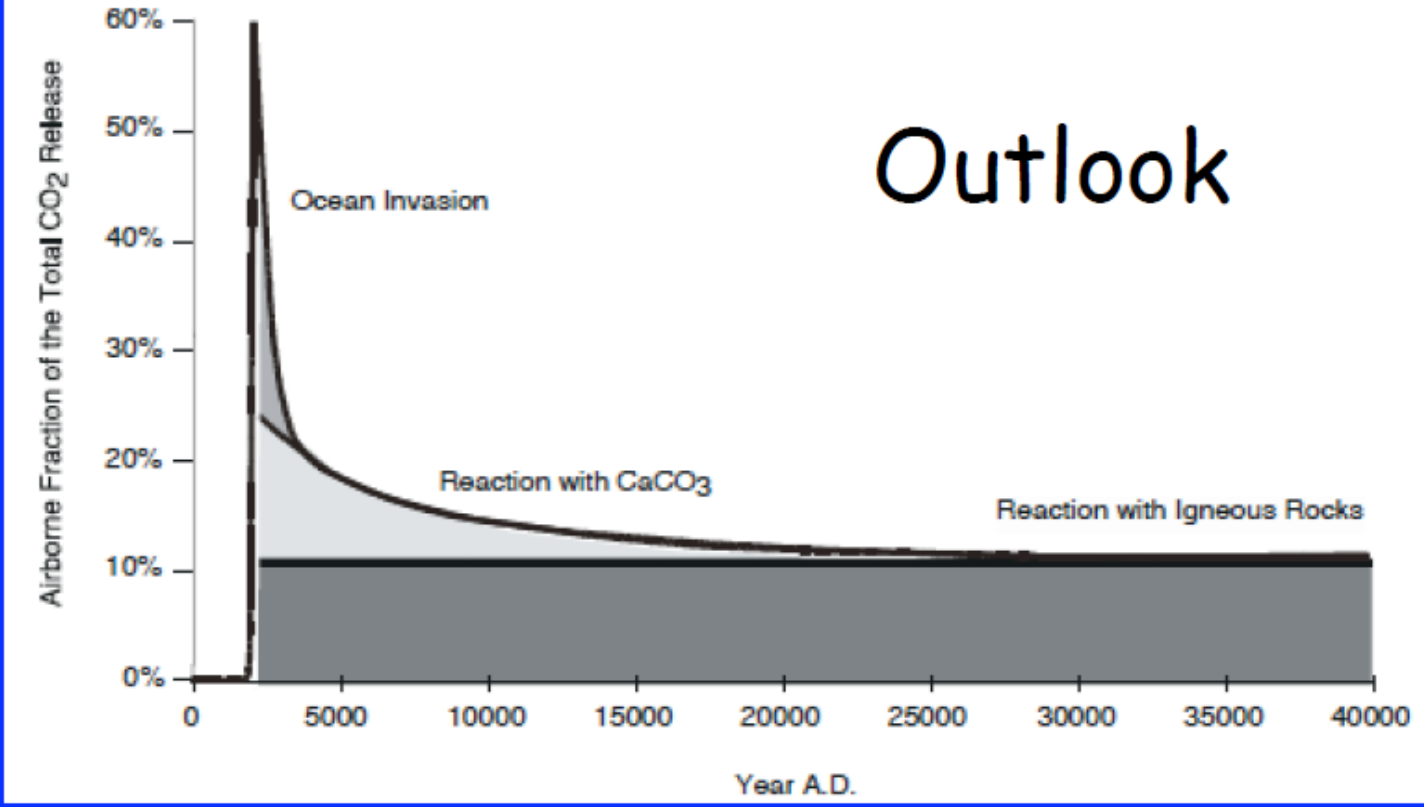
A Few Cents on Geoengineering



Jost Heintzenberg

A Few Cents on Geoengineering



- The natural elimination of CO_2 takes many centuries after which some 20% for more than 1000 years in the air until it is stored by geological processes

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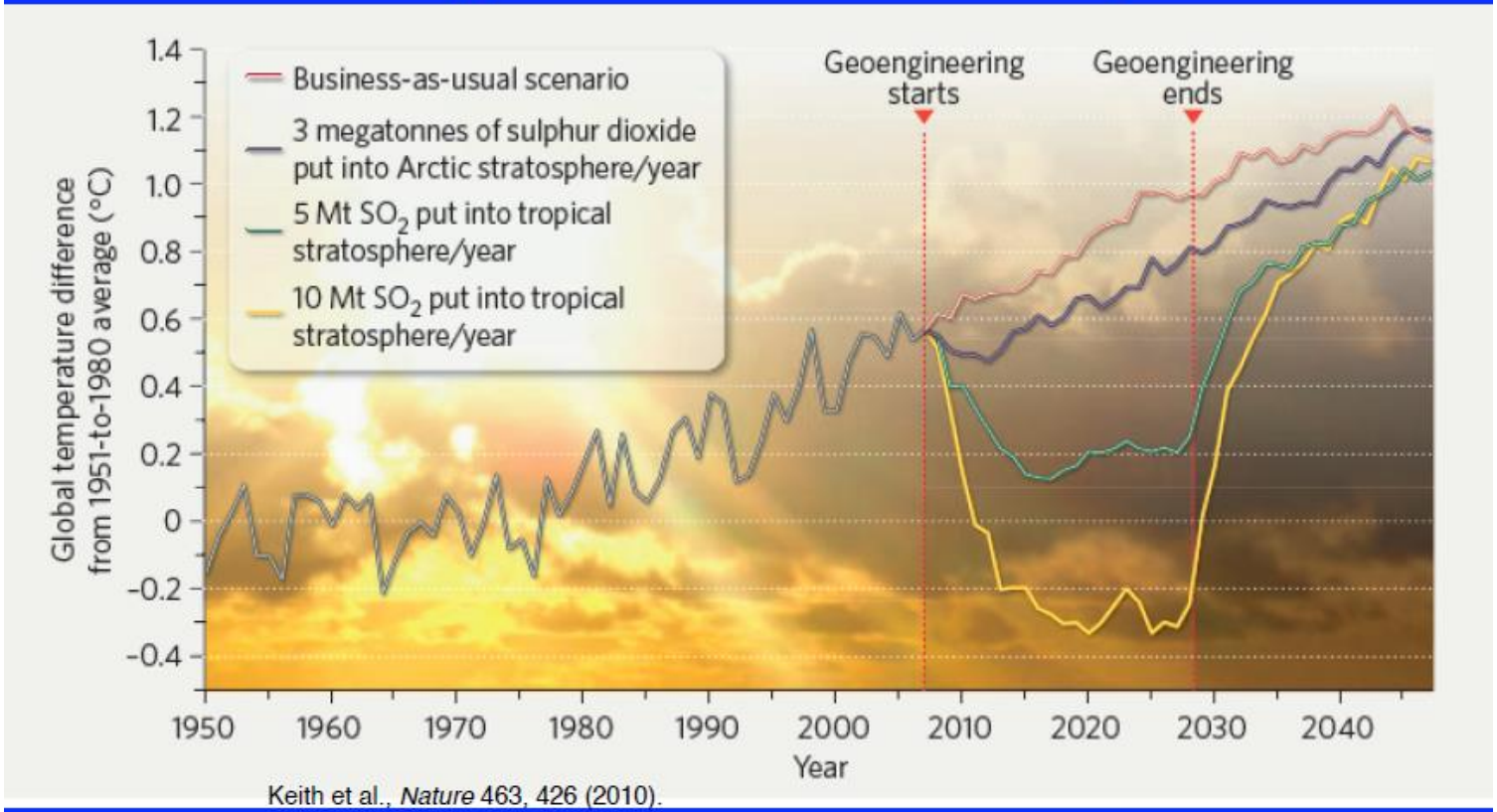
What happens when CE is interrupted?



Keith et al., *Nature* 463, 426 (2010).

Will Earth evolve on new irreversible climate paths?

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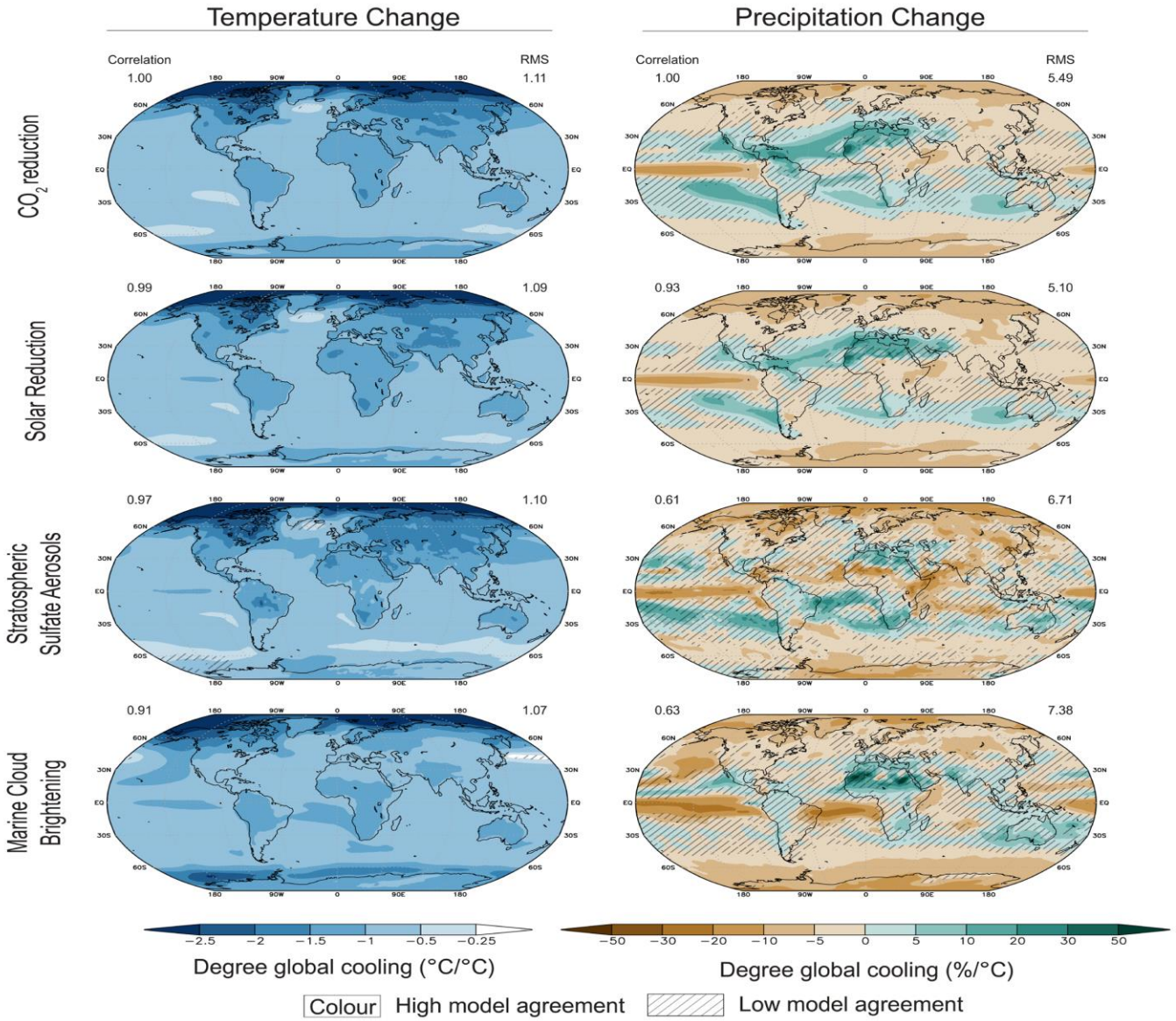
ESM Simulated Effects of Geoengineering



IPCC, 2021

General Discussion on Geoengineering

An important point of GE: buy us some time before we don't have to rely on fossil fuels

But:

- Can we fully understand the cost/benefits of GE?
- How about global versus regional impacts?
- Are we going into a different climate state?
- Will GE unintentionally help the continuous reliance of fossil fuels?

In summary: Are we trying to solve a problem by risking for more problems?

WHAT DO YOU THINK?

THE END

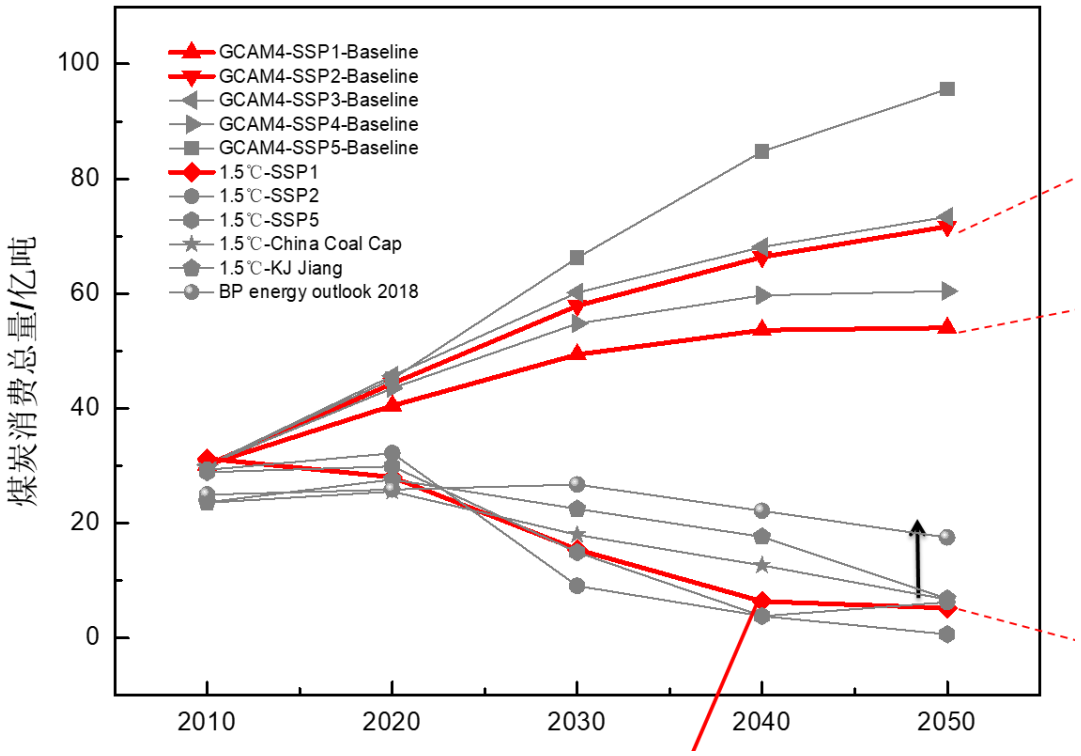
THANK YOU FOR YOUR ATTENTION

A Scientific Framework to Address Environmental Problems

Step 1	From economic activity to energy use
Step 2	From energy use to emissions
Step 3	From emissions to concentrations in the air
Step 4	From concentrations in the air to human exposures
Step 5	From human exposures to health impacts
Step 6	From health impacts to health valuations
Step 7	From health valuations to national damages by sectors or fuels
Step 8	From national damages to cost-benefit of emission control policies

Future of China's Coal Energy

Coal consumption prediction by different research group was summarized.



Source: Xiao Liu