Patterns of Innovation in China's Energy Sector: The Case of Advanced Electricity Generation Technologies

Workshop: China, the West, and the Alternative Energy Innovation Challenge

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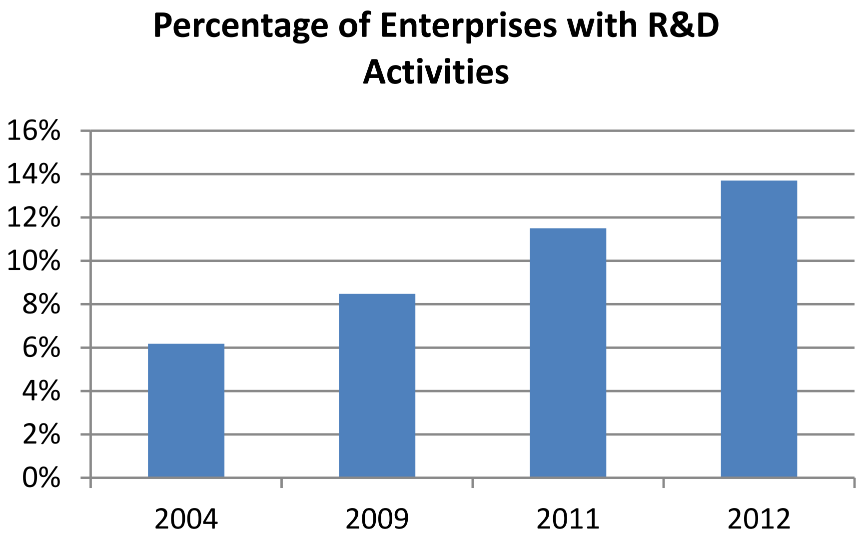
Overview

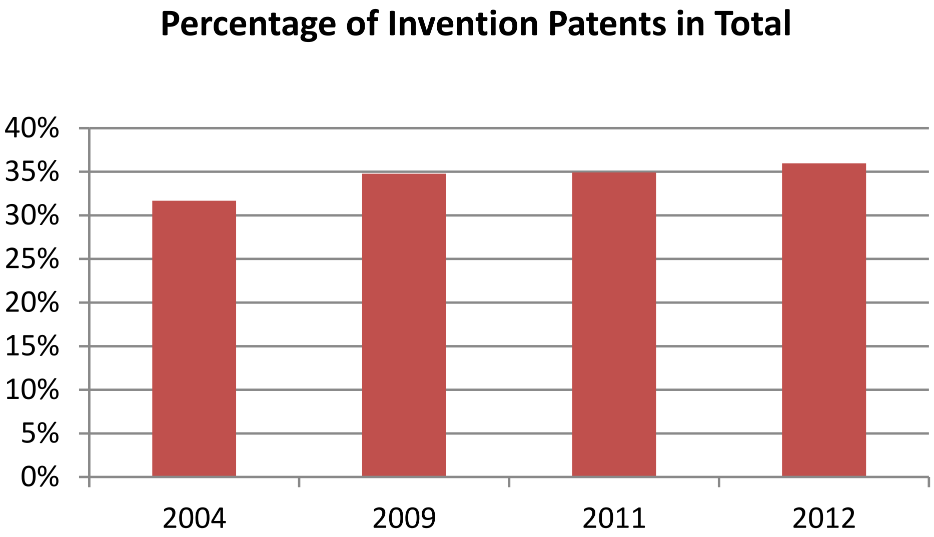
1. Setting for energy innovation in China
2. Overview: China’s electricity system
3. Electricity generation technologies: Four cases
4. Cross-case analysis
5. Conclusions

Context for energy innovation in China

- Since reform and opening began in the late 1970s the institutional setting for innovation in China has evolved.
  - Away from plan and approval system for new projects.
  - Backdrop of economic reform.
  - Strong focus on “applied” innovation.
- Few have connected the institutional dynamics to innovation outcomes during this period.
- This study focuses on ***electricity technologies***, and describes these dynamics.

National statistical measures of innovation system progress

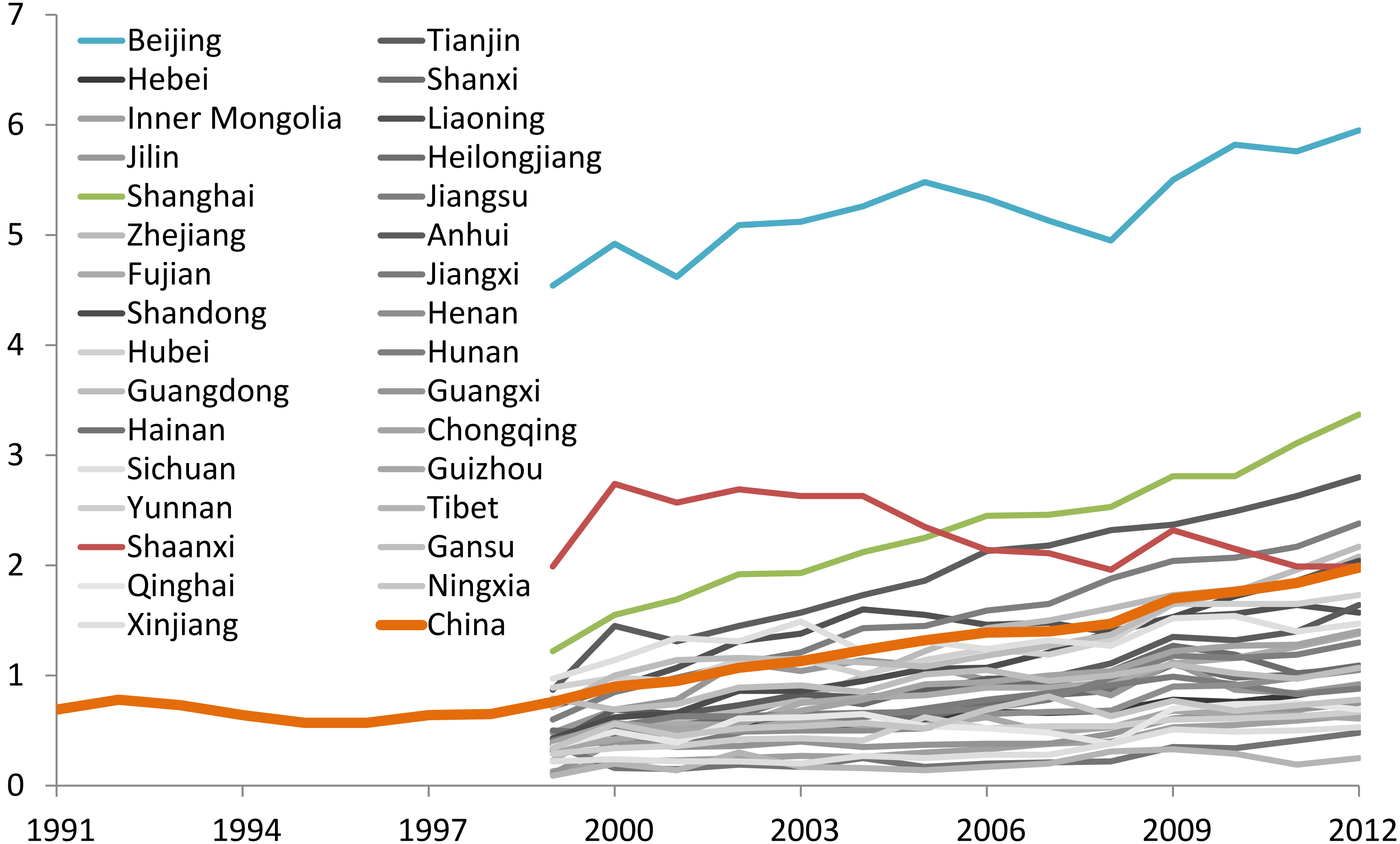




- **Number of R&D projects** are increasing, while the **expenditure per R&D project** is decreasing (~6 billion RMB per project in 2004 compared to 4.6 billion in 2012).
- **Expenditure per new product** developed has almost doubled (1.3 million/product in 2004 compared to 2.5 million/product in 2012).
- Sales revenue per new product has slightly increased (3.4 million/product in 2012 compared to 3.0 million/product in 2004).
- Hard to access these statistics by industry (next phase of this project).

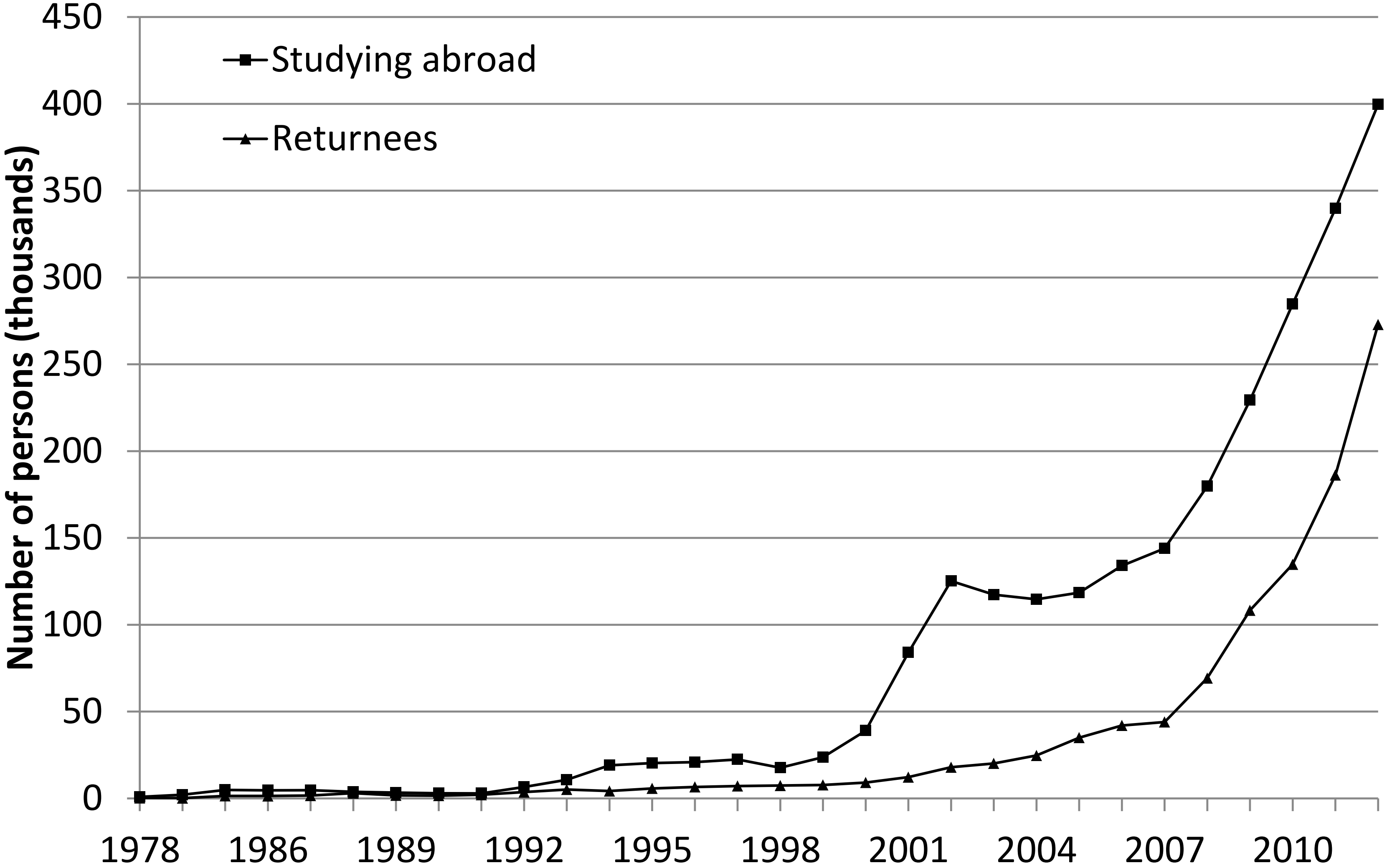
Source: China Statistical Yearbook 2013.

R&D intensity of value added (%) in China has increased, investments mainly concentrated in a few provinces



Source: China Statistical Yearbook 2013.

Students studying abroad increasing, while returnees have increased rapidly in recent years



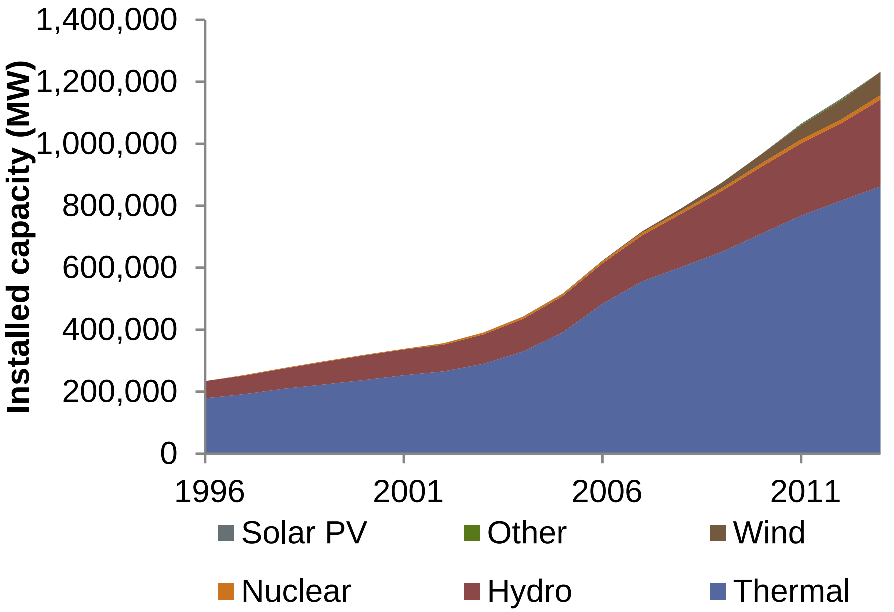
Source: China Statistical Yearbook 2013, 2010.

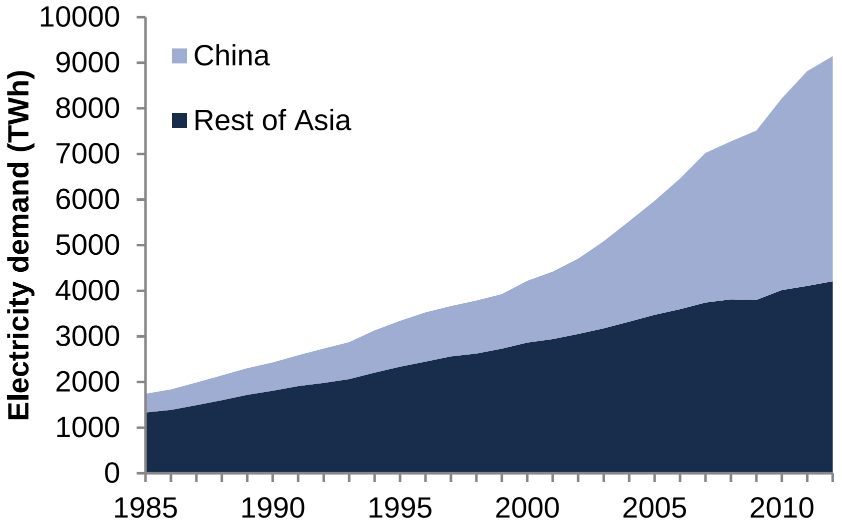
Energy innovation in China: Is it all about cost?

- Cost innovation (definition) – focus on reducing cost without (overly) compromising produce or service quality.[1]
- Documented in many industries (e.g. medical devices, cellular phones, musical instruments, appliances, etc.).
- Seen as a potential competitive threat in global markets.
  - Some multinationals (e.g. GE) have located R&D in China to learn sources of cost advantage and develop products for advanced industrialized markets.[2]

[1]Williamson & Zeng, 2008.
[2]Immelt et al., 2009.

China's electricity system: A snapshot





Source: CEIC China Premium Database, 2014.

- Very rapid growth in demand starting from early 2000s (with frequent shortages).
- Coal continues to dominate.
- Wind and solar are growing, but still limited by challenges related to transmission and integration into the existing electricity mix (which results in high levels of curtailment).

China's near-term targets for non-fossil electricity: Contributing to certainty in market demand

GW	2010	2015	2020
Hydro	194	290	370
Nuclear	17	40	60
Wind	31.5	100	220
Solar	0.95	35	91
Biomass	4.6	13	26

Source: Energy Research Institute, 2013.

Recently increased to absorb overcapacity in solar cell & equipment industry

China's current thermal capacity is much higher – 850 GW.

Final targets for 2020 are still under discussion.

Institutional setting: Electric power

Highly regulated industry with nearly complete state ownership of generating assets. ***(Generators respond to state plans.)***

Grid monopoly is very powerful. ***(Can complicate grid connections for renewable energy.)***

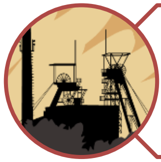
Command-and-control approach to technology choice. ***(Creates certainty.)***

Electricity tariffs differentiated based on technology and location. ***(State guarantees price, economic incentive to adopt low cost technology.)***

Must-run quotas for generators. ***(Contribution of generation by type is mostly fixed in advance.)***

Forced purchase and retirement of inefficient assets. ***(Facilitates upgrading and energy efficiency improvement.)***

Conditions shaping energy innovation in China


History


Factor conditions


Demand conditions


R&D policy

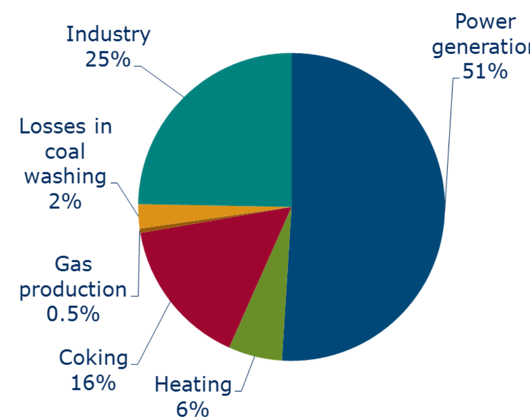

State-sponsored cost reduction/commercialization programs

Cases considered: coal, nuclear, wind, solar

Coal: Enabling conditions for innovation

- Long history of using coal and related technology.
- Low (but volatile) cost, abundant domestic resource (although imported coal is less costly at present).
- 50% of coal use in power generation.
- 25% is directly used in industry, with 25% for coking another uses.
- Current policy aimed at controlling coal use.
- Peak and then decline by 2020?

Local pollution in Beijing



Source: China Energy Statistical Yearbook 2012.

Advanced coal-fired electric power

- China selected ultra-supercritical (USC) technology early on as a target for cost reductions and scale application.
- Costs in China (2012):
  - 650–800 $/kW for a 300 MW sub-critical unit
  - 550–700 $/kW for a 600 MW supercritical unit
  - 550–700 $/kW for a 1000 MW ultra-supercritical unit
- "It now can cost a third less to build an ultra-supercritical power plant in China than to build a less efficient coal-fired plant in the United States." – Bradsher, *New York Times*, 2009

USC has contributed significantly to improved efficiency in China's coal power generation.

Year	Coal consumption (g/kWh)	Efficiency (using actual coal consumption) (%)
1990	427	28.8
1995	412	29.8
2000	392	31.3
2005	370	33.2
2008	345	35.6
2009	340	36.1

Source: Watson et al., 2011.

Future role of cost innovation

- Will China pioneer novel forms of clean coal generation?
  - IGCC is not a strong focus of commercialization efforts at present.
  - National and global climate policy uncertain, but focus in early stage R&D programs remains.
  - USC, coal-to-gas, and coal-to-chemicals technology a focus on coal bases.
  - Availability of domestic technology is a strong driver—dependent on licensing/foreign partnership for advanced conversion technologies (e.g. IGCC, coal-to-gas).
- IGCC with CCS still considered experimental at present – focus on R&D but not commercialization.

“Coal bases” under development: Poly-generation, coal-to-gas, coal-to-chemicals

Source: Google Tour, Coal Bases in China (InsideClimate News).

Nuclear power technology development

- Nuclear development in China began in the 1980s: Daya Bay (Framatome, GE turbines) & Qinshan (indigenous design based on imported models).
- Current focus on assessing AP1000 (CAP1000) and Areva models – select dominant design for scale up.
- Fukushima crisis set back nuclear R&D and approvals by several years.
- Government plans now anticipate 18% annual growth rate in nuclear output, with 28 reactors under construction as of spring 2014.

Photos of AP/CAP1000 construction.

Source: IAEA, 2013.

Nuclear costs

OECD electricity generating cost projections for year 2010 on - 10% discount rate, c/kWh

country	nuclear	coal	coal with CCS	Gas CCGT	Onshore wind
Belgium	10.9	10.0	-	9.3-9.9	13.6
Czech R	11.5	11.4-13.3	13.6-14.1	10.4	21.9
France	9.2	-	-	-	12.2
Germany	8.3	8.7-9.4	9.5-11.0	9.3	14.3
Hungary	12.2	-	-	-	-
Japan	7.6	10.7	-	12.0	-
Korea	4.2-4.8	7.1-7.4	-	9.5	-
Netherlands	10.5	10.0	-	8.2	12.2
Slovakia	9.8	14.2	-	-	-
Switzerland	9.0-13.6	-	-	10.5	23.4
USA	7.7	8.8-9.3	9.4	8.3	7.0
China*	4.4-5.5	5.8	-	5.2	7.2-12.6
Russia*	6.8	9.0	11.8	7.8	9.0
EPRI (USA)	7.3	8.8	-	8.3	9.1
Eurelectric	10.6	8.0-9.0	10.2	9.4	15.5

* For China and Russia: 2.5c is added to coal and 1.3c to gas as carbon emission cost to enable sensible comparison with other data in those fuel/technology categories, though within those countries coal and gas will in fact be cheaper than the Table above suggests.
Source: OECD/IEA NEA 2010, table 4.1.

China plant cost is about a half to 1/3 of USA plant cost (based on AP1000).[1]

Factors: Labor costs, standardized design, scale, localization of component production.[2]

[1]Source: Metzler and Steinfeld, 2012; [2]World Nuclear, *Economics of Nuclear Power.*

Nuclear development: The next generation?

- Several technologies under consideration:
  - High-temperature gas cooled (HTR) reactor
  - Fast breeder reactor
  - Molten salt reactor
- R&D supported by the 863 Hi-Technology Program and the National Key Science and Technology Special Program.
- Despite interest, technology is still viewed as “too costly.”
- Underscores the importance of cost in deployment decisions.

HTR system

Source: CNNC, 2014.

Wind development

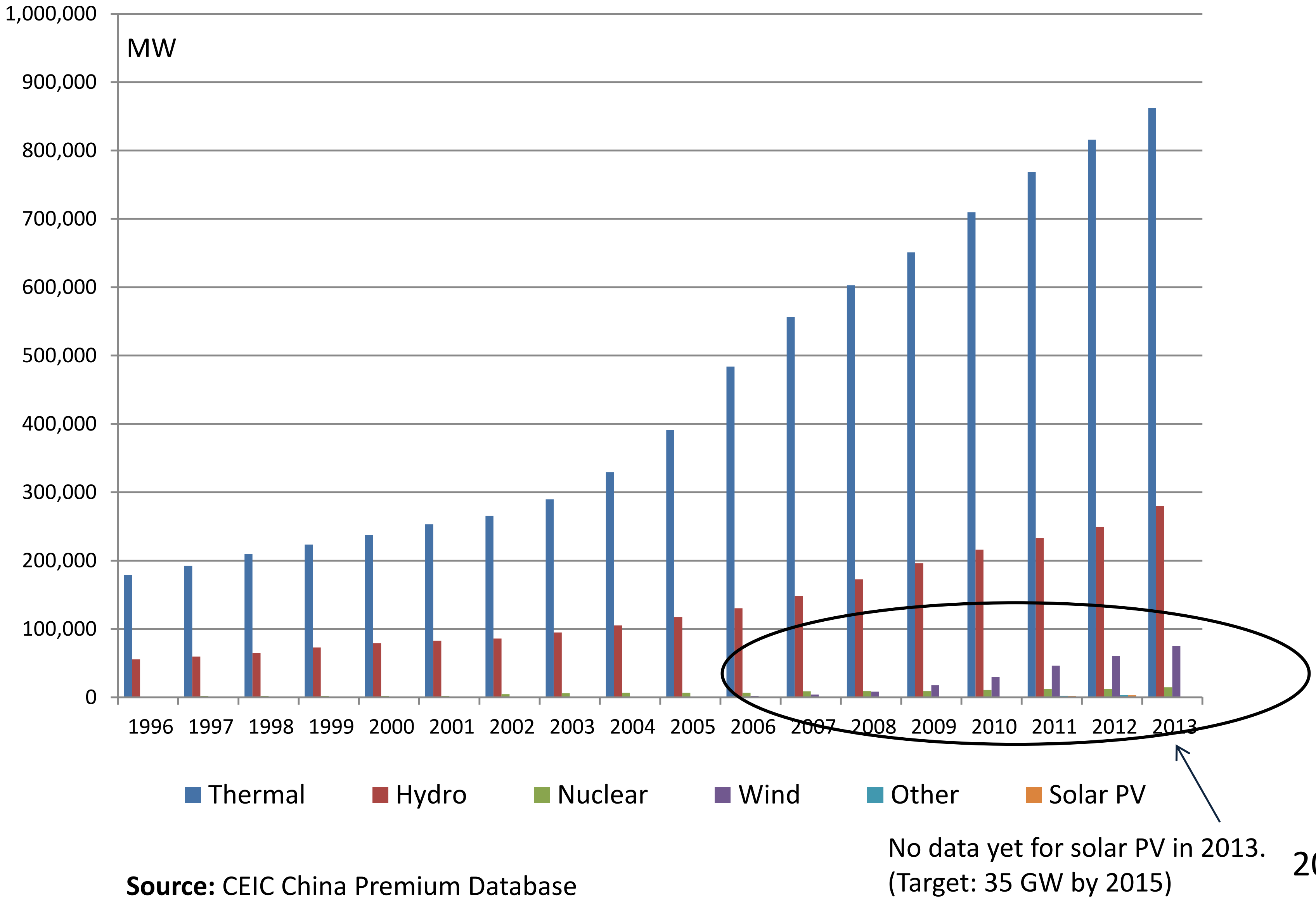
The drop in wind turbine price to about **one third of what the cost was in 2007** has been attributed to the competition posed by Chinese products.

Manufacturer	Technology list	Technology transfer		
		Year	Collaborator	Mechanism
Sinovel	1.5 MW	2003	German Fuhrlander	Joint development
	3 MW	2007	Austrian Windtec	Joint development
	5 MW	2007	Austrian Windtec	Joint development
Goldwind	660 kW	1997	German Jacobs	Licensing
	750 kW	2001	German REpower	Licensing
	1.5 MW	2005	German Vensys	Joint development
	2.5 MW, 3 MW, 5 MW	2008	German Vensys	Purchasing the foreign company
Dongfang Electric	1.5 MW	2004	German REpower	Licensing
	2.5 MW	2005	German Aerodyn	Joint development

Source: Zhang et al., 2011.

70% domestic content required.
Concession bidding process considers technology as well as price.

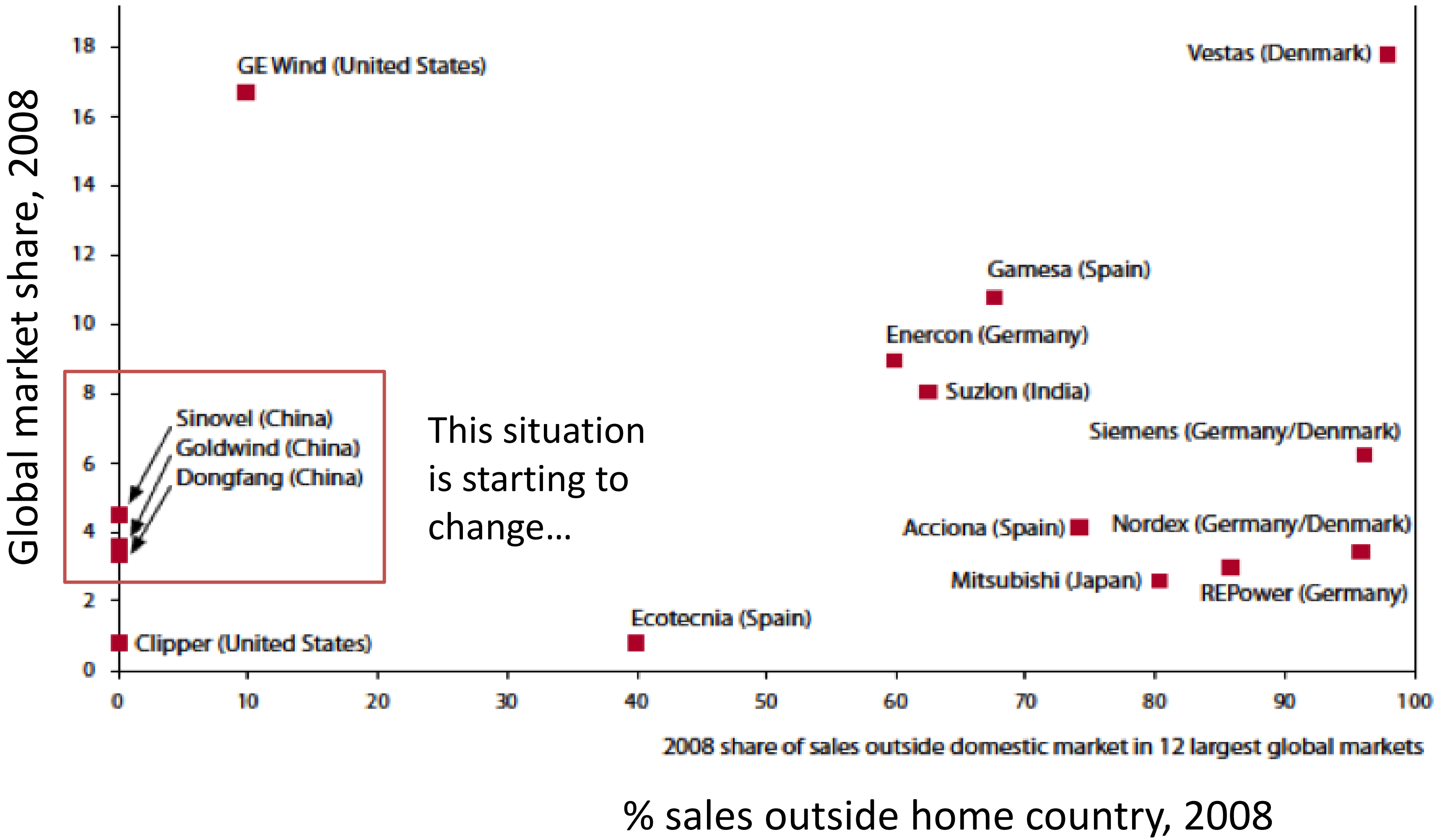
Wind plays a small but rapidly growing role



Source: CEIC China Premium Database

Wind industry globalization

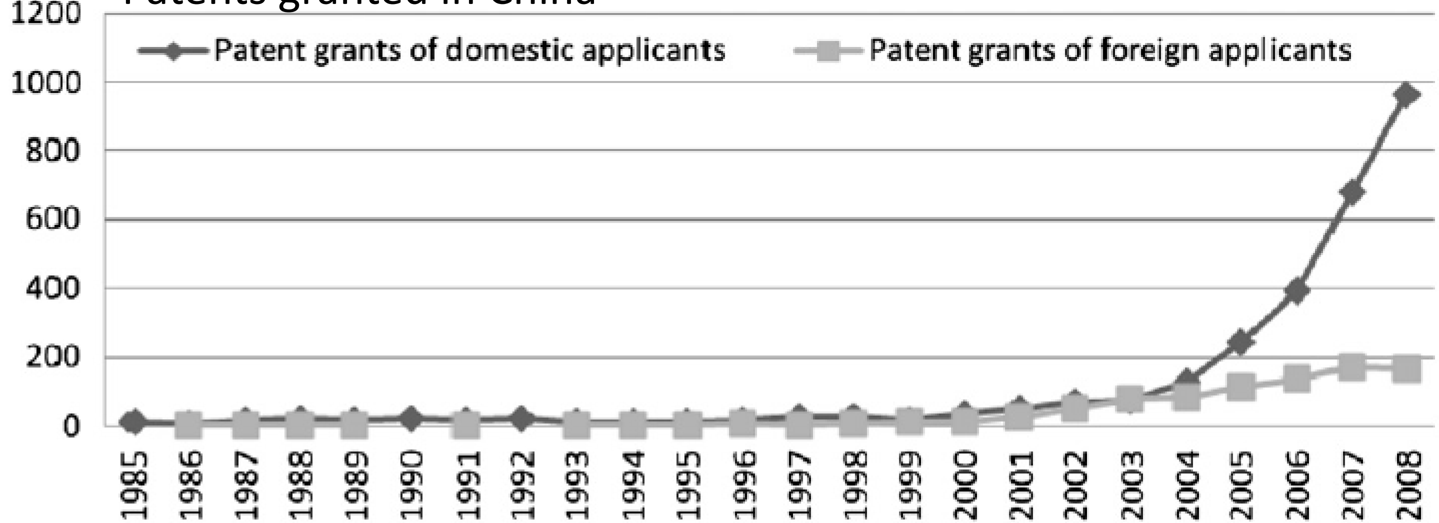
Figure 1 Top 15 wind turbine original equipment manufacturers' major market presence, 2008



Evidence from patents

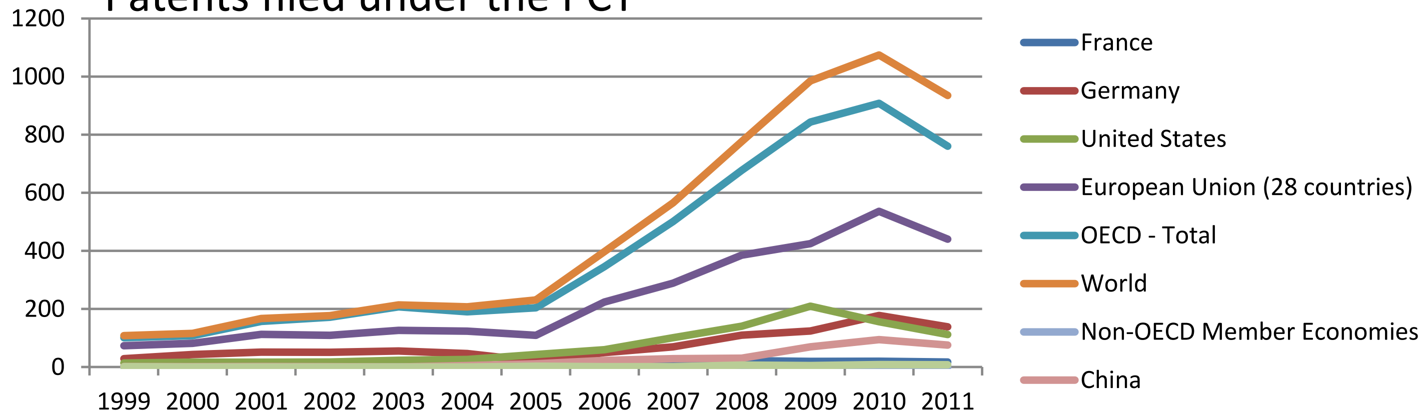
Chinese firms were patenting in China, largely due to cost and language difficulty of patenting overseas, along with domestic market focus.

Patents granted in China



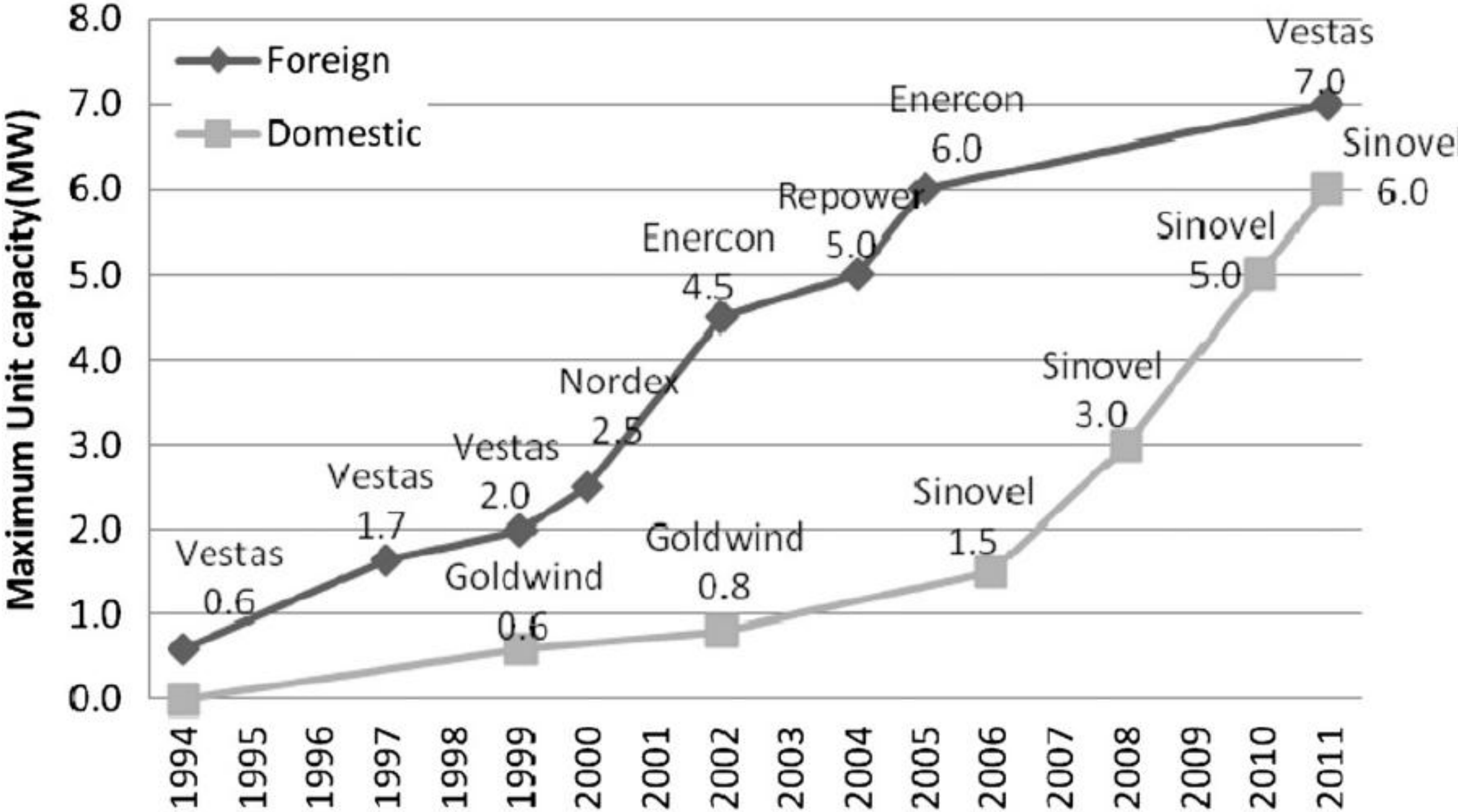
Source: Ru et al., 2012.

Patents filed under the PCT



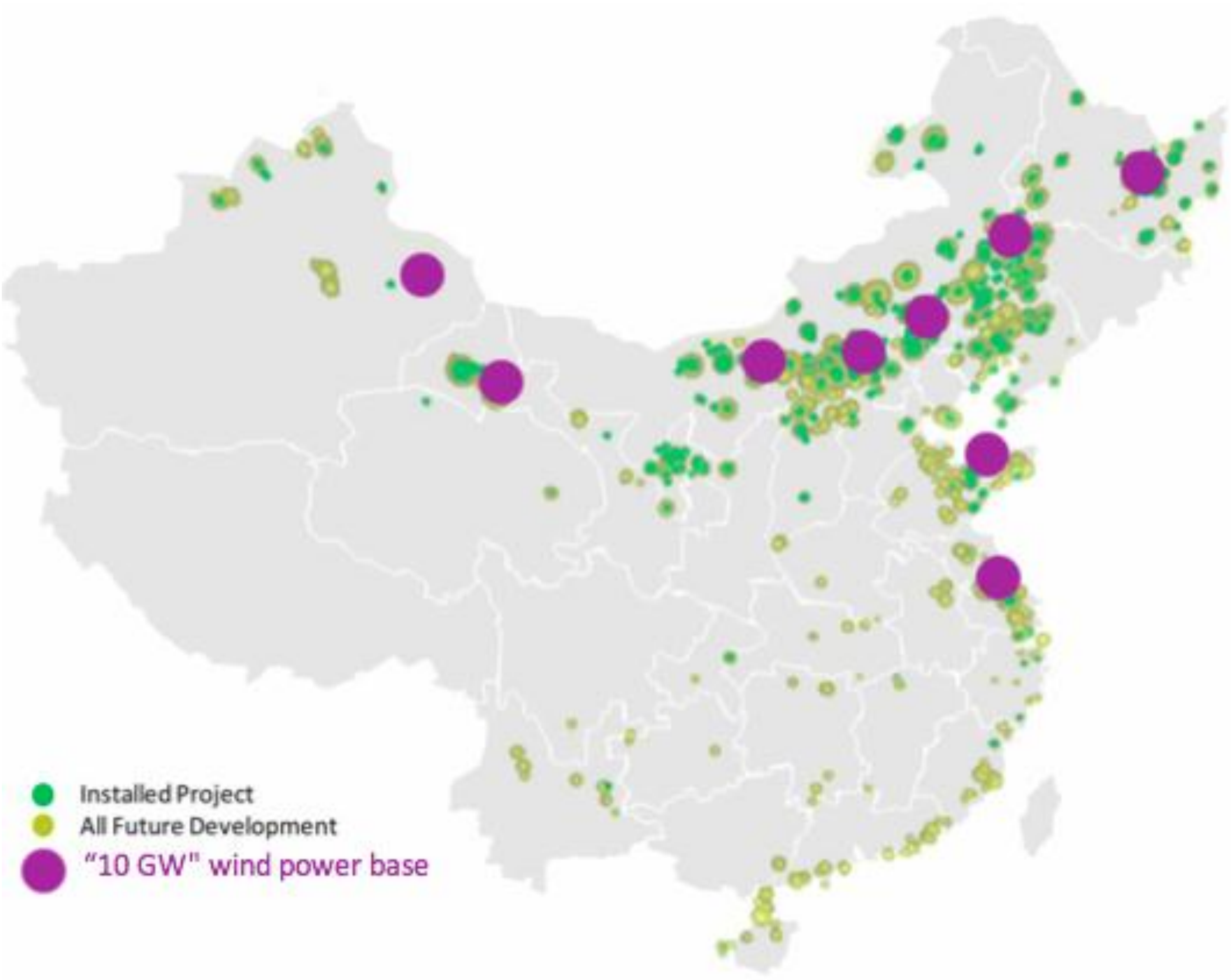
Source: OECD, 2014.

China has been a fast follower in terms of turbine size



Source: Ru et al., 2012.

Wind power construction

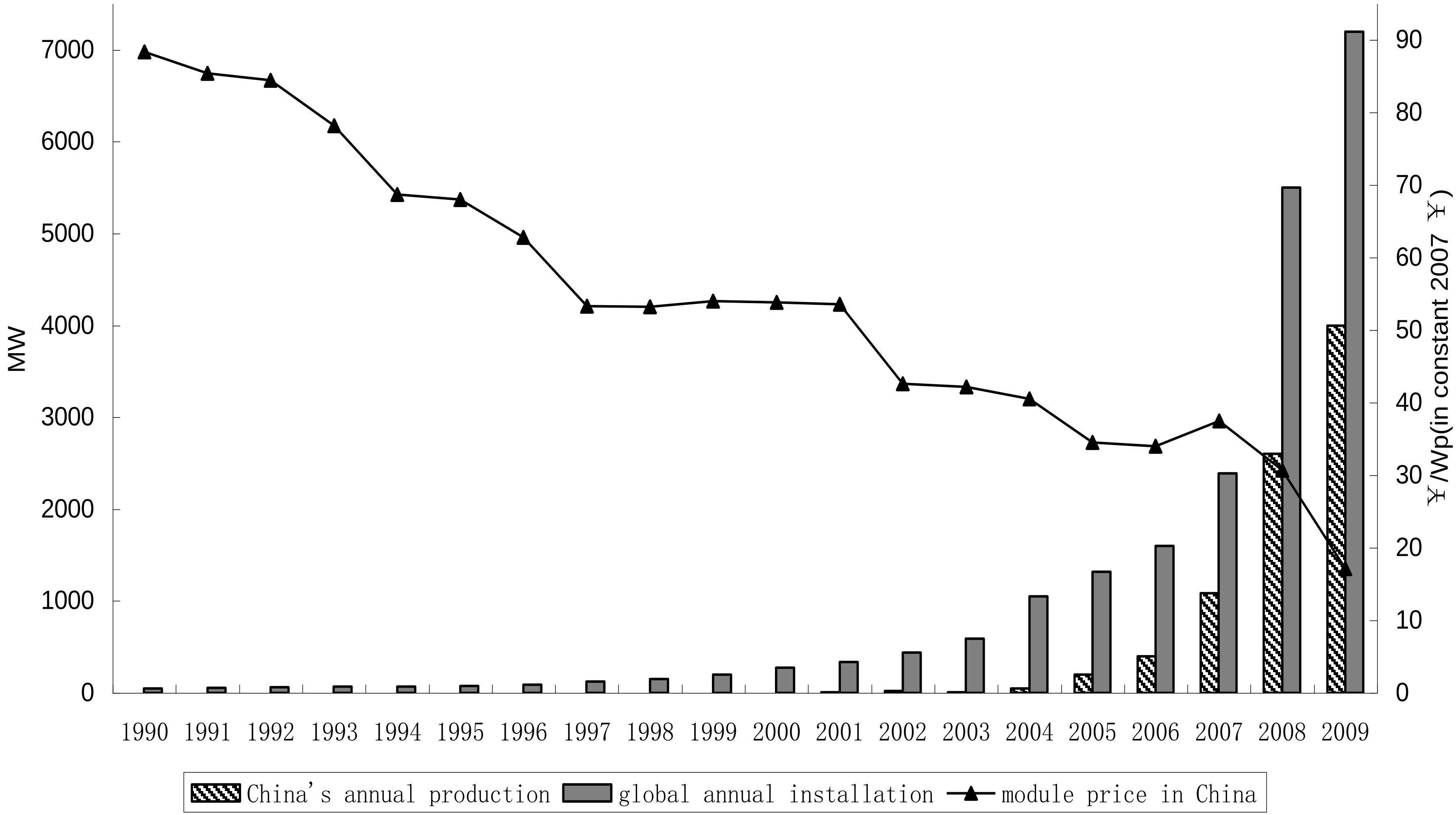


Source: Modified from Azure (2012)

Solar

- Early development occurred in government research institutes, slow development through 1980s and 1990s.
- Deployment of Chinese-made solar PV equipment initially widespread outside of China, not within China, due to the high cost.
- Opposite trend to wind: Cost reductions achieved through global, not domestic, deployment.
- Spectacular successes and failures (e.g. Suntech).
- As industry faces overcapacity, domestic target has been scaled up to absorb output.

Solar PV cost innovation



Source: Grau et al. 2010.

Lessons for natural gas?

- Natural gas in power generation is a major part of future government plans to address air pollution.
- To date, China does not possess either a technological advantage or a cost advantage in natural gas power.
- Despite aggressive current statements, natural gas may play a limited role in the future unless cost barriers can be overcome.

Source: econintersect.com

Incentives and outcomes: electricity technology innovation

Energy source	History	Factor conditions	Demand conditions (domestic/ international)	R&D policies and resources	State-sponsored commercialization policies and programs	Potential gains from further innovation	Innovation performance
Coal	Mainstay of the power generation mix	Favorable: Fuel cost low Capital cost advantage	Strong domestic; Moderate international	Torch Program; 863, 973 funding programs, localization	Deployment of USC according to government plans/support	Without a price on carbon, market opportunity limited	Cost: Strong; Knowledge: Weak/Medium
Nuclear	Stop-start on deployment, but relatively long history	Favorable via suppliers in particular, labor & capital costs, co-location	Large market domestically; Strong but risky potential international	863 Program; Special Key Project Funds	Significant uncertainty, but target was recently increased	Advanced safe designs at low cost have potential	Cost: Strong; Knowledge: Weak/Medium
Wind	Recent, cost reduced through domestic deployment	Favorable: Capital/land cost advantage	Strong domestic and more recently overseas	863, 973 programs, Key Technologies Program	FITs, targets, tax breaks, concessions, local content reqs., CDM	Reduce costs of offshore wind, be able to provide turkey solutions	Cost: Strong; Knowledge: Weak
Solar	Recent, used market abroad to reduce costs	Initial low materials costs in China	Limited domestic; strong overseas	863, 973 programs, Key Technologies Program	Deployment targets, Golden Sun program, FITs, tax breaks	Limited gains from relying solely on manufacturing	Cost: Strong; Knowledge: Weak
Natural gas	Limited application, but new focus	Fuel cost high	Limited for Chinese firms.	Limited focus	Recent emphasis on switch to gas for power generation	Limited. Depends on natural gas supply options and price	Cost: Weak; Knowledge: Weak

Observations:
Innovation in electricity generation technology in China

- Cost innovation in China is both a goal and an outcome of energy technology innovation and supporting policies in the power sector.
  - Market creation/deployment policy emphasized and largely successful.
  - Being a fast follower has advantages.
- Technology deployment still largely follows government plans and choices, favors domestic (industry) interests.
  - Cleaner coal: USC not IGCC?
  - Local content requirements / deployment targets support domestic industry.
  - Role of natural gas in electric power still uncertain.
- Early-stage R&D/knowledge innovation in China is still weak.
  - Need institutional change, or just a matter of time?
  - Nuclear a more likely low carbon solution than CCS?
- In the near term, cost innovation is likely to persist, even as some of China’s cost advantages diminish.

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