Imperial College London

The drivers for China's wind energy innovation system

Innovation and Disruption: the energy sector in transition
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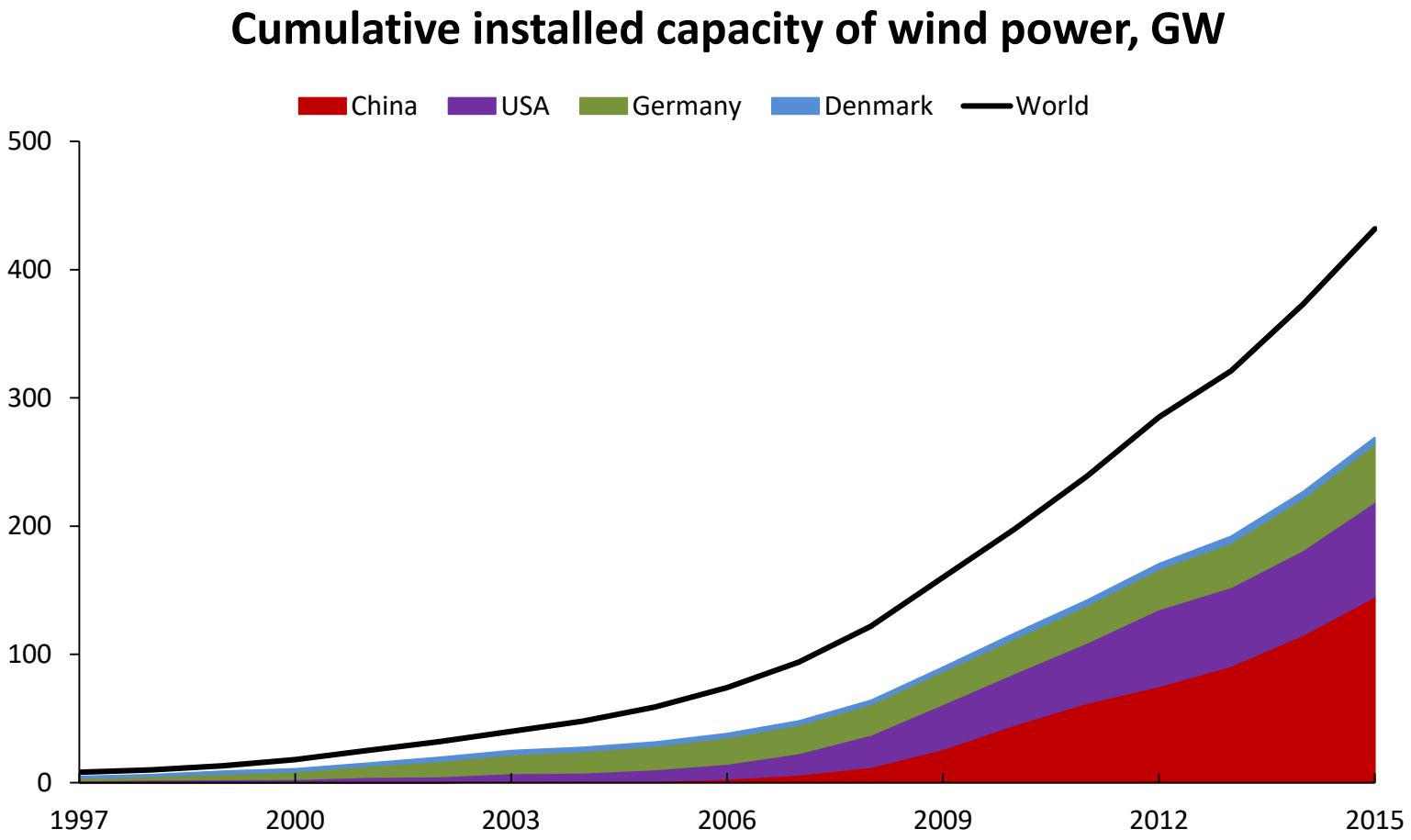
China witnessed an explosive growth in wind energy



Source: GWEC

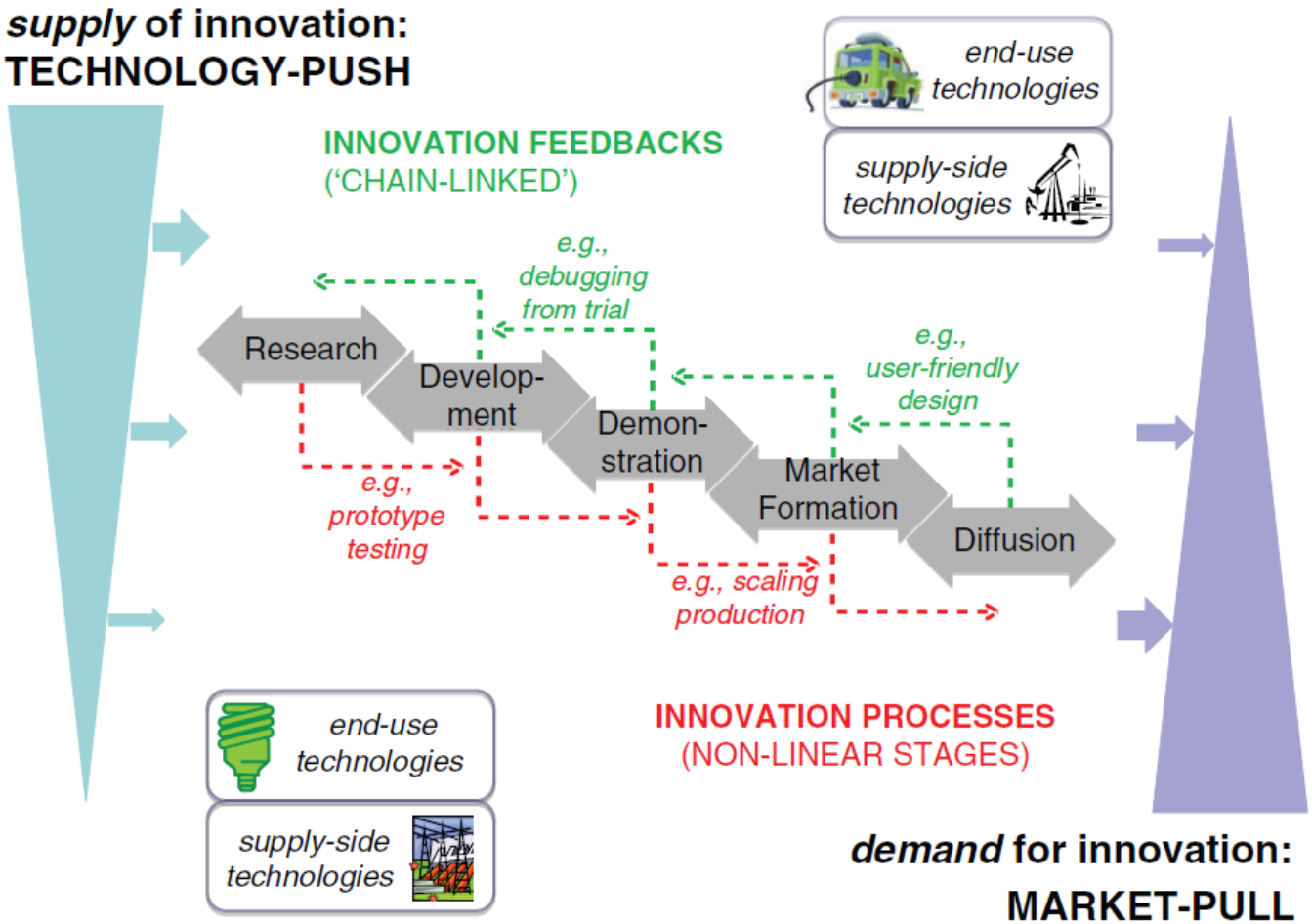
What has driven the technological change of China's wind energy innovation system?

Rongcheng Malan Wind Farm, China, 1986

Shanghai Donghai Bridge Offshore Wind Farm, China, 2009

Energy technology innovation is a systemic process

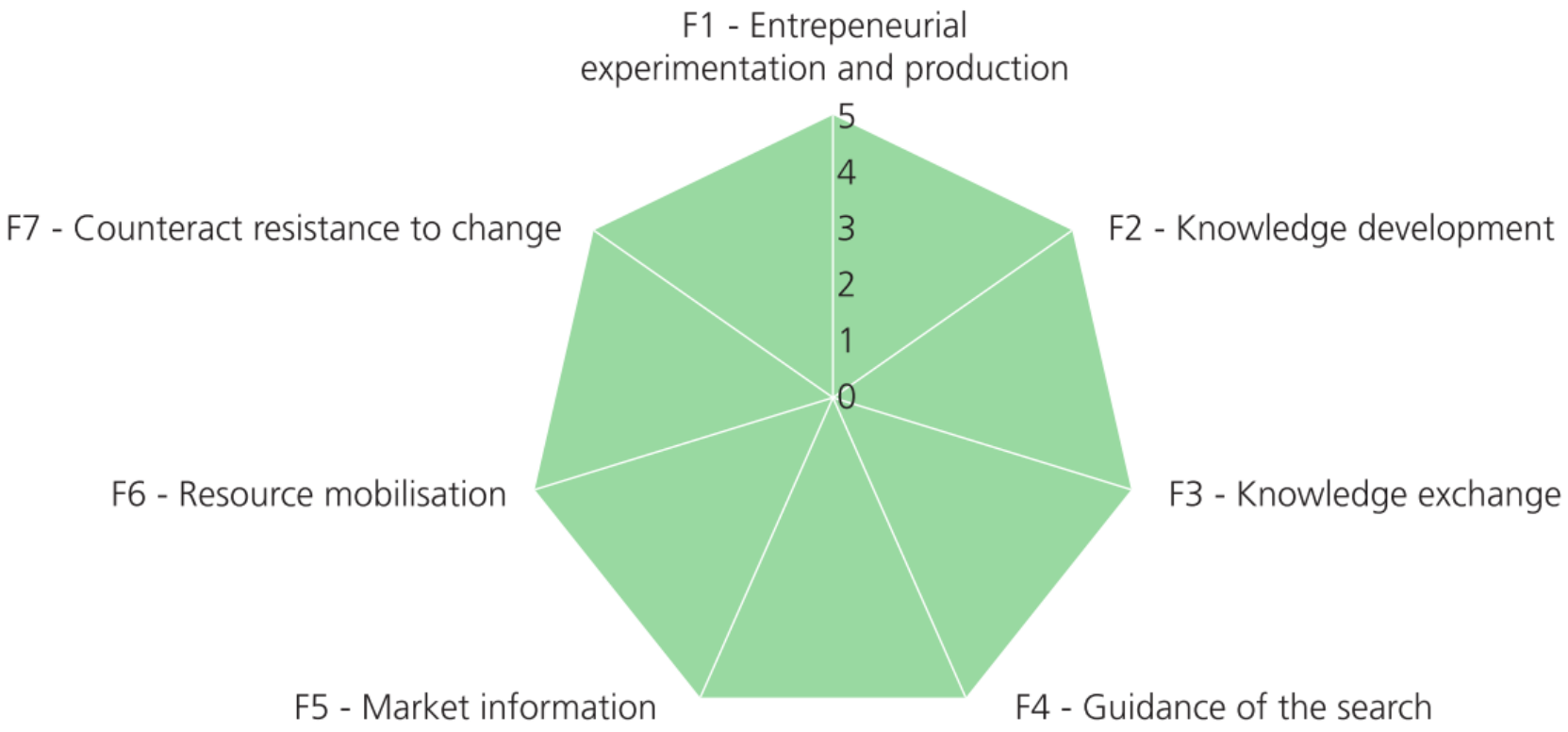
Energy technology innovation chain



Source: Wilson and Grubler (2014)

A well-functioning innovation system is the result of interrelated activities (or functions)

Functions of technological innovation system

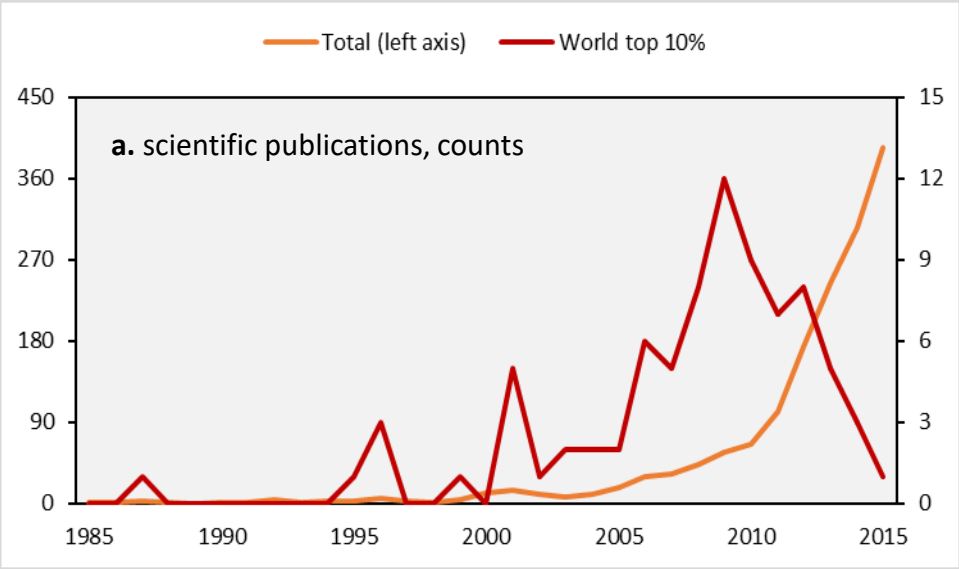


Source: Hekkert et al. (2011)

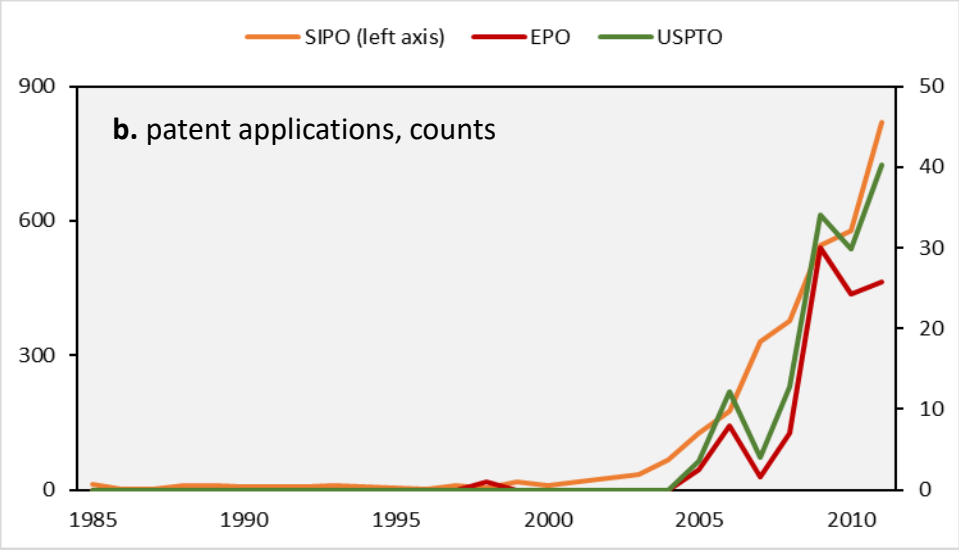
Measuring the functions of energy innovation systems (18 quantitative indicators)

Functions	Indicators
Knowledge development	• Number of (the world's top 10%) scientific publications
	• Number of patent applications to SIPO, EPO and USPTO
Knowledge networks	• Shares of scientific research funded by public and private sectors
	• Linkages between wind turbine producers and wind farm developers
Guidance of the search	• Policy targets on cumulative capacity
	• Policy targets on turbine sizes
	• Policy targets on localisation rate
Entrepreneurial activities	• Number of new entrants
	• Technology development strategies
	• Evolution of turbine sizes
	• Establishment of R&D facilities
Market formation	• Domestic deployment of wind power
	• Foreign exports on wind turbines
Resources mobilisation	• R&D expenditure on wind technology
	• Asset finance for wind power plant projects
	• Subsidy for wind power integration
Creation of legitimacy	• Issuance of laws and regulations
Alignment between supply-push and demand-pull policies	• Presence of supply-push policy
	• Presence of demand-pull policy

Function 1: Knowledge development



- China has performed excellently in knowledge building measured by the ***total number of scientific publications***.
- China has performed less well in terms of the world's ***highly-cited (top 10%)*** publications.



- Chinese patent applications to the ***SIPO*** have increased massively.
- Chinese patent applications to the ***EPO and USPTO*** have increased sharply too.

Source: ISI Web of Knowledge, PATSTAT, PIAS

Function 2: Knowledge exchange

Chinese publications funded by public and private sectors (1970-2015), %

Categories	Funding sources	Total	World top 10%
Public vs. private	public sector	96.0	94.9
	Private sector	1.5	4.4
	State Grid^	2.5	0.6
Public	National High Technology Research and Development Programme ("863" project)	7.6	7.4
	National Basic Research Programme ("973" project)	3.8	4.0
	National Science and Technology Support Programme (NSTSP)	0.7	1.3
	National Major Science and Technology Projects (NMSTP)	0.2	0.0
	state labs	2.6	2.0
	others*	85.0	85.2
Private	within industry	19.1	12.5
	outside industry	18.1	75.0
	State Grid	62.8	12.5

Note: ^State Grid is included in the private sector; others refer to the funds excluding those channels.
Source: ISI Web of Science

Function 2: Knowledge exchange (cont.)

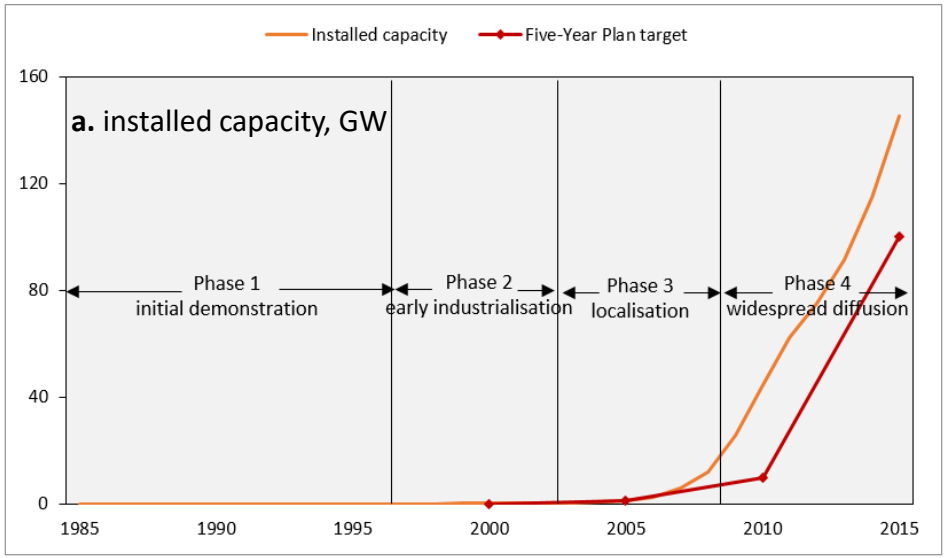
China's top ten wind farm developers and their relationships with turbine producers, 2014

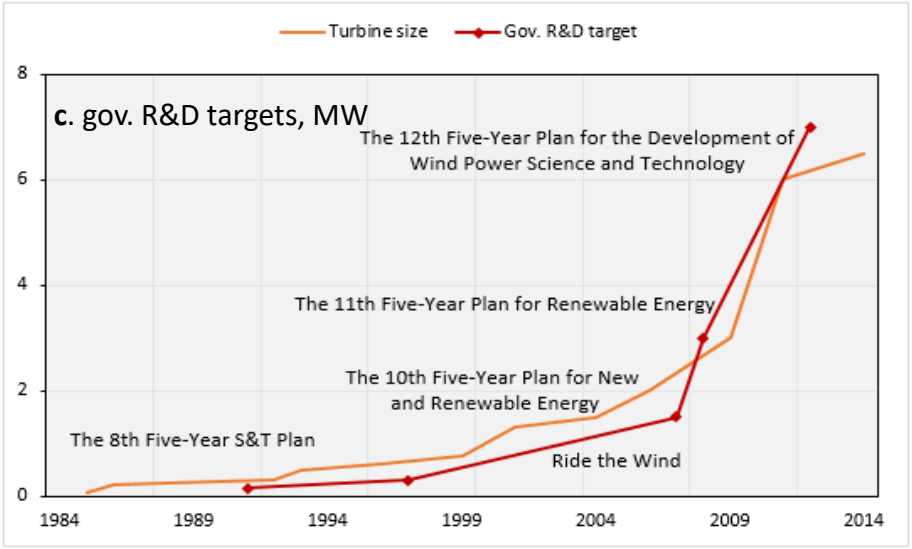
Wind farm developer	Market share of developer (%)	Turbine supplier	Developer-producer relationship	Share from the producer (%)
Huadian	14.6	Goldwind	strategic alliance	15.9 (1st)
Guodian	13.1	United Power	Subsidiary*	60.0 (1st)
CGN	11.0	Goldwind	strategic alliance	27.6 (2nd)
Huaneng	10.6	Mingyang	joint venture^	20.6 (1st)
SPIC	8.7	XEMC	bidding & contract	22.5 (1st)
China Resources	4.7	XEMC	bidding & contract	54.2 (1st)
Datang	3.6	CWE	70% of share#	21.7 (1st)
PowerChina	2.2	Windey	bidding & contract	38.4 (1st)
Three Gorges	2.1	Windey	strategic alliance	20.6 (2nd)
State Grid	1.8	Xuji	subsidiary	11.8 (4th)

Note: * the producer is a subsidiary of the developer; ^ the developer and producer create a joint venture; # percentage of the producer's stock owned by the developer; the number in bracket represents the producer's ranking (by capacity supplied) among the developer's all wind turbine suppliers.

Source: CWEA (2015)

Function 3: Guidance of search





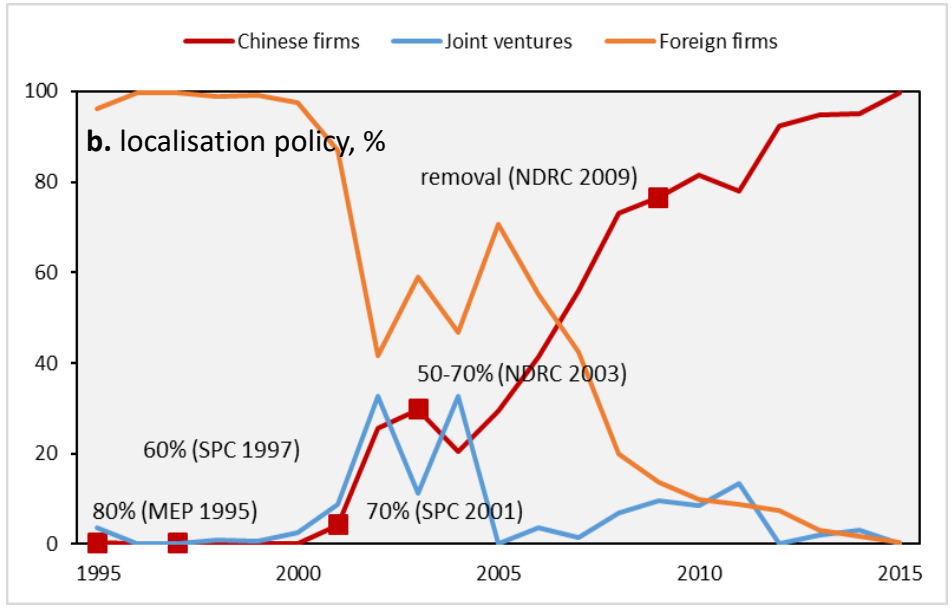


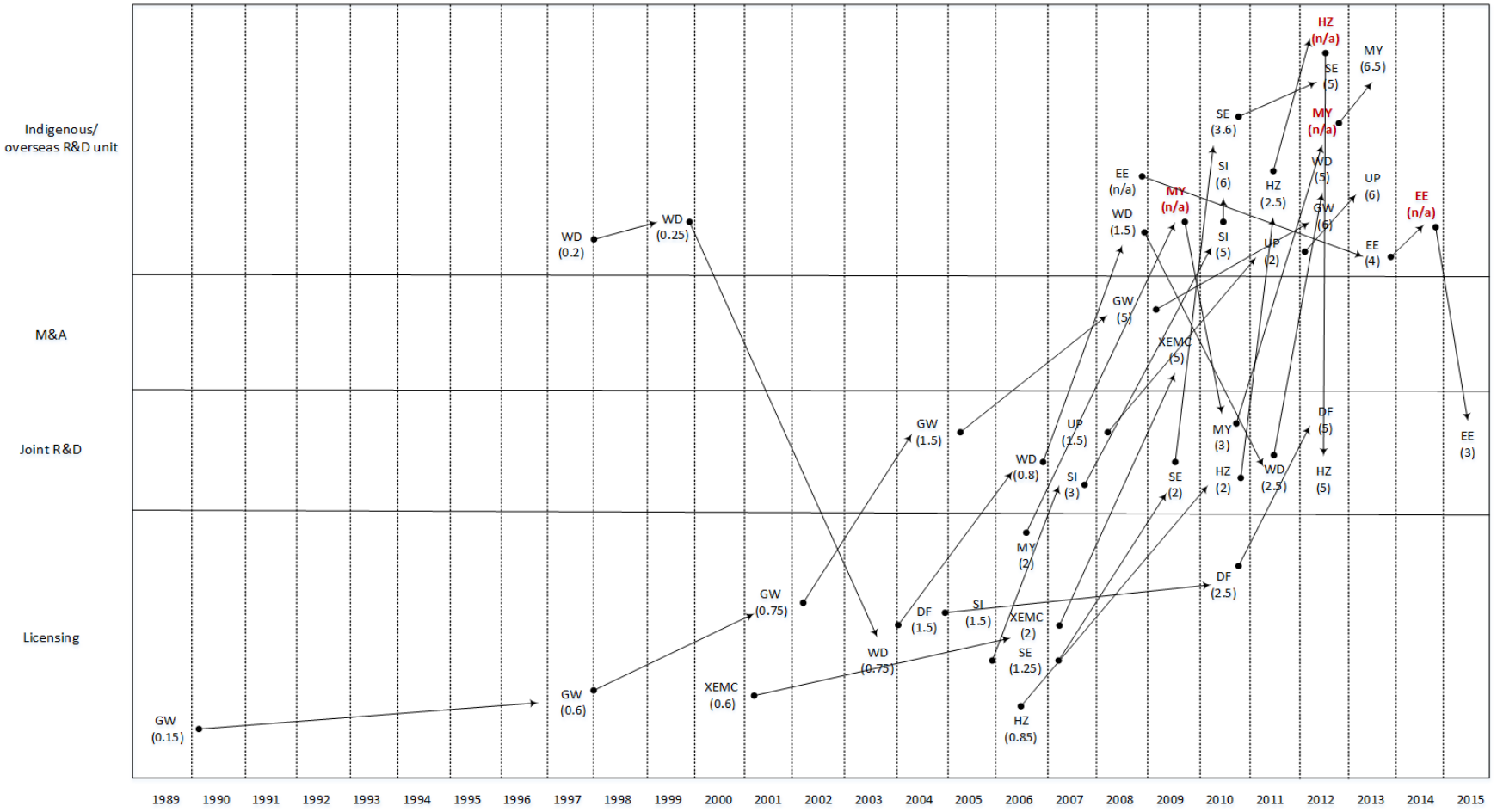
figure a. five-year plan targets vs. installed capacity
figure b. localisation policy vs. market share of Chinese wind turbine manufacturers
figure c. government R&D targets vs. turbine sizes

The Chinese government's guidance of search on wind turbine technology has been very positive.

Source: Shi (2007), CWEA (2015, 2016), IEA/IRENA (2016) and the authors' own database

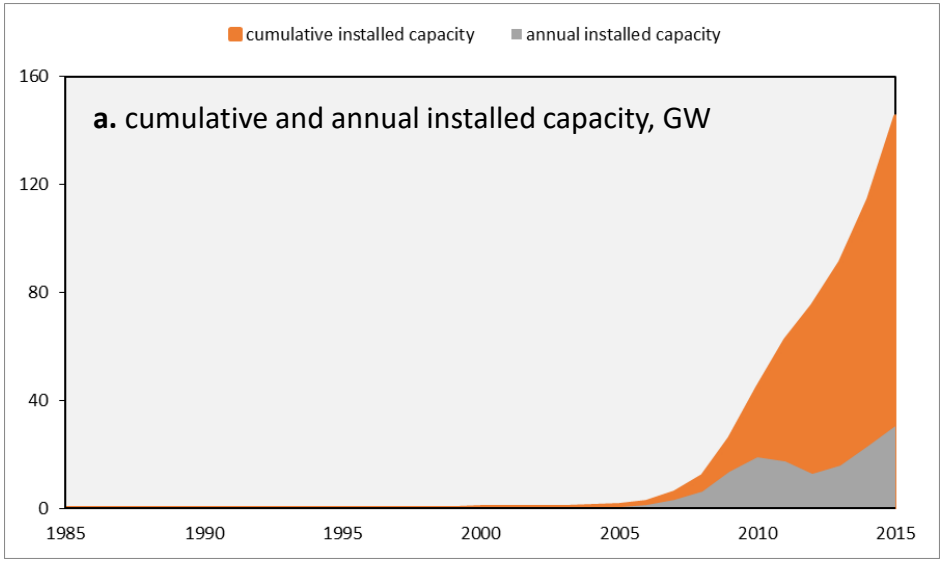
Function 4: Entrepreneurial activities

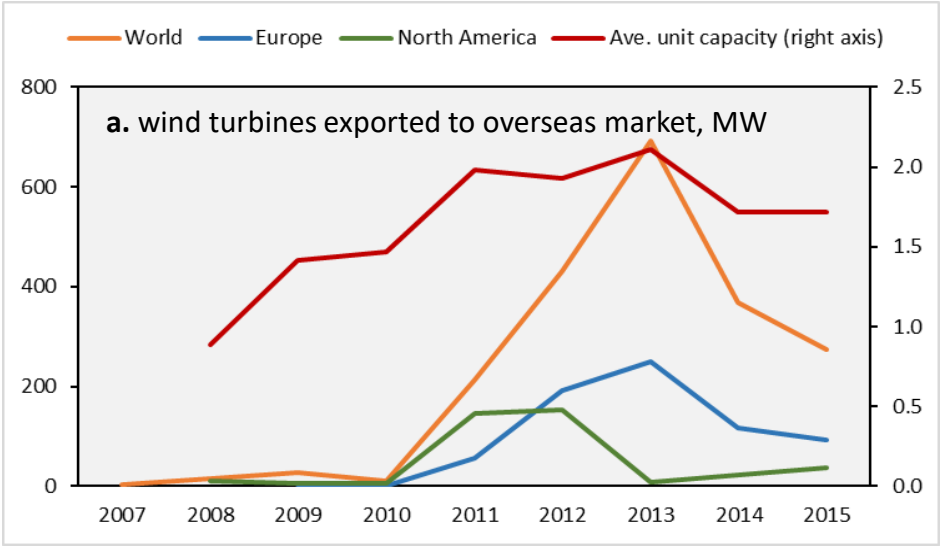
Technology development pathways of the top ten Chinese wind turbine manufacturers



Note: a) overseas R&D units are coloured in red; b) only maximum turbine sizes for each year are displayed.
Source: company websites, Gosens and Lu (2013), Lema and Lema (2013), Silva and Klagge (2013), Ru et al. (2012) and Zhang et al. (2009)

Function 5: Market formation





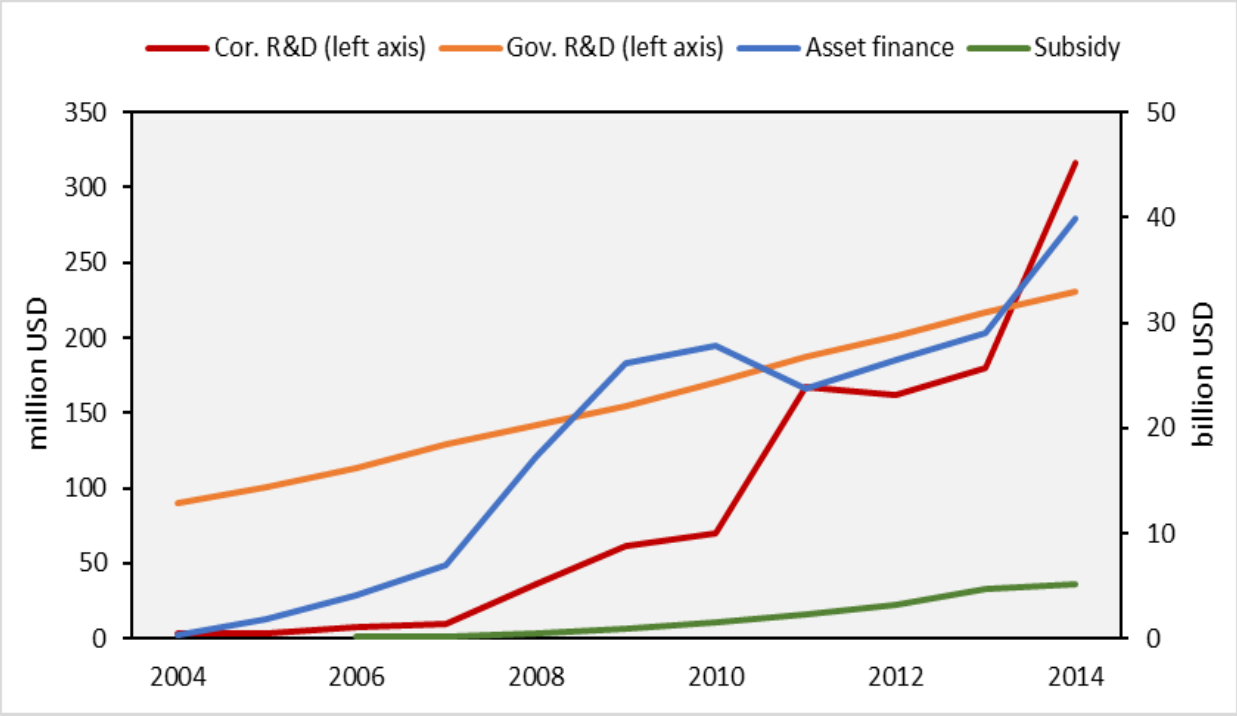
- China has a ***huge domestic market*** for wind turbine technology and begun to export to overseas market.
- Annual new additions: ***at least 10 GW*** by 2020 according to the 13th five-year plan

- China's poor performance in overseas markets is due to the ***lack of certification*** and the requirements on a ***long and solid history of wind turbines*** in the North American and European markets.

Source: GWEC, BJX (2014), CWEA (2015, 2016)

Function 6: Resources mobilisation

Chinese financial resources allocated to wind energy sector

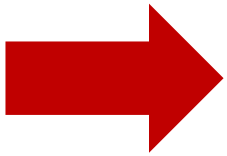


Note: The yearly data was modified (2006-2011) or extrapolated (2012-2014) with a linear regression model (y= -0.0054x + 0.2459, R2=0.959) derived from the datasets of Zhao, Guo, and Fu (2014).

Source: BENF (2016) and Zhao, Guo, and Fu (2014)

Function 7: Creation of legitimacy

Renewable Energy Law
(2005)



Renewable Energy Law
(Amendment, 2009)

- ***The law lays out rules on capacity targets, standardisation, education and training, RD&D, industrialisation and pricing.***

- ***The law was amended in 2009 to emphasise mandatory purchase, grid connection and subsidies.***

Supply-push and demand-pull policies

	Demand-pull policy				Supply-push policy		
Year	CT	GC	LR	L	ST	S	TL
1986					1		
1987							
1988							
1989							
1990							
1991					1		
1992					1		
1993							
1994						1	
1995							1
1996	1						
1997	1		1				
1998			1				
1999							1
2000							1
2001	1		1		2		1
2002							
2003	1		1			1	1
2004							
2005		1	1	1			1
2006	2			1	1	3	
2007	1			1	1	2	
2008					3		
2009	1		1	1		3	
2010	1				2	1	1
2011	1						
2012	4	1		1	6	2	
2013		2				2	
2014	1	1			1	1	
2015		2					

Abbreviations

- CT - capacity targets
- GC - grid connection
- LR - localisation
- L - legislation
- ST - S&T policy
- S - subsidies (incl. feed-in-tariff)
- TL - tax incentives & loans

Note: The values indicate the frequency of the same type of policies presented.

Source: IEA/IRENA (2016) and the authors' own database

Summary of quantitative results

Assessment on the functioning of China's wind energy innovation system

Functions	Sectional score	Overall score
Knowledge development	• Total publications (+2) • Top 10 % publications (-1) • Domestic patents (+2) • Foreign patents (-1)	+1
Knowledge networks	• Public-private knowledge exchange (-3) • Producer-developer connections (-1)	-2
Guidance of the search	• Policy targets on cumulative capacity (+3) • Policy targets on turbine sizes (+3) • Policy targets on localisation rate (+3)	+3
Entrepreneurial activities	• New entrants (+2) • Technology development strategies (+3) • Establishment of R&D facilities (+1)	+2
Market formation	• Domestic deployment of wind power (+3) • Foreign exports on wind turbines (+1)	+2
Resources mobilisation	• R&D expenditure (+3) • Asset finance (+3) • Subsidy (+3)	+3
Creation of legitimacy	• Issuance of laws and regulations (+3)	+3
Alignment between supply-push and demand-pull policies	• Presence of supply-push policy (+2) • Presence of demand-pull policy (+2)	+2

Conclusions

- The system functions approach originating in developed countries can be employed to well examine the dynamics of technological innovation in developing countries like China.

- The functional patterns between developed and developing countries can be quite different – the ***establishment of legitimacy***, ***guidance of search*** and ***resources mobilisation*** have contributed most to China's rise in wind power rather than knowledge development and knowledge exchange.

- The proposed indicators have demonstrated valuable for measuring the functioning of energy innovation systems.