Pathways Towards Renewable Energy in China: Prospects, Politics and Practices

Frauke Urban and Sam Geall

Solar

LOW CARBON INNOVATION IN CHINA
中国低碳创新

China Low Carbon Report 2

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Pathways Towards Renewable Energy in China: Prospects, Politics and Practices

China is not only the world's largest energy consumer and greenhouse-gas emitter by volume, but also boasts the largest investment in renewable energy technologies, including solar, which are essential for a transition to a low-carbon society. How are two different pathways towards solar energy in China – solar photovoltaics (PV) and solar water heaters – supported and constrained by political debates and China's changing policy-making environment? How do they relate to changing practices among different groups of producers and consumers? This report finds two very different approaches to solar energy in China, with solar PV mainly produced for the export market and receiving political and financial support from central government, while solar water heaters remain a 'home-grown' Chinese technology, ubiquitous in China's countryside, that have developed with relatively little government support.

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About China Low Carbon Reports

The project 'Low Carbon Innovation in China: Prospects, Politics and Practice' is led from Lancaster University and is a collaboration between British and Chinese researchers to investigate different models of innovation and their potential role in low carbon transitions. The China Low Carbon Reports detail the project's activities and findings in order to inform research and policy at national and international levels. Further information on this STEPS Centre affiliate project is available on the website **http://steps-centre.org/project/low-carbon-china/**

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70 Pathways Towards Renewable Energy in China: Prospects, Politics and Practices

71 Low Carbon Innovation in Chinese Urban Mobility: Prospects, Politics and Practices

72 Pathways Towards Sustainable Maize Production and Consumption in China: Prospects, Politics and Practices

This is one of a series of Working Papers from the STEPS Centre www.steps-centre.org.

ISBN 978-1-78118-198-0

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STEPS Working Paper 70

Correct citation: Urban, F. and Geall, S. (2014) *Pathways Towards Renewable Energy in China: Prospects, Politics and Practices,* STEPS Working Paper 70, Brighton: STEPS Centre

First published in 2014

ISBN: 978-1-78118-198-0

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Contents

Figures and Tables

Acronyms

CAS	Chinese Academy of Sciences
CEO	Chief Executive Officer
CGTI	China Green Tech Initiative
CO2	Carbon dioxide
CHG	Greenhouse Gas
DPV	Distributed solar PV
EU	European Union
FIT	Feed-In Tariffs
FYP	Five-Year Plan
GDP	Gross Domestic Product
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPO	Initial Public Offering
IPR	Intellectual Property Rights
LCT	Low Carbon Technologies
LCA	lifecycle analysis
MOHURD	Ministry of Housing and Urban-Rural Development
MOST	Ministry of Science and Technology
NDRC	National Development and Reform Commission
NEA	National Energy Agency
NYSE	New York Stock Exchange
PV	Photovoltaic
R&D	Research and Development
SDPC	State Development Planning Commission
SGCC	State Grid Corporation of China
SME	Small and Medium Enterprises
SOE	State-owned firms
TCE	Tons of Coal Equivalent
US	United States

Abstract

This paper examines pathways towards solar energy in China with a specific focus on prospects, politics and practices. It examines two different solar energy technologies, namely solar photovoltaic (PV) and solar water heaters. The paper investigates two case studies in order to understand how different pathways for low-carbon innovation are supported and constrained by political debates and China's changing policy-making environment, as well as how they relate to changing practices among various groups of producers and consumers. The paper finds two very different approaches to solar energy. Solar PV in China is mainly produced for the export market, relies on IP-intensive technology and has received much political and financial support from the central government and provincial governments. Solar water heaters on the other side are a 'home grown' Chinese technology that are ubiquitous in China, particularly in rural areas, and that have developed from grass-roots levels to mass products with relatively little government support.

1. Introduction

The UK-China research project 'Low Carbon Innovation in China: Prospects, Politics and Practices' aims to assess the status of, and opportunities for, China's low-carbon transition and how it is associated with different models of innovation. It thereby goes beyond existing technology-focused approaches and rather focusses on socio-political perspectives of innovation. It will offer a novel empirical, methodological and theoretical contribution to the study of low carbon socio-technical transitions.

The project explores three themes: energy, agriculture and mobility. This paper focuses on the energy theme. Within the energy theme, the project investigates two case studies in order to understand how different pathways for low-carbon innovation are supported and constrained by political debates and China's changing policy-making environment, as well as how they relate to changing practices among various groups of producers and consumers. The case studies are:

1. Solar photovoltaic (PV) panels, their production, installation and use in China; and,
2. Solar water heaters, and their production, installation and use in China.

This paper aims to provide an introduction to the case studies within the context of China's energy innovation system.

1.1 Climate change, low carbon transitions and China's role

About 80 per cent of the global primary energy supply comes from fossil fuels, primarily oil and coal (IEA 2013). Fossil energy resources are limited and fossil energy use is associated with a number of negative environmental effects – most importantly, global climate change. The Intergovernmental Panel on Climate Change (IPCC) estimates that about 70 per cent of all greenhouse gas (GHG) emissions world-wide – primarily, carbon dioxide (CO2) emissions – come from energy-related activities. This is mainly from fossil-fuel combustion for heat supply, electricity generation and transport (IPCC 2007). Avoiding dangerous climate change requires reducing global emissions rapidly (Urban 2014). Energy efficiency and energy from non-fossil fuels, such as renewable and lower carbon sources, are thus crucial for achieving a global low carbon transition.

China is central to such a transition. Today it is the world's largest energy user and absolute CO_2 emitter (IEA 2013). Energy use, production and CO_2 emissions have increased rapidly in China since the beginning of its economic reforms around three decades ago. Furthermore, while China for a long time had low per capita energy use and emissions, and its historic emissions are also lower than many high-income countries, the country has been catching up in recent years. China's per capita CO_2 emissions are increasingly comparable with those of the European Union (World Bank 2014; IEA 2014), and China may lead on cumulative emissions within 10 to 20 years (Stavins 2014).

At the same time, China has also become a world leader in renewable energy, most notably in wind energy, solar energy (both solar PV and solar water heaters) and hydropower. China tops the renewable energy field globally in terms of investments, production and installed capacity (IEA 2013). China invested US$67 billion in renewable energy in 2012 (McCrone *et al.* 2013) and the country reportedly aims to spend 1.8 trillion RMB (US$294 billion) in the five years between 2010 and 2015 in developing renewable energy (Bloomberg 2013).

In recent years a large body of literature on innovation in low carbon technology, and its links to international development, including in solar energy technology, has emerged (e.g. Ockwell and Mallett 2012; Watson *et al.* 2014) and China is often regarded as being in an exceptional position to become a global leader in the low-carbon transition. China's Government is actively pursuing low-carbon development strategies, including building up the innovative capacity of key firms. It has made large sums of state capital available for low-carbon industries and pursues various strategies of accessing the latest low-carbon technologies. Climate change plays a role in driving forward low-carbon innovation in China, but concerns about energy security, creating business opportunities and competitive advantages for Chinese firms have been of equal importance to the government (Urban *et al.* 2012).

Academics working on the governance of social, technological and environmental change have pointed to the key role that different narratives and different configurations and forms of (incomplete) knowledge play in framing, enabling and reinforcing particular 'pathways' to sustainability (Leach *et al*. 2010). Dominant narratives can serve to constrain our understanding of sustainability challenges, leading to policies that shape directions of social and technical change in ways that – whilst addressing some overarching policy objectives – may undermine more marginalised and locally-applicable pathways to low carbon development (Byrne *et al* .2011). While comparative studies of the politics surrounding contemporary transition processes have been carried out in Europe (Lockwood 2013; Smith *et al.* 2014), similar studies in other parts of the world (including China) are notably lacking.

Understanding the narratives that shape pathways to low-carbon transition in China requires understanding not only the prospects, but also the politics and practice of low carbon innovation in China. Since the transition to a low carbon society would require energy demand, use and supply to become transformed from a dependence on the current high-carbon 'system of fossil fuels' to future low carbon systems, such a transition implies changing people's practices and behaviours, changes to government policies and incentives, as well as changes to innovation systems and technological approaches. Thus, as well as studying technologies and their diffusion, there is a need turn our attention to world-making *power* (Smith and Stirling 2007; Kern 2011; Meadowcroft 2009; Shove and Walker 2007), a missing element in most current analysis, and the way in which new political agents (some collective or institutional, including reshaping the 'state'), social practices and subjectivities emerge in a contested process alongside the remaking and reshaping of socio-technical systems (Schwanen *et al.* 2012; Paterson 2007).

Technological development and innovation is complex, messy, non-linear and part of larger economic, social and political development (Saviotti 2005), and innovation is a concept for which no single definition exists. Innovation is defined here as creating something new, developing a new product, service or idea (Rogers 2003). Low carbon innovation – creating and bringing to market new products, services or ideas that reduce greenhouse-gas emissions – is crucial to achieving low carbon energy transitions and thus mitigating climate change. The diffusion of low carbon innovation is a complex process, which includes research, development, demonstration and deployment (Watson 2008). It is not only a technological process, but also depends on the existence of appropriate incentives for firms and other organisations to engage in technological development, for the creation of markets for technologies that are successfully commercialised and skilled labour, including highly trained engineers and technicians. It therefore involves a wide range of actors including firms, public bodies, and research organisations (Ockwell and Mallet 2013; Saviotti 2005).

Historically, low and middle-income countries, including China, have depended to a large extent on international technology transfer and cooperation from high income countries for some low carbon technologies, but over the decades Chinese firms have built up their own productive capabilities as well as their own innovative capabilities. 'Indigenous innovation', according to its typical Western definition, means that a particular country's firms or institutions have invented, conceptualised or built a particular innovation. However, in the Chinese context, 'indigenous innovation' tends also to include innovation that has been licenced and amended, acquired (for example through mergers and acquisitions) or reverse engineered from overseas. These differences in understanding have caused frictions around intellectual property rights (IPRs) in the past.

Such changes in China’s innovation systems have and will take place in a political and social context shaped by China’s own history of approaches to the governance of its environment (Tyfield *et al.* 2014). For example, one needs to attend to the importance of China’s centralised and integrated national Five-Year Plans (FYPs), which continue to set the country’s key strategic and economic priorities; to the government’s varying and often competing narratives around the themes of 'sustainable development' (Meng 2012), 'low-carbon' (CCICED 2011) and 'Ecological Civilisation' (China Daily 2007); to climate-change policies set in key plans by the National Development and Reform Commission (NDRC); and to a system of environmental decision-making characterised by 'fragmented authoritarianism' (Heggelund 2004). Rather than being monolithic, China’s policy-making at the elite level is characterised by protracted bargaining between bureaucratic units, and this vertical fragmentation is matched by horizontal fragmentation, with central government often lacking the capacity to demand enforcement of environmental laws and policies at the local level (Geall and Hilton 2014) This is particularly the case since local officials still tend to be evaluated according to their ability to produce fast economic growth, rather than to enforce environmental targets (Wang 2013).

However, governance of science and the environment has also opened to include a wider range of actors than in previous eras. Not only have some officials and policymakers supported greater citizen oversight and public participation to address this implementation challenge, but also sustainability-focused civil-society groups have proliferated, as concerns have increased about environment issues among China’s public, and particularly its growing middle class, whose opinions are expressed more freely and rapidly than ever before due to near ubiquitous social media and messaging technologies (Geall 2013; CCICED 2013).

In studying two distinct innovation models of solar energy in China, this research aims to go beyond technology-focused approaches to innovation and consider not only the political and power dimensions of the narratives that shape these different energy pathways, but also the perceptions and practices of 'users' and producers. This paper therefore attempts to outline this approach as a distinct approach to the study of solar energy in China, as well as giving a greater understanding of low-carbon socio-technical transitions both in China and more broadly.

2. The Chinese energy sector and low carbon transitions

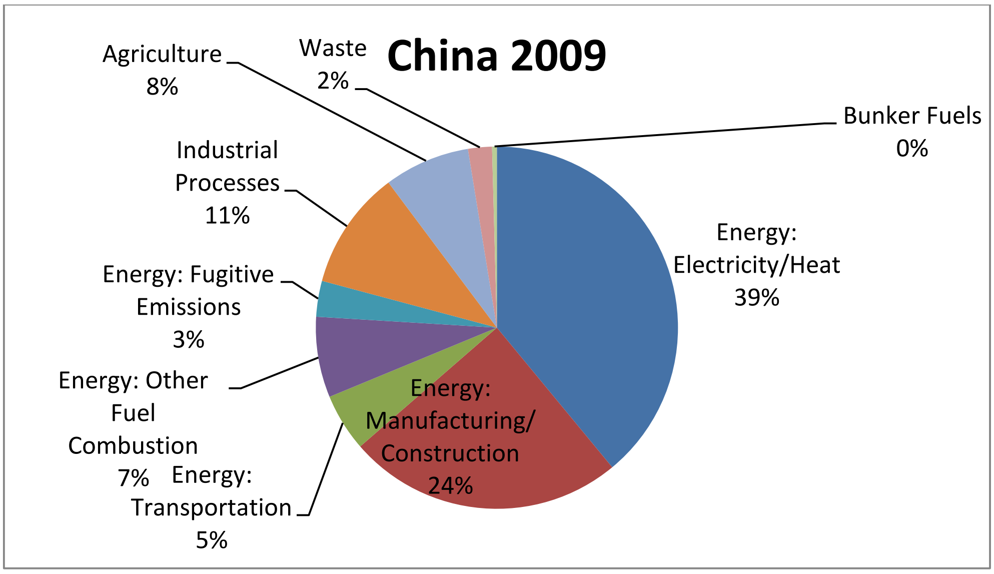
This paper focuses specifically on China's energy sector, since as outlined above, China's three decades of rapid economic growth (an average of 10 per cent from 1990 to 2012, see Figure 2.1) have not only seen serious costs to the environment and public health, but the country has also become the world's largest energy consumer, and in 2007 became the world's largest carbon dioxide emitter by volume (IEA 2013; PBL Netherlands Environmental Assessment Agency 2013).

Figure 2.1: China GDP growth 1990–2012, annual percentage

Source: World Bank 2014

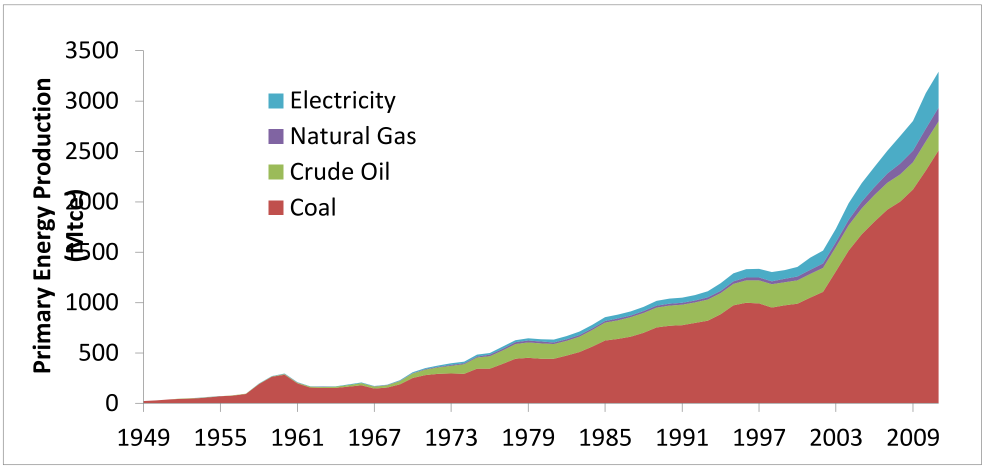
In China in 2009, around 77 per cent of greenhouse-gas emissions came from energy generation (World Resources Institute 2009) (see Figure 2.2). In 2012, around 76.5 per cent of this primary energy production was from coal (China National Bureau of Statistics, 2013), making China's coal sector the world's biggest single anthropogenic source of carbon dioxide. Figures 2.2 and 2.3 illustrate the energy sector's large role in China's greenhouse-gas emissions and the country's historic reliance on coal for energy generation.

Figure 2.2: Greenhouse gas emissions in China by sector and energy subsector 2009



Source: World Resources Institute (chart excludes land use and forestry since it is a net carbon sink)

Figure 2.3: Primary Energy Production by Source, Megatonnes of CO2 equivalent 1949–2011



Source: China Energy Databook

Efforts to move China away from its high-carbon energy pathways, and coal burning in particular, are thus crucially important aspects of achieving a low-carbon transition to address climate change. Fischer (2014) notes that beyond the implementation challenges outlined above, such as structural issues around cadre promotion (see section above), a core challenge faces the take-up of environmentally friendly technologies in China: simply that environmental policies tend to increase the immediate costs of production. Thus, China's strategy has reoriented notably toward 'translating sustainability concerns into drivers of growth' (Fischer 2014).

In other words, in recent years low-carbon innovation has come to be important for future development and competitiveness, and dedicated industrial policies have emerged that have supported low-carbon technologies. This was signalled prominently in China's 12th FYP, and is also likely to be the case in the 13th FYP (Zhang and Xu 2014). The 12th FYP, for 2011–2015, contains both binding and flexible environmental targets and a number of specific sectoral plans for various polluting industries such as steel, nonferrous-metals, building materials, chemicals, electricity, coal, paper, printing, dyeing and tanning.

Of the 12th FYP's many targets one-third concern resources and the environment, including the following binding targets for 2015:

- water consumption per unit of value-added industrial output to be reduced by 30 per cent;
- energy consumption per unit of GDP (energy intensity) to be reduced by 16 per cent;
- forest cover to rise to 21.66 per cent and forest stock to increase by 600 million cubic metres;
- chemical oxygen demand (a measure of water pollution) and sulphur dioxide to be reduced by 8 per cent (targets that were also in the 11th FYP) and ammonia nitrogen and nitrous oxides by 10 per cent (new targets).

Many target are also specifically concerned with climate-change mitigation, including:

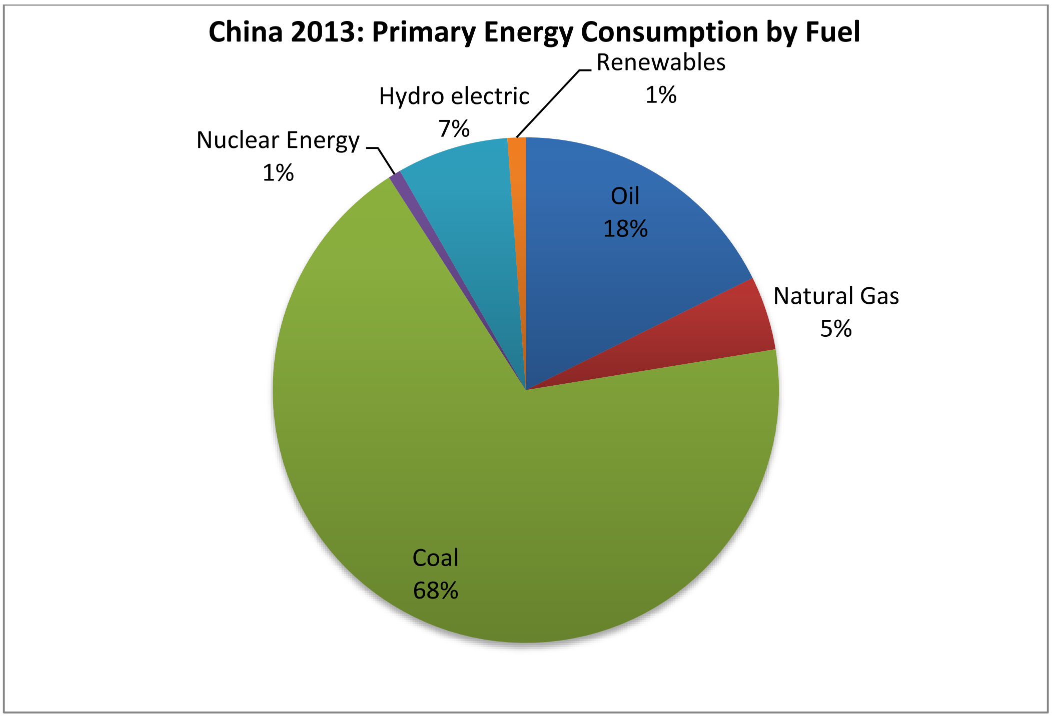
- non-fossil fuel to account for 11.4 per cent of primary energy consumption;
- carbon dioxide emissions per unit of GDP (carbon intensity) to be reduced by 17 per cent.

The 12th FYP also established the Top-10,000 Energy-Consuming Enterprises Programme**,** an expansion of the Top-1,000 Energy-Consuming Enterprises Programme in the 11th FYP (2006-2010), which reportedly saved more than 400 million tonnes of CO2 through the diffusion of energy-monitoring tools and technical support for the top 1,000 energy-consuming industries in China). The Top-10,000 Programme focuses on Chinese industrial enterprises that use more than 10,000 tonnes of coal equivalent per year, as well as transportation companies, public buildings and hotels and commercial enterprises consuming more than 5,000 tonnes of coal equivalent per year.

However, perhaps of most direct relevance to low-carbon innovation, the plan put an emphasis on economic upgrading toward higher-technology and more efficient growth, through central government investment and other preferential industrial policies towards clean energy and other sectors. The 12th FYP established seven new 'strategic emerging industries': new energy; energy conservation and environmental protection; biotechnology; new materials; new information technology; high-end equipment manufacturing; and clean energy vehicles.

Lewis (2012) has suggested the support for renewable energy, promoted by dedicated state funding, increased access to private capital and preferential policies (in tariffs, preferential loans and Research and Development (R&D) funds) represents a shift away from China's old pillar industries, seen as important for national security, public interest, infrastructure development and urbanisation, principally: national defence, telecoms, electricity, oil, coal, airlines and marine shipping. Currently, China gets about 8 per cent of its primary energy from renewable sources, including hydropower (BP 2013) (see Figure 2.4). The 12th FYP not only set out a goal of 11.4 per cent of total primary energy from non-fossil sources by 2015 (see above) but also 15 per cent by 2020.

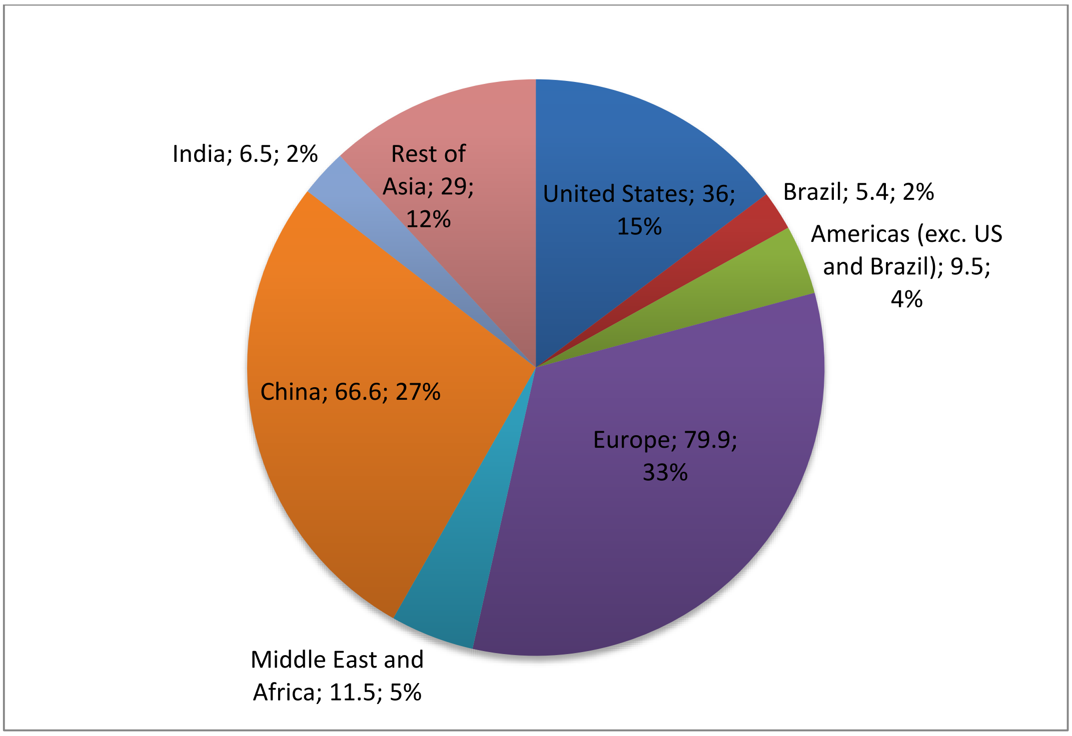
Figure 2.4: China's primary energy consumption by fuel, 2013



Source: BP Statistical Review of World Energy 2013

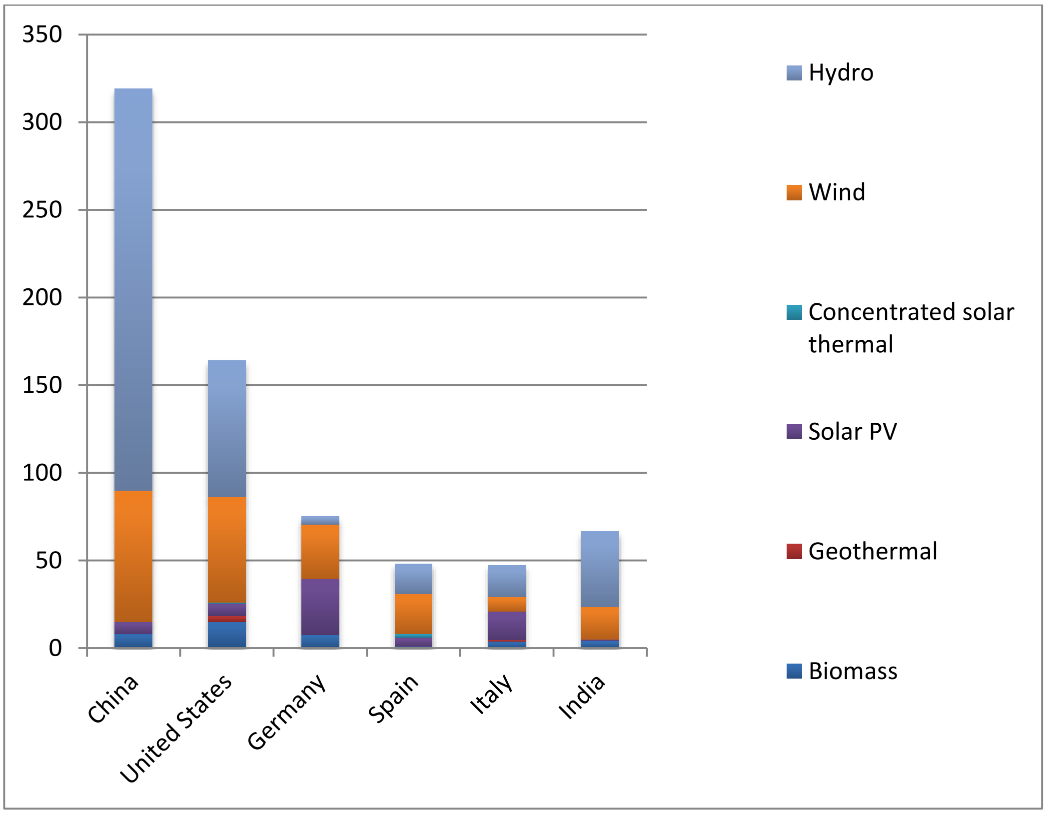
The investment and policies supporting these different technologies, as we will see, differ quite markedly. However, as mentioned above, China is the world's top investor in renewable energy (see Figure 2.5 for investments in 2012) and has the world's largest renewable power capacity, even when hydropower, an industry traditionally supported by the Chinese government, which is often regarded as problematic for environmental, social and economic reasons, is excluded (see Figures 2. 6 and 2.7).

Figure 2.5: Global new investment in renewable energy by region, 2012, US$ billion and percentage



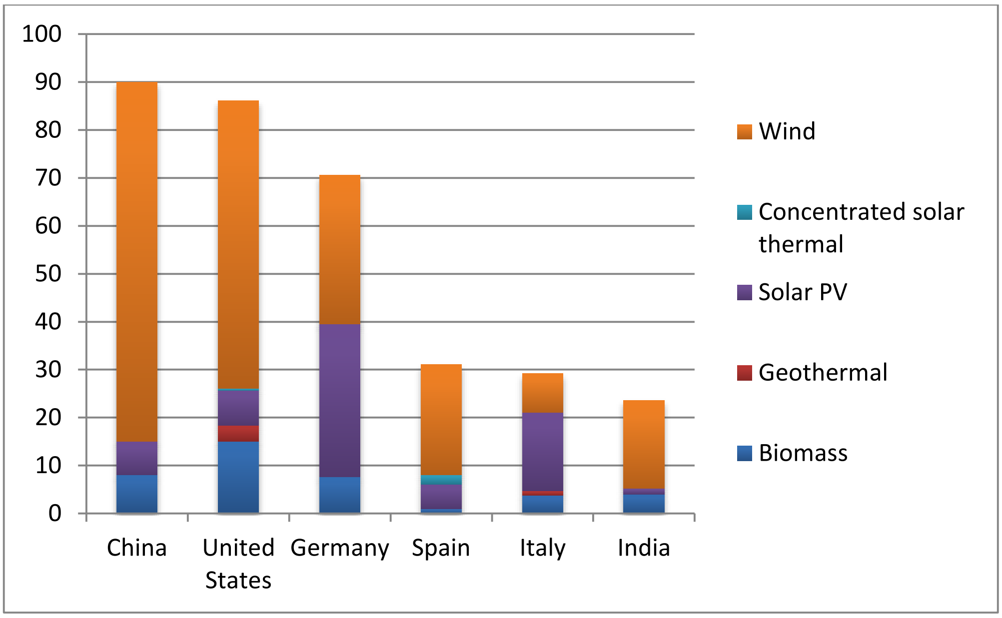
Source: UNEP, Bloomberg New Energy Finance 2013

Figure 2.6: Renewable electric power global capacity, top regions and countries, 2012, GW, including hydro



Source: UNEP, Bloomberg New Energy Finance 2013

Figure 2.7: Renewable electric power global capacity, top regions and countries, 2012, GW, excluding hydro

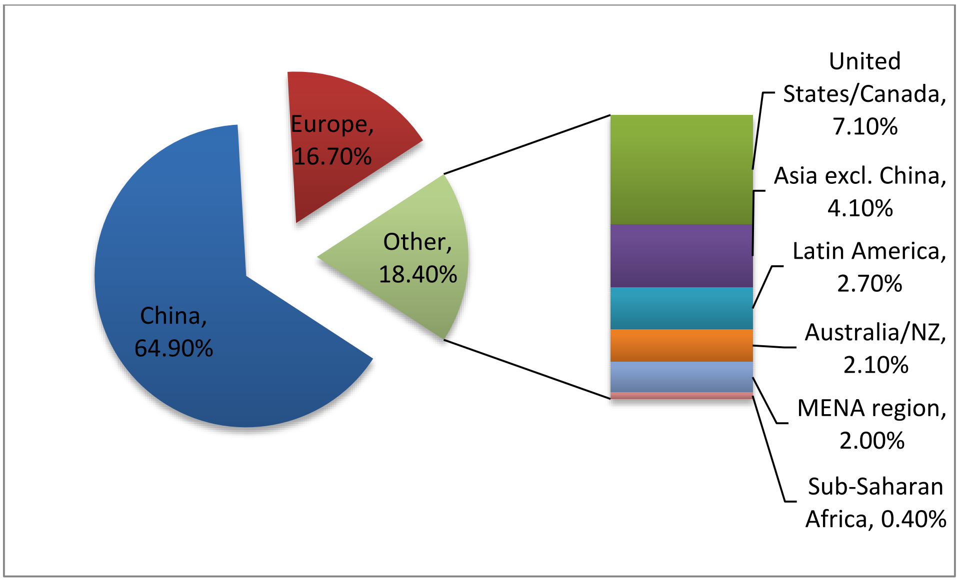


Source: UNEP, Bloomberg New Energy Finance 2013

Given the larger government support that has been given to wind energy in China, and its wider installation, this paper should explain why it focuses on solar energy. First, China is now not only the world's largest investor and producer of solar PV modules (see Section 3 below), but also of solar water heaters (see Section 4). China also has the world's largest installed capacity of solar water heaters (REN21 2012) (see Figure 2.8). Furthermore, with regard to China's role in low-carbon technology, scholars have noted the differentiation between indigenous innovation and technology transfer in innovation pathways (Watson *et al.* 2014; Urban *et al.* 2012). Historically, technology transfer has played a large role in renewable energy pathways in China, including wind energy (e.g. Urban *et al.* 2012). But in recent years, various forms of technology cooperation such as networking, staff exchange schemes, joint ventures, licencing, mergers and acquisitions have played a larger role and 'indigenous innovation' has become more prevalent. This is particularly relevant for solar water heaters, since China uses a technology that is different to those in other countries, and Chinese firms hold most of the solar water heater patents worldwide. On the other hand, innovation in the Chinese PV sector seems to be based less on indigenous innovation and more on building on knowledge, experience, staff and networks in a globalised market, at least following the Western understanding of innovation. From a Chinese perspective, indigenous innovation can also be based on foreign knowledge, experience, staff, networks and technology acquired from and/or licenced by Chinese firms.

Therefore, the solar sector presents an interesting study of the differentiated dynamics of not only innovation diffusion at the global level but also 'indigenous innovation' processes. Beyond these aspects, these two different pathways have other notably different technological, economic and social characteristics and dynamics too. Most solar PV has a higher cost, is of higher technology and, unlike solar water heaters, needs integration with the electricity grid. PV also needs to overcome higher barriers related to intellectual property on key upstream technologies (see Figure 2.9 for a rough summary of these different dynamics, technologies and innovation pathways).

Figure 2.8: Share of the total installed capacity of solar water heating in operation by economic region at the end of 2011



Source: Werner Weiss and Franz Mauthner, Solar Heat Worldwide: Markets and Contribution to the Energy Supply 2011, May 2013 Edition (Weiss and Mauthner 2011)

Figure 2.9: Key differences in solar PV and solar water heaters

Solar PV	Solar water heaters
Higher tech due to systems integration with grid	Lower tech due to stand-alone system
Partly dependent on tech / knowledge transfer	Indigenous innovation
High IP barriers	Lower IP barriers
Higher cost	Lower cost
More centralised due to integration with grid	Decentralised
Export-oriented	Domestically-oriented

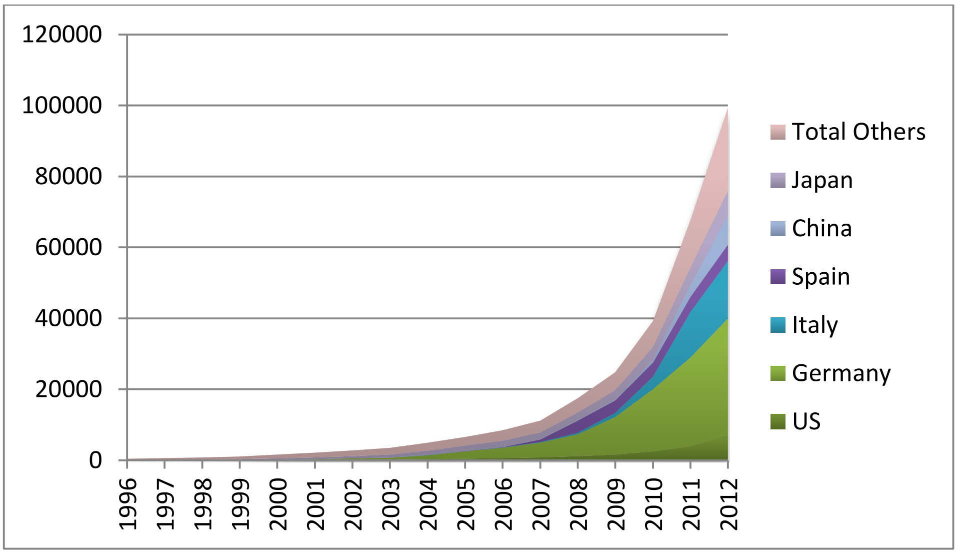
3. Solar PV: prospects, politics, practice

3.1. Solar PV: Prospects

Solar photovoltaics (PV) is not a new technology. The photovoltaic phenomenon, of a semiconductor converting light directly into electrical energy, was first discovered by Edmond Bequerel in 1839 (Leggett 2009: 57). Its development owes a lot to state-regulated monopolies and government initiatives in the United States (US), including the Department of Defense and NASA (Mazzucato 2013: 150), and the breakthrough production of the world's first silicon PV cell took place in 1954 at Bell Laboratories (Leggett 2009: 57). Solar PV modules have been installed off-grid for marginal and specialised uses, and used extensively in spacecraft and satellites, for around 50 years. But the large-scale installation of solar PV is a relatively recent development globally, dating from the late 1990s.

Since 2003, the market has grown exponentially, driven by policy support that has addressed the higher costs of PV generation compared to fossil fuels, particularly through PV feted-in Tariffs (long-term contracts for solar electricity producers) in industrialised countries, notably Germany, Japan, Spain and the US (de la Tour *et al*. 2011: 762) (see Figure 3.1). More recently, both the market prices and underlying costs of PV systems have fallen further. Bazilian *et al*. (2013: 330–331) found that from 2004 until September 2008, the price of PV modules remained largely flat at around US$3.50-$4.00 per watt, as manufacturers improved PV technology and scale, but tariff incentives in Germany and Spain allowed project developers to buy the technology at this price. However, after the incentive regime ended in Spain in September 2008, and a sharp fall in the price of purified silicon, the main raw material for cell production, due to a breakthrough in China in mastering the technology for its production, the price fell to $2.00 per watt by 2009, and by late 2011, crystalline-silicon PV modules had fallen below the $1.00 per watt mark for the first time.

Figure 3.1: Cumulative installed solar PV capacity around the world, megawatts, 2012



Source: BP Review of World Energy 2013

China still accounts for a relatively small share of global PV demand, though it has risen since 2009, and stood at 8 per cent by the end of 2012 (see Figures 3.4 and 3.5). The Chinese Government's renewable energy policies focused on the domestic installation of wind energy, while solar PV was for many years intended as an export industry. For buyers, relatively high prices, a lack of government incentives and the difficulty of installing solar PV modules – many potential consumers do not own or have access to roof space, and connectivity with the grid is technically and bureaucratically challenging – has meant solar PV modules have not been widely installed, and most are used in ground-mounted, large-scale installations, for which financial incentives are particularly crucial. Yet China has, nevertheless, become the world's leading supplier. Around 95 per cent of China's solar PV systems are manufactured for export (REN21 2012). According to China's top economic planner, the National Development and Reform Commission (NDRC), the country accounted for 50 per cent of total global solar cell production by 2010, with an export value of US$20.2 billion (NDRC 2012). In 2011, the global shipment of solar cells stood at around 37.675 GWp (gigawatts-peak), of which shipment from China was 21.157 GWp, accounting for 56.16 per cent of the global market (Sun *et al*. 2014: 222). Iizuka (2014: 10) compared leading PV module manufacturers by percentage share in the world market in recent years and found that China's share remained high. Her table is reproduced below in Figure 3.2.

Figure 3.2: Leading PV module manufacturer by percentage share in the world market 2010-12

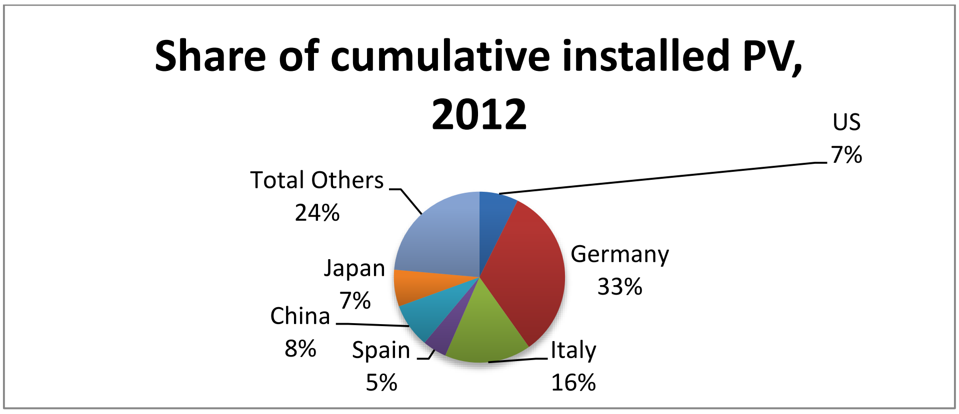
	2010	Country	%		2011	Country	%		2012	Country	%
1	Suntech Power	China	7	1	Suntech Power	China	5.8	1	Yingli Green Energy	China	6.7
2	JA Solar	China	6	2	First power	USA	5.7	2	First Power	USA	5.3
3	First Solar	USA	6	3	Yingli Green Energy	China	4.8	3	Trina Solar	China	4.7
4	Yingli Green Energy	China	5	4	Trina Solar	China	4.3	3	Suntech Power	China	4.7
4	Trina Solar	China	5	5	Canadian Solar	Canada	4.0	5	Canadian Solar	Canada	4.6
6	Q-Cells	Germany	4	6	Sharp	Japan	2.8	6	Sharp	Japan	3.0
7	Kyocera	Japan	3	6	Sunpower	USA	2.8	6	JA Solar	China	2.8
7	Motech	Taiwan	3	8	Tianwei New Energy	China	2.7	8	Jinko Solar	China	2.6
7	Sharp	Japan	3	8	Hanwha-Solar One	China	2.7	8	Sunpower	USA	2.6
7	Gintech	Taiwan	3	10	LDK Solar	China	2.5	10	Hareon Solar	China	2.5
10	Hanwha-Solar One	China	2	10	Hareon Solar	China	2.5	10	Hanwha-Solar One	China	2.5
10	Neo Solar	China	2	12	JA Solar	China	2.4	12	Renesola	China	2.1
10	Canadian Solar	China	2	13	Jinko Solar	China	2.3	13	Kyocera	Japan	2.1
10	Sunpower	USA	2	14	Kyocera	Japan	1.9	14	REC	Norway	2.0
10	REC	Norway	2	14	REC	Norway	1.9	14	Tianwei New Energy	China	2.0
Total share of top 15 firms			55	Total share of top 15 firms			49.1	Total share of top 15 firms			50.2
Of which China accounts for			29	Of which China accounts for			30	Of which China accounts for			30.6

Source: Izuka 2014

By 2013, one fairly typical industry ranking Lian (2014) had found that six of the global top 10 solar PV suppliers were headquartered in China: Yingli Green Energy; Trina Solar; Jinko Solar; Rene Solar; Hanwha SolarOne; and JA Solar.

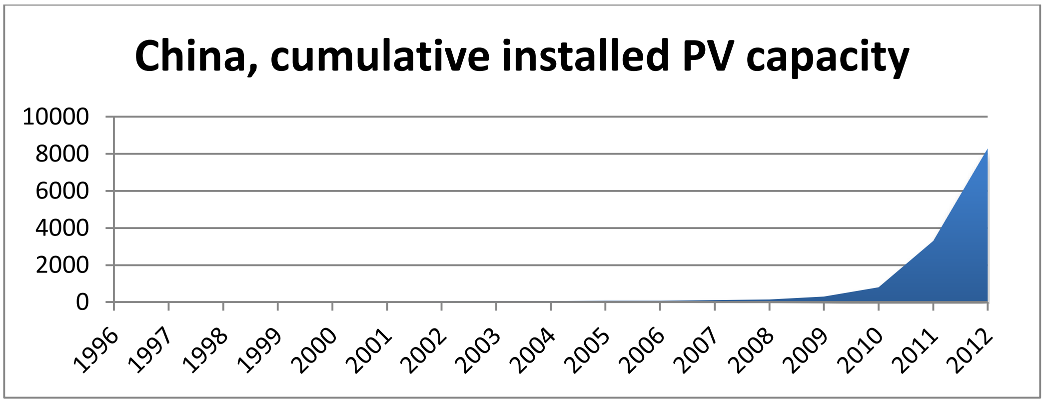
Today the quality of Chinese PV systems is similar to their Western counterparts. Chinese solar firms are not R&D intensive compared to international companies in the sector, but they have a higher propensity to file patents, particularly in order to send a signal to public authorities that allocate subsidies on this basis. Significantly, China's PV industry also filed a large number of patents in upstream segments of the industry, particularly silicon production, where its firms were not yet dominant, suggesting a concerted effort to break a 'technological lock' where the industry is still dependent on foreign suppliers (de la Tour 2011: 767).

Figure 3.3: Share of cumulative installed solar PV capacity in 2012



Source: BP Statistical Review of World Energy 2013

Figure 3.4: Cumulative installed solar PV capacity in China, megawatts, 2012



Source: BP Statistical Review of World Energy 2013

By 2013, China's installed capacity of solar PV had risen to about 12 GW, of which about 8.3 GW were large-scale, ground-mounted PV. China has a target of 35 GW to be installed by 2015, though analysts say it is on track to install 40 GW by that point, and has a target of 100 GW by 2020. According to Sun *et al*. (2014: 222) China aims to create a PV industry with a gross installed capacity of 1,050 GW by 2030. With costs falling and China's solar PV industry thriving, Sun *et al*. (2014: 222) predict that China's PV industry will achieve grid parity on the consumption side by 2015 and on the generation side by 2020, many understandably see in this industry in China the prospect of an important step forward in the large-scale diffusion of low-carbon energy technologies worldwide.

3.2. Solar PV: Politics

The Chinese Government has supported research on solar PV, mainly for uses in space, since the 1950s, but the 6th FYP (1980-1985) was the first to include PV science and technology projects, with research on crystalline silicon cells included in the 7th FYP. By the end of 1994, China's PV module manufacturing capacity was 5 MW, although according to Zhang *et al*. (2014: 903), 'much of this capacity did not meet modern international standards and actual production was only 1.4 MW'.

In the 1990s and early 2000s, the Government promoted a number of PV industry development strategies, mainly focused on the production of solar consumer goods for export (it became the largest producer of these in 2003) and remote rural electrification (Fischer 2012: 136). The Brightness Programme, initiated in 1996, was the first national policy, 'to bring electricity to remote areas of western China by means of renewable energy' (Zhang *et al*. 2014: 905), and in 2002, the State Development Planning Commission (SDPC) now the National Development and Reform Commission (NDRC) launched the 'Power Supply Plan for Rural Areas without Electricity in the Western Provinces and Regions' policy, which encouraged the adoption of renewable energy technology, including solar PV and wind power generation, for household consumption by farmers and herdsmen in western regions lacking grid electrification (Sun *et al*. 2014: 222).

From 2004 to 2008, China's solar PV policy shifted to an 'export-oriented growth stage' (Zhang *et al*. 2014: 906). 'As the Government supported this burgeoning export industry, it invested in technology R&D and a number of firms have been 'equipped with national level key laboratories' (Zhang *et al.* 2014), covering almost every link in the solar PV manufacturing chain. One official document records the achievement thus, 'Through a combination of independent innovation and the introduction of foreign technology, domestic enterprises have built a PV industry with Chinese characteristics.' (NDRC 2012) Today, companies like Yingli Solar and Trina Solar have set up national PV key laboratories, 'with annual R&D investment of 592 million RMB and 610 million RMB respectively between 2009 and 2012' (Sun *et al*. 2014: 226). During this period, technology transfer from industrialised countries enabled the rapid development of China's PV industry, mainly through purchases on the market of manufacturing equipment and the transfer of complementary know-how, as well as the movement of skilled labour across borders. Scientist and entrepreneur Shi Zhengrong did his PhD in solar PV engineering at the University of New South Wales in Sydney, acquiring Australian citizenship in the process, before moving back to China to found Suntech, the solar company that in 2010 and 2011 was China's largest (see Figure 3.2). To a smaller extent, this has also been achieved through foreign direct investment by multinational firms (de la Tour *et al*. 2011: 763-5).

It is clear that boosting solar PV manufacturing became part of core government strategy. As Zhang *et al*. (2014: 906) put it, this lay in the central Government's:

> belief held since the early 2000s that China had an historic opportunity to position itself as an economic and technological leader in a global transition towards low-carbon energy and that those who moved fastest in the transition to a low-carbon economy were likely to gain a significant competitive advantage.
> (Zhang et al. 2014)

China had a 12th Five-Year Plan for Solar Power Generation under the 12th FYP. This set targets to reduce the price of solar power and to increase the production of PV modules (Du 2012), as well as putting forward guiding priorities, such as to, 'Work Out Overall Planning and Support Leading Enterprises', or to support the consolidation of the industry and the growth of leading enterprises, to 'Support Technological Innovation to Reduce the Cost of Power Generation', which includes strengthening R&D for key technologies, including new types of cells and raw materials, to 'Optimize the Industrial Environment and Expand the PV Market', by promoting PV-favouring policies aimed at the domestic market, and to 'Strengthen the Service System to Promote the Industry's Healthy Development', which includes improving PV standards and product quality inspection and certification systems (NDRC 2012).

China has also launched further incentive policies to boost PV market expansion, particularly to expand the PV output through Feed-In Tariffs (FIT), including the State Grid Corporation of China (SGCC)'s 'Relevant Opinions and Regulations on Grid Connection for Distributed PV', the National Energy Agency's (NEA) approval of 18 demonstration zones on distributed solar PV in 2013, and, in August

2013, the NDRC's 'Notice on Giving Play to the Role of Price Leverage in Promoting Healthy Development of the Solar PV Industry', which clarified the FIT policy for PV generation based on solar zones and the subsidy standard for distributed PV. Further, the Ministry of Science and Technology (MOST) has driven forward PV R&D, with an average annual investment of around 500 million yuan (around US$81 million) toward all segments of the manufacturing chain: Poly-Si, wafer, solar cells, PV modules, thin-film technology, CPV, energy storage, BOS components and system engineering (Wang *et al.* 2013: 47–50).

However, the dominant narrative that links China's climate-change efforts with its industrial strategy and support for solar PV has been complicated by a number of other (competing) discourses, circumstances and realities. First, is that in the context of climate-change negotiations, the Chinese Government has often argued that the lack of access to cheap low-carbon technologies (LCTs) is the major reason why China is reluctant to undertake greater climate-change mitigation efforts, an aspect of the argument for 'common but differentiated responsibilities', which emphasises developed countries' role in shouldering the greater part of the burden of climate-change mitigation, but which might be undermined by China's considerable support and successes in developing such industries. Second, a paradox emerges in the large-scale development of the PV industry in the first decade of this century without complementary policy support for the creation of a domestic market, which suggests support for PV diffusion was not triggered by long-term climate change considerations as much as by economic concerns (Fischer 2012: 132).

As solar PV became a Chinese export industry, the domestic market lagged behind considerably, partly since the Government had 'planned wind energy as the main strategic renewable energy for China' (Sun *et al.* 2014: 224). Until 2011, 90–95 per cent of solar PVs were exported, mainly to the European Union (EU) (Germany particularly) and the US. This has changed in recent years. One of the reasons is that the US has added high tariffs to the price of Chinese PVs, making them very expensive (Fischer 2014). Not only did China export up to 95 per cent of its solar PV modules, but it imported 95 per cent of its raw materials for PV, known as the problem of *liangtou zaiwai*, or 'both ends out', due to a 'lack of advanced technologies in producing crystalline silicon (Chen 2014: 5). Zhang *et al*. (2014: 904) suggest that the transition to a low-carbon economy, rather than being orderly, is 'erratic and unpredictable […] due to it being subject to external events and policy priorities from other sectors'. In the case of solar PV, an overlooked actor had been China's local governments, which as a consequence of central Government support for clean energy development, had a 'strong incentive to facilitate the growth of local PV industries and granted them greater preferential treatment compared to other industries'.

This preferential treatment, according to Chen (2014: 11–12), included: 'free or low-cost loans, tax rebates, research grants, cheap land', this land often gained through confiscation 'from the hands of villagers', as well as 'energy subsidies and technological, infrastructure and personnel support'. Furthermore, local governments typically supported indigenous PV producers by instructing local commercial banks to offer 'bountiful loans' at low interest rates. One example is Jiangsu Province, home to Suntech and to some 'particularly aggressive solar development policies' (Zhang *et al*. 2014: 907). Suntech received bank loans worth US$56 million at the end of 2005, but this amount had risen to US$3.7 billion by the end of 2012, mainly due to municipal government's ability to order local state-owned banks to provide low-interest loans (Chen 2014: 11).

These optimistic signals, often from local governments, meant 'many Chinese companies accelerated their investment in the industry, and 'sought to raise funds quickly to expand their production', for which 'central and local government provided great assistance' (Zhang *et al.* 2014). PV manufacturers received export credits at preferential rates from the Import-Export Bank of China and many would raise funds through overseas IPOs, a trend initiated by Suntech, which floated on the New York Stock Exchange (NYSE) in 2005. In part, it was this influx of capital from foreign stock markets that enabled the Chinese PV industry to expand its production capacity at an unprecedented rate (Zhang *et al*. 2014: 907).

Chen (2014: 11) points out, however, that this heavily subsidised credit not only supported PV manufacturers with high productivity, but also those with lower productivity, even where some of these loans faced a high risk of default. Thus, 'local officials encouraged entrepreneurs to take more loans from local banks for capacity expansion, regardless of oversupply and over-competition problems' (Chen 2014: 11). Chen provides the 2005 example of Peng Xiaofeng, the Chief Executive Officer (CEO) of LDK Solar, who after only a half-hour conversation with the mayor of the city of Xinyu, in Jiangxi Province, had reportedly persuaded him to, 'ask local banks to provide loans worth of 200 million yuan (US$ 26 million) for the start-up'. After the global financial crisis hit in 2008, not only China's real economy but, more significantly, its export markets were adversely affected. A solar PV industry built on exports to countries like Germany and Spain was no longer feasible. However, central Government was keen to maintain this level of economic growth, and announced a mix of macroeconomic and industrial policies to both increase the level of central and local support and stimulate domestic demand for PV.

While renewable energy laws and policies had until this point mainly been used to stimulate wind energy usage, in 2009, a number of funds were promoted for the purposes of creating a domestic market: particularly, the Rooftop Subsidy Programme, jointly announced by the Ministry of Finance and the Ministry of Housing and Urban-Rural Development (MOHURD), and the Golden Sun programme for distributed solar PV, launched by the Ministry of Finance, the Ministry of Science and Technology (MOST) and the National Energy Administration (NEA) of NDRC. These Government-sponsored PV projects and their approved capacity are listed below:

Figure 3.5: Government sponsored PV projects in China

Project/phase	**Approved capacity**
Large scale PV First Bidding 2009	2 projects, 20 MW
Large scale PV Second Bidding 2010	13 projects 280 MW
Large scale PV 2011 FIT	2,000 MW
Large scale PV 2012 FIT	2,000 MW
PV Building Project 1st Phase 2009	111 projects, 91 MW
PV Building Project 2nd Phase 2010	99 projects, 90.2 MW
PV Building Project 3rd Phase 2011	106 projects, 102 MW
PV Building Project 4th Phase 2012	250 MW
Golden Sun Demonstration 1st Phase 2009	140 projects, 304 MW
Golden Sun Demonstration 2nd Phase 2010	46 projects, 272 MW
Golden Sun Demonstration 3rd Phase 2011	129 projects, 692 MW
Golden Sun Demonstration 4th Phase 2012	155 projects, 179 MW
PV Building + Golden Sun to Nov 2012	2,830 MW
Total installed and approved PV by the end of 2012	**10, 657 MW**

Source: Wang *et al.* 2013

However, the Golden Sun Programme came under heavy criticism from China's PV industry and others. According to Zhang *et al*. (2014: 909) these criticisms included, 'the lack of criterion for project approval, the failure of the one-off upfront payment of the subsidies to provide incentives for the companies to build high-performance systems, severe fraud and abuse of subsidy funds arising from the lack of oversight of project implementation, and delays in the payment of subsidies.' Thus, this massive government-supported investment boom between 2009 and 2011:

> resulted in even greater overcapacity of solar panel manufacturing by 2012. By this time Chinese production capacity of solar panels had reached 55 GW, representing around 150 per cent of annual global consumption. Excess Chinese production capacity was around 27 GW or some 90 per cent of global demand in 2012.
> Zhang *et al*. (2014: 909–10)

The consequent global decline in prices of solar PV modules caused a number of US and EU solar PV manufacturers to go bankrupt. Between 2011 and 2012, Solyndra (USA), Q-Cells (Germany), BP Solar and others pulled out of the solar PV industry and others downscaled their operations, including Sharp (Japan) and First Solar (USA) (Iizuka 2014: 9). Significantly, this triggered 'antidumping' and 'anti-subsidy' investigations by US and the EU (Sun *et al*. 2014: 222) which, in turn, had an adverse impact on China's solar PV industry. It was in this context that the Chinese Government again promoted a series of policies to provide better support for distributed solar PV (DPV) power, and shifted away from capacity-based subsidies and towards subsidies based on available solar resources, but it was also around this time in 2013 that Suntech Power, then China's biggest solar panel manufacturing firm, announced that it had defaulted on its debt, failing to pay US$541 million worth of bonds.

Suntech, and its founder Shi Zhengrong, once the richest man in China, had been frequently heralded as the vanguard of China's solar PV industry. Shi is an Australian-educated solar scientist who moved to China to set up Suntech, with considerable political support, particularly from the Provincial Government in Jiangsu. After the company's downfall, Chinese observers variously blamed it on the pressure from local government to expand, Shi's own management style, or outside economic forces. The most immediate cause may have been Suntech's long-term contracts for the supply of polysilicon, which became a drain on the firm after its price fell dramatically in 2011, thanks to breakthroughs in the production process.

Mazzucato (2013: 154) used the crisis to suggest that the sustained government support Suntech received, even in the face of its bankruptcy, indicate China's Government support for breakthrough innovation. By contrast, the US-based solar firm Solyndra had also been exposed to the price crash in polysilicon, and for Mazzucato, the fact that Suntech survived, albeit in a smaller form, since its bankruptcy:

> stands in stark contrast with that of U.S.-based Solyndra. Solyndra was overwhelmingly funded by private interests, while Suntech was funded by public interests. The two firms committed the same mistakes, scaling up too rapidly and depending too much on volatile export demand. Yet Solyndra has disappeared from the world, while Suntech survives. Suntech's fate is not to be decided by its investors, whose first priority is to get their money back, and then some.
> (Mazzucato 2013)

3.3. Solar PV: Practice

As we saw in the last two sections, China has seen a remarkable increase in solar PV capacity, yet as Iizuka (2014: 16) points out, while on the surface this might appear to be the 'fruit of implementing effective policy measures', as was arguably the case with the development of wind energy (cf. Lema and Lema 2012), its progress has been more uneven, shaped by divergent political forces and narratives. Yet it can also be 'considered as a windfall benefit from global interaction'. These international interactions include the fall in export demand caused by the global financial crisis and trade disputes with the EU and US, which, in turn, 'triggered and consolidated the shift in policy to deploy solar PV technology in the domestic market' (Iizuka 2014: 16). Furthermore, firm strategy changed during this period too, with several Chinese companies looking to expand their markets elsewhere in the developing world. Thus, Iizuka (2014: 16) concludes that China's 'sustainable transition' (or, at least, its creation of a solar PV industry) 'happened as the combined result of being open to the external market and agents'. As is detailed above, this openness meant learning from incumbent firms overseas, by producing low-barrier technological components before leap-frogging to second and third generation technologies, by building scientific linkages with developed countries, and eventually starting to patent upstream technologies.

With regard to the remaining barriers, Doris Fischer (2012: 132) identified three major barriers to the large-scale diffusion of low-carbon technologies: lack of enabling business and knowledge environment; lack of adequate policy support; and competing strategic policy considerations. Sun *et al*. (2014: 227–8) identified five 'problems and challenges' for China's solar PV industry: a 'severe PV capacity surplus', as is discussed in the section above; the 'deterioration of the international market', referring principally to US and EU anti-dumping proceedings; 'the under-development of the domestic market'; the important but overlooked element of the 'lack of unified coordination and planning for PV power generation and power grid construction; and 'financial institutions' lack of confidence' in the PV industry, which means 'innovative financial products' like 'energy management contracts' that could help the development of PV have been overlooked. However, other barriers to take up and limiting factors at the local and consumer level, particularly in the context of a rapidly changing and urbanising society, may be equally important and require investigation at the level of practice.

In other words, particularly in comparison with the development of solar water heaters (see Section 4), the lack of policy or narrative focus on the practices of solar PV users may help to explain the initial neglect, and slow start, regarding the creation of a domestic market for PV. Solar PV, from the perspective of its users, has been far more difficult to install than solar water heaters. Purchase of the initial units is cost inhibitive, there are issues with space and ownership that come into play when rooftops are involved, and grid connectivity, and particularly the bureaucratic hurdles involved in benefitting from preferential policies like the Feed-In Tariff that rely on grid connectivity, are off-putting, even to committed users. In 2013, environmental NGO Greenpeace China became Beijing's largest solar electricity producer by fitting PV panels on the roof of its suburban warehouse (Cheng 2013). However, this not only had a high upfront cost, of around 50,000 yuan (more than US$8,100), but initial interviews with the participants in this project indicated that even in the capital, with institutional time and support and a strong commitment to low-carbon aims, the long process of applying to benefit from DPV policies that could offset these costs, like the Feed-In Tariff, and to navigate related problems regarding tax and other regulations, was difficult and off-putting.

4. Solar water heaters

4.1. Solar water heaters: Prospects

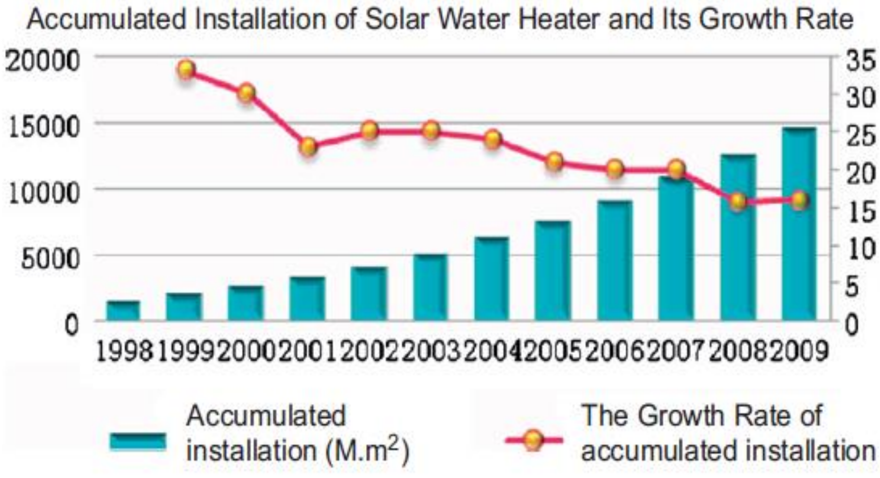
Annini *et al*. (2014) describe solar water heaters as the 'undiscussed protagonist' of a transition from fossil fuels to low-carbon energy. China is the largest solar hot water market worldwide. Solar water heaters were first developed in the 1970s in China. In the 1980s China began to produce flat plate solar water heaters that were based on technology transfer of a Canadian design (similar to the predominant design used in Europe today). However, the production was expensive and there were technical problems. In the 1990s, Chinese scientists at the Beijing Solar Energy Research Institute at Tsinghua University developed and patented the evacuated tube design (also called the vacuum tube), an example of indigenous, low-cost innovation. This follows a trend that we can also see in the wind energy sector, namely the emphasis on university-led R&D for renewables at national level in China. R&D in the evacuated tube design was heavily supported by the national Government until it was commercialised in 1998. Today, leading firms, such as the Himin Solar Energy Group, still cooperate with the Chinese Academy of Sciences (CAS) and universities for R&D in solar water heaters. This requires a skilled work force for developing cutting-edge innovation, in addition to a low-cost work force for production of solar water heaters. (Annini *et a*l. 2014). Today 95 per cent of all the solar water heaters in China are of the evacuated tube design (Hu *et al.* 2012). It is estimated that Chinese firms hold 95 per cent of the patents for core technologies of solar water heaters worldwide (CGTI 2011).

Today, Chinese solar water heaters are predominantly produced for the domestic market, particularly in rural areas. Almost 65 per cent of the world's installed solar water heater capacity was in China in 2009 (REN21 2011), and they are used by over 30 million households (CGTI 2011). It is estimated that about 134 GW of solar thermal heating capacity is currently installed in China (Li *et al.* 2011). The literature is unanimous in suggesting that the potential market for solar water heaters in China is huge. Today, about one million solar water heaters are being manufactured every year (Hu *et al*. 2012), though regional variations exist, with Shandong having the highest penetration rate of solar water heaters, namely about 20 per cent of all households owning water heaters (Li *et al*. 2011). Shandong Province is also home to a solar water heater innovation cluster, which hosts the world's largest solar water heater firms. This cluster has developed partly due to provincial government support, networks among innovative firms, good infrastructure links and the lack of cheap provincial fossil fuel resources (Annini *et al*. 2014).

The sector has seen a rapid increase over the last 15 years (Liu *et al*. 2010). It is estimated that growth rates for solar water heater annual output increased at about 20–25 per cent each year between 2000 and 2010 (Hu *et al.* 2012). Figure 4.1 shows the accumulated installation of solar water heaters and their growth rate.

It is estimated that there are about 3,000 solar water firms in China, of which about 1,800 are solar water heater manufacturers and the remaining 1,200 component suppliers. Of these 3,000 firms, the top ten account for more than a quarter of the Chinese solar water heater industry and about 30 firms are relatively large in terms of sales volume and production. Four have an annual sales volume of approximately 2 billion yuan (around US$326 million), two have an annual sales volume of approximately 0.5–1 billion yuan ($81–$162 million) and more than 20 have an annual sales volume of approximately 100–500 million yuan ($16–$81 million) (Hu *et al.* 2012). Both private and state-owned firms (SOEs) form the solar water heater industry.

Figure 4.1: Accumulated installation of solar water heaters and their growth rate between 1998 and 2009



Source: Hu *et al*. 2012

The top 10 firms are:

1. Shandong Long Guang Tian Xu Solar Energy Co Ltd
2. Shandong Linuo New Material Co Ltd
3. Himin Solar Energy Co Ltd
4. Jiangsu Sunrain New Energy Group Co Ltd
5. Shandong Sangle Solar Energy Co Ltd
6. Shandong Linuo Paradigma Solar Energy Co Ltd
7. Jiangsu Huayang Solar Energy Co Ltd
8. Beijing Tianpu Solar Energy Industry Co Ltd
9. Beijing Huaye Solar New Energy Co Ltd
10. Guangdong Fivestar Solar Energy Co Ltd

There are several innovation clusters in the solar water heater industry, for example in Shandong, Jiangsu and Beijing (Hu *et al.* 2012). China has introduced several national standards to guarantee the quality of solar water heaters and has put the Chinese Committee for the Standardisation of Solar Energy in charge of this process. Three product-testing centres exist in Beijing, Hubei and Yunnan, although some leading firms have their own test centres. The State Administration of Quality Supervision, Inspection and Quarantine, oversees the testing and it is estimated that about 80–93 per cent of the tested solar water heaters pass the standards test. There are also voluntary certification centres that certify the quality of the solar water heaters and/or their impact on the environment (e.g. ISO 14001-type certifications). There is however a continuous problem with some small and medium enterprises (SMEs), particularly in rural areas, that have sub-standard production systems and outputs (Hu *et al*. 2012; Han *et al.* 2010).

Today, the solar water heater supply chain is complex, including manufacturing firms, component suppliers, service providers, distributors, utility firms and sales agents. The sector has increasingly become more efficient, thereby also decreasing costs per unit. Currently a solar hot water heater costs a few thousand RMB, depending on quality and size.

In terms of costs, the solar water heaters have higher upfront costs than electric hot water boilers or natural gas hot water heaters. However, they have minimal annual maintenance costs and lower annual costs than the other hot water heaters when compared by lifecycle analysis (LCA) (Hu *et al*. 2012). The economic break-even point for solar water heaters compared to electric water heaters is usually at around three years, after that electric heaters are far more expensive than solar heaters (Li *et al*. 2011).

Although most solar water heaters are used on a small-scale, they are increasingly being used on a large-scale, for example by industries such as the Zhejiang Shaoxing Dyeing and Weaving Mill, the Kaida Dyeing and Weaving Mill and the Oriental Dyeing and Weaving Mill in Changshu, Jiangsu (Hu *et al*. 2012).

4.2. Solar water heaters: Politics

Solar water heaters make an interesting case as they have had relatively little stable national financing incentives since the evacuated tube design was commercialised in 1998 (although there was national-level support for R&D before its commercialisation), there are fewer formal subsidies at the national level and there is a limited amount of industrial policy that supports the growth of the solar water heater industry. However, there is strong support at the local level for solar water heaters. Unlike solar PV and wind energy, solar water heaters have been developed mainly at the local level after their commercialisation without much Central Government support. However Central Government initiatives played a key role for developing the cutting-edge evacuated tube design in the 1970s to 1990s (Li *et al*. 2011; Annini 2014). These are mainly supply-side policies and subsidies.

Nevertheless, since the introduction of the Renewable Energy Law in 2006 there has been a rapid expansion of solar water heater installation across China. This is mainly due to two policy incentives. First, since 2007, some provincial and municipal governments (including Hainan, Fujian, Jiangsu, Hebei, Henan, Shandong and Ningxia and cities like Shenzhen, Jinan, Rizhao, Yantai, Zibo, Qingdao, Xingtai, Qinhuangdao, Zhengzhou, Sanmenxia, Huhhot, Nanjing and Wuhan) have introduced a mandatory requirement to install solar water heaters as part of every new building. Second, the payment of subsidies for solar water heaters under a 2009 policy on 'household appliances going to the countryside', which aims to increase the availability and use of solar water heaters in rural areas with a subsidy equivalent to a reduction of 13 per cent of the wholesale price (Hu *et al*. 2012).

There is an ongoing discussion among experts as to whether solar water heaters are a mature technology that does not need as many subsidies and financial incentives as solar PV, or wind energy. In addition, solar resources vary significantly in different regions in China. Mandatory requirements by the national government may therefore not be suitable for all regions.

The NDRC's Medium and Long-Term Plan for Renewable Energy in China, which was issued in 2007 and covers plans up to the year 2020, mentions targets for solar water heaters: a total heat collecting area of 150 million square metres to be installed by 2010 and 300 million square metres to be installed by 2020, replacing 30 million tons of coal equivalent (TCE) and 60 million TCE respectively. The 10th FYP for 2001–2005 set national targets for installing 64 million square meters of solar water heaters by 2005 (Annini *et al*. 2014). Interestingly, solar water heaters are mentioned less than solar PV or other renewables in more recent national policy documents. The 12th FYP, covering the period 2011–2015, does not seem to focus on solar water heaters. In terms of solar power, it lays out plans for solar power plants and PV, but less for solar water heaters. This might be due to the assumption Chinese solar water heaters are already at the cutting-edge of innovation and have widely been commercialised and deployed for two decades.

Another issue related to politics and the political economy are the career opportunities for provincial bureaucrats who contribute to building up a successful solar water heater industry at the provincial level. Local bureaucrats who manage to attract solar energy firms to their province and/or municipality and contribute to the success of the firms may be likely to have improved chances for promotion. This is because successful local firms can lead to local employment, tax revenues, economic growth and increased competitiveness for the province and/or municipality. These successes reflect back positively on the leading bureaucrat who may get an opportunity to be promoted into a more senior and more influential role in the future.

4.3. Solar water heaters: Practice

Interestingly, neither the solar water firms nor the industry as a whole enjoys fiscal or taxation incentives in China, yet solar hot water installation and sales have nevertheless increased rapidly in recent years, driven only by a large and rapidly expanding demand, particularly in the rural areas and in smaller towns. Hu *et al*. (2012) argue that solar water heaters meet the demand of millions of Chinese customers by offering good quality, high performance, but at a low cost. Li *et al*. (2011) add that solar water heaters are also based on China's natural endowments for solar energy. It reduces pressure during peak load and thereby contributes to energy security and opportunities for economic growth at the local and provincial level. At the grassroots level it is also suggested that end-users in China have in general a very positive attitude and there are high levels of public acceptance towards low carbon energy due to the general awareness of China's resource scarcity and the fact that solar energy provides employment in many regions in China (Li *et al*. 2011). Another reason that is mentioned for China's rapid rise in solar water heaters is its relaxed building codes that enable setting up solar water heaters on roofs, without planning permission or other bureaucratic rules. However experts suggest that the most important argument for solar water heaters is their low cost. As socio-technical preferences have changed in the last decade with regards to hot water provision, an observed change from the conventional high carbon pathway to the alternative low carbon pathway seems possible.

Han *et al*. (2010), however, argue that further incentives need to be introduced by the Chinese Government to reduce costs of solar water heaters to enable poorer families to purchase them. They also argue that the energy efficiency of the evacuated tube design is rather low and therefore suggest China should introduce a higher share of flat plate solar water heaters (Han *et al*. 2010). These are however more costly and would depend on technology transfer and the acquisition of foreign licences rather than being based on Chinese indigenous innovation and Chinese patents. It seems that in practice, the evacuated tube solar water heater is a dominant Chinese innovation that has already changed socio-technical preferences for millions of Chinese households. What we mean by this is that it is technology that is low cost, abundantly available everywhere in China and it has become the 'standard' way of heating water in rural areas in China, although far less common in urban areas. Social practices in China, at least in the rural areas, have adopted solar water heaters as a mainstream way of heating water.

At the same time, there may be disadvantages to solar water heaters, such as the limited volume of hot water that solar heaters can produce at any one time, and the time it takes to heat up new water once the first volume of hot water has been used. Other disadvantages may be that, as solar radiation varies, the time for heating up water can take longer on cloudy days than on sunny days. As solar hot water heaters are very popular across China, particularly rural areas, the fieldwork to be conducted as part of the research that this working paper feeds into has to establish if and how much this is a problem for users of solar hot water heaters.

For monetary savings from solar hot water heaters there might be negative implications through the rebound effect. The rebound effect is a phenomenon where people are saving money by saving energy or using cheaper energy technology and are then spending the money on other energy-consuming activities. The energy that has been saved by the first energy-consuming activity may be spent again by another energy-consuming activity (such as holidaying or buying new electrical appliances). However, the rebound effect is estimated at around eight to ten per cent of gross domestic product (GDP) which some consider relatively low (Diesendorf 2014), although some might find these figures high. At the same time, economy-wide impacts are unlikely. However the rebound effect needs to be considered when estimating overall energy efficiency savings (Chitnis *et al*. 2014; Sorrell *et al*. 2012;

Druckman *et al.* 2011). In addition, not everyone will spend the saved money on energy-consuming activities. The rebound effect can lead to direct money savings. Energy efficiency technology and energy conservation enables people, households and firms to make real money savings, which is particularly important for people and households that have low incomes or for those who are struggling to pay their bills.

5. Programme of work

The final section of this paper outlines our intended approach to the research questions and areas previously outlined, through 'Low Carbon Innovation in China: Prospects, Politics and Practice', an international collaboration between researchers in the UK and at leading institutions in China, that aims to facilitate low-carbon transition on a global scale. This work will explore the prospects, politics and practice of two pathways, for solar PV and solar water heaters in China. While China is the world leader in both solar water heaters and solar PV, measured as the quantities of energy technology sold and the investments in these industries, this paper found that these two cases are in stark contrast to each other. Solar water heaters are an indigenous innovation that has been developed, commercialised and deployed on a large scale for the last two decades within China. Solar PV, on the other hand, depends partly on foreign innovation and is geared towards the export market rather than for the domestic market. Also, solar water heaters are mainly being used by households, often in rural areas, while solar PV are often used as utility-scale developments in China. Applying these questions to both of the two cases described above, we will ask:

1. Are transitions towards lower carbon energy emerging and why? How are they associated with solar PV and solar hot water pathways?
2. How do these potential transitions in energy relate to broader processes of decarbonisation, such as in agri-food systems and electric mobility?
3. What socio-political changes are emerging in China with implications for changes in the energy system, including the social practices around production and consumption of energy (especially solar energy)? What are these implications?
4. What lessons does China's approach to innovation for low-carbon energy provide for other countries' industrial policies for, (a) low-carbon/solar transitions, and (b) globally competitive, low-carbon industries?

Both case studies will be examined using methods that aim both to appreciate and to engage with the politics of the potential transitions in question, drawing on an approach discussed in more detail in the overarching working paper for this project (Tyfield *et al*. 2014). We hope, not only to record and report on different framings, but also to cultivate a reflective understanding amongst the participants themselves regarding visions, framings and transition pathways, as well as to contribute to debates and policy processes that result in more environmentally sustainable and socially just outcomes (Leach *et al*. 2010). This impact focus will be enhanced by strategic discussions early in the project cycle to explore and map potential impact pathways, an exercise that has in addition proved useful to the research process in other STEPS Centre projects (Ely and Oxley 2014).

The fieldwork will focus on two main groups, one group tentatively called the manufacturers and the other group called the 'users' of solar energy. With regard to the manufacturing of solar PV, we will conduct fieldwork mainly in Jiangsu Province and in Hebei Province, where the largest PV manufacturers Suntech (Wuxi) and Yingli Solar (Baoding) are based. For solar water heaters, most of the top ten firms are located in Shandong Province (e.g. Shandong Long Guang Tian Xu Solar Energy, Shandong Linuo New Material, Himin Solar Energy Group), Jiangsu Province (Jiangsu Sunrain New Energy Group, Jiangsu Huayang Solar Energy) and in Beijing (Beijing Tianpu Solar Energy Industry, Beijing Huaye Solar New Energy, Beijing Solar Energy Research Institute at Tsinghua University). We will also conduct fieldwork at Dezhou in Shandong Province, where our partner Dr Wang Yu is working on a project on solar PV, solar water heaters and the CDM.

The users of solar energy can be found all over China. Shandong Province has the highest penetration rate of solar water heaters amongst households. We will be conducting interviews in the other mentioned provinces (Jiangsu, Hebei and Beijing) with users of solar water heaters too as well as in

Yunnan which also has a very high number of users of solar water heaters. The provinces that have the most users of solar PV are again Hebei and Jiangsu as well as Xinjiang, Inner Mongolia, Gansu and Qinghai.

As the provinces Beijing, Hebei, Jiangsu and Shandong are relatively close together in comparison to China's overall dimensions, we will start our first interviews there, with the leading manufacturers of solar PV and solar water heaters and with users of these technologies. For a second fieldwork trip we aim to look at some of the provinces that are located further to the West, particularly Yunnan.

Fieldwork will be conducted in late 2014/early 2015, based on staff availability.

Ultimately, this research should provide insights for studies on innovation and energy systems, political science, practice theory and China studies, all literatures to which we hope to contribute over the coming years. In addition, taking China as an example, it will document and offer lessons around energy and environmental policy that both meets the political aims of developing a solar industry whilst at the same time contributing to the decarbonisation of the energy system at the national and international level. We hope that this analysis will not only prove relevant to the globally important challenge of low-carbon transitions in China, but also offer insights that can contribute to improved policy processes and decision-making in the UK and other countries.

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