

China's Low Carbon Technology Ambitions: The relationship between indigenous innovation and technological transfer

Paper for Research Network "Governance in China" and Association for Social Science Research on China (ASC) Joint International Conference

University of Hamburg, Germany, 9-11 December 2011

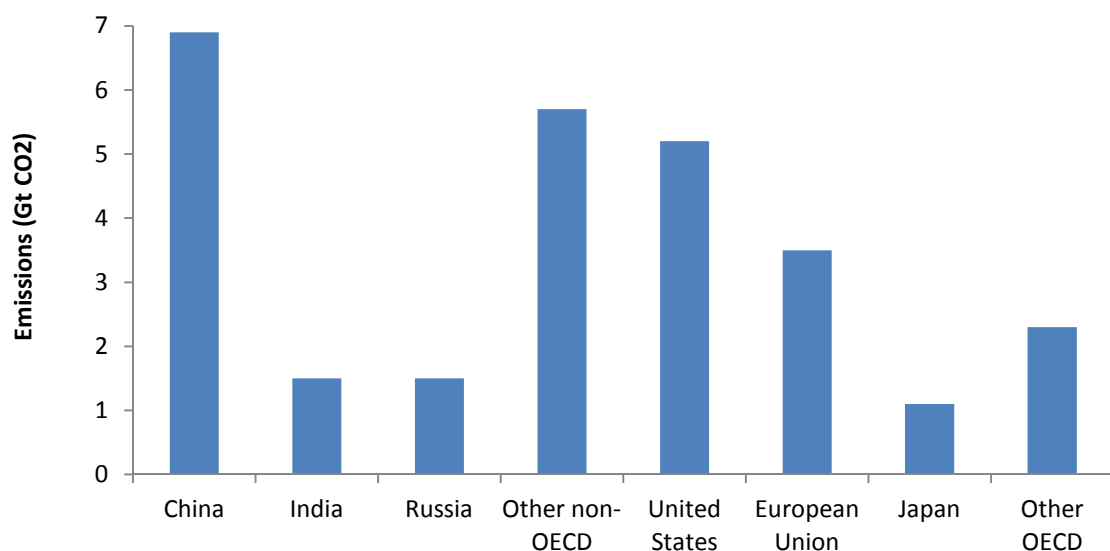
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November 2011

1. Introduction

During the past two decades, China's economy has continued to grow rapidly, at an average rate of around 10% per year (Wang and Watson 2009). At the same time, this economic expansion has led to large increases in energy demand and carbon emissions. These increases have continued through the recent financial crisis which has led to falling emissions in many of the Organization for Economic Cooperation and Development (OECD) countries. As Figure 1 shows, China is now the world's largest emitter of carbon dioxide (CO₂). However, on a per capita basis, China's CO₂ emissions are lower than those of most industrialised countries. Per capita emissions reached the global average level of about 4.5 tonnes in 2006 (UNDP China 2010:29). China is particularly vulnerable to the expected impacts of climate change. Some of these impacts are already being observed, and they are projected to increase in future (NDRC 2007). They include shrinking glaciers in mountain regions (with impacts on water availability), changes in rainfall patterns which have already caused droughts in the North, and sea level rise which could have serious impacts on coastal areas.

Figure 1: Global Energy-related Carbon Dioxide Emissions (2009)



Source: International Energy Agency (IEA, 2011).

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Coal continues to dominate China's energy system, accounting for two thirds of primary energy. According to recent official statistics, total energy consumption rose to 3250 million tonnes of coal equivalent in 2010. The official Chinese news agency stated that China's power generation capacity reached approximately 960 GW by the end of 2010 – an increase of 85GW over the figure a year earlier. Around three quarters of total capacity is coal-fired. This is the second largest generation capacity in the world, and is now close to that of the United States (1010GW)². Imported oil is also increasing sharply to over 50% of total oil consumption in 2009 – up from 29% in 2000 as domestic output has matured. Demand for natural gas keeps growing, but plays a small role in overall primary energy supply – it accounted for approximately 3.8% of primary energy consumption in 2008.

These trends lead to a number of pressing economic and environmental challenges. In its report to the 2011 National People's Congress, the National Development and Reform Commission (NDRC) stated that 'total energy and resource consumption is too large and is growing too quickly, and emissions of major pollutants are high ... energy-intensive and highly polluting industries are still growing too fast. Consequently, we face mounting pressure to save energy, reduce emissions, and respond to climate change' (NDRC 2011: 18).

A new target for carbon intensity reduction was announced in the run up to the Copenhagen Conference of the Parties to the UN Framework Convention on Climate Change (UNFCCC) in 2009. This requires that carbon intensity should fall by 40-45% by 2020 from 2005 levels. Related to this, the State Council ratified a target that 15% of China's overall energy supply should come from non-fossil sources by 2020. Implementation is already underway within the context of successive Five Year Plans. The 11th Five Year Plan from 2005 to 2010 included a 20% energy intensity reduction goal. The NDRC claims that a 19% reduction was achieved during this period, despite an increase in energy intensity in early 2010 which made the target more difficult to achieve (NDRC, 2011). Controversy has surrounded some of the methods used by Provincial governments, such as power rationing, to meet their share of this target (Watts 2010). Significant attention is now being paid to the implementation of the 12th Five Year Plan which runs from 2011 to 2015. It includes targets for a 16% reduction in energy intensity and a 17% reduction in carbon emissions intensity (Wen Jiabao 2011). It also states that non fossil sources should account for 11.4% of primary energy by 2015, up from 9% in 2008 (Zhang 2010).

To achieve these goals, there will be a central role for the development and deployment of low carbon technologies in China, including technologies and measures to improve energy efficiency and low carbon energy supply. This process is already underway, supported by China's own domestic policies (e.g. Chatham House, Chinese Academy of Social Sciences et al. 2010; Lewis 2007; Tan, Seligsohn et al. 2010). Recent examples include research and development (R&D) support, incentives for technology deployment (e.g. renewables) and demonstration trials (e.g. of electric vehicles). Significant Chinese government funding for these technologies was included within the 4 trillion Yuan (approximately £400bn) stimulus package implemented after the global financial crisis.

Of course, international policy frameworks also have a role to play in supporting such innovation processes. There is now some acknowledgement within China that international agreements on technology transfer need to take into account the concerns of leading international firms, including respect for intellectual property. This has led to a modified tone

² Data from the US Energy Information Administration: <http://www.eia.doe.gov>

in speeches by senior officials. Rather than simply calling for subsidised access to intellectual property, officials often couple this with a general emphasis on intellectual property protection. For example, Zeng Peiyan, an influential former Vice Premier of China, stated in May 2010 that: ‘regrettably, we haven’t seen substantive progress in the sharing of these [low carbon] technologies. ... There is a need to develop institutions and finance ... to transfer technologies on concessional terms whilst safeguarding intellectual property rights’³

Our study approach

This paper summarises the results of a collaborative research project by the Sussex Energy Group (University of Sussex, UK) and the Laboratory of Low Carbon Energy (Tsinghua University, China) on low carbon technology transfer to China (Watson et al, 2011). The project was carried out between February 2010 and April 2011, and was funded by the UK government’s Department of Energy and Climate Change. The project was funded to analyse low carbon innovation in China, and the particular role of technology transfer within this.

Much of the research was focused on four empirical case studies: energy efficiency in the cement industry, electric vehicles, offshore wind power, and efficient coal fired power generation. The case studies were chosen in consultation with policy makers in the UK and through a stakeholder workshop in China. The choice was designed to capture the diversity of low carbon innovation in China. They encompass different stages of technological development, different markets (capital and consumer goods) and different parts of the energy system (electricity generation, industry and transport). The case studies include near market technologies (improvements in efficiency in the cement industry and more efficient technologies for coal-fired power) but also focus on future technologies that are still in the process of being commercialised in China (electric vehicles and offshore wind). Some of these cases (e.g. offshore wind) have not been examined in depth within previous studies of low carbon innovation. The research on each case examined the full range of factors that influence innovation and technology transfer including technological capacity, access to intellectual property rights (IPRs) and the role of national and international policy frameworks. The research team were also asked to suggest policy implications, particularly for the international UNFCCC negotiations.

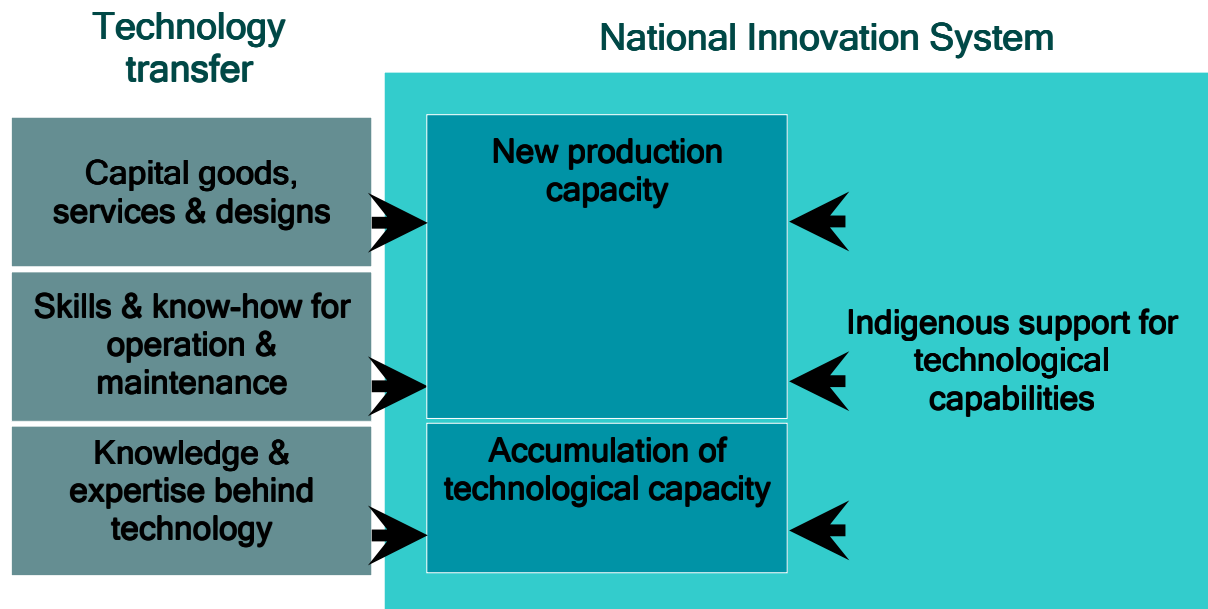
Whilst low carbon technology transfer provided a useful entry point for the research, the study analysed such transfer within the context of broader processes of low carbon innovation in China. Technology transfer from international firms and other organisations is only one source of such innovation. This cannot be analysed in isolation from other, indigenous sources of innovation – or from the wider national and international policy contexts that will affect rates of low carbon technology development and deployment. In addition to this, the research drew on theories of innovation that do not only emphasise the development of new technological hardware. They also place particular importance on the knowledge and skills required to establish production capacity in developing countries, and the technological capacity required to further develop these hardware technologies (e.g. Bell, 1990; Ockwell, Ely et al. 2009). In doing so, the research added to an understanding of how technological capacity is developed in China.

Figure 2 illustrates these two important points: First, the relationship between international technology transfer and indigenous sources of innovation within a developing country’s

³ Speech to International Cooperative Conference on Green Economy and Climate Change, Beijing, China, 9th May 2010.

‘National Innovation System’. Second, the distinction between hardware transfer and the transfer of associated knowledge and skills required to establish new production capacity and technological capacity. The National Innovation system is defined by Freeman as ‘the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies’ (Freeman 1987).

Figure 2: Technology transfer and indigenous innovation



Source: The authors, based on Bell (1990)

The remainder of this paper comprises three further sections. The next section discusses the evidence from four project case study technologies and focuses on a number of key issues including the development of technological capabilities and the role of national (Chinese) policies. This is followed by a discussion of the role of international policy frameworks with a particular emphasis on the Clean Development Mechanism (CDM). The final section summarises the main conclusions and suggests some implications for policy.

2. Cases of low carbon innovation in China

This section sets out our findings with respect to four case study technologies. For each case, the analysis focuses on two main aspects: the current status of technological capabilities within China; and the role of national policy frameworks in fostering innovation and deployment.

Energy efficiency in the cement industry

Globally, the production of cement contributed around 8% of anthropogenic CO₂ emissions in 2006 (Müller and Harnisch 2008). China has been the world leader in cement production for many years, reaching 1.65 billion tonnes in 2009 or more than 50% of world production (CCA 2010). The process of cement production generates CO₂ emissions in two important ways. Currently, the conversion of limestone into lime accounts for about 55% of these emissions, and the combustion of energy carriers needed to drive this conversion process accounts for another 40% (Müller and Harnisch 2008:2). There are many measures that can

reduce primary energy consumption in the production of cement and so could be characterised as energy efficiency improvements. These range from behavioural changes amongst staff to using the most efficient technological hardware and optimised processes (Worrell and Galitsky 2008). In addition, the use of fossil energy carriers as the source of heat can be substituted with waste material or biomass, and waste heat itself can be recycled and/or recovered for power generation (Müller and Harnisch 2008). All of these approaches have been implemented in China to some extent.

China's capabilities in cement production

The energy efficiency of cement production has steadily improved in China, although there remains a significant gap between international and Chinese average efficiencies. The rapid adoption of advanced New Suspension Pre-Heater kiln (NSP) technology has been an important driver of improvements, with well over 1000 units now in operation in China. Some of the 'efficiency gap' can be explained by significant numbers of small and inefficient kilns that remain in operation (Müller and Harnisch 2008). By 2007, the energy-intensity of cement production in China had fallen to 158 kgce/t (kilograms coal equivalent per tonne) but was significantly higher than the international advanced level of 127 kgce/t (Ohshita and Price 2011:53). More recently, it was announced that the energy intensity of cement production fell 16% during the 11th five year plan period (2005 to 2010), suggesting that this gap has been closed further since 2007⁴.

In terms of manufacturing production equipment, we found that Chinese firms are able to make most of the equipment locally. Some have built cement production facilities abroad, beginning as early as 1992. The first plant exported was rated at 700 tpd but this had risen to 10,000 tpd plants by 2005. Moreover, there are now five firms able to construct 10,000 tpd production lines and more than 300 with the capability to construct 5000 tpd facilities. Having said this some technologies and equipment are still imported including vertical mills, grate coolers, precision weighing machines and x-ray diffraction instruments. In addition, some of our interviewees identified difficulties training staff in new and advanced energy efficiency technologies, in integrating these technologies into production systems, and barriers to accessing Intellectual Property Rights (IPRs).

In what is a familiar pattern across our case studies, Chinese firms have developed their technological capabilities through a sequence of increasingly sophisticated and larger-scale activities. With respect to NSP technology, this process started in the late 1970s with the installation of a 700 tpd line supplied by a Japanese firm. Later, a local firm was licensed to supply Japanese separator technology. By 1984, some Chinese firms were able to design and develop a 2000 tpd NSP kiln and source most of the equipment locally. In the early 1990s, the first joint ventures were established, beginning with a 4000 tpd NSP line in 1992 under Dalian Huaneng-Onoda Cement Company. Others followed, including Yantai Mitsubishi, Daewoo Sishui and Qinhuangdao Asano. However, the widespread diffusion of NSP cement kilns did not take place until the mid-2000s.

Through these activities, the Chinese innovation system for cement technologies has developed. A number of Chinese firms say they undertake joint R&D with local research institutes and universities. Such local collaboration is favoured because the technologies are cheaper than foreign-made equipment, it is faster and more convenient to get after-sales

⁴ Xie Zhenhua, Speech to 2011 International Conference on Low Carbon Energy and Climate Change, Tsinghua University, 24th March 2011.

service, easier to pursue continuous improvement strategies, and there is a wish to support the development of the local industrial system. One interviewee summed up this preference by stating that ‘domestic techniques fit the Chinese cement development better’. In addition to this, there are organisations such as the China Cement Association that help to disseminate information and to represent the industry at national level.

Policy frameworks for efficient cement production

The energy intensity target within the 11th Five Year Plan has been one of the most important policy drivers of energy efficiency in recent years. According to Vice Minister of the NDRC Xie Zhenhua, the Plan has led to a reduction in energy intensity by 16% between 2005 and 2010⁵. The target was accompanied by the ‘Top 1000 Energy Consuming Enterprises Programme’ which was launched by the NDRC in 2006 (Wang and Watson 2009). Its aim was to reduce energy intensity within firms accounting for 33% of China’s final energy consumption. Projected savings at the inception of the Programme were 100 million tonnes of coal equivalent by 2010 (equivalent to 260 million tonnes of CO₂ compared to ‘business as usual’). Cement is included within one of nine industrial sectors covered by the Programme.

The Programme included a number of elements (Price, Wang et al. 2008). Targets were agreed with individual provinces, which were then translated into agreements with individual firms. Performance evaluations of provincial officials were adjusted to take account of their relative success in meeting targets. Firms were required to develop goals and plans, and funding was made available for energy efficiency projects specified in these plans. Funding from the Chinese central government for energy efficiency and pollution abatement was 23.5bn Yuan (over £2bn) in 2007 and 27bn Yuan (£2.5bn) in 2008 (Ohshita and Price 2011). The 2008 figure included 4bn Yuan (£400m) for phasing out small inefficient plants – a policy that was backed up by surcharges on their electricity tariffs. Further financial incentives took the form of a reduction in export tax rebates for energy intensive products. Our interviewees within the Chinese cement industry confirmed that incentives for cement plants to implement more efficient technologies and processes have been seen as significant. They had accessed grants from energy saving project funds, subsidised loans and taken advantage of tax breaks. However, they also stated that more could be done – for example to accelerate the uptake of more efficient technologies.

The evaluation of the Programme has been difficult at times due to a lack of data (Price, Wang et al. 2008). With respect to cement, a team at the Lawrence Berkeley National Laboratory found it was not possible to validate stated energy efficiency savings because of the variety of cement technologies in use. With respect to the efforts to close smaller, less efficient plants producing steel, electricity, cement and other products, some progress has been made. Recent figures show that of the 250 million tonnes of cement capacity earmarked for closure within the 11th Five Year Plan, 140 million tonnes had been closed between 2006 and 2008 (Ohshita and Price 2011). It is not clear whether further progress has been made since then – but one of our interviewees pointed out that national closure programmes are often only partially successful. Plants are sometimes kept in operation by local officials, despite being officially declared closed, for economic and employment reasons.

Electric vehicles

China was the third largest automobile producer and the second largest consumer in the world in 2008 (NBS 2009). It became number one on both counts for the first time recently because

⁵ Xie Zhenhua, op. cit..

of domestic subsidies for buyers and shrinking markets in Japan and the USA because of the financial crisis (Xinhuanet 2010). Vehicle sales rose to a record of 9.35 million in 2008 and motorcycle sales reached 25.5 million in 2007 (CATARC 2008). However, vehicle ownership is still much lower than the world average. In 1990, road vehicles accounted for 54% of transport energy demand in China, and grew to 65% in 2005 (IEA 2008). Under a business as usual scenario, this share is projected to become 77% by 2030. Consequently, the Chinese government is keen to reduce transport oil demand through the promotion of ‘new-energy’ vehicles, including hybrid and electric vehicles (HEVs) (Ouyang 2006; Wan 2008). In principle, HEVs can have lower carbon emissions than internal combustion engine (ICE) vehicles, and could be three times more fuel efficient (Zhang, Shen et al. 2008). Clearly this depends on the fuel used to generate electricity – a problematic issue for China where 75% of electricity comes from coal.

China’s capabilities in electric vehicles

Chinese firms have developed large-scale production capacity and significant technological capabilities in ICE vehicles. However, they are not yet able to serve the high-end market which is still dominated by foreign firms. Reasons for this include inconsistent quality of production and risk-aversion (UKTI and SMMT, 2010). It appears that the emphasis is on a cost-conscious mass market where quality matters less. This acts as an important constraint on their ability to adapt their capabilities to develop and commercialise advanced technologies such as HEVs. The design and manufacturing demands of HEVs appear to be much more complex – and costly – than those of traditional ICE vehicles.

Nevertheless, some Chinese firms have established capabilities in HEVs. In electric motors, large investments have been made to increase production capacity. Capacity in 2010 was estimated to be 272,000 electric motor sets - up from 73,000 a year earlier (Ouyang 2010). With respect to batteries, most attention is focused on Lithium-ion (Li-ion) technologies. One battery firm in Shenzhen, Build Your Own Dreams (BYD), became internationally famous by entering the automotive industry with plans for HEV models on an accelerated timescale – though these plans have not yet been fully realised. At present, while Chinese firms can manufacture batteries, there are parts of the process that they have not mastered. For example, there is still need to import a critical membrane that is needed to prevent overheating.

Capabilities are also weak in battery management systems, an area in which Chinese firms are still dependent on foreign suppliers. Similarly, some key components for electronic control systems for HEVs have to be imported into China. Finally, charging infrastructure is also important so that vehicles can be charged conveniently. The development of this infrastructure in China is at an early stage in some cities (UKTI and SMMT 2010), though there are plans to increase coverage.

There is a significant amount of research and development (R&D) being carried out by Chinese firms to build their capabilities in HEVs, but this has not yet had commercial impacts. This includes some joint R&D with foreign firms. Those firms have been attracted by the prospect of access to China’s rapidly growing market for private vehicles. For example, the Shanghai Automotive Industries Corporation (SAIC) have now bought UK capabilities⁶ and so have an R&D base in the UK. They have been using this over the past

⁶ For example, Shanghai Automotive Industries Corporation, who had worked with Ricardo in the past, now own MG Motor in the UK: <http://www.insideline.com/saic/mg-motor-opens-uk-design-studio.html>

two years to help train Chinese engineers. Chang'An Automobile Company has also invested in an R&D base in the UK, recently entering into work with the University of Nottingham. Of course, the acquisition of firms and partnerships between firms / organizations in OECD and developing countries is not unique to China. Previous research done by the Sussex Energy Group and The Energy and Resources Institute (TERI) on India also shows a similar trend in wind and solar power, as well as hybrid vehicles in India (Mallett et al. 2009).

The limited impacts of R&D to date are present across a range of important technologies for the commercialisation of HEVs: in many aspects of batteries, advanced transmission, the integration and management of vehicle systems, and meeting the various regulations necessary for exporting to European and US markets in particular. Where Chinese firms are enjoying more success in developing innovative capabilities appears to be in the domestic electric bicycle market. This may act as a platform from which they can build more complex capabilities over time that could see currently unexpected evolutions of HEVs.

Policy frameworks for electric vehicles

There are two specific ways in which public policy is providing incentives for innovation in electric vehicles in China. The first is in support for some of the R&D activities that have already been mentioned. There has been substantial Chinese government funding for R&D since at least 2002. Under the 863 programme, 860 million Yuan (£80m) was spent between 2002 and 2006 on electric, hybrid and fuel cell vehicles. A follow-on programme which ran from 2006 has spent a further 1.1 billion Yuan (£105m) on these technologies.

One of the significant results of this State-sponsored R&D drive has been China becoming the second most successful country for HEV patents. In such an R&D intensive industry, IPRs can be seen as particularly important. Chinese firms have been successful in creating their own patents. But, according to one analysis, this patent success may have become a source of paralysis in the local market (UKTI and SMMT, 2010). This argues that Chinese firms are reluctant to release their HEVs into the local market because they are fearful that their competitors will imitate them – the converse of the more common concern expressed by some international firms that Chinese firms might engage in reverse engineering.

The second area of support is through demonstration and deployment support programmes. There is a programme to deploy 60,000 'new energy vehicles' in 13 cities, and a plan that these vehicles should account for 5% of total car sales in 2011. This would amount to more than 600,000 vehicles (total sales in China in 2010 were 13 million). Looking slightly further ahead, it is hoped that 0.5-1 million new energy vehicles will have been sold by 2015 (Levi, Economy et al. 2010).

Within this, the Chinese government intends to spend 20 billion Yuan (£1.9bn) on the promotion, manufacture and sale of electric vehicles. This will underpin a new 'Ten Cities, One Thousand Vehicles' plan which plans to demonstrate 1,000 new EVs each year. A recent Accenture report quoted a higher figure for government support for EVs of 115 billion Yuan (£10.9bn) between 2011 and 2020 (Accenture 2011). This includes funding for R&D, commercialisation, component manufacture and electricity infrastructure. The report notes that consumers could receive a subsidy of 50,000 Yuan (£4,700) to purchase plug-in hybrid EVs, and slightly more for a pure EV. It also highlights electricity charging infrastructure as a potential bottleneck, stating that as recently as 2009, 'there were only a handful of public charging stations located in a few cities, such as Shenzhen' (Accenture 2011: 61).

Offshore wind power

Wind power is an important part of China's energy strategy as it looks to reduce the reliance on fossil fuels. It already has a highly active onshore wind industry that has grown from almost nothing at the end of the 1990s to become the largest in the world (Lewis 2007; Levi, Economy et al. 2010). By the end of 2010, installed capacity had reached 42GW⁷. As a result of this explosive growth, the Chinese government raised its 2020 target for installed capacity from 30 GW to 100 GW⁸. It is now looking to exploit its offshore wind potential. However, unlike the onshore wind industry when China entered, the global offshore wind industry is still in its early stages.

Offshore wind presents a particularly difficult challenge. First, the turbines need to be designed specifically for the harsh marine environment. Second, there is a need to build in redundant systems in order to minimise the number of times a turbine needs to be accessed, and to avoid losing a turbine's output for the sake of a simple spare part. One of our interviewees described it as finding constant trade-offs between structural strength, flexibility, sophistication and cost. The blades will typically endure 20 to 50 times the duty cycle of an aircraft wing, while being longer and heavier, but at 5% of the cost.

Chinese capabilities in offshore wind

China has become a world leader in production capacity for onshore wind power. With its long coastline, there is obvious potential to move offshore. There are specific challenges associated with this in China. It experiences frequent typhoons and the environment in areas where wind turbines are cited is harsher than in Europe, particularly in the silt base of the intertidal zone. The first offshore wind farm in China became operational in 2010. A young Chinese firm, Sinovel, won the contract for the project. It designed the 3 MW turbines in collaboration with Wintec (an Austrian firm), and manufactured them in China.

By the end of 2009, there were about 80 wind turbine manufacturers in China, although only 30 of these had actually sold turbines⁹. The top three manufacturers have a combined production capacity of about 8 GW/year, supplying to a domestic market of 13.8 GW/year. For offshore wind, the government introduced an access standard, which means that only those manufacturers that can produce turbines of 2.5 MW or greater will be eligible for selection for offshore wind projects. This has spurred the larger firms such as Sinovel to develop prototype machines to meet this criterion.

The firm Goldwind (55% State-owned) serves as an exemplar of the catching up strategies in the Chinese wind power industry. Established in 1998, it grew to become one of the world's top five wind turbine manufacturers in 2009 (GWEC 2010:10). It started by purchasing a license to manufacture 600 kW turbines from a second-tier German manufacturer, Jacobs, and subsequently bought licenses for other turbines, increasing in size each time (Lewis 2007). By 2009, Goldwind was able to manufacture turbines of 2.5 MW with an annual production of 2.2 GW. Similarly, Sinovel began by licensing to manufacture turbines, purchasing from the Austrian firm Windtec. In time, Chinese firms such as these have sent their employees overseas to learn from experienced firms or to study, and they have entered

⁷ 'China has world's most installed wind-power capacity' Xinhua News Agency, 13th Jan 2011; http://www.china.org.cn/business/2011-01/13/content_21733120.htm

⁸ Speech by Zhang Guobao, chair of the National Energy Administration to the International Cooperative Conference on Green Economy and Climate Change, Beijing, China, 9th May 2010.

⁹ Levi, Economy et al. (2010:88, endnote 144) report the presence of about 100 turbine manufacturers and that the Chinese government intends to set guidelines for the industry that will see only 'twenty to thirty survivors'.

into joint ventures with foreign firms. Sinovel, for instance, worked with Windtec to design the 3 MW turbines for the Shanghai offshore project, and Mingyang and Aerodyn of Germany co-designed the Super Compact Drive 3 MW turbine. More recently, Chinese firms have acquired foreign capabilities by buying foreign firms. For instance, Goldwind bought Vensys in Germany in order to strengthen its R&D capabilities.

In general, however, while the production capacity for wind turbines is high in China, there are problems in certain aspects. The manufacture of blades, gearboxes, converters and spindle bearings are not yet fully indigenised. Discussions with interviewees indicate that poor capabilities for materials processing seems to be the problem rather than design skills, and there are certainly firms manufacturing these components. With respect to offshore wind, some Chinese representatives of industry and government are cautious about Chinese capabilities – and stress that power companies have little knowledge so far, and that it will take time for the technology to mature (Prideaux and Qi 2010).

Policy frameworks for offshore wind

The Chinese government's policies and incentives for wind power have been well documented (e.g. Lewis 2007; Barton 2007; Levi, Economy et al. 2010). Legislation such as the 2005 Renewable Energy Law and incentives such as concessions and mandates have led to rapid deployment during the past five years. Targets for onshore wind power have been revised upwards as rapid growth has unfolded.

Despite this progress, there have been misgivings about the Chinese policy approach. For example, there have been criticisms that incentives aimed at encouraging wind power have focused on the construction of capacity rather than maximising output at the best wind sites. There has also been an ongoing problem of connection to the electricity grid. Around a third of wind farms have not been able to generate and sell their electricity due to bottlenecks in electricity transmission capacity. Recent reforms have sought to tackle this issue, with a greater emphasis on enforcing priority access for wind plants.

With respect to offshore wind, developments are relatively recent. The potential resource has been estimated by a number of official assessments. The Chinese Meteorological Association estimates this to be 750GW in water depths of less than 20m. However, some other assessments have provided lower estimates – and have led some officials to urge caution with respect to offshore wind (Prideaux and Qi 2010). An initial 100MW demonstration plant was constructed by Sinovel for the World Expo in Shanghai in 2010. Coastal provinces are now required to develop plans for offshore wind, and specific targets have been agreed in some cases. The current 'wind base' programme includes a target of 7GW of offshore wind capacity off the coast of Jiangsu Province by 2020.

To support a first tranche of offshore wind capacity, a concession process was launched in 2010 to build 1GW of capacity in Jiangsu Province. Under this concession policy – which is well established for onshore wind - local grid operators are required to sign a long term power purchase agreement with winning bidders. With respect to onshore wind, these agreements typically last for 25 years, with the price paid being fixed for the first 10 years. At present, the rules for offshore wind stipulate that projects should be developed by Chinese firms or by international joint ventures in which the Chinese partner has a controlling share.

As in the case of EVs, the Chinese wind turbine industry has benefited from the government's 863 R&D programme. Support has also been provided under the companion

973 programme which focuses on basic research. As Xiaomei Tan has explained, early efforts by the Chinese government to fund joint ventures between Chinese and international firms had limited success (Tan 2010). She argues that this led to direct funding of Chinese firms' R&D centres under the 863 and 973 programmes. For example Goldwind (one of the leading Chinese wind power firms) received grants under these programmes to scale up its wind turbines – and develop independent capabilities in turbines of up to 1.5MW. The firm also received further R&D support and tax concessions from the government of the Xinjiang Autonomous Region. Goldwind is now one of ten firms that have been officially accredited by the Chinese government to build offshore wind projects.

Improved efficiency in coal-fired power generation

China derives about 80% of its power from coal. The rapid expansion of coal-fired power in the last decade has been a significant factor in China's increasing carbon emissions. Despite the implementation of policies designed to increase the contribution of non-fossil energy in China, coal's role is likely to remain significant for the next few decades. The average efficiency of China's coal-fired power generation stock has been improving over the past two decades, from 28.8% in 1990 to 35.6% in 2008 (IEEPS 2009). One driver for this has been a shift towards more efficient coal-fired power station technologies. As in many other countries, attention has mainly focused on supercritical technology, with some activity to invest in Integrated Gasification Combined Cycle (IGCC) technologies.

Chinese capabilities in more efficient coal-fired power

The interest from China in gaining supercritical (SC) and ultra-supercritical (USC) coal-fired power plants is long-standing and the desire to localise the technology was designated a Key National Programme in the 1990s (Tan 2010). As of 2008, there were 93 SC and USC units in operation, and by 2009 there were more than 100 USC units on order from Chinese power companies. In 2010, it was expected that SC and USC power plants would account for over 40% of new thermal units in China (Chen and Xu 2010).

As a result, there are Chinese firms that can now build SC and USC plants. However, there is still a significant gap in their capabilities compared to the international advanced level. For example, manufacturing companies such as Shanghai, Harbin and Dongfang have not mastered the core design software. The normal practice is for these manufacturers to collaborate with regional design institutions within China on power plant designs. However, they often need to collaborate with leading foreign companies such as Siemens, Hitachi and Alstom when they design new plants. There are also difficulties in manufacturing the high temperature components locally. The special steel materials all need to be imported.

With respect to IGCC technology, the capabilities picture is different. Chinese firms have a long history in coal gasification, through its application for chemicals and fertiliser production rather than for power generation. Since the 1990s, there has been a strategy of acquiring licenses from leading international firms such as Shell (Watson, Oldham et al. 1998). Chinese gasification technology has now developed to the stage where it has been specified for an IGCC plant in the United States. The Thermal Power Research Institute in Xian has developed a design which is being used in China's first full scale IGCC plant (Greengen). This plant eventually plans to fit carbon capture and storage. The gasification technology for the Greengen plant has been specified for the planned Good Spring IGCC in the United States.

The gasifier is, however, only one component of an IGCC plant. Another critical technology is the advanced industrial gas turbine which burns the syngas produced by the gasifier. With respect to this component of IGCC plants, Chinese capabilities are considerably weaker. There are only a handful of leading suppliers of advanced industrial gas turbines world-wide – with GE, Siemens and Mitsubishi as market leaders. Chinese turbine companies have formed collaborations with these suppliers, but there is a long way to go before the Chinese partners have independent capabilities (Liu, Ni et al. 2008). The terms of these collaborations mean that cutting edge technologies and knowledge embodied in high tech parts (such as the first stage turbine blades) are not shared. This controlled approach to knowledge sharing in return for market access has been standard practice among the leading international gas turbine manufacturers for many years (Watson 1997).

Policy frameworks for efficient coal-fired power

As noted above, policy incentives have aimed to improve the efficiency of coal-fired power generation for many years. The power sector was covered by the Top 1000 Energy Consuming Enterprises Programme under the 11th Five Year Plan. Wen Jiabao's recent report to the National People's Congress states that 72GW of small plant capacity had been closed by the end of the Five Year Plan period (Wen Jiabao 2011). The share of coal-fired power generation capacity with unit sizes of over 300MW rose from 47% in 2005 to 69% in 2010¹⁰.

In parallel with this closure programme, the Chinese government has also placed more emphasis on economic incentives for improved power plant efficiency. It reduced the prices paid to power plants with capacities of less than 50MW, and some plants of 100-200MW (Andrews-Speed 2009). New dispatching rules were trialled to reinforce the incentive for the most efficient plants to operate. However, the government has been slow to remove controls on final electricity prices until very recently (IEA 2006). Historically prices to end consumers have been kept artificially low, with consequent impacts on power company finances. According to China's National Energy Administration, 43% of China's coal-fired power plants operated at a loss in 2010¹¹.

It is clear that Chinese government policy has played a strategic role in directing acquisition, innovation and deployment of more efficient technologies. For supercritical technology, the acquisition process started with the operation of China's first supercritical units in 1992. These were sourced from leading international firms - ABB for boilers and General Electric for steam turbines (Tan 2010). The government managed and funded an iterative process of assessment, collaborative R&D and reverse engineering so that Chinese firms developed independent capabilities in this technology. The first Chinese manufactured 600MW supercritical unit entered service in Henan province in 2004 (Chen and Xu 2010).

The acquisition of more efficient USC technology followed in 2000 with the support of the 863 and 973 R&D programmes. It resulted in China's first ultra-supercritical unit at Yuhuan which entered service in 2007 and was part-funded by the Shanghai government (Tan 2010; Tan, Seligsohn et al. 2010). This plant, which entered service in 2006-07, included collaborations between Chinese and international firms for the main components. The boilers were co-supplied by Mitsubishi Heavy Industries and the Harbin Boiler Company, and the turbines were manufactured by Shanghai Electric and Siemens (to a Siemens design). This plant has since been followed by many more USC projects.

¹⁰ Xie Zhenhua, *op. cit.*

¹¹ Reported at <http://www.prlog.org/11349430-chinas-power-plants-operate-at-loss-cost-of-coal-and-energy-efficiency-blamed.html>

With respect to coal gasification – a key element of IGCC plants - the 863 programme played a particularly important role. It supported coal gasification research at the Thermal Power Research Institute (TPRI) in Xian (Osnos 2009). The Institute’s coal gasification technology is being used in the first full scale IGCC plant in China (GreenGen) which is currently under construction. Perhaps more remarkably, as noted earlier, it has also been licensed for use in the Good Spring IGCC plant being planned in the United States. According to some reports, this was chosen over competing technologies from Shell and GE due to its higher efficiency (Osnos 2009). However, it is important to note that other IGCC plant components (most importantly, the gas turbines) are not being sourced or licensed from China.

3. International Finance and Policy

International financial flows are clearly important for low carbon innovation in China and other developing countries. According to the International Energy Agency, \$36.5 trillion of finance will be needed globally between 2011 and 2035 to provide a reasonable chance of limiting average temperature increases to 2°C (IEA 2011). Whilst many analyses show that private sources will provide the majority of finance, public funding has a key role to play in leveraging private sector investment (DECC 2010). Furthermore, international policy frameworks to support low carbon technology transfer and deployment in developing countries will be an important complement to national policy frameworks within these countries.

The Cancun Agreements that were agreed at the UNFCCC’s 16th Conference of the Parties in December 2010 formalised financial commitments by industrialised countries to support mitigation and adaptation in developing countries. The text of the Agreements included a goal of ‘mobilising jointly USD 100 billion dollars a year by 2020 to address the needs of developing countries’ (UNFCCC 2010: 15). Whilst this level of funding would represent a large increase from current levels, it would also build on existing international initiatives that have already had an impact on low carbon innovation in China.

With respect to our case study technologies, bilateral and multilateral initiatives have already made some contributions to the innovation process. One example of this is the Global Environment Facility (GEF) which is the official financial mechanism of the UNFCCC. Since it was created in the early 1990s, the GEF has provided modest funding to projects in China – with a total value of less than \$500m¹². This includes the China energy efficient boiler project which arguably had some success in subsidising licenses to Chinese firms. It was a difficult project that suffered from delays, and only resulted in licences from ‘second tier’ international suppliers (Birner and Martinot 2005). These ‘second tier’ firms believed they would gain more from selling licenses than they would by operating directly in the Chinese market, whereas leading international boiler firms held the opposite view. This demonstrated how difficult it can be to offer licensing terms that are attractive to leading players.

Another example is the support for supercritical and IGCC technology in China by the Asian Development Bank (Watson, Oldham et al. 1998). The Bank financed an early supercritical plant in the late 1990s. It was also involved in funding feasibility studies for an IGCC plant in

¹² This figure includes on-going or completed projects documented on the GEF website, including those not directly connected to energy and/or mitigation activities, since 1994 up to June 2009.

Yantai during the same period. Plans for this plant suffered from repeated delays, and it has not been constructed. More recently, the ADB provided a loan of \$135m to the GreenGen IGCC plant¹³ which is under construction in Tianjin.

Bilateral agreements for wind power have also been important sources of finance and other assistance. Two examples illustrate this: the Danish-Chinese Wind Energy Development Programme¹⁴ (with Denmark as partner) and the China Wind Power Research and Training Project¹⁵ (with Germany as partner). Both agreements have led to the transfer of onshore wind technologies from firms in Europe (Vestas and RE-Power) to their counterparts in China. Similarly, a number of international collaborative activities are underway on electric vehicles (EVs) in China. One of the most prominent is a US-China co-operative programme that aims to develop standards, implement joint demonstration projects in a number of cities and a technology roadmap (White House 2009). To complement this, there are partnerships being built between Chinese and US firms (Levi, Economy et al. 2010). According to our interviews, some Chinese partners argue that the partnerships lack depth. At the same time, some international firms are wary about potential loss of their technological leadership as a result of such partnerships (Levi, Economy et al. 2010).

By far the most important international financial mechanism for the deployment of low carbon technologies in developing countries is the Clean Development Mechanism (CDM). Created as part of the Kyoto Protocol, the CDM aims to reduce carbon dioxide emissions and to contribute to economic growth and development within developing countries. The mechanism combines these objectives by allowing approved emissions reduction projects to generate Certified Emissions Reductions (CERs) for each tonne of greenhouse gas emissions they abate. In addition, CDM projects are also encouraged to contribute to sustainable development and to incorporate technology transfer. While the CDM started as a project-based system, it has become increasingly important amongst some beneficiaries in supporting specific national policies and programmes (Schroeder 2009).

As of November 2011, 3589 CDM projects had been approved by the official Executive Board, 1662 of which were in China¹⁶. Therefore, China has received more CDM project investment than any other developing country – with total investment of more than \$50bn¹⁷. The total emissions reductions attributed to China's projects amounted to 287 million tonnes of CO₂ equivalent per year. Approximately 200 projects in China claim that they include a direct form of technology transfer, which is usually in the form of hardware transfer.

The CDM has played a fundamental role in the development of at least two of our case study sectors: wind energy (Yang et al. 2010), and energy efficiency in large cement companies (Yan et al. 2009). Based on the available data (Stua 2011), we can see that other sectors and technologies within China have also benefited from the CDM. These include developments in hydroelectric power, coal methane recycling, the substitution of coal with natural gas in power plants, and energy efficiency projects in the iron and steel industries.

¹³ See <http://www.adb.org/Documents/News/PRCM/prcm201006.asp>

¹⁴ <http://www.dwed.org.cn/>

¹⁵ <http://www.cwpc.cn/cwpc/en/cwpp>

¹⁶ See 'CDM in numbers' at: <http://cdm.unfccc.int/Statistics/index.html>

¹⁷ Data obtained from project design documents for electricity production CDM projects: <http://cdm.unfccc.int/Projects/projsearch.html>

The CDM has had a particularly important impact on Chinese wind power development. It is clear that the Chinese government has made strategic use of the CDM to support the rapid expansion of wind power. More recently, China's first offshore wind farm in Shanghai has also been part-financed through the CDM.

A recent analysis by Joanna Lewis shows that a large number of Chinese wind power projects have been registered as CDM projects and have requested CERs (Lewis 2010). More than half of wind projects built in 2007 and more than a third of those developed in 2008 were registered. As Joanna Lewis notes, there are questions to be asked about the extent to which CDM financing was necessary to make many of these projects financially viable (i.e. whether they are leading to 'additional' emissions reductions). According to He and Morse (2010), apart from one exception, the baselines used to determine the additionality of wind projects in China for the CDM are not benchmarked against coal-fired plants – something they suggest is problematic in a country that is so coal-dependent for their electricity. Furthermore, they state that China's NDRC 'determines power tariffs in a proprietary, non-market-based manner – as is their right in making sovereign decisions about energy policy – [and so] there is no real way to know what is business as usual and what constitutes gaming of the CDM' (He and Morse 2010: 3).

With respect to the cement industry, the CDM has also been strategically important. Almost 50% of China's CDM projects that focus on energy efficiency (43 out of 88 projects) involve cement plants. Whilst many of these projects do not claim technology transfer – and deploy established Chinese technologies – a number of the Project Design Documents refers to the Japanese origin of the hardware employed. More efficient coal-fired generation (at utility power plant scale) has not been a focus for Chinese CDM projects. However, one project has recently been approved by the CDM Executive Board in December 2010. This is for an ultra supercritical coal-fired power plant at Waigaoqiao, with a capacity of 2000 MW.

A key question for this chapter is the extent to which CDM projects lead to technology transfer. A number of authors have found significant emphasis on technology transfer within CDM project documentation (e.g. Haites et al 2006). It is important to interpret such claims with care since it is not possible *ex ante* to know the extent to which particular projects will lead to technology transfer in practice – and hence the improvement of innovative capabilities in recipient firms. Furthermore, it is not always clear to what extent the meaning of technology transfer within CDM project documentation is purely focused on hardware transfer – or whether it also includes knowledge transfer.

4. Conclusions and implications

The analysis in this paper and the longer report upon which it is based (Watson et al, 2011) lead to six main conclusions.

First, the analysis of low carbon innovation in China reveals important differences between low carbon technologies. This confirms the findings from the previous UK-India studies that were led by our research group (e.g. Ockwell, Watson et al, 2008; Mallett, Ockwell et al. 2009). The extent to which Chinese firms are 'catching up' with the international frontier varies widely. As might be expected, Chinese technological capabilities are stronger in more near-market technologies such as supercritical coal fired plants and onshore wind. With respect to more early stage technologies such as electric vehicles (EVs) and possibly offshore wind, significant gaps in capabilities are more apparent.

Second, the case of China is unique, and should not be used as a proxy for developing countries in general. China is now the second largest economy in the world, the number one consumer of energy, and largest emitter of carbon dioxide. Whilst China still faces many development challenges, and many of its citizens remain on very low incomes, rapid economic development means that resources are available to support low carbon innovation and deployment. The strong role of the Chinese government is evident in our case studies –in directing technology acquisition, providing R&D support, implementing policy frameworks and in taking advantage of the CDM.

Third, a range of policy mechanisms have been used within China to promote low carbon technology development and deployment. The strong government role means that targets and regulations have often been favoured. Examples include the 11th Five Year Plan's energy intensity target and regulations to mandate the closure of inefficient industrial capacity. Whilst some of these policies are far from perfect, they have been extremely important. To complement this, we found examples of the use of economic incentives, such as reforms to coal-fired electricity tariffs which have started to encourage the use of the most efficient plants. Whilst the policies required to support low carbon innovation will differ between technologies and sectors we support the NDRC's wish for a greater role for market-based mechanisms to help meet the new Five Year Plan targets (NDRC, 2011).

Fourth, Chinese firms and institutions are developing their capabilities in our case study technologies rapidly. As noted above, domestic policy interventions have been important in supporting the acquisition and assimilation of many low carbon technologies. A combination of market support, regulations and R&D support has been crucial in many cases. However, there are some limitations – for example in access to advanced component technologies and associated knowledge, and in engineering and design skills. Some of these reflect the early stage of a technology (such as electric vehicles) whilst others reflect a significant competitive disadvantage (e.g. advanced gas turbines for IGCC plants).

Fifth, access to intellectual property rights (IPRs) is not a fundamental barrier to the development of low carbon innovation capabilities in China. This does not mean that IPR issues are unimportant. We found that the resources required to identify, acquire and assimilate low carbon technologies slowed the development of capabilities and/or diffusion of some of these technologies. Sometimes, the impression is given that Chinese firms have a wholly independent capability in some low carbon technologies, but this can be misleading. In some cases of more advanced technologies (e.g. EVs and gas turbines for IGCC power plants), barriers to entry for Chinese firms remain high due to a lack of affordable access to IPRs and/or gaps in knowledge and capabilities. Therefore, technological leadership remains with leading international firms outside China. With respect to low carbon technologies that are more mature, the capabilities of Chinese firms tend to be greater. However, some of these firms are still partly dependent on licenses from international firms (e.g. for some wind turbines for offshore use and in supercritical boiler technologies). Whilst such licenses are clearly affordable, their continuing presence indicates that independent innovation by the Chinese firms concerned is some way off.

Sixth, international institutions and policy frameworks have also played an important role in our case study technologies. The Clean Development Mechanism has been used strategically by the Chinese government – a unique approach that helps to explain why such a large proportion of CDM projects are located in China. China's considerable institutional capacity

has enabled this, and has included an alignment between the CDM and national policy frameworks. The result has been particularly significant support from the CDM for onshore wind power and cement industry energy efficiency. Other multilateral institutions have also been important in China including multilateral development banks (though they have been criticised for not focusing enough on low carbon technologies). There are also a large number of bilateral arrangements, some of which have yielded tangible results for Chinese technological capabilities – for example in wind power technology.

These conclusions lead to a number of implications for the UNFCCC negotiations. They are particularly relevant to the debate about the form and functions of the new Climate Technology Centre (CTC) and Network that was agreed in the Cancun talks in 2010 (UNFCCC 2010; UNEP 2010). The broad aim of the CTC and Network is to assist developing countries in the development and deployment of low carbon technologies. At the time of writing their scope and remit remains the subject of significant debate.

Most importantly, they suggest that low carbon innovation within the UNFCCC should not be approached from a ‘one size fits all’ perspective. The level of international assistance required (and its type) will differ by country and by technology. It is therefore important that the CTC and Network is implemented in a way that takes account of national, sectoral and market differences that characterise a complex low carbon innovation landscape.

For developing countries like China that have significant resources and capabilities, the CTC and Network could include existing institutions. The experience of China with respect to the CDM suggests that international mechanisms and institutions can be particularly effective when integrated into existing national strategies and policy priorities. This does not mean that international mechanisms are a prerequisite for low carbon innovation. But if such mechanisms are to add value, it is important that they recognise and work with national policy frameworks and capabilities.

There are many potential functions that the CTC and Network might perform. The evidence from China suggests that a broad range of functions are likely to be important including investment (e.g. in R&D), diffusion support (e.g. in wind power concessions), a focus on ‘soft technologies’ (e.g. for coal gasification), collaborative Research, Development and Demonstration (e.g. for EVs) and national plans (e.g. for industrial energy efficiency). China’s experience shows that a minimal version of the CTC and Network that is mainly concerned with sharing information and best practice would be less likely to make a significant contribution to innovation.

Finally, an important element of the implementation of the CTC and Network is evaluation of past programmes. Such evaluations will promote learning from existing institutions that run programmes designed to fulfil some of the functions foreseen for the CTC and Network. Examples include the World Bank Climate Investment Funds (which aim to achieve transformational investments in low carbon technology diffusion) and smaller pilot innovation centres (such as those being run in India and Kenya by Infodev).

Acknowledgements

We would like to thank our colleagues who contributed to the original report that formed the basis for this paper: Michele Stua, David Ockwell and Gordon MacKerron at SPRU,

University of Sussex, Alex Mallett of Carleton University, Canada, and Zhang Xiliang, Zhang Da, Zhang Tianhou, Zhang Xiaofeng and Ou Xunmin at Tsinghua University. We would also like to thank all those who agreed to be interviewed for our research and to provide comments on drafts of the final report. The research was made possible through funding from the UK Department of Energy and Climate Change.

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