International Energy Agency

Energy Investments and Technology Transfer Across Emerging Economies

The Case of Brazil and China

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Global technology transfer and co-operation are undergoing profound changes. Growing innovation capacity among emerging markets and increasing investment flows between them are creating new, reciprocal opportunities through the deployment of technological innovations and knowledge transfer.

The case of Brazil and China is particularly relevant in this context. Between 2005 and 2012, the Brazilian energy sector absorbed USD 18.3 billion worth of investments from China. Sino-Brazilian trade and political relations have intensified over the past decade. Brazil's abundant energy resources, China's financial means and expanded technological capabilities on both sides underline the significant opportunities that exist for further investment and co-operation. Commercial interests in the areas of wind energy and power transmission are further advancing this bilateral energy partnership.

Energy Investment and Technology Transfer Across Emerging Economies: the Case of Brazil and China focuses on three main questions. What are the drivers behind Chinese investment in the Brazilian energy sector? What potential exists for inter-firm technology transfer between the Chinese and Brazilian companies involved? Do government-sponsored activities and academic exchanges complement inter-firm technology transfer?

This publication's analysis highlights the potential of energy technology co-operation between Brazil and China, the deployment of innovations in third countries and, more generally, the intensification of global co-operation in energy-related research and development.

International Energy Agency

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Energy Investments and Technology Transfer Across Emerging Economies

The Case of Brazil and China

Joerg Husar and Dennis Best

INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate was – and is – two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 28 member countries and beyond. The IEA carries out a comprehensive programme of energy co-operation among its member countries, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency's aims include the following objectives:

- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations and other stakeholders.

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The European Commission also participates in the work of the IEA.

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Executive summary

The global landscape of investment, innovation, and technology transfer is undergoing profound changes, underlined by two main trends: first, growing domestic innovation capacity among emerging economies; and second, increasing investment flows between them. These trends create new avenues for global technology transfer and co-operation. In turn, these avenues relate to jointly generated knowledge and its application in bilateral relationships, as well as increased co-operation for the deployment of innovations and know-how in third countries.

The bilateral relationship between China and Brazil is a particularly relevant one in this context: between 2005 and 2012, the Brazilian energy sector absorbed USD 18.2 billion of investments from China. Until recently, Brazil represented the single largest destination for Chinese energy investments (it is now second only to Canada, because of the China National Offshore Oil Corporation's [CNOOC's] purchase of the Canadian oil and gas company, Nexen Inc., for USD 15.1 billion in 2012). In parallel to this surge in Chinese investments, Sino-Brazilian trade and political relations have intensified rapidly over the past decade: In 2004, China and Brazil set up the China-Brazil High-Level Co-ordination and Co-operation Committee (CBHCCC), including a subcommittee on energy and mining in 2006. China became Brazil's largest trading partner in 2009. Several technology co-operation agreements have been signed in recent years between national oil companies in Brazil and China (notably the China Petroleum and Chemical Corporation [Sinopec]/Sinochem agreement with Petróleo Brasileiro S.A. [Petrobras] and the China Three Gorges Corporation's [CTGC's] agreement with Centrais Elétricas Brasileiras [Eletrobras]), as well as between the Federal University of Rio de Janeiro (UFRJ) and Tsinghua University.

This report focuses on three main questions: what are the drivers of Chinese investments in the Brazilian energy sector? What is the potential for inter-firm technology transfer between the main Chinese and Brazilian companies involved? Do government-sponsored activities and academic exchanges complement inter-firm technology transfer?

Challenges and complementarities

The case of China and Brazil highlights areas of challenge, as well as areas of synergy and mutual benefit that provide a backdrop for technology transfer and co-operation. The most obvious complementarity is that Brazil has the fossil fuel resources that China lacks, while China has the financial means to contribute to their development. In addition, Brazilian national oil company (NOC) Petrobras over the past decades has developed leading technology capabilities in the area of deep water exploration and production (E&P), an area in which Chinese NOCs lack expertise. In terms of wind energy, with some of the highest capacity factors in the world, Brazil has significant market potential, but lacks its own wind technology and experience in deployment. China is emerging as an independent supplier of wind turbines with its own technology capabilities, which makes it an attractive supplier of components and potential investor in Brazilian wind farms. In the transmission sector, similarities of geographical distribution of renewable energy resources and load centres constitute a potential for applying Chinese ultra-high voltage (UHV) transmission technology in the essential upgrading and expansion of the Brazilian power grid.

Oil and gas

However, actualising areas of potential synergies is not straightforward. In the oil sector, despite co-operation agreements and high-level political support for technology transfer, Petrobras is reluctant to involve Chinese NOCs in its prolific pre-salt deep water development. Sinopec's role is rather envisaged in terms of a partnership in the construction of Petrobras' refineries. The only direct co-operation in oil production was agreed to in the form of a farm-in agreement on two blocks of shallow water, which do not expose Sinopec to frontier technology. Sinopec, in turn, took advantage of the liquidity shortage of other major players in the Brazilian oil sector and acquired stakes in Repsol and Petrogal. This fulfils Sinopec's goal of increasing its expertise in deep water E&P, however, its involvement in research and development (R&D) in the framework of these investments is limited to the petrochemical area, rather than strategic E&P technology.

Power transmission

In the power transmission sector, the acquisition of seven Brazilian companies by the State Grid Corporation of China (State Grid) in 2010 was the first time a Chinese company not only bought, but managed, its assets, thus providing significant potential for operational learning and technology transfer in Brazil's energy sector. State Grid also successfully partnered in tenders with the Brazilian state-owned power utility company, Eletrobras (Furnas), and Companhia Paranaense de Energia (COPEL), a regional generation and transmission company and one of the pioneers in the area of smart grids in Brazil. State Grid is an ideal technology partner, with 228 completed smart grid demonstration projects across the value chain and established standards for technology adoption, which State Grid is eager to export abroad in order to secure markets for its products. Both countries plan significant investments in power transmission (State Grid will invest USD 10 billion annually by 2015) and the market potential of smart grid deployments in China and Brazil offers significant research, development, demonstration and deployment opportunities across these partnerships. Thus far, Chinese transmission activities are restricted to the operation of their assets in Brazil, while Chinese companies are still familiarising themselves with the functioning of the Brazilian market. Further joint participation in tenders with both Eletrobras and COPEL is under consideration.

Wind energy

In the wind sector, technology transfer takes place predominantly via turbine imports from China, which began in 2012. Mutual interests seem to be quite clear: Brazil would like to partner with China to bring down the costs of wind components in order to advance its bourgeoning wind sector, while China could build a comparative advantage in serving this growing market through joint research. However, early co-operation has met some challenges, for instance, in a recent Brazilian project developer's involvement in legal disputes over intellectual property rights (IPRs). Announcements of co-operation agreements between Eletrobras and CTGC are also promising as they bring together one of the most ambitious players in the South American wind market with the operator of 1 gigawatt (GW) of wind energy capacity in China. This partnership may also create significant opportunities on both sides, if the competences gained through joint offshore wind projects in China would lead to the development of projects in Brazil, as well. CTGC has thus far positioned itself as a wind project developer, but as it continues to grow its operations and acquire minority stakes in Chinese technology enterprises, it may become a technology provider.

State-led co-operation

As a product of the intergovernmental dialogue, China and Brazil have set up the China-Brazil Center for Climate Change and Innovative Technology for Energy, which brings together experts from leading research and engineering institutions at Tsinghua University and the Federal University of Rio de Janeiro (UFRJ). In the framework of this centre, the two countries intend to build technology co-operation and develop partnerships in four initial areas: biofuels; wind energy; deep water oil; and carbon capture and storage (CCS) technologies. A first outcome worth highlighting is an agreement on increased academic exchange in the area of petroleum engineering, opening an alternative channel of technology transfer to the operational learning potential constituted by Chinese investments in Brazil.

Main conclusions

Sino-Brazilian technology transfer and co-operation are substantial, and investments are increasing. Yet, the objectives of high-level agreements on increasing technology transfers have yet to be solidified, due to the absence of immediate commercial interests in some areas such as oil and gas. This lack of progress is partly due to the fact that both governments have a limited degree of influence in the international activities of their NOCs, even though they are state-owned entities. Both China and Brazil are strategically applying local content requirements and technology standards to create export opportunities for their national industries, or to ensure that foreign direct investment (FDI) aligns with broader economic development and technology policy goals. Local content requirements create obstacles to bilateral technology flows, *e.g.* in that they may impede access to finance by development banks, however both sides have agreed to reduce such obstacles. Another obstacle that still needs to be overcome is the alleged IPR infringement by Chinese wind companies, which may slow down their expansion not only on the Brazilian market, but globally.

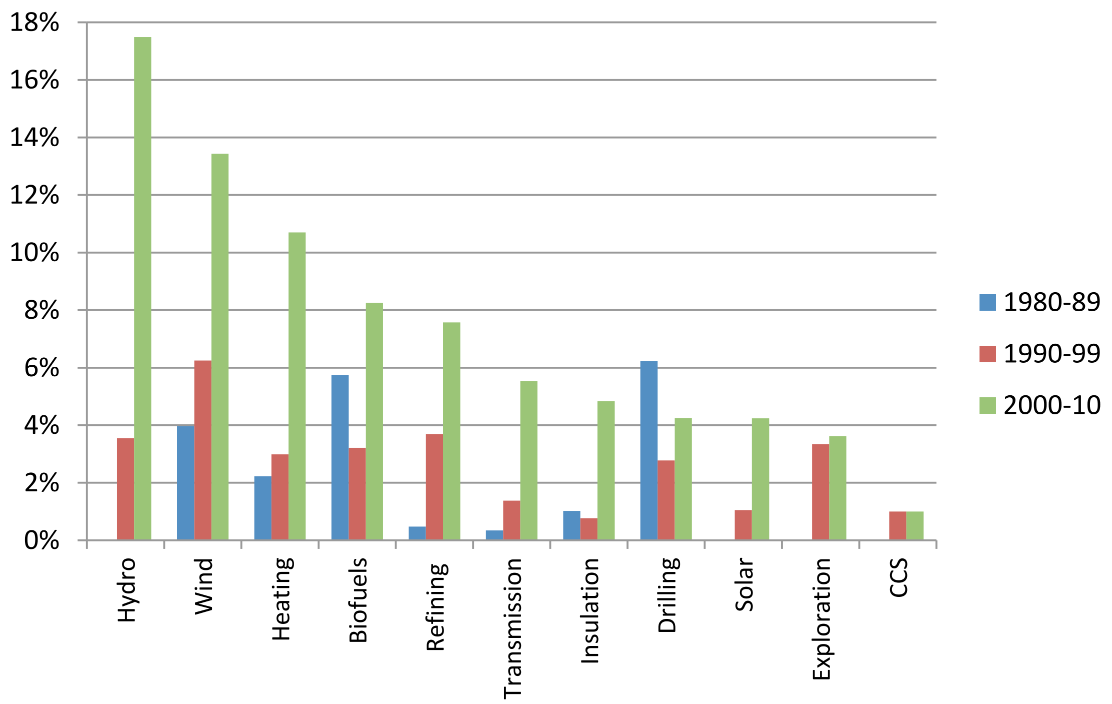
In the longer term, given the capabilities of the corporate actors, this relationship could grow into a significant bilateral technology partnership, especially in the wind and transmission sectors, where commercial interests are already driving co-operation. China and Brazil are uniquely placed to develop and adopt modalities and practice for technology transfer with impact on broader technology transfer agreements at the international level. This could be useful, for example, in the context of broader climate agreements: as China and Brazil are both eligible for financing from Annex I parties, both could reap the co-benefits of technology transfer, with access to international funds sourced from developed countries.

The intensification of such ties could result in a more rapid deployment of clean energy technologies in emerging economies, offering new avenues for climate change mitigation. However, it could also contribute to increasing heterogeneity in global technology standards, if these countries work together exclusively. The International Energy Agency (IEA) multilateral technology co-operation initiatives may provide useful channels for both to access international policy best practice, demonstrate technology innovation potential and leadership, while also pursuing respective priorities through the IEA energy technology networks.

Introduction: global investment flows, innovation and technology transfer

Global investment flows are increasingly driven by outward FDI from transition economies, which is mainly directed towards transition or developing economies. The intensification of these investment flows has the potential to increase technology transfer, be it in the form of increased trade in components and equipment (technology diffusion) or inter-firm technology transfer (joint R&D, operational learning in joint ventures [JVs], and mergers and acquisitions). Governments complement investments through sponsored co-operation programmes (*e.g.* bilateral research centres or academic exchanges), which broaden investment flows in technology co-operation in the academic and institutional realm. FDI from Brazil, Russia, India and China (BRIC) countries can illustrate these trends: in 2011, 65% of FDI projects from the BRIC countries were invested in developing and transition economies (UNCTAD, 2012). Intra-BRIC trade flows increased to USD 379 billion in 2011 (9.3% of total BRIC trade [EC, 2013]).

Figure 1 • Patent applications from IEA key partner countries as % of total IEA member countries' patent applications, by sector, 1980-2010



Source: IEA calculations based on the Organisation for Economic Co-operation and Development (OECD) patent database, http://stats.oecd.org, updated January 2013, retrieved July 2013. For more details on method, please refer to the annex.

In addition to increasing investment flows, technology innovation is no longer the exclusive domain of developed countries (OECD, 2012). The contribution of developing countries to innovation is increasing; however, the extent of technological expertise varies by quantity and quality from sector to sector. The number of patent submissions can serve as an initial proxy to illustrate different dynamics in various countries and sectors.[1] In the area of hydropower, over

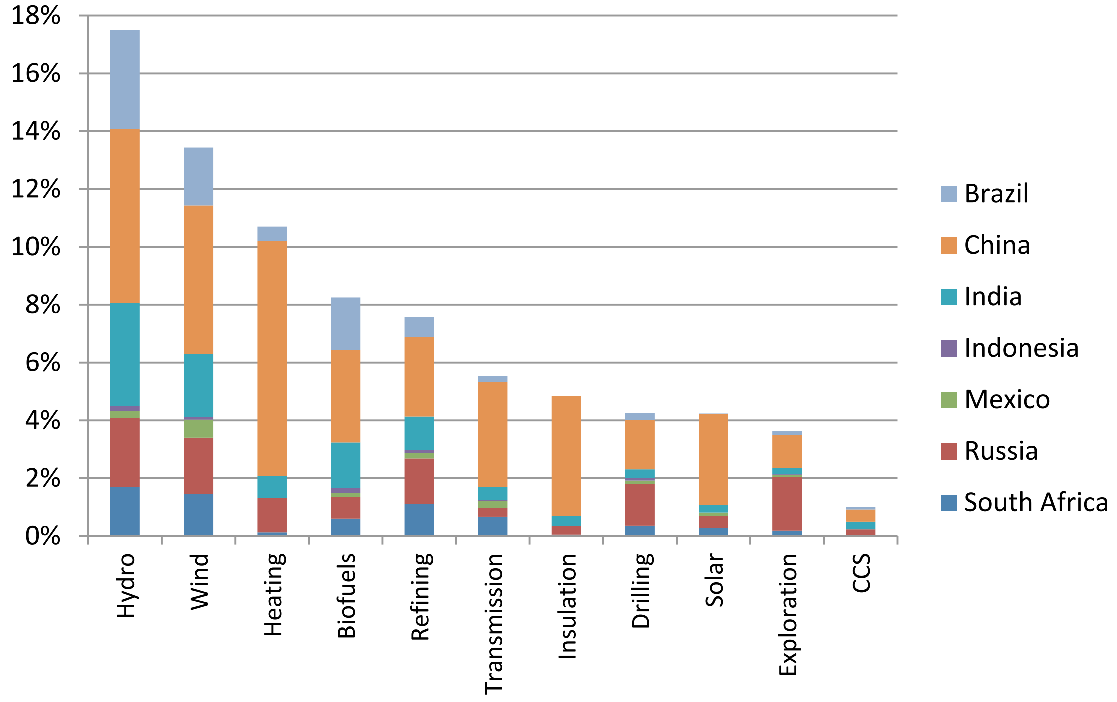
[1] The number of patents is widely used to reflect countries' technological dynamism. The drawbacks of this indicator are well-known: innovations may not be patented or are covered by multiple patents; also the technological or economic value of patents varies greatly (OECD, 2005). In addition, the indicator tends to be biased towards the developed countries, so that comparisons have to be taken with a grain of salt.

the past two decades, the number of patents submitted by the seven key IEA partner countries[2] under the Patent Co-operation Treaty (PCT) increased from 3.5% to 17.5% of the total patents submitted by all 28 IEA member countries combined (Figure 1).

The majority of these patents were submitted by the BRIC countries. Overall, patenting activity from China has accelerated impressively, particularly in the areas of heating, wind energy and hydropower. India and Brazil are present mainly in the areas of wind, hydro and biofuels. Russia shows the greatest patenting activity in the areas of exploration, drilling and refining, along with wind and hydro (Figure 2).

Taken together, the two trends of growing domestic innovation capacities in emerging economies and increasing investment flows between them create a new potential for global technology innovation, deployment of new energy technologies globally and co-operation between key global technology centres. This potential relates not only to jointly generated knowledge and support for bilateral relationships, but also to co-operation on the deployment of innovations and know-how in third countries. For the IEA, as a major hub in international energy technology co-operation, it is important to study these trends and identify new ways of engaging partner countries to jointly advance the goals of ensuring reliable, affordable and clean energy.

Figure 2 • Patent applications from IEA key partner countries as % of total IEA member countries' patent applications, by sector and country, 2000-10



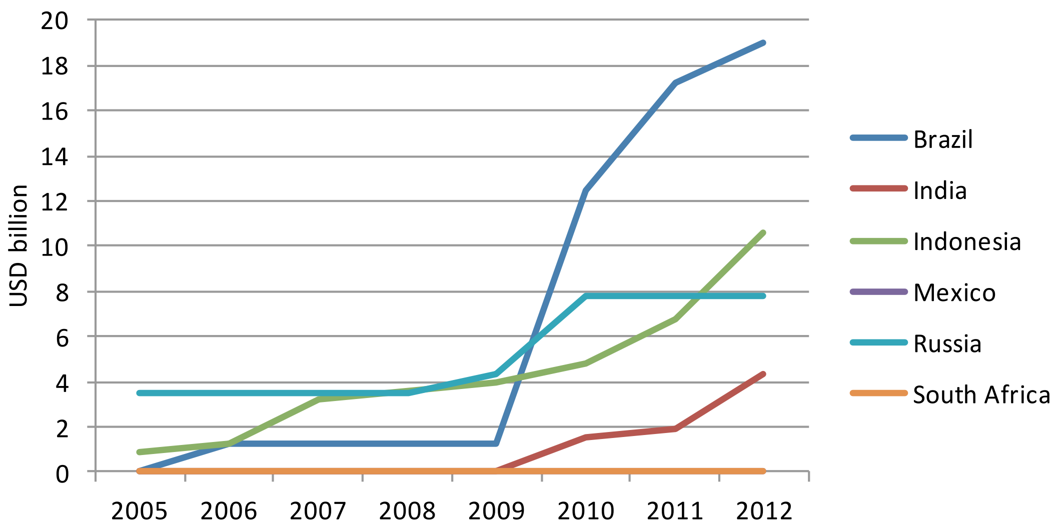
Source: IEA calculations based on the OECD patent database, http://stats.oecd.org, updated January 2013, retrieved July 2013. For more details on method, please refer to the annex.

[2] "Partner countries" refers to key IEA non-member countries, as approved by the June 2012 IEA Governing Board: Brazil, China, India, Indonesia, Mexico, Russia and South Africa.

A case study: energy investments and technology transfer between China and Brazil

The bilateral relationship between China and Brazil provides a compelling case to emphasise the aforementioned trends in energy investment and technology transfer. China's ascendance as a global technology developer and leader across energy technologies over recent decades is unparalleled. China's solar and wind energy sectors provide prime examples (de la Tour *et al.*, 2011; Klagge, Zhigao and Pedro, 2012; Ru *et al.*, 2012); in terms of wind energy, for example, China's proportion of global annual newly installed capacity increased from less than 10% in 2006 to 49% in 2010, while its total grid-connected wind power capacity reached 296 GW in 2010. In four short years, China's wind turbine manufacturing industry scaled up production; four Chinese wind turbine manufacturers now rank in the top ten in the world. Low-cost manufacturing and a large domestic market have made the country a "global learning laboratory" for energy technologies (Liu and Liang, 2013), and an increasingly important contributor to energy technology global diffusion and co-operation. Currently, Brazil is one of the largest destinations for outbound Chinese energy investments for oil and gas, renewable energies and the transmission sectors. This relationship is one of the strongest bilateral energy investment relationships among IEA partner countries, as measured by cumulative investments (Figure 3).

Figure 3 • Cumulative Chinese energy investments in other key IEA partner countries, 2005-12



Source: Heritage Foundation, 2013.

Surging investment, consolidating political dialogue

Between 2005 and 2012, the Brazilian energy sector absorbed USD 18.2 billion of investments from China, 70% of total Chinese investment in the country. Prior to CNOOC's announcement of its purchase of Nexen (USD 15.1 billion), Brazil represented the single largest destination for Chinese energy investments (Heritage Foundation, 2013).

The majority of this investment to date has flowed in one direction: from China to Brazil. In general, Brazilian investment activity in China is quite low and has stagnated over the past ten years. According to the Chinese Ministry of Commerce (MOFCOM), between 2000 and 2010, USD 572.5 million was invested by Brazilian companies, making up a meagre 0.04% of total foreign investment in China. As of 2012, only 57 Brazilian companies were represented in China. Most of them focused on sales or sourcing activities. In terms of energy, only Petrobras is active in China, where it has managed China's imports of Brazilian oil since 2004. In 2012, however, Electrobras announced plans to partner with CTGC to develop an offshore wind project in Jiangsu province.[3] Yet, the benefits of increased investment flows can be realised on both sides through the financing projects that enable both countries to develop operational experience in key sectors and build a base for globally competitive industries (CEBC, 2012).

In parallel to the surge in Chinese investments, Sino-Brazilian trade and political relations have also intensified over the past decade: in 2004, China and Brazil set up the CBHCCC, adding a subcommittee on energy and mining in 2006. China became Brazil's largest trading partner in 2009. In 2010, the CBHCCC produced a joint action plan that details support for energy investment projects, as well as the intention to increase co-operation in energy technology. The emphasis on technological issues underlines that China's energy investments in Brazil have not entirely been driven by the objective of gaining control over energy resources. Among other factors, technology and market access play a significant role in driving Chinese energy investments abroad.

The intensification of Sino-Brazilian energy relations has to be viewed in the larger context of China's "going abroad" policy, first announced in 1997, when President Zemin Jiang stated the intention to "establish highly competitive large enterprise groups with transnational operations" and to "encourage Chinese investors to invest abroad in areas that can bring China's competitive advantage into play so as to make better use of both Chinese and foreign markets and resources" (Jiang, 1997). China's FDI outflows rose from USD 2.7 billion in 2002 to USD 74.7 billion in 2011. According to the United Nations Conference on Trade and Development (UNCTAD), China was the 9th largest source of global FDI, with the cumulative stock of USD 384.9 billion in 2011 (Morrison, 2013).

Technology challenges and complementarities in the energy sector

In addition to China's "going abroad" orientation for foreign investments, there is a range of bilateral energy-related complementarities between the two countries, in terms of their approach to major energy challenges. Focusing on the three main subsectors targeted by Chinese investments in Brazil (oil and gas, wind and transmission), the following challenges can be identified:

- China's high oil import dependence, its concentration of suppliers in very few countries, high oil price and stagnant domestic oil production, combined with rising oil demand, make the case for diversification and an accelerated shift towards renewable energy. This shift also contributes towards dealing with a second major challenge: growing environmental problems and carbon dioxide (CO_2) emissions from China's high dependence on coal-fired power plants make the case for a switch to gas and renewables. The inclusion of renewables, however, creates further infrastructural challenges, in terms of managing variability, and building new transmission lines between the location of hydropower and wind resources (in the west) and distant load centres (mainly on the east coast).
- Brazil's major challenge is its development of the large pre-salt oil and gas resources, which requires massive investments in E&P and infrastructure over the next decades. The country's power generation is highly dependent on hydropower and the diversification into wind energy creates considerable challenges of grid integration and variability, although the hydro reservoirs can serve as buffers against daily fluctuations. Brazil aims to maintain its low-carbon power mix despite the envisaged surge in domestic oil production from the pre-salt area. However, the majority of its untapped hydro potential is located in the Amazon region, including national

[3] In addition, Brazilian engineering firms have opened offices in China due to their involvement in the construction of large hydro dams in the country.

parks and/or areas inhabited by indigenous communities. These characteristics of hydropower in Brazil have had an impact on the country's ambitious expansion plans for large hydropower plants and have created pressure to accelerate the deployment of other renewable energy sources, particularly wind. As in the case of China, renewable energy resources and load centres are geographically distant, and as the blackouts since 2009 have shown, the Brazilian transmission grid is in need of greater investment to cope with strong demand growth.

Obvious areas for co-operation lay in Brazil's oil and gas resources, which China lacks, while China has the financial means to contribute to their development. The Brazilian NOC Petrobras has acquired leading technology capabilities in the area of deep water E&P, an area in which Chinese NOCs are lacking expertise. In terms of wind energy, Brazil has locations enjoying some of the highest capacity factors in the world, with high market potential, but it lacks wind technology and deployment experience. China is emerging as an independent supplier of wind turbines, making it an attractive supplier of components and potential investor in Brazilian wind farms, as well as the solar photovoltaic (PV) market. In the transmission sector, similarities of geographical distribution of renewable energy resources and load centres provide a potential opportunity to apply Chinese transmission technology in the essential upgrading and expansion of the Brazilian power grid.

Making use of these potential synergies is not straightforward. A strong increase in resource-seeking FDI from emerging economies in Asia to South America in 2010-11 raised concerns among some countries over trade patterns. South America primarily exports commodities and imports manufactured goods, which could have a negative effect on development and growth prospects. Also, IPR issues could delay bilateral technology co-operation as some components supplied by China have recently been subject to scrutiny for potential IPR infringements. Local content requirements provide another challenge, yet also an opportunity for Chinese investment in Brazil. In some sectors, *e.g.* the electricity and wind sectors, international operators that bid for projects in Brazil must meet the criteria of sourcing locally manufactured equipment; the Brazilian Development Bank (BNDES) has targeted the assembly of wind turbines as part of its move to increase locally produced content. The bank aims to achieve this by setting targets which have to be accomplished by the manufacturers according to a previously established schedule. However, as China seeks to expand into overseas market operations, Chinese firms may be more willing than other international competitors to develop manufacturing operations in Brazil.

Main questions

This paper analyses Chinese energy investments in Brazil in terms of potential for technology transfer and enhancing co-operation and knowledge transfer between China and Brazil, and examines the range of drivers and obstacles. This section will focus on the subsectors that absorbed the largest share of recent investments: oil and gas, power transmission and wind energy, and asks the following questions:

- What are the drivers of Chinese investments in the Brazilian energy sector?
- What is the potential for inter-firm technology transfer between the main Chinese and Brazilian companies involved?
- Do government-sponsored activities and academic exchanges complement inter-firm and market driven technology transfer?

Key drivers of Chinese investments in Brazil

Chinese engagement in the Brazilian energy sector is concentrated in three key subsectors. First, Chinese investments in the Brazilian oil and gas sector have increased significantly over 2010-11, when several deals and agreements were announced and materialised. Second, the power transmission sector has seen considerable acquisitions through the Chinese utility giant, State Grid. Third, the Brazilian wind sector has attracted increasing interest from China through its attractive market growth potential.

Oil and gas

Since 1995, private companies have been allowed to carry out oil and gas activities in Brazil on the basis of concession agreements, removing the monopoly of Petrobras. However, in order to maintain control of the country's expanding pre-salt fields, Brazil passed a pre-salt law in 2012. The law introduced a production-sharing contract (PSC) to be applied to the pre-salt area and other areas deemed strategic by the federal government. The law also created Pré-sal Petróleo S.A., a 100% state-owned company to represent the Brazilian government in any consortium in the exploration and development of pre-salt blocks, and added new stipulations that Petrobras be the sole operator of all pre-salt consortia awarded with the PSC, with a minimum participating interest of 30%. Existing fields and future non-pre-salt discoveries remain governed by the concession system.

Table 1 • Overview of Chinese investments and co-operation in the Brazilian oil and gas sector

Year	Chinese partner	Local partner	Value of deal (USD million)	Status	Means of market entry
2006 2008	Sinopec Corporation	Petrobras (Gasene pipeline)	1 290	Completed	Contract
2008	Sinopec Corporation	Petrobras	n/a	Confirmed	Strategic partnership (MoU)
2010	Sinopec Corporation	Repsol Brasil	7 111	Completed	JV (60/40)
2010	Sinochem Group	Statoil ASA (Peregrino oilfield)	3 070	Completed	Partial acquisition (40%)
2010	Sinopec Corporation	Petrobras (blocks BM-PAMA-3 and -8)	undisclosed	Completed	Farm-in agreement
2011	Sinochem Group	Petrobras	n/a	Confirmed	Strategic partnership (MoU)
2011	Sinopec Corporation	Petrogal Brasil	4 800	Confirmed	Partial acquisition (30%)
2011	CNPC (Baoji Oilfield Machinery Company)	Brasil China Petroleo and Asperbras	25	Confirmed	JV (34% CNPC stake)
2012	Sinochem Group	Perenco (five blocks in Espirito Santo basin)	undisclosed	Confirmed	Minority stake purchase (10%)
			TOTAL: 16 296		

Note: CNPC = China National Petroleum Corporation; MoU = Memorandum of Understanding.
Source: compiled by the IEA from news coverage and annual reports.

Over the past five years, 50% of new discoveries of oil worldwide were made in deep water areas. Brazil accounts for 63% of these discoveries (Petrobras, 2012). In the coming decades, Brazil is expected to become the fastest growing oil producer outside the Middle East, with the majority of this increase is expected to come from the pre-salt area. According to IEA projections, Brazilian oil production increases from 2.2 million barrels per day (mb/d) in 2011 to 4.0 mb/d in 2020 and 5.7 mb/d in 2035 (IEA, 2012a).[4] Gas production is projected to more than double from

[4] The *World Energy Outlook 2013*, to be released in November 2013, will include a special focus on the Brazilian energy outlook.

15 billion cubic metres (bcm) in 2010 to 32 bcm in 2020. These projections are more conservative than those of Petrobras and the Brazilian government.[5] However, local content restrictions and the mandatory controlling stake for Petrobras remain downside risk factors due to potential logistical and organisational bottlenecks (IEA, 2012b). Petrobras plans to invest USD 236.7 billion under its 2013-17 business plan. The E&P area will continue to lead the portfolio of investments, with USD 147.5 billion (Petrobras, 2013).

Sinopec and Petrobras

Following President Hu Jintao's state visit to Brazil in 2004, Chinese NOCs have intensified efforts to become major players in Brazil's oil and gas sector. Thus far, Sinopec has been the most successful. In 2004, Petrobras and Sinopec concluded an agreement on the study and development of business opportunities in various fields, ranging from deep water oil E&P to the supply of oil and gas infrastructure, as well as the refining and petrochemical industry. In 2005, the Sinopec International Petroleum Service do Brasil Ltda was founded as a subsidiary to Sinopec. In 2006, Sinopec was contracted by Petrobras to construct the first 300 kilometres (km) stretch of the major natural gas pipeline project Gasene (Gasoduto Sudeste-Nordeste), from the state of Rio de Janeiro to the north east of the country. In 2008, Sinopec was also contracted for another 940 km stretch, from Cacimbas to Catu. The Gasene project received a USD 750 million loan from the China Development Bank (CDB).

The global credit crisis of 2008 ushered in a new stage in Chinese engagement in Brazil, as Petrobras struggled to raise capital for the development of its pre-salt resource, requiring USD 174.4 billion by 2013. In February 2009, Petrobras entered into an oil sales agreement with Sinopec that covered the supply of 200 000 barrels per day until 2019 in exchange for loans of up to USD 10 billion through the CDB. Furthermore, two memoranda of agreement were signed, which cover potential collaboration in exploration, refining and petrochemicals, and the supply of goods and services to Petrobras.

In 2010, Petrobras and Sinopec signed a strategic co-operation agreement, together with the CDB, for a two-year joint exploration for oil in Brazil. On the basis of this agreement, in 2011 it was announced that Sinopec would take a 20% stake in the blocks BM-PAMA-3 and BM-PAMA-8 in the Pará-Maranhão basin owned by Petrobras.

In the future, Sinopec sees Petrobras as its major partner in Brazil. As China aims for a larger presence in the pre-salt area, Petrobras is the natural operating partner of choice. Not only do they have the necessary experience and local market knowledge, but the company, above all, holds exploration rights to 60% of Brazil's pre-salt fields and is the operator of 9 out of 11 blocks in the Santos basin. However, Petrobras has so far been reluctant to partner with Sinopec in pre-salt projects.

Other companies

In December 2010, Sinopec invested USD 7.1 billion for a 40% stake in Repsol's Brazilian upstream unit, which provided the Spanish energy company with the necessary funds to develop its local offshore fields. This marked Sinopec's very first move into Brazil's offshore fields. The agreement aims for full collaboration between Sinopec and Repsol in the development of existing projects, as well as joint or individual participation in future bids. Beyond that, the partnership offers several market opportunities in Argentina and Venezuela. The JV received a significant boost in early 2012 when one of the biggest pre-salt oil discoveries was made in the Pão de Açúcar field in the Campos basin, which is jointly owned by Repsol-Sinopec Brasil (35%), Petrobras (30%) and

[5] The Brazilian government's Ten-Year Energy Expansion Plan projects 5.4 mb/d of oil production and 74 bcm of gas production in 2020.

Statoil (35%) (*Oilgram News*, 2012a). In 2012, Repsol-Sinopec Brasil committed USD 947 million to pre-salt projects and is planning to invest a total of USD 4.2 billion in its pre-salt projects in the Santos basin to 2016, which will be directed toward production rather than exploration (*Oilgram News*, 2012b).

In March 2012, Sinopec acquired a 30% stake in Portugal's Galp Energia's Brazil operations for USD 5.2 billion. This gives Sinopec access to Galp's Brazilian upstream assets, a total of 21 projects including stakes in four deep water blocks in the pre-salt Santos basin. The capital increase raised the needed funds for financing the company's participation in several pre-salt offshore projects in Brazil and significantly increased China's presence in the Brazilian oil sector (*Platts Commodity News*, 2012; *Financial Times*, 2011).

Sinochem Group, another Chinese state-owned oil company, acquired a 40% stake in Norwegian Statoil's Peregrino field in the Santos basin for USD 3 billion in 2010. An MoU was agreed upon by the two companies to jointly explore other opportunities in the country and elsewhere (*Financial Times*, 2010b). In early 2012, Sinochem announced the acquisition of a 10% working interest in five offshore oil blocks in the Espirito Santo basin owned by Perenco and OGX Petroleo e Gas. The agreement was approved in October 2012 by Brazil's National Petroleum Agency and will provide Perenco with the necessary funds for exploration of its Brazilian blocks. Sinochem signed another MoU on strategic co-operation in oil and gas E&P, and brownfield recovery with Petrobras in 2011 (IHS Global Insight, 2012; *Platts Commodity News*, 2011).

Finally, Baoji Oilfield Machinery Company, a subsidiary of CNPC, entered into a JV with two Brazilian manufacturers to establish the company Bomcobras (34% CNPC stake), which will supply equipment for land and sea-based oil exploration, including mud pumps, drilling pipes and towers, cranes and probes.

Drivers of Chinese investments in the Brazilian oil and gas sector

Earlier IEA research has highlighted the motivations for Chinese NOCs' investments abroad. Central investment objectives include: diversifying supplies to avoid (business) risks; becoming an "international NOC"; developing an integrated supply chain; and gaining technical know-how (Jiang and Sinton, 2011). The stated objective of Sinopec Brazil is to "establish itself firmly in the Brazilian offshore segment" by 2020 (Sinopec Brasil, 2012). However, in the case of the Gasene pipeline, Sinopec did not improve its access to Brazilian oil and gas.

It took several years for Chinese investments to materialise in the Brazilian energy sector, despite highest-level government support. Initial attempts from 2004-06 to apply its infrastructure-for-oil investment pattern in Brazil – first applied in Angola – were only partially successful. While Sinopec was contracted for the Gasene pipeline, it did not receive an oil supply contract in return, and had to agree to sourcing a minimum of 75% of the project's goods and services from Brazil. In part, this outcome was due to the checks and balances of the Brazilian oil sector's governance structure, and the influence of Brazilian trade unions, which have successfully lobbied against the large-scale contracting of Chinese workers and services (Alves, 2011).

In the context of the global credit crisis, Petrobras agreed to partner directly with Sinopec on oil fields, although this only concerned fields in shallow waters, where mature technologies could be applied. Petrobras agreed to partially use Sinopec equipment, and views these projects as a "trial before venturing together into ultra-deep water" (Alves, 2011). This hesitancy is due to Sinopec's lack of expertise in deep-sea production and Petrobras' reluctance to share its frontier expertise in this area.

Petrobras has been reluctant to involve Chinese NOCs in the pre-salt area to date (defined by the Brazilian Law 12,351/2010). Chinese involvement in the pre-salt has rather been accomplished via the acquisition of companies, beyond the inter-governmentally supported line of projects. While the minority stakes in pre-salt fields contribute to Chinese energy security by providing equity oil that can be potentially imported, these stakes do not guarantee the acquisition of technology. This depends on the willingness of partners to engage in technology transfer, the degree of involvement of Chinese staff on the ground and the absorptive capacity of the Chinese companies involved.

While interest in resource access on the Chinese side and the need for finance on the Brazilian side are primary drivers, a shift towards a deeper relationship can be observed in the form of several technological and strategic co-operation agreements. Chinese firms also stand to gain from broader expertise and regional operational understanding of the South American market that, beyond resource extraction and technology acquisition, may contribute in the long term to Chinese international oil companies (IOCs). This brings a new level of collaboration with the objective of benefitting mutually from the partner's expertise and technology. PetroChina's investment in the oil industry equipment manufacturer Bomcobras could improve the ability of CNPC to meet local content requirements in future bidding rounds. Going forward, the attractiveness of the Chinese partners to Brazil depends on how much expertise of real interest Chinese NOCs can contribute to the Brazilian sector, particularly with competition by IOCs and suppliers, which have already established R&D centres in Brazil.

Power transmission

The Brazilian power transmission sector is dominated by large domestic government-controlled firms, with 69% held by Eletrobras and its various subsidiaries (Woolf *et al.*, 2010; REEEP, 2012). Transmission was almost exclusively under federal and state government control until 2007, when a new sector regulatory model and auction system for the expansion of transmission lines and generation capacity were implemented, and private investment started to target the sector. The total length of the Brazilian transmission grid was almost 100 000 km at the end of 2010. Brazil's power industry offers enormous future investment potential, with electricity consumption rising steadily.

Table 2 • Overview of Chinese investments and co-operation in the Brazilian transmission sector

Year	Chinese partner	Local partner	Deal value (USD million)	Status	Means of entry
2010	State Grid	Plena Transmissoras	989	Completed	Full acquisition
2012	State Grid	COPEL (Tele Pires transmission line)	n/a	Confirmed	Consortium (51%/49%)
2012	State Grid	ACS (Actividades de Construcción y Servicios S.A.) (seven transmission assets)	942	Announced	Partial acquisition
2012	State Grid	Neoenergia	undisclosed	Speculation	Partial acquisition (39%)
2012	State Grid	COPEL, Furnas (Eletrobras)	438	Confirmed	Consortium
			TOTAL: 2 369		

Source: compiled by the IEA from news coverage and annual reports.

The Brazilian government's Ten-Year Energy Expansion Plan 2020 estimates that BRL 46 billion (USD 21 billion) of investment will be needed to expand the interconnected system by 42 000 km and build new substations by 2021 (EPE, 2013). The expansion is put into practice via auctions held by the regulator Agência Nacional de Energia Elétrica (ANEEL). The market is characterised by high initial investments, but high earnings before interest, taxes, depreciation, and amortisation (EBITDA) margins, and presents low operation and maintenance costs (Neoenergia, 2012). This makes the market attractive for Chinese power transmission companies struggling with the highly regulated and less profitable Chinese transmission sector.

State Grid in Brazil

State Grid is one of the world's largest utility companies. It entered Brazil in December 2010 by acquiring seven Brazilian power transmission companies for a total of USD 989 million (*Financial Times*, 2010a; IHS Global Insight, 2010). The seven companies[6] own a total network of 3 173 km of 500 kilovolts (kV) of transmission lines in south-east Brazil. According to Shu Yinbiao, an executive vice-president at State Grid, the company envisions a long-term commitment in Brazil and is planning considerable investments in the fields of transmission, renewable energy, as well as R&D (*Valor Econômico*, 2010).

This commitment was underlined in 2012 by yet another acquisition of seven electricity transmission assets previously owned by the Spanish company ACS. The Brazilian assets were bought for a total of USD 942 million, making State Grid the owner of a further 2 792 km of power transmission lines across eight Brazilian states (*China Knowledge Press*, 2012; *China Daily*, 2012a).

In December 2012, State Grid – along with minority partners COPEL, Paraná state's utility company, and Furnas Centrais Elétricas S.A. – successfully bid on a project to build a 967 km, or 600 mile, transmission line, with an investment of BRL 910 million (USD 438 million). Once completed, State Grid said, it will operate a total of 9 931 km of transmission lines in Brazil.

In March 2012, State Grid and, COPEL, won licences to build 1 600 km of transmission lines and four substations in the Amazon's Tele Pires river basin. The contracts are usually assigned to bidders who accept the lowest annual revenue from the transmission assets; in this case, the two companies accepted a discount of 43% (State Grid) and 37% (COPEL) below the government-established cap (*Business News Americas*, 2012a; *Dow Jones International News*, 2012b).

In 2012, State Grid was reported to have been interested in a 39% stake in the Brazilian power holding company Neoenergia, held by Spanish Iberdrola. Furthermore, a potential partnership is under discussion between Eletrobras and State Grid to participate in tenders for the installation of over 6 000 km of transmission lines, connecting the Belo Monte dam to the south east and north east of the country.

Drivers of Chinese investments in the Brazilian power transmission sector

What distinguishes State Grid's investment in Brazil from other energy investments in recent years is the focus on the involvement of State Grid in daily operations. State Grid is committed to be a long-term strategic investor in Brazil, "engaged in the construction of electrical power transmission projects and the development of hydraulic resources" (State Grid, 2012b). According to State Grid's development director, Brazil is one of the main areas of concentration of investment in the coming years. By 2015, State Grid plans to invest USD 10 billion in the expansion of its regional activities; close to half of this figure will go into transmission projects, while the rest will be assigned to electricity generation projects (*Business News Americas*, 2012b).

The 2010 deal with Plena Transmissoras was China's first investment in the Brazilian energy sector whereby it not only secured assets, but also operated and managed them (China Economic Review, 2011). State Grid's main concern here is profitability. According to internal sources, the company expects returns on overseas projects to be considerably higher than those within the Chinese home market due to more advantageous pricing policies in the energy sector in other countries (*China Daily*, 2012b). According to one State Grid international division official, in line with a fundamental company principle, an overseas project is only considered if expected returns

[6] Expansion Transmissão de Energia Elétrica S.A., Expansion Transmissão Itumbiara Marimbondo S.A., Itumbiara Transmissora de Energia S.A., Poços de Caldas Transmissora de Energia S.A., Ribeirão Preto Transmissora de Energia S.A., Serra da Mesa Transmissora de Energia S.A. and Serra Paracatu Transmissora de Energia S.A.

are at least twice or three times as high as can be achieved in China (*Caixin Online*, 2010). State Grid aims to more than quadruple its overseas assets from USD 8 billion to at least USD 30 billion by 2020 (*Wall Street Journal*, 2012).

Brazil offers considerable bidding opportunities for the construction of transmission lines linking the Belo Monte dam, which is expected to start energy generation in 2015, to the national electricity grid (*Dow Jones International News*, 2012a). The first, so-called "Pre-Belo Monte" transmission auction was held in May 2013, paving the way for investments of BRL 5.3 billion (USD 2.4 billion).

Aside from establishing itself in a more lucrative market than at home, State Grid will gain expertise from its Brazilian venture in developing systems separating power grid and power generation facilities. This could be beneficial for further operations within the country, as well as for reforms to China's own power system.

Wind energy

Over the next five years, Brazil and China will be key drivers of growth in the global wind sector, with an installed capacity expected to hit 193 GW in China and 11 GW in Brazil by 2018 (IEA, 2013). Brazil's wind resources alone are estimated at more than 350 GW, at a height of 80 metres (m) to 100 m (GWEC, 2011). This growing market has therefore attracted increased interest from turbine manufacturers who look to establish production plants in the country in order to comply with the local content requirement and qualify themselves for project financing by the BNDES. Capacity additions are guided by government-sponsored power auctions held by the regulator, ANEEL, which award long-term (up to 30 years) power purchase agreements. Brazil's installed generation capacity from wind power rose above the 1 GW mark in 2011, with a total of 70 wind farms in operation. According to the Ten-Year Energy Expansion Plan 2011-2021, Brazil aims to reach over 15 GW of installed capacity by 2021.

Table 3 • Overview of Chinese investments and co-operation in the Brazilian wind energy sector

Year	Chinese partner	Local partner	Deal value (USD million)	Status	Means of entry
2010	XJ Wind Power	Brazil Santa Catarina state government	4 500	Announced	Strategic partnership (MoU)
2011	CTGC	Eletrobras (Furnas)	n/a	Confirmed	Strategic partnership (MoU)
2011	CTGC	Energias de Portugal (EDP)	3 500*	Completed	Partial acquisition (21.35%)
2012	CTGC	Eletrobras	n/a	Confirmed	Strategic partnership (MoU)
2012	Sinovel	Desenvix	Undisclosed	Completed	Contract
			TOTAL: 8 000**		

* Of total investment an estimated USD 732 million located in Brazil, including 84 megawatts (MW) of wind projects.

** Total investment figure includes EDP assets outside of Brazil.

Source: compiled by the IEA from news coverage and annual reports.

Brazil's wind energy industry is becoming increasingly competitive, with more players arriving and driving down prices, allowing wind to compete with other electricity sources. Rising competition among international equipment suppliers also contributed to the low bid prices that wind generators were able to make at concession auctions. The global financial crisis and a reduction in investment in wind energy in the United States and Europe attracted big wind manufacturers to Brazil, causing a significant reduction in implementation costs. High wind capacity factors may enable sustained profitability even at low prices, as Brazil's capacity factor of up to 50% at the best locations compares to an industry average in Europe of around 30%. Bid prices offered at concession auctions as low as BRL 88 per megawatt hour (/MWh) or EUR 31/MWh, increase the pressure to minimise costs for wind turbines – the major capital cost. Key factors including grid access through transmission and distribution lines and wind velocity are also important for projects competing for auctions. Responsibility for some project developers to offset additional grid connection costs has also reduced profit margins.

A further key variable in the development of the Brazilian wind sector are the funding conditions offered by the BNDES: In December 2012, the BNDES announced a new methodology, which qualifies producers for preferential funding if they meet at least three of the following four criteria:

- manufacturing of towers in Brazil, with at least 70% of the steel plates manufactured in the country or domestically reinforced concrete;
- manufacturing of blades in Brazil in their own plant or that of a third party;
- assembly of the nacelle (main part of the wind turbine) in Brazil, in their own plant; and
- assembly of the hub (the part that houses the nacelle) in Brazil, with a domestic dye-cast (BNDES, 2012).

This methodology does away with an earlier 60% national-content requirement for manufacturers and project developers seeking BNDES financing. It also provides more room for manoeuvre in meeting a range of requirements to meet Brazil's industrial policy objectives – namely to build high-skilled technical capacity and expertise – while providing more project developers some flexibility required to meet tight deployment timelines.

Opportunities in Brazil exist not only for equipment manufacturers, but also for Chinese project developers interested in overseas markets. China's wind energy industry has experienced challenges since the National Energy Bureau released the second round of wind farm projects in April 2012, as part of China's 12th Five-Year Plan (2011-15), with a total generation capacity of 14.92 GW, nearly half the size of the first round (28.83 GW). This reduction reflects the Chinese government's aim to control the pace of wind farm construction to prevent it outpacing growth of the grid and increases the incentives for Chinese wind firms to look for markets abroad (*Windpower Monthly*, 2012c).

XJ Wind Power

Co-operation between China and Brazil in the wind sector is a fairly recent phenomenon. State Grid, the first Chinese company to enter the Brazilian market, signed an agreement with the state government of Santa Catarina in December 2010. The co-operation agreement involves State Grid's subsidiary XJ Wind Power, in future state development projects of 2 000 MW by 2014, with a total estimated investment value of about USD 4.5 billion (The Trade Council of Denmark, Beijing, 2011). However, to date these projects have not materialised, as State Grid concentrates on projects in the transmission sector. Despite the lack of wind project investments, representatives from XJ Wind Power are on the advisory board of the bilateral China-Brazil Technology Centre (see sub-section "The China-Brazil Center for Climate Change and Innovative Technology for Energy" for more details).

CTGC in Brazil

In September 2011, CTGC established a basis for its co-operation with Furnas, a subsidiary of Eletrobras, through an agreement to partner mainly on wind projects. The six-year agreement targets joint identification of technical and commercial opportunities within the renewable energy sector, as well as through the exchange of technology and expertise. The company values CTGC's technology and their ability to provide good equipment at a low cost (*Recharge News*, 2011).

In late 2011, CGTC successfully outbid German company, E.ON, and Brazil's Cemig and Eletrobras in the tender for a 21.35% stake in the Portuguese energy utility, EDP. The Portuguese government sold EDP's stake under the terms of a rescue funding agreement with the International Monetary Fund (IMF) and the European Union. EDP's wind industry expertise and renewables technology were attractive components for CTGC, along with EDP's renewables subsidiary, EDP Renováveis (EDPR). EDPR is the world's third-biggest wind power producer, with installed capacity of about 7.3GW across eight countries. At the end of 2011, EDPR S.A. owned and operated a wind farm with a generation capacity of 84 MW and a project pipeline of 1 614 MW (EDP, 2011). The prospect of expansion into Latin America made EDP's assets more attractive to CTGC. EDPR is also a potential partner in China, with the necessary experience required for Chinese offshore plans. Furnas and CTGC have invited EDPR to participate in a previously established JV to develop an offshore wind farm with a capacity of 200 MW off Jiangsu province in eastern China (*Windpower Offshore*, 2012).

Sinovel in Brazil

Chinese wind turbine supplier, Sinovel Wind Group Corporation (Sinovel) provides another example and approach to Chinese engagements in Brazil's wind sector. In 2011, Sinovel signed a contract to supply 23 turbines of 1.5 MW to the Brazilian renewable power generating company, Desenvix. The turbines will be used for a 34.5 MW wind farm in north-east Brazil (Renewable *Energy Magazine*, 2011). This deal makes Desenvix the first South American developer to buy Chinese wind turbines. High cost pressures in the Brazilian market make the lower cost Chinese turbines and technology more attractive. Following this sale, Sinovel has considered establishing a wind turbine manufacturing facility in the country (*Renewable Energy Magazine*, 2011). Desenvix has also received USD 55 million from the CDB, reflecting a wider trend in the financing of projects in Brazil.

For all the enthusiasm in Brazil about the potential of low-cost turbines from China, a potentially inhibiting factor consists in allegations of IPR infringements by Chinese turbine manufacturers. In July 2012, Desenvix filed a court case against Sinovel over allegations that the company stole turbine software codes from a former supplier, United States (US) components manufacturer, American Superconductor (AMSC). Sinovel was already sued by AMSC in China in 2012 (*Financial Times*, 2012). Depending on the outcome of this case and broader considerations of IPRs, project developers may continue to face such challenges when sourcing components from China.

Drivers of Chinese investments in the Brazilian wind sector

Chinese investments in the Brazilian wind sector have evolved quickly since 2010. As the global wind industry has experienced increased consolidation, overcapacity issues, increased competition and some policy challenges (several markets may reduce wind sector specific subsidies), growth of the wind sectors in China and Brazil provide significant opportunities. Chinese firms are also eager to expand abroad and specifically into Brazil's thriving market as a recent demand slowdown in China halved the number of wind farm projects in the country's 12th Five-Year Plan.

Furthermore, policies such as the Programme of Incentives for Alternative Electricity Sources (PROINFA) initiated by Brazil's Ministry of Mines and Energy, and developments in the auction system may provide an opportunity for large-scale deployment if the current trends that led to competitive bidding continue, in line with Brazil's 2020 wind deployment target. This opportunity for both onshore and potential future offshore projects makes the Brazilian wind sector uniquely attractive to develop Chinese integrated wind projects at more competitive pricing, while building from established technology and project development experience. The initial cost advantage for turbine manufacturers, gear boxes, etc., puts Chinese wind turbine manufacturers in a good starting position. Establishing partnerships in China's offshore market could also bring a big upside for actors such as CTGC if Brazil's offshore potential is tapped. Offshore wind on China's coast is close to demand centres, similar to Brazil's potential offshore sources, which could mean considerable transferable expertise.

State Grid's MoU with the government of Santa Catarina State (see Figure 3) has not yet resulted in the construction of new wind farms, the reasons for which remain unclear. However as these developments are rather recent, State Grid's activities in transmission and grid infrastructure may prove beneficial for furthering this wind farm partnership. CTGC has pursued a different approach by engaging directly with Eletrobras (Furnas), which has even led to the consideration of a future partnership with CTGC for the next power generation auction (*Windpower Monthly*, 2012b).

Sinovel was the first Chinese wind turbine manufacturer to sell to a Brazilian project developer, with financing assistance of USD 55 million from the CDB. CDB's loans play an important role in China's "going abroad" strategy – the international expansion of the country's firms in order to secure energy supply and natural resources, build national champions and acquire advanced technologies (Downs, 2011).

According to the Chinese Wind Energy Association, while Chinese manufacturers are encouraged to "go abroad", government support beyond assisting registration of Chinese firms abroad and navigating local requirements may be limited. However, government actions in larger World Trade Organisation (WTO) discussions are important in mediating ongoing trade disputes that could impact overseas operations (IEA, 2013). Chinese wind firms appear more focused on exporting their products than pursuing operations in China. As Sinovel seeks to develop its capabilities for the Brazilian wind market, the future support of CDB is rather important. However, if plans to develop local manufacturing capacity are executed, potential for securing financing from the BNDES will increase. Such developments may be helped by Brazil's plans for rapidly developing its industry, which have already led to a relaxation of the local content requirement, originally set at 60%, but replaced by the current system of phases and physical targets.

However, recent allegations of IPR infringements faced by Sinovel could raise ongoing concern and undermine Chinese technology providers' cost competitiveness and successful partner relations, particularly if similar allegations surface in the future. To the extent to which the development of the Brazilian wind sector depends on the availability of low-cost Chinese technology, the resolution of these allegations will be an important factor in determining the future pace of investments and trade in wind energy components.

The potential for Sino-Brazilian technology transfer: capabilities and needs of key participants

Energy has long been one of the main focus areas of China's national science and technology strategies. In the 1980s and 1990s, the attraction of inbound FDI into JVs with local partners was considered the main avenue to cutting-edge technology. When China opened its coast to oil exploration in the 1980s, it fostered JVs between CNOOC and IOCs to acquire offshore capabilities (Warhurst, 1994). Similarly, the 1996 "Riding the wind programme" tried to encourage establishment of JVs between Chinese firms and global wind technology leaders. However, the "trade market access for technology" approach in some cases had limited success, since foreign investors largely preferred to install fully owned subsidiaries (Klagge, Zhigao and Pedro, 2012).

Direct government funding for domestic R&D has therefore played a significant role in Chinese technology development, *e.g*. the 11th National Five-Year Development Plan for Science and Technology (2006-10) called to focus on energy-saving technologies, 2 MW to 3MW wind turbine commercialisation, and UHV transmission technology and equipment (Tan, 2012). In the longer term, however, China aims for enterprises and the business sector to become the driving force of the innovation process (15-Year Plan for Science and Technology 2006-20) (Schwaag Serger and Breidne, 2007). In this context, the acquisition of technology by outbound FDI will have to make a significant contribution.

Indeed, the growth of Chinese investments in the Brazilian energy sector underscore the potential for technology transfer in the sense of "processes covering the flows of know-how, experience and equipment" including the "process of learning to understand, utilise and replicate the technology [and] the capacity to choose it and adapt it to local conditions and integrate it with indigenous technologies" (IPCC, 2000). The following sections take a closer look at the technological capabilities and needs of key actors involved in tapping this potential – at the inter-firm level, as well as the level of intergovernmental dialogue.

Inter-firm technology transfer

The most dynamic field of technology transfer between Brazil and China is driven by interactions between individual firms, via trade in components, joint operations or joint R&D. Both countries rank high in international comparisons of corporate R&D spending: out of the top ten companies from emerging economies in terms of R&D spending, six are from China and two are from Brazil, including Petrochina and Petrobras (EC, 2011).

Oil and gas

Petrobras-Sinopec

Petrobras is the largest oil and gas producer in Brazil, producing 2 mb/d of crude oil, condensate and natural gas liquids in 2012 and 21.8 bcm of natural gas (59.6 million cubic metres per day). Following a strategic decision by the Brazilian government to become independent of oil imports, the company developed technology leadership in deep water exploration over the past four decades (Dantas and Bell, 2011). Sinopec is China's largest oil refiner and petrochemical producer, with a refining throughput of 217 million tonnes in 2011. Its specialty lies in the ability to process increasingly sour crude oils imported from the Middle East and to produce a high proportion of light-finished products. Upstream activities are a secondary business area accounting for about 20% of revenue. In 2011, the company produced 0.88 mb/d of oil and 1.4 billion cubic feet per day of natural gas (IHS, 2013).

Though Sinopec has engaged in large-scale projects in China, including the country's second-largest oilfield in Bohai Bay, it lacks overseas E&P expertise, and its extracting and treatment equipment, and key electronic instruments are imported or assembled in China (Carvalho and Goldstein, 2009). However, Sinopec intends to enter the upstream sector in a much more determined manner in the future, making Petrobras a priority target for technology transfer. While it seeks to enhance its overseas E&P exposure, it may be well-positioned to offer its refining expertise, since Petrobras will need to adapt its refining and petrochemical capabilities to changing demand patterns and new feedstock, and could profit from Sinopec's long-standing expertise in refining. However, potential technology transfer may be limited by the characteristics of Campos basin crude oil (high acidity, nitrogen compounds), which demand additional technologies.

Diverging technology profiles may create a hurdle to co-operation for potential R&D activity. In 2011, Petrobras spent USD 1.4 billion on R&D, equivalent to 1% of its sales revenues. The company engages closely with engineering departments of several universities, especially the University of Campinas and the UFRJ. The technological leadership in deep water oil production has incentivised 14 of the NOCs' suppliers to install joint R&D centres in Brazil, including Schlumberger, Baker Hughes and FMC Technologies. Sinopec on the other hand, spent USD 775 million on R&D in 2009 (Sinopec, 2010) and has eight research centres, including one on petroleum engineering. However, the company is not among those that have been invited to install their researchers in Petrobras' research centre in Rio de Janeiro, although the two companies have concluded a technological co-operation agreement for exchange of expertise in geophysics, geology, reservoir engineering and assessment.

In terms of operational learning, the Sinopec-Petrobras JV on shallow water blocks will likely not provide Sinopec with exposure to frontier technology. At this point, Petrobras seems unwilling to share its expertise with less experienced players.

Oil and gas: other actors

In the 1980s, when Petrobras was still in the process of developing its deep water expertise, it entered into a technology transfer agreement and JV with CNOOC for offshore exploration in China. Amid growing Sino-Brazilian energy relations, CNOOC was outpaced in the Repsol bidding process by Sinopec, which has been more assertive in developing concrete projects on the ground (*e.g.* the Gasene pipeline). Petrobras has also been more reluctant to share its expertise with CNOOC. Despite this, CNOOC has acquired deep water expertise elsewhere. In 2006, CNOOC acquired a 45% working interest in OML 130 in Nigeria, where Total acts as operator and Petrobras participates with a 16% stake. CNOOC has invited foreign companies to bid for 26 more offshore blocks in China in a second round of joint development tenders and has expanded its activities in the South China Sea.

Sinopec's engagement with Repsol holds further potential for technology transfer: Repsol is recognised for its *Proyecto Calaidoscopio*, currently the world's fastest seismic imaging system, which uses supercomputers to process data gathered by exploration and drilling.[7] In March 2012, Repsol-Sinopec announced that R&D investment in Brazil will increase by ten times over the next four years, from USD 2.75 million in 2012 to around USD 27.5 million in 2016. This investment coincides with the start of production in the Sapinhoá (formerly Guará) field in 2013 and the Carioca prospect in 2016. Since 2006, the company has invested USD 16.5 million in Brazil. Repsol-Sinopec's R&D focuses on petrochemical areas rather than petroleum engineering, particularly biodegradation, glycerin acetates, drilling fluids and paraffin deposits. This reflects Sinopec's expertise in this area and indicates Repsol's interest in keeping E&P-related R&D efforts separate

[7] A joint R&D project with IBM, Centro Superior de Investigaciones Científicas, Universidad Politécnica de Cataluña and Stanford University.

from the research in Repsol-Sinopec. Finally, despite a co-operation agreement with Petrobras, Sinochem has started to focus its practical co-operation on smaller oil operators in Brazil. In particular, the farm-out agreement with French independent drilling company Perenco and Brazilian OGX Petroleo e Gas could expose the company to deep water E&P technology (up to 2 000 m water depth); however, the details of the agreement have yet to be disclosed.

The participation of CNPC subsidiary Baoji Oilfield Machinery Company in the JV between two Brazilian partners provides a direct channel for technology transfer. However, the company's products remain on a relatively low technological level (*e.g.* mud pumps and cranes), so that the potential for actual technology transfer in this bilateral relationship is limited.

Power transmission

COPEL – State Grid

The Tele Pires transmission consortium brings together two different players in terms of size. COPEL is a regional generation and transmission company that accounts for 6% of Brazil's electricity production, 2 000 km of transmission lines and 31 transformer stations, as well as 6 500 km of optical fibre cables in the state of Paraná. Its own generation park of 4500 MW of installed capacity is almost exclusively hydropower (except a 20 MW coal plant and a wind park of 25 MW). State Grid is one of two transmission and distribution companies in China, operating 160 000 km of transmission lines at 220 kV, satisfying 80% of Chinese power demand.

However, there is significant potential for technology transfer since COPEL is among the pioneers in the area of smart grids in Brazil. By 2014, the company plans to invest more than USD 330 million in projects related to smart grids until 2014. The local government's main objective is to transform the state capital, Curitiba, into a "digital city". In 2011, State Grid also announced plans to invest USD 250 billion in electric power infrastructure upgrades over the following five years; USD 45 billion was earmarked for smart grid technologies. It expects to add an additional USD 240 billion between 2016 and 2020, with USD 45 billion for smart grid technologies (Hart, 2011).

In China, State Grid is confronted by excess intermittent supply in the windiest regions of China, which requires new UHV power lines to shift excess elsewhere, but also management and forecasting tools to maintain grid stability, active and reactive power flow control, and low-voltage ride-through (LVRT) technology (China Greentech Initiative, 2011).[8] In all of these areas, COPEL has similar interests, due to its reliance on large hydro and the intention to venture into wind energy. As State Grid develops its capabilities in wind energy expansion, both in China and Brazil, synergies may develop in this collaboration with COPEL. Given the relative size and scale of operational experience, and ability to focus resources in an integrated grid company, State Grid may be well-positioned to contribute its resources and experience as COPEL expands its business in smart grid and transmission deployments.

State Grid vertically integrated its operations in 2009 by acquiring a 60% stake in leading domestic electric power equipment manufacturer, Xuji Group. After completing 228 smart grid demonstration projects, State Grid established standards for technology adoption and is eager to export these standards abroad to secure markets for its products (China Greentech Initiative, 2012). In 2010, the company spent 6.1 billion yuan (USD 988 million) in technical R&D (State Grid, 2011). State Grid's research centre has set up an industrial cluster headed by NARI Group Corporation, which will turn research results into marketable products for export.

[8] LVRT capability keeps wind turbines from shutting down when there is a large voltage dip on the grid, thus increasing the reliability of supply.

Transmission: Other actors and opportunities

Brazil's high-level representatives, have shown interest in Chinese smart grid and transmission technologies. In June 2012, the President of the Chamber of Deputies of Brazil, Marco Maia, visited NARI Group and expressed interest in deepened energy co-operation between the two countries (State Grid, 2012a). State Grid provided power to the 2008 Olympic Games in Beijing and 2010 Shanghai World Expo; several large events are upcoming in Brazil. The provision of power supply to the Fédération Internationale de Football Association (FIFA) World Cup was recently awarded to Furnas (Eletrobras), which could provide a first opportunity for them to co-operate with State Grid in the future.

China and Brazil share similar needs and geographic distribution of resources in developing their grid infrastructure, and integrating a large hydroelectric capacity and variable renewable energy transmission and grid infrastructure. From both a capital and technology perspective, both are likely to benefit from the demonstration, deployment and experience of operating projects together and applying existing experience to new projects.

Wind energy

CTGC (CTGC New Energy) and Furnas (Eletrobras)

The co-operation agreement between CTGC and Eletrobras seems promising and complementary given their respective capabilities. Eletrobras operates 42.3 GW of installed generation capacity in Brazil and 36% of total installed capacity in the country. This includes 37 hydro power stations, 127 thermal plants, two wind parks and two nuclear power plants. It also operates 61 534 km of transmission lines, about 55% of total transmission grid in Brazil and – via its subsidiary Furnas – has obtained the authorisation to build a further 17 wind parks with an installed capacity of 427 MW, making the company one of the most ambitious players in the Latin American market. Eletrobras is the second-largest corporate investor in R&D in Brazil (after Petrobras) and maintains the largest research network in the Latin American electricity sector with close to 90 labs and technology centres. One of the highlights in this network is the Electrical Research Center (CEPEL) with 35 labs, 500 employees and a budget of BRL 162.3 million (USD 74 million) in 2010. Main areas of research include monitoring and diagnostics, energy efficiency and transmission technologies.

CTGC operates the 22.5 GW Three Gorges Dam, however, since 2008, via its subsidiary, CTGC New Energy, it has ventured into renewable energy beyond hydropower, particularly with regard to wind. CGTC currently operates 1 GW of wind power capacity and solar development projects. It also has a 13.7% stake in wind turbine developer, Goldwind, among other minority stakes in various technology enterprises, including: Xinjiang Wind Energy Company Ltd. (43.44% CTGC stake); Sinoma Science and Technology Company, Ltd. (4.70% CTGC stake); Sinoma Wind Power Blade Company, Ltd.; and Tianjin Xinmao Xin Wind Energy Technology Company, Ltd.

These investments and partnerships reflect a growing technology capability that contributes to the presence of CTGC technology in Brazil, as well as Latin America. In 2011, Goldwind won a 20-year contract for the 16.5 MW Villonaco project in Ecuador in a tender held for Chinese companies last year through Ecuador's electricity company, Celec (*Recharge News*, 2012). CTGC's main focus is as a wind project developer, but it continues to grow its wind operations through the acquisition of manufacturing capacity and partner developments, which position the firm as a technology provider. Recent developments have also signalled that Chinese power companies, which also have technology subsidiaries, are increasingly favoured in Chinese wind farm contracts and may be better positioned to offer a range of services in expanding markets in the future. In this context, this integration for both CTGC and Eletrobras offers important technical and operational capability in connecting wind generation to grid infrastructure, a key challenge that faces growing markets.

Sinovel-Desenvix

Sinovel's expansion in foreign markets over the past five years has enabled more competitive bidding for projects at a lower cost than other international firms. China's strategic advantage as a low-cost manufacturer of wind power components has enabled China to compete with gas projects in competitive Brazilian power auctions.

Sinovel has positioned itself as a global R&D leader, being the first company in China to develop advanced 5 MW and 6 MW series wind turbines. It partnership with Shanghai Jiaotong University in a wind energy R&D centre was approved by the Chinese National Energy Administration (NEA)[9] to develop offshore technology (Klagge, Zhigao and Pedro, 2012). Sinovel has also produced a 3 MW series of onshore, offshore and intertidal wind turbines. The company supplied all 34 wind turbines of 3 MW for the Shanghai Donghai Bridge Offshore Wind Farm, which is the first offshore farm built outside Europe and China's first demonstration offshore farm. However, in developing its 3 MW turbine, Sinovel partnered with AMSC and did so for all of its 1.5 MW turbines (Bloomberg News, 2012).

Sinovel is building the National Energy Offshore Wind Power Technology and Equipment R&D Centre, which according to their website utilises "cutting-edge technologies, state-of-the-art equipment, and leading R&D and laboratory capabilities". It is also constructing an integrated base for the manufacturing, assembly, testing, ocean transportation and ocean installation service for large-size offshore wind turbines. Sinovel's strategy is to develop large-capacity wind turbines in order to achieve higher gross profit margins and significantly raised proportions of 3 MW, 5 MW and 6 MW turbines in its order structure (*Windpower Monthly*, 2012a).

Brazil's Desenvix has a portfolio of renewable energy assets of 221 MW in operation, 116 MW under construction, as well as a large portfolio of projects under development of about 1 600 MW. The assets are mainly hydropower, located in the south and south east regions of Brazil, but also include two wind farms and a biomass plant under construction. The trade relationship between Sinovel and Desenvix – the first ever importer of Chinese wind energy components – could pioneer larger-scale technology flows, involve further players on both sides, and create knock-on effects to Brazil's manufacturing capacity.

The global wind industry is increasingly specialised across suppliers of blades, gearboxes, electric generators, hubs, main shafts, bearings and other components, including electronics and software and services. While China maintains leadership across these areas, there is some concern over production quality of turbines and components. For instance, thousands of China's turbines lack more expensive technology that keeps them operating amid disturbance on the power grid, as recently experienced in April 2011 with a large-scale disruption across wind farms in two provinces. LVRT capability can address this problem; however, it requires costly software enhancements powered by AMSC electronics, Sinovel's American partner company. In 2010, Sinovel's Chairman created a new company, Dalian Guotong Electric, to directly compete with AMSC. This action has given rise to IPR infringement accusations by AMSC and has led to a law suit against Sinovel by Desenvix.[10] However, in September of 2012, Desenvix dropped their case and received a loan from CDB for a 34.5 MW wind farm, emphasising the drive to deploy and fund projects in Brazil.

Wind: Other actors and opportunities

China's recent drop in demand has hurt Chinese wind manufacturers, as three-quarters of listed companies predicted a decline in performance forecasts in 2012. Goldwind and Sinovel saw an

[9] In 2010, the NEA approved 38 such R&D centres, five of which were wind energy related (Klagge, Zhigao and Pedro, 2012).

[10] AMSC's claims that Sinovel is using their source code to operate the software on Sinovel turbines, while reneging on their AMSC 20-year service contract.

estimated decline of over 50%, and the two companies are now downsizing, curtailing expenses and closing plants. In May 2012, Sinovel dismissed 350 graduates, 80% of the staff recruited for 2012 including R&D and project development (*Windpower Monthly*, 2012c). As market opportunities develop in Brazil, China may need to develop further collaboration with local academic R&D institutions to offset a reduction in capabilities, while also helping to meet local content requirements.

In 2010, Brazil had a total wind turbine manufacturing capacity of 1 500 megawatts per year (MW/yr), led mainly by JVs and global manufacturers, including market leaders Wobben, Impsa, and Gamesa. In recent years, local content requirements and market conditions have brought several other international players into the manufacturing supply chain. For rotor blades and wind towers (with a total capacity 2 000 MW/yr and 1 600 MW/yr, respectively), there is increasing leadership from indigenous Brazilian firms, including: TECSIS, based in Sorocaba, Brasilsat, Engebasa and Tecnomaq, among others (GWEC, 2011). Since 2010, a host of firms, including Chinese manufacturers, have considered developing increased local manufacturing capacity. In addition, turbine manufacture China Guodian United Power Technology has announced possible entrance into Brazil's wind market and the establishment of wind turbine manufacturing facilities. According to the Global Wind Energy Council, Brazil is poised to be a major manufacturing hub for completed wind turbines and for partly assembled parts in Latin American (Cleantech Investor, 2011).

State-sponsored technology transfer

Initial approaches to technological co-operation between Brazil and China in energy-related areas date back to the 1980s when the first bilateral agreement on scientific co-operation was signed (1984), followed by specific agreements in the areas of peaceful uses of nuclear energy (1984), geosciences (incl. marine geology, 1985), the agreement on joint development of the China-Brazil Earth Resource Satellite (CBERS), as well as co-operation in the electricity sector, incl. large hydro (1988) and small hydro (1995).

The flagship success of bilateral technological co-operation is the CBERS satellite programme. Since 1988, three earth observation satellites have been launched and another three launches are planned by 2016. CBERS' publicly available imagery is used in Petrobras to map environmental sensitivity, monitor pipelines and reforestation efforts, as well as for impact assessments. Future applications may include the mapping of wind energy potential and real-time monitoring of oil spills. Notably, when it comes to the specific purpose of using remote sensing in oil exploration, Petrobras co-operates with a Japanese partner (Japan Space Systems). Also, on occasion of developing a new satellite to monitor Brazilian coastline and oil exploration, the Brazilian Space Agency preferred to co-operate with Argentina (Sabiá-Mar Satellite). This indicates certain reluctance on the part of Brazil to engage with China in this more sensitive area.

China-Brazil technology co-operation agreements on energy

More recently, Brazil and China have set strategic priorities in the development of joint technology programmes and increasing investment by private and state-owned companies in developing projects. In February 2009, the two countries signed a protocol of energy and mining co-operation that covers a broad range of activities – information exchange, joint R&D, and the promotion of JVs to increase trade in energy equipment (Itamaraty, 2009). In 2010, as a result of negotiations in the CBHCCC, then-President of China, Hu Jintao, and then-President of Brazil, Luiz Inácio Lula da Silva, signed a joint action plan, which contained an entire section on energy and mining to guide bilateral co-operation over 2010-14. These agreements will enhance engagement on oil trade, oil exploration and development, financing, engineering services and equipment, as well as mutual investment in the oil and gas supply chain.

The action plan not only reiterates the commitment to "promote the implementation of a number of important investment co-operation projects in the energy and mining sector", but it also stresses the intention of co-operation on renewable energy (wind, solar, hydropower and biofuels and biomass) as well as nuclear energy and the promotion of each other's energy technologies. One model of co-operation is the China-Brazil Center for Climate Change and Innovative Technology for Energy, established in 2009, it brings together experts from leading research and engineering institutions at Tsinghua University with the UFRJ's Alberto Luiz Coimbra Institute for Graduate Studies and Research in Engineering (COPPE).

The China-Brazil Center for Climate Change and Innovative Technology for Energy

In the framework of the China-Brazil Center, the two countries intend to build technology co-operation and develop partnerships in four initial areas: biofuels; wind energy; deep water oil; and CCS technologies. These activities will foster academic and business links, support new technology development and identify areas for the creation of economic clusters. The centre is sponsored by the Brazilian Science and Technology Ministry via its Innovation Agency Financiadora de Estudos e Projetos and supported by funds for research from ANEEL. It is headed by an academic executive board and an advisory council, which includes many industry representatives. For Brazil, MPX Energy, Petrobras, Vale and the BNDES are represented on the council. China has nominated National Biomass Energy Company Ltd. (25% owned by State Grid), XJ Wind Power (100% owned by State Grid), as well as the Chinese branch of the Danish company Novozymes.

In the area of wind power, the first aim is to adapt wind power generators to the prevailing winds in Brazil. Growth in this area could hinge on the progress made by the centre's council member, XJ Wind Power, and its wind projects in Santa Catarina state. Additionally, according to the chair of the centre, immediate projects have focused on developing near-term opportunities in biodiesel technology and have established Chinese solar thermal applications in the Brazilian market.

In the area of biofuels, the main goal is to evaluate Brazilian and Chinese state-of-the-art technology and suggest public policies for bilateral co-operation. A project involving a two-month research stay by Brazilian researchers in China consists of the assessment of biodiesel production costs including the question of optimal usage of vegetable oil and its residuals. Over the past ten years, China has introduced an enzymatic catalysis process for biodiesel production, but given resource scarcity and feedstock choices in China, Brazil may be a future user of such technology.

In the area of CCS, the centre aims to identify the most promising technology and elaborate a research roadmap. As established by several national R&D policies and coal technology development plans, China has continued to invest in CCS technologies across a range of technical and research areas. This includes applications across a range of capture technologies, such as post-combustion, pre-combustion and oxy-fuel combustion capture processes. A considerable amount of research goes into identification of suitable subsurface storage sites, and behaviour and application of CO_2 in the subsurface. Several small-scale demonstration projects have been launched in China, with an emphasis on identifying near-term uses for the CO_2 captured from these processes. In recent years, Petrobras has also engaged in some early research into CCS applications. In terms of future CCS R&D efforts as part of this collaborative relationship, fluidised bed combustion and supercritical combustion seem to raise the most interest on the Brazilian side.

In the area of deep water oil technology co-operation, COPPE agreed to academic exchanges with China University of Petroleum in subsea technology and floating systems. In addition, the centre aims at including Brazilian and Chinese oil companies and suppliers in a joint effort for the development of technology for deep water applications.

An alternative channel for technology transfer?

In general, co-operation across defined focus areas remains at a very early stage with partners still evaluating the potential for co-operation; it is thus difficult to assess the future potential of technology co-operation and joint projects. However, increasing academic exchanges in the area of petroleum engineering provide a new avenue of technology transfer and operational learning potential for Chinese investments in Brazil. While this collaboration has focused on identifying near-term commercial applications, research in other areas is likely to depend on sustainable funding sources to drive these longer-term collaborations, once the incipient academic co-operation consolidates.

Conclusions

Despite growing investment and bilateral co-operation across the energy sector, technology transfer between China and Brazil has yet to reach its full potential and faces several challenges.

In the area of deep water oil, Petrobras has little incentive to share its technology with Sinopec, given the NOCs' lack of expertise in this area. The same applies to Repsol within its JV, Repsol-Sinopec. Going forward, Brazil and China will have to make use of the academic channels for initiating co-operation. In the medium term, Petrobras' interest in upgrading its refining capacity could create a potential for a mutually beneficial relationship between the two.

In the area of wind energy, technology transfer is largely limited to turbine imports from China, which began only recently and immediately led to Brazilian involvement in a legal dispute over IP rights. However, mutual interest remains clear: Brazil would like to acquire low-cost, highly efficient equipment from China – or have it built in Brazil – to nurture its booming wind sector, while China can build its comparative advantage in serving this market by joint research, adapting Chinese components to specific local wind conditions in Brazil.

There is considerable potential in the transmission sector for applying Chinese smart grid and UHV technology in Brazil, while using Brazilian expertise in renewable energy (hydro) variability in China. Operational learning opportunities exist in the deployment of transmission and distribution lines suited to both Chinese and Brazilian geographies, leaving Chinese developers well-positioned in Brazil. The experience gained from such activities could be applied in the development of joint projects, both in Latin America and elsewhere. This is increasingly important as such partnerships may begin to out-compete other established European or US firms in a more competitive global wind market. Currently, however, Chinese transmissions activities are restricted to operating the acquired assets in Brazil, while Chinese companies are still in the process of familiarising themselves with the Brazilian market.

Across all areas, objectives of high-level agreements on increased technology transfer have yet to be realised. The lack of pronounced progress made is partly due to the fact that governments have less say in the international activities of their NOCs than the status as (partially) state-owned may suggest. The state-sponsored China-Brazil Center for Climate Change and Innovative Technology for Energy is designed to make use of some of the untapped potential of bilateral investments. However, the attempt to replicate the success of the joint satellite programme in other areas of technology will render different results, largely because of very different levels of capabilities on both sides.

Both China and Brazil are strategically applying local content requirements and technology standards to foster industrial development and ensure alignment of FDI alongside broader policy goals. Requirements and standards create obstacles to bilateral technology flows, *e.g.* by impeding access to finance by development banks and consequently preventing project deployment. To counter this, both sides have agreed to reduce such obstacles. As China's investment in key Brazilian sectors increases, a challenge for the country will consist in developing a track record for sustained overseas FDI that demonstrates Chinese firms' commitment to developing indigenous capabilities. China itself encourages foreign investors to support advanced manufacturing, the service sector, R&D, energy-saving and strategic emerging industries, as evidenced by the Foreign Investment Industry Guidelines, issued in 2011. This entails that Chinese firms will likely also be tested for their commitment to creating added value over the long term in Brazil (*China Daily*, 2012b). Issues over quality, reliability and sound socio-economic and environmental impacts will also weigh in.

Another interesting area of technology co-operation between China and Brazil lies in the context of the United Nations Framework Convention on Climate Change (UNFCCC). China and Brazil are uniquely placed to develop and adopt modalities for technology transfer with impact on broader technology transfer agreements at the international level. This bilateral partnership may present pioneering approaches that run in parallel to broad climate agreements. As China and Brazil are both eligible for financing from Annex I parties,[11] both could reap the co-benefits of technology transfer, while also accessing international funds sourced in developed countries. Additionally, if both engage in projects in other developing countries, it is possible that finance for projects they put forward using their own technologies may also be eligible for emissions reductions credits.[12]

The expanding ties in energy technology co-operation in this specific relationship may prove to have significant impact on the role of both China and Brazil in leading dialogue among Brazil, South Africa, India and China (BASIC) and Brazil, Russia, India, China and South Africa (BRICS) countries to contribute to producer and consumer dialogues, climate change, and energy access agendas. According to one of the directors in the China-Brazil Center for Climate Change and Innovative Technology for Energy, some of the partners in the center already aim to expand their activities in the BASIC countries. However, Sino-Brazilian efforts at technology transfer are still at an early stage of identifying capabilities, suitable project partners, and removing regulatory, IP and trade-related barriers.

In the longer term, there is potential for this relationship to grow into a significant bilateral technology partnership, especially in the wind and transmission sectors, where commercial interests can be expected to continue to drive co-operation. The intensification of such ties could result in a more rapid deployment of clean energy technologies in emerging economies, offering new avenues for climate mitigation. However, it could also contribute to increasing heterogeneity in global technology standards, if these countries work together exclusively. The IEA multilateral energy technology initiatives may provide useful channels for both to engage in exchange of international policy best practice, as well as to demonstrate technology innovation potential and leadership.

[11] Industrialised countries that were members of the OECD in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States.

[12] For instance, availability and requirements for financing of low-carbon technology deployment through the Global Environmental Facility, the Green Climate Fund, the Clean Development Mechanism and related approaches for nationally appropriate mitigation actions (NAMAs) may benefit the technology development, demonstration and deployment in this bilateral relationship.

Annex: method of patent data retrieval

Data for Figure 1 and Figure 2 were retrieved from the OECD patent database, section *Patents by Technology* (http://stats.oecd.org/Index.aspx?DatasetCode=PATS_COOP#), using the following parameters:

- **Patents office and triadic patents families**: patent applications filed under the PCT.
- **Reference country**: inventor's(s') country(ies) of residence.
- **Country**: IEA member countries.
- **Reference date**: priority date.
- **Technology domains and international patent classification (IPC)**: predefined categories were used where available (biofuels, CCS, heating, hydropower, insulation, solar energy and wind energy). In all other cases (drilling, exploration, power distribution and refining) IPC codes were used as listed in Table 4.

Table 4 • Categories used for patent data retrieval

Technology domains	Search category/IPC code
Biofuels	Database predefined category: **biofuels**.
CCS	Database predefined category: **CCS**.
Drilling	IPC category: **E21B**: earth or rock drilling; obtaining oil, gas, water, soluble or meltable materials or a slurry of materials from wells; database predefined category: **C09K**: Materials for applications not otherwise provided for, including: compositions for drilling of boreholes or wells (C09K 8/00).
Exploration	IPC category: **G01V**: geophysics, gravitational measurements, detecting masses or objects, including: radar, sonar, lidar or analogous systems specifically designed for geophysical use.
Heating	Database predefined category: **heating (including: water and space heating: air conditioning)**.
Hydro	Database predefined category: **hydro energy – conventional**.
Insulation	Database predefined category: **insulation (including: thermal insulation; double-glazing**.
Power distribution	IPC categories: **H02B**: boards, substations, or switching arrangements for the supply or distribution of electrical power; **H02G**: installation of electrical cables or lines; **H02J**: circuit arrangements or systems for supplying or distributing electric power, systems for storing electric energy.
Refining	IPC categories: **C 10C**: petroleum, gas or coke industries; **C10G**: cracking hydrocarbon oils; production of liquid hydrocarbon mixtures; **C10L**: fuels not otherwise provided for; **C10M**: lubricating compositions.
Solar energy	Database predefined categories: **PV energy and solar thermal**.
Wind energy	Database predefined category: **wind energy**.

Acronyms, abbreviations and units of measure

Acronyms and abbreviations

ACS	Actividades de Construcción y Servicios S.A.
AMSC	American Superconductor
ANEEL	Agência Nacional de Energia Elétrica (Brazilian Power Sector Regulatory Agency)
BASIC	Brazil, South Africa, India and China
BNDES	Banco Nacional de Desenvolvimento Econômico e Social
BRIC	Brazil, Russia, India and China
BRICS	Brazil, Russia, India, China and South Africa
BRL	Brazilian real
CBERS	China-Brazil Earth Resource Satellite
CBHCCC	China-Brazil High-Level Co-ordination and Co-operation Committee
CCS	carbon capture and storage
CDB	Chinese Development Bank
CEPEL	Eletrobras Electrical Research Centre
CNOOC	China National Offshore Oil Corporation
CNPC	China National Petroleum Corporation
CO_2	carbon dioxide
COPEL	Companhia Paranaense de Energia
COPPE	Alberto Luiz Coimbra Institute for Graduate Studies and Research in Engineering
CTGC	China Three Gorges Corporation
E&P	exploration and Production
EBITDA	earnings before interest, taxes, depreciation, and amortisation
EDP	Energias de Portugal
EDPR	Energias de Portugal Renováveis
Eletrobras	Centrais Elétricas Brasileiras
EUR	euro
FDI	foreign direct investment
FIFA	Fédération Internationale de Football Association
IEA	International Energy Agency
IMF	International Monetary Fund
IOC	international oil company
IPC	international patent classification
IPRs	intellectual property rights
JV	joint venture
LVRT	low-voltage ride-through
MOFCOM	Chinese Ministry of Commerce
MoU	Memorandum of Understanding
NAMAs	nationally appropriate mitigation actions
NEA	National Energy Administration (China)
NOC	national oil company
OECD	Organisation for Economic Co-operation and Development
PCT	Patent Co-operation Treaty
Petrobras	Petróleo Brasileiro S.A.
PROINFA	Programme of Incentives for Alternative Electricity Sources
PSC	production-sharing contract
PV	photovoltaic

R&D	research and development
Sinopec	China Petroleum and Chemical Corporation
UFRJ	Federal University of Rio de Janeiro
UHV	ultra-high voltage
UNCTAD	United Nations Conference on Trade and Development
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USD	United States dollar
WTO	World Trade Organisation

Units of measure

bcm	billion cubic metres
GW	gigawatt
km	kilometre
kV	kilovolt
m	metre
mb/d	million barrels per day
MW	megawatt
MW/yr	megawatts per year
MWh	megawatt hour

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