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# LOW CARBON CHINA: DISRUPTIVE INNOVATION AND THE ROLE OF INTERNATIONAL COLLABORATION

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## ABSTRACT

China is now the world's largest emitter of greenhouse gases and emissions are set to grow dramatically in the coming decades. Many hope that China can "leapfrog" to a new sustainable model of development, while others have launched strident attacks on its carbon footprint. The development of low carbon innovation, and innovation *capacity*, in China is crucial for the leapfrog scenario to prevail – as well as a goal that is in accordance with Beijing's existing policy of encouraging indigenous innovation (*zizhu chuangxin*). Yet while there is now some impressive low carbon innovation in China, overall capacity remains patchy and its progress is highly uncertain. The future development of such capacity hinges on policy to support it and the definition of "low carbon innovation" that these policies employ. Through an analysis of current developments in low carbon innovation in China (focusing on the energy sector in particular), we argue for the importance of two issues in the understanding of "low carbon innovation" that fit well with the existing state of Chinese innovation: "disruptive" innovation and international collaboration. Regarding the former – which we define as developing "cheaper, easier-to-use alternatives to existing products or services often produced by non-traditional players that target previously ignored customers" (Willis *et al.* 2007) – we argue such innovation plays to the existing strengths of China's innovation system. Regarding the latter, we argue that the challenge is to move towards *joint* international setting of low-carbon socio-technical trajectories, rather than that of Europe or the United States handing over ready-made (but non-existent) technological fixes to China.

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**Low Carbon China: Disruptive Innovation and the Role of International Collaboration**

**David Tyfield and James Wilsdon**

## 1. Introduction

Climate change as a result of global heating is amongst the gravest challenges confronting the world today. As a huge country undergoing unprecedented economic growth, China's contribution to global efforts to tackle climate change will evidently be crucial. This includes developments in "low carbon innovation" that will be a key ingredient in the shift to a sustainable mode of development. Indeed, there are hopes that China, being relatively unencumbered by various infrastructures and socioeconomic systems such as that of the car,,can "leapfrog" straight from developing country status to the very forefront of a new, ecologically-friendly form of prosperity, thereby skipping the high-carbon dependent growth model of current developed economies.

It is now widely recognised that climate change is not merely an ecological, but also irreducibly a social problem. The analysis of both climate and its interaction with social formations also has led to recognition of the need to assume a complex systems perspective (Rial *et al.* 2004). The challenge of climate change, therefore, is the challenge of moving from unsustainable and high-carbon to sustainable, low-carbon socioeconomic systems and on a global scale. This must also be effected within the stringent time constraints imposed by the ecological process of global heating. In this light, we argue that the goal of low carbon innovation must also be understood as the realisation of such a systems change and in good time.

Undoubtedly, China has enormous environmental challenges, but it is making important strides in low carbon innovation (Climate Group 2008). This progress, however, is both patchy and highly uncertain, making a single definitive statement on current prospects for low carbon innovation in China effectively impossible. One crucial factor in this regard is the way in which the central government's commitment to issues of climate change is crucially compromised by its (understandable) demand that global North makes significant strides first, seeing as the aggregated concentrations of GHGs remains overwhelmingly their responsibility. For their part, governments in the global North respond by saying that since China is now the national economy with the highest overall GHG emissions, and one in which these are set to continue to grow rapidly (IEA 2007), they cannot commit to a global deal unless China also comes on board. These positions spell deadlock, while time is too short to delay action any further.

Against this positioning, therefore, we argue here that, as a global problem and one without existing technological and innovative solutions – a point that is too often simply overlooked – the challenge of climate change is best understood from this geopolitical perspective as one of the *joint global setting* of the sociotechnical trajectory of change towards a low carbon systems transition. The way forward is thus neither continuation of the *status quo ante*, with a dominant global North trying to go it alone, nor a one-off jamboree of "technology transfer" handouts from the North to developing countries like China. Rather the key issue regarding China is a global governance regime for innovation that affords the establishment and development of Chinese innovation capacity, so that it can fully contribute to the *ongoing* global project of responding to climate change.

In this spirit of international cooperation, international collaboration in research and innovation has rightly begun to receive a lot of attention and is often seen as being crucial to the global effort against climate change. Certainly it will, *prima facie*, be a crucial part of the process of joint global setting of the trajectory of transition to a global low carbon society. It also clearly has an important role to play in the improvement of Chinese domestic capacity for low carbon innovation, especially given the time constraints. International collaboration, however, is not identical or completely co-extensive with the joint global setting of socio-technical trajectory, most obviously in that it need not always be beneficial to the improvement of Chinese low carbon innovation capacity, but may be just exploiting Chinese resources without significant domestic spillovers. Hence, in order to have policies that support international collaboration where it contributes to a global low carbon transition, we need to understand the differences between various forms of international collaboration and the diverse and many-levelled effects. In this paper we explore these issues on the basis of evidence collected on collaborative networks in low carbon innovation, primarily between China and UK.

The paper proceeds as follows:

In **Section II** we explore in greater detail the importance of China in the global effort on climate change and discuss the current policy situation in China regarding environmental protection, mitigation of emissions and adaptation. **Section III** then explores the definition of low carbon innovation and the importance of how it is defined for assessment of the current state of low carbon innovation capacity in China, as well as for recommendations on how it should be developed. We argue that a broad definition of "innovation" should be paired with a systems-transition understanding of "low carbon"

and that this leads to an understanding of the problem concerning low carbon innovation in China being one of how to maximize its contribution to the joint global setting of the socio-technical trajectory leading to systems transition. In **Section IV** we turn our attention to international collaboration and discuss the issues that affect the role of international collaboration in low carbon innovation in the light of the previous sections. We also present a framework for analysis of the various effects and diverse forms of international collaboration. This analysis is then furnished with empirical illustrations in **Section V**, where we discuss the current status of low carbon innovation and the role of international collaboration in one key sector, namely energy, in the light of some empirical case studies. Finally, we conclude with some policy recommendations.

*II: China and Climate Change*

The Intergovernmental Panel on Climate Change is not known for hyperbole. Its reports are the product of painstaking analysis and consensus building. But in February 2007, it issued its starkest warning yet. Its latest assessment, which drew on the expertise of 600 authors, 620 expert reviewers and representatives from 113 countries, concluded that average temperatures are likely to rise by four degrees Celsius towards the end of the century. The Panel concluded that temperature rises were the direct result of human action, through emission of greenhouse gases, particularly carbon dioxide. Climate change will result in food and water shortages, floods and extreme weather events, the displacement of hundreds of millions of people and the loss of numerous species (IPCC 2007). In essence, the IPCC said that climate change will be more severe than previously thought, and its impacts will be felt by rich and poor alike.

Climate change is now the urgent global problem.[1] And in the past five years, China's contribution to this problem has come under increasing scrutiny. China's staggering economic development is the primary cause of its environmental impact. While this growth has lifted more than two hundred million people out of poverty, it has come at a great environmental cost, to the extent that the outspoken head of China's (then) State Environmental Protection Agency (SEPA), Pan Yue, stated in 2005 that "the economic miracle will end soon because the environment can no longer keep up".[2] Similarly, Professor Li Zheng (2007), an expert in energy systems at Tsinghua University, reflects that while China is unlikely to run out of coal, it may run out of air. A World Bank report in 2006 concluded that 16 of the 20 most polluted cities in the world are in China.[3] Water pollution is also a serious problem, with huge lakes that provide water to millions

[1] See Lovelock (2006) & Monbiot (2006), which refer to "global heating" rather than mere warming.
[2] Quoted in Economy (2007). See also Economy (2005).
[3] See e.g. Watt (2005).

of people, such as Tai Hu bordering Jiangsu and Zhejiang provinces outside Shanghai, subject to terrible contamination and algal blooms.

China is also now the world's largest absolute emitter of GHGs, overtaking Japan in 2006 and the United States in 2007. One driver of this has been the rapid construction of coal-fired power plants to meet growing energy needs. China is already approaching the cumulative emission levels since 1960 of a small but highly industrialised economy like Australia, though its per capita emissions remain relatively low (approximately 25 times less than those of the US, and 10 times less that the UK's) (Wang & Watson 2007). Secondly, its emissions are growing rapidly. A recent report by the International Energy Authority (2007) reports that China (and India) is an "emerging giant" of the international energy market but that unfettered growth of its energy demand is "alarming".

These figures are the result of numerous factors. In energy, the primary source of emissions is industry, with economic growth taking the route of developing a massive industrial sector. Admittedly this includes much manufacturing expressly for export and hence is effectively an offshored form of the energy consumption of the global North. A recent report from the New Economics Foundation (2007) terms this process 'Chinadependence', and argues that "it is demand from countries like the UK which leads to smoke from Chinese factories and power plants entering the atmosphere. As a result, China has become the environmental or carbon 'laundry' for the Western world." This fact must also be borne in mind when comparing the energy inefficiency of China's industry to that of other countries in terms of GHG emissions per unit of GDP, which is 12 times lower than Japan's and even three times lower than India's: a more reasonable basis of comparison would be GHG emissions per unit of industrial GDP. Yet even on this revised calculation, China is highly inefficient in its consumption of fossil fuels. Growing domestic energy consumption and China's overwhelming dependency on coal, its most abundant domestic fossil fuel, are also major issues.

In transport and urban mobility, the process of urbanisation without precedent in human history and a massive increase in car use are singular problems facing China. Indeed, on one calculation, if China were to have the same density of cars as that of the US today, it would mean some 970m cars there, 50% more than the entire worldwide car fleet in 2003 (Girardet 2004). We have seen that climate change is not just about emissions though. In agriculture and land-use China also faces some severe problems. These include land shortages as urbanisation of small rural settlements takes over arable land, over-fertilisation, over-grazing and land degradation, all of which threaten

biodiversity and increase the carbon footprint of agriculture. Inefficient farming practices that produce great heaps of straw that can only be burned also create large amounts of GHGs and soot, which has the effect of temporary cooling but long-term warming of the atmosphere (Pearce 2007).

In agriculture, China has some 20% of global population but only 8% of farmable land and food demands look set to increase as incomes rise, both directly through larger portions and indirectly through greater consumption of meat.[4] The country is also already facing severe shortages of water in populous northern areas and extraordinary rates of desertification. Already 4% of the entire land surface of China is human-created desert, adding to the existing 14% of natural desert (Alleyn 2007). Sandstorms from the deserts encroaching on the city are now regular events in Beijing during several months of the year. Similarly, the great Yellow River does not reach its mouth during the dry summer months. On the other hand, while water is relatively plentiful in the south, the melting of Himalayan glaciers and increase in freak weather patterns are causing a commensurate increase in the frequency of major floods. Both of these trends would be massively exacerbated by climate change (Lynas 2007).

Furthermore, with over 60% of the population still rural peasants, these environmental changes will hit hardest a huge and politically explosive section of Chinese society; the section of Chinese society traditionally responsible for repealing the "Mandate of Heaven" and effecting regime change. A taster of the political repercussions of such developments is already in evidence, with the existing environmental problems eliciting ever-higher levels of popular discontent and unrest, adding to the 90,000-odd disturbances officially reported in 2006. The cruel irony, however, is that these environmental problems are being created by the very process of development that has proven so successful in economic terms over the past 30 years and the continuation of which the Chinese government considers to be equally crucial to political stability. In short, China's current model of development is increasingly confronted by a tension between continuing economic growth and environmental catastrophe.

Taken together, then, all these issues put China at the heart of the inseparable issues of climate change, development and the global economic order and make it something of a crucible for the profound social and political changes these issues entail. Given the importance of China to these issues, it is encouraging that China's government is increasingly taking environmental issues seriously. This can be seen in a legislative drive

[4] Greater meat consumption also threatens to increase livestock, the GHG emissions from which have considerable impact regarding climate change.

regarding climate change, renewable energy and fuel-efficiency in cars and the upgrading of SEPA to Ministry level, as well as in the slogans which set the agenda for government, of sustainable economy, harmonious development and scientific development. In June 2007, the State Council announced China's national climate change programme and set up a 'National Leading Group' on climate change, energy conservation and pollution control, headed by Wen Jiabao. Investment in renewables is rising fast, with around 1300MW of new wind capacity installed in 2006 and at least 250 research projects underway on new energy sources.

To be sure, problems of implementation remain, in particular of central government policy at the local level, where demands of economic growth continue to trump environmental concerns. But popular unrest and a rising environmental movement are adding to the political pressure. China's leadership now recognises that it in China's national self-interest to embark as a matter of urgency upon the transition from a high to low carbon society. But to do this will require new and sustained forms of low-carbon innovation. It is to this challenge that we now turn.

*III: Defining Low Carbon Innovation and the Effect on Assessment of LCI in China*

Carbon use is embedded into everyday life. If China is to reduce its carbon emissions drastically, it will have to create an economy that places greater value on carbon, and rewards those who reduce it. It will need to develop different ways of building, travelling and shopping, and it will need innovators who can use these alternative pathways to develop successful products, services and business models. [5] However, it is difficult to predict how and where these radical shifts may occur. Much will depend on the broader health and dynamism of China's innovation system. The central policy platform here is the 15-year Medium to Long Term Plan of 2006, in which the explicit goal of making China a global leader in science & innovation by 2020 is set out.

While China has long been established as a location for low-cost manufacturing, it is now making a concerted effort to move "up the innovation value chain" and to develop "indigenous innovation" (*zizhu chuangxin*, 自主创新). Since 1999, its spending on R&D has increased by more than 20% each year and the ambitious 15-year plan aims to boost investment to 2.5% of GDP by 2020. As such, while the development of China's STI capacities started from very humble beginnings in the late 1970s, the high levels of investment are yielding significant results, as reflected in recent scientific publications and citations, patents and flows of multinational R&D, the rising profile of Chinese

[5] See, for example, The Carbon Trust (2006).

research universities and institutes and a staggering outflow of graduates in science, engineering and maths.[6] A recent survey by the OECD (2007) concludes that "there can be no doubt that China is now a major R&D player."

But significant problems and constraints remain and at many levels. First, while many of the statistics are indeed impressive in absolute terms, the sheer size of China renders such figures something of a "hall of mirrors", with *per capita* concentrations still modest (Leadbeater & Wilsdon 2007). Secondly, numerous weaknesses remain, including the quality of much scientific research and of graduates, an educational culture of rote-learning that discourages independent exploration and critical thought, access to venture capital finance, and poor connections both between academia and business and amongst academic institutions, which are often still jealously guarded fiefdoms suspicious of other laboratories.[7] More generally, major issues of corruption, bureaucratic burdens and the lack of a political culture of openness affect the potential for innovation, especially of the disruptive and social kind needed to tackle climate change. A recent editorial in *Nature* (2008) asked of China whether "a truly vibrant scientific culture is possible without a more widespread societal commitment to free expression."

In this context, it may seem that the prospects for tackling climate change are not bright. But China does have great potential for breakthroughs in low carbon innovation. In addition to rapid improvements in its overall innovation capacities, it has a massive domestic market, which easily provides the critical mass needed to roll out new products and services, including low carbon innovations. Thirdly, China remains relatively unencumbered by some infrastructures, such as the automobility system (though this lessens by the day), thereby sparing it from the paralysis of sociotechnical "lock-in" and opening up the possibility of "leapfrogging" to more sustainable economic model (Gallagher 2006, Zhao 2006). Finally, there is widespread and growing acknowledgement both across the levels of government and within the population of the importance of environmental sustainability. The question thus becomes whether and how China can lead the global shift that is necessary from high to low carbon societies.

### *What do we mean by low-carbon innovation?*

"Low carbon" refers not just to that which increases the efficiency of GHGs (or CO2 even more specifically) emissions of products or processes but to anything that contributes to a transition in social system to one built upon low (or even zero) consumption (and hence oxidation) of carboniferous resources. Similarly, innovation is more than

[6] Wilsdon & Keeley (2007), OECD (2007).
[7] *Ibid.*, See also Xue & Forbes (2007), Schwaag-Serger & Breidne (2007), Gu & Lundvall (2006), Segal (2003).

technology but about the development of socio-technical systems and hence the *setting of socio-technical trajectories*. Innovation, on this definition, thus includes not only hi-tech innovation (whether radical or incremental) but also wider forms of innovation.

The temptation is to focus on the most obvious 'big ideas' – hydrogen fuel cells, carbon capture technologies, hybrid cars – and see these as the answer to our climate crisis. But solutions will come from other places too. In response to the ecological imperative articulated by the IPCC and others, a growing number of individuals, companies and organisations in China as elsewhere are thinking and investing in new ways to reduce carbon. Some of these will succeed; others will certainly fail. But cumulatively, they could produce the breakthroughs that we need for a lower-carbon society.

What is often lost in the welter of statistics about R&D investment and engineering graduates is a sense of the raw power of the changes that are under way, and the dizzying potential for Chinese innovation to head in new and surprising directions. A lot still depends on the playing out of a complicated set of tensions: between the planned economy and the market; national and global priorities; the hardware of research infrastructure and the software of culture and ethics; the skills and creativity of the scientific workforce and the entrepreneurialism and networks of returnees. But in charting possible futures for Chinese science, we must resist the temptation to ask only 'how much? or 'how fast?', and instead start to consider 'which direction?', 'says who?' and 'why?' Following a decade of chaos and destruction during the Cultural Revolution, China's innovation system had to be rebuilt from scratch. To have come so far, so fast in just 30 years is little short of astonishing. Looking ahead, as China begins to tackle a fresh set of daunting social and environmental challenges, the big unknown is whether it might choose to direct its growing capabilities for innovation towards an alternative vision of development.

Most importantly, the issue is one of the *joint* global setting of socio-technical trajectories towards a low-carbon systems transition. This effects a significant change in perspective to those currently motivating policy negotiations, both in global North and in China itself, which sees issue rather in terms of the zero-sum terms of who pays. As such, it may open up negotiations that otherwise threaten mutually-destructive deadlock. A broader perspective on innovation also facilitates these negotiations by setting up a fairer assessment of current Chinese innovation capacity and of what it may be aiming for, thereby opening up entirely new avenues for discussion and policy.

*IV: The Role of International Collaboration in Low Carbon Innovation*

We have argued so far that the problem of global low carbon innovation is best viewed as one of *joint international* setting of socio-technical trajectories of change. This perspective immediately suggests that international collaboration, of one form or another will be crucial. Furthermore, a growing literature of the importance of collaboration *per se* in an age of (possibly globalised) innovation networks has shown the extraordinary, and indeed counter-intuitive, productivity of such partnerships (e.g. Narin 1991, Royle *et al.* 2007, Wagner & Leydesdorff 2005). International collaboration is thus likely to be a key ingredient in the global efforts to tackle climate change.

International collaboration, however, is not coextensive with the joint setting of innovation trajectories, and we have argued it is the latter that is the overarching goal. For instance, one can readily see that if each individual nation-state were to take significant steps to mitigate global heating regardless of the actions of others, the overall effect would be greatly positive. Given that the nation-state remains the key site of political economic decision-making, national efforts must not be overlooked. The problem is that it is unlikely that such efforts alone will be sufficient. This is not only because of the prisoner's dilemma game of geopolitics regarding states' fears of free-riding by other states on their expensive mitigation initiatives. It is also the case that the very global nature of the problem itself will require both considerable coordination of innovation efforts and the full weight of global innovation resources, just as the WHO (2007) argues that no single nation-state now has sufficient capacity alone to deal with the global pandemics of the future. We may summarise the situation of international collaboration, therefore, under the banner of "global efforts where necessary, national or local ones where appropriate".

If we accept that policies should be designed in the light of explicit consideration of the *goals* they are intending to serve and offering new *means* for their fulfilment, our question is thus "what is the role for (different forms of) international collaboration in global low carbon systems transition?" In this section, we explore an analytical framework that allows us to begin to address this question. When conjoined with empirical analysis of the factors that support and constrain international collaboration, we can then proceed (in our Conclusion) to make some policy recommendations regarding policies that are needed to deepen and facilitate forms of international collaboration that support global low carbon systems change. Before proceeding, however, we note, in the spirit of dispersed participation in socio-technical change that we have advocated above, that our goal here is *not* to provide an analytical framework to allow us, i.e. the analyst, or any other user to derive a "scientific" judgement through some sort of axiom but rather to make explicit all the various important dimensions

relevant to assessment of international collaboration in order to afford informed policy and informed policy *debate*. Indeed, as will become clear, the complexity of the issues involved are such that there simply *is no such* unique and ideal resolution between all the contradictory demands on such a policy (Rodrik 2007). The policy agenda thus depends irreducibly on a political decision.

These incompatible demands are particularly important given our focus here on low carbon innovation and the recognition that climate change is a *social* problem (not just an ecological one). This demands that we also acknowledge the social context of efforts to create low carbon capacity, in particular competitive nation-state economies and globalizing neoliberal capitalism. In this way we can explore the role of international collaboration under current socio-historical conditions rather than in the idealised abstract. This in turn adds another dimension in which it is crucial to consider the importance of the local, or rather national, nature of almost all relevant institutions in our analysis of international collaboration. For in this context we must acknowledge that international collaboration pursued as a good in itself too easily lends itself to the harmful misinterpretation as simply an instrument of the prematurely universalistic "global" logic of hegemonic neoliberal politics, which directly contradicts our cosmopolitan goal of a participatory global politics of innovation. An issue of singular importance regarding international collaboration *in the current social context*, therefore, is how to distinguish between international collaboration that supports a global systems transition, *including* through development of *national* innovation capacity, and that which only merits support insofar as international collaboration is a good in itself and above all others.[8] This issue arises again and again in our analysis of international collaborations and we will return to it below in discussion of our analytical framework, of which it is a prominent feature. Indeed, in the case of collaboration with China, even from a pragmatic or instrumentalist perspective regarding the success of international collaborations, particular account must be taken of issues of national development. For a striking feature of Chinese culture is primary importance many attach to this consideration. Our question is thus, more accurately, "what is the role for (different forms of) international collaboration in global low carbon systems transition *given* the present context of competitive nation-state economies in globalizing capitalism?"

With these points in mind, let us now turn to our analytic framework. It has been developed both deductively, through analysis of the conceptual issues in play, and inductively, on the basis of issues raised in concrete empirical analysis of international

[8] Rodrik (2007) makes a similar point regarding the importance of assessing global connectivity and free trade from a perspective of national economic development and poverty alleviation.

collaborations in low carbon innovation between Chinese and British teams. First, we can distinguish between descriptive and evaluative classification. These two may then be sub-divided respectively into description of type and of motivation, and evaluation of effects/outcomes and of efficacy/ means.[9]

These four may also in turn be broken down thus:

**Table 1**
**A Classification of International Collaboration (IC) in Science & Innovation**

| ***Classification*** | ***Sub-Classification*** | ***Major Examples*** |
|---|---|---|
| **Descriptive** | | |
| *Type of IC* | Spheres | Business, (Academic) Research, Governance, Education, Development Assistance… |
| | Levels | Big multi-party projects, High-level formal institutional agreement, Active institutional interaction, Funded joint projects, Joint institutions or ventures, Informal long-term individual contact… |
| | Forms/ Relations | TNC In-house, TNC-TNC, TNC-SME, SME-SME, TNC-RI, SME-RI, RI-RI, NGO-RI, NGO-TNC… |
| | Fields | Climate modelling, Energy, Mobility, Agriculture… |
| | Innovation Types | Radical or breakthrough hi-tech R&D, Product/process improvement, Organisational, Cost disruptive, Low-tech social… |
| | Location of Parties | In China: Triad Cities (Beijing-Tianjin/Shanghai-Jiangsu/Pearl River Delta), Eastern Seaboard, Central, Western/Remote… |
| *Motivation for IC* | Goals | Commercial product development, Commercial capacity building, Commercial long-term relationship, Scientific knowledge development, Scientific capacity building… |
| | Attitudes[10] | Selfish-exploiting, Sharing-exchanging, Sharing-exploring, Sidelining-excluding |
| **Evaluative** | | |
| *Effects* | Types of Effects/ To Whom do the Benefits Accrue? | Knowledge creation & exchange, Innovation capacity and absorptive capacity building, (National or local) Economic development, Employment, Poverty reduction, Technology transfer and spillovers, Labour up- or down-skilling, Environmental improvement (urban pollutants, GHGs, resource use, biodiversity…), Social regeneration, Political enfranchisement, Socio-technical system restructuring, Governance reorganisation, Education restructuring, Cultural change |
| | Levels of Effects | Individual participants, Institutional participants, Other stakeholders at Municipal/Local/Provincial/ National/Regional/Global levels. |
| | Interaction of Effects | Positive, zero or negative sum effects of the interaction of international and local levels |
| *Efficacy* | Modus Operandi | Management issues, Clear goals, Established joint work patterns, Development of trust, Definite and practicable schedule, Means to overcome cultural differences and misunderstandings… |
| | Funding Mechanisms | Source, Availability, Duration, Allotment mechanisms, Types of project funded |

Taking the descriptive classification elements of Table 1 first, what is perhaps most striking from this framework is that the term "international collaboration" includes so many different forms that it is, at best, a huge simplification to talk of "international

[9] Compare Melin's (2000) analysis of the "reason", "form" and "effects" of international collaboration in science.
[10] Huxham & Hibbert (2005)

collaboration" as if it were a single identifiable social relationship. Such a descriptive system of classification thus affords much greater accuracy in the comparison of projects or schemes of international collaboration and allows for the separation of baby and bathwater. Note also how the wider definition of innovation highlights the importance of forms of international collaboration that are not generally considered.

It is the evaluative analysis, however, that is particularly important and on which we focus. Here again, the most striking feature of the table is the sheer multiplicity of the evaluative dimensions of international collaborations. In this respect, however, the framework is merely reflecting the argument that international collaboration is not the end in itself, but that the goal is rather building of capacity for the joint global setting of the sociotechnical trajectory. As discussed above, implicit in the latter is acknowledgement of the fact that domestic national concerns and development of innovation capability are also crucial. Analysis of the role of international connectedness in current innovation capacity and competitiveness shows that the regions and firms that flourish are those that (can) pay due attention to both internal capacity development and external connectivity. Successful innovation appears to need both development of local concentrations or clusters and the "buzz" to which they give rise, and international linkages via global "pipelines" (Bathelt *et al.* 2004). Similarly Scott (2003) notes that "contributions to the literature typically view R&D partnerships and in-house R&D as complementary strategies rather than alternatives", and argues that partnerships can even be used as alternative modes for the development of "absorptive capacity", the all-important capacity to absorb and utilise innovation leads productively (Cohen & Levinthal 1992). Likewise Altenburg *et al.* (2008) note that "all industries in our sample show a combination of successfully *tapping into international pools of knowledge* on the one hand, and *strong investments in national skills development and innovation capabilities* on the other" ([original emphasis]). The goal, therefore, must be to fashion policies that balance "the development of the national innovation system and strategic integration in global value chains and international research communities" such that they "create a virtuous circle of technological catch-up" (*ibid.*) The exact nature of such balance, however, is not derivable *ex ante* but dependent upon particular circumstances (Miao *et al.* 2007).

It cannot be argued, therefore, that our framework introduces unnecessary complexity into the analysis, for the complexity is there in the (systemic) phenomena under investigation. This is especially the case in the context of examining the role of international collaboration regarding climate change. As we have already stressed, climate change is irreducibly both an ecological and a socioeconomic problem and both

aspects must be considered. As the UNDP (2008) emphasised, while there is an undeniable link between the high-carbon consumption lifestyles of developed economies and climate change, economic underdevelopment is also one of the greatest threats to global attempts to tackle climate change. The developing countries concentrated between the Tropics are those most likely to suffer most heavily from global heating but also those least capable of adapting to it (Roberts & Parks 2007). In these circumstances, adverse climate changes lead to a positive feedback loop of deepening poverty and worsening adaptive capability. It follows that any assessment of how to support international collaboration that will impact positively on efforts to move to low carbon social systems must include these socioeconomic factors. To be sure, for some individual collaborations or types of collaboration, some of the types of effect mentioned may be relatively remote or insignificant. Nevertheless, it remains immanent in the systems transition approach that effects from one sphere of social activity may be expected to have some effect in others, all of which are crucially implicated in the social systems transition.

Finally, the importance of considering all these factors is particularly stark in the case of international collaborations with China. While China is undoubtedly highly economically developed and scientifically sophisticated in the pockets of its huge Eastern cities, it remains a developing country with a rural peasantry of some 700 million people. In these circumstances, it is entirely understandable, and legitimate, that Chinese innovators and scientists are acutely aware of the need for their efforts to serve the economic development of the nation and not just generate pockets of international excellence.[11] Such awareness or sensitivity is even more understandable in the context of China's turbulent history over the last two centuries and the even deeper roots of national pride of Chinese culture. National industrial policy for the growth of domestic innovation capacity – legitimate concerns about the political centralization and potential corruption of the state notwithstanding – thus remains a crucial element of development policy in developing countries, with most of sub-Saharan Africa providing a stark example of how *under*-development follows in the absence of such national policy (Forje 2006).

Furthermore, the importance of national policy holds not only for issues of economic development, but also for the development of a system of scientific research and education. Today, such a research system must not only be capable of cutting-edge knowledge production and be functionally well-integrated into innovation networks, but also be capable of providing knowledge that contributes to the needs of that particular

[11] See e.g. Xue (2008)

social formation, be it national or local (e.g. Juma *et al.* 2001). Amongst the most obvious trade-offs that a policy on international collaboration must consider, therefore, is the extent to which limited monies, whether of government or private institutions, should be used to support the deepening of international connections or be used for direct investment in domestic factors. Clearly, the straightforward analysis of international collaboration as a good in itself entirely overlooks this crucial consideration (Georghiou 1998, Katz & Martin 1997, Wagner & Leydesdorff 2005).

Furthermore, as discussed above, assessment of international collaborations and their effects cannot be done in the abstract set against idealised and ahistorical conditions, but only in the light of the specific socio-historical conditions of the present. This also adds to the complexity of the framework. Important considerations here include the current conditions of turbulence, transition and emergence in the global political economy: turbulence regarding the unfolding of the full economic effects of the collapse in US credit markets; transition regarding the shifting centre of the global political economy from the US to Asia; and emergence regarding the novel development of global, and not merely international, social forces.[12] Also important are changes to the organisation of the economy such as the changing organisation of competitive manufacturing to networked production chains (Altenburg *et al.* 2008, Ernst & Kim 2002, Steinfeld 2004)) or the emergence and importance of open and networked innovation models (Chesbrough 2005).

Acknowledging the concrete circumstances of the case in this way, however, has consequences for the argument regarding the importance of national development. For instance, both of these latter examples (of the emergence of networked production and innovation) have significant, but as yet unclear, implications for models of economic development and industrial policy, such as the two major success stories of the integrated state-led development of Japan's *keiretsu* or South Korea's *chaebol* and the statist-but-networked-SME model of Taiwan (Wang 2006, Wade 1991, Amin & Thrift 1992, Saxenian 1994). It has been argued that the former in particular may be less important in the current context than they were even twenty years ago (Steinfeld 2004, Altenburg *et al.* 2008). In any case, the present domination of the WTO and its policing of global free trade imposes constraints on China's development that were absent for both Japan and South Korea at the equivalent stage of their own development. It follows that even to the significant extent that industrial policy retains great importance (Nolan & Wang 1999), countries such as China simply cannot now follow the same paths of

[12] See Tyfield *et al.* (2008) and references therein.

economic development (e.g. Lall 2004, Wang 2006).[13] In fact, China has not clearly taken either the Korean or Taiwanese route but sits somewhere – arguably uncomfortably – between the two (Nolan & Wang 1999, Wang 2006), complicating evaluation of international collaborations with China even further.

We raise these issues, however, not in any attempt to resolve them here but rather to highlight the sheer complexity of the issues, as brought out by our framework, regarding assessment of international collaboration (with China) in light of the importance of developing "indigenous innovation" (*zizhu chuangxin*) capacity and the particular path China has taken in this regard to date. In short, taking all these factors together, the role of international connectivity in the development of China's innovation capability and industrial strength is an open question, because it is pursuing a model of development without precedent in new and particularly challenging circumstances and with, what remains to date, ambiguous and uncertain success. At the very least, therefore, developed countries (and parties from them) seeking international collaboration with China cannot and should not expect it, or other developing countries, simply to ape their routes to sustainable development (e.g. Jin 2004).

The inclusion of one final issue in our framework deserves explicit discussion, namely "cultural changes". There are two senses in particular in which this may be seen to be a crucial factor in assessment of international collaboration. First, as discussed above, the social complexity of innovation and technoscientific processes are such that it is not possible to analyse them in the absence of consideration of the cultural particularities of (the governance of) various science and innovation systems, what Jasanoff (2005) has called their specific "civic epistemologies". Secondly, cultural issues take on a particular importance regarding the issue of low carbon innovation and climate change because of its global nature, and hence its dependence on global political negotiations. In this context, the emergence of a cosmopolitan ethic, which simultaneously expresses a global ethic of concern and sensitivity to local differences, is a crucial element of the global campaign to tackle climate change because such an aspirational ideal or vision is an absolute necessity for the bringing about of material circumstances that simply do not yet exist. It follows that the contribution of individual international collaborations (and programs thereof) in *low carbon innovation* to the development of such an ethic of "cosmopolitan innovation" (Leadbeater & Wilsdon 2006) – thereby contributing to the

[13] Indeed, our framework also satisfies the important condition of leaving open the question whether the role of the WTO may itself need to be changed as part of the measures necessary to stimulate a cosmopolitan innovation regime of international collaboration: for instance, changing the primary responsibility of the WTO from facilitating free global trade in order to maximise trade volumes to a "primary goal [of] enable[ing] countries to grow out of poverty" as Rodrik (2007) has argued (see also Lall (2004)).

potential emergence of a broader institutionalised cosmopolitan innovation governance regime – is of singular importance and would be a grave omission in any analysis. Indeed, there is clearly significant resonance between such a vision of cosmopolitan innovation and the goal of building capacity for the joint global setting of the socio-technical trajectory. It is thus possible that fostering such cosmopolitanism may be amongst the most important effects of international collaborations.

*V: Sectoral Analysis and Case Studies – The Example of Energy*

Having introduced our analytical framework, in this section we illustrate its application by briefly discussing the role of international collaboration in a sector of supreme importance regarding climate change, namely energy. Clearly, the manifold issues regarding energy and low carbon innovation in China merit much fuller analysis than we can offer here. Our primary purpose, however, is simply to offer examples of the kinds of insights that arise from adoption of our systems perspective regarding international collaboration. As such, we begin with a brief discussion of the current status of low carbon innovation in China in the energy sector under the wider perspective advocated above. This affords a more balanced assessment of China's current progress. This is followed by identification of some significant continuing problems in China's low carbon innovation capacity and various gaps that international collaboration could play a crucial role in filling. Finally, we discuss examples of international collaboration in that sector that should be supported and the particular benefits they bring, as evidenced by evaluation of a number of case studies that are part of an ongoing project we are conducting on international collaboration in low carbon innovation between the UK/EU and China.[14] This leads to some policy recommendations in our Conclusion. The goal here is obviously not to go through all the criteria of the framework exhaustively but just to highlight some particular examples of issues that have arisen in this project to date. We also focus here primarily on the evaluative dimensions of our framework rather than the descriptive ones, though we employed the latter in choosing our case studies.

The most striking aspect of Chinese efforts regarding low carbon innovation in energy is their focus on energy efficiency rather than production. It must be acknowledged that this could indeed have a major impact of global consumption of fossil fuels, given the sheer size and rapid growth of China's energy needs (e.g. IEA 2007). Furthermore, there are obvious gains to be made here, as the country's energy efficiency remains

[14] This project is funded by the UK's Economics and Social Research Council under the auspices of the Targeted Initiative of the Advanced Institutes of Management. We gratefully acknowledge their support for this research. Along with energy, our project is also studying low carbon innovation in two other key sectors, namely (urban) mobility and agriculture, but we omit discussing these sectors here for reasons of space.

behind that of the developed countries, regarding both industrial and household consumption. As such, this is a perfect example of China making significant domestic efforts, for which it should be applauded.

Regarding production, however, China is also making significant strides. First, it has successfully capitalised upon the opportunities for environmental upgrading from the Clean Development Mechanism, representing nearly 70% of the market. To be sure, this is an international mechanism, but the widespread take-up of CDM opportunities is due in no small part to government policy. In any case, China is also making important progress domestically. Most obvious is the growth of its firms in renewable energy technologies, particularly wind and solar (PV and water heaters) energy. Such is the strength of China's wind industry now that the central government has set the astronomical target of 100 GW of wind power by 2020, compared to a current *global* capacity of around 55 GW. Similarly, Suntech is a singular Chinese success story, going from its establishment in 2001 to its successful listing on NASDAQ in 2005, and representing merely the most high-profile case of a burgeoning solar power industry. A trip to any large Chinese city will also bear witness to the ubiquity of solar water tanks on roofs. Both the wind and solar industries, however, are growing through cost reduction and mass production, rather than further breakthrough innovation, as, for instance, in the German solar industry, which is now investigating transparent films that can be used to cover the entire surface area of office buildings.

In other non-fossil fuel energy sources, China is also making significant efforts, though these efforts are not uncontroversial. In hydropower, the gigantic Three Gorges Dam exemplifies a host of hydro-dam projects across the country, though these have been alleged by some scientists to be connected with the catastrophic earthquake in Sichuan in May 2008. In nuclear power too, China has an ambitious construction program, enlisting the help of the French amongst others for assistance in some, but by no means all, projects. These measures may be expected to reduce dramatically the country's carbon footprint and should be welcomed, on that score at least. However, they are motivated much more by the government's concern for energy security rather than climate change. This, of course, is not a problem in itself, but it is indicative of greater weaknesses in China's overall energy strategy from the perspective of mitigating global heating.

No other issue exemplifies this better than China's strategy regarding coal. Coal is by far the country's most abundant fossil fuel and there are vast reserves, particularly in Shanxi and the north east of the country. Given the projections of China's growing

demand for energy and its concerns about security of access on international markets, it is understandable that China is committed to use its coal for the foreseeable future. Yet it is already suffering grievously from the effects of the pollution of mass coal combustion. This has led to a focus on efforts to develop "clean coal" technologies, but this terminology means only reduction of NOx and SOx emissions and incomplete combustion, hence soot. Even perfectly clean and complete combustion, however, must release GHGs, i.e. $CO_2$. The sequestration of $CO_2$ with carbon capture and storage (CCS) systems, however, is a very low priority for China, not least because it remains a technology that is unproven and expensive (both in terms of investment and in terms of energy loss); and one, moreover, that the *developed world* itself has yet to demonstrate. As such, CCS is widely seen across Chinese policy circles as a "next generation" technology at best, though they are happy to participate in international consortia if the partners bear the cost.

Overall, then, China is making significant efforts regarding the emissions from the energy sector, but its innovation capacity, particularly in hi-tech and breakthrough innovations, remains comparatively weak. This is not, however, due to a lack of research expertise or of business acumen. On the one hand, there is excellent science, for instance at the Chinese Academy of Science or Key State laboratories, such as the Dalian Institute of Chemical Physics. On the other, the meteoric rise of the Chinese economy in the last 30 years is testament to the extraordinarily entrepreneurial culture of the country. What is lacking, however, is the connection of these two. The researchers thus often have what one senior representative of a major TNC called "Rembrandts in the attic", but they lack development experience. Conversely, entrepreneurs rarely have the access to these ideas or the means or motivation for the substantial investment development would require. Clearly, international collaboration could play a crucial role in bridging this gap and accelerating the learning process.

One may ask, however, whether China needs to rely on such hi-tech innovation in order to make its mark on global markets and/or make its singular contribution to global efforts to deal with climate change. In particular, we must not overlook the potentially key role of the Chinese economy to develop disruptive cost innovations, particularly (regarding low carbon) of renewable energy technologies. If this is their comparative advantage, the argument may run, why demand that China does what it cannot do as well as the developed economies? This is an important point and it needs careful consideration. Certainly, the dramatic cheapening and mass production of solar panels and wind turbines could make a significant impact on the global market for renewable energy, and China does excel at such disruptive cost innovation (Zeng & Williamson

2007). However, it is also arguable that to base policy regarding international collaboration on this functional international division of labour may be to condemn China to permanent second-tier status in the global economy and to deprive the global effort, in the medium term of decades, of the full exploitation of an extraordinarily rich resource, namely China's potential for innovation.

Indeed, it is arguable that accounts that emphasise the emergence of a new and disruptive innovation model in Chinese industry underplay the continuing weaknesses of China's innovation capacity. According to some critics of this position, this weakness may be diagnosed to be the result of China's equivocal and ineffective industrial policy, stuck as it is between the mutually incompatible Korean and Taiwanese models (Steinfeld 2004, Wang 2006). Far from representing a new model, therefore, on this argument China is currently hobbling along trying to reconcile two irreconcilable strands of its innovation policy. In this context, then, the goal of international collaboration policy must be to encourage the development of China's growth of innovation capacity and not to prolong the delay of the full realisation of its potential contribution to a new sustainable mode of development. However, such an analysis must not overplay the weaknesses of China, nor can it overlook the changes that have occurred in the organisation of the global economy. For instance, as Altenburg *et al.* (2008) have argued, with its massive market and its huge accumulation of capital China has considerable bargaining power, while transformation of the manufacturing process through "organizational decomposition of the innovation process" (Schmitz & Strambach 2007) may allow the purchase of capabilities that have previously been entirely dependent on slow organic processes of maturation.

Nevertheless, even with these qualifications in mind it remains the case that there is a clear role for international collaboration in the development of hi-tech low carbon innovation capacity in China, including, for instance, CCS given the importance of coal to China. From our wider definition of innovation, however, international collaboration need not be limited to this mandate alone. Although China appears to be doing well regarding the development of relatively low-tech or disruptive innovations, such as energy efficiency or cheaper mass production of renewable energy technologies or energy-efficient light bulbs, another significant gap is the lack of institutional connectivity within the country, in particular between researchers and business, other researchers and "civil society".[15] This significantly undermines the potential for disruptive and social innovation. Yet it is clear that the continuing absence of hi-tech innovation and the

[15] We put "civil society" in scare quotes due to the continuing awkwardness of this term as an apt description of Chinese society. See e.g. Metzger (2001).

country's incomplete socioeconomic development – with a population of many hundreds of million still effectively poor by global standards – mean that such forms of innovation could be expected to play a significant role in contributing to China's low carbon systems transition. Nor does the low-tech nature of such innovation necessarily limit it to a purely domestic national affair. Indeed, international connectivity can act as a catalyst or axis stimulating domestic partnerships that would not occur in the absence of the international partner and their novel approach and perspectives. Similarly, international collaboration could also play a significant role in accelerating learning of other forms of innovation, such as policy innovation through the development of capacity for energy strategy.

These issues are well exemplified by a number of case studies we are examining of low carbon international collaborations between Chinese and UK teams in the energy sector.[16] Let us conclude this section, then, with a brief discussion of some of the relevant issues that have arisen to date from these investigations. Tables 2 and 3 summarize a number of pertinent points from these case studies using our analytical framework. As can be seen in the descriptive classification, the two case studies are:

1) A research centre for the development of Chinese energy strategy capability, housed in an elite Chinese university with funding from a major UK transnational energy company; and
2) A primarily UK government-sponsored consortium, involving academic and government research institutions and major energy companies, for the development of CCS capacity in China.

[16] These case studies are ongoing. The evidence discussed here is based on fieldwork to date of over 70 interviews with scientists, businesses, NGOs and policy-makers in the UK and China between October 2007 and June 2008.

**Table 2**
**Some Salient Features of an International Collaboration in Energy: Case Study 1**

| ***Classification*** | ***Sub-Classification*** | ***Project Details*** | |
|---|---|---|---|
| **Descriptive** | | | |
| *Type of IC* | Spheres | Academia – Policy and Business relevant research | |
| | Levels | Institutional establishment | |
| | Forms/ Relations | Research Institution in University with MNC support | |
| | Innovation Types | Policy innovation, Institutional innovation through novel connections | |
| *Motivation for IC* | Goals | The development of national capacity for energy strategy | |
| **Evaluative** | | | |
| *Effects* | Types of Effects/ To Whom do the Benefits Accrue? | Effects of particular importance include: | |
| | | Knowledge creation & exchange | Regarding Chinese energy strategy and low carbon options |
| | | Economic development | National economic development explicitly treated as top priority |
| | | Socio-technical system restructuring | Policy recommendations to institute novel energy systems, e.g. polygeneration systems |
| | | Cultural change | Changing the relation between institutions in the Chinese research system/ Deepening international ties and emergence of cosmopolitan sentiments |
| | Interaction of Effects | Development of an international profile for the research centre, with the TNC "bringing [them] to the world", has in turn been the basis for deeper integration within its host institution. | |
| *Efficacy* | Modus Operandi | Means to overcome cultural misunderstandings | Long term connections, regular and consistent contact leading to development of personal bonds of trust |
| | | Appropriate management structure | Project run by Chinese partners, hands-off approach from TNC |
| | Funding Mechanisms | Source/Availability | Dependence upon singular foresight of particular individuals in TNC's senior management as "seed corn" to establish the research centre |

The two case studies are very different in form and unsurprisingly, therefore, have offered their own particular insights. Equally striking, however, are the common threads between them – threads, moreover, that are also in evidence across our case studies in

other sectors as well.[17] We focus on the latter insights here and on five of these in particular.

**Table 3**
**Some Salient Features of an International Collaboration in Energy: Case Study 2**

| ***Classification*** | ***Sub-Classification*** | ***Project Details*** | |
|---|---|---|---|
| **Descriptive** | | | |
| *Type of IC* | Spheres | Academic Research, Business, Governance | |
| | Levels | Big multi-party project | |
| | Forms/ Relations | Bilateral UK-China consortium involving particular research groups with project management overseen by a privatised UK energy consultancy and a Chinese government body | |
| | Innovation Types | Technological innovation primarily | |
| *Motivation for IC* | Goals | The development of national capacity for carbon capture and storage, working towards development of a demonstration plant by 2014 | |
| **Evaluative** | | | |
| *Effects* | Types of Effects/ To Whom do the Benefits Accrue? | Effects of particular importance include: | |
| | | Knowledge creation & exchange | Regarding detailed expertise in the construction of a CCS plant |
| | | Economic development | Funding from UK partners Project explicitly to develop Chinese capacity in what may be a key future technology |
| | | Socio-technical system restructuring | Working towards the goal of standard use of CCS on all Chinese coal power stations |
| | | Cultural change | Deepening international ties and emergence of cosmopolitan sentiments |
| *Efficacy* | Modus Operandi | Means to overcome cultural misunderstandings | Regular and consistent contact between partners in various work programmes/ Crucial role of UK-based Chinese scientist for one team |
| | | Appropriate management structure | Data and IP left with Chinese partners |

1) First, a striking feature of both collaborations is the recognition by the UK partners of the importance of handing over (much of the) control and management of the project to the Chinese partners, and acknowledgement of the importance these partners attach to such Chinese leadership. As discussed, it cannot be overestimated how important to

[17] See footnote 14 above.

many Chinese partners is the broader national project of re-establishing China's position on the world stage, after over 150 years of extraordinary turmoil and relative loss of global stature.[18] This is manifest in both case studies in their distinct *modus operandi*. In Case Study 1, the contribution of the TNC takes the form primarily of a relatively small (from its perspective) but significant (from the research centre's perspective) financial stipend, the use of its name for international branding purposes and regular contact with several senior members of the TNC's China team. The TNC also has some seats on the research centre's board, but maintains little or no control over its day-to-day activities or research projects, and allows, or rather encourages, the research centre to accept consultancy projects from other TNCs including its competitors. Furthermore, the TNC are aware that for the research centre's management their primary task is "to serve national development", but in full awareness that this is best done through encouraging openness and international engagement.[19] The TNC thus supports this venture explicitly in order to develop *domestic* capacity for energy strategy in China, seeing that this will lead to considerable benefits for it in turn.

In Case Study 2, while overall project management is divided between the British lead institution and the Chinese counterpart, the project is being run expressly in order to develop Chinese capacity for CCS that would not otherwise be pursued. In this context, the British partners are taking part in the project for the opportunity of developing their own expertise of CCS issues in the process of knowledge sharing with their Chinese colleagues and in order to build links with Chinese partners who may in time call upon their services again, whether through collaboration or consultancy, for their (now demonstrated) expertise. The particular intellectual property and data that is being developed in the project – e.g. geological surveys, plant location suitability, plant specifications etc. – can thus readily be left with the Chinese partners since these are not the primary benefits of the project for the UK partners. Indeed, to the extent these data are actually used in the successful construction of a Chinese CCS demonstration plant, the project will be an overwhelming success.

In both cases, therefore, what could be thorny issues of ownership and divergent motivations have been skilfully circumvented by simply admitting the importance of benefits accruing to Chinese national development for the whole-hearted participation of

[18] As an indication of the importance of this national pride, if not nationalism, in one interview with a Chinese energy scientist in May 2008, the single most important barrier to successful international collaboration was identified as being not any factor directly affecting the arrangement or management of such cooperative work but "cultural differences" with Western partners regarding opinions on the issue of Tibetan autonomy. On Chinese nationalism more generally, see Hughes (2007).

[19] The quotation is taken from an interview in April 2008 with the Chinese managers of the research centre.

their Chinese colleagues. Indeed, Case Study 2 also illustrates the importance of such geopolitical sensitivity, especially for the issue of low carbon innovation, in a slightly different way. A particular difficulty it faces is that its credibility as a project is dependent upon evidence of concrete progress in CCS technology in the developed countries. For until that occurs, China understandably views it as grossly unfair to expect it to invest in the technology and so clean up its act while the main historical polluters have themselves done nothing. In this respect, low carbon innovation with China is seen to be set within a broader web of national trust and goodwill, and not merely that between individual collaborators.

2) The second issue is the way in which these international collaborations are fostering connectivity between various institutions *within* China. For Case Study 1, this has taken the form of the research centre becoming a reputed international centre of excellence, which has in turn acted as the focal point to seed a crystal of networked connections between disparate departments across the university. Such cross-departmental connections are extremely rare in China, not least due to the continuing influence of the Soviet organisation of much of the research system. Indeed, this "low carbon" network is arguably the first such cross-departmental initiative at this leading university and a source of great pride for the university's management.

For Case Study 2, the simple formation of the consortium has brought together partners that would not otherwise be engaged with each other's work. The forging of unusual connections between Chinese partners is also a key outcome in some of our other case studies in other sectors, including one that is transforming the interaction between researchers, the government agricultural extension service and farmers. As this example illustrates, therefore, international collaboration can also play a crucial role in the development of relations that are effectively culturally alien at present in China but which have the potential to develop disruptive social innovations.

Furthermore, the two case studies discussed here exemplify how international collaboration has acted as a crucial mediator for the formation of *interdisciplinary* research teams. Such interdisciplinarity is absolutely crucial for effective grappling with the multi-dimensional and systemic problems of climate change and low carbon innovation, but it remains exceptionally rare in China, trumping even the usual disciplinary chauvinism of peer review processes in the developed countries.[20]

[20] Again, our agricultural case studies also demonstrate this point particularly clearly.

3) Thirdly, the unusual funding arrangements of both of our case studies demonstrate the particular need for unorthodox and enlightened funding mechanisms for many such international collaborations, and hence the potential difficulty of securing financial backing. The establishment of the research centre in Case Study 1 appears to have been almost entirely dependent on the individual foresight and support of a handful of senior executives, while Case Study 2 is also a singular project. Similarly, our fieldwork has continually thrown up the difficulty of securing substantial joint funding for research projects with Chinese partners of sufficient duration actually to do significant work together. In the case of such joint (academic) research projects, matters are complicated further by the different approaches to funding in the UK and Chinese systems, paradigmatically as bottom-up and top-down. There are currently various initiatives underway to attenuate the relative dearth of funding, for instance with the extension of the European Framework Programme (now on round 7) to encourage Chinese scientists as possible third parties or various targeted funding schemes run by the British research councils. While they are steps in the right direction, however, these efforts would still have to be dramatically scaled-up to make a significant impact. And the situation is even more testing for applied research, rather than research aiming at high-impact international publications, despite the fact that such applied research has a crucial role to play in low carbon innovation. Development agenda funding is one possible source for such projects, but the relative affluence of China's eastern seaboard means that China as a whole is increasingly excluded from such development programs. In short, therefore, funding schemes for international collaboration across the various dimensions of innovation remain inadequate.

4) This leads us to the fourth issue, which is that these case studies illustrate perfectly a central claim of this paper, namely that neither partner of these international collaborations yet has the capability for low carbon innovation actually to effect the low carbon systems transition that is necessary. In Case Study 1, the research centre is developing energy strategy capacity that China does not yet have. But in doing so, it is also contributing to the innovation of energy solutions that are also currently lacking in the developed global North and from which Northern energy TNCs evidently feel they have a great deal to learn. In Case Study 2, on the other hand, the very nature of the project is to build up capacity for the development of a technology that arguably could be a major contribution, albeit a temporary one, to the transition to a low carbon society but which is currently not up-and-running and commercially viable *anywhere in the world*. Against both monotonous China-bashing critics and those Chinese commentators and policy-makers who see the solution to the China's environmental problems in handouts of existing technological solutions, therefore, it is clear that the way forward

for the development of global low carbon innovation capacity is collaboration towards the joint international *setting* of the still-to-be-formed socio-technical trajectory.

5) One final issue of potentially great significance is the way in which these international collaborations are fostering a cosmopolitan ethic amongst their participants. Given the strength of nationalist sentiment in China – which, we stress, is not *necessarily* the sinister development that an alarmist Western media too easily portrays – the emergence of a cosmopolitanism is particularly significant amongst the Chinese partners.[21] Furthermore, Chinese participants we have interviewed have continually emphasised (often with great emotion) the benefits of the development of universalistic fellow-feeling and openness to foreigners that has developed from their own experience of international collaboration, while acknowledging that this was largely absent before that encounter as being culturally relatively unfamiliar. For instance, a leading Chinese partner in Case Study 1 stated categorically that his experiences of establishing the research centre with his Western colleagues from the TNC had taught him "what partnership means". Indeed, in many cases, interviewees have ranked this change in their own attitudes as the most important personal outcome of international collaboration, and a primary motivation for their continued whole-hearted support for it for their colleagues and staff. Finally, far from diminishing their national pride, it also seems that such international openness actually increases it, but sets it in a broader context that loosens the defensiveness with which it is often associated. We have discussed above the potential importance of such a cultural development regarding global efforts to deal with climate change. As with point 4), then, it seems that international collaboration has a central role to play in the cementing of the project of broader *de facto* international cooperation towards low carbon systems transition.

*VI: Conclusions and Policy Recommendations*

We have explored the growth of low carbon innovation capacity in China and the role of international collaborations in contributing to this process. This exploration has been based on the argument that the goal of policy in this area should be the creation of mechanisms for the joint global setting of the sociotechnical trajectory of a systems transition to low carbon societies. As such, a respect for the need to maximize China's contribution to this global social transformation demands that we acknowledge its need to concentrate on domestic development of innovation capacity – a policy orientation that is, crucially, compatible with the particular challenges that climate change poses China as a developing country and its existing innovation policy of "indigenous

[21] For a full discussion of the cosmopolitanism of China, with particular regard to low carbon innovation, see Tyfield & Urry (forthcoming).

innovation" (*zizhu chuangxin*). This recognition of the importance of national innovation capacity, however, does not license a closed, protectionist techno-nationalism, not just because this would cripple efforts to tackle "global heating" but also because it would be self-defeating for China itself. Nor is it necessarily at the expense of the global North. As Altenburg *et al.* (2008) have argued "the development of [China's] national innovation system and strategic integration in global value chains and international research communities may well create a virtuous circle of technological catch-up" from which all parties gain. Innovation in general and low carbon innovation in particular now often need to be globally networked to succeed. The opportunities for win-win international collaborations are thus legion.

What is distinctly lacking, however, are the institutional mechanisms to support such international collaborations, both in "basic science" and business or social innovation. Accordingly, our primary policy recommendation is for viable mechanisms to be proposed and implemented as a matter of urgency. In particular, global, multilateral and bilateral mechanisms are needed for effective long-term research collaborations on low carbon issues, and institutions are needed to connect and stimulate low carbon business innovations around the world in order to maximize their impact.

These mechanisms may take many forms, but the following are some possibilities. As regards the former issue of scientific research, EU efforts such as the opening up of Framework Programme 7 funding must be deepened and in the UK too, greater attention and funding must be paid to international collaborations with China. Reforms should also be made by both China and other countries, to update existing mechanisms for collaboration so as to reflect the evolution of the relationship between Chinese and overseas partners towards one of mutual learning and away from that of follower and leader. At the global level, one further possibility could be a Global Research Council for low carbon research administered by an appropriate body, such as the UNDP. Funded primarily by the developed economies, this could also contribute significantly to trust in the ongoing post-Kyoto negotiations by demonstrating genuine *bona fides*.

As regards the latter issue of business innovation, a Global Disruptive Innovation Network and Fund may also be needed. Given the importance of low-tech innovation to developing countries such as China, this would respond to the difficulties in establishing international networks that face the small businesses and research teams in the global North leading such disruptive innovation. This could work by offering a web-based platform to facilitate the formation of these networks, along with advice of doing business overseas and rules of membership. It could also provide seed-corn funds

available to incentivise development of joint projects forged through the network. In this way, establishing global networks of low carbon innovation may be transformed into a simple matter of strategic self-interest.

To be sure, deeper and more intransigent institutional changes may also be needed, both within China and globally, to effect the global low carbon systems transition. For instance, at the global level, WTO rules may need to be amended to allow policies in developing countries that support domestic development of low carbon innovation capacity. Conversely, internally, China must admit the importance of climate change not only in the abstract future but to China and now. Hence it must continue to strengthen the Ministry of Environmental Protection, provincial Environmental Protection Bureaus and enforcement of environmental regulation. It must also set up widespread incentives for low carbon innovation to make it a strategic priority for research and, crucially, business and must tailor these policies in recognition of the importance of disruptive innovation. Furthermore, as the only possible check to a state-led development policy is the oversight and accountability of broad political participation – a lesson that it is clear is equally applicable to the global North, given the current attempts of governments to bail out the self-inflicted crisis of global finance – China must also continue efforts to expedite political reform. Similarly, to encourage disruptive and social innovation, it must also incubate a culture of open enquiry and support the emergence of civil society. Together these global and domestic developments then have the potential for positive interaction with each other, leading to the emergence of a critical mass of innovation efforts. The complexity of the issues and their inter-relations, however, must not be used as an excuse for inaction. The initiatives we suggest to stimulate international collaboration, and thus institutionalise a global regime of cosmopolitan innovation, would be as good a place as any to make that crucial first step.

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